NATIONAL DECISION MAKING AND NUCLEAR FUEL CYCLES: AN ANALYSIS OF INFLUENCES

A Thesis
Presented to the Faculty
of
The Fletcher School of Law and Diplomacy
by
JAMES EDWARD PLATTE
In partial fulfillment of the requirements for the
Degree of Doctor of Philosophy
FEBRUARY 2013

Dissertation Committee
WILLIAM C. MARTEL, Chair
WILLIAM MOOMAW
ROBERT L. PFALTZGRAFF, JR.

CURRICULUM VITAE

EDUCATION

Tufts University, Fletcher School of Law and Diplomacy

Medford, Massachusetts

Doctor of Philosophy, International Relations Sep 2006-Feb 2013

- Dissertation title: “National Decision Making and Nuclear Fuel Cycle: An Analysis of Influences.”
- PhD Summer Research Award from Fletcher School. Conducted field research in India on the development of Indian nuclear fuel cycle policy through archival research, interviewing key individuals from the government, private sector, and academia, during August 2011.
- Student Summer Thesis Research Grant from Hitachi Center for Technology and International Affairs. Conducted field research in Japan on the development of Japanese nuclear fuel cycle policy through archival research, interviewing key individuals from the government, private sector, and academia, and touring the Rokkasho nuclear facility during June and July 2011.
- U.S. Department of State Critical Language Scholarship for intensive Korean language study at Kyung Hee University in Suwon, South Korea during summer 2007.
- Coursework GPA: 3.93 out of 4.00.

Sogang University Korean Language Education Center

Seoul, South Korea

Korean Language for Foreigners Program Dec 2008-Aug 2009

- Graduated from program by completing levels 4 through 6 (of six total levels)

George Washington University, Elliott School of International Affairs

Washington, District of Columbia

Master of Arts, Science, Technology and Public Policy Sep 2003-May 2005

- Studied abroad at Graduate School of International Studies, Ewha Womans University in Seoul, South Korea during spring 2004 semester.
- Coursework GPA: 3.64 out of 4.00.

University of Michigan, College of Engineering

Ann Arbor, Michigan

Master of Science in Engineering, Nuclear Engineering Sep 2001-Dec 2002

- U.S. Department of Energy Advanced Accelerator Applications Fellow
- Master's Project: "Spectral Unfolding with STAYSL Using an Accelerator-Driven System."
- Coursework GPA: 7.25 out of 9.00 (equivalent to 3.66 out of 4.00).

University of Michigan, College of Engineering

Ann Arbor, MI

Bachelor of Science in Engineering, Nuclear Engineering Sep 1997-Apr 2001

- Graduated *Cum Laude*.
- Coursework GPA: 3.25 out of 4.00.

ACADEMIC EXPERIENCE

Council on Foreign Relations

Tokyo, Japan

International Affairs Fellow in Japan, sponsored by Hitachi Ltd. Oct 2012-

- Conducting research on Japanese energy policy, particularly nuclear energy and fuel cycle policy, and perceptions of energy security in the wake of the accident at the Fukushima Daiichi Nuclear Power Plant in March 2011. Hosted by the Institute of Energy Economics, Japan.

Harvard Kennedy School

Cambridge, Massachusetts

Stanton Nuclear Security Predoctoral Fellow Sep 2011-Aug 2012

- Research fellow with International Security Program/Project on Managing the Atom, Belfer Center for Science and International Affairs, Harvard Kennedy School. Conducted research and writing several chapters of doctoral dissertation as a predoctoral fellow during the 2011-12 academic year. Presented research plan at Stanton Nuclear Security Fellows Seminar in October 2011 in Washington, DC. Conducted dissertation field research in South Korea during November 2011. Gave two seminars on results of research at Harvard Kennedy School during spring 2012 semester.

Tufts University, Fletcher School of Law and Diplomacy

Medford, Massachusetts

Teaching Assistant Jan 2011-May 2011

- Teaching assistant for Professor Sung-Yoon Lee’s courses titled "North Korean State and Society," and "International Relations of The United States and East Asia: 1945 to the Present." Responsibilities included assisting Prof. Lee in preparing and distributing lecture materials, replying to student inquiries, participating in classroom discussions, and grading written final exams. Delivered impromptu presentations on the accident at the Fukushima Daiichi nuclear power plant in Japan after the Great East Japan Earthquake on March 11, 2011.

Project on Managing the Atom

Cambridge, Massachusetts

Student Associate Sep 2006-May 2007, Jan 2008-Jun 2008

- Worked with Professor Matthew Bunn. Wrote profiles of Southeast Asian countries that have expressed interest in developing a civilian nuclear power industry, including those countries’ nuclear energy policies, goals, and current nuclear research and infrastructure. Assisted with Project’s regular update of *Securing the Bomb* and Nuclear Threat Initiative website.

University of Michigan, College of Engineering

Ann Arbor, Michigan

Graduate Student Instructor Jan 2003-May 2003

- Instructor for Nuclear Engineering and Radiological Sciences 211, the introductory nuclear engineering course for non-majors. Authored and graded homework assignments along with aiding the authoring of quizzes, exams, and the term project. Taught weekly one hour discussion section and administered periodic quizzes in the section. Helped maintain course website that contained online homework assignments, reading assignments, course schedule, announcements, and other resources for students.

Los Alamos National Laboratory

Los Alamos, New Mexico

Graduate Student Research Assistant Jun 2002-Aug 2002

- Conducted master’s research at Los Alamos National Laboratory's Neutron Science Center. Master’s research part of an effort that studied the use of particle accelerators in nuclear waste management. Assisted in proton irradiation of lead-bismuth eutectic spallation target. Performed gamma spectroscopy of neutron activated foils that were placed on target. Analyzed activation data using spectral unfolding code STAYSL. Evaluated performance of computer models of the irradiation experiment based on STAYSL results.

PROFESSIONAL EXPERIENCE

U.S. Department of Defense

Washington, District of Columbia

Counterproliferation Analyst Jul 2008-Dec 2010

- Selected as a Pat Roberts Intelligence Scholar in 2008 and studied Korean at Sogang University in Seoul, South Korea from December 2008 to August 2009 under auspices of program. Worked as a counterproliferation analyst from September 2009 to December 2010. Provided timely, actionable analysis in the form of written reports and oral presentations to meet customer needs and fulfill requests. Monitored daily news and reported information in order to keep internal database updated and analyze short and long term trends to inform customers' situational awareness. Conducted long-term, all-source strategic research on current and historical proliferation issues to fill information gaps and answer customer requirements.

