Strengthening the Nonproliferation Regime – Using Case Studies to Determine the Potential of Multilateral Arrangements

by
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Abstract

The resurgence of global interest in nuclear energy is fueled by growing energy demands, concerns of global warming, and the desire to diversify energy supply. In order for the nuclear renaissance to be safely realized, a number of concerns must first be addressed. Foremost among them are the dual-use nature of nuclear technology and the spread of nuclear weapons. As small nuclear power programs expand and new states introduce nuclear power into their electricity grid, states must decide whether or not to develop indigenous enrichment and reprocessing facilities that may be misused for a weapons program. One of the must discussed instruments to strengthen the nonproliferation regime and limit the dangerous spread of sensitive fuel cycle technologies is the multilateralzation of the nuclear fuel cycle. Through multilateral mechanisms, multilateral arrangements to the nuclear fuel cycle attempt to limit the spread of fuel cycle technologies by removing the incentives to do so.

Concepts and proposals for multilateral arrangements have been around since the advent of nuclear energy in the 1940s but have received a lukewarm response from the international community. It is postulated that this response is driven by difficulties multilateral arrangements have in addressing all of the motivations for the establishment of fuel cycle facilities. An investigation is presented within to detail the most powerful motivations that multilateral arrangements may have been overlooking to this date. In order to achieve this, three case studies are performed to uncover the most powerful motivations for the development of fuel cycle facilities. The motivations are complex and include a variety of economic, political, and potentially proliferation related incentives. Brazil, South Korea, and Iran are chosen for the case studies because they are currently in the process of introducing sensitive facilities into their nuclear fuel cycles, or are strongly considering it. Following the description of the various motivations for the pursuit of sensitive fuel cycle facilities, an analysis is provided to determine which, if any, of the proposed multilateral arrangements are in best position to be successfully implemented.

The study found that the establishment of regional nuclear fuel cycle facilities and centers offers the greatest potential to strengthen the nonproliferation regime by targeting the state's political power incentives. Supply assurances do not address the needs of any of the studied states, indicating they are not applicable to well-developed nuclear power states or those in possession fuel cycle technologies. Supply assurances do however, provide strong confidence building measures in the establishment of regional fuel cycles. Lastly, the development of multilateral spent-fuel repositories may be the most sure-fired way to prevent the spread of reprocessing facilities.

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1 - Introduction

1.1 – The Next Nuclear Renaissance

Around the world a number of states are seriously looking into the expansion or introduction of nuclear power into their electricity grid. Nuclear power has historically been adopted by highly developed and industrialized states. There are thirty states that currently operate nuclear power plants but only 4.3% of generation derives from non-OECD (Organization for Economic Co-operation and Development) states. By 2030, the International Atomic Energy Agency projects this number to increase to 15%.[1] There are over 50 states which have recently expressed their interest in introducing their first nuclear power plant onto the electricity grid. It is unlikely all of these states are capable of developing nuclear power in the short to medium term however. José Goldemberg argues that if countries with a GDP smaller than 50 billion dollars and an electric grid smaller than 10 GWe are eliminated from the list, the potential for 16 realistic new nuclear power states remain.[2] The vast majority of these states are within the Middle East and South East Asia.

The recent growth of interest in nuclear energy is fueled primarily through the following motivations:[3]

- Increasing energy demand, particularly in the developing world. Worldwide electricity demands are projected to double by 2030.
- In the coming decades, countries are expected to face shortages in fresh water supply. Nuclear power can contribute to energy-intensive desalination facilities.
- Nuclear energy contributes very little greenhouse gas emissions. A large scale global deployment of nuclear power, including to developing countries, can contribute toward the mitigation of climate change. This motivation is a much stronger consideration amongst the developed world as opposed to the developing world.
- Nuclear energy can improve a countries level of energy security and diversification by reducing the need for fossil fuel in electricity generation.

Nuclear power is positioned to become an increasingly important member of the global energy portfolio. To do this however, concerns about another possible motivation for developing nuclear power must be addressed. Nuclear technology is dual-use in nature and the nuclear fuel cycle can be misused to produce nuclear weapons. In the past, a number of countries have attempted (with varying levels of success) to proliferate nuclear weapons from a peaceful nuclear power program. Given that the list of developing countries looking to build nuclear power plants have a high degree of corruption or low level of political stability,[4] many fear nuclear weapons proliferation will occur simultaneously with nuclear power expansion. If these fears cannot be assuaged, the global nuclear renaissance may never get started, or worse, the number of states with nuclear weapons will increase, igniting a new nuclear arms race.

This fear is compounded by the eroding confidence in the nonproliferation regime. The nonproliferation regime is the global regulatory system developed to oversee global nuclear developments and ensure its

will be heavily strained by a global nuclear renaissance and as President Barack Obama said on April 5, 2009 in Prague "we could reach the point where the center cannot hold." Unless the nonproliferation regime is strengthened, a global expansion of nuclear weapons may occur.

1.2 - Strengthening the Nonproliferation Regime

The most challenging aspect in the creation of nuclear weapons is the acquisition of fissile material. In the front-end of the fuel cycle, enrichment facilities are needed to provide usable fuel for the world's fleet of nuclear reactors. In the back-end of the fuel cycle, reprocessing is being considered as a means to increase fuel supply and reduce the stocks of spent-fuel to be disposed of. Enrichment and reprocessing facilities however, may also be converted to produce highly enriched uranium and plutonium for weapons use.[6] States looking to expand or introduce the use of nuclear-generated electricity must decide whether or not to incorporate the development of enrichment and or reprocessing facilities in their plans. Widespread adoption of these dual-use facilities may result in widespread nuclear weapons proliferation.

The non-proliferation regime has historically been successful in stemming, although not preventing, the proliferation of nuclear weapons. Recent events over the past couple of decades however, have put a significant strain on the current structure of the nonproliferation regime. Most prominent among them are: Regional tensions, compliance problems with safeguards agreements, clandestine nuclear supply chains, and terrorist organizations.[7] The coming decades will continue to face these threats but must also adjust to the worldwide expansion of the civilian nuclear industry. If a large number of states develop and construct enrichment and reprocessing facilities, the nonproliferation regime may be unable to limit the rapid spread of nuclear weapons around the world. The nonproliferation regime does not currently have the ability to restrict the development and spread of these facilities. Enrichment and reprocessing rights are guaranteed under Article IV of the NPT. Furthermore, old policies to deny sensitive technologies through export controls will not be effective in today's world of secret supply chains, such as the A.Q. Khan Network, and increased technology access.[8] In order to strengthen the nonproliferation regime, efforts are being undertaken to limit the access to or incentives for dual-use technologies in the nuclear fuel cycle. The multilateralization of the nuclear fuel cycle, in its many forms, is one of the most discussed instruments being proposed to adapt and strengthen the non-proliferation regime in preparation for a nuclear renaissance.

Multilateral arrangements place various components of the nuclear fuel cycle under international control and oversight. Proposals and concepts for multilateral arrangements of the nuclear fuel cycle are currently aimed at limiting the widespread diffusion of fuel cycle facilities to non-nuclear weapons states, although the primary goal is to create better institutional mechanisms to manage fissile material and sensitive technologies. A complete cessation of the development of new fuel cycle facilities is not a requirement to better manage nuclear material and reduce the likelihood of nuclear breakout, diversion, or misuse. For instance, increased involvement of outside parties in the nuclear fuel cycle prevents a state from unilateral diversion of nuclear materials or misuse of sensitive fuel cycle technologies. Sovereign nations are not likely to give up their right to nationally owned and operated fuel cycle technologies unless the proper incentives are in place. In this light, most mechanisms are developed to improve a state's economic and political position within the nuclear fuel cycle. Mechanisms for a multilateral fuel cycle are non-technical in nature and vary in scope and strategy, although the most prevalent mechanism is the reinforcement of supply assurances in the commercial

enrichment market.[9] As an acknowledgement to the current political environment, efforts have thus far focused on establishing voluntary incentive based mechanisms as opposed to regulatory ones[10].[10] In the long term, it is hoped these political constraints can relax allowing for a more comprehensive and aggressive set of multilateral fuel cycle arrangements.

1.3 – Thesis Objectives

There have been a number of proposals and concepts for the multilateralization of the nuclear fuel cycle put forward for consideration. The proposals and concepts offer a variety of economic and political strategies for minimizing the spread of sensitive fuel cycle technologies. The proposed and conceptual arrangements are for the most part considered effective at ensuring the reliable access to competitively priced nuclear fuel while strengthening the nonproliferation regime.[11] To this date however, efforts at multilateral arrangements have received a lukewarm response in the international community.

There has been a great deal of thought put into formulating the strategies in multilateral arrangements to strengthen the nonproliferation regime. There is an exhibited awareness in the proposals that the arrangements must reduce the motivations for developing nuclear power states to pursue indigenous fuel cycle facilities. However, focus may be too centered on ensuring the strong nonproliferation credentials of an arrangement as opposed to addressing the strongest motivations for pursuing sensitive fuel cycle facilities. The lack of interest in the arrangements from consumer states must be because states are either satisfied with the supply assurances currently present in the commercial market or they view multilateral arrangements as an attempt to openly deny access to indigenous fuel cycle facilities.[11]

This is not to say that multilateral arrangements are incapable of being successfully implemented. Considering all the proposals have thus far come from the suppliers of fuel cycle services,[11] the arrangements may be overlooking various motivations for the pursuit of fuel cycle facilities. There is a need to analyze the applicability of multilateral arrangement from the perspective of the consumer states. Similar to the decision to proliferate nuclear weapons,[12] the motivations to develop sensitive fuel cycle technologies are complex. In addition to the economic motivations to establish a cheap or reliable supply of fuel cycle services, there are a number of political incentives to develop enrichment or reprocessing facilities. The objective of this thesis is twofold: Investigate the motivations behind the pursuit of fuel cycle technologies and determine which, if any, of the proposals or concepts for multilateral arrangements are in best position to significantly contribute to the strengthening of the nonproliferation regime.

1.4 – Thesis Organization

An understanding of some basic tenants of the nonproliferation regime and the two sensitive fuel cycle technologies that can be misused for nuclear weapons material production is required. A brief overview into these two areas is provided. For the nonproliferation regime, attention is given to the structure of the NPT and the export control regimes. There is a variety of other components to the nonproliferation regime but these two areas are the most important when considering the applicability of multilateral arrangements. The NPT provides the primary legal structure to the nonproliferation regime while the export control regime sets up the primary means through which nuclear related trades can occur. Next is an overview of the concepts and proposals for the multilateralization of the nuclear fuel cycle. The

purpose and ideas behind their establishment is followed by a detailed description of the proposals and ideas that have been presented to date.

The primary means of investigation in the thesis will be undertaken through three case studies used to analyze the primary motivations behind the establishment of sensitive fuel cycle facilities. Through these three case studies, valuable lessons will be gained and later applied to determine whether or not multilateral arrangements can be successful instruments to strengthen the nonproliferation regime. Most often, particular proposed multilateral arrangements are not analyzed, but rather the ideas they offer. Iran, South Korea, and Brazil have been chosen for the case studies. Each of these states is currently in the process of, or is strongly considering, introducing enrichment or reprocessing facilities into their domestic nuclear infrastructure. In order to determine the motives for the development of these facilities, the states will be characterized by their nuclear power and infrastructure, and their historical nuclear program development and related political interactions. The presence and relative importance of various potential economic, political, and strategic motivations for the establishment of fuel cycle facilities are detailed.

2 – The NPT and Nuclear Export Controls

The nuclear non-proliferation regime refers to the collection of treaties, export control arrangements, United Nations Security Resolutions, and other initiatives aimed at preventing the spread of nuclear weapons around the world.[13] The Nuclear Non-Proliferation Treaty (NPT) was opened for signature in 1968 and is the centerpiece to the non-proliferation regime. In 1995 the NPT was indefinitely extended. The NPT is the most universally accepted treaty in the world with a total of 189 member states. Only India, Pakistan, Israel, and North Korea are not party to the treaty, all of which are in possession of nuclear weapons.[13] Five states are recognized as nuclear weapon states by the treaty. They are: The United States, China, the United Kingdom, France, and Russia. These same five states are the permanent members of the United Nations (UN) Security Council. The NPT is often regarded as the "Grand Bargain" between nuclear weapon states and non-nuclear weapon states.[14] The Grand Bargain consists of three pillars. [12] As President Barack Obama said in his Prague 2009 speech, "countries with nuclear weapons will move to disarmament, countries without nuclear weapons will not acquire them, and all countries can access peaceful nuclear energy.[14] An overview of the treaties language for the three pillars is presented below.

Non-Proliferation - In Article I of the NPT,[15] nuclear weapon states agree not to "transfer to any recipient whatsoever nuclear weapons or control over such weapons" to non-nuclear weapons states. Nuclear weapon states also commit "not in any way to assist...any non-nuclear weapon State to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices, or control over such weapons or explosive devices." Article II of the NPT holds analogous responsibilities for non-nuclear weapons states not to "receive the transfer from any transferor whatsoever of...manufacture...or receive any assistance in the manufacture of" nuclear weapons. In Article III of the NPT, "each non-nuclear weapon State Party to the Treaty undertakes to accept safeguards...negotiated and concluded with the International Atomic Energy Agency." The implementation of safeguards should "avoid hampering the economic or technical development...in the field of peaceful nuclear activities."

Inalienable Right to Peaceful Nuclear Technologies - Article IV of the NPT[15] affirms that "nothing in this Treaty shall be interpreted as affecting the inalienable right of all the Parties to the Treaty" to the peaceful application of nuclear power. The inalienable right is only valid if the treaty member is "in conformity with Articles I and II" of the NPT. Article IV of the NPT also states that all parties to the treaty should undertake to provide aid to each other, especially to the developing world, in the development of peaceful nuclear applications.

Nuclear Disarmament - Article VI of the NPT[15] commits the parties of the NPT to pursue in "good faith on effective measures relating to the cessation of the nuclear arms race" and eventually "complete disarmament under strict and effective international control."

The "Grand Bargain" of the NPT has received a lot of publicity over the last few years. Non-nuclear weapon states have been very critical over the lack of progress by the nuclear weapon states to move to disarmament. Proponents for nuclear disarmament argue that progress is needed in fulfilling Article VI of the NPT in order to influence non-nuclear member states to maintain their stay within the NPT and fulfill their obligations.[14] In respect to Article IV of the NPT, certain non-nuclear weapon states have long argued that access to peaceful nuclear technologies has been discriminatorily applied. There is an

important distinction that is at times overlooked, if a state is not in conformity with its Article I or Article II obligations it has given up its right to peaceful nuclear technologies.[14] The safeguards agreement with the IAEA is the primary means to verify conformity with Article I and II of the NPT.

Safeguards are not intended to prevent the spread of nuclear weapons. Instead, safeguards are designed to detect the diversion of significant quantities of nuclear material, within defined timeliness goals.[16] A significant quantity is defined as the amount of material needed to make a nuclear weapon. Timeliness goals vary by nuclear material and conversion mechanism. For plutonium, highly enriched uranium (HEU), and uranium-233 material in metal form, the timeliness goal is one month, while it is three months for irradiated fuel.[17] If the IAEA finds a state in non-compliance with its safeguards agreements, the issue is reported to the UN Security Council and General Assembly. The UN Security Council decides upon the appropriate action to take in response to the report.[14]

The discovery of Iraq's clandestine nuclear weapons program after the Gulf War motivated a change to the international safeguards structure. The Additional Protocol (AP) was developed in response.[18] The AP provides the IAEA a greater degree of access to a state's facilities in order to verify the completeness of the state's declared nuclear activities. In other words, the AP gives the IAEA the ability to detect clandestine nuclear activities. Most states have agreed to voluntarily implement the AP while a few see the AP as overly intrusive.

Nuclear export controls gained traction following India's nuclear test explosion in 1974, achieved through the aid of Canadian exports.[18] The Unites States passed the Nuclear Non-Proliferation Act of 1978 (NNPA). The NNPA requires partner states in nuclear supply deals with the United States to be a member of the NPT and have full safeguards agreements in place.[18] The NNPA requires that new nuclear trade agreements contain consent rights over the uses of United States supplied nuclear material or reactors.[19] These consent rights indicate that a state cannot reprocess or enrich nuclear material of American origin or the spent-fuel from an American supplied reactor without the approval of the United States. The Federal Code of Regulations also requires the American consent before any retransfer of nuclear material to another state.[20]

The Nuclear Suppliers Group (NSG) published its first set of export guidelines in 1978.[21] The NSG is a collection of states that have set a number of agreed to nuclear export principles aimed to ensure that nuclear transfers could not be diverted or used for nuclear weapons. Individual states can and do implement their more stringent export policies not within the guidelines of the NSG. For instance, almost all nuclear export deals today require the implementation of the AP which is not a guideline of the NSG. At the time of formation, the NSG could incorporate non-NPT member states such as France and Germany into the export control efforts.[22] One of the primary objectives of the early NSG was to come to agreement that enrichment and reprocessing technologies would not be included in deals by nuclear power plant providers in order to gain a competitive advantage in the marketplace.[23] The NSG has been criticized at times for acting as a supplier's cartel and undermining the bargain of the NPT.[22] The current guidelines of the NSG can be found in INFCIRC 254.[24] For the export of trigger list items, guidelines require recipient states to have a safeguards agreement in place with the IAEA. No state receiving transfer of enrichment facilities or technologies can enrich beyond 20% without consent of the supplier state. Trigger list items are those that require the implementation of safeguards once exported or are necessary components in the construction and use of safeguarded items.[24] Following the Iraq discovery in 1991, an expanded list of guidelines was put into place for dual use items in INFCIRC 254

Part 2.[25] These more stringent guidelines require consent rights for retransfer. Additionally, the guidelines have supplier states request statements of end-use from consumer states along with a commitment to not use supplied material or items in manufacture of nuclear weapons or unsafeguarded facility. The guidelines in INFCIRC 254 Part 2 are very similar to the restrictions imposed in the American NNPA.

3 - Sensitive Fuel Cycle Technologies

The civilian nuclear fuel cycle is the collection of industrial activities associated with the production of power in nuclear reactors.[9] The preparation of uranium resources into fuel is referred to as the front-end of the nuclear fuel cycle and the management of spent-fuel is referred to as the back-end of the nuclear fuel cycle. Front-end processes include: Uranium mining and milling; uranium conversion; uranium enrichment; fuel fabrication; and nuclear power generation. Back-end processes include the storage of spent-fuel and potentially the reprocessing of spent fuel. Not all reactor designs require all aspects of the nuclear fuel cycle for operation.[9] For instance, the CANDU reactor design uses natural uranium as fuel, meaning the enrichment process is not necessary. Most nations also employ an open fuel cycle instead of a closed fuel cycle. A closed fuel cycle reprocesses spent fuel and recycles some of the material for later use in a power reactor. An open fuel cycle forgoes reprocessing, leaving the storage of spent-fuel the only activity in the back-end of the fuel cycle. Within the civilian nuclear fuel cycle there are two primary pathways that can be employed to create the fissile material needed for use in a nuclear weapon. In the front-end of the nuclear fuel cycle, uranium enrichment processes can be used to create highly enriched uranium (HEU) for direct use in the manufacturing of nuclear weapons. In the back-end of the fuel cycle, reprocessing can be used to separate plutonium, an alternative material in the construction of nuclear weapons, from the spent-fuel. It is the diffusion of the technological capabilities and physical facilities for these two dual-use fuel cycle processes which give concern over the spread of nuclear weapons. Below each process is described with regard to their civilian uses and potential military applications.

3.1 - Uranium Enrichment

Natural uranium is around 99.3% U-238 and 0.7% U-235. The nuclear properties of these isotopes are very different. Nuclear energy is produced through the fission of atoms. Fission occurs as an atom is split into smaller parts. Specific isotopes can be induced to fission through the absorption of neutrons. U-238 is a *fissionable* material but, by itself, is not capable of sustaining a nuclear chain reaction. In comparison, U-235 is *fissile*. A fissile material can undergo nuclear fission upon the absorption of thermal neutron and is capable of sustaining a nuclear chain reaction.[9] It is because of its fissile properties that U-235 is the major contributor to the nuclear chain reaction used for large scale nuclear power production.

The most popular design of nuclear reactors in the world, Light Water Reactors, requires fuel with the enrichment of U-235 from natural levels to a concentration 3-5%.[9] Nuclear weapons typically have enrichment levels around 90% but the IAEA considers any level of enrichment above 20% as HEU. 20 kg of HEU represents a significant quantity.[17] A number of research reactors use uranium enriched to 20% for fuel. HEU is regarded as a direct use material, with higher enrichment levels, weapon designs become more powerful and easy to fabricate.[9] Up to this point, enrichment is typically performed through physical processes, although a few chemical processes have been demonstrated. There are currently two enrichment technologies under large scale commercial use around the globe.

Gaseous diffusion was the first enrichment method to be commercially developed and currently accounts for 25% of world enrichment supply.[26] A uranium conversion facility first forms the uranium

into UF_6 gas for use in the enrichment process. In a single stage of enrichment, the UF_6 gas is pumped through a porous nickel membrane. The UF_6 molecules with the lighter U-235 diffuse more rapidly across the membrane than the heavier molecules containing U-238.[7] More than a thousand stages are linked together to form the enrichment process which is repeated many times in a cascade.[12] Gaseous diffusion facilities require a large amount of floor space and consume an extremely large amount of electricity during operation.

The gaseous centrifuge technology currently accounts for roughly 65% of world enrichment supply and also requires the uranium to be converted into UF_6 and.[26] The gas centrifuge is a long and hollow cylindrical chamber rotating on its axis. While spinning, the heavier UF_6 gas molecules containing U-238 are pushed to the outside of the chamber. The gas near the center of the chamber, which is more concentrated with U-235 UF_6, is removed and placed into another centrifuge chamber to undergo the same process for further enrichment.[7] The space and electricity requirements for gaseous centrifuge facilities are significantly less than an equal capacity gaseous diffusion facility. A gaseous centrifuge facility requires around 5% of the electricity that a gaseous diffusion facility requires.[27] This helps make gaseous centrifuge facilities much more economical than gaseous diffusion facilities. In fact, it is projected by 2017 that all gaseous diffusion plants will be phased out of use.[26] The smaller and less resource intensive gaseous centrifuge technology also allows for the easier construction of a clandestine facility for weapons production.

