

AU/AFF/NNN/2007-04

AIR FORCE FELLOWS

AIR UNIVERSITY

**BOTTLING PROLIFERATION OF THE URANIUM GENIE:
IDENTIFYING AND MONITORING CLANDESTINE
ENRICHMENT PROGRAMS**

by

Ferdinand B. Stoss III, Lieutenant Colonel, U.S. Air Force

A Research Report Submitted to the CADRE/AR
In Partial Fulfillment of the Graduation Requirements

Advisor:
Mr. Larry G. Carter

Air Force Fellow
Oak Ridge National Laboratory

Maxwell Air Force Base, Alabama

April 2007

Distribution A: Approved for Public Release; Distribution is Unlimited

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE APR 2007		2. REPORT TYPE		3. DATES COVERED 00-00-2007 to 00-00-2007	
4. TITLE AND SUBTITLE Bottling Proliferation of the Uranium Genie: Identifying and Monitoring Clandestine Enrichment Programs				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air University,Air War College,325 Chennault Circle,Maxwell AFB,AL,36112				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT see report					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 87	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Disclaimer

The views expressed in this academic research paper are those of the author and do not reflect the official policy or position of the U.S. government or the Department of Defense. In accordance with Air Force Instruction 51-303, it is not copyrighted, but is the property of the United States government.

Contents

	<i>Page</i>
DISCLAIMER	ii
TABLES	iv
ABSTRACT	v
INTRODUCTION	1
THE PATH TO NUCLEAR WEAPONS.....	6
Why Some Nation-States Desire Nuclear Weapons.....	6
International Nonproliferation Efforts.....	8
U.S. Nonproliferation Policies and Programs	12
Ways to Acquire Nuclear Weapons.....	17
THE URANIUM NUCLEAR FUEL CYCLE.....	25
Obtaining and Processing Natural Uranium.....	26
Uranium Enrichment	27
Electromagnetic Isotope Separation	28
Gaseous Diffusion	29
Aerodynamic Separation	31
Gas Centrifuge.....	32
Other Methods of Separation.....	33
Comparison of Enrichment Methods.....	33
Weapon Production	34
CASE STUDIES	39
South Africa.....	39
Iraq.....	44
Pakistan.....	49
Libya.....	55
Iran.....	57
CONCLUSIONS AND RECOMMENDATIONS	67
GLOSSARY	75
BIBLIOGRAPHY	76

Tables

	<i>Page</i>
Table 1. Reasons for Wanting Nuclear Weapons	7
Table 2. Comparison of Enrichment Methods.....	34

Abstract

America must develop robust capabilities to identify and monitor clandestine nuclear weapons programs. Accurate and timely intelligence are essential elements in combating the spread of nuclear weapons, of which the President's 2006 *National Security Strategy* succinctly describes as "the greatest threat to our national security."

This paper first delves into why the leadership of some countries desire nuclear weapons. A brief discussion on international agreements and American policies in relation to nuclear nonproliferation follows. Then, the uranium nuclear fuel cycle is described along with several pertinent case studies. Finally, conclusions and recommendations for American nonproliferation efforts are presented.

An increased emphasis on nuclear nonproliferation within the United States government is required. Nonproliferation programs are spread across many agencies and departments within the Executive Branch, lending to inefficiencies and a lack of synergistic direction. Just as a cabinet post was recently created to enhance America's intelligence assessments, similar attention is warranted for America's nonproliferation endeavors.

There are shortfalls in the intelligence capabilities of the United States to detect clandestine nuclear weapons programs, as was discovered following the 2003 invasion of Iraq. To remedy this deficiency, the United States must acquire the capability to accurately detect and monitor proliferators' nuclear weapons programs. Only by

understanding what proliferators are doing, can approaches be developed to stop or delay their efforts as long as possible.

There is a compelling case that Iran's uranium enrichment effort is not exclusively for nuclear energy, as they claim. Rather, Iran's objective is likely to develop nuclear weapons. But the evidence must be air-tight before the United States embarks on options to deal with Iran, possibly including a preemptive war. Improved technologies to detect uranium enrichment could provide the key to finding the "smoking gun" in Iran.

Chapter 1

Introduction

America must develop robust capabilities to identify and monitor clandestine nuclear weapons programs. Accurate and timely intelligence are essential elements in combating the spread of nuclear weapons, of which the President's 2006 *National Security Strategy* succinctly describes as "*the greatest threat to our national security* [emphasis added]." ¹

The mere thought of a nuclear weapon detonating within the United States conjures tremendous emotion in any American. Such an act is almost unthinkable, yet this event, while not likely, is at least plausible when one looks at the recent history of nuclear weapons proliferation. Nuclear proliferation, especially to unpredictable and unstable countries, puts America and the world at risk. Recent events are indeed troubling, to include the discovery of the A.Q. Khan network, North Korea's 2006 nuclear test, and Iran's commitment to enrich uranium.

Dr. Mohamed ElBaradei, the Director General of the International Atomic Energy Agency, believes that many countries are "hedging their bets" by possessing the knowledge and technologies that would allow them to rapidly develop nuclear weapons for possible future contingencies, labeling them as "virtual nuclear weapon states." Dr. ElBaradei believes that 20 to 30 countries fit into this category in addition to the current nine nuclear powers.² An even greater number of less technologically-advanced countries could also produce nuclear weapons, albeit with more challenges than that of the "virtual" states. All told, there are perhaps 50 countries that could build nuclear

weapons if its leadership so desired; some could do so quickly and for others it could take a decade or more.³ Proliferation of nuclear weapons is a vital issue and the President's *National Security Strategy* correctly underscores this threat to America's national security.

Concern about the spread of nuclear weapons is not a new theme. During the 1960s, after China and France successfully joined the nuclear club and other countries were eyeing nuclear weapons programs, the prevailing belief was that nuclear proliferation was on the verge of rapidly spreading across the globe. In the early-1960s, President Kennedy stated: "I see the possibility in the 1970's of the President of the United States having to face a world in which 15 or 20 or 25 nations may have these [nuclear] weapons."⁴ Yet today, there are "only" nine countries with nuclear weapons, so it might appear as if proliferation pessimists overestimated the threat. But the fact of the matter is that nonproliferation efforts by the United States and others limited the spread of nuclear weapons and without continued attention on this serious problem, many additional countries might have nuclear weapons today than the current nine.

Once a country develops nuclear weapons, the tendency is for it to retain them. There are only two unique exceptions where countries decided to disassemble their nuclear weapons programs.⁵ Conversely, proliferation continues to climb with North Korea demonstrating its nuclear capability in 2006. The United States along with other countries are trying to entice North Korea to reverse its nuclear program, although the verdict is still out on whether or not their efforts will be successful. Nevertheless, it does not appear that any of the eight other nuclear powers intend to dismantle their nuclear weapons programs anytime in the foreseeable future. Furthermore, there are additional

threats on the horizon, with countries such as Iran that are almost certainly pursuing a nuclear weapons capability. If Iran were to attain nuclear weapons status, it would likely relish its heightened power, which is a dangerous situation with a country that is committed to exporting terrorism and that has a history of attacking Americans abroad.⁶ As the situation in the Middle East continues to evolve, along with a high-likelihood that Iranian and American interests will increasingly collide, the regional implications of a more powerful Iran are worrying.

Inevitably, some countries will endeavor to build nuclear weapons. As such, America requires the means to detect clandestine nuclear weapons programs. This capability is essential not only for nonproliferation, but for counter-proliferation efforts as well. For nonproliferation, such information is critical to resoundingly prove to the international community the problem at hand and to then develop an effective strategy to convince the leadership of the country in question to terminate its nuclear weapons program. If nonproliferation efforts fail, it is essential to know as much as possible about an emerging nuclear power's program to include the locations of its facilities, as the international community and the United States might need to consider a range of options to deal with the proliferator, possibly including counter-proliferation measures.

First, this paper delves into why the leadership of some countries desire nuclear weapons along with the role that international agreements and programs specific to the United States play in the proliferation arena. Then follows a discussion on what is known as the "nuclear fuel cycle." Any entity, be it a nation-state or a non-state actor wanting to have an effective and sustainable nuclear weapons program, must master the nuclear fuel cycle. It is within the nuclear fuel cycle that the core material is produced that then can

be assembled into a nuclear device. While there are two main “routes” or options that can be followed to produce nuclear weapons-grade material, the method most en vogue appears to be the process of highly enriching uranium, hence this study’s focus on the uranium route.

Next, several case studies are analyzed to determine why certain countries made the decision to covertly start a nuclear weapons program. An overview of each country’s uranium fuel cycle is discussed along with lessons learned. Finally, conclusions and recommendations for American nonproliferation programs in relation to clandestine proliferators are presented.

There is a wealth of literature on nuclear nonproliferation, as would be expected of a topic of such importance. Yet relatively few works focus specifically on proliferation issues associated with clandestine nuclear programs. There are two monographs that deal with certain aspects of this topic quite well. The first example written by Robert F. Mozley provides an excellent summary of the nuclear fuel cycle and the key issues with nonproliferation, yet his conclusions are limited by a reliance on international solutions to stop emerging proliferators; a strategy that was not successful with North Korea and has yet to yield results with Iran. The second book edited by Allan S. Krass, et al, though dated, has excellent descriptions of nonproliferation concerns pertaining to uranium enrichment, but the book’s proposed solutions deal almost exclusively with verification regimes. This paper attempts to bridge the gap not addressed in other works by connecting the nuclear fuel cycle with pertinent examples of past and current proliferators, then providing recommendations for how the United States should strengthen its efforts to identify emerging, clandestine nuclear weapons programs. Only

with accurate identification of threats can an effective strategy be developed to stop nuclear proliferation.

Notes

¹ White House, *The National Security Strategy of the United States of America* (Washington D.C.: Office of the White House, 2006), 19.

² The nine nuclear powers are the United States, Russia, United Kingdom, France, China, Israel (assumed), India, Pakistan, and most recently, North Korea. South Africa had a nuclear capability at one point, but has since dismantled it. Mohamed ElBaradei, “Addressing Verification Challenges” (symposium, International Safeguards, Vienna, Austria, 16 October 2006).

³ In 1984, Stephen Meyer developed a model to analyze countries that had indigenous materials and the knowledge necessary to build a nuclear weapon. His model was later updated by Rice University. The most recent version from Rice University, dated 1992, indicated that 48 countries could eventually develop a nuclear device, given the desire to do so. That number almost certainly would be higher today. Stephen Meyer, *The Dynamics of Nuclear Proliferation* (Chicago: University of Chicago Press, 1984); for the revised model, reference: <http://es.rice.edu/projects/Poli378/Nuclear/Proliferation/>.

⁴ John F. Kennedy, “News Conference 52,” *John F. Kennedy Presidential Library and Museum* (address, State Department auditorium, 21 March 1963).

⁵ South Africa covertly acquired then later dismantled its nuclear weapons. Also, three “Former Soviet Union” (FSU) countries, Belarus, Kazakhstan, and the Ukraine, surrendered the nuclear weapons they inherited from the breakup of the Soviet Union, giving them to Russia.

⁶ Iran’s support of Hezbollah is well-documented. The 1983 bombing of the Marine barracks in Beirut, killing 241 Marines, and the 1996 Khobar Towers bombing in Saudi Arabia, killing 19 Americans, are cited as evidence for Iranian attacks on American’s abroad. Finally, Iran is complicit in killing U.S. forces in Iraq and undermining international efforts to resolve the conflict. Kenneth M. Pollack, *The Persian Puzzle: The Conflict Between Iran and America* (New York, NY: Random House Inc, 2004), 203 and 282. Also: James A. Baker III and Lee H. Hamilton, et al, *The Iraq Study Group Report* (Washington D.C.: 2006), 24-5, 38.

Chapter 2

The Path to Nuclear Weapons

The international community, especially the United States, recognizes the temptations for nuclear weapons faced by some countries. This chapter explores the rationale of why some countries aspire for nuclear weapons, and also addresses international and American efforts to stem the tide of proliferation.

Why Some Nation-States Desire Nuclear Weapons

The history of the United States' nuclear program provides an example as to why some countries might want nuclear weapons. America initially pursued the “atomic bomb” as a hedge against Germany’s growing nuclear weapons program. Later, after America learned that Germany did not have as robust of a nuclear program as was initially thought and whose defeat seemed certain, then decided to employ its newly found nuclear weapons capability against Japan as means to end the war.¹ As relations deteriorated between the United States and the Soviet Union into what became known as the Cold War, “deterrence” became the main purpose for America’s nuclear weapons program. After the end of the Cold War, the United States’ nuclear forces continue to serve as a means to deter against the use of weapons of mass destruction against America.² As this example illustrates, often there can be more than one reason why a country begins a nuclear program, although deterrence tends to be a common theme, as

will be highlighted in later case studies. Nor is a country's rationale for nuclear weapons necessarily static when world or regional events change. Kenneth Waltz tersely, yet effectively summarizes into seven reasons why some countries want nuclear weapons:

Table 1. Reasons for Wanting Nuclear Weapons

- | |
|--|
| <ul style="list-style-type: none"> • Great powers tend to imitate other great powers. • Fear that a nation-states' great power-ally may not come to its aid if it is attacked by another great power. • A nation-state will want nuclear weapons if its adversaries have nuclear weapons. • If a nation-state is in fear of another nation-state's present or future strength. • Nuclear weapons could present a cheaper alternative to a conventional arms race. • For offensive purposes. • To enhance the nation-state's international standing. |
|--|

Source: Kenneth N. Waltz, "Peace, Stability, and Nuclear Weapons," *Institute on Global Conflict and Cooperation* (University of California: IGCC Policy Paper 15, 1995), 5-6.

Rarely does the impetus to develop a nuclear program originate from the masses within a nation-state.³ Usually a country's leadership, be it a body of individuals or a sole dictator, tends to have one or more of the above perceptions of why they require nuclear weapons, often without public debate. But once the seed is planted, it can be very difficult to persuade the country to choose a different course.⁴

It stands to reason that the ideal approach with nuclear nonproliferation is to assuage the leadership of potential proliferators' insecurities or concerns before they decide to begin their journey towards nuclear weapons. Perhaps the most successful example of this is the nuclear aspect of the North Atlantic Treaty Organization (NATO), where a combination of the NATO alliance, the American nuclear umbrella, in addition to nuclear weapons sharing with select NATO members, convinced several European countries,

especially Germany, not to develop indigenous nuclear weapons programs.⁵ Similarly, a country's leadership can sometimes be swayed through diplomacy to stop their nuclear weapons program. Case in point is South Korea, where it began a covert effort to develop the necessary technologies to highly enrich uranium, but later ended their program after a combination of pressure and security guarantees from the United States.⁶ Thus, "carrots" sometimes can persuade countries from fulfilling their desire for nuclear weapons.

Yet there are limitations with the above strategies in that they are only applicable to countries that are friends or allies with the United States. Attempts to entice nation-states that operate outside of international norms may not only be ineffective, but also can have the unsavory taint of "appeasement," with all of the baggage that this approach carries from the European experience with Adolph Hitler's Germany. This brings to the fore the notion of using "sticks" as a means to compel a country to end its nuclear proliferation activities, with options ranging from sanctions to preemptive war. Case studies in Chapter 4 will delve into these aspects, but suffice to say, the use of "sticks" has mixed effectiveness.

International Nonproliferation Efforts

International treaties and agreements provide several effective measures to encourage nuclear nonproliferation. One of the most successful international agreements yet devised is the Nuclear Non-Proliferation Treaty (NPT). The only international agreement that surpasses the number of ratified members to the NPT is the United Nations charter itself. As of February 2007, 189 of 193 nation-states recognized by the United Nations are parties to the NPT. Not surprisingly, the only countries that are not

signatories to the NPT today either have, or are suspected of having nuclear weapons: India, Israel (assumed), North Korea, and Pakistan.⁷

The NPT entered into force in 1970, implementing several important provisions. For the countries already in possession of nuclear weapons, it was agreed that they would not transfer nuclear weapons expertise or materials to non-nuclear weapons nation-states. Up until this point, nuclear powers had provided assistance to specific countries, for example the Americans assisted the British with their nuclear weapons program, the Soviets helped the Chinese, and the French provided similar assistance to Israel.⁸ The NPT also required the non-nuclear weapons-states not to accept any of the aforementioned aid from the nuclear weapon nation-states. Additionally, all of the parties agreed to participate in a safeguard and verification regime conducted by what became known as the International Atomic Energy Agency (IAEA). Another critical aspect of the NPT confirmed that all nation-states had the right to pursue peaceful applications of atomic energy.⁹ This final point was essential to the success of the NPT, allowing the world to benefit from peaceful uses of the atom with the intention of satisfying their nuclear needs via energy, research, and medical uses of nuclear science in lieu of nuclear weapons.

The success of the NPT is undeniable. The treaty has considerably stemmed the spread of nuclear weapons knowledge and materials, and the proliferation rate in the world dropped dramatically after its implementation. Yet at the same time, several nation-states subsequently violated their treaty obligations with clandestine nuclear weapons programs--a trend that continues to this day. Efforts to enforce compliance of the treaty by the international community have not been very successful. One strategy to enforce NPT compliance is the use of economic sanctions, be they unilateral, multilateral

or in exceptional cases, from the UN Security Council. North Korea provides an explicit instance of NPT non-compliance, where it, as an NPT member, conducted nuclear weapons research and even production of nuclear materials in the face of severe international sanctions, and then pulled out of the treaty when it all but had assembled nuclear weapons. In fact, the IAEA was unable to properly verify North Korea's nuclear safeguards program shortly after it signed the NPT in 1985 until 2003 when it formally withdrew from the treaty.¹⁰ The IAEA and the international community at large knew that North Korea was not complying with the NPT, but since the IAEA was at least given minimal access to loosely monitor the status of North Korea's nuclear program, it was perhaps decided that North Korea should remain in the NPT, albeit in name only, rather than kick them out for non-compliance. The North Korean case thus highlights the inherent weakness of international agreements, in that the international community largely is hesitant to enforce even the most blatant violations.