The Wisconsin Project on Nuclear Arms Control

Washington, District of Columbia

Intern Aug 2004-May 2005, Mar 2006-May 2006

- Used open sources to research entities confirmed of conducting activities to aid the proliferation of weapons of mass destruction (WMD) and/or terrorism, particularly exporters and importers. Aided updating and maintaining Risk Report database of WMD proliferation entities. Monitored breaking news stories related to WMD and terrorism to write brief summaries for Risk Report. Wrote concise primers describing the physics and technology behind WMD and their delivery systems.

National Nuclear Security Administration

Washington, District of Columbia

Nonproliferation Graduate Program Intern Jun 2005-Feb 2006

- Worked on the Highly Enriched Uranium Transparency Program (HEU-TP). Provided support for resolving technical and logistical issues with the Blend Down Monitoring System (BDMS) used to verify the elimination of excess highly enriched uranium from the Russian stockpile. Drafted correspondence to Rosatom and other programmatic materials on BDMS activities. Tracked monthly contractor and laboratory spending and overall program budget. Interacted with staff from multiple laboratories to coordinate activities and give headquarters guidance.

University of Michigan Washington DC Office

Washington, District of Columbia

Assistant to the Director of Federal Relations for Research Sep 2003-Dec 2003

- Reviewed and analyzed fiscal year 2004 appropriations legislation with a focus on those containing funding for the Department of Energy Office of Science and science and technology programs in the Department of

Homeland Security. Advocated scientific issues to the Michigan Congressional delegation. Assisted the director with coordinating inter-university efforts via the Association of American Universities and other academic associations. Attended Congressional hearings and provided summaries to the University community.

Westinghouse Electric Company

Monroeville, Pennsylvania

Core Technologies Intern May 2001-Aug 2001

- Created optimal fuel rod placement patterns for a 17 by 17 rod array nuclear fuel assembly with different burnable neutron absorbers. Performed cost analysis studies for implementing Erbia as a burnable neutron absorber. Studied the effects of using a larger diameter fuel rod. Developed equilibrium cycle reactor core patterns for a standard four loop reactor core.

Michigan Ion Beam Laboratory

Ann Arbor, Michigan

Research Assistant Nov 1999-Aug 2000

- Assisted nuclear engineering graduate students with research regarding the effects of radiation on various materials. Aided with the installation of a new ion source. Designed new radiation shielding around the beam line to accommodate use of the new, stronger ion source. Aided lab manager in the maintenance and operation of the beam and accelerator.

CONFERENCES AND SEMINARS

International Security Brown Bag Seminar

Cambridge, Massachusetts Apr 2012

- Presenter: "Nuclear Fuel Cycle Decision-Making: An Analysis of Influences"

Project on Managing the Atom Seminar Series

Cambridge, Massachusetts Jan 2012

- Presenter: "Japanese Nuclear Fuel Cycle Decision Making"

Fletcher School Japan Roundtable

Medford, Massachusetts Nov 2011

- Presenter: "Japan's Nuclear Energy Policy Before and After 3/11"

Fletcher Doctoral Conference

Medford, Massachusetts Sep 2011

- Presenter: "Japan's Quest for 'Semi-National' Energy Resources: Motivations and Implications"

Fletcher Doctoral Conference

Medford, Massachusetts Oct 2010

- Organizer: “The Nexus Between Nuclear Power and Nuclear Proliferation”

PUBLICATIONS

- Platte, James, Ernesto Pitruzzella, Youssef Shatilla, and Baard Johansen. “Implementation of Erbia with ZrB_2 in 17x17 Assemblies for a 4-loop core with a 24-month cycle.” *Proceedings of the Tenth International Conference on Nuclear Engineering*. Washington DC, 2002.
- Platte, James E. “Northeast Asia’s Nuclear Future.” *The Fletcher Forum of World Affairs*, April 1, 2012, http://www.fletcherforum.org/2012/04/01/platte/.

ABSTRACT

This study examines the factors that influence national decisions about developing nuclear fuel cycle technology, and the central question for this study is why countries have developed different national nuclear fuel cycles. Prospect theory is used as the basis of an analytical framework for studying nuclear fuel cycle decision making. In essence, prospect theory states that nations are risk averse when in a gains domain and risk acceptant when in a losses domain. This study hypothesizes that a country's nuclear fuel cycle decision making is determined by the frame of reference and domain (either gains or losses) and that security concerns are a factor driving policy behind all nuclear programs.

A structured, focused comparison of Indian, Japanese, and South Korean nuclear fuel cycle decision making was conducted in order to test the hypotheses. Major nuclear fuel cycle decisions made between approximately 1950 and 1990 in each country were analyzed. The results verified this study's hypotheses. Decisions were mostly made according to the tenets of prospect theory, and security concerns (national security or energy security) were a driver for the nuclear programs in all three countries. The study also emphasized that nuclear fuel cycle technology is strategic and highly valued by countries and that national leaders are involved with making major nuclear fuel cycle decisions.

Prospect theory proved to be a more powerful analytical tool than existing theories of nuclear weapons proliferation. Prospect theory accounts for a country's capabilities, intentions, and situational and temporal context. In this way, prospect theory gives a holistic view of how all nuclear technologies fit into

strategic interests and how a country's leadership's frame of reference with regard to strategic interests influences the direction of nuclear fuel cycle decision making. Prospect theory on its own does not offer a model or predictor of nuclear fuel cycle technology development, but it illuminates how leaders viewed nuclear fuel cycle decisions and why certain decisions were made.

I dedicate this dissertation to my parents, Dana and Gayle Platte, for their unending love and support.

ACKNOWLEDGEMENTS

I am deeply grateful for the support, assistance, and encouragement that I received during my approximately six and a half years in the doctoral program at the Fletcher School. First, I would like to thank my thesis adviser, William Martel, for his enthusiastic guidance and helping me better understand prospect theory, decision making, leadership, and technology policy making. My other two committee members, William Moomaw and Robert Pfaltzgraff, also provided valuable advice and assistance during the crafting of my dissertation. I am thankful to Jenifer Burckett-Picker and the rest of the administration at the Fletcher School for keeping me on track, even when I got distracted with other endeavors.