The amount of work required to obtain a certain degree of enrichment is called a Separative Work Unit (SWU).[12] In the enrichment process there are three streams of materials; feedstock, product, and the tail end or waste material. Tail end material has an enrichment level lower than the feedstock. If the tail material has an enrichment level below natural levels it is called depleted uranium. The amount of SWU required to reach a certain enrichment level of the product is a function of the feedstock and tail end enrichment level. It is typical for the capacity of an enrichment facility to be displayed in units of kg-SWU per year.[12] The amount of SWU needed to enrich a certain quantity of feedstock exhibits increasing marginal returns as the product enrichment level is increased. In other words, most of the SWU is needed at lower enrichment levels. Figure 1 below is taken from the World Nuclear Association[26] and shows the amount of SWU needed to achieve certain levels of enrichment using a feed of 1000 kg of natural uranium.

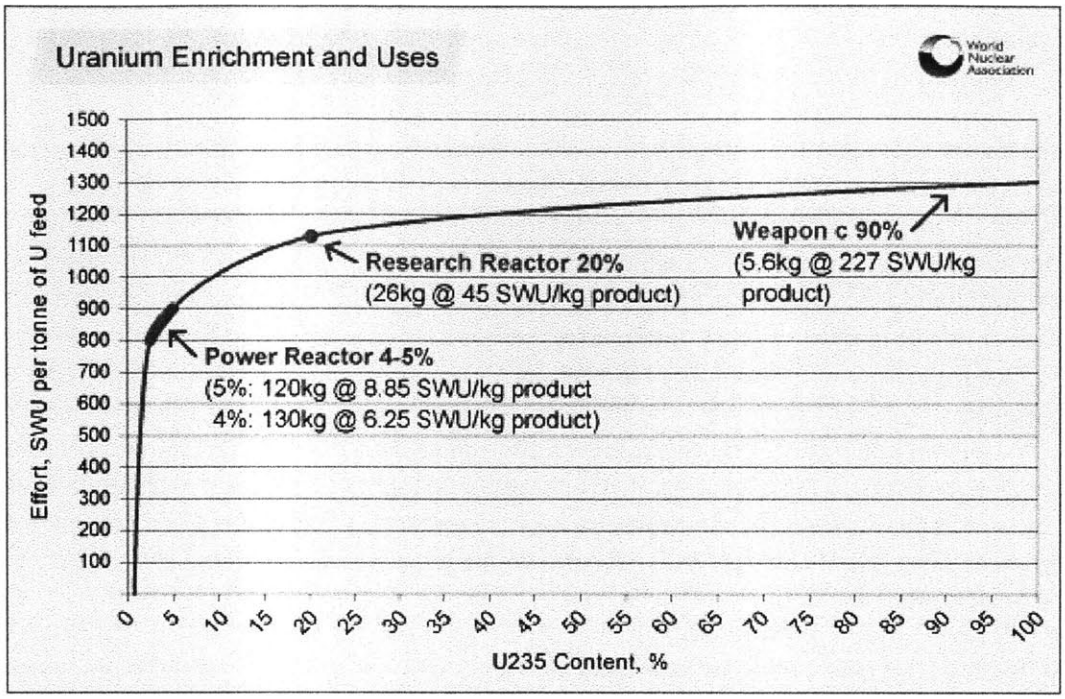

Figure 1 – Increasing Marginal Returns in the Enrichment Process

The increasing marginal return of enrichment is particularly important in nuclear weapons development. Once the uranium has been enriched to higher level, it can be used as feedstock in a break-out scenario. A break-out scenario represents the decreased amount of time or facility capacity needed to produce weapon-grade HEU (93%) by using higher feedstock enrichment levels. In a break-out scenario the material for a nuclear weapon may be produced in a commercial enrichment facility within the IAEA's timeliness criteria, or in a small-scale clandestine centrifuge enrichment facility. For example, it takes 197.34 kg of natural uranium feedstock with a work of 214.03 SWU to produce 1 kg of 93% enriched uranium. In comparison 33.73 kg of 3% enriched LWR fuel feedstock requiring 87.04 SWU is needed to produce 1 kg of 93% enriched uranium.[12] 4.7 kg of 20% enriched research reactor uranium feedstock requiring 20.34 SWU will p produce 1 kg of 93% enriched uranium.

3.2 - Spent-Fuel Reprocessing

Plutonium is produced in a nuclear reactor following the absorption, without fission, of a neutron by U-238.[9] Plutonium, like uranium, has a number of isotopes which exhibit different nuclear properties. The plutonium discharged from a nuclear reactor has strong fissile properties and is considered to be direct-use material for a nuclear weapon.[9] Spent-fuel from nuclear reactor consists mostly of U-238 with significant quantities of U-235 and plutonium isotopes. Within spent-fuel there are also a number of actinides and fission products. The fission products in the spent-fuel are highly radioactive. Short-lived fission products make the handling of spent nuclear fuel very dangerous after discharge from a nuclear reactor. After a number of years, the radioactivity of the spent-fuel decreases as the short-lived fission products decays away.[9] Spent-fuel remains radioactive however for hundreds of thousands of years because of long-lived fission products and actinides. Spent-fuel must eventually be disposed of for long term storage. Reprocessing chemically separates the uranium and plutonium from the other components in the spent-fuel. A 1,000 MWe nuclear power plant operating at 70% capacity produces

250 kg of plutonium per year, 175 kg of which is fissile material.[28] 8 kg of plutonium is considered to be a significant quantity in terms of nuclear weapons production.[17]

Most states do not reprocess their spent fuel, in other words they have opted for an open nuclear fuel cycle. The civilian nuclear fuel cycle can use reprocessing technologies for a couple of reasons. The separated plutonium can be fabricated with depleted uranium into mixed oxide (MOX) fuel for use in commercial nuclear power plants.[7] Around thirty nuclear reactors in Europe use MOX fuel for power generation and there are ten reactors licensed to use MOX in Japan.[29] Reprocessed uranium can also be used in nuclear power plants but must undergo further enrichment. Recycling the plutonium into MOX fuel can reduce the demand for uranium resources by 15% and recycling the uranium can reduce uranium resources by 10%.[30] Currently, the low prices of uranium resources has made the use of MOX fuel in nuclear power generation a more expensive alternative than the once through fuel cycle which does not use reprocessing.[9] Reprocessing also reduces the amount of high-level nuclear waste requiring disposal, by up to one fifth.[31] Although reprocessing may reduce the physical burden for waste disposal, it is important to note than no matter the fuel cycle employed, long-lived wastes are created that must eventually be disposed of.

An alternative "closed" nuclear fuel cycle employing fast reactors can recover up to 50 times the amount of energy from mined uranium in comparison to LWRs.[30] Fast Reactors use the plutonium from spent-fuel to fabricate the initial fuel core for the fast reactor. The requirements for plutonium are very high; 30 years of spent-fuel from a single LWR power plant is required. After the initial core however, the spent-fuel from the fast reactor provides the necessary fuel for another core. In other words, a fleet of fast reactors would eventually become self-sufficient in fuel supply. Fast reactors have for some time been under development but have so far proven to be an uneconomic alternative to the current fuel cycle.[30]

All of the current commercial reprocessing plants use the PUREX technology originally developed for nuclear weapons production.[7] The spent fuel is first dissolved in nitric acid and, through a solvent extraction process using tributyl phosphate, the uranium and plutonium is separated from the fission products and minor actinides. The plutonium and uranium are also separated from each other. The technology behind reprocessing is not very complicated, especially in comparison to enrichment, but requires a great deal of caution in handling the highly radioactive waste material.[9] The separated plutonium is weapons-usable material and presents a proliferation concern. Research is underway exploring the possibility of using different reprocessing techniques, some of which do not isolate plutonium.

All of the nuclear weapon states with the exception of Pakistan have used reprocessing to produce material for use in nuclear weapons.[9] Historically, enrichment processes were too technically complex and expensive for states with a limited industrial base to successfully pursue.[12] Reprocessing was the preferred method of developing a state's first nuclear weapons. The trend has recently reversed. Gaseous centrifuge facilities are not as expensive as their gaseous diffusion predecessors and the technological knowhow has become easier to obtain. Most importantly it is easier to defend the construction of an enrichment facility for civilian purposes than a reprocessing facility. Reprocessing is no longer seen as a viable economic alternative to the open fuel cycle.[12]

4 – Multilateralization of the Nuclear Fuel Cycle

4.1 – Exploring the Features to be addressed by Multilateral Arrangements

The existing fleet of light water nuclear power plants requires LEU fuel for operation. Historically, gaseous diffusion enrichment facilities were the commercial means of enrichment. Enrichment through gaseous diffusion is technically complex and requires a large installation and supply of electricity.[7] The newer gas centrifuge technology has replaced gaseous diffusion as the preferred means of enrichment, in large part because of significantly lower electricity requirements.[7] Enrichment facilities can now be constructed by marginally developed states. Despite this, due to large economies of scale and development costs, it is more financially sound for states with a small number of nuclear power plants to rely on the established international market for enrichment services.[7]

From an economic standpoint, the desire to improve a state's security of enriched uranium supply is the largest motivator to develop indigenous enrichment capabilities. A disruption of enriched fuel supply would prevent electricity generation from a state's nuclear power fleet, a potentially devastating outcome. In other words, because nuclear power requires such long lead times and large capital investments, a state needs to have strong assurances of supply in fuel and services for its nuclear power program. Indeed the most sensible justification for developing states to develop nuclear power in the first place is to enhance the state's energy security.

Given the large set of commercial suppliers of enrichment services and excess global capacity, a state should not have trouble securing enrichment services from international sources. The existing worldwide enrichment capacity can provide enough fuel for approximately six hundred 1,000 GMWe nuclear power plants, double the current global demand.[2] The only times enriched fuel supply has been threatened or disrupted have been a result of political motivations. Historically bilateral long-term supply contracts have been the primary means of transactions in enrichment services.[7]

The most important disruption of fuel supplies occurred during the 1970s due to a change in American export policy in the nuclear industry. Obtaining government approval of exports will be the most difficult consideration in obtaining secure enrichment supplies. Furthermore, because bilateral agreements are of such a long or indefinite term, governments are not able to foresee all changes in circumstances that might affect the adequacy of the provisions.[32] The dependency on enrichment suppliers located in and controlled by a small number of Western states may give incentive toward the creation of indigenous facilities to bolster energy independence and avoid the disruption of fuel supply for political reasons.

Thus far, the international community has been focusing on developing multilateral arrangements to deal with the front-end of the nuclear fuel cycle. At one point, it was the other way around. The 1970s saw efforts focus on the back-end of the nuclear fuel cycle. There were concerns over the long term sustainability of the once through fuel cycle due to a lack of uranium resources. The development of a closed nuclear fuel cycle would see the propagation of reprocessing facilities, creating a large stock of plutonium that could be diverted for weapons use.[10] These concerns diminished during the 1980s after the expected global growth in nuclear expansion did not occur and projections of uranium resources became more optimistic.

A closed nuclear fuel cycle is no longer considered to be an economic solution because of low uranium prices. Indeed current reprocessing capacity is expected to meet future demand for recycled plutonium fuel for the next few decades. Most countries have accepted interim storage as their near to medium tern plan for the back-end of the nuclear fuel cycle. Spent-fuel may also be of some concern, since small reprocessing plants can be constructed and operated with data available in open literature.[32] The disposal of nuclear fuel in storage facilities is problematic due to an unwillingness of public institutions to dispose of waste locally. Some states may consider reprocessing technologies in order to lessen public tensions over medium and long term waste disposal.

All efforts to dispose of spent fuel are national in nature. Fuel suppliers have been reluctant to take back their supplied fuel after it has been spent. The international community is in position to reap significant benefits if multilateral efforts in spent fuel can be undertaken. In particular, multinational repositories could provide significant economies of scale while minimizing the number of locations needing public approval for disposal.[7]

The International Nuclear Fuel Cycle Evaluation[32] (INFCE) report describes many of the qualities needed to improve security of supply for fuel cycle services. Although released in 1980, the general observations made in the report are still paramount today. The following three points made in the INFCE are important in understanding the basic logic behind the proposed arrangements for a multilateral nuclear fuel cycle.

- Assurances of supply and non-proliferation are complimentary. Non-proliferation assurances go a long way in ensuring supply of fuel cycle services.
- A uniform, consistent and predictable application of export and import controls can mitigate uncertainties about supply and demand.
- Supplier and consumer confidence can be increased by encouraging arrangements in which both parties share in the risk and benefits of the arrangement.

The established commercial market for uranium fuel supply is diverse and competitive. Supplier states have been willing to supply fuel services to consumer states with nonproliferation commitments consistent with expectations. Multilateral arrangements for supply guarantees reinforce this fact, and at times build upon it by requiring states to forgo the right to build indigenous enrichment facilities. A supplier state will not provide services to a state that may use the services and supplied material for illicit means. This usually includes provisions restricting the importing nation from employing the supplied fuel or technologies outside of preapproved ventures. Although consumer states are at times unsatisfied with these arrangements, they most strongly fear a future disruption in supply by a modification of exporter policies. Short term proposals seek to reinforce the commercial market to enhance security of supply guarantees, while a few long term proposals call for more drastic change.

Arrangements in which both parties share in benefit and risk provide additional incentives for consumer state participation. This is most often seen in arrangements offering multilateral ownership of a nuclear fuel cycle facility and cooperation in education and technological development. Participating states have the opportunity to better ensure the supply of fuel cycle services and potential profits, while supplier states reduce their domestic financing needs and lower the risk of proliferation. Improved

assurances of non-proliferation derive from the increased level of international oversight and involvement in the operation of facilities.[7] There are concerns however; that it is unlikely consumers would participate unless they received reasonable assurance from the outset against interruption by the host state. Furthermore, supplier states are concerned about providing sensitive fuel cycle technologies which could be used to develop clandestine facilities.

In 2003, the Director General of the IAEA suggested all sensitive nuclear fuel cycle facilities should be under multilateral control.[33] If undertaken, the NPT itself would need modification. The established commercial market and governments are reluctant to take the drastic steps required to achieve these far reaching goals. The consensus believes small steps must first be taken before larger more politically challenging arrangements are undertaken.

4.2 Proposals for the Multilateralization of the Nuclear Fuel Cycle

The first proposal for a multilateral arrangement to the nuclear fuel cycle was made in the Acheson-Lilienthal Report in 1946.[34] Recognizing the dual nature of nuclear technologies, the report made a series of recommendations to proceed with the international control of atomic energy. The authors of the report did not believe a system relying on inspections and policing could truly prevent the spread of nuclear weapons. One particular quote does a very good job of describing their viewpoints.

> *It has become clear to us that if the element of rivalry between nations were removed by assignment of the intrinsically dangerous phases of the development of atomic energy to an international organization responsible to all peoples, a reliable prospect would be afforded for a system of security. For it is the element of rivalry and the impossibility of policing the resulting competition through inspection alone that make inspection unworkable as a sole means of control. With that factor of international rivalry removed, the problem becomes both hopeful and manageable*

The report proposed the creation of the Atomic Development Authority (ADA). The ADA was proposed to act as an international organization to own and control the more dangerous aspects of the nuclear fuel cycle. A country seeking to establish their own facilities would be signaling to the world their intent to develop materials for use in nuclear weapons. The proposal was used as a template for the Baruch plan presented to the UN later that year. Early cold war politics eventually prevented its implementation.[35]

Historically, past proposals for the establishment of multilateral arrangements in the nuclear fuel cycle have largely failed to gain any traction. It is possible that supplier states did not feel proliferation concerns to be pressing enough to provide strong enough incentives or supply assurances for consumer states to forgo the development of indigenous nuclear technologies.[7] National pride on the part of both consumer and suppliers also contributed, especially if the arrangements were viewed by consumers to be counter to Article IV of the NPT. The potential nuclear renaissance has the ability to create an environment more conducive to the serious consideration and establishment of multilateral arrangements for the nuclear fuel cycle.

Answering a call by the Director General of the IAEA, various states and organizations have put forward proposals over the past few years to create multilateral arrangements for the nuclear fuel cycle. The discussion below presents a summary for some of these proposal's objectives and mechanisms. For a

more detailed discussion please refer to the *Multilateralization of the Nuclear Fuel Cycle: Assessing the Existing Proposals* by Yury Yudin.[9] All of these proposals have various technical, legal, and political obstacles to overcome before they can be implemented. This thesis is not directly concerned with addressing these problems and will only consider whether these proposals are capable of addressing the various motivations for pursuing sensitive fuel cycle facilities.

Table 1 provides a brief comparison of the various arrangements that have been proposed for the multilateralization of the nuclear fuel cycle. All of these proposals have the primary aim of limiting the spread of fuel cycle facilities and technologies. Although all of the arrangements strive to achieve stronger supply assurances in some form, they are separated into three logical groupings.

Table 1 – List of Proposals and Concepts for the Multilateralization of the Nuclear Fuel Cycle

Arrangement	Objective	Mechanism
Supply Assurances		
World Nuclear Association (WNA)Proposal	Strengthen the supply assurances currently provided by the commercial enrichment market by reinforcing commitments.	Commercial suppliers agree to fill-in lost supplies as a result of political interruptions. As a last resort, stocks of LEU held by national governments are released.
Six Country Concept	Improve upon the WNA proposal by increasing the level of trust in the arrangement.	Involve the IAEA in re-establishing fuel supplies and distributing stocks of LEU. The IAEA legitimizes the objectivity of the supply assurance.
Nuclear Fuel Assurance Proposal	Reduce the possibility of political interruptions of fuel supply.	Supplier states abdicate right to prevent export of enriched fuel. Export decision is made by the IAEA and is based upon the non-proliferation credentials of recipient state.
IAEA Standby Arrangement System	Expand the range of front-end services to be assured.	Provide assurances for fuel fabrication and uranium conversion. The IAEA acts as intermediary between consumer state and suppliers.
LEU Fuel Banks	Provide backup to the commercial market.	Stocks of LEU fuel are held and released after the political interruption of fuel supply. The IAEA determines the eligibility of the state based on non-proliferation credentials.
*Multinational Fuel Procurement Arrangement**	Strengthen commercial market supply assurances by increasing market power of small power states.	A group of states form a fuel procurement company. The fuel procurement company would be in charge of negotiating contracts with supplier.
Fuel Leasing and Take-Back	Remove plutonium from consumer state. Reduce need for consumer state to develop domestic spent-fuel storage facilities.	Supplier State "leases" fuel to consumer. Once the fuel is spent and left in spent-fuel pools for some time it is returned to supplier or third party state for disposal or reprocessing.
Multilateral Facilities		
International Consortium	Provide consumer states guaranteed output share of facility or involve	The Urenco and Eurodif models. Involve participating states in the operation and financing of enrichment

	consumer states in export decisions.	facility. This represents the basic multilateral facility.
International Uranium Enrichment Center (IUEC)	Provide consumer states guaranteed access to enriched uranium and share in profits.	Negotiate contracts directly with the Angarsk enrichment facility. Equal and non-discriminatory membership in the IUEC.
Multilateral Enrichment Sanctuary Project	Provide consumer states guaranteed access to enriched uranium and share in profits. Reduce tensions over nationalization of facility.	Group of interested states create a company to finance, operate, and construct an enrichment facility. A state provides extraterritorial real estate for the facility. The IAEA regulates the export and licensing of fuel.
Regional Fuel Cycle/ Fuel Cycle Centers	Provide consumer states guaranteed access to fuel cycle services and share in profits. Increase regional cooperation and trust in nuclear endeavors.	A regional body is formed to participate in regional fuel cycle facilities. The regional fuel cycle facilities provide services for the region. The regional body oversees the operation of the facility and enforces appropriate safeguards.
Spent-Fuel Storage Facilities	Remove the need for countries to establish indigenous back-end fuel cycle facilities.	A host state offers to construct spent-fuel storage facilities on their land. Participating members help in the financing and operation of the project.
Fuel Cycle Restructuring		
Global Nuclear Energy Partnership	Prevent spread of fuel cycle facilities through commercial dissuasion.	Provide fuel supply assurances and take-back guarantees. Invest in research and development cooperation for future fuel cycle technologies, including reprocessing.
Russian Global Nuclear Power Infrastructure	Create a global supply mechanism based upon regional fuel cycle centers. Replaces the current commercial market.	Three to five regional centers hosting a variety of fuel cycle services are established. Establish regional cooperation in regulatory structures.
Multilateralization of the Nuclear Fuel Cycle	Replace the commercial market with a multilateral structure to remove all incentives to develop domestic facilities.	Nuclear fuel services are provided exclusively through multilateral facilities. A Nuclear Fuel Bank handles all transactions.

*Italicized arrangements are not described within the *Multilateralization of the Nuclear Fuel Cycle: Assessing the Existing Proposals* by Yury Yudin.

Assurances of Fuel Supply

Assurances of fuel supply mechanisms are intended to guarantee the supply of fuel in the event of fuel supply interruptions resulting from political considerations not associated with non-proliferation obligations. Arrangements would guarantee the supply of fuel as a back-up to the established commercial market but would not be triggered in the case of technical or commercial failures. The intent is to reduce the need to build indigenous fuel cycle facilities for the purposes of supply security. To be effective, assurances need to have a clearly defined procedure for triggering fuel supply.

Private sector companies, including: AREVA, Tekhsnabeksport, URENCO, and USEC put forward the World Nuclear Association (WNA) Proposal. The arrangement would have a three tiered system to guarantee fuel supply after a disruption. First, the commercial market will attempt to re-establish the fuel supplies. In the event a supplier is unable to meet commitments, due to political pressure from its government, then all other suppliers party to the agreement would contribute equal shares to meet the supply needs. Stocks of fuel held by national governments would act as the last resort. The consumer state must abdicate its rights to indigenous enrichment facilities and be in full compliance with its safeguards agreements to participate in the proposed arrangement.

A modified version of the WNA proposal called the Six Country Concept was offered by the governments of France, Germany, the Netherlands, the United Kingdom, and the United States. The proposal includes involvement of the IAEA in the second and third tiers of the arrangement. Once supply is disrupted, the IAEA would certify the state's compliance with its safeguards agreements and subsequently seek to establish supply arrangements with alternative suppliers. The implementation of the additional protocol is necessary for the consumer state to obtain supply guarantees. States could also agree to transfer the rights to distribute stocks of fuel to the IAEA in the third tier.

The United Kingdom, with support from the Netherlands and Germany, put forward the Nuclear Fuel Assurance Proposal. In the proposal, an agreement is made between supplier states, the consumer state and the IAEA. Supplier states would withdraw their right to deny export approval of enriched uranium. The IAEA would make the final export decision based upon the non-proliferation commitments of the consumer state. The agreement would only be triggered if the consumer state is unable to obtain enrichment services through the commercial market. In order to qualify, consumer states must be in full compliance with their safeguards agreements and have the additional protocol in force. Consumer states must not re-transfer the material and also commit to only use material for peaceful purposes.