There are additional problems with the NPT. When the NPT was drafted in the late-1960, its authors did not fully consider the various twists and turns that future proliferators might attempt and apparent "loopholes" were later discovered in the original text. One such example is that the NPT relies heavily on verification of nuclear activities at specific facilities that countries *declare* to the IAEA in their comprehensive safeguard agreement. Nuclear facilities that a particular country *refuses to declare* were not specifically addressed in the NPT's verification scheme, thereby limiting the effectiveness of the inspection regime.¹¹ To address this shortcoming, in the late-1990s the United States and others proposed what is called the "Additional Protocol" to the comprehensive safeguards agreement with the intention of strengthening the safeguard

and verification aspects of the IAEA. The Additional Protocol requires signatories to declare to the IAEA all aspects of its nuclear fuel cycle, to include items such as uranium mining which was not covered by the NPT. Parties to the protocol must also allow the IAEA access to all nuclear-related sites, in some cases, on short-notice. Significantly, the IAEA is also permitted to collect environmental samples beyond locations declared as “nuclear related,” whenever such inspections are deemed necessary.¹² The IAEA’s increased access can more aggressively and accurately detect those cheating on the NPT. But the Additional Protocol has not enjoyed the degree of success as that of the original NPT in terms of world-wide acceptance, as the protocol is currently in force in only 78 countries thus far, although 34 additional countries intend on joining the agreement as of February 2007.¹³ While the Additional Protocol offers improvements to the NPT, for that very reason, countries that are either actively engaged in nuclear proliferation or those wanting to leave open the option for future clandestine programs will simply not sign the agreement.

Another aspect of international safeguards is that of export controls. Export controls as part of what is today known as the Nuclear Supplier Group (NSG) and are an attempt to limit the sale of nuclear-related technology.¹⁴ While the NSG is not formally associated with the IAEA, the program certainly operates in concert with it. Without export controls, many technologies and equipment critical to nuclear weapons programs could otherwise be widely available for purchase on the open market by proliferators. In accordance with export controls, nation-states are required to ensure materials or equipment that are able to be employed for nuclear weapons production, cannot be sold or exported unless specific criteria are met to guarantee that its use will be for peaceful

purposes. Currently, there are 45 countries party to the NSG.¹⁵ But lack of compliance and enforcement are the shortfalls of export controls. The United States, for example, has aggressive export controls but it is possible that some items can slip through its net. Unfortunately in Europe and Asia, there are many cases of non-compliance.

International agreements and export controls make covert proliferation more difficult, but they are not a panacea. As for international agreements and associated IAEA inspections, at best they provide a means for the international community to verify that a nation-state is in compliance with agreements, and can sometimes detect undeclared nuclear activities, possibly leading to consequences such as sanctions. At worst, international agreements merely increase the amount of time that it takes a proliferator to acquire nuclear weapons. Export controls have certainly made it more difficult for proliferators to obtain necessary equipment and materials, but as case studies will later show, they are only as good as are the measures that a specific nation-state takes to ensure its government and private industry complies with export regulations, and there have been atrocious examples of turning a blind eye to exports by some countries.

U.S. Nonproliferation Policies and Programs

The United States' nonproliferation efforts are three-tiered. Specifically they include programs aimed at eliminating and securing nuclear materials, strengthening safeguard and verification regimes, and improving enforcement efforts against proliferators.

A prime example of the first aspect of America's nonproliferation strategy is the Nunn-Lugar Cooperative Threat Reduction (CTR) program that has made notable progress in securing and reducing the number of nuclear weapons in Russia.¹⁶ Also, for several years now the United States has worked closely with G-8 countries to secure and

reduce nuclear materials world-wide. During the 2004 G-8 summit, \$20 billion was allocated to this effort over a ten-year period, with half of the money coming from the United States to help countries reconfigure their nuclear reactors so they can operate without the need of weapons-grade uranium and to retrain nuclear scientists and technicians in countries such as Iraq and Libya.¹⁷

Second, the United States is pressing for increased international safeguards and verifications. An emphasis is placed on the Additional Protocol, which the United States would like to link with the NSG to only allow exports of nuclear materials to countries that are party to the protocol. The premise of this American policy is to entice, or depending on one's perspective, to coerce countries that operate civil nuclear power programs to sign the Additional Protocol or else their access to nuclear related equipment and even uranium reactor fuel could be denied.¹⁸ This is a back-door approach to close a loophole that countries like Iran appear to be using. Iran has chosen not to adopt the Additional Protocol and proclaims that since it is a member of the NPT, it is therefore guaranteed access to civilian nuclear power materials and expertise. Iran further asserts that it has the right to produce its own nuclear reactor fuel by enriching uranium. But the United States and the international community at large have serious concerns that Iran not only intends to enrich uranium for nuclear fuel, but that it ultimately plans on enriching weapons-grade uranium. There is also the belief that Iran may have additional enrichment facilities that have not been declared to the IAEA.¹⁹ Without the provisions of the Additional Protocol, the IAEA is not allowed to inspect suspicious, undeclared locations. If the American proposal to link international nuclear assistance with the Additional Protocol takes seed, it could make nuclear proliferation more difficult.

The purpose of the third component of America's nonproliferation strategy is to improve enforcement against proliferators. This avenue includes methods to better international cooperation in identifying and interdicting efforts by proliferators attempting to obtain nuclear materials. The Proliferation Security Initiative (PSI) is a prime example of this approach, where the United States works in concert with other countries to enforce national and international agreements, to include tracking suspected exports and intercepting them before a proliferator acquires them.²⁰ The PSI program proved to be a success when many tons of nuclear equipment was confiscated en route to Libya in 2003. Additionally, Security Council Resolution 1540, sponsored by the United States and subsequently passed by the Council in 2004, extends this principle by forbidding any nation-state to assist a non-state actor in the acquisition of weapons of mass destruction materials and technologies.²¹

United States policy includes another aspect with enforcement in regard to nuclear proliferation--preemptive actions, to include military attacks. The President's 2006 *National Security Strategy* states:

If necessary, however, under long-standing principles of self defense, we do not rule out the use of force before attacks occur, even if uncertainty remains as to the time and place of the enemy's attack. When the consequences of an attack with WMD are potentially so devastating, we cannot afford to stand idly by as grave dangers materialize. This is the principle and logic of preemption. The place of preemption in our national security strategy remains the same. We will always proceed deliberately, weighing the consequences of our actions. The reasons for our actions will be clear, the force measured, and the cause just.²²

This relatively new American policy and its impact with regard to future proliferation will be addressed in more depth later. But with the Iraq War in 2003, however controversial, America's preemptive war doctrine was undeniably executed.

As with many programs within a government as large as that of the United States, no one agency is solely responsible for nonproliferation. Some nonproliferation programs reside almost exclusively within a single department, for example, the role of diplomacy rests primarily with the State Department. But as is more often the case, nonproliferation programs are spread across several agencies and departments--the critical role of intelligence is a fine illustration of this aspect, as many governmental organizations contribute to American nuclear proliferation intelligence.

Nonproliferation programs within the United States are buttressed with intelligence. Effective intelligence is essential for a wide range of nonproliferation activities, from identification of countries attempting to covertly develop nuclear weapons programs to finding suspected exporters that are assisting with such programs.

As a result of intelligence failures following Operation IRAQI FREEDOM, President Bush inaugurated a new cabinet post with the goal of improving the coordination and quality of the various intelligence agencies and departments. The new agency under the Director of National Intelligence (DNI) also has a proliferation directorate, the National Counter-proliferation Center, to perform intelligence coordination and analysis in that vital area.²³ But since the DNI does not enjoy overall control of the many agencies and departments involved in nonproliferation, there are limits in the degree of cooperation between organizations.

Switching from the intelligence aspect of national security to that of nonproliferation, it must be noted that no individual below the President of the United States has sole authority for nonproliferation programs, therefore, unity of effort can be problematic. One department could find an innovative method to detect uranium

proliferators, but its efforts might be meaningless if the agencies or departments that are charged with active intelligence gathering do not adopt the idea and budget for it. This is not to say that cooperation does not exist in the nonproliferation arena, however. To be sure, the many organizations and agencies involved with intelligence and nonproliferation do cooperate and coordinate their activities with each other. But without a hierarchical structure headed by single individual responsible for all activities within a specific area, such as nonproliferation for example, as well as having the authority that a centralized budget can provide, there undoubtedly will be limitations with the current construct.

Of the departments whose budgets are transparent, the Department of Energy (DOE) has the largest nonproliferation budget. For 2006, DOE's budget included \$1.6B appropriated for nuclear nonproliferation.²⁴ Other agencies with nonproliferation responsibilities and corresponding budgets include the Department of State and the Department of Defense, each funded for roughly \$410M and \$416M, respectively, for Fiscal Year (FY) 2006.²⁵ The DOE office charged with developing technologies to detect, locate, and analyze foreign nuclear fuel cycle components is called the Office of Nonproliferation Research and Development, or "NA-22" for short.²⁶ The budget for NA-22 for FY05 and 06, and proposed for FY07 is \$220M, \$319M, and \$269M, respectively. While the monies allocated to nonproliferation programs such as NA-22 are not trivial, they also are not a large amount when considering the importance and complexity of their mission.

When looking deeper into the difficult task of discovering technologies and methods to find clandestine uranium enrichment, DOE assessed that its progress was only three

percent complete toward its end state during 2005, with a goal of program completion in 2016.²⁷ The complexity of this undertaking is no doubt a contributing factor to the extended timeline for attaining a capability to detect covert uranium enrichment programs. Yet, it begs the question of what is the realm of the possible if more resources were focused on the technical challenges with this critical program.

Despite the best efforts from the international community and by countries such as the United States, some nation-states will make every attempt to develop a nuclear weapons program. Only by understanding how they do it can approaches be developed to stop or delay proliferators as long as possible.

Ways to Acquire Nuclear Weapons

Simply stated, there are three ways for an emerging proliferator to obtain nuclear weapons: they can steal them, buy them, or produce indigenous nuclear weapons themselves.

There are no known instances of stolen or purchased nuclear weapons from an existing nuclear power, but there are concerns with both of these possibilities. This is the case with the FSU countries that have abundant nuclear material, and with Russia in particular, that has an ample stockpile of nuclear weapons with less than ideal security.²⁸ The United States has several programs to assist these countries in securing their nuclear weapons to mitigate this problem.²⁹ While these programs certainly make it more difficult than it would otherwise be for an entity to get a nuclear weapon, they cannot provide fail-safe guarantees against proliferation. Recently, Georgian officials claim that a Russian citizen attempted to sell a few ounces of highly enriched uranium to Islamist

extremists. The amount of uranium was not nearly enough to make a bomb, but this event was a very troubling scenario nonetheless.³⁰

Buying or stealing a nuclear weapon may achieve the objectives of a non-state extremist group wishing to use the device as a terror weapon, but it would not likely accomplish the goals of a nation-state that desires a genuine nuclear weapons capability. To be taken seriously as a nuclear power, a country must have a sustainable nuclear program.

Mastering the nuclear fuel cycle is the basis for developing nuclear weapons. This can be done by following either the plutonium or uranium route, or in several cases, simultaneously pursuing both routes.³¹ Fortunately, neither is an easy path to follow. Despite the challenges, several nation-states have strived to develop fission nuclear weapons.³² It is a hard choice for a proliferator to decide which route, either plutonium or uranium, that it should follow as its best means for nuclear weapons. An anonymous scientist once stated “the easiest route to a nuclear device is the opposite from which they pursued.” Either trail they chose will certainly be rock strewn with many hills and valleys.

There are advantages with the plutonium route. First, a plutonium device requires less material to achieve a nuclear yield than that of uranium.³³ Producing either weapons-grade plutonium or uranium is an expensive, highly technical, and time-consuming effort, so there are incentives in selecting a method that requires less material to develop a fission weapon, namely, using plutonium. Hand-in-hand with requiring less material than a uranium-based weapon, plutonium bombs can produce a greater yield

than that an equivalent amount of uranium because of its increased efficiency during detonation.³⁴

Yet, there are several challenges with a plutonium nuclear weapons program. A prerequisite for a nation-state wanting to develop a plutonium nuclear weapons capability is that it must have an operational nuclear reactor. This is because plutonium is not indigenous to the earth; it is a man-made element. Plutonium, specifically the isotope plutonium-239, can only be obtained by chemically extracting it from used nuclear fuel.³⁵ The international community recognized the high proliferation potential of nuclear reactor technology with the implementation of the safeguards associated with the NPT in 1970. Since then, reactor technology and expertise has largely been provided only to countries that are parties to safeguards designed to minimize the likelihood of using the spent reactor fuel for nuclear weapons, although there have been exceptions where nuclear reactor assistance was not carefully controlled.

Historically, several countries selected the plutonium route as their primary path to nuclear weapons, to include India and Israel, whereas others pursued the plutonium and uranium paths simultaneously, such as the United States, the Soviet Union, France and the United Kingdom. For these countries, plutonium was the ideal path toward nuclear weapons because of the availability of nuclear reactor technology, material, and expertise. Another contributing reason that these countries preferred plutonium was that until 1970, international protocols to curb the spread of nuclear weapons technology were almost entirely absent. In fact, most of the countries that went with the plutonium route did so before the 1970 implementation of the NPT, probably because today's verification and safeguard regimes are generally effective in addressing the plutonium route, in

addition to the difficulty of covertly developing and operating a nuclear reactor. Since 1970, North Korea and India stand out as the only countries to develop their initial nuclear weapons capability via the plutonium route.³⁶

Invariably, proliferators today will be members to the NPT, as the only countries in the world today that are not members to the NPT already have nuclear weapons, or in the case of Israel, are assumed to. So this leaves the clandestine proliferator “want-to-be” with three options. They can either attempt to operate a nuclear reactor outside of current international nonproliferation verification regimes knowing that it will not be easy since nuclear reactors are difficult to hide from prying eyes, they can withdraw from the NPT and face possible international consequences, or finally, they can attempt the uranium route.³⁷

Emerging proliferators appear to now favor the uranium path because it too has advantages over the plutonium method. Most prominently, a nuclear reactor does not play any role in development of a uranium-based weapon. As detailed earlier, the international community appears to be doing a reasonably good job of safeguarding the transfer of reactor technology and implementing verification regimes to keep a tighter lid on proliferation stemming from nuclear reactors. With the uranium path, this aspect with reactors is entirely absent. Also, natural uranium is available in many parts of the earth and while the process of refining the uranium to the point where it can be weaponized is very complex, the raw element of uranium is not difficult to acquire. An additional reason why proliferators may go down the uranium route is that some methods of uranium enrichment are well-suited for a clandestine program. Finally, it is easier to assemble a nuclear weapon using uranium than that of plutonium. During World War II,

American scientists were so confident that its first uranium weapon would work, that it was not even tested before being used operationally over Hiroshima on August 6, 1945.³⁸ Once a country has mastered the ability to enrich uranium, everything else is downhill from there.

There are a number of countries that recently used uranium for their nuclear weapons programs. South Africa and Pakistan selected uranium as their nuclear material of choice in their successful weapons programs.³⁹ Several other countries also used uranium before they ceased their programs, such as Argentina, Brazil, and South Korea.⁴⁰ Iran continues on its journey toward enriching uranium. It should also be noted that while North Korea derived its nuclear weapons capability via the plutonium route, it was North Korea's non-compliance with the "1994 Agreed Framework" after American accusations about its undeclared uranium enrichment program that led to the confrontation between the United States and North Korea in 2002.⁴¹ Recently, American officials decreased their confidence in the 2002 assessments on North Korea's enrichment program; nevertheless, it was their alleged uranium enrichment program that led to America's hard-line approach with North Korea.⁴²

The next chapter focuses on the uranium nuclear fuel cycle, but in no way does the emphasis on the uranium path minimize the importance of dealing with issues related to the plutonium route. The latter is merely beyond the purview of this study. The spotlight on the uranium route is because it appears to be the preferred nuclear material for clandestine proliferators.

Notes

¹ Henry L. Stimson, “The Decision to Use the Atomic Bomb,” *Harpers Magazine*, February 1947, 98-101.

² Chairman of the Joint Chiefs of Staff, *The National Military Strategy of the United States of America* (Washington D.C.: Government Printing Office, 2004), 12.

³ A notable exception to this is Pakistan, where after several perceived humiliations from India, the populace supported Pakistan’s nuclear program.

⁴ Jacques E.C. Hymans, *The Psychology of Nuclear Proliferation: Identity, Emotions, and Foreign Policy* (Cambridge, UK: Cambridge University Press, 2006), 1-12.

⁵ Germany was likely to develop nuclear weapons as it had a combination of tremendous nuclear technical expertise along with the need for security with the ensuing Cold War, nonetheless Germany chose not to realize its nuclear potential. Jenifer Mackby and Walter B. Slocombe, “Germany: The Model Case, A Historical Perspective,” in *The Nuclear Tipping Point: Why States Reconsider Their Nuclear Choices*, ed. Kurt M. Campbell, et al, (Washington D.C.: Brooking Institution Press, 2004), 191 and 209.

⁶ South Korea agreed to end its program in the late-1970s, but continued to conduct enrichment experiments until the early-1990s. After confrontation by the IAEA, South Korea admitted to the experiments and finally relented to full IAEA safeguard verification. Dafna Linzer, “S. Korea Nuclear Project Derailed,” *The Washington Post*, 12 September 2004, A24.