In order to carry out my research, I received gracious grants from the Fletcher School PhD Program and from the Hitachi Center for Technology and International Affairs in 2011. The Stanton Foundation funded my predoctoral fellowship with the International Security Program/Project on Managing the Atom (MTA), Belfer Center for Science and International Affairs, Harvard Kennedy School during the 2011-12 academic year. During my time with MTA, I learned much from Steven Miller, Matthew Bunn, Martin Malin, and the other staff, and the fellowship gave me much needed time and space to write the bulk of my dissertation.

I am indebted to Sung-Yoon Lee for being a personal mentor, supporter, and indulger of my musings on North Korea. During my time at the Fletcher School, I was fortunate to be surrounded by a wonderful, supportive group of

friends in the Boston area (in no particular order): Grace C., Ivan, Wilfred, Kei, Katsuya, Sungyeol, Courtney, Joon, Seoho, Sooyeon, Takuya, Guktae, Mark, Grace K., Jong-yun, Mike, and Jeff, among many others. The personal and professional relationships that I formed while a PhD student at the Fletcher School are what made this process truly worthwhile and memorable. Finally, I thank my family in Michigan for all of their love.

TABLE OF CONTENTS

1. INTRODUCTION

As with any other source of energy, nuclear power uses a fuel cycle in order to produce electricity. There are general steps in the front and back ends of the nuclear fuel cycle that are shared by all types of nuclear power plants; however, it would be an oversimplification to say that there is a single "nuclear fuel cycle." Different types of nuclear power plants can use different types of fuel that require diverse fuel fabrication steps at the front end of the cycle, and the waste produced at the back end of the cycle can be dealt with in various ways. Therefore, different nuclear plants, companies, and countries around the world employ similar, but distinct, nuclear fuel cycles.

Given the high cost of building nuclear facilities and the civilian and military dual nature of nuclear energy, governments have been intimately involved with the development and use of nuclear power. Indeed, many critical decisions regarding the nuclear fuel cycle have been made at the national government level and will continue to be for the foreseeable future. The international nature of the nuclear fuel and technology markets and the military applications of nuclear technology also mean that national nuclear decisions often have implications for a country's foreign policy.

This study examines the factors that influence national decisions about developing a nuclear fuel cycle. In addition, the risks involved with particular decisions regarding a nuclear fuel cycle will be explored, and three country cases – India, Japan, and South Korea – will be studied in this regard. Prospect theory will be utilized in this study to delve into how countries, particularly the three country cases, make these decisions in the context of their domestic and international frames. Many factors, such as national goals, economic conditions, security concerns, and regional relations, determine a country's frame of reference.

This research is important because nuclear politics, whether regarding nuclear weapons or civilian power, continues to play a major role in international affairs. Thus, understanding how and why countries have developed certain nuclear fuel cycle policies can help to understand how countries interested in developing some level of indigenous nuclear capacity will set their nuclear fuel cycle policies.

1.1 Research Questions and Hypotheses

The central question for this study is why countries have developed different national nuclear fuel cycles. This question will be answered by using prospect theory in the context of a technical understanding of the nuclear fuel cycle to form the basis for an analytical framework. Research will then focus on determining the frame of reference associated with important decisions during the development of a country's nuclear fuel cycle.

Based on the central question stated above, three main research questions and corresponding hypotheses will drive this study. This research will first attempt to demonstrate that countries do indeed develop differing nuclear fuel cycles at the national level. Second, it will examine the factors that drive policy, with a particular focus on security concerns that influence the development of national nuclear fuel cycle policies, primarily by determining a country’s frame of reference as described in prospect theory.

Q1: Do countries develop and employ distinctly different national nuclear fuel cycles?
H1: Countries establish nuclear fuel cycle policy at the national government level, and different countries do develop and employ different nuclear fuel cycles based on their national policies and interests or goals.

The indicators of developing distinctly different nuclear cycles should be relatively straightforward to identify: purchasing different steps of the nuclear fuel cycle on the international market, using different fuel types and reactor designs, using an open or closed fuel cycle, etc. The more important part of this question is demonstrating that the major decisions regarding a country’s nuclear cycle policy are made at the national government level and not at the local government level or by the private sector.

Q2: Does the frame of reference in which a country views itself and a country's context guide the development of its nuclear fuel cycle policy?
H2: A country’s decisions regarding nuclear fuel cycle policy are determined, in large part, based on that country’s frame of reference (in terms of gains and losses frames described by prospect theory), while the frame of reference is determined by various factors, such as a country’s economic and security

situation, relations with major powers and status in the international community, technological capability, etc.

Q3: Is a large-scale nuclear program, and the related nuclear fuel cycle, ever purely civilian in nature, or is there always a military or security-related aspect to a nuclear program?
H3: Security concerns, be it defined traditionally in terms of national security or in terms of economic security, are always a primary driver of starting and maintaining a nuclear program, even if the program does not include developing nuclear weapons. This is due to the technological experience that a country gains through operating a large-scale nuclear program.

Once the first question is answered, I will proceed to explore how countries arrive at differing nuclear fuel cycle policies. By using prospect theory, question two will explore the factors that explain the differences and similarities between the nuclear fuel cycles employed in different countries. Finally, question three will examine whether security is the common, primary driver among countries that have developed large-scale nuclear programs.

Null Hypotheses

1. Different countries do not develop distinct national nuclear fuel cycle policies.

2. There is no relation between a country's frame of reference (in terms of gains and losses frames described by prospect theory) and its nuclear fuel cycle policy.

3. Security is not always a primary driver behind developing a nuclear fuel cycle, and there are countries that have purely civilian nuclear programs.

1.2 Problem Background and Context

Nuclear science is still a relatively young field, essentially having its origins in the twentieth century. However, in just over a hundred years, nuclear science has had a tremendous impact on the world, and a brief overview of the history and development of nuclear weapons and power will demonstrate this. This will also set the stage for a more in-depth examination of the steps in the nuclear fuel cycle.