Japan proposed the IAEA Standby Arrangement System. The IAEA would act as intermediary in the event of a supply disruption. The IAEA would not be directly involved in negotiating new contracts with a supplier state, only setting the stage for negotiations to take place. In addition to enrichment services, natural uranium supply and fuel fabrication and conversion services would also be assured. Fuel fabrication and conversion facilities are not technologically challenging to establish, however this provision is importation to new nuclear power states that do not have domestic capabilities. In order to set the stage for negotiations, the IAEA would use a database of fuel cycle services to find suitable customer and supplier pairs. Consumer state participation would require the state to be in full compliance with their safeguards agreements. The state would not need to abdicate the right to develop indigenous fuel cycle facilities.

Two proposals to create physical fuel banks for LEU fuel have been undertaken in recent years. A fuel bank is a physical stock of enriched uranium to be distributed to consumer states in the event of supply disruptions. Russia established the Angarsk[36] fuel bank in late 2010 with 120 tons of enriched uranium, enough to supply two refills of a 1,000 MWe nuclear power plant. One third of the enriched fuel is 4.95%, while the rest may be as low as 2%. Costs for maintaining the fuel bank are covered by Russia. The IAEA will control the distribution of fuel bank supplies. Consumer participation in the Angarsk facility only requires the state to be under compliance with its safeguards agreement.

The Nuclear Threat Initiative (NTI) proposal for the establishment of an IAEA controlled fuel bank was approved in late 2010.[37] Location for the fuel bank will be determined by the fall of 2011, Kazakhstan is currently positioning itself to be host.[38] NTI provided 50 million dollars for the establishment of the fuel bank, conditional on an additional 100 million dollars contribution from IAEA member states. The United States, Norway, European Union, United Arab Emirates, and Kuwait have all contributed to the 100 million dollar total. Consumer States must be in compliance with their safeguards agreements.

Another potential mechanism for fuel supply assurances is a multinational fuel procurement arrangement.[39] Small and new nuclear power states would create a multinational fuel procurement company. The company would be in charge of negotiating with the commercial market for fuel supplies. Supply assurances are provided because the company would be in a greater position to secure alternative sources of fuel supply. International oversight and cooperation within the company would provide strong material control.

Although none of these proposals or mechanisms directly addresses the back-end of the fuel cycle, there are models under consideration to deal with a state's spent fuel. Under a fuel leasing and take-back arrangement, the supplier state issues an export license for the fuel.[40] Once spent, the fuel is sent either back to the supplier state or to a third party through the IAEA. Implementation problems include transportation difficulties and political difficulty in getting public support to accept another states spent fuel. Russia is the only country willing to import fuel, and only in Russian-supplied reactors.[41]

Multilateral Facilities

Multilateral facility arrangements establish fuel cycle facilities under international ownership or control. Supply assurances are provided by including the consumer state directly in the operation of the fuel cycle facility, thus incorporating them into export decision making. Security of supply is strengthened beyond the proposed arrangements in the above section. Additionally, involving states in a multilateral fuel cycle facility can alleviate concerns over the existence of a supplier's cartel. Concerned supplier states can be reassured of peaceful facility use and material accounting. The institutions and proposals below do not necessitate the disruption of current commercial markets for fuel services. Multilateral efforts have received a lukewarm response because they are portrayed as infringing upon Article IV rights. If conveyed properly a strong argument can be made that multilateral facilities enhance Article IV considerations. Multilateral facilities can provide aid to non-nuclear weapon states in accessing peaceful nuclear fuel cycle applications.

The first multilateral facilities for enrichment were founded in the 1970s under the names EURODIF URENCO.[7] Both consortia are still in operation. In EURODIF, participating states include France, Italy,

Belgium, and Spain. Iran initially signed on for a ten percent membership in the facility, but later left the group of participating states. In the EURODIF model, each participating state is entitled to an output share equal to its level of investment. The host state (France) maintains technological security by maintaining a "black-box." Plans are underway to replace the current gaseous diffusion enrichment facility with a centrifuge plant. URENCO is jointly owned by the United Kingdom, Germany, and the Netherlands. EURODIF and URENCO have experienced their share of troubles in the past. URENCO experienced troubles as member states competed amongst themselves to develop the most efficient enrichment technology. As for EURODIF, participating states overinvested in the facility and were not able to use their output share. Renegotiations left EURODIF as a mostly French facility.

In the last few years, Russia has established the International Uranium Enrichment Center (IUEC) "to provide guaranteed access to uranium enrichment capabilities to the center's participating organizations."[42] The IUEC sets contracts with the Angarsk centrifuge enrichment facility, with a capacity of 2,600,000 SWU/year or enough to fuel more than 20 1,000 MWe nuclear power plants. Russia intends to maintain 51% capacity of the plant. Currently, Armenia, Kazakhstan, and the Ukraine have each agreed to take a 10% share in the IUEC. Russia has extended offers to other states for the remaining 19%.[42] States participating within the IUEC must forgo the development of domestic enrichment facilities and be compliant with safeguards agreements. Enrichment technology at the facility remains under a "black box" mechanism to prevent the spread of sensitive technologies.

The German Multilateral Enrichment Sanctuary Project (MESP) proposal sets to establish a multilateral enrichment facility within an extraterritorial area. Under the proposed arrangement, a host country agrees to provide a certain amount of sovereign territory to the IAEA. The host state would relinquish administrative and sovereign rights over the territory. A group of interested states would create an international company to finance, construct, and manage an enrichment facility on a commercial basis. Enrichment technology would be under a "black box." Participating states would not need to abdicate their right to indigenous enrichment facilities. The group of interested states would form an agreement with the IAEA over the separation of responsibilities. In the least, the IAEA should be in charge of establishing the regulations over facility licensing, inspection, and export controls.

Opportunities exist to use multilateral facility mechanisms in a variety of means that have not been officially undertaken or proposed. In the back end of the nuclear fuel cycle, multilateral spent-fuel storage facilities can alleviate domestic political tensions over nuclear waste and provide large economic benefits through economies of scale. A host state can either volunteer land for the facility or, similar to MESP, an extraterritorial facility can be established. Another possible multilateral arrangement includes the establishment of fuel cycle centers[40] or the creation of a regional nuclear fuel cycle. A fuel cycle center could establish in one location fuel conversion, fuel fabrication, enrichment, and back-end fuel cycle facilities. By placing fuel cycle services in the same location, transportation costs can be minimized and more robust safeguards and material accounting can be developed. Many countries are also very interested in having secured fuel cycle services beyond enrichment capabilities. This type of endeavor may work well within a regional fuel cycle. Multilateral mechanisms can be used within a regional context to help lower regional tensions and rivalries over sensitive technology acquisition.

Fuel Cycle Restructuring

Proposals which offer to alter the current market based model for enrichment services are grouped as proposals for Fuel Cycle Restructuring. The Russian IUEC is part of a larger proposal called the Russian Global Power Nuclear Infrastructure. The proposal calls for the establishment of three to five centers similar to the IUEC around the world to essentially replace the existing market. In addition, the proposal seeks to establish similar international facilities for the back-end of the nuclear fuel cycle. Many states are having political difficulties establishing spent-fuel storage facilities, a great deal of benefits can be realized by minimizing the number of locations needing to overcome the "not in my backyard" syndrome.[43] States with smaller nuclear programs may also benefit economically by avoiding the construction and operation of capital intensive long-term storage facilities. The proposal suggests utilizing reprocessing technologies to minimize the amount of space required for disposal. Infrastructure for educational training on cooperative research would also be established in support of the proposal.

In 2006, the United States established the Global Nuclear Energy Partnership (GNEP). GNEP was set to act as a research and technology initiative with policy workings. Domestically, GNEP builds upon the Advanced Fuel Cycle Initiative established by the United States Department of Energy in 2003. Advanced technologies would be researched and developed with international cooperation in order to reprocess spent-fuel. High level waste would be deposited, while recycled material would be used within Generation IV fast-neutron reactors. This would alter a long standing American policy, established in 1977, to not reprocess spent fuel. GNEP was intended to be a domestic policy in the United States to reestablish reprocessing as a viable solution for the back-end of the nuclear fuel cycle. Under the arrangement, a group of supplier states would provide enriched fuel supply assurances to consumer states which would return the spent-fuel back to the supplier states. No plan had been formalized to deal with the high level waste, ultimate disposal might take place in supplier state, consumer state, or a third party state. Initially GNEP would have separated the world into nuclear suppliers and consumers, requiring participating non-supplier states to abdicate their rights to nuclear fuel cycle facilities. International opposition to this plan made it untenable and GNEP was later changed so that participating members need not abdicate their right to domestic enrichment or reprocessing facilities. Instead GNEP would work to prevent the spread of sensitive facilities through commercial dissuasion. After this policy change took place, GNEP can no longer be viewed as a Fuel Cycle Restructuring Proposal. Financial support for the program took a major hit in America in 2008 after a new administration which did not believe in GNEP's mission took office. The domestic component of GNEP was cancelled in 2009. GNEP was subsequently renamed the International Framework for Nuclear Energy Cooperation (IFNEC) in 2010.[44] IFNCE is now concerned with promoting the spread of nuclear energy worldwide and developing comprehensive fuel cycle services such as fuel leasing.

Austria proposed the Multilateralization of the Nuclear Fuel Cycle. First, the proposal calls for an increased level of transparency in nuclear programs beyond those required by safeguards today. Next, the plan would lead to the creation of a Nuclear Fuel Bank. The Nuclear Fuel Bank would place all enrichment and reprocessing transactions under the control of an international organization. Ultimately, all nuclear fuel would be supplied through multilateral facilities and institutions eliminating the need for states to develop indigenous enrichment facilities. The proposal also calls for all spent-fuel to be placed within a limited number of multilateral disposal facilities. The Multilateralization of the Nuclear Fuel Cycle is the proposal that comes closest to the nuclear fuel cycle envisioned by the Director General of the IAEA in 2003.

5 – Case Studies - Overview and Methods

Case studies are undertaken in order to access the applicability of multilateral arrangements to the nuclear fuel cycle. Most often, particular arrangements are not analyzed, but rather the ideas they offer. This is accomplished through a comprehensive description of the state's motivations behind the pursuit of sensitive nuclear fuel cycle facilities in order to identify opportunities in which multilateral arrangements can be effectively employed. Iran, South Korea, and Brazil have been chosen for the case studies. Each of these states is currently in the process of, or is strongly considering, introducing enrichment or reprocessing facilities into their domestic nuclear infrastructure. In order to determine the motives for the development of these facilities, the states will be characterized by their nuclear power and infrastructure, and their historical nuclear program development and related political interactions. Through these three case studies, valuable lessons will be gained and later applied to formulate the conclusions of this thesis.

5.1 – Rationale for State Selections

The three states chosen for case studies have either recently established a sensitive fuel cycle facility or is strongly considering developing one. All of the states are members of the NPT but have in the past pursued a nuclear weapons program. In other words, these states are expected to have complex motivations for pursuing nuclear fuel cycle technologies and should prove to be a good barometer in accessing the applications of multilateral arrangements. Critics of multilateral arrangements do not believe the arrangements are capable of eliminating proliferation. This may very well be true but the non-proliferation regime can certainly be strengthened through multilateral arrangements.[40] By studying states with motivations to proliferate, the applicability of multilateral arrangements in dealing with the most complex motivations for constructing nuclear fuel cycle facilities can be determined.

There are also important differences between the three states. South Korea has strong ties to the United States and is mainly interested in pursuing reprocessing technologies. The tensions leading to Brazil's nuclear weapons program have been relaxed, but the state continues to pursue and develop its enrichment capabilities. Iran is believed to be currently in the process of using its burgeoning enrichment program to pursue nuclear weapons.

5.2 – Nuclear Power and Infrastructure

A state must decide whether it is in their best interest to support nuclear power generation with an indigenous nuclear fuel cycle. This section seeks to identify the economic needs for the nuclear fuel cycle and whether the state's stated logic is consistent with its nuclear infrastructure. Motivations for a nuclear fuel cycle outside of economics vary across different states but the economic motivations remain relatively constant. A successful set of multilateral arrangement to the nuclear fuel cycle must at minimum be able to address the economic concerns of states. Indeed, current proposed multilateral arrangements to the nuclear fuel cycle have been heavily focused on addressing the economic concerns of nuclear fuel supply. A small degree of political analysis is performed though inferences gained from any over or under aggressive development of the nuclear fuel cycle in relation to its need.

Energy Economy and Nuclear Power

The energy economy incorporates the state's domestic demand for primary energy consumption and the state's international trade in energy resources. Nuclear power is among the handful of alternatives a state can choose to pursue in developing policies for its energy future. Most commonly, civilian nuclear power is developed to pursue greater levels of diversification and security within the state's electricity generation capabilities. Although a few regions of the world, such as the Middle East, are seeking nuclear power to help reinforce their fossil fuel exports. Once the need for nuclear power in the energy sector is identified, the economic needs for the nuclear fuel cycle facilities can be put into context.

Nuclear Fuel Cycle Infrastructure and Economy

An overview of the state's nuclear fuel cycle capabilities and proposed developments is provided. It is determined whether or not the nuclear fuel cycle is able to satisfy the state's nuclear power needs. Both the front-end and the back-end of the nuclear fuel cycle will be looked at. If domestic fuel cycle facilities are not present, the sources of services are identified. Particular emphasis is given to analyzing the state's future plans for fuel cycle development to determine if it is consistent with the nuclear power needs.

5.3 – Nuclear History and Political Interactions

This section seeks to identify the other motivations the state has in pursuing nuclear technologies. Motivations vary, but may include the development of nuclear weapons, promoting national pride, increasing the levels of international interactions. Historically, multilateral arrangements have received lukewarm attention due to the difficulty in engaging these non-economic motivations.[9] Most of the proposals for multilateral arrangements do not even directly attempt to address these motivations and some may actually intensify them. The descriptions provided in this section are used to provide discussion to determine whether a few proposals or some modification and combination of proposals can be directed to engage the most powerful motivations. Given the uncertain nature in evaluating political motivations, well informed conjectures, provided through literature, constitute the descriptions.

Nuclear Program History and Motivations

The origins and major events leading to the development of the state's nuclear program, both civilian and weapons, are detailed. All of the states chosen for a case study have exhibited a number of potential proliferation incentives. The presence of a threat environment and regional tensions is an important factor, as is the desire to improve a state's international prestige.[45] A balanced description also looks at the disincentives for proliferation. Commitment to non-proliferation norms are indicative of national intent but are not in themselves a disincentive. Close ties to Western allies can be a large disincentive to openly commit to a nuclear weapons program particularly because economic sanctions could cripple the economy. A nuclear weapons program could also serve to isolate the state politically. A comprehensive analysis of the nuclear programs history and motivations is needed to discern the most powerful motivations for the development of the nuclear fuel cycle.

Recent Nuclear and International Interactions

Recent events are structurally separated from the nuclear program history and motivation sub-sections. Separation provides a smoother flow to the case study; otherwise the section examines the same topics as the Nuclear Program History and Motivations section. The point of separation is taken at the last major shift in the states policies affecting the nuclear program. For South Korea and Iran, this occurred within the last five years. The recent nature of the events means there is not a consensus in literature evaluating the impact on the state's motivations in comparison to the previous section. Personal conjecture is used to fill in the gaps.

6 - Case Study - South Korea

6.1 - Nuclear Power and Infrastructure

Energy Economy and Nuclear Power

South Korea imports over 83% of its energy resources.[46] 92.1 billion dollars were spent on energy imports in 2009, representing about 28% of South Korea's total imports. Oil accounts for 45% of the nation's primary energy consumption, down from 66% in the mid-1990s.[47] South Korea has no domestic oil resources and is very vulnerable to world oil prices and shocks. A 10% increase in oil prices is estimated to increase the rate of inflation by 0.2%.[46] South Korea is also the world's 2nd largest importer of coal and liquefied natural gas (LNG), after Japan.[48] Coal reserves stand at 149 million short tons, while consumption is 2009 was 117 million short tons. All natural gas is currently imported as liquid natural gas (LNG) from the Middle East or South East Asia.[47]

South Korea has a variety of programs to minimize energy dependence and diversify energy sources. State-owned oil and gas companies are actively involved in overseas exploration and production. In 2010, South Korea was able to produce around 9% of its domestic oil and consumption through overseas fields. Policies aim to increase this number to 40% by 2030.[49] A renewable portfolio standard policy passed in 2008 requires utilities to increase renewable power generation from around 2% today to 10% by 2022.[50] South Korea also plans on investing 35 billion dollars in renewable energy by 2015, much of which is to boost the industry for technology exports. A deal with Russia has been signed to provide at least 10 billion cubic meters of natural gas per year for thirty years, starting in 2015.[51] Delivery of the natural gas may use a pipeline through North Korea, although this in unlikely due to political and technical risks. These programs are important to South Korea's energy plan and they help to exemplify the importance of nuclear power in reducing the burden of energy imports and enhancing the security of cheap electricity supply.

Nuclear power satisfied 36% of electricity demand in 2008, making South Korea the fifth largest nuclear power generator in the world.[52] 43% and 20% of generation came from coal and natural gas plants, respectively. Electricity consumption is projected to grow at an average of 1.9% through 2024 (30% increase over the period). Nuclear power is planned to provide 48.5% of electricity generation in this scenario.[53] In other words, the expansion of nuclear power could account for 90% of the nation's electricity growth. By 2030, nuclear power will expand and contribute 59% of electricity generation in South Korea.[52]

Nuclear power is South Korea's most economical choice of electricity generation because of the high import prices for coal and natural gas. As of March 2011, South Korea has 21 nuclear power plants worth a net capacity of 18.7 GWe.[52] The oldest reactor began operation in 1978, while there are an additional five reactors under construction to begin operation by 2014.[54] In order to meet the projected growth scenarios, 18 new reactors are in the works for completion by 2030, more than doubling the installed capacity from 19 GWe in 2010 to 43 GWe in 2030.

Nuclear Fuel Cycle Infrastructure and Economy

South Korea does not possess any significant sources of uranium reserves. Uranium is imported from a diverse set of suppliers including Australia, Kazakhstan, Canada, South Africa, the United States, and France.[55] South Korea is also actively involved in partnering with foreign entities, in locations such as Niger, in uranium exploration and mining in order to secure a more stable supply.[56] Fuel conversion and enrichment services are performed abroad through diversified suppliers and long term contracts. Suppliers include TENEX, Urenco, and Areva. Fuel fabrication is then performed domestically. South Korea has also purchased a 2.5% equity stake in Areva's new EURODIF centrifuge facility, the George Besse II plant.[57] As an additional measure to secure fuel supply, South Korea maintains a strategic inventory with two years' worth of enriched fuel supply.[58] South Korea is self-sufficient for roughly 7% of uranium and hopes to increase this number to 50% by 2030.[59]

The country aims to export 80 reactors by 2030, worth 400 billion dollars.[60] By 2012, the industry will be technologically self-sufficient with no intellectual property constraints.[52] A deal with the United Arab Emirates has been signed to provide 4 reactors scheduled to begin supplying power by 2017 for 40 billion dollars.[60] Additionally, South Korea has one of the most robust nuclear research programs in the world, most of which is done under the Korean Atomic Energy Research Institute (KAERI). Research is involved in developing advanced reactor systems and fuel cycles for domestic use and export.

The back end of the nuclear fuel cycle is considered to be problematic for South Korea. Spent fuel is currently stored on reactor sites; however the spent fuel pools in some reactors are expected to reach full capacity by 2016.[61] A storage site for low and intermediate waste has been selected, through a community volunteer. The South Korean government paid 300 million dollars for the rights to establish the 2 square kilometer facility.[61] A similar deal for a high level waste storage facility requiring 30-40 times more space could cost significantly more. A high level waste storage facility has not been selected because of significant political opposition. The government attempted and failed to establish storage facilities in the 1980s and 2005.[62] Local governments are not allowing South Korea to construct on-site dry cask storage facilities and are reluctant to provide a centralized interim storage facility in fear that they may end up becoming more permanent establishments. The inability to resolve the back-end of the nuclear fuel cycle may put South Korea's nuclear expansion plans on hold. Given the political circumstances, South Korea argues it cannot maintain an open fuel cycle, despite its economic advantages. South Korea is the only country without a reprocessing facility that is interested in establishing one. South Korea believes a domestic reprocessing facility is more desirable, in large part because of the high transportation costs associated offshore reprocessing.

KAERI has proposed pyroprocessing as the solution to waste storage problems.[63] A sodium-cooled fast reactor program would be developed to take advantage of the reprocessed spent fuel and increase self-reliance in nuclear fuel supply. South Korea argues that pyroprocessing is a proliferation resistant method of reprocessing because the process does not produce isolated plutonium. Instead, a mixture of transuranic elements is separated and can be used as fuel without further purification. However, the process leaves plutonium material within a transuranic mix with significantly reduces radiation field. The mix could easily be handled outside of the heavy shielding environment required of spent fuel. Critics proclaim the technology indeed poses proliferation opportunities.[64]

KAERI has proposed the construction of a research type facility by 2016 and prototype facility by 2025 with reprocessing capacities of 10 and 100 tons per year, respectively.[64] The proposed research facilities could separate enough plutonium for around 100 nuclear weapons annually. KAERI believes the

reprocessing technology can reduce the required size of a long-term storage facility by a factor of 100[61]. This figure has been questioned, stating the analysis assumes a Yucca Mountain type repository, instead of the repository type currently being considered by KAERI.[64] Under this type of repository, capacity would only expand by a factor of two, equivalent to storing the spent fuel 100 years instead of 30 before disposal.

In Context

South Korea's is heavily reliant on nuclear power to provide a significant proportion on its electricity generation. Due to the limitations in natural resources and South Korea's isolated geographical location, nuclear power in economically favorable and will continue to expand in the coming decades. Projections envision nuclear power contributing 59% of electricity generation for South Korea by 2030. Fuel supply services are currently obtained through a diverse source of long-term contracts. Although there are no established plans for an indigenous commercial enrichment facility, 50% self-sufficiency in uranium resources is planned for by 2030. South Korea is improving its uranium security by partnering with foreign entities in uranium mining and enrichment. Nuclear power is also being developed into a major exporting industry for South Korea, with hopes of becoming the countries' fourth most profitable industry by selling 80 nuclear power plants by 2030.

Multilateral arrangements to increase supply assurances are not needed for South Korea's domestic demand of enriched uranium. South Korea has well established connections to a diverse range of suppliers within the commercial market. Furthermore, the nuclear program in South Korea is too large for any sort of fuel bank to accommodate supply needs. South Korea is much more likely to be interested in multilateral enrichment facilities. Indeed South Korea has already become a partner in EURODIF. Further participation in multilateral facilities can be used to provide fuel supply assurances to potential customers of South Korean supplied nuclear power plants. South Korea may even want to provide its customers the opportunity to participate in a multinational enrichment facility. This would certainly give South Korea a competitive advantage in the marketplace.