⁷ India, Pakistan, and Israel were never a party to the NPT. North Korea was a member to the agreement beginning in 1985, but withdrew in 2003.

⁸ The Wisconsin Project on Nuclear Arms Control provides an excellent overview of several nuclear capable countries and can be found at: <http://www.wisconsinproject.org/countryinfo.html>.

⁹ This is merely a brief summary of the NPT’s key provisions. To view the complete document, reference: International Atomic Energy Agency, *Treaty on the Non-proliferation of Nuclear Weapons* (Vienna, Austria: IAEA document INFCIRC/140, 22 April 1970).

¹⁰ Ibid, *Implementation of the Safeguards Agreement with the Democratic People’s Republic of Korea Pursuit to the Treaty on the Non-Proliferation of Nuclear Weapons* (Vienna, Austria: IAEA document: GC/48[17], 16 August 2004), 1-3.

¹¹ Ibid, *IAEA Safeguards: Stemming the Spread of Nuclear Weapons* (Vienna, Austria: 2002), 2.

¹² Ibid, 3. Also: Ibid, *Model Protocol Additional to the Agreement(s) Between State(s) and the International Atomic Energy Agency for the Application of Safeguards* (Vienna, Austria: IAEA document: INFCIRC 540, Corrected).

¹³ Ibid, “Status of the Additional Protocol,” http://www.iaea.org/OurWork/SV/Safeguards/sg_protocol.html.

¹⁴ This effort initially began as the Zangger Committee that issued “trigger group” documentation to help nation-states understand what equipment and technologies can and cannot be exported. This endeavor was refined by the Nuclear Suppliers Group that

Notes

further elaborated on the Zangger Committee, and added additional equipment that has dual-use potential.

¹⁵ The NSG maintains a current list of its membership at <http://www.nuclearsuppliersgroup.org/member.htm>.

¹⁶ James E. Goodby, et al, *Cooperative Threat Reduction for a New Era* (Washington D.C.: National Defense University, September 2004), 1-2.

¹⁷ George W. Bush, "Remarks by the President on Weapons of Mass Destruction Proliferation," (Washington D.C.: Office of the White House, 11 February 2004).

¹⁸ Ibid.

¹⁹ Gregory Schulte, "Address to German United National Association," *Iran Watch*, 8 Feb 2007, <http://www.iranfocus.com/modules/news/makepdf.php?storyid=10109>.

²⁰ State Department, "Factsheet on the Proliferation Security Initiative" (Washington D.C.: June 2004), <http://usinfo.state.gov/products/pubsproliferation/proliferation.pdf>.

²¹ United Nations Security Council, *Resolution 1540* (New York, NY: document S/Res/1540/2004).

²² White House, *The National Security Strategy of the United States of America*, 23.

²³ Director of National Intelligence, "National Counter-Proliferation Center Fact Sheet," <http://www.dni.gov/aboutODNI/organization/NCPC.htm>.

²⁴ Department of Energy, "Budget Highlights," *FY 2006 Congressional Budget Request* (Washington D.C.: document DOE/ME-0053, February 2005), 17.

²⁵ The DOD budget numbers reflect only the monies dedicated for the Former Soviet Union non-proliferation efforts. The funding for the CIA and other such agencies are not available. Congressional Research Service, "Nuclear Nonproliferation Issues," *CRS Report for Congress* (Washington D.C.: 20 January 2006), 9-10.

²⁶ Department of Energy, "Fact Sheet on NA-22," http://www.nnsa.doe.gov/na-20/detect_prolif.shtml.

²⁷ White House, "Detailed Information on the NNSA Non-proliferation and Verification Research and Development Assessment" (Washington D.C.: Office of the White House), <http://www.whitehouse.gov/omb/expectmore/detail.10003408.2005.html>.

²⁸ Congressional Research Service, *Nuclear Weapons in Russia: Safety, Security and Control Issues* (Washington D.C.: Library of Congress, 25 November 2002), 6.

²⁹ The Cooperative Threat Reduction program assists Russia with dismantlement of its retired nuclear weapons and constructs storage shelter for Russia's fissile material. The Materials, Protection, Control, and Accounting program upgrades security of Russian nuclear weapons. Also, the United States is buying weapons-grade uranium from Russia and blending it down for use in American nuclear reactors. Robert L. Civiak, *Closing the Gaps: Securing Highly Enriched Uranium in the Former Soviet Union and Eastern Europe* (Washington D.C.: Federation of American Scientists, May 2002), 31-2.

³⁰ Associated Press, "Russian Smuggled Nuclear-Bomb Uranium, Source Says," *CNN.com*, 25 January, 2007, <http://transcripts.cnn.com/TRANSCRIPTS/0701/25/cnr.07.html>.

³¹ There are several fissionable isotopes that theoretically could be used to develop nuclear weapons, but Plutonium-239 (Pu-239) and Uranium-235 (U-235) are the core

Notes

isotopes for fission weapons. A third method using U-233 derived from thorium constitutes what is known as the “Thorium Route.” Producing a weapon from thorium is somewhat more complex than that of plutonium and it is unlikely that proliferators would choose the thorium route since there are no advantages in doing so. Other fissionable isotopes include neptunium-237 and several isotopes of americium, curium, and californium, but producing them in quantity is more difficult than the plutonium or uranium routes. National Academy of Sciences, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities* (Washington D.C.: National Academics Press, 2005), 113 and 221.

³² In short, “fission” is a process where the nucleus of an atom is split, causing a chain-reaction that creates significant energy. “Fusion” weapons, also known as “thermonuclear” weapons, require the heat of a fission explosion, where they in turn, produce much greater energy. Samuel Glasstone and Phillip J. Dolan, ed., *The Effects of Nuclear Weapons* (Washington D.C.: Department of Defense and Department of Energy, 1977), 5-6.

³³ A plutonium weapon requires a minimum of 5-8 kg of Pu-239 to develop super-critical mass for a nuclear detonation, whereas a uranium weapon requires at least 10-25 kg of highly-enriched U-235. Center for Nonproliferation Studies (CNS), *CNS Nuclear Proliferation Treaty Briefing Book* (CNS, 2005), 3.

³⁴ Robert F. Mozley, *The Politics and Technology of Nuclear Proliferation* (Seattle: University of Washington Press, 1998), 77.

³⁵ Nuclear reactors using U-238 as its fuel source is the only way to produce Pu-239. Plutonium is produced when the U-238 absorbs a neutron (becoming U-239) which it then decays to neptunium-239, then later decaying to Pu-239. The Pu-239 must then be chemically separated from fuel rods through complex processes. Mozley, *The Politics and Technology of Nuclear Proliferation*, 43 and 57.

³⁶ It bears noting almost any country with a nuclear reactor could “break-out” from the NPT and eventually extract enough plutonium for nuclear weapons.

³⁷ Of note, the chemical conversion process to develop plutonium-239 releases several radioisotopes, to include the noble gas, krypton-85, that is difficult to hide from “national technical means.” National Academy of Sciences, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials*, 203-4.

³⁸ Richard Rhodes, *The Making of the Atomic Bomb* (New York, NY: Simon & Schuster, 1986), 651 and 710.

³⁹ Joseph Cirincione, Jon B. Wolfsthal, and Miriam Rajkumar, *Deadly Arsenals: Nuclear, Biological, and Chemical Threats* (2nd edition) (Washington D.C.: Carnegie Endowment of International Peace, 2005), 246 and 410.

⁴⁰ Ibid, 49, 385, and 395.

⁴¹ Congressional Research Service, “North Korea’s Nuclear Weapons Program,” *CRS Report for Congress* (Washington D.C.: CRS, 1 August 2006), 4-5 and 11.

⁴² David E. Sanger and William J. Broad, “U.S. Concedes Uncertainty on North Korean Uranium Effort,” *NYTimes.com*, 1 March 2007, <http://www.nytimes.com/2007/03/01/washington/01korea.html?ei=5088&en=37430b9fcca9512c&ex=1330405200&pagewanted=print>.

Chapter 3

The Uranium Nuclear Fuel Cycle

A specific isotope of uranium, U-235, is the key to developing a uranium-based nuclear weapon.¹ Under the right conditions, when U-235 is bombarded with neutrons, it begins a super-critical nuclear chain reaction capable of producing great energy.

It is a difficult challenge for proliferators to obtain the all-important U-235. Very little U-235 exists in natural uranium found on the earth. In fact, U-235 constitutes only 0.72 percent of natural uranium ore.² To build a uranium-based nuclear weapon, the concentration of U-235 must be significantly increased, or “enriched,” in order to provide an adequate ratio of the fissile material to achieve super-critical mass, resulting in a nuclear yield. Although there is no magic number for the required level of uranium enrichment for a weapon, ideal U-235 concentrations are about 90 percent.³ If the U-235 is enriched to 90 percent, roughly 15 kilograms (kg) are required to achieve a super-critical mass. Significantly more material is required for a nuclear yield at lower fractions of enrichment, adding more weight, size, and complexity to the weapon design.⁴ Yet, obtaining even a modest 15 kg of highly enriched uranium is a tremendous challenge for a proliferator.

Obtaining and Processing Natural Uranium

The first step is to procure natural uranium. The earth has sizable reserves of natural uranium ore. The composition of natural uranium in the earth's crust is comparable to that of tin; uranium is about 40 times more prevalent than silver.⁵ Just like many other elements found in the earth, only a portion of uranium is economically recoverable, but for the foreseeable future, there will be no shortages of the earth's natural uranium supply.⁶

Mining uranium is similar to that of coal and is relatively simple to accomplish. If a country is blessed with economically recoverable uranium resources, the ore can be mined without outside assistance. Case in point, Iran has several uranium mines, one of which is said to be capable of producing 132,000 tons of uranium ore. Despite international consensus that does not want Iran to enrich uranium, short of bombing Iran's mines, there is nothing that can be done to prevent them from extracting their own resources.⁷ For countries that want to hide their uranium activities, some methods would be quite visible to aerial reconnaissance like that of "strip mining," but other forms such as "in situ leach" mining are more difficult to detect.⁸

Not every country has economically recoverable uranium. For these countries, there are options to buy uranium ore, either on the open markets that are loosely monitored by the IAEA, or covert purchases through private contracts. The degree of IAEA verifications that a specific country is subject to varies by which agreements it has signed. Countries that are only a party to the basic provisions associated with the 1970 NPT do not need to declare uranium mining activities and purchases, while those

countries that adopted the Additional Protocol must report such activities and are subject to IAEA inspections.

A proliferator that lacks their own reserves would need to covertly purchase natural uranium ore. But intelligence agencies of several countries undoubtedly are on the lookout for under-the-counter export of natural uranium. The alleged sale of processed uranium ore from Niger to Iraq was one of the reasons cited by the United States as evidence that Iraq was pursuing a nuclear weapons program prior to the 2003 Iraq War. It was later established that Niger had not recently exported uranium to Iraq and that America's intelligence analysis was flawed.⁹ The behind-the-scenes acquisition of uranium is watched as closely as possible, and while in the Niger case incorrect conclusions were drawn, it shows that it may be difficult for a proliferator to buy uranium on the sly, yet nothing is impossible.

After the uranium is mined or procured abroad, it must be milled into what is commonly called "yellowcake." Yellowcake is not enriched--it is simply crushed and concentrated uranium. Yellowcake is the form of uranium that it is most often sold abroad. The final step before uranium enrichment can begin is to convert the yellowcake into a form that can be put through various enrichment methods. The most common is to convert the yellowcake into "uranium hexafluoride" or UF-6, which is used in several of the enrichment processes.

Uranium Enrichment

There are many techniques that a proliferator can select from to enrich uranium. As mentioned earlier, none of the methods to enrich uranium are easy; in fact, all are complex, though some are harder than others to accomplish. The reason for the

complexity involved with uranium enrichment is that it is difficult to separate the miniscule amounts of the highly-sought after and fissile U-235 from the bulk of natural uranium, the non-fissile U-238. The chemistry of the different uranium isotopes are almost identical, so mainstream chemical processes cannot separate the isotopes. Instead, other aspects of the isotopes must be exploited to separate the U-235 from the U-238, such as by differences in the isotope's mass and size.¹⁰

Electromagnetic Isotope Separation

The first method used to enrich uranium on a significant scale was developed by the United States as part of the Manhattan Project during World War II, and became known as the Electromagnetic Isotope Separation (EMIS) method. This technique uses electric “calutrons” to magnetically separate U-235 from U-238. This process in conjunction with other methods produced all of the uranium for the world's first uranium nuclear bomb, *Little Boy*. Of note, the Soviet Union's initial means to enrich uranium used EMIS as well.¹¹

In short, the EMIS process takes heated uranium ions and propels the gas through a magnetic field that bends its path 180 degrees. The U-235 molecules, being slightly lighter than the more prevalent U-238, will have a tendency to bend in a tighter radius than the U-238 molecules, thus providing a means to separate the U-235.¹² It sounds easier than it actually is, as the EMIS method is a messy and delicate process, as it requires a careful balance of the right amount of amperes to the calutrons to create the conditions to separate the uranium isotopes, but not so much power so as to cause hot spots or sparking. Even with ideal operations, invariably the calutrons will incur damage over time, requiring heavy maintenance. Ionized uranium is also very corrosive and it is

difficult to remove from the accumulators in the calutrons, so the machines must be shutdown periodically for uranium deposit removal and cleaning. Therefore, calutrons have significant downtime during uranium enrichment.¹³

EMIS is a very inefficient way to enrich uranium. Only a small amount of U-235 can be separated with each pass through the magnetic field. It took over 1,000 calutrons operating for about one year at a cost of about 5 billion dollars for America's initial effort to obtain enough uranium for a single weapon during 1944-5.¹⁴ The downtime of the calutrons for uranium collection and maintenance resulted in a painfully slow process to highly enrich uranium. Calutrons are also energy-hungry. During the latter years of World War II, the uranium enrichment methods employed at Oak Ridge, Tennessee, used one-seventh of America's total electricity, with a substantial amount of the energy powering the calutrons.¹⁵ Today with improved technologies, there could be increased efficiencies with EMIS than was the case during World War II, but nevertheless, EMIS's inherent processes require significant amounts of energy to produce sizable quantities of enriched uranium.

Because of its inefficiencies and tremendous power consumption, it was thought that EMIS was obsolete. But after Operation DESERT STORM, inspectors were surprised to learn that Iraq had developed their own calutrons and had made notable progress with enriching uranium, thus EMIS continues to be a possible means to enrich uranium, albeit an inefficient one.

Gaseous Diffusion

Another early method of enriching uranium used the gaseous diffusion process. This technique pumps uranium hexafluoride (UF-6) through a large system of specially

designed porous barriers. The lighter U-235 molecules pass through the barriers faster than the U-238 molecules, thereby separating the isotopes.¹⁶ But there are complexities with this method as well, as each barrier only slightly enriches the amount of U-235. To get the U-235 to about 90 percent enrichment, it could take up to 3,000 stages.¹⁷ Also, the holes in the barriers through which the UF-6 passes, must be minutely small making the barriers difficult to produce, in addition to the fact that UF-6 is corrosive to most metals, as Iraqi scientists discovered when they briefly pursued the gaseous diffusion method.¹⁸

Many countries have successfully used the gaseous diffusion method to enrich uranium, including Russia, China, the United Kingdom, the United States, and France. In fact, for the three decades following World War II, gaseous diffusion was the most commonly used technique for uranium enrichment. As recently as 1980, approximately 95 percent of the world's uranium enrichment was accomplished with gaseous diffusion.¹⁹ But while it has a long track record of success, gaseous diffusion is energy inefficient and requires a lot of capital to enrich uranium, hence its almost exclusive use by only the most developed countries of the world.²⁰ The costs of the barriers, compressors, piping and the construction of the facility itself are immense. So while the gaseous diffusion method has produced vast quantities of highly enriched uranium in the world, it is unlikely that a proliferator would choose this means, because of its cost, energy demands, and the difficulty in hiding such a large undertaking from other countries.²¹ But this technique cannot be wholly discounted either, as Argentina demonstrated that it could covertly construct a gaseous diffusion plant in the late 1970s.²²

Aerodynamic Separation

Another way of enriching uranium involves aerodynamic methods. The principle behind the aerodynamic approach is to introduce UF-6 into a hydrogen gas stream, and then to force the gas into a specially designed nozzle that aerodynamically separates the lighter U-235 from the heavier U-238, albeit in very small quantities, thus requiring a large number of stages and cascades to enrich the uranium to weapons-grade levels. This idea was theorized as early as World War II by British scientists, but at the time it was thought that aerodynamic isotope separation was unsuitable for large-scale operations.²³ It was not until the German scientist, E.W. Becker, perfected the “separation nozzle” technique that it became apparent that an aerodynamic method was a viable approach to enriching uranium. Germany later cooperated with a Brazilian company to further this effort. To date, the original “separation nozzle” method has not yielded a nuclear weapon, however, South Africa designed a derivative method called the “advanced vortex tube process” that proved successful.²⁴

This method resembles gaseous diffusion in the sense that it requires a lot of energy to compress the gas through the nozzles, and it is probably even a bit more inefficient than that of the former. This is because the UF-6 is highly diluted into a hydrogen carrier gas, requiring many stages and much time to obtain significant quantities of highly enriched uranium.²⁵ Proliferators may be hesitant to select this technique due to the enormous power consumption that it requires. Yet as highlighted above, South Africa successfully used this process for its nuclear weapons program.