1.2.1 Development of Nuclear Weapons

The first country to embark upon developing a nuclear fuel cycle was the United States. During World War II, the United States made it a national priority to produce nuclear weapons, which required the production of fissile material in some type of nuclear reactor, through the Manhattan Project. There are two main routes to producing fissile material, uranium enrichment and reprocessing spent nuclear fuel to recover plutonium, and the United States choose both routes by setting up a uranium enrichment facility at Oak Ridge, Tennessee and a plutonium production facility at Hanford, Washington. Even during the exclusively military-oriented Manhattan Project, the dual nature of the nuclear fuel cycle and technology was demonstrated by the fact that the B Reactor built at Hanford was the first large scale nuclear power plant in the world.[1]

The Manhattan Project culminated with the dropping of nuclear bombs on the Japanese cities of Hiroshima and Nagasaki, on August 6, 1945 and August 9, 1945, respectively. The bomb used on Hiroshima, dubbed "Little Boy," used uranium enriched at Oak Ridge, and the Nagasaki bomb, called "Fat Man," used plutonium produced at Hanford. Immediately after the end of World War II, the United States enjoyed a monopoly on nuclear weapons, but this situation would not last long.

On August 29, 1949, the Soviet Union became the second member of the nuclear club by detonating a plutonium bomb that was an exact copy of Fat Man. The Soviets had used plutonium production reactors, the first nuclear reactors in Europe, similar to the ones at Hanford to produce the fissile material for their first weapons.[2] In October 1952, the United Kingdom successfully conducted its first nuclear weapon test, also by using a plutonium bomb,[3] and France followed suit by detonating a plutonium device in February 1960.[4] The People's Republic of China became the first country to have its initial nuclear test be of a uranium device when it successfully conducted a test on October 16, 1964.

These first five members of the nuclear weapons club are collectively referred to as the "P5" and are coincidentally the five permanent members of the

---

[1] "B Reactor," U.S. Department of Energy Hanford Site, last modified December 9, 2012, http://www.hanford.gov/page.cfm/BReactor.

[2] Carey Sublette, "The Soviet Nuclear Weapons Program," last modified 12 December 1997, http://nuclearweaponarchive.org/Russia/Sovwpnprog.html.

[3] "Our History," Atomic Weapons Establishment, accessed December 28, 2012, http://www.awe.co.uk/aboutus/our_history_f77a4.html.

[4] Carey Sublette, "France's Nuclear Weapons – Origin of the Force de Frappe," last modified December 24, 2001, http://nuclearweaponarchive.org/France/FranceOrigin.html.

UN Security Council. The P5 were recognized as the only legal nuclear weapons states with the ratification of the Treaty on the Non-Proliferation of Nuclear Weapons, otherwise known as the Non-Proliferation Treaty (NPT), in 1970.[5] However, the NPT did not put a halt to the spread of nuclear weapons, and India, Israel, South Africa, Pakistan and the Democratic People's Republic of Korea (DPRK, otherwise known as North Korea) all developed nuclear weapons after the NPT was ratified. South Africa has since relinquished their nuclear arsenal.

Interestingly, only China, South Africa, and Pakistan used enriched uranium as the fissile material in their first weapons, and the other seven nuclear states started off with plutonium devices. In general, plutonium has seemed to be the fissile material of choice for building nuclear weapons, despite requiring a more difficult implosion design than an enriched uranium gun assembly design.[6] Using plutonium or enriched uranium for a weapons program is, of course, a good example of a nuclear fuel cycle decision, which will be explained in more detail in section 3.

An overview of the history of nuclear weapons would be incomplete without mentioning thermonuclear weapons, which were first developed by the United States in the early 1950s. Today, the P5 all possess thermonuclear weapons, and India claimed that it tested a thermonuclear device during a series

---

[5] "Treaty on the Non-Proliferation of Nuclear Weapons," United Nations Office for Disarmament Affairs, accessed December 28, 2012, http://www.un.org/disarmament/WMD/Nuclear/NPTtext.shtml.

[6] The first U.S. nuclear test on 16 July 1945 at Alamogordo, New Mexico, called "Trinity," was of a plutonium implosion device called the "gadget," which was similar in design to Fat Man. However, the first nuclear weapon used in combat, Little Boy, used uranium in a gun assembly design that Manhattan Project scientists were so confident in that they did not believe that it required testing.

of nuclear tests in May 1998.[7] Thermonuclear weapons utilize both nuclear fission and fusion in a multi-stage device. The fission stage or stages are typically implosion devices that use either plutonium or uranium, but the fusion stage typically uses lithium deuteride. Since the production of fusion fuels, such as lithium deuteride, differs significantly from the production of fissile materials and nuclear fusion has yet to be developed into a commercially viable form of energy, thermonuclear weapons and fusion power will not be covered in this paper.

1.2.2 Current Status of Nuclear Weapons

The spread of nuclear technology after the end of World War II led former U.S. President John F. Kennedy to predict that by the 1990s, over 20 countries would possess nuclear weapons.[8] However, the nuclear weapons situation in the world today is much different than the one predicted by Kennedy. In addition to the P5, India, Israel, Pakistan, and the North Korea all currently possess nuclear weapons, but South Africa, Belarus, Ukraine, and Kazakhstan all gave up nuclear arsenals. That means that the total number of nuclear weapons states in the world today is nine. Table 1.1 summarizes the current estimated arsenals of the nuclear weapons states.[9] It should be noted that the table shows the total warhead inventory, including both deployed and reserve warheads.

---

[7] Carey Sublette, "What Are the Real Yields of India's Tests?" last modified November 8, 2001, http://nuclearweaponarchive.org/India/IndiaRealYields.html.

[8] International Atomic Energy Agency, *The IAEA's Safeguards System: Ready for the 21st Century* (Vienna: International Atomic Energy Agency, 1997), under "Introduction," http://www.iaea.org/Publications/Booklets/Safeguards2/intro.html.

[9] "Status of World Nuclear Forces," Federation of American Scientists, last modified December 18, 2012, http://www.fas.org/programs/ssp/nukes/nuclearweapons/nukestatus.html.

COUNTRY	ESTIMATED INVENTORY
China	240
France	300
India	80-100
Israel	80
North Korea	<10
Pakistan	90-110
Russia	8,500
United Kingdom	225
United States	7,700
World	**17,300**

Table 1.1 – World Nuclear Weapons Arsenals

Many other countries had or were suspected of having nuclear weapons programs during the twentieth century, such as Argentina, Brazil, Iraq, Libya, South Korea, and Taiwan. Other countries, such as Japan and many of the ones just listed, have large, advanced civilian nuclear industries that could give them the capability to produce fissile material and/or nuclear weapons in the future. The United States and the European Union both suspect that Iran is pursuing nuclear weapons and using its developing civilian nuclear industry only as a cover. Regardless of Iran's intentions, the proliferation and dual nature of nuclear technology make it certainly possible that the number of nuclear weapons states could grow in the years ahead.