South Korea does not have an established solution for the back-end of the nuclear fuel cycle. The government is interested developing a reprocessing facility due to the political difficulties in establishing interim and long-term storage facilities. There are however, a lot of arguments to be made against the pursuit of reprocessing technology. Reprocessing will not remove the need for a long term high-level waste repository but is expected to reduce the space requirements for disposal. The extent and significance of the size reduction is debatable, dependent on the repository technology to be employed. Furthermore, the proposed development pathway for reprocessing will not begin to ease the burden of spent fuel until at least 2050, many years after on-site pool storage become filled. The government justifies the proposal by asserting the establishment of reprocessing as a long term solution, for the back-end of the fuel cycle, will be enough to ease public tensions over the construction of an interim storage facility and repository. This line of argument is very suspect and some elements within the government are not convinced instead believing the reprocessing program would be too expensive to support. Weak arguments for reprocessing needs and unfavorable economics lead concern that the pursuit of reprocessing is actually for a nuclear weapons program. A multilateral reprocessing facility or commitment by another state to import South Korean spent fuel would extinguish the dubiously argued need for a South Korean reprocessing facility. South Korea would certainly be willing to fund a great

deal of the project given the alternative of constructing both expensive reprocessing facilities and domestic storage facilities.

6.2 - Nuclear History and Political Interactions

Nuclear Program History

South Korea's nuclear energy program began in the years following the devastation of the Korean War. Early development in the nuclear program was heavily induced by the United States. South Korea was one of the first beneficiaries of the Atoms for Peace program proposed by President Eisenhower. The first bilateral arrangement between the United States and South Korea was signed in 1955 to govern the supply of nuclear technology, materials, and information.[65] Before the end of the decade, South Korea joined the IAEA and created the Office of Atomic Energy with its subsidiary, the Korea Atomic Energy Research Institute (KAERI). As part of early nuclear knowledge development, South Korea sent many of its top trainees to study abroad. The scale and scope of efforts put into nuclear knowledge development was instrumental in establishing the importance of science and technology in Korea's educational process.[65]

In 1958 South Korea signed a contract with General Atomics to construct a 100 kW TRIGA Mark-II research reactor, completed in 1962.[65] Half of the initial financing for this project was subsidized by the United States. In 1969, Westinghouse was contracted to construct a 500 MWe PWR at the Kori site in South Korea. At the time, total electricity demand stood at approximately 1000 MW.[65] The plant became operational in 1978. A total of 9 nuclear reactors had been connected to the grid by 1990.

Limited coal and gas resources led to the early consideration of nuclear power as an economical electricity source. The oil crisis in 1973 and the lack of alternative energy sources exacerbated the desire to promote nuclear power as a means to greater energy security. Additionally, political leaders believed that unless South Korea was able to develop its own independent source of energy, it might not be able to join the league of advanced nations.[65] A national plan to establish a standardized nuclear power plant design and technical self-reliance was set forth during the mid-1980s. A technology transfer agreement was made with Westinghouse in 1987 as part of the plan.[66] By 2012, technological self-reliance will have been achieved in South Korea. Not all of South Korea's nuclear history is centered on peaceful uses. The early 1970s saw South Korea attempt to pursue a program to develop nuclear weapons.

The United States established the Nixon doctrine on July 25th, 1969.[66] The Nixon Doctrine encouraged and expected its allies to become more self-reliant in security matters. The Unites States removed the seventh infantry division from South Korea in 1971. Leadership in the South Korean state soon began to question whether America was committed to defend the nation from the North Korean threat. South Korea developed programs to increase the level of self-sufficiency in national defence.[67]

The Agency for Defense and Development was established and developed a plan to construct nuclear weapons within 6-10 years.[66] In order to obtain nuclear weapons material, South Korea pursued a deal with France to construct a nuclear reprocessing facility in 1972.[67] A CANDU reactor from Canada was also sought. Aware of the proliferation motive, the United States sought to strengthen the Korean non-proliferation commitments. The U.S.-Korea Atomic Energy Agreement of 1972, later amended in 1974

restricted South Korea from using any United States supplied nuclear material in a manner not previously approved.[68]

South Korea nonetheless proceeded with its procurement of sensitive nuclear facilities. Plans were derailed by the United States in 1975 when the sale of sensitive nuclear facilities was prevented.[67] The United States threatened that all security and political relationships with South Korea were jeopardized unless the nuclear weapons program was abandoned.[66] The NPT, with a full scope safeguards agreement, was ratified in 1975 by South Korea to signal a halt of nuclear weapons ambitions.[67]

Tensions with North Korea, particularly over nuclear weapons, appeared to be on the down swing in the early 1990s. The Joint Declaration on the Denuclearization of the Korean peninsula was agreed upon and went into effect in 1992.[67] The arrangement maintained that neither North nor South Korea would pursue nuclear weapons or possess any enrichment or reprocessing facilities. North Korea subsequently signed a safeguards agreement with the IAEA in 1993 and soon submitted a report of all its nuclear activities.[69] North Korea had been party to the NPT since 1985. The IAEA uncovered inconsistencies with the report and reported North Korea's non-compliance to the UN Security Council. Feeling international pressure, North Korea threatened to leave the NPT.[69] During multilateral negotiations, North Korea began replacing spent fuel rods from its 5 MW gas-graphite reactor without IAEA supervision. Events escalated to the point that the Americans would use military force against North Korea if it felt more plutonium would be separated for weapons usage.[69] South Korea was gripped with fear of war and felt the cost of a potential conflict to be too great. Tensions subsided after the United States proposed the Agreed Framework to provide two light water reactors and large quantities of heavy oil fuel in return for an end to North Korea's graphite reactor program.[69]

A deteriorating economy and a leadership change in North Korea led many in the international community to believe that North Korea might open up or collapse. Taking a few strategies from the Agreed Framework, South Korea developed the "Sunshine Policy" in 1998 as a means to deal with North Korea.[69] The Sunshine Policy would establish a series of comprehensive economic and political engagements with North Korea. The hope was that North Korea would open up, eventually to unification, through interaction and economic assistance.[69] The policy also entailed establishing identities within South Korea to view North Korea in a more sympathetic light.

A second North Korean nuclear crisis in 2002-2004 questioned the viability of the Sunshine Policy. A clandestine nuclear program was admitted to in 2002[69] and North Korea withdrew from the NPT in 2003. Reaction to the admission was drastically different than in 1994. Many South Koreans did not see the admission of a nuclear program to be all too concerning. North Korean actions were believed to be part of a "confession diplomacy", an attempt to negotiate to save its crippling economy.[69] North Korea was no longer perceived to be much of a military threat, even though Seoul was in jeopardy of being destroyed in any conflict. Rather, many South Koreans wished the United States would have taken a less blazing set of actions and discourse.[69]

South Korea signed the Additional Protocol in 1999 with a ratification date of February 19th, 2004. Later that year, the IAEA revealed South Korea had failed to report a few instances of nuclear fuel cycle research since the 1980s.[70] From 1979-1981 research was conducted to assess the feasibility of a chemical process to enrich uranium up to 3%. In the early 1980s, South Korea performed experiments at its TRIGO Mark III research reactor to produce and separate plutonium. A total of 0.7g of plutonium

were said to have been produced. Fuel conversion experiments were undertaken to make 154 kg of natural uranium metal.[70] Most concerning was the admission of uranium enrichment experiments using the atomic vapor laser isotope separation method in 2000.[70] A total of 200 mg of enriched uranium was produced. A few sources indicate enrichment levels may have reached as high as 77% during the experiment.

Although the events revealed in 2004 were very minor in comparison to North Korea's weapons program, the international community quickly became concerned with South Korea's potential proliferation intent. South Korea spent a great deal of effort in convincing the international community and its neighbors of its non-proliferation intent.[70] Diplomats were dispatched to Japan in order to ease concerns. Measures were taken to increase the transparency within the nuclear industry.

Historical Motivations

The civilian nuclear program in South Korea was able to develop in large part due to engagements with the United States. Nuclear power was an opportunity to explore new sources of energy technology for the resource deprived state. More importantly, the ability to develop scientific knowhow and technologies was a major factor for the initiation of the peaceful nuclear power program during the 1950s and 1960s. Into the 1970s and 1980s, the civilian nuclear program became very important to national security and prestige. Efforts to become technologically independent in the nuclear power industry were undertaken. Fossil fuel supply constraints made nuclear power an economically favorable option for a more nationally secure electricity generation sector. Furthermore, the opportunity to become a technological leader in an advanced industry was important in improving the international status of South Korea.

Security concerns with North Korea came to a tipping point in the early 1970s as changes in American foreign policy forced the South Koreans to consider the use of a nuclear weapons program. South Korea observed the United States diminish their military presence in Eastern Asia, including the retreat in Vietnam.[66] The Shanghai Communiqué was signed, diminishing the importance of Taiwan on the global scene. Fears over American military and political abandonment, as well as regional entrapment, loomed large. Up to this point the North Koreans had put many more resources into building a conventional military force than South Korea, the American nuclear umbrella and security commitment was the primary deterrent to war.[66] Nuclear weapons would have allowed South Korea to create a strong security deterrent without the need for American aid.

Once the prospect of a South Korean weapon became a possibility, the United States threatened to cut off political and economic ties with the country. At the time, South Korea's economic and political growth was highly dependent upon the significant contribution from American relations.[66] It would still be a long time before a nuclear weapon could be developed. In this respect, South Korea had no sensible alternative other than to cancel their weapons program. The United States did reaffirm its security commitment to South Korea during this episode.[66]

The 1990s and early 2000s saw a change in the tensions between North and South Korea. The relationship between the United States and South Korea grew uneasy over the same period. Although it is hard to pinpoint the effect of these changes on South Korea's domestic nuclear policy, civilian and weapon, it may be important in partially explaining the status quo at the time. By this point the South

Korean economy had taken off, while the North Korean economy collapsed. The perceived threat from North Korea was declining while many in South Korea became embittered by American influence in security matters.[69] The 1994 nuclear crisis in North Korea momentarily reignited security fears. However, South Korean leaders may have been more frightful of an American preemptive strike on a nuclear facility initiating conflict.

The Sunshine Policy attempted to alter the course of tension with North Korea, in essence by offering a variety of olive branches. When North Korea admitted to a nuclear weapon program in 2003, the South Koreans maintained a level of sympathy with the North. The threat was not treated with the same level of urgency as in 1994. A peaceful, more conciliatory, resolution to the problem was desired by South Korea, in line with their Sunshine Policy principles.[69] The United States and Japan however, did not normalize their treatment of North Korea. In order to gain American favor in the multilateral talks, South Korea committed to aid the United States led war in Iraq.

The instances of South Korean experimentation into enrichment and reprocessing from 1979-2000 were probably dual-use in their nature. The South Korean reaction to the 2004 reveal of domestic enrichment and reprocessing experiments is also telling. South Korea first attempted to prevent the disclosure from leaking out of the IAEA.[70] There were even threats to undermine the current director general's bid for reelection.[70] Once the information was revealed, South Korea felt embarrassed by the coverage. Although the North Koreans had broken the Joint Declaration on the Denuclearization of the Korean Peninsula, South Korea did not wish to antagonize the North. South Korea also felt a burden to recover the Korean people's credibility and image within the world.[70] A perceived nuclear weapon program could also damage KAERI's research capabilities and interrupt the supply of nuclear fuel needed to support South Koreas nuclear power plants.

South Korea happens to be in a position to acquire nuclear weapons and related technologies in the event of a Korean unification. A decision would have to be made to either keep the capabilities or disarm. A number of complex motives arise. The nuclear weapon could give credibility to the unified Korea by giving itself the opportunity for security self-reliance. Although without the inter-Korean threat environment there may be little need for a nuclear arsenal.

Recent Political Interactions

Recently, China has overtaken the United States as South Korea's primary trading partner, partially relieving the dependence on the United States for economic prosperity.[71] This is a result of South Korea's ascension to one of the most developed countries in the world, although international trade is more important than ever for South Korean prosperity. Regional trade cooperation and technological competition, especially with Japan, is important both to Korea's growth.

On security matters, South Korea is still dependent on United States. The 2006 North Korean nuclear test seriously once again called into question the effectiveness of the Sunshine Policy. Engagement continued for the time being without interruption, as South Korea was in shock. For perspective, the South Korean president even stated the North's development of a nuclear weapon was for defensive purposes.[72] At this point it is important to point out a few surveys conducted before the North Korean nuclear test. In 1999, the vast majority of respondents to a poll believed South Korea should pursue nuclear weapons in the event North Korea became a nuclear weapon power state.[70] South Korean

leaders have not been afraid to openly discuss pursuing nuclear weapons. A 2005 survey found that 52% of respondents gave positive answers to a nuclear-armed South Korea.[70]

New leadership elected in 2008 moved away from the Sunshine Policy and began to take a harder line with North Korea.[73] The day after North Korea's second nuclear test in 2009, South Korea agreed to participate in the Proliferation Security Initiative (PSI).[72] By joining the PSI, South Korea made a commitment to interdict possible shipments of nuclear materials or technologies to North Korea. A statement from the North indicated its view that any interdiction was to signify an act of war.[72] The nuclear arena was not the only area in which the Sunshine Policy had little effect, North Korea never opened up as was hoped.

In late 2010, North Korea bombarded a South Korean civilian island.[74] The first time a civilian area has been attacked since 1953. Earlier, that month North Korea sunk a South Korean naval warship killing 46 sailors. These events enraged South Korea to a far greater extent than the previous nuclear weapons tests. In response, South Korea and the United States held joint naval exercises as a display of power over the Yellow Sea.[74] Regional tensions were elevated as it was not known how North Korea would respond. No retaliatory action has been taken to date. The long term effects on regional politics have yet to be seen, although it is indicative of a continuing long term alliance with the United States of America. The United States would like to continue building its security and trade arrangements with South Korea and prevent China from gaining too much influence. South Korea hosts the only substantial American troop presence on the mainland of East Asia. There have been rumblings from South Korean politicians about reintroducing American tactical nuclear weapons in South Korea, removed in the 1990s, although this is unlikely.[75]

Recent Nuclear Interactions

South Korea has been a strong supporter of non-proliferation credentials and is a member of all the major organizations within the non-proliferation regime. The government has been a participant in the formulation of resolutions objecting to Iran's non-compliance with its safeguards agreements.[76] Iran went so far as to blacklist South Korean trading partners. South Korea admitted to experimenting in enrichment and reprocessing technologies in 2004 after its ratification of the Additional Protocol in order to display the increased importance of nuclear transparency.[76] The recent move from the Sunshine Policy and aggressive actions by North Korea has led many, from outside and inside the government, to question the incentives for a South Korea to remain a non-nuclear weapon state. There has been little indication that South Korean leadership would move away from its non-proliferation stance.

On the civilian side of nuclear power, South Korea is pushing very strongly to become a major exporter of nuclear technology and facilities around the world. A deal with the United Arab Emirates has been signed to provide four reactors scheduled to begin supplying power by 2017 for 20 billion dollars. An additional 20 billion dollars are being provided to operate and maintain the reactor for 60 years. Another preliminary deal has been signed with Turkey to provide two nuclear power plants and is actively targeting contracts with other states. South Korea aims to have the nuclear industry become a major exporter, behind only the automobile, semiconductor, and ship building industries in terms of profitability.[77] Currently, export policy does not require buyers to have the Additional Protocol in

place.[78] This is surely an attempt to gain an advantage over its competitors in nuclear technology supply.

Once it achieved technological independence in power plant construction, self-reliance in nuclear fuel supply has become the next goal of South Korea. There are active engagements in uranium mining around the world, and South Korea has become a 2.5% owner of a new Areva enrichment facility in France. Some within the government have suggested a domestic enrichment facility would do well to achieve their goals.

South Korea is interested in developing a reprocessing facility to ease tensions over domestic spent-fuel disposal. Political difficulties have prevented attempts to establish long term or intermediate storage facilities in 1988 and 2005. South Korea joined GNEP in 2007[79] as a venue to legitimately pursue the research of its pyroprocessing technology, which the United States has been reluctant to approve of. There are currently two bilateral arrangements effectively preventing South Korea from developing a reprocessing facility: The 1992 Joint Declaration on the Denuclearization of the Korean Peninsula, and the 1974 U.S.-Korea Atomic Energy Agreement. The first of which has been broken many times by North Korea. The second of which concludes in 2014 with current negotiations ongoing for a new replacement agreement.[68] South Korea is pushing very strongly to have reprocessing allowed within the new agreement. It is unclear what avenue South Korea would pursue if the United States denies the South Korean request.

South Korea believes it should be granted the opportunity to develop its reprocessing technology and points towards discriminatory treatment in the international community for justification. South Korea believes it should not be limited in its ability to fully develop its nuclear fuel cycle. There is a large deal of animosity over the difference in treatment with regional economic rival Japan.[70] Japan already possesses full-scale enrichment and reprocessing facilities and has been permitted to do so under a 1967 agreement. South Korea is also frustrated with the treatment of India, Pakistan, and Israel, who it argues is being rewarded for not being committed to non-proliferation norms.

In Context

Motivations to pursue nuclear weapons in South Korea have derived from their protracted conflict with North Korea. During the Cold War period, tensions with North Korea remained high. When the United States began shifted their foreign policy objectives to have a smaller military presence in the region during the early 1970s, South Korea feared they would be abandoned and left to deter a North Korea attack by themselves. A nuclear weapons program was pursued to provide South Korea the means to become self-sufficient in national defense. Once the United States threatened to cut off all peaceful relations with South Korea if the weapons program persisted, South Korea abandoned the program. The relationship with the United States put South Korea into a dilemma. On one hand, South Korea wants to gain independence from the United States, especially on national security matters. On the other hand, the diplomatic relationship and economic ties were too strong to jeopardize.

Tensions with North Korea have escalated in the last five years following the North's nuclear weapons tests and military attacks on a South Korean submarine and civilian populated island. South Korea may

no longer be as economically dependent on the United States compared to the 1970s. Recently China became South Korea's primary trading partner. However, these events indicate South Korea still relies on the American security umbrella to deter North Korea. South Korea has also positioned itself very closely with the United States in international activities, such as applying economic sanctions against Iran. In addition, South Korea believes it needs to represent the Korean people well on the international stage. In other words, even though the incentives to proliferate are as strong as ever, the disincentives will prevent South Korea from openly embarking in a nuclear weapons program.

In this respect, the desire for a reprocessing facility is unlikely to have economics as its only justification. The Nuclear Power and Infrastructure section of this case study pointed out the weak economic arguments for the reprocessing facility. A reprocessing facility would provide South Korea latent nuclear weapons capabilities. The latent capabilities could be useful for a few reasons. In the event American policy once again shifts and South Korea finds herself without America's extended deterrent, a nuclear weapon could be developed. Additionally, the latent nuclear capabilities could give South Korea greater leverage in dealing with American activities in the region. South Korea believes the American influence and actions in the region often times do not coincide with South Korean desires. A latent nuclear capability could be a subtle threat to the United States because South Korea could always abandon the American security assurances and provide for itself in the event that American influence in the region is perceived to be more costly than beneficial. In the least, a reprocessing facility would place South Korea on equal footing with Japan in terms of nuclear capabilities and provide a small boost to national pride.

With respect to multilateral arrangements, it seems unlikely the national security motivations can be addressed. This may not be entirely necessary however. If multilateral arrangements are able to effectively address the economic motivations behind the pursuit of reprocessing, or potentially enrichment, South Korea will most likely give up its pursuit as well. South Korea would no longer have their economic arguments to fall back on and because South Korea does not wish to openly antagonize the United States or the international community, the pursuit for sensitive fuel cycle facilities will be abandoned.

6.3 - Discussion

South Korea has one of the most robust nuclear power programs in the world including a top of the line research institute, KAERI. By 2030, nuclear power is planned to provide 59% of domestic electricity production. This level of expansion would make South Korea have the highest density of nuclear generation per population in the world. A lot of spent nuclear fuel has and will be built up in the state. Political difficulties in establishing storage facilities have given South Korea an argument to pursue a reprocessing facility. South Korea is also interested in becoming one of the largest nuclear power plant exporters in the world, with a goal to sell an astonishing 80 nuclear power plants by 2030. Although there are no plans for a domestic enrichment facility, an argument could certainly be made to pursue a facility in order to gain a competitive advantage in exporting nuclear power plants by packaging the deal with fuel supply assurances. These arguments for developing sensitive fuel cycle technologies are dubious but cannot wholly be dismissed.

South Korea has the incentive to establish the capability to develop nuclear weapons, providing another motive to pursue reprocessing or enrichment facilities. The conflict with nuclear North Korea is unsettling to those in South Korea. Up to this point, South Korea has relied on the United States to provide an extended security deterrent. The relationship with the United States at times has been uneasy and provides South Korea with an interesting dilemma. In the 1970s, South Korea decided to embark on a nuclear weapons program because it feared the United States would one day relinquish its security deterrence for South Korea. The nuclear program was abandoned once the United States threatened to cut off diplomatic ties. The United States still supplies South Korea with a security deterrent today but South Korea cannot guarantee its existence in the future. Additionally, the American presence undermines South Korea's position and influence in regional security matters and negotiations. A nuclear weapon program could provide South Korea security independence. To do so openly would antagonize the United States and most of South Korea's allies. South Korea is not willing to risk damaging its economic and international political standing for a nuclear weapon.

The strongest motivation to pursue sensitive fuel cycle facilities in South Korea is to develop the latent nuclear capabilities. This motivation does not have to be addressed directly, however. Removing the other incentives should be enough to prevent South Korea from pursuing the fuel cycle facilities. South Korea provides an excellent opportunity for multilateral arrangements to prevent the potential spread of nuclear weapons capabilities. In order to succeed, the arrangements must be able to remove the stated public reasons for establishing the fuel cycle facilities. In the back-end of the nuclear fuel cycle, a long term option for South Korean spent fuel must be provided. In the front end of the nuclear fuel cycle, South Korea does not currently have plans to build an indigenous enrichment facility but multilateral arrangements can remove the incentive to do so. South Korea must have the opportunity to provide supply assurances for its customers.

The fuel leasing and take-back arrangement model has potential to work, although the take-back aspect of the arrangement is much more important. South Korea has a well-established supply of uranium and enrichment services. A growing portion of these services are falling under South Korean ownership meaning there may not be opportunity for the leasing aspect. Furthermore, there is already a great deal of spent-fuel within the state which must be exported to another country. A multilateral spent-fuel storage facility would work in a much more straightforward manner. The multilateral facility would need to be established outside of South Korea. South Korea would also most certainly be willing to become a large financial partner in the venture. The costs of developing indigenous facilities to deal with spent-fuel are likely to be astronomical for South Korea.