Gas Centrifuge

The gas centrifuge appears to be the most popular method amongst nuclear weapons proliferators today. This technique uses centrifugal forces to separate the UF-6 by molecular weight. Although centrifuges were used in scientific laboratories for more than a hundred years, it was not until post-World War II Germany made improvements in the size, speed, and efficiency of centrifuges that isotope separation became a possibility. With centrifuges, the rotor spins very fast, making the heavier U-238 move towards the outer wall of the device while the lighter U-235 that is not as close to the wall, is scooped out of the rotor.²⁶ Just like the other methods, the amount of enrichment in one pass through a centrifuge is very slight, thus hundreds or thousands of centrifuges arranged in stages and cascades are required to sufficiently enrich uranium to weapons-grade levels.²⁷

The gas centrifuge technique has attributes that make it attractive for both clandestine and overt uranium enrichment programs. The electric motors of the centrifuges have relatively low power demands compared to other enrichment methods; centrifuges are perhaps 20-30 times more efficient than that of gaseous diffusion in terms of separative capacity. Second, while the hundreds to thousands of centrifuges require considerable space to house them, the facilities need not be as expansive as that needed for EMIS or gaseous diffusion.²⁸

Yet successful operation of gas centrifuges is a demanding task. Since only high-speed centrifuges are effective in separating uranium isotopes, special materials must be used in the construction of the rotors and other key components in addition to complex processes such as electron beam welding to name only one. There are also challenges with controlling resonances at certain frequencies of operation, along with ensuring that centrifuges are leak-proof and able to withstand the corrosive UF-6.²⁹ Another aspect

with centrifuges is that the dangers of their use for nuclear proliferation were apparent shortly after its invention and centrifuge technologies were appropriately classified.³⁰ Centrifuge components therefore have tight export controls, and the combination of the necessary knowledge and required material makes it difficult to develop a centrifuge program from scratch. However, proliferators can overcome these difficulties with outside help, as was the case with the A.Q. Khan network and the Iraqi centrifuge program prior to Operation DESERT STORM.³¹

Other Methods of Separation

There are additional techniques to enrich uranium but that have thus far not been used on an industrial scale. For example, lasers have successfully separated U-235 from U-238 in the laboratory. There are several enrichment methods using lasers, with the atomic-vapor laser isotope separation (AVLIS) technique seemingly being the most-researched.³² The technical challenges of using lasers to enrich uranium are immense. Many countries have experimented with laser enrichment methods, ultimately terminating their programs, to include the United States, Japan, France, United Kingdom, and Germany.³³ Yet some countries, Iran being one, continue to explore this technique.

Chemical and ion exchange methods also can separate uranium isotopes using complex processes. This method requires a large uranium input with a long equilibrium time for a relatively low enrichment rate. It is considered a poor method of enrichment with little possibility of attaining highly enriched uranium.³⁴

Comparison of Enrichment Methods

Perhaps the most encouraging aspect with nonproliferation is that to date, there does not seem to be a easy way to enrich uranium. It has been over 60 years since the

Manhattan Project successfully enriched U-235 to about 90 percent, yet it appears that there are no technological breakthroughs that permit easy separation of uranium isotopes.

Table 2 shows the key uranium enrichment methods and evaluates each through the eyes of a proliferator.

Table 2. Comparison of Enrichment Methods

Method	Degree of Complexity	Difficulty to Conceal	Efficiency of Method	Speed of Enrichment
EMIS	Medium	High	Low	Slow
Gaseous Diffusion	Hard	High	Low	Slow
Aerodynamic Separation	Medium	Medium	Low	Slow
Gas Centrifuge	Hard	Medium	Medium	Medium
Laser	Very Hard	Low	Low	Medium
Chemical/Ion Diffusion	Hard	Medium	Low	Very Slow

Source: Derived from Allan S. Krass, et al, *Uranium Enrichment and Nuclear Weapons Proliferation* (Stockholm, Sweden: Stockholm International Peace Institute, 1983), 19; and Robert F. Mozley, *The Politics and Technology of Nuclear Proliferation* (Seattle: University of Washington Press, 1998), 125.

No technique stands out significantly above that of others, as each has trade-offs. From a proliferator's perspective, the decision will probably come down to which technologies it has the best access to in terms of equipment and expertise.

Weapon Production

As was described earlier, nuclear weapon construction using uranium is simpler than that of plutonium-based weapons. This is because plutonium weapons must be imploded to achieve super-critical mass requiring advanced use of conventional explosive to ensure

the plutonium mass is quickly and evenly compressed. Uranium weapons, however, can be detonated one of two ways. Sub-critical uranium masses can be compressed just like plutonium, or more significantly, uranium weapons can be assembled using the so-called “gun-type” method.³⁵ The gun-type method, while not as efficient as the compression method, nonetheless is a very reliable technique of producing a nuclear detonation. In essence, the gun-type design has the uranium masses divided into two pieces. One part, the “target,” and the other, the “bullet,” is positioned in a gun barrel with a high explosive charge. When the device is fired, the uranium bullet slides into the target, and if done properly, the now single uranium mass will immediately begin a nuclear chain reaction.³⁶ Basic gun-type method theories are available via open source. To recall the American experience with its initial uranium weapon, *Little Boy*, a test was not deemed necessary as the scientists were very sure that the method would work. This makes the uranium route that much more complicated for intelligence services, because a country that goes down this path need not test a weapon in order to have reasonable confidence that it will work. South Africa had a nuclear weapons capability for more than a decade, yet may have never tested a weapon.³⁷ The bottom line is if a country can enrich uranium, everything else after that is downhill.

Notes

¹ An isotope is the sum of its atomic number (the number of protons) and the number of neutrons in an element. The element of uranium has an atomic number of 92 with U-235 having 143 neutrons (92 protons plus 143 neutrons equals the isotope 235). U-235 and 233 are the only fissionable isotopes of uranium (reference endnote 31 in Chapter 2 for more information pertaining to U-233). Allan S. Krass, et al, *Uranium Enrichment and Nuclear Weapons Proliferation* (Stockholm, Sweden: Stockholm International Peace Institute, 1983) 1-4.

² Natural uranium ore mined from the earth has only 0.72 percent of the fissile isotope U-235. Uranium-238 constitutes the bulk of the earth’s uranium ore at 99.27 percent, with U-234, a non-fissile isotope, making up a mere 0.006 percent. National

Notes

Academy of Sciences, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials*, 115.

³ The International Atomic Energy Agency defines low enriched uranium (LEU) as U-235 concentrations or enrichments above that of natural uranium up to 20 percent enrichment, which is a level that is considered to be too low for use in a nuclear weapon. Enrichment of U-235 above 20 percent is considered to be high enriched uranium (HEU), and can be used in nuclear weapons. International Atomic Energy Agency, *Management of Highly Enriched Uranium for Peaceful Purposes: Status and Trends* (Vienna, Austria: document IAEA-TECDOC-1452, 2005), 1. Also: National Academy of Sciences, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials*, 115 and 236.

⁴ Krass, *Uranium Enrichment and Nuclear Weapons Proliferation*, 5.

⁵ Uranium Information Center, *Uranium and Depleted Uranium: Nuclear Issues Briefing Paper #53* (2005), <http://www.uic.com.au/nip53.htm>.

⁶ In 2005 for example, an estimated 42,000 tons of uranium was mined throughout the world. Years from now, if the natural uranium reserves become cost prohibitive to recover from the earth, uranium could be derived from filtering seawater, as natural uranium is present in the earth's ocean water, providing an almost inexhaustible supply of uranium. Uranium Information Center, *World Uranium Mining: Nuclear Issues Briefing Paper #41*, (2006), <http://www.uic.com.au/nip41.htm>. Also reference A.K. Saxena, "Experiments for the Recovery of Uranium from Seawater by Harnessing Tidal Energy," *Bhabha Atomic Research Center Newsletter* (BARC, Issue 249, 2004), <http://www.barc.ernet.in/webpages/letter/2004/200410-36.pdf>.

⁷ Associated Press, "Iran Discovers Uranium Deposits, Continues Enrichment Program," *Foxnews.com*, 2 May 2006, <http://www.foxnews.com/story/0,2933,193938,00.html>.

⁸ "In Situ Leaching" is where chemicals are piped into the earth to loosen and dissolve the uranium ore, then are pumped to a processing plant. This process does not disturb the surface nearly as much as other mining methods and would therefore be more difficult to detect.

⁹ Laurence H. Silberman and Charles S. Robb, co-chairmen, *Commission of the Intelligence Capabilities of the United States Regarding Weapons of Mass Destruction* (Washington D.C.: 31 March 2005), 58 and 64.

¹⁰ Krass, *Uranium Enrichment and Nuclear Weapons Proliferation*, 6.

¹¹ Mozley, *The Politics and Technology of Nuclear Proliferation*, 84.

¹² Rhodes, *The Making of the Atomic Bomb*, 487-8.

¹³ Mozley, *The Politics and Technology of Nuclear Proliferation*, 91-3.

¹⁴ The cost of \$5B dollars is adjusted to FY96 dollars. Brookings Institution, "The Costs of the Manhattan Project," *Global Politics* (Washington D.C: Brookings Institution, 2002), <http://www.brookings.edu/fp/projects/nucwcost/manhattan.htm>. Also: Krass, *Uranium Enrichment and Nuclear Weapons Proliferation*, 178-9.

¹⁵ Keith McDaniel, *Secret City: The Oak Ridge Story, The War Years* (Oak Ridge, TN: The Secret City Film Institute, 2005), DVD.

¹⁶ Rhodes, *The Making of the Atomic Bomb*, 492.

¹⁷ Mozley, *The Politics and Technology of Nuclear Proliferation*, 99.

Notes

¹⁸ Mahdi Obeidi and Kurt Pitzer, *The Bomb in My Garden: The Secrets of Saddam's Nuclear Mastermind* (New Jersey: John Wiley & Sons, 2004), 59-60.

¹⁹ D. Massignon, "Gaseous Diffusion," in *Topics in Applied Physics Volume 35: Uranium Enrichment*, ed. S. Villani (Berlin, Germany: Springer-Verlag, 1979), 55.

²⁰ Sean Tyson, "Uranium Enrichment Technologies: Proliferation Implications" (Monterey, CA.: Center for Nonproliferation Studies: 1999), www.nti.org/db/archives/nuc/eos/tyson.htm.

²¹ Krass, *Uranium Enrichment and Nuclear Weapons Proliferation*, 128.

²² Joseph Cirincione, et al, *Deadly Arsenals*, 385.

²³ E.W. Becker, "Separation Nozzle," in *Topics in Applied Physics Volume 35: Uranium Enrichment*, ed. S. Villani (Berlin, Germany: Springer-Verlag, 1979), 245.

²⁴ David Albright, "South Africa's Secret Nuclear Weapons," *ISIS Report* (ISIS, May 1994), available at: <http://www.isis-online.org/publications/southafrica/ir0594.html>.

²⁵ S. Villani, *Topics in Applied Physics Volume 35: Uranium Enrichment* (Berlin, Germany: Springer-Verlag, 1979), 8-9.

²⁶ Soubbaramayer, "Centrifugation," in *Topics in Applied Physics Volume 35: Uranium Enrichment*, ed. S. Villani (Berlin, Germany: Springer-Verlag, 1979), 183 and 186.

²⁷ Mozley, *The Politics and Technology of Nuclear Proliferation*, 104.

²⁸ National Academy of Sciences, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials*, 228.

²⁹ Mozley, *The Politics and Technology of Nuclear Proliferation*, 104-108.

³⁰ Villani, *Topics in Applied Physics Volume 35*, 6-7.

³¹ In brief, A.Q. Khan stole European centrifuge technology and then built a largely Pakistani indigenous uranium enrichment capability, ultimately resulting in a successful nuclear weapons program, in many cases, circumventing export controls. He subsequently sold centrifuge equipment and expertise to Iran, North Korea, and Libya. As for the Iraqi case, Saddam Hussein's head centrifuge expert successfully acquired materials and limited knowledge that resulted in a budding centrifuge program. Both of these cases will be more completely discussed in chapter 4. Sources: Gordon Corera, *Shopping for Bombs: Nuclear Proliferation, Global Insecurity, and the Rise and Fall of the A.Q. Khan Network* (New York, NY: Oxford University Press, 2006) and Mahdi Obeidi and Kurt Pitzer, *The Bomb in My Garden*.

³² Other methods of enrichment using lasers includes molecular laser isotope separation (MLIS) and laser-assisted separation. Mozley, *The Politics and Technology of Nuclear Proliferation*, 121-2.

³³ Federation of American Scientists (FAS), "Uranium Production" (Washington D.C.: FAS), <http://www.fas/nuke/intro/uranium.htm>.

³⁴ S. Villani, *Topics in Applied Physics Volume 35*, 10.

³⁵ The reason why plutonium weapons can only be detonated from an implosion method is because plutonium must achieve super-critical density very rapidly via uniform compression of the plutonium pit using high-explosives. The gun-type method cannot assemble plutonium quickly enough to achieve super-critical mass--it would most likely "fizzle" instead of producing a nuclear detonation because the neutron chain reaction

Notes

begins very quickly as the plutonium assembles, which is too fast for the gun-type method. Uranium on the other hand can be assembled somewhat slower than that of plutonium before its neutrons begin the atomic chain reaction. Mozley, *The Politics and Technology of Nuclear Proliferation*, 126-133.

³⁶ Ibid, 126-133.

³⁷ It is controversial whether or not South Africa detonated a nuclear device in 1979, in what is known as the “Vela Incident.”

Chapter 4

Case Studies

When looking at nation-states that concentrated on uranium enrichment for their nuclear weapons programs, five countries stand out as great examples to draw lessons from: South Africa, Iraq, Pakistan, Libya, and Iran. For each case study, a brief description is offered as to why they desired nuclear weapons, followed by how they chose to enrich uranium, then the degree of effectiveness that the United States achieved in monitoring their program, and finally lessons that can be drawn from each example.

South Africa

South Africa is a good case to analyze, as it was a country that successfully developed an operational nuclear weapons capability without direct assistance from the major nuclear powers...then later elected to unilaterally dismantle its nuclear weapons.

Post-World War II South Africa operated outside of international norms with its Apartheid policies, and while not in the same league as that of Iran or North Korea today, South Africa was increasingly viewed by the West as a pariah by the 1970s. In addition to its flawed internal policies, South Africa encountered strife in the region. The southern areas of the African continent were destabilized with conflict after Portugal's rapid departure from Angola and Mozambique in 1975. South Africa also found itself militarily engaged in Angola, fighting well-supplied Communist forces that included

50,000 Cuban soldiers. With the Soviet Union actively supporting several insurgencies in the region, the United States initially supported the South Africans economically and militarily.¹ The Cold War had spread to the African continent and South Africa was caught in the middle of it.

But American support eventually dried up due to South Africa's racial internal policies, especially after President Carter assumed office. South African leaders then became increasingly concerned that its isolation could make it a victim of the Cold War and of Soviet-sponsored aggression without any assistance from the West.² South Africa's reclusive nature along with regional instability led its leadership to a conclusion that South Africa required nuclear weapons as a deterrent, albeit with an unusual twist. South Africa's leadership believed that a proxy war led by the Soviet Union on South African territory was a distinct possibility. The South African leaders knew that only the United States could protect them in this scenario, thus they wanted a means to get America's undivided attention if such a situation became an eventuality, despite Apartheid. They believed that a solution for this possible future crisis would be to conduct a well-timed test of a nuclear device. This, they thought, would likely entice the West and especially the United States to come to their rescue before conditions worsened to the point that a nuclear weapon might be operationally used in the region.³

From the time that South Africa's leaders determined that they wanted nuclear weapons, it only took them seven years to build their first device.⁴ To be sure, South Africa had the raw material to start a nuclear weapons program. In the 1970s, indigenous mines in South Africa made it one of the world's largest exporters of yellowcake.⁵ South Africa also had the benefit of several years' worth of nuclear expertise given to them by

several countries before it became a pariah by the mid-1970s. Under the Eisenhower Administration's "Atoms for Peace" program, the United States built South Africa's SAFARI-1 nuclear research reactor, thereby providing their scientists with valuable experience and knowledge.⁶ The CIA was also convinced that limited nuclear cooperation occurred between South Africa and another proliferator of the 1970s, Israel, although the connection remains unclear to this day.⁷ Nonetheless, with South Africa's refusal to sign the Nuclear Non-Proliferation Treaty (NPT), peaceful atomic assistance from the nuclear weapons countries, to include the United States, vanished. That certainly made it more challenging for South Africa's scientists, but it did not prevent them from successfully completing their mission.

As was briefly discussed in Chapter 3, South Africa selected an aerodynamic approach to enriching uranium. Although the German scientist E.W. Becker is credited with developing the separation nozzle method, the South African's refined the technology to what became known as the "advanced vortex tube process." The South African nuclear scientists likely learned from Becker's work from published, open sources. Indeed, several aspects of Becker's separation nozzle were published in unclassified documents. David Albright, the President of the Institute for Science and International Security, also argues that the incredible skill and initiative of the South African nuclear scientists and technicians were important assets, along with the fact that they had adequate funding to solve tough problems through trial and error.⁸ As it turned out, the increasingly stringent export controls placed on South Africa in the 1970s did not significantly hinder their ability to enrich uranium. After South Africa gave up its nuclear program in the early-1990s in conjunction with the fall of Apartheid, the IAEA

inspectors were surprised by the low-levels of technology that South Africa was able to successfully employ in its quest for nuclear weapons.⁹ The South Africa example underlines that nuclear expertise does not only reside within the most developed countries and that ingenuity can supersede the effectiveness of export controls.