1.2.3 Development of Nuclear Power

As mentioned previously, the first large-scale nuclear reactors made in the world were used for producing weapons-grade fissile material during the Manhattan Project. Thus, from the very beginning, nuclear power and nuclear weapons have been connected to each other. However, the use of nuclear energy for civilian purposes does have its own distinct history.

On December 20, 1951, the dawn of nuclear power occurred when the Experimental Breeder Reactor-I (EBR-I) located near Arco, Idaho produced enough electricity during an experiment to light up four light bulbs. The primary goal of EBR-I was not to produce electricity but to demonstrate the potential of breeding nuclear fuel in a reactor,[10] and scientists did calculate that the EBR-I design was indeed breeding new fuel at the same rate that the reactor consumed fuel.[11] Despite this accomplishment, breeder reactors have not had commercial success, and the United States has not been able to employ a breeder fuel cycle in the civilian nuclear power industry.

The Soviet Union became the first country to connect a nuclear reactor to a power grid on June 26, 1954 when a five megawatt reactor went online in the Russian town of Obninsk.[12] The first industrial-scale nuclear power station, Calder Hall, opened in 1956 in Sellafield, England and was fueled with natural uranium.[13] On December 18, 1957, the first commercial nuclear reactor in the United States, the Shippingport Atomic Power Station in Pennsylvania, began

---

[10] All uranium-fueled nuclear reactors inherently produce plutonium during reactor operation. Since both uranium and plutonium can be used as nuclear fuel, a nuclear reactor could theoretically create new fuel to replace, or exceed, the initial fuel loading in what is known as a breeder reactor.

[11] "Experimental Breeder Reactor No. 1," Idaho National Laboratory, accessed December 28, 2012, http://www.inl.gov/ebr/.

[12] "From Obninsk Beyond: Nuclear Power Conference Looks to Future," International Atomic Energy Agency, last modified February 18, 2011, http://www.iaea.org/NewsCenter/News/2004/obninsk.html.

[13] "Calder Hall Power Station," *The Engineer*, October 5, 1956, http://www.theengineer.co.uk/journals/pdf/21835.pdf.

producing electricity.[14] The Shippingport reactor was a pressurized water reactor (PWR), a type of light water reactor (LWR), and PWRs have subsequently become the dominant nuclear reactor design in the United States.

In addition to the military and civilian nuclear programs of the P5, nuclear technology spread rapidly to other countries throughout the 1950s and 1960s, and during the 1960s, civilian programs began to appear in countries such as Canada, Japan, and India. Many other countries, both in the industrialized and developing world, embarked on nuclear research and development (R&D) and made ambitious plans for building nuclear power plants. The spread of nuclear technology was helped in part by U.S. President Dwight D. Eisenhower's Atoms for Peace program, and the International Atomic Energy Agency (IAEA) and the European Atomic Energy Community (EURATOM) were both established in the 1950s with the goal of promoting the peaceful uses of nuclear energy.

The oil crisis in 1973 that caused a global economic recession and more emphasis on energy conservation also helped to boost the nuclear industry. Many countries looked to decrease their dependence on oil for energy, and nuclear power was looked to as an alternative source for electricity production. Countries like Japan and France decided to nearly altogether stop using oil for electricity generation and turned to nuclear power as the country's dominant source of electricity. Installed nuclear capacity around the world reached 100 gigawatts by the late 1970s, doubled to 200 gigawatts in the mid-1980s, and had reached 300

---

[14] "Historic Achievement Recognized: Shippingport Atomic Power Station, A National Historic Mechanical Engineering Landmark," American Society of Mechanical Engineers, accessed December 28, 2012, http://files.asme.org/ASMEORG/Communities/History/Landmarks/5643.pdf.

gigawatts by the end of the 1980s.[15] The majority of reactors built during this growth phase were some form of light water reactor, either pressurized water reactors or boiling water reactors, and this factor has played a large role in shaping the nuclear fuel cycle in many countries.

However, rising economic costs of nuclear power in the 1970s and 1980s led to a curtailing of the industry's growth, and the currently installed global capacity stands around 370 gigawatts.[16] In addition to the economic factors, the accidents at Three Mile Island in 1979 and at Chernobyl in 1986 aroused suspicions and fears concerning the safety of nuclear plants, and anti-nuclear public sentiment have negatively affected the nuclear industry in many countries. No new nuclear plants have been ordered in the United States since 1978, and much of the growth in the industry has been confined to East Asia, particularly China.

There does appear to be renewed interest in nuclear power in the United States and around the world. As concerns about global climate change caused by the emission of greenhouse gases during the combustion of fossil fuels grow, many countries are looking to carbon free sources of energy, such as nuclear power, to generate electricity. In addition, dependence on fossil fuels from politically unstable regions and predictions about a looming peak in global oil production are making countries think about looking at alternative sources of energy.

---

[15] "50 Years of Nuclear Energy," International Atomic Energy Agency, accessed December 28, 2012, http://www.iaea.org/About/Policy/GC/GC48/Documents/gc48inf-4_ftn3.pdf.

[16] "Nuclear Power Capacity Trend," International Atomic Energy Agency, last modified December 28, 2012, http://www.iaea.org/PRIS/WorldStatistics/WorldTrendNuclearPowerCapacity.aspx.

The U.S. Department of Energy's (DOE) Office of Nuclear Energy is overseeing various R&D programs aimed at creating new technologies for the advancement of nuclear power. Among them are the Advanced Fuel Cycle Initiative (AFCI), the Global Nuclear Energy Partnership (GNEP), and Nuclear Power 2010.[17] In addition, the United States is partnered with Argentina, Brazil, Canada, China, EURATOM, France, Japan, Russia, South Africa, South Korea, Switzerland, and the United Kingdom in the Generation IV International Forum (GIF), which is working to develop the next generation of nuclear reactors.[18] There are also domestic U.S. and international efforts, such as ITER,[19] to develop commercially viable nuclear fusion power systems, but these fusion systems are drastically different from fission reactors and, as with thermonuclear weapons, are outside the scope of this paper.

1.2.4 Current Status of Nuclear Power

Currently, 30 countries operate 437 civilian nuclear power reactors that provide over 13 percent of the world's electricity. In addition, about 240 nuclear research reactors are in use in 56 countries.[20] Table 1.2 lists the number of reactors in operation and the share of electricity generated by nuclear power

---

[17] "Our Programs," U.S. Department of Energy Office of Nuclear Energy, accessed December 28, 2012, http://www.ne.doe.gov/nePrograms.html.