In the front-end of the nuclear fuel cycle, South Korea would be most interested in being directly involved in providing its customers with supply assurances. Fuel banks and supply assurances from the international community would be beneficial to South Korea's potential customer but it would not provide South Korea the opportunity to gain a competitive advantage in nuclear power plant sales. Involvement in a multilateral enrichment facility would indeed provide South Korea the involvement it would be looking for. South Korea is already has a 2.5% stake in the George Besse II centrifuge plant under construction in France. The size of this deal is likely to be insufficient for South Korea's needs. Further stake in the George Besse II plant or a similar facility would be one option. The establishment of

another facility could be undertaken in a multitude of ways. The Multialteral Enrichment Sanctuary Project offers an interesting option. South Korea along with a group of its customer could develop an enrichment facility in an extraterritorial area, with South Korea most likely being the technological leader. This way a facility would not need to be built within South Korean or any of its customer's land. Another possibility would entail a partnership with uranium suppliers such as Australia who are looking to move up the supply chain of the nuclear fuel cycle. More ambitious multilateral arrangements that would place all enrichment facilities under international control would certainly remove South Korea's motivation to develop any indigenous capabilities. That being said, South Korea is likely to be ambivalent toward these proposals because they would essentially maintain the status quo for South Korean interests.

7.0 - Case Study – Brazil

7.1 - Nuclear Power and Infrastructure

Energy Economy and Nuclear Power

Brazil is one of the most energy independent countries in the world. Oil, and other liquid fuels, accounts for roughly 50% of Brazil's primary energy consumption.[80] Brazil has the second largest oil reserves in South America, 14 billion barrels (1% of global reserves) compared to 172.3 billion barrels in Venezuela.[47] Despite this, Brazil is the largest producer of liquid fuels in South America. Due to the large ethanol industry, and recent discovery of the large off-shore pre-salt oil reserves,[81] Brazil should be well positioned to act as a net liquid fuel exporter in the medium term.[80] In the electricity sector, hydropower accounts for 84% of Brazil's generation. Brazil has a technical hydropower capacity of 260 GWe,[82] 77 of which were exploited in 2006. Natural gas, which accounts for 8% of Brazil's primary energy consumption, is the only major energy source Brazil heavily relies on imports for.[801] In 2009, 40% of natural gas consumption was imported, all of which came from neighboring Bolivia.[47] Brazil has the natural gas reserves to meet its demand, however low domestic prices and an underdeveloped transportation infrastructure have led to low level levels of production. The nationalization by Bolivia of its natural gas industries in 2006 has pushed Brazil to seek greater independence in natural gas.[83] The Bolivian subsidiary of Petrobas, a Brazilian company, stood to lose 1.5 billion over the twelve years following 2006 due to the nationalization. The discovery of off-shore pre-salt fields will help achieve natural gas independence.[80] Wind power is not a large contributor to the energy sector at this time, but a potential of 143 GWe of wind capacity exists and may be an important component in the future.[82]

Brazil faces a number of energy and environmental challenges in the future. A November 2009 blackout caused by short-circuits in nearby transmission lines, removing the 14 GWe Itaipú dam from the grid, was as a reminded of the energy crisis in 2001.[84] Energy capacity expanded only 28% during the 1990s while demand expanded 45%. A long drought then helped Brazilian dams reach their lowest levels in 20 years, causing the crisis in 2001 which almost crippled Brazil's economic development. In addition to the restructuring of the countries regulatory structure, the 2001 crisis saw a commitment to expand and diversify electricity generation capabilities.[84] This will help Brazil avoid the risks of power outages during periods of drought. In addition to being susceptible to drought, Brazil's hydropower resources tend to be located far from population centers, increasing the demand for robust transmission lines.[84] The government hopes to expand the use of nuclear power, natural gas, wind power, and small hydropower facilities.

In 2009, Brazil generated 467.6 terawatt-hours of electricity from an installed capacity of 104 GWe, the ninth largest consumer of electricity in the world.[47] This represents a 1.2% percent increase from 2008 and a 34% increase from 2000. Thermal and nuclear power plants accounted for 13 and 3 percent of generation, respectively.[80] Brazil is a rapidly growing economy; and will need to considerably expand its generation capacity in order to meet future demand. In the Brazilian National Energy Plan (2008-2017), a goal was set to establish 54 GWe of installed capacity, with non-hydroelectric power making up the majority of contributions.[85] The BP Energy outlook to 2030 projects Brazil's electricity consumption to increase to 990 terawatt-hours by 2030.[86] 72% of the electricity generation is projected to come from hydropower, a large diversification in electricity supply from today. Natural gas is projected to be the largest sector of growth. Nuclear power and wind power are projected to grow by a moderate amount,

primarily to maintain a diversified generating capability. Most importantly, all of this expansion can take place through domestic supplies.

Brazil has a modest fleet of nuclear power plants. There are currently two nuclear power plants in operation, the Angra-1 plant with a capacity of 626 MWe and the Angra-2 plant with a capacity of 1270 MWe.[54] A third plant, the 1270 MWe Angra-3, began construction in June 2010 with an expected commercial operation date of 2015. There are also plans underway to construct four new power plants to begin operation around 2025.[87] The leading candidate design for these plants is the Westinghouse AP1000. Brazil hopes to construct 70% of these power plants by using Brazilian industries, up significantly from the construction of previous reactors.[88] Brazil is also considering the construction of four additional reactors, to bring the total installed capacity by 2030 to 11.3 GWe. Brazil is actively engaged in other components of the nuclear fuel cycle.[88]

Nuclear Fuel Cycle Infrastructure and Technology

Brazilian uranium reserves stand at around 278,000t, or 5% of world reserves.[89] Recent exploration, in cooperation with Russia, has led the government to estimate the actual number of reserves may be around 1.1 million tons.[90] If these resources can be exploited, Brazil can be a self-sufficient supplier of nuclear fuel. Currently, 400t/year is mined, with plans to expand to 2700t/year by 2017.[88] This mining rate would be more than enough to satisfy all domestic fuel requirements under the growth scenario.

Brazil does not currently have any fuel conversion plant, and signed a five year deal in 2010 with Areva to convert uranium concentrate into UF_6.[88] These services will help prepare the fuel for enrichment before use in the state's nuclear reactors. Brazil has plans to construct its own fuel conversation facility. A capacity of 1200t is expected by 2014 with an additional 1200t by 2018.[88] These facilities will also provide enough conversion capability for Brazil's nuclear expansion plans unto 2030.

Brazil operates the Resende ultra-centrifuge enrichment facility. At current capacity, the enrichment facility is capable of producing 26-31 implosion type nuclear weapons per year.[91] In other words, Brazil can develop material for nuclear weapons before the world will be able to react. Stage one of the facility began operation in 2006, and will have a capacity of 114,000 SWU/year by 2012, enough to supply 60% of demand from the Angra-1 and Angra-2 power plants.[92] Stage two will soon be completed, taking the capacity to 200,000 SWU/year. Brazil is committed to use 100% nationally-produced fuel within Angra-3.[93] At this moment, the facility is not cost competitive with the international enriched fuel market. A large capacity increase, satisfying the projected future demand of seven nuclear power plants by 2025, would make the facility economically advantageous by taking advantage of economies of scale.[94] Brazil has also recently been exploring the option of exporting enriched uranium to China, South Korea, and France.[95] The front end of the nuclear fuel cycle is then completed through Brazilian fuel fabrication facilities.

In the back end of the fuel cycle, Brazil is currently developing a plan to deal with the radioactive waste. A long-term solution for the low and intermediate-level waste must legally be in effect before the Angra-3 plant comes online.[87] The first national repository is expected to come online in 2015. Spent-fuel is currently stored at the Angra facilities pending a policy decision on reprocessing or direct disposal.

In Context

Brazil's energy sector is nearly independent. Brazil has increased domestic oil production and is the second largest producer of biofuels in the world. The ethanol industry in is a prime example of Brazilian[96] policies to increase energy independence. In the 1970s, Brazil was importing 80% of the oil it consumed. In 1975, the National Alcohol Program was initiated, mandating that all fuels be blended with 22% ethanol. The ethanol blend mandate has changed overtime; recently it has been decreased to 20%.[97] Nonetheless, production is expected to increase dramatically to meet growing domestic demand. In the electricity sector, energy independence largely derives from Brazil's vast hydropower resources. Hydropower accounts for 84% of the nation's electricity generation, and there is over 200 GWe of unexploited hydropower. Natural gas in the only energy resource in which Brazil acts as a net importer and recent gas field discoveries can drastically reduce this foreign dependence.

Due to the energy crisis in 2001, Brazil has decided to diversify its electricity generation. Brazil must also be increasingly concerned with the consequences of global climate change. Any significant change in precipitation patterns may have a disastrous impact upon Brazil's hydropower generation. Alternative energy sources must be expanded to increase electricity diversification. Brazil is working to expand its natural gas production, which will contribute the majority of Brazil's non-hydropower generating capacity by 2030. Nuclear power is also going to be an important part of Brazil's electricity future. One power plant is currently under construction, with an additional 4-8 planned by 2030. The pursuit of nuclear power as a source of electricity diversification may be questionable, especially in relation to the cheaper alternative in natural gas and the abundance of unexploited wind power. However at this modest growth rate, Brazil can develop the nuclear industry without sacrificing economic principles. In keeping with Brazil's energy independence, the front end of the nuclear fuel cycle will soon be completely mastered. Brazil has also been maintaining a high degree of consistency between its nuclear power expansion plans and the capacity of its fuel cycle service facilities. By constructing a domestic enrichment facility, Brazil is protecting itself against high enrichment and uranium prices. Brazil also hopes to one day become an international supplier of enrichment services.

Multilateral arrangements for the nuclear fuel cycle should have a limited impact on Brazil from an economic standpoint. Enriched fuel supply assurances may be beneficial on the short term but in the long term Brazil has the natural resources and technology to be completely independent in nuclear fuel supply. No matter the strength of the multilateral supply assurance, they cannot be as strong as the ability to mine and enrich all nuclear fuel domestically. Additionally, if the investment is made to expand the Resende facility, the international enriched fuel market will most likely not be an economically superior option for Brazil. International involvement in the Resende enrichment facility may be beneficial to Brazil if technology transfer and cooperation can make the facility more profitable. This motivation however, is unlikely to be strong enough to overcome the incentives to stay autonomous. Domestic enrichment ensures energy independence for nuclear power in a diversified electricity sector in Brazil.

7.2 - Nuclear History and Political Interactions

Nuclear Program History

Brazil's nuclear history is long, and rooted in interest for a nuclear weapon. In response to Argentina's false claim to have mastered thermonuclear fusion in a laboratory in 1951, Brazil's nuclear program was

initiated through the creation of a national nuclear research program.[98] Two years later, Brazilian agents convinced scientists from West Germany to develop centrifuge technologies in secrecy.[99] The plan was soon discovered by British and American authorities and abandoned. Soon after signing an agreement with the United States under the Atoms for Peace program in 1955,[99] Brazil established its national nuclear regulatory body. In 1961 plans were made to develop a natural uranium power reactor similar to the ones being considered by France at the time.[99] The plans were halted in 1964 once the Brazilian government was overthrown by a military power that remained in control until 1985. The military regime shifted its policy on a few key proliferation issues. Before 1964, Brazil was a leader in the development of the Treaty of Tlateloco.[100] The Treaty of Tlateloco established a nuclear weapons free zone, prohibiting the development of nuclear weapons in Latin America. After the military coup, Brazil was very resistant to the establishment of the treaty. Furthermore, Brazil was in opposition to the NPT on the ethical grounds that the treaty was discriminatory in nature.[100] In 1971, Brazil's first nuclear power plant, the Angra-1, was purchased from Westinghouse.[98] The reactor did not begin commercial operation until 1985, and was plagued with a 25% capacity factor for the early part of its lifetime.[54] The United States began to put intense pressure on Brazil in the mid-1970s to sign the NPT and implement safeguards.[101] In the 1970s and early 1980s Brazil embarked on a series of program to enhance their position in their rivalry with Argentina for regional military and technological prestige.

The military regime signed an agreement with West Germany in 1975 to provide a number of civilian nuclear services.[99] The agreement was referred to as the "nuclear deal of the century" and was worth billions of dollars.[102] The deal included two 1250 MWe reactors and an option for an additional six reactors.[102] Facilities for fuel fabrication and conversion were included. Concern over the deal arose due to the part of the agreement that provided Brazil an enrichment facility and a pilot reprocessing facility.[102] The deal did not only offer physical infrastructure to Brazil, it also provided the opportunity for many Brazilian engineers to get training in Germany and around the world. In the arrangement, Brazil would participate in the construction of components for the facility and fuel cycle technology transfers.[99] Brazil hoped to soon gain the know-how and knowledge to independently manage its own nuclear industry and fuel cycle.[103]

It is easy to say the deal was intended for a nuclear weapons program from the start but Brazil certainly also had motivations for pursuing a civilian nuclear power program. Officially the program was to address Brazilian energy concerns and provide a significant technology transfer to improve Brazilian technical expertise.[103] A nuclear power capacity of 10 GWe was planned for by 1990, and in 2010, nuclear energy would provide 41% of energy in Brazil.[99] The Brazilian scientific community expressed their opposition to the viability of the plan to address Brazil's energy concerns. Scientists pointed out that nuclear energy could not alleviate the problems associated with oil imports and nuclear power was not needed in the electricity grid which was heavily supported by hydro-power.[103] The deal presented itself as an opportunity to become a leader in an advanced technology sector to increase Brazil's regional and international standing.[103] The timing of the deal was important to both Brazil and West Germany. The United States recently altered their nuclear export policies and refused to negotiate new orders for the supply of enriched uranium.[98] West Germany gained access to Brazil's large reserves of uranium, while Brazil secured a means to develop enrichment technology.

The deal was heavily criticized by the United States and due to fears of Brazilian proliferation.[101] The United States convinced the West Germans to impose international safeguards beyond those required by the NPT.[98] Brazil soon become dissatisfied with the deal, as West Germany began withholding

reprocessing and enrichment technologies. Additionally, the enrichment technology offered in the deal seemed unpromising on its own merits.[102] Financial troubles and budget cuts imposed by the International Monetary Fund (IMF) also restricted the deal's implementation and called into question whether Brazil could afford the deal with West Germany.[101]

America enacted the Nuclear Non-Proliferation Act in 1978.[98] The policy required nuclear recipient states to impose full-scope safeguards on all nuclear facilities. The centerpiece of the Brazilian civilian nuclear program, the Angra-1 facility was threatened, as fuel supplies were conditional on Brazilian implementation of more extensive safeguards required by the act. Together with the difficulties in the West German deal, the Nuclear Non-Proliferation Act caused Brazil to develop an indigenous research program.[103] The international community could not be relied upon. In 1979, the regime opted to develop, in concurrence with the civilian nuclear program, three secretive parallel military nuclear programs. These programs served both military and civilians needs, with the potential for developing a nuclear weapon. The army researched graphite-moderated reactors, while the Navy and Air Force looked into centrifuge and laser enrichment technologies for use in nuclear submarines and satellites.[103] Within a few years, the navy succeeding in developing enriched uranium through their centrifuge technology.[103] Brazil's current enrichment capabilities derive from this program. The United States was very skeptical of these programs and restricted the export of high-end technology goods to Brazil.[104]

Military rule in Brazil ended in the late 1980s. Aware of foreign pressure, and a shift in national motivations, Brazil took significant steps to improve transparency of their nuclear programs. The new constitution in 1988 mandated that all nuclear activities be for peaceful purposes.[103] In the previous year, Brazil reciprocated an Argentinian offer, and allowed the Argentinians to tour the Brazilian enrichment facility. Shortly afterward, the two countries signed the Joint Declaration of Common Nuclear Policy.[102] The Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC) and the Quadripartite Safeguard Agreement was signed in 1991 and setup to be similar Euratom.[102] The agreement allows full-scope safeguards in Brazil and Argentina, to be jointly implemented by the IAEA and ABACC. Brazil and Argentina were allowed to retain rights to their technological secrets and to develop nuclear energy for use in electricity production and submarines. The Brazilian nuclear program was reported to have officially ended in 1991.[104]

Historical Motivations

Much of the motivation for a nuclear program stems from the rivalry with Argentina, whose proclamation of successful nuclear fusion led Brazil to initiate the program in the 1950s. Brazil was very concerned with Argentina's nuclear program. The Argentinian program was more advanced (by an estimated 7 years in the late 1970s) and more secretive than the Brazilian program at the time.[103] Additionally, Argentina selected heavy-water reactors for their nuclear power plants, which could be more easily used for a nuclear weapons program.[103] Politically the Argentinian program was being used as a means to equalize the regional political playing field with Brazil, who had technical and economic advantages in other areas.[103] A nuclear program in Brazil was needed to keep with Argentina. The weapons program was needed in the event Argentina acquired the ability to create a weapon.

Interestingly, the rivalry between Brazil and Argentina did not have any real threat of conflict.[102] Brazil wanted to develop and research nuclear technologies to prevent Argentina from taking the

technological lead and potentially using this as political or diplomatic leverage. The dual use technologies could be used in essence for demonstration effects, in the absence of real effective military power.

In addition to promoting nuclear weapons development, the 1975 civilian nuclear deal with West Germany was intended to help achieve technological independence and national prestige. Furthermore, the 1973 oil crisis had put a severe strain on the Brazilian economy and placed doubt upon the governments legitimize toward independence and economic growth.[103] The Brazilian leadership attempted to use the West German deal to assuage some of these fears. After it became clear that nuclear power was not be needed for Brazil's energy sector and because importing nuclear technology was becoming increasingly difficult, the Brazilian government diverted most of its nuclear resources from the civilian program into the three parallel programs to continue developing important technologies. The success of the parallel programs in achieving technological gains, in contrast to the civilian deal with West Germany, helped to legitimize the goal of technological autonomy and the government's role in the nuclear industry.[103]

The end of the military regime and democratization of Brazil, along with the relaxation of the Argentinian rivalry, led to a reevaluation of the weapons program. Brazil has since instituted their participation into international non-proliferation norms. The Quadripartite Agreement and ABACC agreement with Argentina has created a strong regional norm against proliferation. The agreement also allows Brazil and Argentina to build a strong sense of trust with each other and minimize the chances of future tension. Reservations over the Treaty of Tlatelolco were removed in 1994, the NPT was ratified in 1998, Brazil joined the Nuclear Suppliers Group in 1996, and the Comprehensive Test Ban Treaty has also been ratified. The civilian nuclear industry in Brazil is being revitalized and there is concerns over Brazil's enrichment capabilities and, despite their commitments to nonproliferation norms, desire to proliferate.

Recent International Interactions

Brazil is one of the fastest growing economies in the world and is very influential amongst developing countries. Brazil has the largest population, land mass, and economy in South America, placing the country in position to be a world power and a regional hegemon. Brazil has a diversified set of trading partners, with roughly 13% of trade going to the USA and China, and 8.6% going to neighboring Argentina.[71] Brazil does not have any major security threat in the region or abroad.

Brazil has been a leader in developing policies for the regionalization of South America, with actions consistent with an intent to become a consensual regional hegemony.[105] This is achieved by leading movements toward regional inclusion and collective action. Brazil has been instrumental in the creation and evolution of Mercosur.[105] Mercosur, signed in 1991, is an agreement to open trade and economic cooperation in South America. In 2007, the Union of South American Nations (UNASUR) was formed, a regionalization effort modeled to emulate the European Union.[105] These undertakings undermine American (America is the historical hegemon) influence in the region and enhance Brazil's leadership position. The success of Mercosur and UNASUR in the future will depend on how Brazil can manage regional tensions.

In lines with its consensual hegemony policies, Brazil has allowed South American countries to deal with their internal political issues with little intervention. Regional democratic and sovereignty norms have been supported with statements, often made through Mercosur or UNASUR.[105] Security intervention only took place through multilateral mechanisms and in instances where failure may impact Brazil's larger regional and global goals. Brazil acted as one of the arbitrators in the Ecuador-Peru conflict in 1995 because the conflict threatened prospects for a more cooperative South America.[105] Brazil took leadership in a regional security crisis and led the United Nations mission to Haiti in 2004 in order to support their long term goal of becoming a permanent member of the UN Security Council.[105] The South American Defense Council (CSD) was recently agreed upon and will work under UNASUR.[106] The CSD is part of a policy to promote the regional cooperation in arms and will enhance the influence of Brazil's war machine. Brazilian efforts in the region are not going unnoticed on the international scene.

In recent years Brazil has become a stronger player in the global community, becoming highly influential among the world's developing countries. Economically, Brazil is an important player on the G8 and G20 scene[107] and has been very vocal over the economic crisis in 2008 stating that developing countries should not bear the costs of American and European irresponsibility.[108] Together with India and South Africa, Brazil has argued for the developing world to have a larger say in the international decision making processes, particularly within the United Nations.[109] Brazil is not shy in supporting international views which are contentious with the developed world. Brazil decided to recognize Palestine as an independent state, with Argentina and following suit.[110] In reference to the Israel-Palestine peace process, former President Jimmy Carter said of Brazil, "it can help because it has a lot of influence among developing countries. Brazil can be one of the leaders in this process".[111] The developed world also looks toward Brazil as a potentially strong ally who has strong influence over the developing world, such as in climate change negotiations.

Over the past decade, Brazil has been increasing its footprint on the world stage, from an isolated giant to a growing power. Historically, Brazil has been a chief rival with Argentina, but recently the relationship has been characterized by friendly behavior, and Brazil has a growing influence over the other nations in South America. Brazil is striving to become a regional superpower and mitigate the developed world's dominance on global affairs while enhancing its national prestige. Interactions involving nuclear technology can open doors for Brazil in the international community.

Nuclear Related Interactions

Brazil did not ratify the NPT until 1998, despite disclosing the military programs and abandoning its nuclear weapons ambitions in 1991. Since its inception, Brazil has been critical of the NPT. Brazil argued that the treaty should provide guarantees that nuclear weapons states would not use nuclear weapons against non-nuclear weapon states.[112] More recently, Brazil has voiced concerns that the NPT threatens the sovereignty of non-nuclear weapons states to the treaty. Brazil has argued that bilateral and multilateral agreements would be more pragmatic than the NPT, especially in terms of enforcement.[113] This statement exemplifies Brazil's satisfaction over the progress and implementation of the ABACC. Additionally, Brazil is a member of the New Agenda Coalition within the NPT, calling for a world without nuclear weapons.[114] Brazil has not signed the Additional Protocol, arguing it is an infringement of national sovereignty.[115] Brazil does not believe AP implementation should be a requirement for the export of nuclear goods.[116] Reluctance to sign the AP can also be viewed as a means to gain influence

amongst the developing world. Brazil has been concerned over the United States-India deal, believing India broke the rules and got rewarded for it.[117]

Brazil and the IAEA reportedly had tense negotiations over the safeguards approach to its centrifuge enrichment facility at Resende in 2004.[118] Brazilian actions were reminiscent to the period before the ABACC, in which the nuclear program was highly secretive and dual purpose. Brazil on two occasions refused to allow inspectors to see the facility. Brazil feared the inspectors would gain access to Brazilian proprietary technology. Rumors have persisted that the Brazilians were attempting to hide the proprietary nature of their facility, because its technology is remarkably similar to that of Urenco.[118] Nonetheless, Brazil claims there is a significant proprietary difference at the Resende ultra-centrifuge facility which is 100% Brazilian in origin. However, a number of states have proprietary technology and working safeguards agreements.