Specific details of South Africa's nuclear weapons program were successfully hidden from the nuclear powers at the time, although it was highly suspected that the South Africans were eyeing nuclear weapons.¹⁰ This was largely because South Africa chose not to sign the NPT, which was a clear signal that they probably had nuclear ambitions. President Carter correctly recognized South Africa's nuclear proliferation desire shortly after assuming office, and that, combined with his concerns of human rights violations by the Apartheid government, resulted in termination of all American nuclear assistance to South Africa.¹¹ The first clear signal that the South Africans were serious about developing a nuclear capability was when a Soviet reconnaissance satellite spotted South African preparations in 1977 for an underground nuclear test in the Kalahari Desert. The Soviet Union quickly informed the United States about what they had detected and the United States subsequently pressured South Africa not to conduct a nuclear test, although it was later determined that their program probably was not ready for prime time at that juncture.¹² Regardless, from this point forward, the United States kept a closer eye on South Africa. A declassified CIA document from 1984 indicated that South Africa had the capability to produce several nuclear weapons on short-notice.¹³ By this time, the CIA's assessment was spot-on.

As alluded to earlier, after obtaining a limited nuclear deterrent for perhaps a decade, South Africa's leaders decided to give up, or "roll-back" its nuclear weapons program.

This decision probably was made as a result of several factors, including a resolution of its external threats in the region along with the eventual collapse of the Soviet Union, a change in the presidency, a realization that its internal apartheid policies were corrupt, and perhaps a desire to return to the international community.¹⁴ Pressure from the United States and others contributed to South Africa's decision, but one will never know if South Africa would have rolled-back its nuclear program if other factors did not present themselves as well, especially that of regional stability and a change in leadership.

Several conclusions can be drawn from the South African case study. The first is that if a country has skilled scientists, adequate capital, and a strong will to develop nuclear weapons, it can do so in a relatively short time. For South Africa, it only took seven years from development of an enrichment capability to having a weapon ready for possible use. In addition, South Africa was able to successfully pioneer a derivative approach to the aerodynamic method of uranium enrichment, ultimately making it more efficient than E.W. Becker's initial design. It would be troubling indeed if alternative or perhaps better methods of uranium enrichment could be discovered from a relatively small number of resourceful scientists in a developing country seeking nuclear weapons. Also, the South African example highlights the limitations of export controls, which the South African scientists were able to circumvent through innovation. Finally, when a country's policies are contrary to international norms, sanctions tend to have little effect on its behavior, and in fact can further solidify a nation-state on its current course, as was the case of South Africa.

Iraq

Iraq is an excellent example of a country whose leadership, Saddam Hussein, desperately wanted nuclear weapons and attempted to enrich uranium with almost every possible method, but was in the end, unsuccessful. Also, the aspect of waging preemptive war against clandestine nuclear weapons proliferators is highlighted with the Iraqi case study.

Saddam Hussein had several motives behind his desire to acquire nuclear weapons. Foremost, he wanted “the bomb” for prestige reasons--for his personal stature and for that of Iraq as well. Nuclear weapons would cement Saddam as the leader of the most powerful country in the Middle East. Second, nuclear weapons could have provided Saddam with a means to deter Iraq’s adversaries, especially his bitter enemy to the east, Iran, of which had an off-and-on history with pursuing nuclear weapons itself. Nuclear weapons could also deter the United States. Saddam had a complicated perception of the United States that ranged from a long-term desire to be an ally of sorts with America, to seeking out opportunities to confront the world’s only superpower. Nuclear weapons would certainly have helped with the latter, potentially even preventing direct American attacks against Iraq.¹⁵

Initially, Iraq was primarily interested in the plutonium route for its nuclear program with the French-built Osirak reactor. But before the Osirak reactor was operational, it was destroyed by an Israeli preemptive attack in 1981. After the attack, Iraq hoped to rebuild the Osirak reactor or to buy another one. Iraqi leaders decided to also pursue the uranium route in parallel. By the late-1980s, there was little hope of Iraq getting its reactor program going again, so it shifted exclusively to uranium enrichment.¹⁶ The

Israeli attack can be viewed in two veins. First, it was incredibly successful in preventing Iraq from developing a means to obtain weapons-grade plutonium and it delayed Saddam's overall nuclear program by many years. Conversely, while a delay in Iraq's nuclear program was a better outcome than allowing it to continue unabated, the Israeli strike was merely that...a single wallop...that did nothing to curtail Saddam's intention to develop a nuclear weapons capability. Perhaps the attack may have even hardened his desire to acquire nuclear weapons. Nevertheless, with the advantage of hindsight, Israel's raid on the Osirak reactor was a tremendous success. It provides a great illustration of how a small-scale attack can have a significant effect on a country's proliferation efforts.

The Iraqi uranium enrichment program tried almost every method of enrichment, including chemical diffusion, laser separation, gaseous diffusion, electro-magnetic isotope separation (EMIS), and centrifuge separation.¹⁷ The latter two methods were the most promising in the Iraqi nuclear program and deserve attention.

After more effective uranium enrichment methods were devised, EMIS was thought to be of little risk for proliferation. As explained in Chapter 3, EMIS was quite inefficient and required substantial energy to operate. Those factors, along with the "Atoms for Peace" program sponsored by President Eisenhower that envisioned a more constructive role for atomic research than that of weapons programs, led to the declassification of parts of the United States' EMIS program and other aspects of the Manhattan Project.¹⁸ Khidhir Hamza, one of the scientists of the Iraqi nuclear weapons effort later said of the documents that were provided to Iraq in 1956: "I was sure that if

the U.S. officials knew how valuable its Manhattan Project reports would be to us years later, they would have kicked themselves.”¹⁹

More troubling was that the United States did not know of Iraq’s EMIS program, that is, until after an Iraqi defector came forward in 1991.²⁰ The Al Tarmiya EMIS facility was considerable in size, measuring about 800 x 1000 meters, and it was observed by American reconnaissance assets.²¹ But, the facilities purpose was unknown. Al Tarmiya was bombed during Operation DESERT STORM, although it is a mystery as to why it was targeted by American strike planners--perhaps it was attacked as an economic or industrial target of opportunity during the air campaign. Nevertheless, after the conflict and armed with key information from an Iraqi defector, the IAEA found the facility to be part of a fast-paced EMIS program capable of eventually producing weapons-grade enriched uranium.²² Iraq’s EMIS was on the right track towards achieving their objective as IAEA inspectors found trace quantities of uranium enriched up to 40 percent.²³ Inspectors also discovered that deception was inherent in the design of the facility. For example, the power grid was buried underground, apparently to hide the significant energy required for the facility, a key signature associated with the EMIS method.²⁴ EMIS not only proved to be an effective, albeit inefficient, means to enrich uranium. Had Saddam Hussein not taken his dangerous gamble of invading Kuwait in 1990, in several years time he might have had enough enriched uranium for a small nuclear deterrent, and perhaps enough of one to prevent American-led military actions against Iraq.

The second-tier effort of the Iraqis’ uranium enrichment effort was its centrifuge program. As detailed in Chapter 3, the technologies for the advanced gas centrifuges

were classified since its inception because the risks of proliferation were apparent even then. Yet, the Iraqi scientists proved that without indigenous experience with centrifuge technology, they were able to at least get the program off the ground with outside assistance. Dr. Mahdi Obeidi, the chief scientist for the Iraqi centrifuge program, detailed how they were able to accomplish this notable feat. Of prime importance to the Iraqis were technical advice and knowledge on how to build a centrifuge system. Iraq successfully bribed European centrifuge experts, mostly from Germany, to gain the necessary knowledge and materials to assemble their program.²⁵ Some of the scientists that committed the most damaging illegal exports to Iraq died before they could be prosecuted, except for one of the Germans that aided the Iraqis centrifuge efforts who was tried and convicted, but received a light sentence.²⁶ This aspect of proliferation is a reminder of the power of greed. Putting centrifuge technology under lock and key does not necessarily ensure that a proliferator cannot gain access to it. It also highlights that developed countries such as Germany, even though they are members of the Nuclear Suppliers Group (NSG) and other nonproliferation regimes, lack effective measures to curtail exports to proliferators. Furthermore, when violations were discovered, in some countries, the consequences tend to be relatively minor, which is hardly a deterrent for individuals and businesses that may be considering an illegal proliferation enterprise.

Iraqi scientists made considerable headway with their gas centrifuge program, but were never able to get the program into the production stage, largely due to the IAEA inspections after Operation DESERT STORM. As opposed to EMIS, Iraq was suspected of having a centrifuge program, so after the conflict, the IAEA launched an investigation within Iraq to find what they could. The IAEA discovered solid evidence and hesitant

admissions about the program from several Iraqis, but even after invasive inspections, the IAEA knew that all was not revealed.²⁷ Indeed, the chief Iraqi centrifuge scientist hid documents and critical centrifuge components that would be essential for a renewed Iraqi effort in his backyard. The materials were not “discovered” until he presented them to American military forces after Operation IRAQI FREEDOM in 2003.²⁸ Even after years of attempting to diffuse Iraq’s centrifuge program, the reality is that it may be nearly impossible to completely destroy a proliferator’s ability to regenerate a nuclear program.

The Iraq example also sheds light on the challenge to obtain accurate intelligence in order to ascertain the status of a specific country’s nuclear program. This is a tremendous challenge since most proliferators operate clandestine nuclear programs. In the case of Iraq, one of America’s stated objectives for deposing Saddam Hussein in the months preceding the 2003 invasion of Iraq was the alleged concealment and possession of weapons of mass destruction in addition to a suspected uranium enrichment program.²⁹ But in the end, Iraq’s nuclear program was found to be dormant. After Operation IRAQI FREEDOM and the many efforts to find Hussein’s weapons of mass destruction, several panels looked into the flawed American and British intelligence estimates. One study, the *Commission of the Intelligence Capabilities of the United States Regarding Weapons of Mass Destruction*, a bi-partisan committee, concluded that the American intelligence community “was dead wrong in almost all of its pre-war judgments about Iraq’s weapons of mass destruction.”³⁰ The infamous “aluminum tubes” was a prime example of the flawed intelligence on the Iraqi program. Most of the intelligence community believed that the tubes were likely purchased by the Iraqis to be converted into gas centrifuge rotors, though notably the Department of Energy and the State Department dissented with

this assessment. After the 2003 invasion, the latter agencies were proved correct.³¹ There was little doubt that Iraq retained the ability to restart its nuclear weapons program at some point in the future, but clearly American intelligence agencies had difficulty in determining the current status of Iraq's nuclear program right up until the invasion of 2003.

Finally, Iraq highlights the issue of "preemptive war." One of President Bush's objectives was to depose Saddam Hussein before he acquired nuclear weapons, in which case he would be a tougher opponent in future conflicts with the United States and a dangerous regional threat as well. The success of the American preemptive war policy was called into question when it was determined that Iraq's nuclear weapons program was, in fact, inactive. From one perspective, America's preemptive war ensured that Saddam Hussein would never reconstitute his nuclear program again. By all accounts, Saddam Hussein likely intended to recommence Iraq's nuclear weapons programs at some future point. After the American occupation and for the foreseeable future, there is little risk of Iraq restarting a nuclear weapons program, so in that sense, the preemptive attack was a success. On the other side of the coin, America's intelligence, for the most part, was mistaken in its assessments of Iraq's nuclear program. As a result, the American people and the international community will probably be wary of future assertions for the need of a preventative war in the near future.

Pakistan

Pakistan is a prime illustration of a nation-state that had a weak industrial and scientific infrastructure, but was ultimately successfully in building nuclear weapons. Further, Pakistan proliferated uranium enrichment expertise and technology to several

other nation-states, and thereby damaged international nonproliferation efforts for decades to come.

Pakistan initiated a nuclear weapons program as a counter to their larger neighbor, India, especially after India's intervention in East Pakistan (known today as Bangladesh) in the early-1970s, in addition to the numerous battles the two countries had fought over Kashmir. Although Pakistan had a friendship of sorts with the United States, its leaders knew that they could not rely on America to solve their issues regarding India.³² India sealed Pakistan's resolve to go nuclear with its "peaceful" nuclear detonation of 1974; Bhutto, Pakistan's President, years before India's nuclear test, said: "If India builds the bomb, we will eat grass or leaves, even go hungry. But we will get one of our own."³³ Pakistan strongly believed that it required a nuclear deterrent.

The Pakistani government learned that it had an ace up its sleeve when Abdul Qadeer Khan, a Pakistani scientist working in Europe, volunteered his services to help his native country develop a nuclear weapons capability. Khan acquired a working knowledge of gas centrifuges while living in the Netherlands as an employee of a sub-contractor for URENCO, a Dutch uranium enrichment company. After becoming an agent for Pakistan, he stole many classified documents pertaining to centrifuges before returning to Pakistan to play a pivotal role in its nuclear program.³⁴ Pakistan simply was unable to develop nuclear weapons without foreign expertise and technology; Khan proved to be effective in obtaining both ingredients from the West.³⁵ Eventually Khan became the head of Pakistan's nuclear program, where he earned hero status from the masses for delivering "the bomb" to Pakistan.

Khan's first and most primitive centrifuge is known as the Pakistan-1, or "P-1" device. Apparently the P-1 centrifuge design is similar to URENCO's original machine. Although the P-1 model is relatively inefficient when compared to other designs, it is nonetheless effective, provided that enough units are connected in stages and cascades.³⁶ The "P-2" centrifuges are more advanced than the P-1 devices, using maraging steel as rotors instead of aluminum and with different dimensions which resulted in a corresponding increase in enrichment capability.³⁷ Just like with the Iraq illustration, several European companies either outright violated or skirted nuclear weapon export controls as part of the A.Q. Khan network. European, African, Middle Eastern, and Asian companies did their part to assist Khan.³⁸ With Khan's knowledge of the URENCO-designed centrifuges, he knew exactly what materials were essential for a centrifuge system along with who made them. Greed played in Khan's favor, as he paid substantial amounts of money to obtain parts on his shopping list, keeping his suppliers loyal and quiet, making intelligence gathering difficult.³⁹

As a result of Khan's uranium enrichment program, Pakistan probably attained nuclear weapons status by the mid-1980s, though it waited to demonstrate their new capabilities until May 28 and 30, 1998 with several nuclear tests, which immediately followed nuclear tests conducted by India.⁴⁰

For many years the world was aware that Pakistan was on a journey to develop nuclear weapons. A key indicator was that Pakistan was one of only a handful of countries that did not sign the Nuclear Non-Proliferation Treaty, providing a clear signal of their intent. A declassified State Department report indicated that by 1983, there was "unambiguous evidence that Pakistan is actively pursuing a nuclear weapons

development program.”⁴¹ The United States must have had hard evidence that Pakistan had a nuclear weapons program, because American aid was cut-off to Pakistan in 1979 as required by the Symington Act of 1961 due to the latter’s pursuit of nuclear weapons.⁴² Thus began a trend with the United States-Pakistan relationship, where the United States would eliminate its aid packages to Pakistan only to restore the assistance, usually with handsome increases in monetary value because of perceived higher national interests than that of nuclear nonproliferation. Two examples are noteworthy. The first is the aforementioned 1979 restrictions on Pakistan where the American elimination of aid was merely temporary in nature. Shortly after the sanctions went into effect, in December 1979, the Soviet Union invaded Afghanistan and the United States sought a means to provide support to the Afghani Mujahideen. Pakistan had a long relationship with Afghanistan so it was a natural choice for Pakistan to be the main operating base for American support to the Afghani Freedom Fighters. Pakistan sensed the opportunity to leverage a restoration of American military and economic aid and rejected the initial American offer of \$400 million. In 1981, although President Reagan could not assure Congress that Pakistan had ended their nuclear weapons program, Congress nevertheless agreed to suspend the Symington Act and authorized a \$3.2 billion aid package for Pakistan.⁴³ During this period, the United States even sold Pakistan a frontline fighter, the F-16. Then in 1985, Congress passed what became known as the Pressler Amendment, requiring that the President of the United States certify that Pakistan did not have nuclear devices as a condition of continued American aid. Yet American support continued to flow to Pakistan unabated. It was not until 1990, that President George H.W. Bush finally certified that Pakistan likely had a nuclear device and sanctions were

renewed. President Clinton edged toward ending the sanctions after Pakistan's nuclear tests of 1998, apparently because the sanctions seemed to be ineffective in curbing its nuclear proliferation, but the 1999 military coup and Pakistan's debt payment arrears with the United States kept sanctions on Pakistan.⁴⁴ But once again, after the events of September 11, 2001, the United States required support from Pakistan for Operation ENDURING FREEDOM in Afghanistan and the broader global war on terrorism. The sanctions were quickly terminated once Pakistan chose to be an ally in the war against terrorism. Of note, Pakistan recently was allowed to buy more F-16s, even though it is assumed that they could be used as nuclear-capable aircraft.⁴⁵

Not only had Pakistan covertly acquired nuclear weapons despite their repeated denials while receiving American financial and military assistance, but they also proliferated critical nuclear technologies and expertise to at least three other countries: Iran, Libya, and North Korea. American and British intelligence agencies were on the trail of A.Q. Khan's proliferation efforts for several years, even before 9/11. Initially, the details were spotty, but as time went on, the evidence was clear-cut.⁴⁶ The last straw was the interception of the *BBC China*, a large transport ship under German registry captured by a joint United States-United Kingdom effort, and was found to be full of Pakistani centrifuges and related equipment bound for Libya.⁴⁷ Up until this point, President Musharraf had rebuffed requests from the United States to arrest and prosecute A.Q. Khan, probably because Khan was a national hero as a result of the successful Pakistani nuclear weapons program. But with increased pressure from the Bush Administration, Khan was arrested and later confessed to his proliferation activities claiming that he acted

alone, without the knowledge of senior Pakistani officials, and was placed under house-arrest that continues today.⁴⁸

Foremost, this example highlights the fact that nuclear weapons nonproliferation has not historically been America's highest priority when balanced against other objectives. Twice, America turned a blind eye to Pakistan's weapons development or active proliferation as a result of American policies dealing with Afghanistan vis-à-vis the Soviet Union and the war on terrorism, that were viewed as more critical than nuclear nonproliferation. This is not to say that America's nonproliferation policies must always be held in highest regard. But in the same breath, it is important to have a high degree of consistency with policies in general, and nonproliferation should not be an exception. On one hand, America went to war with Iraq in 2003, with one of the main reasons being to prevent Saddam Hussein from developing nuclear weapons. Then on the other hand, Pakistan provided critical nuclear weapons technology, material, and expertise to some of the worst state-actors in the world, and in the end, was rewarded handsomely with American military aid because of its geographical position and cultural link to Afghanistan.