[18] "GIF Membership," Generation IV International Forum, accessed December 28, 2012, http://www.gen-4.org/GIF/About/membership.htm.

[19] ITER is a cooperative effort between China, EURATOM, India, Japan, Russia, South Korea, and the U.S. to develop a fusion reactor using a tokamak design, which employs magnetic confinement fusion. ITER originally stood for International Thermonuclear Experimental Reactor, but the program is now simply known as ITER. For more information, see http://www.iter.org.

[20] "Nuclear Power in the World Today," World Nuclear Association, last modified April 2011, http://www.world-nuclear.org/info/inf01.html.

plants in 2011 for the P5 and other select countries.[21] Of the nuclear power plants currently in operation, 272 (about 62 percent) are PWRs, and another 84 are BWRs (about 19 percent), which means that LWRs comprise over 80 percent of the power reactors in operation today and account for about 88 percent of total installed capacity.[22]

COUNTRY	OPERATIONAL REACTORS	NUCLEAR SHARE OF ELECTRICITY (2011)
Brazil	2	3%
Canada	20	15%
China	16	2%
Finland	4	32%
France	58	78%
Germany	9	18%
India	20	4%
Japan	50	18%
Pakistan	3	4%
Russia	33	18%
South Korea	23	35%
Sweden	10	40%
Ukraine	15	47%
United Kingdom	16	18%
United States	104	19%
World	**437**	**13%**

Table 1.2 – Operational Reactors and Nuclear Share of Electricity in 2011

There has been noteworthy growth in the global nuclear power industry in recent years, especially considering the dreary state of the industry during the

---

[21] For a full list of numbers of nuclear reactors and share of nuclear-generated electricity by country, see "Operational & Long-Term Shutdown Reactors – By Country," International Atomic Energy Agency, last modified December 28, 2012, http://www.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx; and "Nuclear Share of Electricity Generation in 2011," International Atomic Energy Agency, last modified December 28, 2012, http://www.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx.

[22] "Operational & Long-Term Shutdown Reactors – By Type," International Atomic Energy Agency, last modified December 28, 2012, http://www.iaea.org/PRIS/WorldStatistics/OperationalReactorsByType.aspx.

1990s. Sixty-four reactors are currently under construction worldwide, as summarized in Table 1.3.[23] China is often cited as the driver behind the recent growth in nuclear power, but there are also significant numbers of plants under construction in Russia and India. Although small in number, the plants under construction in Finland Slovakia will increase their already relatively high shares of nuclear-generated electricity.[24]

COUNTRY	REACTORS UNDER CONSTRUCTION	ELECTRICAL CAPACITY (MW)
Argentina	1	692
Brazil	1	1,245
China	26	26,620
Finland	1	1,600
France	1	1,600
India	7	4,824
Japan	2	2,650
Pakistan	2	630
Russia	11	9,297
Slovakia	2	782
South Korea	4	4,980
Ukraine	2	1,900
United Arab Emirates	1	1,345
United States	1	1,165
World	**64**	**61,930**

Table 1.3 – Nuclear Power Reactors under Construction

As with currently operating reactors, the majority of reactors under construction are PWRs, but some of the reactors under construction are of different designs, such as fast breeder reactors (FBR), pressurized heavy water

---

[23] "Under Construction Reactors," International Atomic Energy Agency, last modified December 28, 2012, http://www.iaea.org/PRIS/WorldStatistics/UnderConstructionReactorsByCountry.aspx.

[24] For more information on future plans for nuclear power reactor construction around the world, see "Plans for New Reactors Worldwide," World Nuclear Association, last modified August 2012, http://www.world-nuclear.org/info/inf17.html.

reactors (PHWR), and light water-cooled graphite-moderated reactors (LWGR). These non-PWRs will require somewhat different nuclear fuel cycles than is typically used for PWRs. Regardless of the reactor design or fuel cycle, nuclear power will clearly continue to play an important role in meeting the world’s increasing demand for electricity.

2. LITERATURE REVIEW

There are many options in the nuclear fuel cycle that countries can and have chosen. To highlight this point, consider that only Argentina, China, Russia, and the United States have developed domestically each step at the front end of the cycle (from mining and milling to fuel fabrication).[1] Of those four countries, only Russia performs all steps in its nuclear fuel cycle, including spent nuclear fuel reprocessing, exclusively at domestic facilities, while the other three buy some services on the international market to augment domestic capabilities.[2] Another example is the fact that 30 countries operate nuclear power reactors, but just nine countries, including two countries that do not operate civilian power reactors (Israel and North Korea), have nuclear weapons. Clearly, significantly different decisions have been made regarding the nuclear fuel cycle by countries across the world. Of particular concern is whether a country has decided to develop uranium enrichment and spent nuclear fuel reprocessing technology (ENR technology) and whether a country decides to develop a fuel cycle for military or civilian use (or both).

The question is why have these different decisions been made? What risks do countries perceive to be associated with nuclear power, in general, and specifically with each step of the nuclear fuel cycle? How can the nuclear fuel cycle decision making process be analyzed? First, existing theories and models of nuclear weapons proliferation will be reviewed with a view toward whether these

---

[1] International Atomic Energy Agency, *Country Nuclear Fuel Cycle Profiles*, 2nd ed. (Vienna: International Atomic Energy Agency, 2005), 11-12, http://www-pub.iaea.org/MTCD/publications/PDF/TRS425_web.pdf.

[2] *Country Nuclear Fuel Cycle Profiles*, 13-17.

models can be applied to explain nuclear fuel cycle decision making, especially the decisions concerning ENR technology.

Next, a decision making theory called prospect theory will be introduced. Prospect theory has gained attention for potential application in international relations and also could be useful for analyzing nuclear fuel cycle decision making if existing models of nuclear weapons proliferation prove insufficient analytically. Some of the major literature regarding prospect theory will be reviewed in this section, including criticisms of its application to international relations. Finally, this section will provide a brief technical overview of the nuclear fuel cycle in order to provide a basis for the analysis in this study.