In the past, Brazil had shrouded the centrifuges cascades during inspections in their pilot plants. They did not see why a different approach was necessary for a commercial enrichment facility.[119] The negotiations ended after a compromise was struck in which Brazil was allowed to shroud certain more technologically sensitive portions of the centrifuges in return for a greater degree access to the IAEA.[119] The IAEA inspectors have been satisfied with the results of the agreement and have found no problems when inspecting the Resende facility.

The Navy has remained heavily involved in the nuclear industry. Plans are still underway to develop a nuclear submarine, although there is still substantial progress to be made.[119] Nuclear submarines typically require highly enriched uranium, although Brazil claims they can be done with 10% enrichment. In the event that nuclear submarines are constructed, their reactors would not be subject to international safeguards.[119] Brazilian leaders point out that no other country allows IAEA inspectors into military facilities.[115]

Brazil has also been using its nuclear technological capabilities to grow its reach in the international scene. Brazil is a member of the Nuclear Suppliers Group and has recently started looking to become a supplier of enriched uranium. They would join the United States, France, the United Kingdom, the Netherlands, and Russia as enriched uranium exporters. This is a technological achievement that Brazil hopes will give it increased international prestige. In 2010, Brazil, Turkey, and Iran agreed to the Joint Declaration on Nuclear Fuel. The deal allowed Iran to transfer 12,000 kg of LEU to Turkey for storage in exchange for fuel rods to be used within the Tehran Research Reactor, deflecting international pressure from the West on Iran.[113] The Western countries were previously unsuccessful in negotiating a deal with Iran concerning its stocks of LEU. Reception to the deal was mixed, with the West looking unfavorable upon it. The deal allowed Iran to continue enrichment activities and deflected international pressure from the West which Iran hoped would be enough to prevent future sanctions.[113] By venturing into the Iran issue, Brazil is using nuclear technology to show its relevance and legitimacy on the international stage. Brazil is in a unique position on the nuclear topic, positioning itself as a leader among the developing nations, offering legitimized arguments in difference to the perceived inequitable policies by the West. Brazil has consistently argued that all countries in good standing with the NPT should be allowed to develop their nuclear fuel cycle. The nuclear program in Brazil serves its purpose in increasing Brazil's foreign policy footprint, one that is trending towards becoming a world power.

In Context

Brazil's nuclear program grew out of competition with its regional rival in Argentina. The military regime conducted both civilian and weapons programs during the rule of the military regime. The nuclear deal with West Germany in 1975 was intended to provide Brazil with the technology and knowhow for Brazil to manage its own nuclear fuel cycle in the future. The deal certainly had some proliferation motivation behind it but Brazil was genuinely motivated to develop their civilian nuclear fuel cycle to enhance energy security and national prestige. Once the deal fell far short of its initial promises, in large part due to Western efforts, the nuclear efforts shifted to the three parallel military programs. Today's current enrichment facility has roots in the technologies developed by the Brazilian Navy. The secrecy of these programs attempted to remove foreign influence in the development of Brazil's nuclear technologies however, it also helped to bring a halt to the civilian program and hamper economic growth as the West imposed trade restriction on Brazil. The end of military rule and softening tensions with Argentina led to the abandonment of the weapons program.

Given the lack of an external security threat in Brazil today, there is little to indicate Brazil is still interested in developing nuclear weapons. Brazil has a number of political motivations for pursuing a civilian nuclear program. The nuclear program is viewed as a means to enhance Brazil's international prestige and negotiating position. Nuclear technology can aid in Brazil's aspirations to become a regional hegemon and a global power representing developing nations. The Civilian nuclear program seems to provide Brazil this opportunity while a weapons program will break nonproliferation norms. Brazil's current foreign policy walks a fine line between cooperation with the West and dissenting leadership in developing countries. A nuclear weapon would cause Brazil to lose credibility in the West and could bring undesired trade restrictions. A nuclear weapons program is not consistent with Brazil's current international interactions.

The ability to master enrichment and the nuclear fuel cycle autonomously gives Brazil greater credibility and importance in nuclear matters, as seen in the Joint Declaration on Nuclear Fuel with Iran and Turkey. In other words, Brazil's enrichment facility is an instrument to gain access to first world politics. The fact that the technology was developed indigenously only enhances Brazils claim to the global stage. The West may not be entirely content with Brazil's statements and actions regarding nuclear technologies, but it does make Brazil more influential amongst those in the developing world.

The enrichment facility enhances Brazil's access to international nuclear politics, an area in which Brazil can have an important role balancing the agendas of the West and the developing world. A successful multilateral arrangement will provide Brazil the opportunity to gain favor among Western states while maintaining or strengthening its position as a regional and developing state world leader. Brazil cannot be viewed as going back on its previous statements and positions on nuclear policy or Brazil risks losing credibility amongst the developing world. Not to mention technological independence is heavily stressed domestically in Brazil. Abdicating its rights to a domestic enrichment facility would therefore be out of the question. International involvement and oversight into the nuclear fuel cycle is a possibility. A potential multilateral facility offers opportunities to Brazil but there may be more to lose than to gain in any arrangement. Brazil can use a regional nuclear fuel cycle to showcase its technological prestige in the region while improving regional cooperation on politically challenging matters. Western states may also view the facility as a favorable outcome if it is seen as enhancing the nonproliferation regime and preventing other regional states from developing their own indigenous facilities. However, such an arrangement would involve very difficult negotiations which could

potentially damage Brazil's political position within the region. Unless the arrangement is carefully crafted, it will be difficult to maintain Brazil's favorable view in the West and the developing world. Brazil would also be very reluctant to share its proprietary enrichment technology which could cause difficulties.

7.3 - Discussion

Nuclear power is an important source of energy for Brazil's future and the enrichment facility at Resende allows Brazil to obtain full independence over the nuclear fuel cycle. The domestic nuclear fuel cycle gives Brazil the security of fuel supply needed to diversify the nation's electricity sector while maintaining the self-sufficiency Brazil currently possesses. At this point, the enrichment facility at Resende is not competitive with the international fuel supply market but as nuclear power in Brazil expands in the coming decades, the enrichment facility will be a worthwhile economic investment. Brazil also has the ability to establish excess surplus in the enrichment facility for fuel service exports.

The enrichment facility creates opportunities for Brazilian engagement in international politics and is a source of national pride and prestige. Nuclear technology has helped Brazil establish strong bonds with regional neighbor Argentina, and positioned Brazil as the technological leader in South America. Furthermore, the facility positions Brazil as one of the leaders of the developing world. Brazil is not afraid to offer opinions different from the United States or other world powers. Brazil's reluctance to sign the AP and their views over the equitability of the NPT is popular amongst developing nations. The enrichment facility gives Brazil credibility in these areas, and helps to make Brazil an important player in first world politics. The negotiations with Iran and Turkey exemplify the unique position Brazil is able to maintain in the international arena and especially nuclear politics.

Multilateral arrangements to the nuclear fuel cycle are unlikely to provide enough incentives to convince Brazil to abdicate its Resende enrichment facility. Fuel supply assurances will not be effective in Brazil. Brazil has a fully independent nuclear fuel cycle and once it is expanded, the Resende facility will be economically competitive with the international fuel market. In terms of multilateral facilities, Brazil is very proud and protective of its proprietary enrichment technology. International involvement will not be welcome, although shrouding the technology in a "black box" can mitigate some of these concerns. There is little to no political incentive for Brazil to accept Western involvement in its enrichment activities.

A multilateral arrangement must capitalize on Brazil's current political ambitions for it to have potential for implementation. Regional involvement in the enrichment facility may be an intriguing possibility for Brazil. Outside of economics, the enrichment facility is a tool to enhance Brazil's national prestige and influence in the international community. A multilateral facility has the potential to expand these aims, especially on the regional scale. The arrangement can be an important means to foster regional cooperation and get out in front of any future regional concerns arising from the expansion of nuclear power in the region. A number of Latin American states have already shown interest in developing nuclear power.[4]

The most sensible approach would be to establish a regional nuclear fuel cycle. Any benefits Brazil and the region would obtain from a multilateralization of enrichment services can be enhanced by including other aspects of the nuclear fuel cycle. There are already a variety of regional organizations and

arrangements that can be made to support such an effort. The Treaty of Tlatelolco is the regional nuclear weapons free zone arrangement. ABACC has experience in building regional trust over safeguards in Brazil and Argentina. Mercosur, UNASUR and the CSD are important regional efforts at economic and military cooperation. Brazil, with Argentina, can work to provide nuclear technology and create a robust nonproliferation regime in the region.

Brazil could view the opportunity for technological leadership and supply in the region to be advantageous toward its quest of consensual regional hegemony. The leadership in creating a regional fuel cycle can also give benefits in the global community. The West would most likely view Brazil's actions as strengthening the nonproliferation regime by providing a good example to other developing nations in managing nuclear technologies and material. The developing world would see in Brazil an alternative to the restrictive approaches which have been suggested by the developed world. A regional nuclear fuel cycle presents good opportunities for Brazil but implementation of the arrangement may prove difficult and damaging to Brazil's regional standing if not approached properly. Brazil may seek to maintain its technology in a "black box" which would certainly be acceptable and advisable under nonproliferation merits. Brazil cannot be seen as imposing the arrangement on the region and must respect the rights of its neighbors to pursue their own fuel cycle technologies. Participation in the regional fuel cycle would need to treat all member states as equally as possible. Having the fuel cycle facilities within an extraterritorial area, similar to the Multilateral Enrichment Sanctuary Project (MESP) proposal, could be seen as a strong confidence building measure. Supply assurances from outside states would be beneficial in addressing the supply disruption concerns of regional partners. Intuitively it seems more likely that political disruptions would occur over regional disagreements in comparison to the international market. As a whole, the arrangement would look very similar to a voluntary regional version of the Austrian proposal, the Multilateralization of the Nuclear Fuel Cycle. The Nuclear Fuel Bank would be composed of interested regional states. Although the arrangement presents many opportunities to benefit Brazil, Brazil also risks losing credibility as a regional hegemon if the proposal is made and there is little to any enthusiasm from the region for it. In respect to a global solution placing all enrichment activities under international control, there would be no incentive for Brazil to accept such an arrangement because all of the potential for political gains would be lost.

8 - Case Study – Iran

8.1 - Nuclear Power and Infrastructure

Energy Economy and Nuclear Power

Iran is in possession of the world's third and second largest proved oil and gas reserves, respectively.[47] Primary energy consumption is dominated by the two fossil fuel energy sources, oil contributing 44% and natural gas contributing 53%.[47] Currently, oil export revenue accounted for 21.5% of Iran's GDP, although this number has fluctuated around 26% for the last two decades.[120] Major oil export destinations include: Japan, China, India, and South Korea.[121] The Iranian government has been attempting to increase its non-oil exports with some recent success. Last year, non-oil products accounted for 28.4 billion dollars' worth of exports, a 22% increase from the previous year.[122] 66.2 billion dollars of oil products were exported during the year. Despite its vast reserves, Iran has historically been a net importer of natural gas.[121]

Iran produced 4.2 million barrels of oil per day in 2009, exhibiting negligible level of growth since 2003.[47] Domestic oil consumption in the same period has risen over 16% and now stands at 42% of total oil production. Iranian oil field recovery rates average 25%, well below the world's 35% average.[123] Furthermore, oilfields are experiencing a natural decline rate just under 10% per year.[123] Rising demand and a poor infrastructure could reduce Iranian oil exports to zero within 12-19 years[124]. The vast majority of domestic oil demand is in gasoline and diesel fuel, although in 2007, 12.5% of electricity production came from petroleum products.[125]

Iran has been a major importer of gasoline because of significant energy subsidies and an underdeveloped refinery infrastructure. Iran imported 130 thousand barrels (one third of consumption) of gasoline per day in 2009.[121] Gasoline prices in 2009 and early 2010 were 10 cents per liter, the second lowest price in the world.[126] Gasoline prices are subsidized in Iran[121]. After sanctions by the Unites States in July 2010 to limit energy exports to Iran, imports fell 50% from previous levels.[127] Additionally, in December 2010 gasoline prices nearly quadrupled to $0.38 per liter as policies to reduce government subsidies in a variety of sectors were implemented.[128] Together with new refinery installations, Iran should no longer be an importer of gasoline within a few years.

Iran has been significantly increasing its production of natural gas. From 2000 to 2009, natural gas production has grown by 115% to 131.2 bcm.[47] Consumption has remained slightly above production, with imports from regional neighbors such as Turkmenistan. There are plans to become a major exporter of natural gas, contributing up to 10% of total world gas trade.[129] Such an expansion could provide a very large financial boon for Iran. European and Indian markets are potential customers for Iranian natural gas. The viability of future trading prospects depends not only on a variety of political factors, but also the extent to which production and domestic demand is increased. The Iranian government aims to increase production capacity to 1300 mcm/day by 2025,[129] resulting from the exploitation of the South Pars gas field. In addition to the demand increases in transportation and power sectors, natural gas for oil field reinjection (16% of production in 2007) is expected to increase to between 104-205 bcm by 2020.[130] The higher end of which is close to more conservative estimates of production levels.

In the electricity sector 196 terawatt-hours were produced in 2009[47] with an installed capacity of 53,000 MWe.[131] Iran exported 5.5 terawatt-hours of electricity in 2009.[132] Additionally, an estimated 18.5% of electricity generation is wasted due to technological inefficiencies.[133] Natural gas accounts the vast majority of Iranian electricity generation. Iran's first nuclear power plant at Bushehr is expected to join the electric grid sometime during 2011.[54] No deals for further nuclear plants have been agreed upon, although Iran will begin the construction of an indigenous 360 MWe nuclear power plant in 2011.[134] The government is looking to construct 20,000 MWe of nuclear power in the next twenty years.[124] This goal may prove extremely difficult to reach given the lack of international support for such a venture. Iran envisions nuclear power to substitute for fossil fuel usage in power generation to free up resources for exports.

Nuclear Fuel Cycle Infrastructure and Economy

Iran has been working to establish a complete and indigenous front-end of the nuclear fuel cycle in order to promote technological independence and energy security.[124] Domestic uranium resources are not sufficient however, to support long term independence in nuclear fuel. There are currently two uranium mines in operation in Iran, with an estimated output of 21 and 50 tons of uranium per year.[135] Plans are under way for further exploration, but Iran will not be able to produce enough uranium from indigenous sources for its reactor program. A 2005 study indicates Iran has up to 16,477 metric tons of uranium resources, only around 2,000 of which have been identified.[135] A 1000 MWe nuclear reactor requires supplies of about 220 metric tons of natural uranium a year. Assuming all resources are used, one 1,000 MWe reactor could be domestically supplied for 75 years, while the planned 7,000 MWe could be supplied for 11 years.[135] Recently, Iran has also been attempting to acquire uranium from foreign sources. In 2009, the IAEA reported that Iran was close to a deal to a secret deal to import 1,350 tons of purified uranium ore from Kazakhstan.[136] Iran and Kazakhstan both denied the claims in the report released by the IAEA. In 2010, Iran signed a deal with Zimbabwe for exclusive access to uranium mines with 20,000 tons of extractable uranium.[137] It is also important to note that Russia is under agreement supply the fuel for Bushehr nuclear reactor.[138]

Iran has also established a uranium conversion and a fuel fabrication facility. Each of these facilities has the capacity to provide services for one 1,000 MWe nuclear reactor.[135] These facilities will support the 40 MWth heavy water research reactor at Arak. The yet to be completed Arak facility will use natural uranium for fuel and according to officials will be used for radioisotope production.[139] A clandestine plutonium separation facility could be used to make nuclear weapons from the Arak spent fuel.

Proliferation concerns also arise over Iran's enrichment program. The Natanz enrichment facility has the physical capacity for 54,000 gas centrifuges.[135] Each centrifuge is currently operating at less than 1 SWU/year,[140] although this should increase as operational experience is gained and new designs are tested. For comparison, The New Urenco facility in New Mexico will operate centrifuges with a capcity of 50 SWU/year.[141] All 54,000 Natanz centrifuges operating at the current capacity would not provide enough enriched fuel to supply one 1,000 MW nuclear reactor.[135] The facilities full capacity has not been reached as shortages of raw materials to construct centrifuges may limit construction to 15,000 centrifuges.[142] Currently, there are an estimated 8,000 installed centrifuges, 4,816 of which are operating.[140]

In 2009, Iran sought to purchase 20% enriched fuel for its Tehran Research Reactor. Efforts to formulate a deal stagnated and Iran began enrichment to 20% in two cascades at Natanz (300-350 centrifuges).[140] The West was concerned over the buildup of LEU in Iran as well as the enrichment of higher grade fuel. In a breakout scenario, the LEU stock can be used as a feedstock into the cascades to produce HEU at a much higher rate. Approximately 1200-1300 kg of LEU is needed to make one SQ (Significant Quantity, or amount needed to make one nuclear weapon).[143] The Natanz facility could produce enough HEU for a weapon in five months using LEU.[143] Using higher grade material as feedstock would reduce the amount of time needed in a breakout scenario. One month is all the time that would be necessary to produce enough HEU for a weapon from 20% enriched uranium.[143] 43.6 kg of 20% enriched uranium have been produced over the last year,[140] about one fifth of the amount needed for a weapon.[143] In 2010 Iran formed an agreement with Brazil and Turkey to transfer 1,200 kg of LEU to Turkey in exchange for 20% enriched fuel rods to be used within the Tehran Research Reactor.[144] Iran's LEU fuel stocks at the time of the deal were roughly twice the amount of LEU to be transferred. The deal also allowed Iran to continue enriching fuel at 20% within its Natanz facility.[144]

Iran does not have plans for any declared reprocessing facility. Russia has also agreed to take back any spent fuel from the Bushehr reactor.[138]

In Context

An analysis of current technological experience, political difficulties, and lack of any current contracts, demonstrate the unrealistic nature of current plans for nuclear power growth. Despite the overly ambitious plans, nuclear power certainly seems to have a place within Iran's energy sector. Iran depends on oil exports for a large proportion of their GDP and export revenue. Nuclear power can be used to substitute for fossil fuels in domestic electricity production, freeing more resources for significant export and economic benefit. In 2007, 12.5% of electricity generation came from petroleum products. The first two or three nuclear power plants could completely offset electricity generation from petroleum.[135] If natural gas production expands as planned, it too will also become a major part of Iran's export portfolio. Even in the event natural gas does not become a major export, nuclear power will still allow further use of gas in oil field reinjection.

There is an insufficient amount of domestic uranium reserves to support a nuclear power program. Iran seems to be acknowledging this fact by securing foreign sources of natural uranium, although the secretive nature of these deals call into question the Iranian motive. Iran may be looking to secure a supply of uranium that does not have restrictions upon its end use as most supply arrangements do. It is also possible that Iran may have difficulty obtaining uranium from the commercial market due to outside political pressure upon the supplier. The Natanz enrichment facility may not need to provide fuel for a power reactor anytime soon as Russia has agreed to a fuel supply and take-back arrangement for the Bushehr power plant. Additionally, the facility does not have the current capacity to fuel a 1,000 MWe nuclear reactor nor the 360 MWe plant under consideration. This is likely not deliberate, rather a result of technical difficulties and material shortages. The facility does however have the capacity to produce enough material for weapons use. Centrifuge technology advancements or the construction of additional centrifuges could achieve sufficient levels to supply a power plant. Likewise, fuel fabrication and conversation facilities do not have the capacity to provide services for more than one power reactor but could conceivably be expanded. As nuclear expansion plans move forward it will be important to monitor the expansion of Iranian fuel cycle capabilities in order to see if it is consistent with needs.

The attempt to establish an independent nuclear fuel cycle in search of energy security has been controversial and may also be difficult to justify on an economic basis. Multilateral arrangements make a good deal of sense in Iran if the nuclear program is intended primarily for civilian power purposes. Domestic reserves of uranium are insufficient. The Natanz enrichment facility can contribute to energy security and fuel cycle independence; however Iran is currently having difficulty in getting the facility to operate at a capacity large enough to supply a power plant. Two instances in recent past may indicate supply assurances will not be enough incentive to stop enrichment activities. Supply assurances are already in place for the Bushehr power plant and yet the enrichment plant produces LEU when there is no demand. Western attempts to negotiate a deal with Iran to trade 20% enriched fuel for LEU stocks were reportedly rejected because Iran was not offered "concrete assurances" of fuel supply.[145] Once a deal was finally negotiated for a fuel swap with Brazil and Turkey, Iran's stockpile of LEU had nearly doubled to 2,500 kg. Furthermore, Iran continued to enrich to 20%. In other words, the argument for "concrete assurances" seems dubious because an agreement was only made when Iran was allowed to have in possession of all its nuclear weapons manufacturing capabilities. It is possible Iran has not been convinced that future supply of fuel has been sufficiently assured. It is possible Iran is enriching to gain operational experience for a future in which technological independence will be possible. It is also possible that Iran's enrichment activities are aimed at a nuclear weapons program.

Involvement in a multilateral enrichment facility may be able to provide the additional assurances of supply needed by Iran. Providing Iran direct access to operation and export decisions would allow Iran to maintain the strongest of supply assurances. An arrangement involving technology transfer is likely to be viewed positively by Iran because the centrifuges at Natanz are significantly inefficient in comparison to competitor models around the world. Of course, such an arrangement would be ineffective if Iran's primary intent is pursuing a nuclear weapons program.