Second, greed is a powerful motivator and despite treaties and export controls, if a proliferator is committed to its nuclear program, they can always find a seller of nuclear expertise and technology. Treaties and export controls are not meaningless; rather, Pakistan and other examples simply indicate their limitations.

Libya

Libya is yet another prime example of a troublesome nation-state largely because of Colonel Gadhafi's historical support of terrorism, that eventually lead to international sanctions and its labeling as a "rogue" country.⁴⁹

Libya became a ratified member of the NPT in 1975. Nevertheless, under direction of its leader, Colonel Gadhafi, Libya likely began its pursuit for a nuclear weapons capability around the time that it ratified the NPT.⁵⁰ Libya had no natural enemies thus dictating a nuclear deterrent, although its export of terrorism often led to confrontation with the United States and the United Kingdom. Gadhafi probably desired a nuclear weapons capability mostly for prestige reasons, but deterrence of America may have played a role as well.

Libya, lacking indigenous industrial and scientific capabilities, built its nuclear program entirely from scratch with a heavy reliance on foreign technologies and experts. Gadhafi spent millions of dollars, perhaps hundreds of millions of dollars, yet over a thirty year period the Libyan effort yielded almost nothing. The following is merely a short list detailing how Libya was challenged with its program. First off, Libya imported over 2,000 tons of uranium yellowcake, mostly from Niger beginning in 1978, but they were unable to convert it into uranium hexafluoride.⁵¹ Without such conversion, Libya was unable to begin even the first step toward indigenously enriching uranium. Libya also attempted to build its own centrifuge program, but after a 10-year effort, there was nothing to show for it.⁵² Enter the A.Q. Khan network. Khan offered Libya just what it needed, a "turn-key" uranium enrichment program, with everything from uranium hexafluoride, to thousands of gas centrifuges, to basic plans of how to construct a nuclear

device.⁵³ Libya received a handful of preassembled centrifuges from Pakistan, very similar to the “P-1” design and parts to build many more. Furthermore, Libya bought a small number of the improved “P-2” design and apparently had placed an order with A.Q. Khan to buy up to 10,000 of the advanced Pakistani centrifuges.⁵⁴

As discussed in the above, the capture of the *BBC China* with Pakistani centrifuge materials en route to Libya was the nail in the coffin of the A.Q. Khan network. But, Gadhafi’s reaction to the *BBC China* situation was almost immediate. Even before the *BBC China* was intercepted, Colonel Gadhafi was already in negotiations with the United States and the United Kingdom to find a solution to end Libya’s pariah status. After only two months since the ship’s discovery, Gadhafi publicly pledged to give up his nuclear and chemical weapons programs and completely adhere to the NPT and all of its provisions.⁵⁵ There has been much speculation as to why Gadhafi made this monumental decision. One perspective links Gadhafi’s decision with the Bush Administration’s preemptive war doctrine demonstrated by Operation IRAQI FREEDOM.⁵⁶ Alternatively, some believe that Gadhafi wanted to put an end to Libya’s status as a rogue-state and desired economic privileges that were denied as a result of the sanctions placed against Libya. Shokri Ghanem, Libya’s Prime Minister said: “They [Libya’s nuclear weapon program] are not making us safe. They are making us poorer, and having troubled relations ... we decided to concentrate our way on our economy.”⁵⁷ Perhaps after years of trying to develop a nuclear weapons program and sinking considerable capital into the project with practically no results to show for effort may have been another factor why Gadhafi gave up his program.⁵⁸

The Libyan case study reveals some interesting aspects on nonproliferation. It validates that enriching uranium is a very difficult task even with foreign assistance, in this case, from the Khan network. Although Libya acquired the necessary hardware to enrich uranium, it still lacked the expertise, and was unable to make effective progress. Second, once again, export controls and treaties did not deter Libya from attempting a nuclear program, nor did more exceptional international repercussions that included UN sanctions, deter Libya.

Iran

Iran publicly denies that it has a nuclear weapons program.⁵⁹ Yet, there is compelling evidence that the leadership of Iran intends to enrich uranium for a nuclear weapons capability. As such, Iran shares the spotlight with North Korea as one of the most concerning nuclear weapons proliferators in the world today.

Iran's history with nuclear weapons dates back several decades to the last Shah of Iran. But the Shah's nuclear program was not very ambitious and concentrated more on energy than on weapons. After the fall of the shah, Ayatollah Khomeini initially stopped Iran's pursuit of nuclear weapons with the belief that they were contrary to the principles of Islam. But the Iran-Iraq War initiated by Saddam Hussein, that included the use of chemical weapons against Iranian forces, quickly changed Khomeini's mind and the program was restarted. Other factors later attracted Iran to nuclear weapons in light of their hostile policies against America and Israel. Therefore, deterrence of the two aforementioned countries has probably taken the centerpiece in Iran's desire to develop nuclear weapons, coupled with a related goal of restoring Persian prestige.⁶⁰

Iran's initial attempt with an indigenous centrifuge program in the mid-1980s failed. Iran then contracted with the A.Q. Khan network. It was the Pakistani early gas centrifuges that finally got their program going, initially with the "P-1" type, but more recently, with the advanced "P-2" centrifuges as well.⁶¹ The IAEA states that Iran has been operating a test cascade of 164 P-1 centrifuges with another cascade of equal size and type installed in 2006.⁶² Iranian President Ahmadinejad has openly stated that they intend to build and operate 3,000 centrifuges in an underground facility near the city of Natanz, with plans to ultimately install over 50,000 centrifuges.⁶³

Like Libya, Iran is a party to the NPT, and as such, is required to report its nuclear activities to the IAEA. Yet only after aggressive accusations by the IAEA, did Iran release limited information about its previously undisclosed nuclear activities, including a long list ranging from converting yellowcake to uranium hexafluoride, to experimenting with laser and centrifuge enrichment technologies. Even after Iran's clandestine enrichment efforts were uncovered by the IAEA, Iran initially claimed that the gas centrifuges were of indigenous manufacture using open source designs.⁶⁴ When the IAEA subsequently proved that they were of foreign origin, probably from Pakistan, only then did Iran admit that the IAEA was correct in this regard.⁶⁵ After three years of back-and-forth between Iran and the IAEA, only scant details about the involvement of the Khan network has come to light. In short, Iran's legacy with its nuclear program indicates that their statements cannot be trusted, furthering suspicion as to Iran's claims of a "peaceful" enrichment program.

After Iran's uranium enrichment program became public knowledge, Iranian leaders found a twist to legitimize their enrichment efforts by using the NPT itself as a

justification. The NPT forbids non-nuclear weapons states from enriching uranium for the purposes of producing nuclear weapons, but it does not explicitly discuss uranium enrichment for peaceful reasons; in other words, the NPT does not prevent a non-nuclear weapons state from producing low enriched uranium as fuel for nuclear reactors. There are many non-nuclear weapons states that produce slightly enriched uranium for use in their own reactors and for sale abroad.⁶⁶ Iranian leaders state that they merely intend to enrich uranium just like that of other countries.

The United States does not take stock in Iran's proclamations about a peaceful nuclear program. The problem is that there is no irrefutable way to reveal Iran's true intent, until evidence becomes available which shows they are enriching uranium to levels above 20 percent. Nonetheless, lacking a "smoking gun," the circumstantial evidence strongly indicates that Iran's uranium enrichment is for a nuclear weapons program. Iran intentionally did not report their nuclear fuel cycle activities to the IAEA, as they were required to by the NPT. Once their program was discovered, Iran provided little information after repeated requests from the IAEA. The most logical explanation for their clandestine activities is because Iran intends to not comply with all provisions of the NPT.

North Korea set precedence in 2003 after years of violating the NPT. When North Korea was very close to completing its first weapon, it formally withdrew from the treaty. North Korea has a long history of sanctions and of being ostracized by the international community. In fact, North Korean leaders intentionally place themselves at odds with the world as a means for the regime to retain power over its people. As such, North Korea did not fear Security Council or even counter-proliferation actions after their withdrawal

from the NPT, and four years hence, they remain obstinate. It is a valid concern that Iran might follow the North Korean model once it has mastered the nuclear fuel cycle for highly enriching uranium. Iran also has a history of international rebuke of which it easily shrugs off. Indeed, President Ahmadinejad's agenda clearly includes standing firm against the West. Since Iran enjoys a significant share of the world's oil supply, short of a total oil embargo that is unlikely to be enacted by the Security Council, Iran will have plenty of capital to do as it pleases, as it has done so since the Islamic revolution of 1979.⁶⁷

The centrifuge technique of uranium enrichment fits Iran's strategy perfectly. The gas centrifuge is a proven method for industrial low-enriched uranium to produce fuel for nuclear reactors throughout the world. Many countries already employ centrifuges for this purpose, so it matches Iran's cover story of merely wanting to produce indigenous nuclear fuel. As Iranian scientists master centrifuge technology, and if Iran succeeds in building a reliable centrifuge cascade for production of low-enriched uranium without attracting a preemptive attack from Israel or the United States, then Iran will have completed the most difficult aspects towards acquiring nuclear weapons. This is because once a centrifuge system can enrich uranium up to about five percent U-235, it simply requires additional cascades to produce weapons-grade uranium. If Iran can bide time similar to the North Korean precedent and clandestinely develop a nuclear weapons capability while proclaiming it is NPT-compliant, Iran could ensure that it has a nuclear deterrent in place before it formally withdraws from the NPT. At that point, the risks associated with counter-proliferation attacks would increase considerably for any country that might attempt to destroy Iran's nuclear weapons capabilities.

Like some of the world's proliferators in the past, Iran is generally categorized as a "rogue-state." The United States has enacted sanctions against Iran for many years including bans against the import of Iranian oil, although many other countries continue to buy Iranian oil. President Bush has significantly increased the pressure on Iran beginning with his State of the Union address in 2002, where he branded Iran as part of the "axis of evil" for its pursuit of nuclear weapons and export of terrorism.⁶⁸ More recently, President Bush stated that "all options are on the table" if Iran does not halt its nuclear program, also adding "the use of force is the last option for any president...[but] we've used force in the recent past to secure our country."⁶⁹ In December 2006, the United Nations Security Council issued a resolution that called upon Iran to suspend its nuclear activities.⁷⁰ It seems to have had no effect as Iranian President Ahmadinejad resolutely stated that Iran will continue on its journey to enrich uranium as quickly as possible.⁷¹ As described in the introduction, Iran's history of international terrorism, their proxy attacks on Israel through Hezbollah, and the antagonist role they play in the current Iraqi War very well may place Iran in American crosshairs in the future.

It is difficult to determine when Iran will have nuclear weapons. The United States predictions were reasonably accurate with several of the aforementioned case studies, but the intelligence community has been all over the map with estimates on Iran. In 1995, it was believed that Iran could have a weapon by 1997-2000 at the latest. Later this was extended to 2005.⁷² More recently, a national intelligence estimate in 2005 is said to predict that it will take Iran up to 10 years to have a nuclear weapon.⁷³

It is not possible to tell if the Bush Administration's aggressive statements towards Iran is a prelude to an imminent preemptive attack, or is diplomatic posturing with the

purpose of pressuring Iran to halt its enrichment activities. Iran does not have a track record of bowing down to international criticism, especially criticism originating from the United States. Yet as described above, President Bush alluded to the fact that the United States has acted on the doctrine of preemptive war with Iraq, so Iran is certainly taking a significant risk in ignoring American threats. On one hand, it seems that the United States has time to ponder this difficult decision as Iran is not expected to have a nuclear weapons capability in the near-term. But on the other hand, perhaps Iran's uranium enrichment program would be just one more reason on the pretext list of American grievances to provide justification to deal with Iran sooner rather than later, especially with Iran's probable meddling in Iraq.

Notes

¹ Frank V. Pabian, "South Africa's Nuclear Weapon Program: Lessons for U.S. Nonproliferation Policy," *The Nonproliferation Review* (Monterey, CA: CNS, Fall 1995), 2-3.

² Ibid.

³ Waldo Stumpf, "50 Years After Hiroshima," (address, presented to a conference organized by Unione Scienziati per il Disarmo in Castiglione della Pescaia, Italy, 28 September - 2 October 1995).

⁴ Al J. Venter, *Iran's Nuclear Options: Tehran's Quest for the Atom Bomb* (London: Greenhill Books, 2005), 182.

⁵ Central Intelligence Agency, "South Africa Seeks Uranium Hexafluoride Technology," *Weekly Surveyor* (Washington D.C.: 4 May 1970, declassified and released in September 1991), 1, <http://www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB181/sa02.pdf>.

⁶ It should be noted that the U.S. aid ended in 1976 as a result of the Carter Administration's emphasis on NPT compliance as a cornerstone of U.S. nuclear export policy. Pabian, "South Africa's Nuclear Weapon Program," 2.

⁷ Central Intelligence Agency, "New Information on South Africa's Nuclear Program and South African-Israeli Nuclear and Military Cooperation," memorandum, 30 March 1983 (Washington D.C.: declassified, released in May 1996), 2-3, <http://www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB181/sa26.pdf>.

⁸ David Albright, "South Africa's Secret Nuclear Weapons," *ISIS Report* (Washington D.C.: Institute for Science and International Security (ISIS), May 1994), <http://www.isis-online.org/publications/southafrica/ir0594.html>.

⁹ Venter, *Iran's Nuclear Options*, 185.

¹⁰ Frank V. Pabian, "South Africa's Nuclear Weapon Program," 1.

Notes

¹¹ Ibid, 1-3.

¹² JDL Moore, *South Africa and Nuclear Proliferation: South Africa's Nuclear Capabilities and Intentions in the Context of International Non-proliferation Policies* (London: Macmillan Press, 1987), 112, and Pabian, "South Africa's Nuclear Weapon Program," 1.

¹³ Central Intelligence Agency, *Trends in South Africa's Nuclear Security Policies and Programs* (Washington D.C.: October 1984), 1, <http://www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB181/sa27.pdf>.

¹⁴ Frank V. Pabian, "South Africa's Nuclear Weapon Program," 9-10.

¹⁵ Iraq Survey Group, *Comprehensive Report on the Special Advisor to the DCI on Iraq's WMD* (Washington D.C.: CIA, 30 September 2004), 3-5.

¹⁶ David Albright, "Iraq's Programs to Make Highly Enriched Uranium and Plutonium for Nuclear Weapons Prior to the Gulf War" (Washington D.C., ISIS, 1997, revised in October 2002), 4, http://www.isis-online.org/publications/iraq/iraqs_fm_history.html.

¹⁷ Ibid.

¹⁸ For examples of several documents regarding EMIS that were unclassified, see: United States Atomic Energy Commission, *Twentieth Semiannual Report on the Atomic Energy Commission* (Washington D.C.: Government Printing Office, July 1956), 163, <http://www.osti.gov/opennet/servlets/purl/16360386-28xm8G/16360386.pdf>.

¹⁹ Khidhir Hamza, *Saddam's Bombmaker: The Terrifying Inside Story of the Iraqi Nuclear and Biological Weapons Agenda* (New York, NY: Scribner, 2000), 69.

²⁰ R. Jeffrey Smith, "Iraqi Defector," *Washington Press*, 14 June 1991.

²¹ Richard Kokoski, *Technology and Proliferation of Nuclear Weapons* (Oxford, England: Oxford University Press, 1995), 110.

²² International Atomic Energy Agency, *Report of the Fourth On-site Inspection in Iraq* (Vienna, Austria: IAEA, August 1991), 3-5.

²³ Ibid, *Report of the Third On-site Inspection in Iraq* (Vienna, Austria: IAEA, July 1991), 4.

²⁴ Tim C. Harris, *Proliferation Aspects of Electromagnetic Isotope Separation Programs* (Air Force Institute of Technology: March 2001), 43.

²⁵ Mahdi Obeidi and Kurt Pitzer, *The Bomb in My Garden*, 90-1.

²⁶ Institute for Science and International Security, "Acquisition of Gas Centrifuge Technology: Part III," (Washington D.C.: ISIS), <http://www.exportcontrols.org/centpart3.html>.

²⁷ International Atomic Energy Agency, *Report of the Third On-site Inspection in Iraq* (Vienna, Austria: IAEA, July 1991), 10,

²⁸ Obeidi and Pitzer, *The Bomb in My Garden*, 151-154 and 217.

²⁹ George W. Bush, "Global Message" (Washington D.C.: Office of the White House, 17 March 2003), <http://www.whitehouse.gov/infocus/iraq/news/20030317-10.html>.

³⁰ Laurence H. Silberman and Charles S. Robb, co-chairmen, *Commission of the Intelligence Capabilities of the United States Regarding Weapons of Mass Destruction* (Washington D.C.: 31 March 2005), cover memo.

Notes

³¹ Ibid, 57.