2.1 Theories of Nuclear Weapons Proliferation

Given the connection between nuclear fuel cycle technology, particularly uranium enrichment and spent nuclear fuel reprocessing (“ENR technology”), and nuclear weapons, it seems prudent to review existing theories of nuclear weapons proliferation. Reviewing these theories could help give insight into nuclear fuel cycle decision making, as well as test the ability of prospect theory to describe this decision making. If prospect theory is to provide a framework for nuclear fuel cycle decision making analysis, then it must perform better than the existing theories of nuclear weapons proliferation. This section will review some of the major theories of nuclear weapons proliferation.

2.1.1 Sagan’s Three Models

Scott D. Sagan wrote a now classic article with three models that describe why countries pursue nuclear weapons. Sagan started by stating a traditionally held view regarding nuclear weapons proliferation: “Many U.S. policymakers and most international relations scholars have a clear and simple answer to the proliferation puzzle: states will seek to develop nuclear weapons when they face a significant military threat to their security that cannot be met through alternative means; if they do not face such threats, they will willingly remain non-nuclear-states.”[3] This sums up a common assumption in the proliferation literature that states naturally want to develop nuclear weapons, and it leads into Sagan’s first model of why states pursue nuclear weapons.

Sagan’s first model is dubbed the “security model” and stems from neorealist theory. Neorealism assumes that states exist in an anarchic system and that states must rely on themselves to guarantee sovereignty and national security. Based on this, the security model claims, “…any state that seeks to maintain its national security must balance against any rival state that develops nuclear weapons by gaining access to a nuclear deterrent itself.” Accordingly, the security model predicts that strong states “…can pursue a form of internal balancing by adopting the costly, but self-sufficient, policy of developing their own nuclear weapons” and that weak states “…can join a balancing alliance with a nuclear power, utilizing a promise of nuclear retaliation by that ally as a means of extended deterrence.”[4]

---

[3] Scott D. Sagan, “Why Do States Build Nuclear Weapons? Three Models in Search of a Bomb,” *International Security* 21, no. 3 (Winter 1996/97): 54.

[4] Sagan, 57-63.

The picture of proliferation drawn here is a simple proliferation begets proliferation. As Sagan points out, though, this appears to be an oversimplification of the issue, and this has led to analysts working backwards from when a country crosses the nuclear threshold to find what security threat must have caused the original decision. A more rigorous analysis of the factors that drive a decision to develop nuclear weapons leads to Sagan's second model, the "domestic politics model."

Sagan's domestic politics model states that the acquisition of nuclear weapons can "…serve the parochial bureaucratic or political interests of at least some individual actors within the state." Such actors can include "…the state's nuclear energy establishment…important units within the professional military…and politicians in states in which individual parties or the mass public strongly favor nuclear weapons acquisition." These actors "…create the conditions that favor weapons acquisition by encouraging extreme perceptions of foreign threats, promoting supportive politicians, and actively lobbying for increased defense spending." This counters the security model by stating that security threats are "…not the central cause of weapons decisions…they are merely windows of opportunity through which parochial interests can jump."[5]

Sagan dubbed his third model the "norms model." As opposed to the previous two models, the norms model claims that state behavior is determined "…by deeper norms and shared beliefs about what actions are legitimate and appropriate in international relations." Simply, this model focuses on the shift in global norms concerning nuclear weapons before and after the signing of the Non-

---

[5] Sagan, 63-73.

Proliferation Treaty (NPT) in 1968. Before 1968, developing and testing nuclear weapons were viewed as sources of state power, legitimacy, and prestige, but after 1968, norms started to shift to shunning the development and testing of nuclear weapons. Sagan summarizes this shift as going "…from the 1960s notion of joining 'the nuclear club' to the 1990s concept of joining 'the club of nations adhering to the NPT.'"[6]

2.1.2 Models Involving Domestic Politics and Identity

In a recent book, Jacques E. C. Hymans stated that the following points constitute an emerging scholarly consensus on proliferation studies.[7]

1. Proliferation has been historically rare.
2. The demand for nuclear weapons cannot be taken for granted.
3. Domestic politics and identity considerations play crucial roles in shaping proliferation choices.
4. Theory-guided, in-depth comparative case studies are the most appropriate means of advancing the state of knowledge on proliferation at this time.

Etel Solingen made a major contribution to the third point above. Solingen attempted to create a model that demonstrated that how national leaders seek to gain and maintain power provides important information regarding nuclear decisions. Essentially, Solingen's model centers on two contrasting political economy philosophies. First, "…leaders advocating economic growth

---

[6] Sagan, 73-85.

[7] Jacques E.C. Hymans, "The Study of Nuclear Proliferation and Nonproliferation: Toward a New Consensus?" in *Forecasting Nuclear Proliferation in the 21st Century: Volume 1. The Role of Theory*, ed. William C. Potter and Gaukhar Mukhatzhanova (Stanford, CA: Stanford University Press, 2010), 15.

through integration in the global economy ('internationalizing models' henceforth) had incentives to avoid the costs of embarking on nuclear weapons programs."[8] Second, "…leaders relying on inward-looking bases of support had greater tolerance – and in some cases strong incentives – for developing nuclear weapons."[9] Solingen summarized this model thus, "whereas inward-looking models might have regarded nuclear weapons programs as assets in the arsenal of building a regime's legitimacy and prestige, outward-oriented ones thwarted such latent utility."[10] A point of Solingen's model that seems to relate to prospect theory is that her model is "…about the way in which leaders define the very nature of their states' place in the global political economy and associated institutions."[11] The proposition that a leader's conception of a state's place in the world influences nuclear decision making was explored further by Hymans in a separate work.

In *The Psychology of Nuclear Proliferation*, Hymans states "…some political leaders hold a conception of their nation's identity that leads them to desire the bomb; and such leaders can be expected to turn that desire into state policy."[12] Hymans uses a concept that he terms "national identity conception (NIC)" to describe why some leaders choose to pursue nuclear weapons and other leaders do not pursue nuclear weapons. The NIC is a leader's "…sense of *what*

---

[8] Etel Solingen, "Domestic Models of Political Survival: Why Some Do and Others Don't (Proliferate)," in *Forecasting Nuclear Proliferation in the 21st Century: Volume 1. The Role of Theory*, ed. William C. Potter and Gaukhar Mukhatzhanova (Stanford, CA: Stanford University Press, 2010), 40.

[9] Solingen, 40-41.

[10] Solingen, 41.

[11] Solingen, 42.