8.2 - Nuclear History and Political Interactions

Nuclear Program History

The Iranian government signed a nuclear cooperation agreement with the United States in 1957 as part of the Atoms for Peace Program.[146] A strategic regional ally of the United States at the time, Iran received technological assistance and research materials and facilities from the United States in return for the promise to not develop nuclear weapons. In 1967, a nuclear research center was completed in Tehran. The research center included the 5 MW Tehran Research Reactor. Highly enriched fuel for the reactor was provided by the United States.[146]

Toward the end of the 1960s, the Iranian leadership decided upon an ambitious plan to pursue nuclear power for domestic energy production. Iranian leadership was interested in nuclear power as a means to enhance national prestige and support the exports of fossil fuels. Iran signed the NPT on the first day it was open for signature in 1968.[147] The treaty was ratified in 1970 and a full scope safeguards agreement was soon in place. Plans were set to establish 23,000 MW of nuclear capacity within 20 years.[146] International agreements were aggressively pursued with Western states. In 1974, the United States agreed to provide eight reactors[148] and the Germans agreed to build two reactors at the Busherh site.[147] An additional agreement was made with France in 1977 for two reactors at the Darkovin site.[148]

The Germans began construction at the Busherh site in 1974 and were more than half complete by 1979.[148]

As part of the nuclear program, Iran sought to grow its nuclear fuel cycle capabilities and became interested in enrichment technology. In 1974, Iran lent France 1 billion dollars for the construction of the Eurodif enrichment plant and later paid 180 million dollars for enrichment services.[149] The loan gave Iran rights to a 10% share in the facility. Iran then signed a deal to finance an Enrichment Facility South Africa in exchange for a shipment of yellowcake to Iran.[146] Furthermore, an American company was contracted to provide an experiment laser enrichment technology to Iran in 1976.[146] Iran was also planning to pursue reprocessing capabilities.

Egypt and Iran proposed the creation of a Middle-East Nuclear Weapons Free Zone (NWFZ) in 1974.[150] Although never established, the UN General Assembly and Security Council have long endorsed the NWFZ's establishment. It was also around this time that concerns over proliferation erupted in response to the Indian nuclear test.[151] To make matters worse, the Shah of Iran was quoted saying that Iran would "without a doubt" have nuclear weapons.[148] The United States also had concerns that the political situation in Iran was becoming unstable.[151] Germany and France were pressured to not provide Iran with any sensitive fuel cycle technologies.[146] At this time, it was not clear if Iran had made the decision to pursue nuclear weapons during the 1970s, but they were at least trying to develop the ability to do so in order to keep the option open for a later date.[146]

The United States became heavily involved in negotiations with Iran over the establishment of a reprocessing facility.[151] The United States wanted Iran to set an example by forgoing the creation of reprocessing capabilities.[151] The United States made proposals to either buy back Iran's spent fuel or to establish multilateral/bilateral reprocessing facilities. Iran was not interested and instead wanted an indigenous facility in Iran.[151] Concerns also grew over safeguards agreements and the United States supply of HEU for the Tehran Research Reactor.[151] A final deal was proposed to Iran in which the United States would have a veto power over the usage all American supplied fuel.[151] Negotiations were ultimately halted as nuclear related endeavors except for the reactors already under construction were halted in 1978 as the Iranian regime began to collapse.[151]

The Iranian revolution occurred in 1979. The new leader, Ayatollah Khomeini, halted the nuclear programs[148] including the cancellation of orders with Eurodif.[149] Western companies froze their previous supply and construction agreements.[148] The previously amicable relationship between the United States and Iran fell apart. The revolution contained a large deal of anti-American endeavors, including a student attack on a U.S. embassy in which 63 staff members were taken hostage.[146] The United States then imposed their first round of sanctions.[146] Iranian financial assets in the U.S. were frozen, exports to Iran were prohibited (except for clothing, food, and medical supplies), and imports of all Iranian goods were prohibited.[152]

The origins of the revolution help to explain why the relations with the West quickly disintegrated after 1979.[146] The Iranian Revolution was in large part motivated by anger towards the monarch regime and its Western ties. In the early 1950s, a democratically elected leadership in Iran moved to nationalize the Oil industry in Iran.[148] Shortly after in 1953, The United Kingdom, with support from the United States, orchestrated an overthrow of the democratically elected government in Iran and replaced it with the

monarchy[146] to help ensure a monopoly on Iranian oil. The revolution held strong sense of anti-American and Western sentiment as a driving force.

Taking advantage of Iran's weakened state as a result of the revolution, Iraq invaded Iran in 1980.[146] The war lasted until 1988. It was during this protracted conflict that the Iranian leadership decided to restart its nuclear program in the mid-1980s to address future security challenges.[146] A missile development program was also initiated at this time. Iran found it difficult to find international support in developing its nuclear technologies. Increasingly, Iran resorted to the black market for technological help due to American influence. Efforts were made to procure uranium and, through the A.Q. Khan network in 1987, Iran was able to acquire technical drawings and other components to begin work on a centrifuge facility.[153] Experiments in enrichment and reprocessing were conducted in the last 1980s and 1990s.

In the early 1990s, in addition to continuing technological development and procurement with the A.Q. Khan network, Iran sought nuclear deals with China and Russia.[148] In a transaction not reported to the IAEA, China provided Iran with a metric ton of uranium hexafluoride, believed to be used to experiment with centrifuge technologies.[147] Russia agreed to complete construction of the Busherh reactor, and provide Iran with an enrichment facilities as well as the Arak heavy water reactor.[147] America prevented the transaction from occurring. Frustrated it could not gain access to nuclear technologies; Iran became increasingly critical of the NPT and considered withdrawing in 1995.[146]

The nuclear program rapidly picked up in the 2000s. Iran was moving forward with its civilian pursuit of nuclear technologies, although this was a guise to hide their motives for proliferation.[146] In 2002, previously undisclosed nuclear activities at Natanz and Arak were revealed.[148] The Natanz enrichment facility uses centrifuge technology most likely acquired from its dealings with the A.Q. Khan network in the 1980s and 90s.[153] The international community quickly became concerned over the presence of a potential weapons program. No proof of a nuclear weapons program was detailed, although many questions remained.

Multilateral talks with Britain, France, and Germany ensued. Iran agreed to halt progress on its enrichment facility in 2003 and enforce the Additional Protocol during talks. Furthermore, the National Intelligence Estimate of 2007 concluded that Iran had indeed halted the development of its nuclear weapons program in 2003.[146] Iran hoped to gather European commitments for nuclear power plant construction and recognition of Iran's enrichment rights in return for enhanced safeguards. Proposals were made to provide fuel supply assurances to Iran if enrichment was halted for 10 years; another proposal by Russia offered to involve Iran in a joint enrichment effort on Russian soil.[154] The deals were refused and Iran continued its insistence on its right to pursue indigenous enrichment technologies. As talk started to collapse, Iran resumed enrichment activities in 2005 and later stopped the implementation of the Additional Protocol in 2006.[154]

Historical Motivations

The civilian nuclear program in Iran moved forward in the 1960s and early 1970s through western support. The Iranian leadership viewed civilian nuclear power as a means to support the export of fossil fuels upon which the economy heavily depended. National prestige was also a strong motivator, as Iran strove to see itself as a regional economic and technological power. These are the same non-weapons

related motivations that Iran currently has to the development of nuclear power and the nuclear fuel cycle.[124]

The Iranian motivation to proliferate is complex but originated from national security considerations. Iran has maintained a dyadic conflict with Iraq for the past 50 years.[146] The conflict involves regional posturing for power but emanated most strongly over a key strategic waterway near the Gulf. The waterway was needed to establish ports for oil exports.[146] An agreement in 1937 accorded all but three miles of the Shatt-al-Arab waterway to Iraq. Iran expressed their dissatisfaction with the arrangement in 1959, initiating a series of border skirmishes for the next few decades.[146] The Iranian motivation to consider a nuclear weapons program in the 1970s stemmed from this conflict with Iraq who was believed to be pursuing nuclear weapons at the time.[146] In 1975, the Algiers accord made the waterway a shared common border between the two states.[146] Following the Iranian Revolution, Iraq invaded Iran in 1980. Domestic turmoil had left Iran unprepared to fight the protracted war against Iraq that lasted until 1988.[146]

The war held a series of ramifications for Iran. Iran expresses to this day its chagrin over the actions perpetuated by the international community during the war. The threat environment with the United States that started before the war and included heavy economic sanctions were heavily enhanced. Iraq was able to occupy over 30,000 square miles of Iranian territory before the UN Security Council called for a ceasefire in the conflict.[146] The Security Council did not ask Iraq to withdraw, and Iran did not comply with the Security Council Resolution. Throughout the duration of the conflict, the United States blocked the sales of arms to Iran and supported Iraq with military and economic assistance.[146] When Iraq used chemical and biological weapons against Iran, the United States and United Kingdom blocked the condemnation of Iran in the UN Security Council.[146] In fact Iran believed the United States and its western allies helped Iraq acquire such weapons. The Israeli bombing of the Osiraq facility in Iraq confirmed to the world the presence of an Iraqi nuclear program.[146] The Iraqi threat and distrust of international norms established through Western leadership, motivated Iran to embark on its nuclear weapons program in the mid-1980s.

It was also during the late 1970s and 1980s that Iranian tensions with Israel began to grow. Iran had not been an involved party within the Arab-Israel conflicts during the previous two decades.[146] In 1977, Egypt allied itself with Israel. A Syrian call for aid pulled Iran into the conflict.[146] In 1982 Israel attacked invaded Lebenon, upon which Iran sent its support.[146] Since then, Iran has retained close ties to Hezbollah, which Israel and America view as a terrorist organization.[146] Iranian leadership is infamous for making inflammatory remarks denying the legitimacy of an Israeli state in the Middle East and supporting the Palestinian cause. Iran also believes Israel should not maintain a nuclear arsenal, viewed as the clearest violation of Western inconsistencies in applying international non-proliferation norms. For its part, Israel wishes to maintain its regional nuclear monopoly and has on two occasions taken military measures to ensure it does.[146] Israel also maintains close ties to the United States whose regional influence Iran strongly disapproves of.[146] Although Iran is concerned with Israel, it is not its primary threat as Iran has allies within the conflict.[146] Involvement in the Israel conflict is an opportunity to gain influence within the region.

The 1991 Gulf War can be seen as shifting Iran's primary threat from Iraq to the United States.[146] Iran was surely pleased to see its regional rival defeated, but concerns grew over American influence in the region. Iran remained neutral during the conflict and viewed it, in part, as a war between the West and

Islam.[146] Iran views itself as a regional superpower; however the United States humiliated Iran by engaging in a regional military conflict without consulting with Iran.[146] The United States was now the world's lone superpower and was able to form an international coalition and overwhelm the Iraqi forces with ease. More troubling was the amount of regional support the United States was able to amass for the conflict.[146] A nuclear weapon could enhance national prestige and give itself more regional weight to the American hegemon. A nuclear weapon could also be used to deter future American attacks on Iranian soil. Iran found itself in a troubling position as Iran did not adhere to the Western political doctrine or cultural principles.[146] The United States had been referring to Iran in public discourse as a rogue state for its support of terrorist organizations and its pursuit of nuclear weapons. The United States could target Iran in a future display of regional asymmetric power. Furthermore, 1992 sanctions by the United States prohibited the export of military arms and equipment to Iran, limiting Iran's ability to defend itself.[146]

Iran moved forward very rapidly with its civilian nuclear program. A nuclear weapons program was never admitted; Iran was either leaving the ultimate decision to a later date or strictly using the civilian program as a cover. Progress was slow due to Western intervention in nuclear technology transfers. 2001 and the subsequent years would be important in shaping the direction of Iran's nuclear programs. Iran was subsequently labeled as one of the "axis of evil" states by the United States.[146] The people of Iran were increasingly humiliated by its portrayal in the international community.[146] Aggressive military posturing by the United States in the region elevated the threat environment.[146]

The invasion of Iraq momentarily cooled Iranian nuclear developments. America was willing to engage in wars in the Middle East to prevent the spread of weapons of mass destruction.[146] It was clear that Iran was next in line for a potential military strike. Additionally, the reveal of the previously secret Natanz enrichment facility intensified international pressure and concerns over an Iranian nuclear weapons program. Given the circumstances, Iran was more than willing to engage in talks with Western states. The round of talks which occurred within the next few years can offer an insight into Iranian motivations for its nuclear program. Early on, a wide scoped proposal was made from Iran to the United States in 2003.[155] The proposal addressed concerns with Iraq, the Iranian nuclear program, relations with Israel, and terrorism.

The proposal first offered to take "decisive" actions against all terrorist organizations in Iran, with emphasis on Al-Qaeda.[155] In fact, efforts had already been made to cooperate with the west versus Al-Qaeda. In return the United States would offer its aid in fighting against the MEK, an anti-Iranian terrorist organization.[155] Iran offered its regional influence to help in coordinating with the West to establish a democratic and non-religious government within Iraq. Iran agreed to recognize the Israeli state if Israel retreated back to pre-1967 boundaries (essentially the two-state solution).[155] Iran would end all support of aggressive actions by opposition groups such as Hamas, and Hezbollah. As for its nuclear weapons program, Iran was willing accept complete transparency in its nuclear program, accept the most stringent IAEA safeguards on all activities, and ensure there were no attempts to pursue any WMDs.[155] In return, Iran wanted "full access to peaceful nuclear technology." Through the deal, Iran also expected to be removed from the states supporting terrorism and axis of evil lists. The deal was, for the most part, ignored by the United States.[155]

Negotiations with European states ensued for the next few years as Iran agreed to halt all enrichment activities and voluntarily impose the AP. An Iranian proposal[156] offered to fully adopt the AP, ensure an

open nuclear fuel cycle, and legislate against any pursuit of nuclear weapons. In return, Iran wanted greater access to European markets, agreements to construct nuclear power plants in Iran, European support for a Middle Eastern NWFZ, and recognition of the Natanz enrichment facility. This proposal was also quickly rejected. After a couple of years talks began to quickly stall. The Iran case was sent to the UN Security Council in 2006 upon which Iran stopped implementing the AP.[154] By this time, Iran was fairly confident the United States would be unable to engage in a third war in the Middle East.

From these negotiations, it is clear Iran was trying to use its nuclear program to enhance its national prestige and economic position. The people of Iran believe American influence has deprived their nation their rightful standing of regional superpower.[148] Allowing the United States to influence Iranian policies, especially its right to indigenous peaceful nuclear technologies granted to it by the NPT is unacceptable. The Iranian people insist its nuclear program is for peaceful purposes and ask why Iran should give up its enrichment program while other states like India, Pakistan, and Israel have not.[148] As long as this position is maintained, Iran is unlikely to give up an enrichment facility on its soil. Iran views its nuclear program, and potential development of a nuclear weapon, as a tool to create and influence political negotiations. Foremost, Iran wants to be respected as a regional power in the Middle East. A nuclear weapon would not only provide security assurances but also enhance national prestige. Conversely, Iran could renounce nuclear weapons in return for international recognition of Iranian power in the Middle East. The proposal made to Europe would enhance Iran's economic position and improve national prestige by obtaining international support of Israeli denuclearization. The proposal made with the United States would similarly enhance Iran's regional power status by negotiating a deal in the Palestinian-Israeli conflict. The proposals displayed the political value Iran places in its enrichment facility.

Recent International Interactions

A nuclear agreement was signed with Russia in 2005 to complete the Bushehr power plant, but also provide fueling services for the reactor.[138] The agreement also entails Russia to take back the Bushehr spent fuel but this is meant more to alleviate global concerns over the presence of spent-fuel in Iran's possession rather than to be to Iran's benefit. The power plant has been completed, but has been having difficulty in beginning operation. In early 2011, the reactor was defueled due to complications.[157]

After negotiations with the European broke down in late 2005, Iran restarted its enrichment program. Iran installed 3,000 of its centrifuges in the Natanz facility by 2006 with the aim to eventually construct 54,000 centrifuges. At full capacity, the plant could supply sufficient enrichment services for one 1,000 MWe nuclear power plant. Material supply constraints may limit the buildable capacity to around 15,000 centrifuges, 8,000 of which have already been built. Attempts have been ongoing to improve the centrifuge capacity from the currently inefficient levels.

In late 2006, the UN Security Council passed resolution 1737, requesting Iran to stop all enrichment activities within 60 days.[158] Iran has called resolution 1737 and subsequent resolutions reaffirming it to be illegal because Iran's enrichment program has never been proven to be a threat to world peace.[154] Iran has raised its voice on multiple occasions over the NPT. Iran has released statements claiming the United States to be in violation of the NPT for providing nuclear weapons to NATO allies and not disarming its nuclear arsenal, violating Article I and VI of the NPT.[159] Iran's threat to withdraw from the NPT is a political tool to be used for negotiations.

Negotiation attempts were once again pursued in 2008. Iran presented the Package for Constructive Negotiations to the United Nations on May 13th.[160] The "Package" was comprehensive in scope, and covered economic, regional politics, and nuclear concerns, but was not specific in the details. The scope of the proposal would involve Iran in the center of global politics, improving national prestige. Interestingly, Iran was willing to consider the establishment of international enrichment consortiums around the world, including in Iran. It was unclear however, if the enrichment consortium would need to be in Iran and if it would replace the Natanz domestic facility.[161] Remarks by the Iranian ambassador to the UN made to the Boston Globe clarify both issues. "The ambassador said Iran would not suspend its own enrichment program, but would consider establishing an international owned consortium inside Iran that could produce nuclear fuel with Iranian participation." The ambassador said the issue has become one of national pride.[161] The Western countries responded in June, tabling an updated proposal supporting Iran in nearly all the ventures proposed.[154] Absent from the proposal was an offer to cooperate with Israel to solve the Palestinian issue.[162] More importantly, although the Western proposal agreed to recognize Iran's right to pursue its peaceful nuclear technologies, it did not mention whether an Iranian enrichment facility would be acceptable. Nothing further came from these negotiations.

Domestic political unrest took place in Iran starting on June 13th, 2009 following the reelection of President Mahmoud Ahmadinejad.[163] The opposition leader declared the vote a fraud, and millions took to the street in a movement to voice their objections over the electoral process and the current progress of Iran. "The regime is plagued by double-digit inflation, massive flight of capital, and unprecedented levels of unemployment."[163] There has also been internal opposition to the uncompromising attitude on the nuclear program because it has needlessly fueled American treatment of Iran.[163] Rioting took place, and at times violence was used to suppress the people. The initial protests are regarded as the most forceful since the Iranian revolution in 1979.[163]

In late 2009, international tensions were elevated following the reveal of the Fordow enrichment facility near Qom by the United States, France, and United Kingdom.[163] The Western states had been aware of the facility since 2007. The yet to be completed facility is to have a 3,000 centrifuge capacity, far too small to supply a nuclear power plant.[163] According to Iran, the facility is needed to provide enrichment services in case of an attack on the Natanz facility.[163] A number of facilities similar to the one at Fordow would be needed to fulfill the stated purpose. The reveal may have a more significant meaning though. Given that the Natanz facility is under safeguards, it is unlikely Iran could produce enough material for a nuclear weapon without alerting the international community. The western states must realize a clandestine enrichment program is much more likely to be used by Iran to produce the needed weapons material. The Fordow facility could be used in a breakout scenario by using feedstock of LEU or 20% enriched uranium to rapidly produce enough HEU for a nuclear weapon. The reveal may be a signal to Iran indicating the Western states are capable and aware of detecting Iranian covert efforts at a nuclear weapons program. If true, Iran would be taking a large risk in pursuing a covert enrichment program. A reveal of weaponization attempts before attainment could bring extreme pressure from the international community.

The United States took the weakened domestic situation in Iran to impose some of the harshest sanctions yet.[152] In 2010, the United States, European Union, Japan, and South Korea sanctioned the Iranian energy industry. Previously, economic sanctions were unilateral efforts from the United States.

The inclusion of the European Union and America's East Asia allies provide much more restrictive sanctions. China and Russia have for the most part continued its trade relations with Iran. The sanctions prevent future investments into the Iranian energy industry.[152] This can be highly damaging to Iran, which desperately needs to improve its oil and gas infrastructures in order to keep export revenue flowing. The West is hoping the loss of jobs and inflation resulting from the sanctions, together with its domestic unrest, will be enough of an incentive for the Iranian leadership to give up its enrichment facility and nuclear weapons pursuit. Indeed, Iran has recently removed domestic internal energy subsidies raising the price of gasoline almost four fold, as Iran struggles to meet domestic demand.

A wave of civil unrest, starting in Tunisia, overtook the Middle East and Northern Africa in early 2011.[164] Peaceful uprisings in Egypt led to the resignation of previous president Hosni Mubarak on February 11th. In Libya, the UN is enforcing a no fly zone as opposition forces wage battle with Muammar Gaddafi's forces on the ground. Unrest has been seen to some extent in Bahrain, Yemen, Oman, Syria, Jordan, and Saudi Arabia. Unrest has for the most part has not spread to Iran yet, even if it does not, the regional shakeup may alter Iran's strategic outlook in the region.

In context

The Iranian nuclear program had peaceful roots in the 1960s, with a good deal of Western involvement. Moving into the 1970s, ambitious plans at civilian nuclear power expansion called for 23,000 MWe of nuclear power within 20 years. The first attempts at multilateral arrangements for the nuclear fuel cycle with Iran occurred during this time period. Iran purchased 10% of the Eurodif facility, although this later caused trouble as Iran tried to back out of the arrangement after the Iranian revolution. The United States proposed multilateral reprocessing facilities, but Iran would not settle for a deal not involving a facility on Iranian soil. The Iranian Revolution put a temporary halt to civilian nuclear efforts.

The nuclear weapons program is not new, resulting from large security threats over the past five decades. Iraq was a regional rival with a territorial dispute that escalated with the onset of the Iran-Iraq war one year after the Iranian revolution in 1979. Tensions with the United States were high during the Iranian Revolution and escalated during the Iran-Iraq war. The Iranian people felt betrayed by the international community during the war. Iran partly blames the aid the West gave to Iraq for their struggles and lost a good deal of respect for international norms when the United States blocked the condemnation of Iraq in the UN for its usage of chemical weapons. The nuclear weapons program resulted from the culmination of these tensions in the mid-1980s. The Gulf War signaled a transition to the United States as Iran's primary security threat. Increasing regional involvement by the United States and asymmetric weapons posturing to Iran has elevated the threat environment. International tensions concerning the nuclear program have elevated in the last decade as the Iranian program has rapidly grown. Western efforts delayed Iranian technological acquisitions during the 1980s and 1990s; however enrichment capabilities have been achieved.

The Iranian nuclear program, though initiated because of a threat environment, has come to mean significantly more to Iran. Iran views itself as a regional power, and would like to be respected as such. American involvement in the region diminishes Iran's perceived influence in the region. The nuclear program is a means to negotiate with the most powerful states of the world. Iran hopes to gain political or economic concessions for giving up its nuclear weapons program. Negotiating concessions from Israel or impressive levels of economic growth through access to European markets would drastically

improve Iran's regional influence. It is not likely that Iran would give up its nuclear program without obtaining something Iran views as providing equivalent political gain. In other words, Iran is interested in gaining far more than security of fuel supply from its enrichment capabilities.