³² Gordon Corera, *Shopping for Bombs: Nuclear Proliferation, Global Insecurity, and the Rise and Fall of the A.Q. Khan Network* (New York, NY: Oxford University Press, 2006) 3, 9, and 13.

³³ George Russell, "Who has the Bomb," *TIME Magazine*, 3 June 1985, <http://www.time.com/time/magazine/article/0,9171,957761-1,00.html>.

³⁴ Gordon Corera, *Shopping for Bombs*, 14, 18, and 21.

³⁵ David Albright and Cory Hinderstein, "The A.Q. Khan Illicit Nuclear Trade Network and Implications for Nonproliferation Efforts," *Strategic Insights* (Volume V, Issue 6, July 2006).

³⁶ Marvin Miller, "The Gas Centrifuge and Nuclear Proliferation," *A Fresh Examination of the Proliferation Dangers of Light Water Reactors* (Washington D.C.: The Nonproliferation Policy Center: 22 October 2004), 37-8.

³⁷ David Albright and Corey Hinderstein, "Uncovering the Nuclear Black Market: Working Toward Closing Gaps in the International Nonproliferation Regime," (prepared for the Institute for Nuclear Materials Management 45th Annual Meeting at Orlando, FL, Institute for Science and International Security: 2 July 2004), 4.

³⁸ Ibid, "Unraveling the A.Q. Khan and Future Proliferation Networks," *The Washington Quarterly* (Washington D.C.: Center for Strategic and International Studies and Massachusetts Institute of Technology, 28:2, Spring 2005), 117-8.

³⁹ Corea, *Shopping for Bombs*, 22-3.

⁴⁰ Joseph Cirincione, et al, *Deadly Arsenals*, 240.

⁴¹ State Department, "The Pakistani Nuclear Program," (23 June 1983), http://www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB6/ipn22_1.htm.

⁴² State Department. Fact Sheet "Background Note: Pakistan" (Washington D.C.: Bureau of South and Central Asian Affairs, October 2006), <http://www.state.gov/r/pa/ei/bgn/3453.htm>.

⁴³ Paul Leventhal, "Testimony by Paul Leventhal, President, Nuclear Control Institute, on Pakistan and U.S. Nuclear Non-proliferation Policy, Before the House Foreign Affairs Committee" (Washington D.C: Nuclear Control Institute, 22 October 1987), <http://www.nci.org/t/t102287.htm>.

⁴⁴ Congressional Research Service, "Pakistan's Nuclear Proliferation Activities and the Recommendations of the 9/11 Commission," *CRS Report for Congress* (Washington D.C.: CRS, 24 May 2005), 10-11.

⁴⁵ Ibid, "Combat Aircraft Sales to South Asia: Potential Implications," *CRS Report for Congress* (Washington D.C.: CRS, 19 May 2005), 4.

⁴⁶ Corea, *Shopping for Bombs*, 157 and 197.

⁴⁷ George W. Bush, "Remarks by the President On Weapons of Mass Destruction Proliferation," (Washington D.C.: Office of the White House: 11 February 2004).

⁴⁸ Corea, *Shopping for Bombs*, 207-210.

⁴⁹ Sanctions were imposed by either the United States or the UN Security Council in 1986, 1992, and 1996. *Public Papers of the Presidents of the United States: Ronald Reagan, Book I: January 1 to Jun 27, 1986* (Washington D.C.: Government Printing

Notes

Office, 1988), p. 17; and David Hoffman, "President Imposes Boycott on Business with Libya, Qadhafi's Isolation Urged," *Washington Post*, 8 January 1996.

⁵⁰ Joseph Cirincione, et al, *Deadly Arsenals*, 318-9.

⁵¹ Ibid, 322; and International Atomic Energy Agency, *Implementation of the NPT Safeguards Agreement of the Socialist People's Libyan Arab Jamahiriya* (IAEA document: GOV/2004/12, 20 February 2004), 4.

⁵² Corera, *Shopping for Bombs*, 108

⁵³ The nuclear weapons plans were allegedly of Chinese origin that Pakistan received decades earlier from China. Joseph Cirincione, et al, *Deadly Arsenals*, 322-3.

⁵⁴ International Atomic Energy Agency, *Implementation of the NPT Safeguards Agreement of the Socialist People's Libyan Arab Jamahiriya* (Vienna, Austria: IAEA document: GOV/2004/59, 20 August 2004), 5-6; and Joseph Cirincione, et al, *Deadly Arsenals*, 322-3.

⁵⁵ Congressional Research Service, "Disarming Libya: Weapons of Mass Destruction," *CRS Report for Congress* (Washington D.C.: CRS, 22 April 2004), 1-2.

⁵⁶ Dick Cheney, "VP's Remarks in Dayton, Ohio," (Office of the White House: 12 August 2004), <http://www.whitehouse.gov/news/releases/2004/08/print/200408123.html>.

⁵⁷ Shokri Ghanem, "The New Gadhafi," *60 Minutes II* (CBS News: aired 10 March, 2004).

⁵⁸ Laurence H. Silberman and Charles S. Robb, co-chairmen, *Commission of the Intelligence Capabilities of the United States Regarding Weapons of Mass Destruction*, 254.

⁵⁹ BBC News, "Iran Swiftly Seeks Nuclear Goal," *BBC World News Online*, 21 February 2007, http://news.bbc.co.uk/2/hi/middle_east/6381477.stm.

⁶⁰ Pollack, *The Persian Puzzle*, 258-9.

⁶¹ Joseph Cirincione, et al, *Deadly Arsenals*, 299-300.

⁶² International Atomic Energy Agency, *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran* (Vienna, Austria: IAEA document GOV/2006/53, 31 August 2006), 2.

⁶³ Ali Akbar Dareini, "Iran Vows to Ramp Up Uranium Enrichment," *ABC News*, <http://abcnews.go.com/International/wireStory?id=1835531>.

⁶⁴ International Atomic Energy Agency, *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran* (Vienna, Austria: IAEA document: GOV/2003/75, 10 November 2003), 9.

⁶⁵ Ibid, *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran* (IAEA document: GOV/2004/83, 15 November 2004), 8.

⁶⁶ For example, the Netherlands and Japan to name only two.

⁶⁷ According to the Department of Energy, Iran currently has ten percent of the world's proven oil reserves. Department of Energy, Energy Information Administration, "Oil," <http://www.eia.doe.gov/emeu/cabs/Iran/Oil.html>.

⁶⁸ George W. Bush, "The President's State of the Union Address" (Washington D.C.: Office of the White House: 29 January 2002, <http://www.whitehouse.gov/news/releases/2002/01/20020129-11.html>).

Notes

⁶⁹ Associated Press, “Bush: ‘All Options Are On the Table’ Regarding Iran’s Nuclear Aspirations,” *USA Today.Com*, 13 August 2005, http://www.usatoday.com/news/washington/2005-08-13-bush-iran-nuclear_x.htm.

⁷⁰ United Nations Security Council. *Resolution 1737* (United Nations: document S/Res/1737, 2006), 27 December 2006.

⁷¹ BBC News, “Iran ‘Swiftly Seeks Nuclear Goal’.”

⁷² Jeffrey T. Richelson, *Spying on the Bomb* (New York, NY: W.W. Norton & Company, Inc, 2006), 507-509.

⁷³ Congressional Research Service, “Iran’s Nuclear Program: Recent Developments,” *CRS Report for Congress* (Washington D.C.: CRS, 6 September 2006), 4.

Chapter 5

Conclusions and Recommendations

After reviewing America's nuclear nonproliferation challenges from a number of angles to include international agreements, American policies and programs, the uranium fuel cycle, along with select case studies, several conclusions and recommendations can be made.

Despite well-intentioned efforts by the international community and that of the United States, some countries will continue to strive for a nuclear weapons capability. Recent history indicates that leaders of some nation-states believe that they require a nuclear weapons capability, in some cases regardless of the cost. It is not surprising that when looking back at the last three decades, nuclear weapons proliferators were largely countries that fit the mold of "rogue or "pariah" nation-states, namely, North Korea, Pakistan, and South Africa. This trend continues today with Iran's maturing nuclear program. Also troubling, as relationships change between countries in the developed world, a new trend might also begin where countries with advanced technological bases believe they need the deterrent or prestige effect that nuclear weapons can seemingly provide; this category of countries, the "virtual" nuclear countries, could also proliferate rapidly.

International agreements, treaties, and export controls are helpful in combating the proliferation of nuclear weapons, but they are not a panacea. The IAEA plays a beneficial role with verification of safeguards, especially with more robust inspections as part of the comprehensive safeguard agreement and supplemented with strengthened capabilities in the Additional Protocol. Yet it is not in the interest of potential proliferators such as Iran to voluntarily submit to such inspections, thus the success of the Additional Protocol will be limited, just as the NPT was limited by India, Israel, Pakistan, and South Africa. The plan pressed by the United States to more or less make the Additional Protocol a prerequisite for continued nuclear energy assistance throughout the world may be a bridge too far. Countries cannot be forced into agreements beyond the original text of the NPT if they chose not to do so. Nevertheless, the United States must continue its attempt to strengthen international agreements and the IAEA's inspection regime, in addition to export controls.

Nuclear proliferation policies of the United States government are applied inconsistently. America is at war in Afghanistan, Iraq, and indeed globally in the war against terrorism. It is intuitive that these efforts must be robustly and continuously supported as America fights the "long war." Yet as was described in Chapter 1, proliferation of nuclear weapons is assessed by the Bush Administration as the greatest threat to America, and nuclear nonproliferation programs should be appropriately supported in policy and in budgetary practice. America's inconsistent policies with Pakistan have not only provided an example of de facto acceptance of nuclear proliferation in an unstable region of the world, but have also tolerated the spread of nuclear equipment and expertise to other countries, including Iran and North Korea. The

consequences of antagonists to the United States gaining nuclear weapons and associated delivery systems could threaten continental America with destruction hereto unseen.

An increased emphasis on nuclear nonproliferation within the United States government is required. Nonproliferation efforts are spread across many agencies and departments within the Executive Branch, lending to inefficiencies and a lack of synergistic direction. Many departments and agencies have their hands in the nonproliferation pie, and no single office below that of the President of the United States is responsible for the implementation of America's nonproliferation policies and efforts as a whole. While the various departments and programs that deal with nonproliferation do not intentionally skimp on nonproliferation programs, it should not be a surprise that departments or agencies will tend to focus their budgets on core aspects of the organization's mission, and not on programs that address secondary tasks that includes nuclear weapons proliferation. It bears repeating again that this is the most significant threat to America's national security...and the Executive Branch is not organized for this challenge. America should view nuclear proliferation as a "war" of sorts and organize accordingly.

Just as a cabinet post was recently created to enhance America's intelligence assessments, similar attention is warranted for America's nuclear nonproliferation efforts. A couple of possibilities could help solve this problem. One option is to create a new cabinet post to head America's nonproliferation programs. A derivative of this idea was recently heralded by Governor Bill Richardson from New Mexico. This post would enjoy immediate access to the President, and could influence the budgets and associated nonproliferation programs within the rest of the Executive Branch. The downside to this

concept is that adding an additional cabinet post might only increase the bureaucracy of an already large nonproliferation footprint, in addition to the fact that this new cabinet member would be still only be an equal amongst peers with the heads of the numerous agencies and departments involved in nuclear nonproliferation, and it may not necessarily yield an improvement in current priority setting practices. Another possibility is to place all nuclear nonproliferation monies under one cabinet member, be it a new post or that of an existing position. Since the Department of Energy has the bulk of the nonproliferation technical base as well as monies, it may be the optimum agency to serve in this role. This option would bode well for increased synergy between the various agencies and departments, by allocating the nonproliferation budget with a centralized approach. But this solution also is not without potential problems. Inter-department rivalries in competition for resources would almost certainly increase. Also, innovation and basic research into nonproliferation could suffer from a centralized budgeting process. Other options no doubt can and should be explored to properly organize government efforts in this critical area of America's national security.

Improved methods and technologies must be developed to find and monitor clandestine nuclear weapons programs. The United States intelligence agencies have an amazing track record for identifying countries whose leadership intends on developing nuclear weapons. The analysis by America's intelligence community may in fact be perfect to date in predicting those countries that desire nuclear weapons. Yet, the intelligence community has a mixed record on accurately determining the status of a country's nuclear weapons program. There are several reasons for this to include the tremendous technical challenge in mastering the ability to detect these secretive

programs. Proliferators also know that the world is watching them, to include countries with sophisticated intelligence capabilities such as the United States, and they correspondingly attempt counter-detection efforts. The scientists and those associated with covert programs are usually small in number, and in some cases there are genuine threats against them and their families if they would become agents of a foreign power, thus human intelligence tends to be unavailable, or at least, an unreliable intelligence collection method.

America invaded Iraq for several reasons, but in the days preceding the invasion, Saddam Hussein's supposed active nuclear weapons program ranked at the top. Only afterward was it determined that the program was in fact dormant, though evidence indicates that Saddam intended to restart the program at some point in the future. Regardless, America's reputation has been impaired because of our inability to make accurate assessments with covert uranium enrichment programs. To remedy past mistakes and to shape the future in regard to nuclear proliferation, the United States government must concentrate on finding methods to accurately identify and monitor clandestine proliferators.

The uranium route appears to be the method of choice for most proliferators.

Three of the four most recent nuclear weapons proliferators concentrated their programs on highly enriching uranium. The case studies from the prior chapter further highlight that the gas centrifuge is the most prolific technique for clandestine uranium enrichment. As the chapter on the uranium nuclear fuel cycle underscored, there are many different ways to enrich uranium. While proliferators seem to be leaning towards gas centrifuges at the moment, the Iraq case study clearly indicates that a country also may pursue

several enrichment methods, even ones seemingly outdated such as the EMIS method of World War II fame.

In some cases, preemptive war may be the only effective means to end a proliferator's nuclear weapons program. As indicated by the examples in Chapter 4, once a country's leadership is intent on developing nuclear weapons, it usually will succeed in its mission. Of the five nation-states evaluated, only Libya and Iraq proved unable to reach their end state. Libya's shortfall was largely its scientific incompetence. Whereas with Iraq, its nuclear program made significant progress, and only after a preemptive strike by Israel in 1981, coalition-attacks led by the United States in 1991, and finally, by an invasion once again led by the latter in 2003, that terminated Iraq's nuclear weapons program. International rebuke, while necessary, does not have a record of success, as South Africa, Iraq, Pakistan, Libya, and Iran all proved that a variety of consequences ranging from United Nations Security Council resolutions to multilateral sanctions had little to no effect on their actions. North Korea, though not analyzed in detail in this study, also provides evidence to the shortcoming of international measures. In fact, in several of the aforementioned cases, such actions may have further cemented the desire of proliferators to acquire nuclear weapons.

Preemptive strikes can delay a country's nuclear weapons program, but may not yield an enduring solution. Israel's strike on the Osirak nuclear reactor in 1981 postponed Iraq's nuclear weapons program considerably. Yet its effect was not permanent, as Saddam Hussein switched to the uranium route, and was clearly on the right course towards a nuclear weapons capability before he detoured into Kuwait, which led to another effective attack by a coalition led by the United States, stemming his

program once again. But it still did not end Saddam's desire for nuclear weapons...he merely shelved the program, and it was not until the 2003 invasion and subsequent regime change, albeit controversial and with several unintended implications, that closed the door on Iraq's nuclear weapons program.

Clearly, preemptive war should not be the first...or even the seventh alternative to stop a proliferator. But it may be a necessary option. Carl von Clausewitz's timeless lesson reminds us that "war is not merely an act of policy, but a true political instrument, a continuation of political intercourse, carried on by other means."¹ If, after all non-military efforts have failed to roll-back a proliferator of nuclear weapons, then "other means" might very well be required.

The importance of detecting clandestine programs is heightened with the evolving Iranian crisis. President Bush has reiterated that the United States reserves the right to consider the use of all options to deal with Iran if it continues with its uranium enrichment program. Prior estimates with Iran's nuclear program were markedly wrong, believing that Iran may have "the bomb" as early as 1997. As of 2005, the intelligence community assessed it could take Iran at least ten years to have a nuclear weapon. But the consequences might be very damaging if that estimate too is incorrect.

There is a compelling case that Iran's uranium enrichment effort is not for the reasons it claims, rather the program's main objective is likely to obtain nuclear weapons. But the United States must be careful before embarking on a preemptive war with Iran over this issue. The Iraq example has likely influenced potential allies to be cautious before supporting the United States with tough measures against Iran. The bottom line is that before military action is taken, the evidence with regard to Iran's nuclear weapons

program must be air-tight. Better intelligence gathering, especially improved technologies to detect uranium enrichment, could provide the key in finding the “smoking gun” disproving Iran’s claims about a peaceful nuclear program.

Notes

¹ Carl von Clausewitz, *On War*, ed. and trans. Michael Howard and Peter Paret (Princeton, NJ: Princeton University Press, 1984), 87.

Glossary

AVLIS	Atomic-Vapor Laser Isotope Separation
CTR	Cooperative Threat Reduction
EMIS	Electro-magnetic Isotope Separation
DOD	Department of Defense
DOE	Department of Energy
DNI	Director of National Intelligence
FSU	Former Soviet Union
IAEA	International Atomic Energy Agency
NATO	North Atlantic Treaty Organization
NPT	Nuclear Non-Proliferation Treaty
NSG	Nuclear Suppliers Group
PSI	Proliferation Security Initiative
Pu-xxx	Plutonium-(specific isotope)
U-xxx	Uranium-(specific isotope)
UF-6	Uranium Hexafluoride
UN	United Nations
USAF	United States Air Force
WMD	Weapons of Mass Destruction

Bibliography

- Albright, David. "Iraq's Programs to Make Highly Enriched Uranium and Plutonium for Nuclear Weapons Prior to the Gulf War." Washington D.C.: Institute for Science and International Security (ISIS), 1997, revised in October 2002. Available from http://www.isis-online.org/publications/iraq/iraqs_fm_history.html.
- . "South Africa's Secret Nuclear Weapons." *ISIS Report*. Washington D.C.: ISIS, May 1994. Available from <http://www.isis-online.org/publications/southafrica/ir0594.html>.
- Albright, David and Hinderstein, Cory. "The A.Q. Khan Illicit Nuclear Trade Network and Implications for Nonproliferation Efforts." *Strategic Insights*. Volume V, Issue 6, July 2006.
- . "Unraveling the A.Q. Khan and Future Proliferation Networks." *The Washington Quarterly*. Washington D.C.: Center for Strategic and International Studies and Massachusetts Institute of Technology, 28:2, Spring 2005.
- . "Uncovering the Nuclear Black Market: Working Toward Closing Gaps in the International Nonproliferation Regime." Address. Institute for Nuclear Materials Management 45th Annual Meeting at Orlando, Fl, Institute for Science and International Security: 2 July 2004.
- Associated Press. "Bush: 'All Options Are On the Table' Regarding Iran's Nuclear Aspirations." *USA Today.Com*. 13 August 2005. Available from http://www.usatoday.com/news/washington/2005-08-13-bush-iran-nuclear_x.htm.
- . "Iran Discovers Uranium Deposits, Continues Enrichment Program" *Foxnews.com*, 2 May 2006. Available from <http://www.foxnews.com/story/0,2933,193938,00.html>.
- . "Russian Smuggled Nuclear-Bomb Uranium, Source Says." *CNN.com*, 25 January, 2007. Available from <http://transcripts.cnn.com/TRANSCRIPTS/0701/25/cnr.07.html>.
- Baker, James A. III and Hamilton, Lee H., et al. *The Iraq Study Group Report*. Washington D.C.: 2006.
- BBC News. "Iran Swiftly Seeks Nuclear Goal." *BBC World News Online*, 21 February 2007. Available from http://news.bbc.co.uk/2/hi/middle_east/6381477.stm.
- Becker, E.W. "Separation Nozzle." In *Topics in Applied Physics Volume 35: Uranium Enrichment*. Edited by S. Villani. Springer-Verlag, Berlin, 1979.
- Brookings Institution. "The Costs of the Manhattan Project." *Global Politics*. Washington D.C: Brookings Institution, 2002). Available from <http://www.brookings.edu/fp/projects/nucwcost/manhattan.htm>.
- Bush, George W. "Global Message." Washington D.C.: Office of the White House, 17 March 2003. Available from <http://www.whitehouse.gov/infocus/iraq/news/20030317-10.html>.

- . “Remarks by the President on Weapons of Mass Destruction Proliferation.” Washington D.C.: Office of the White House, 11 February 2004.
- . “The President’s State of the Union Address.” Washington D.C.: Office of the White House: 29 January 2002. Available from <http://www.whitehouse.gov/news/releases/2002/01/20020129-11.html>.
- Center for Nonproliferation Studies (CNS). *CNS Nuclear Proliferation Treaty Briefing Book*. CNS: 2005.
- Central Intelligence Agency. “New Information on South Africa’s Nuclear Program and South African-Israeli Nuclear and Military Cooperation.” Memorandum. 30 March 1983. Washington D.C.: declassified, released in May 1996. Available from <http://www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB181/sa26.pdf>.
- . “South Africa Seeks Uranium Hexafluoride Technology.” *Weekly Surveyor*. Washington D.C.: 4 May 1970, declassified and released in September 1991. Available from <http://www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB181/sa02.pdf>.
- . *Trends in South Africa’s Nuclear Security Policies and Programs*. Washington D.C.: October 1984. Available from <http://www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB181/sa27.pdf>.
- Chairman of the Joint Chiefs of Staff. *The National Military Strategy of the United States of America*. Washington D.C.: Government Printing Office, 2004.
- Cheney, Dick. “VP’s Remarks in Dayton, Ohio.” Office of the White House: 12 August 2004. Available from <http://www.whitehouse.gov/news/releases/2004/08/print/200408123.html>.
- Cirincione, Joseph, Jon B. Wolfsthal, and Miriam Rajkumar. *Deadly Arsenals: Nuclear, Biological, and Chemical Threats* (2nd edition). Washington D.C.: Carnegie Endowment of International Peace, 2005.
- Civiak, Robert L. *Closing the Gaps: Securing Highly Enriched Uranium in the Former Soviet Union and Eastern Europe*. Washington D.C.: Federation of American Scientists, May 2002.
- Clausewitz, Carl von. *On War*. Edited and translated by Michael Howard and Peter Paret. Princeton, NJ: Princeton University Press, 1984.
- Congressional Research Service (CRS). “Combat Aircraft Sales to South Asia: Potential Implications.” *CRS Report for Congress*. Washington D.C.: CRS, 19 May 2005.
- . “Disarming Libya: Weapons of Mass Destruction.” *CRS Report for Congress*. Washington D.C.: CRS, 22 April 2004.
- . “Iran’s Nuclear Program: Recent Developments.” *CRS Report for Congress*. Washington D.C.: CRS, 6 September 2006.
- . “North Korea’s Nuclear Weapons Program,” *CRS Report for Congress*. Washington D.C.: CRS, 1 August 2006.
- . “Nuclear Nonproliferation Issues.” *CRS Report for Congress*. Washington D.C.: CRS, 20 January 2006.
- . *Nuclear Weapons in Russia: Safety, Security and Control Issues*. Washington D.C.: Library of Congress, 25 November 2002.
- . “Pakistan’s Nuclear Proliferation Activities and the Recommendations of the 9/11 Commission.” *CRS Report for Congress*. Washington D.C.: CRS, 24 May 2005.

- Corera, Gordon. *Shopping for Bombs: Nuclear Proliferation, Global Insecurity, and the Rise and Fall of the A.Q. Khan Network*. New York, NY: Oxford University Press, 2006.
- Dareini, Ali Akbar. "Iran Vows to Ramp Up Uranium Enrichment." *ABC News*. Available from <http://abcnews.go.com/International/wireStory?id=1835531>.
- Department of Energy. "Budget Highlights." *FY 2006 Congressional Budget Request*. Washington D.C.: document DOE/ME-0053, February 2005.
- . Energy Information Administration. "Oil." Available from <http://www.eia.doe.gov/emeu/cabs/Iran/Oil.html>.
- . "Fact Sheet on NA-22." Available from http://www.nnsa.doe.gov/na20/detect_prolif.shtml.
- Director of National Intelligence. "National Counter-Proliferation Center Fact Sheet." Washington D.C.: <http://www.dni.gov/aboutODNI/organization/NCPC.htm>.
- ElBaradei, Mohamed. "Addressing Verification Challenges." Address. International Safeguards Convention. Vienna, Austria: 16 October 2006.
- Federation of American Scientists (FAS). "Uranium Production." Washington D.C.: FAS. Available from <http://www.fas/nuke/intro/uranium.htm>.
- Ghanem, Shokri. "The New Gadhafi." *60 Minutes II*. CBS News: aired 10 March, 2004.
- Glasstone, Samuel and Phillip J Dolan, ed. *The Effects of Nuclear Weapons*. Washington D.C.: Department of Defense and Department of Energy, 1977.
- Goodby, James E, et al. *Cooperative Threat Reduction for a New Era*. Washington D.C.: National Defense University, September 2004.
- Hamza, Khidhir. *Saddam's Bombmaker: The Terrifying Inside Story of the Iraqi Nuclear and Biological Weapons Agenda*. New York, NY: Scribner, 2000.
- Harris, Tim C. *Proliferation Aspects of Electromagnetic Isotope Separation Programs*. Air Force Institute of Technology: March 2001.
- Hoffman, David. "President Imposes Boycott on Business with Libya, Qadhafi's Isolation Urged." *Washington Post*, 8 January 1996.
- Hymans, Jacques E.C. *The Psychology of Nuclear Proliferation: Identity, Emotions, and Foreign Policy*. Cambridge, UK: Cambridge University Press, 2006.
- International Atomic Energy Agency (IAEA) *IAEA Safeguards: Stemming the Spread of Nuclear Weapons*. Vienna, Austria: 2002.
- . *Implementation of the NPT Safeguards Agreement of the Socialist People's Libyan Arab Jamahiriya*. Vienna, Austria: IAEA document: GOV/2004/12, 20 February 2004.
- . *Implementation of the NPT Safeguards Agreement of the Socialist People's Libyan Arab Jamahiriya*. Vienna, Austria: IAEA document: GOV/2004/59, 20 August 2004.
- . *Implementation of the Safeguards Agreement with the Democratic People's Republic of Korea Pursuit to the Treaty on the Non-Proliferation of Nuclear Weapons*. Vienna, Austria: IAEA document: GC/48[17], 16 August 2004.
- . *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*. Vienna, Austria: IAEA document: GOV/2003/75, 10 November 2003.
- . *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*. IAEA document: GOV/2004/83, 15 November 2004.

- . *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*. Vienna, Austria: IAEA document GOV/2006/53, 31 August 2006.
- . *Model Protocol Additional to the Agreement(s) Between State(s) and the International Atomic Energy Agency for the Application of Safeguards*. Vienna, Austria: IAEA document: INFCIRC 540, corrected.
- . *Report of the Third On-site Inspection in Iraq*. Vienna, Austria: IAEA, July 1991.
- . *Report of the Fourth On-site Inspection in Iraq*. Vienna, Austria: IAEA, August 1991.
- . *Report of the Third On-site Inspection in Iraq*. Vienna, Austria: IAEA, July 1991.
- . “Status of the Additional Protocol.” Available from http://www.iaea.org/OurWork/SV/Safeguards/sg_protocol.html.
- . *Treaty on the Non-proliferation of Nuclear Weapons*. Vienna, Austria: IAEA document INFCIRC/140, 22 April 1970.
- Institute for Science and International Security. “Acquisition of Gas Centrifuge Technology: Part III.” Washington D.C.: ISIS. Available from <http://www.exportcontrols.org/centpart3.html>.
- Iraq Survey Group. *Comprehensive Report on the Special Advisor to the DCI on Iraq’s WMD*. Washington D.C.: CIA, 30 September 2004.
- Kennedy, John F. *John F. Kennedy Presidential Library and Museum*, “News Conference 52.” Address. State Department auditorium, 21 March 1963.
- Kokoski, Richard. *Technology and Proliferation of Nuclear Weapons*. Oxford, England: Oxford University Press, 1995.
- Krass, Allan S., et al. *Uranium Enrichment and Nuclear Weapons Proliferation*. Stockholm, Sweden: Stockholm International Peace Institute, 1983.
- Leventhal, Paul. “Testimony by Paul Leventhal, President, Nuclear Control Institute, on Pakistan and U.S. Nuclear Nonproliferation Policy, Before the House Foreign Affairs Committee.” Washington D.C.: Nuclear Control Institute, 22 October 1987. Available from <http://www.nci.org/t/t102287.htm>.
- Linzer, Dafna. “S. Korea Nuclear Project Derailed.” *The Washington Post*, 12 September 2004.
- Mackby, Jenifer and Slocombe, Walter B. “Germany: The Model Case, A Historical Perspective.” In *The Nuclear Tipping Point: Why States Reconsider Their Nuclear Choices*. Edited by Kurt M. Campbell, et al. Washington D.C.: Brookings Institution Press, 2004.
- Massignon, D. “Gaseous Diffusion.” In *Topics in Applied Physics Volume 35: Uranium Enrichment*. Edited S. Villani. Berlin, Germany: Springer-Verlag, 1979.
- McDaniel, Keith. *Secret City: The Oak Ridge Story, The War Years*. Oak Ridge, TN: The Secret City Film Institute, 2005.
- Meyer, Stephen. *The Dynamics of Nuclear Proliferation*. Chicago: University of Chicago Press, 1984.
- Miller, Marvin. “The Gas Centrifuge and Nuclear Proliferation.” *A Fresh Examination of the Proliferation Dangers of Light Water Reactors*. Washington D.C.: The Nonproliferation Policy Center: 22 October 2004.

- Moore, JDL. *South Africa and Nuclear Proliferation: South Africa's Nuclear Capabilities and Intentions in the Context of International Non-proliferation Policies*. London: Macmillan Press, 1987.
- Mozley, Robert F. *The Politics and Technology of Nuclear Proliferation*. Seattle: University of Washington Press, 1998.
- National Academy of Sciences. *Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities*. Washington D.C.: National Academics Press, 2005.
- Pabian, Frank V. "South Africa's Nuclear Weapon Program: Lessons for U.S. Nonproliferation Policy." *The Nonproliferation Review*. Monterey, CA: CNS, Fall 1995.
- Pollack, Kenneth M. *The Persian Puzzle: The Conflict Between Iran and America*. New York, NY: Random House Inc, 2004.
- Public Papers of the Presidents of the United States: Ronald Reagan, Book I: January 1 to Jun 27, 1986*. Washington D.C.: Government Printing Office, 1988.
- Obeidi, Mahdi and Kurt Pitzer. *The Bomb in My Garden: The Secrets of Saddam's Nuclear Mastermind*. New Jersey: John Wiley & Sons, 2004.
- Rhodes, Richard. *The Making of the Atomic Bomb*. New York, NY: Simon & Schuster, 1986.
- Richelson, Jeffrey T. *Spying on the Bomb*, New York, NY: W.W. Norton & Company, Inc, 2006.
- Russell, George. "Who has the Bomb," *TIME Magazine*. 3 June 1985. Available from <http://www.time.com/time/magazine/article/0,9171,957761-1,00.html>.
- Sanger, David E. and William J. Broad. "U.S. Concedes Uncertainty on North Korean Uranium Effort." *NYTimes.com*, 1 March 2007. Available from <http://www.nytimes.com/2007/03/01/washington/01korea.html?ei=5088&en=37430b9fcca9512c&ex=1330405200&pagewanted=print>.
- Saxena, A.K. "Experiments for the Recovery of Uranium from Seawater by Harnessing Tidal Energy." *Bhabha Atomic Research Center Newsletter*. BARC: Issue 249, 2004. Available from <http://www.barc.ernet.in/webpages/letter/2004/20041036.pdf>.
- Schulte, Gregory. "Address to German United National Association," *Iran Watch*, 8 February 2007. Available from <http://www.iranfocus.com/modules/news/makepdf.php?storyid=10109>.
- Silberman, Laurence H. and Charles S. Robb, co-chairmen. *Commission of the Intelligence Capabilities of the United States Regarding Weapons of Mass Destruction*. Washington D.C.: 31 March 2005.
- Smith, R. Jeffrey. "Iraqi Defector." *Washington Press*. 14 June 1991.
- Soubbaramayer. "Centrifugation." In *Topics in Applied Physics Volume 35: Uranium Enrichment*. Edited by S. Villani. Berlin, Germany: Springer-Verlag, 1979.
- State Department. Fact Sheet "Background Note: Pakistan." Washington D.C.: Bureau of South and Central Asian Affairs, October 2006. Available from <http://www.state.gov/r/pa/ei/bgn/3453.htm>.

- . “Fact Sheet on the Proliferation Security Initiative.” Washington D.C.: June 2004. Available from <http://usinfo.state.gov/products/pubsproliferation/proliferation.pdf>.
- . “The Pakistani Nuclear Program.” Washington D.C.: 23 June 1983. Available from http://www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB6/ipn22_1.htm.
- Stimson, Henry L. “The Decision to Use the Atomic Bomb,” *Harpers Magazine*, February 1947.
- Stumpf, Waldo. “50 Years After Hiroshima.” Address. Presented to a conference organized by Unione Scienziati per il Disarmo in Castiglioncello, Italy, 28 September - 2 October 1995.
- Tyson, Sean. “Uranium Enrichment Technologies: Proliferation Implications.” Monterey, CA.: Center for Nonproliferation Studies: 1999, available from <http://www.nti.org/db/archives/nuc/eos/tyson.htm>.
- United Nations Security Council. *Resolution 1540*. New York, NY: document S/Res/1540/2004. 28 April 2004.
- . *Resolution 1737*. United Nations: document S/Res/1737, 2006. 27 December 2006.
- Uranium Information Center (UIC). *Uranium and Depleted Uranium: Nuclear Issues Briefing Paper #53*. UIC: 2005. Available from <http://www.uic.com.au/nip53.htm>.
- . *World Uranium Mining: Nuclear Issues Briefing Paper #41*. UIC: 2006. Available from <http://www.uic.com.au/nip41.htm>.
- United States Atomic Energy Commission. *Twentieth Semiannual Report on the Atomic Energy Commission*. Washington D.C.: Government Printing Office, July 1956. Available from <http://www.osti.gov/opennet/servlets/purl/1636038628xm8G/16360386.pdf>.
- Venter, Al J. *Iran’s Nuclear Options: Tehran’s Quest for the Atom Bomb*. London: Greenhill Books, 2005.
- Villani, S. *Topics in Applied Physics Volume 35: Uranium Enrichment*. Berlin, Germany: Springer-Verlag, 1979.
- Waltz, Kenneth N. “Peace, Stability, and Nuclear Weapons.” *Institute on Global Conflict and Cooperation*. University of California: IGCC Policy Paper 15, 1995.
- White House. “Detailed Information on the NNSA Nonproliferation and Verification Research and Development Assessment.” Washington D.C.: Office of the White House, 2006. Available from <http://www.whitehouse.gov/omb/expectmore/detail.10003408.2005.html>.
- . *The National Security Strategy of the United States of America*. Washington, D.C.: Office of the White House, 2006.