It is important to recognize the civilian nuclear program can also be a source of national pride to Iran. The perception of a civilian nuclear program is important for Iran in domestic politics. Iran often presents itself as a victim of Western involvement and inconsistencies in international norms. The Iranian people do not feel they should give up Iran's nuclear fuel cycle rights while other states are allowed to maintain theirs. Iran also points to Israel, India, and Pakistan as non-NPT countries that have nuclear weapons and are still allowed access to peaceful nuclear technologies. Allowing the United States to dictate the Iranian nuclear policy would diminish the national pride Iran has for itself. Indeed, the Iranian ambassador to the UN has proclaimed that the ability to enrich uranium has become an issue of national pride and that the Iranian people will not accept the suspension of the enrichment program. After being referred to as an axil of evil state, and suffering under a number of severe sanctions and technological restrictions from the West, obtaining a self-sufficient civilian nuclear program in itself would be an accomplishment. Iran would have succeeded despite America's best attempt to influence Iranian policy. Even though Iran seems intent on developing a nuclear weapon, it should not be seen as inevitable. A nuclear weapon has not been developed, up to this point the weapons program is strictly a tool to gain leverage in the international community. A package that allows a thriving civilian nuclear program in Iran with a select number of outside political concessions could provide the sufficient boost to Iranian pride and prestige.

In this respect, multilateral negotiations have been ongoing to solve the Iranian nuclear problem. Not all of Iran's negotiating efforts have been deceptive; there have been multiple efforts to establish a base of negotiations to grow on. A multilateral enrichment facility seems to be agreeable by Iran, but the West is unwilling to construct one on Iranian soil. Iran may desire to maintain its current enrichment program even if a multilateral facility is constructed in Iran. It is possible Iran could be given enough political concessions in negotiations to give up its domestic enrichment program for a multilateral one, though this does not seem to have been an avenue pursued in negotiations. Unless the West is willing to move away from its no enrichment in Iran policy, a multilateral enrichment arrangement is unlikely to happen. The two sides seem to instead be interested in political maneuvering. By revealing the Fordow facility, the United States is signaling to Iran that a covert enrichment program will not be easy. Is Iran willing to give up the perception of a purely peaceful nuclear program? The recent Western political condemnations and economic sanctions to deal with Iran are risky because they may only enhance the Iranian desire to develop a nuclear program by furthering the repression to be suffered. The West hopes domestic political turmoil will succeed in pressuring a reversal in Iranian policies before Iran is able to complete its nuclear weapon. The sanctions aimed at the energy industry in Iran face a number of challenges to succeed however. Foremost is the rising oil demand from China and India that Iran can turn to for their exports. Iran certainly feels pressure from the international community but Iran may be able to produce a nuclear weapon before the situation becomes unmanageable. How long can the United States and her Western allies wait to determine the effectiveness of sanctions while Iran moves closer to its goal?

8.3 - Discussion

Iran's nuclear power programs date back to the 1950s and became very ambitious during the 1970s. Iran planned to introduce 23,000 MWe of nuclear power in Iran by 1990 and a number of deals had been arranged with Western states to accomplish this plan. Nuclear ambitions were halted at the start of the Iranian revolution in 1979. The civilian nuclear program has faced delays and troubles ever since. Iran's first nuclear power plant has only recently been completed but is still facing technical difficulties in coming into commercial operation. Iran's nuclear power ambitions today are just as strong as they were during the 1970s; legislation is in place to pursue 20,000 MWe of installed nuclear capacity within the next 20 years. Nuclear power is intended to support fossil fuel exports by substituting for the use of petroleum and natural gas in electricity generation. The expansion plans are certainly over ambitious given the amount of political difficulty Iran will have in securing deals to supply a large number of nuclear power plants. The current Bushehr reactor is contracted to receive fuel from Russia. In this light it is easy to claim that Iran has no economic incentive to pursue a domestic enrichment facility and a more independent fuel cycle. However, an expansion of the nuclear power industries to the levels legislated would certainly provide a great deal of incentive to develop an indigenous enrichment facility. At those levels a domestic enrichment facility should be financially advantageous in comparison to the international market. More importantly, security of enriched fuel supply would be extremely important in order to prevent a large scale disruption of electricity generation. Iran is for the most part isolated politically and does not see the international community as being a reliable source of fuel supply. The Iranian revolution has never been fully seen as legitimate in the West. Perpetual sanctions and hard line rhetoric by the United States have certainly exacerbated the issue. While it is true that most of these problems are largely caused through Iran's actions, it cannot be denied that Iran is not in a position to trust the international community and has incentives to pursue technological independence. Furthermore, the hardships endured by Iran, perceived to be discriminatory in nature, have made the establishment of a domestic enrichment facility a matter of national pride and prestige. Iran cannot allow the United States to influence domestic policy and, in its efforts, Iran has gained sympathy from the developing world. The nuclear program in Iran certainly has a weapons component to it, but it is important to not dismiss the purely civilian motivations for a nuclear fuel cycle because they heavily influence whether certain multilateral arrangements can be successful in Iran.

The nuclear program in Iran is certainly motivated by proliferation intents. Protracted conflicts with Iraq and the United States have provided the incentive to develop nuclear weapons. Not only would national security be enhanced by a nuclear weapon, Iran would limit the impact American attempts at political influence can have. America would be much less likely to militarily invade Iran due to fears of an Iranian launch on American forces or Israel. Israel is not a security threat to Iran in the conventional sense. The Israel-Arab conflict threatens Iran's position as a regional superpower. A nuclear weapon can help swing regional favor toward Iran because Iran would be in a position to counter the Israeli asymmetric nuclear posturing. Israel also makes a nuclear weapons program a matter of national prestige and pride. Why should Israel, perceived to be an illegitimate state by Iranian leadership and not a member of the NPT, be allowed to have a nuclear arsenal while Iran is discriminatorily denied access to a facility that *could* be used to make nuclear weapons? During recent negotiations, Iran has indicated the value it places upon a nuclear weapons program. First and foremost, Iran will not be sacrificing its civilian nuclear program. Iran wants the international community to acknowledge Iran's right to peaceful nuclear technology, including a domestic enrichment facility. Additionally, Iran has requested a variety of vague measures to improve its international standing and prestige in the world. Including: A relaxation of sanctions and portrayal of Iran as a rogue state; full support for a Middle East Nuclear Weapons Free Zone, increased economic access to European markets, assistance in developing

Iran's oil and natural gas infrastructure, access to deals to construct nuclear power plants in Iran, and efforts to move toward global nuclear disarmament.

Multilateral arrangements do have the opportunity to contribute to improved non-proliferation merits in Iran but any agreement will probably require additional political incentives. Sanctions and political rhetoric against Iran may be relaxed. For this to occur, Iran must renounce the terrorist activities of Hezbollah and Hamas. Access to European markets could certainly be arranged, as well as increased cooperation in the oil and gas industry and nuclear power plant development. Full public support for a Middle Eastern Nuclear Weapons Free Zone including Israel may be politically challenging, but progress can be made. The point is any negotiation with Iran involving its enrichment facility will be complex and will involve a variety of issues not directly related to the nuclear program. Unless the involved political bodies can agree on these other issues, it may not be possible to stop Iran from continuing its enrichment program and potentially developing nuclear weapons. Multilateral arrangements can play an important part in negotiations by providing concerned states the necessary non-proliferation assurances for a deal to be negotiated.

Supply assurances will not be enough to dissuade Iran from continuing on its current path. Any multilateral arrangement must allow for Iran to have an enrichment facility on its soil. Iran will not accept any proposal offering an alternative to this. The Natanz facility should no longer present itself as the primary concern because Iran has acquired the technological capability necessary to clandestinely develop nuclear weapons material. If Iran decides to develop the nuclear material for a weapon it is like to place within a clandestine facility and under a breakout scenario. Iran would not want to alert the international community of its nuclear intentions before it is in possession of the weapon. The Fordow facility near Qom would have served very well for a nuclear breakout scenario. To provide the necessary non-proliferation assurances, the multilateral arrangement would need to include a provision requiring Iran to implement the AP.

Geoffrey Foden and John Thompson at the Massachusetts Institute of Technology have proposed a moderately detailed multilateral arrangement to address the Iranian enrichment concern. [165] The proposal argues for the establishment of a multilateral enrichment facility on Iranian soil. The Natanz facility would ultimately be stripped of its current centrifuges and replaced with more advanced models, most likely of Urenco desings. The more advanced centrifuges would remain under a "black box." The enrichment facility would enjoy real estate status similar to a diplomatic mission. International partners in the facility would include France, Germany, the United Kingdome and potentially others. The proposal is well formulated and contains a number of important considerations. It may be difficult to gather the necessary international support to implement the Thompson and Forden proposal. For instance, the initiative was not embraced by Urenco and has not been pursued much further. In difference to the Forden and Thompson proposal, it may also be argued that Iran would be unwilling to replace its enrichment facility with one internationally managed. Otherwise the Forden and Thompson proposal is an ideal solution to the Iran's troublesome enrichment program using a multilateral arrangement.

In speaking to the Boston Globe, the Iranian ambassador said Iran "would not suspend its own enrichment program, but would consider establishing an internationally owned consortium inside Iran that could produce nuclear fuel with Iranian participation." It is possible the wording of the phrase is being overly analyzed but it appears Iran is indicating it would be willing to establish an international

consortium in addition to, not in place of Iran's own enrichment program. Iran may not trust Western states enough to suspend its own enrichment program and leave it open to potential politically caused supply disruptions. Iran may also consider the domestic enrichment program to be too important to national pride to relinquish. It is also possible Iran has no intentions of giving up its nuclear weapons ambitions and intends to use indigenous enrichment facilities to meet this goal.

An alternative multilateral arrangement to the Forden and Thompson proposal would have Iran maintain primary control of the enrichment facility at Natanz. The technology would remain 100% Iranian unless Iran is able to secure an outside source of technological improvements. Indeed one benefit of this arrangement is that international companies such as Urenco would not be required to take a heavy risk in providing Iran with valuable enrichment technologies. Regional involvement in the facility could improve Iran's regional prestige and provide the necessary international oversight for stronger non-proliferation assurances. A few states such as the United Arab Emirates, Kuwait, Jordan, Syria, Saudi Arabia, Turkey, and Egypt can become partial investors in an expanded Iranian facility. Western states would provide participating members in the Iranian facility outside fuel supply assurances in the event Iran breaks the arrangement.

The Natanz facility would not be capable of supplying enough fuel for Iran's ambitious nuclear power ambitions in the short term. In the meantime, Iran can obtain strong fuel supply assurances by becoming a participating member in an already established enrichment facility. The most like candidate would be the Russian IUEC at Angarsk. Russia is already heavily involved in the Iranian nuclear industry and is looking for more participants in its IUEC facility. Once the Iranian enrichment program is capable of sustaining itself and member states, participation in the IUEC would end.

The time for a multilateral solution to Iran's nuclear ambitions is running out. The United States and her allies imposed a very tough round of sanctions on Iran in 2010 hoping to take advantage of domestic political unrest in Iran. If these sanctions are unable to stop Iran's progress in its enrichment program, it is likely that no amount of achievable sanctions will. A solution to the Iranian problem will require the West to move away from its hardline position of no enrichment facilities on Iranian soil. Focus will then shift to developing sustainable mechanisms to gain the necessary oversight of Iran's nuclear programs to ensure proliferation is prevented.

9 - Conclusions

Renewed interest in nuclear energy as a means to cope with rapidly increasing energy demand, especially in the developing world, has caused concern over the possibility of a global spread in nuclear weapons. Over 50 developing countries have expressed interest in introducing nuclear power into their electricity grid. Developing states must decide the best course of action for them to acquire the fuel cycle services needed to operate their fleet of nuclear power plants. The pursuit of domestic nuclear fuel cycles is an alternative to the established commercial market for fuel cycle services. Of particular concern are enrichment and reprocessing facilities and technologies which can be used to produce the material needed for nuclear weapons. A large number of these states interested in developing nuclear industries have a high degree of political corruption or low level of political stability. There is a growing consensus that the current nuclear non-proliferation regime will be unable to adequately suppress the spread of nuclear weapons if projections concerning nuclear power expansion are correct. I set out to analyze the potential effectiveness of various proposed multilateral arrangements to the nuclear fuel cycle in curbing the spread of sensitive fuel cycle technologies and managing nuclear material. The three case studies in this thesis have provided valuable insight into determining the primary motivations for the establishment of fuel cycle facilities and how multilateral arrangements can be employed to strengthen the non-proliferation regime. To be successful, it is not necessary for the arrangements to stop the development of new enrichment and reprocessing facilities. The spread of nuclear weapons can be minimized by using multilateral facilities to better manage nuclear material and increase international oversight into the industry. The first observation is that states have various incentives to develop fuel cycle facilities, and there will not be a single multilateral arrangement that is able to effectively respond to every state's motivations. Certain important trends have emerged however.

Supply Assurances

In all of the three case studies, supply assurances do not have the ability to address any of the important motivations for pursuing sensitive nuclear fuel cycle technologies. There is a potential exception of a spent-fuel take back arrangement for South Korea because political difficulties have prevented South Korea from implementing a spent fuel management plan. Reprocessing is currently one of the options being considered. If South Korea can negotiate with another state an agreement to export its nuclear fuel, the South Koreans would lose all defendable motivations for the pursuit of reprocessing facilities. That being said, Brazil and Iran have exhibited little interest in developing plans for the back-end of the fuel cycle. This I consistent with small and young nuclear power programs that do not yet feel the pressure to develop a solution to back-end of the fuel cycle. Fuel leasing and take-back arrangements may not be as beneficial to these states as the current literature would suggest.

The effectiveness of the established commercial market to offer supply assurances is most apparent in South Korea. South Korea has an extremely well developed nuclear power infrastructure and is on very good relations with all major enrichment suppliers around the world. South Korea is also actively partnering with foreign entities to become self-sufficient in uranium mining and enrichment. Any multilateral arrangements offering additional supply assurances would be redundant. Supply assurances are also unlikely to dissuade Brazil from advancing its enrichment program. Brazil is fully capable, both materially and technologically, to have an independent nuclear fuel cycle. No matter the arrangement, supply assurances cannot be as strong as the ability for Brazil to completely manage its own fuel supply. In Iran, supply assurances can alleviate some of the economic motivations behind the

pursuit of an enrichment facility but they cannot address Iran's primarily political motivations for pursuing an enrichment facility.

It is important to note that these conclusions are to a great extent a function of the particular states chosen for the case studies. Brazil and Iran have established domestic enrichment facilities, while South Korea has had a large nuclear power industry since the 1980s. Supply assurances are surely aimed toward new nuclear power states that do not have much market power and have not yet decided to develop enrichment facilities. This thesis does find that supply assurances are still important contributors for the establishment of multilateral facilities, especially regional nuclear fuel cycle facilities. States are unlikely to participate in a regional nuclear fuel cycle where they are not a technology or real estate holder of the facility. Supply assurances can provide these states guarantees that they will not lose fuel supply in the event that regional tensions or disagreements cause a politically motivated disruption. That being said, supply assurances deal almost exclusively with the economic motivations to pursue enrichment facilities. As states develop their nuclear programs and become more industrialized, there are a variety of politically motivated reasons for pursing fuel cycle technology that may or may not be related to nuclear weapons.

Multilateral Facilities

In Brazil, enrichment technology is not only used to provide security of supply for the developing nuclear power infrastructure, it is also being used to improve Brazil's international standing and prestige. The fact that Brazil's enrichment facility has proprietary technology that is 100% Brazilian in nature extends its claim for national prestige. Brazil will not abdicate its rights to its enrichment facility for both economic and political reasons. Multilateral arrangements can however play off Brazilian motives to become a regional hegemon and leader among the developing world. The current enrichment program serves these needs well but a multilateral facility presents an opportunity to significantly further these aims. Promoting regional cooperation in the nuclear fuel cycle and technologies would strengthen Brazil's leadership positions among its neighbors. The Western world would support these actions because they can reduce potential nuclear tensions in the region and provide a good example of a collection of states taking initiative to control and monitor fuel cycle technologies. If portrayed properly, the developing world would see the Brazilian initiative as offering a strong alternative to the discriminatory practices offered by the West. Brazil has before said that it believes regional solutions to safeguards and regulatory structures make more sense than the NPT, especially from the standpoint of enforcement. Brazil provides a great example in which multilateral arrangement provide little to no economic benefit for the host state, but can provide large political opportunities. To be successful, Brazil would need to be the state making the proposal to its regional neighbors. It is unclear if the proposal would be openly welcomed by the region, but given the amount of cooperation present in economic and political endeavors, it seems probable. The proposal can be benefitted by including some confidence building measures, such as placing the fuel cycles facilities in an extraterritorial region (similar to the MESP proposal) and by obtaining outside supply assurances for all participating members. No other multinational facility arrangement could successfully take advantage of Brazil's politically inclined motives.

Iran has much more complicated motives for its enrichment facility than Brazil. Most importantly, Iran seems highly interested in developing nuclear weapons, while Brazil ended this pursuit in 1991. Multilateral arrangements by themselves will not be able to provide enough incentive for Iran to discontinue their nuclear weapons program. Negotiations would need to include a variety of political and economic issues that are not directly related to Iran's enrichment facility, which Iran hopes to use a bargaining chip. If an appropriate package can be formed that provides Iran with a series of benefits, Iran may take the opportunity instead of risking further political repercussions. Multilateral arrangements can be important in these deals for providing non-proliferation assurances to the international community. Iran will not give up the right to an indigenous enrichment facility. Iran has long ratcheted up rhetoric proclaiming its peaceful nuclear program and the discrimination it endures in the international community because of its pursuit. Even if the nuclear program is to remain peaceful, the enrichment facility is a matter of national pride that will not be compromised due to foreign pressure. Geoffrey Forden and John Thompson proposed the establishment of a multilateral enrichment facility with Western participation and technology on Iranian soil to replace the Natanz facility. Support for the plan will be hard to come by as Urenco has already decided not to pursue the venture and Iran will prefer to keep control over its indigenous enrichment facility. A regional multilateral facility in Iran can take advantage of Iran's desire to be a regional superpower and allow Iran the prestige of having an enrichment facility on its soil. The arrangement would increase international oversight into Iran's enrichment program, and assuming the AP is implemented, make the pursuit of nuclear weapons much more difficult for Iran. Regional states would have an incentive to participate in the deal in order to diffuse the regional tensions surrounding Iran's nuclear weapons program. Strong supply assurances would be needed to assuage the supply concerns of regional partners in the facility.

South Korea is in a different position that Brazil and South Korea. Despite its robust economy and technological infrastructure, South Korea is not in position to be a regional hegemon. South Korea appears to have the intent to pursue the capability to develop nuclear weapons but will most likely only do so over the guise of a peaceful nuclear program. South Korea would like to gain security independence from the United States but is not in a position to openly pursue it. South Korea is encountering domestic political opposition to the establishment of spent-fuel storage facilities and is using the argument to validate its pursuit of a reprocessing facility. A multilateral spent-fuel storage facility can remove the argument for pursuing reprocessing and South Korea will most likely drop the issue. The spent-fuel storage facility could be placed in any willing host state, or in an extraterritorial area. Although South Korea does not currently have any plans to develop an indigenous enrichment facility, the incentive to provide supply assurances to potential customers of its nuclear power plants may give South Korea another argument for developing the technologies needed to pursue nuclear weapons. A multilateral facility can address these concerns. South Korea and a collection of its customer states can jointly develop an enrichment facility similar to the current Urenco and Eurodif models. A facility could also be setup in an extraterritorial area, similar to the MESP proposal. South Korea may appear to be in a unique situation here as most suppliers of nuclear technology are already in possession of enrichment facilities. This is not entirely true however, states such as Australia and Canada which are large suppliers of natural uranium have an incentive to move up the value chain in the

nuclear fuel cycle and construct an enrichment facility. An enrichment partnership (MESP or Consortium) amongst these states and South Korea could present interesting commercial opportunities.

While supply assurances focus on delegitimizing the economic claims to enrichment facilities, multilateral facilities have a more diverse range of applications. It is true that multilateral facilities are still intended to reduce the economic incentives for enrichment facilities but the most useful aspect of multilateral facilities arises because of their ability to address non-economic incentives. Nuclear power and technologies are often viewed as a gateway to first world politics and national prestige. As long as enrichment and reprocessing technologies are treated as forbidden by the international community, this perspective is unlikely to change. Regional fuel cycles are advantageous over other variations of the multilateral facility proposal. Not only does a technology leader gain prestige within the region, but the regional nuclear fuel cycle can foster stronger relations among close neighbors. Regional cooperation in nuclear technology can be an important step in reducing the likelihood of a potentially dangerous technological or nuclear arms race. In addition to supply assurances, having the enrichment facility established in the same form as the MESP arrangement would be a strong confidence building measure.

Multilateral spent-fuel storage facilities have the abilityl to be large contributors to the non-proliferation regime. As the nuclear power programs of states begin to age, the political pressure to develop long-term solutions to nuclear waste will become stronger. A reprocessing facility is not attractive from an economic standpoint but states may look toward the dual-use nature of the technology as an incentive to pursue reprocessing in the plans. A multilateral spent-fuel storage facility would remove all defensible motives for pursuing reprocessing technologies.

Fuel Cycle Restructuring

Fuel Cycle Restructuring proposals aim to alter the global organization of fuel cycle services. None of the three states studied would look very positively on these proposals, at least in the short term. Fuel Cycle Restructuring proposals do not offer any commercial benefits and, unlike the Multilateral Facility proposals, are politically unable to reinforce some of the primary incentives for pursuing enrichment facilities. In fact, Fuel Cycle Restructuring proposals operate to remove the political incentives to develop fuel cycle facilities from the equation. The exclusive and privileged nature of fuel cycle technologies would be removed and replaced with a global structure denying all states the ability to nationally control fuel cycle facilities. The national prestige and pride associated with fuel cycle facilities would be lost. Brazil and Iran would be heavily opposed to these proposals because they would make their investment in enrichment facilities not worthwhile. South Korea would be indifferent to the proposals because it is unclear if they are capable of providing any economic benefits to South Korea. Furthermore, all of these states may not like these proposals because they near permanently restrict the ability for non-nuclear weapons states to pursue weapons if they so desired. This may make these proposals unobtainable unless current nuclear weapons states, all states including those not member to the NPT, commit to the nuclear disarmament they have agreed to in Article VI of the NPT. The developing world, including Brazil and Iran, would certainly stand behind the current status of the NPT, arguing that Fuel Cycle Restructuring arrangements would further enhance technological discrimination.

It is not to say these proposals are unobtainable, in the long term they may actually result from a natural progression in the multilateralization of the nuclear fuel cycle. If a few regions are successful in establishing regional nuclear fuel cycles, the proposed Russian Global Nuclear Power Infrastructure arrangement may only be a few legal and structural changes away from realization. Given enough time, the states who have established regional nuclear fuel cycles would be willing to cooperate on a global scale as most of the benefits to national prestige come from the establishment and short term management of such an organization, not its long term operation.

10 - References

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