[12] Jacques E.C. Hymans, *The Psychology of Nuclear Proliferation: Identity, Emotions, and Foreign Policy* (New York: Cambridge University Press, 2006), 1.

the nation naturally stands for and of *how high it naturally stands*, in comparison to others in the international arena [emphasis in original].”[13] The others in that definition refers to “key comparison others,” which are “…outgroups that serve as the primary basis for ingroup self-definition…”[14]

Regarding the question of for what the nation naturally stands, Hymans states that there are “oppositional” and “sportsmanlike” conceptions. The former stems from “…starkly dichotomizing identity conceptions...,” and the latter comes from “…other identity conceptions that nest the us-them distinction within a broader, transcendent identity conception.”[15] Regarding the question of how high the nation naturally stands, Hymans gives nationalists and subalterns. Nationalists believe “…the nation can hold its head high in dealings with its key comparison other(s)…,” and subalterns do not necessarily think “…their nations could or even should hold equal status with their key comparison others.”[16] Thus, the four NICs are sportsmanlike nationalist, oppositional nationalist, sportsmanlike subaltern, and oppositional subaltern.

Hymans proposes that only oppositional nationalists are driven by both fear (the oppositional aspect) and pride (the nationalist aspect), and for this reason, only oppositional nationalists will decide to pursue nuclear weapons. For oppositional nationalist leaders, “…the decision to acquire nuclear weapons is not only a means of getting them; it is also an end in itself, a matter of self-

---

[13] Hymans, *The Psychology of Nuclear Proliferation*, 18.
[14] Hymans, *The Psychology of Nuclear Proliferation*, 21.
[15] Hymans, *The Psychology of Nuclear Proliferation*, 22-23.
[16] Hymans, *The Psychology of Nuclear Proliferation*, 24.

expression."[17] The emphasis here is on the decision to acquire nuclear weapons, not necessarily the actual development of the weapons themselves. Other intervening factors may ultimately lead to not acquiring nuclear weapons, but the "…top-down political decision to go nuclear is the most significant, and indeed unavoidable, step along the way to the acquisition of nuclear weapons."[18]

Hymans does comment briefly on the applicability of the NIC model to nuclear decision making other than the decision to pursue nuclear weapons. He considers the decision to pursue nuclear weapons a revolutionary one, a typical "big" decision, but he cautions about extending this to other nuclear decision making. "Ancillary nuclear decisions are less revolutionary – less 'big' – than the decision to acquire the bomb itself."[19] Hymans suggests that other conventional political science or economic theories could be used to explain these ancillary nuclear decisions. This is an important point to keep in mind when attempting to apply the NIC model to this study's analysis of nuclear fuel cycle decision making

2.1.3 Technology Development Models

An important point to keep in mind when reviewing these proliferation models is that they are all concerned with decision making regarding nuclear weapons, but this study is concerned with decision making regarding nuclear fuel cycle technology. Applying proliferation models may implicitly assume that all fuel cycle technology, particularly ENR technology, is related to nuclear weapons

---

[17] Hymans, *The Psychology of Nuclear Proliferation*, 36.
[18] Hymans, *The Psychology of Nuclear Proliferation*, 44.
[19] Hymans, *The Psychology of Nuclear Proliferation*, 37.

proliferation. There certainly are some parallels because all states that desire nuclear weapons must also develop or acquire ENR technology in order to produce fissile material, but the existence of these parallels does not necessarily mean that weapons proliferation models also can explain the decision to develop ENR technology.

Some scholars have attempted to explain some of the decision making specifically regarding the development of ENR technology. James Acton points out that economic models alone are insufficient in explaining nuclear energy policy making. "Nuclear-energy policy…necessarily involves weighing up incommensurable variables."[20] In addition to economics and energy security, Acton cites prestige, nuclear-weapons hedging, and "received wisdom," which is defined as "…the assumed belief, often based on the actions of other states, that a given nuclear technology is too lucrative to be missed."[21] Acton claims that received wisdom can explain the shift in norms related to ENR technology in the mid-1970s. Prior to 1976, the United States promoted the development of ENR technology, and all U.S.-aligned states during that time had plans to develop ENR technology. However, when Washington changed its policy in 1976 and began to oppose the spread of ENR technology (partly in response to India's nuclear test in 1974), then many states dropped their ENR technology development plans, with a notable exception of Japan.

William Walker wrote that the development of large technological systems can have an entrapment effect. Walker writes that the natural

---

[20] James M. Acton, "Nuclear Power, Disarmament and Technological Restraint," *Survival* 51, no. 4 (August-September 1999): 104.

[21] Acton, 105.

development of technology necessitates that some technologies and technology paths must be discarded for the sake of economic progress. However, in the case of complex products and infrastructures that take long periods of time to development, "…the unfit can attract huge investment and can survive long after they should have been sent to the grave."[22] Walker continues, "All innovation and all entrepreneurial activity entails commitment which is risk's necessary bedfellow."[23] ENR technology is an example of such complex products and infrastructure that can entrap a state, and Walker cites the example of the United Kingdom's reprocessing program persisting despite undesirable economics. The very decision to develop a complex system like ENR technology can entrap a state and make the political, bureaucratic, and economic costs of withdrawal from that system very high.

2.1.5 Test/No-Test vs. SQ/No-SQ

Although not directly related to the actual decision making, the idea of when a state becomes a nuclear weapons state has some relevance to this study on nuclear fuel cycle decision making. Traditionally, a state was considered to have crossed the nuclear threshold and become a nuclear weapons state after its first successful test of a nuclear weapon. This was the test/no-test standard for determining nuclear weapons state status. However, Hymans points out that many scholars and analysts wished to go one step back from the testing stage to avoid strategic surprise. This led to the standard of whether a state had

---

[22] William Walker, "Entrapment In Large Technology Systems: Institution Commitment and Power Relations," *Research Policy* 29 (August 2000): 834.
[23] Walker, 834.

accumulated enough fissile material for a nuclear weapon, otherwise known as significant quantity (SQ). Thus, the current trend is to measure nuclear weapons states on the SQ/no-SQ standard.[24]

Hymans lists four critiques of the SQ/no-SQ standard of declaring when a state becomes a nuclear weapons state.[25]

1. Avner Cohen and Benjamin Frankel asserted that Israel's "opaque proliferation" (i.e., becoming an accepted nuclear weapons state without testing) marked the beginning of a second wave of proliferation. Hymans doubts that this mode of proliferation would be appealing to other states aspiring to achieve nuclear weapons state status, and the examples of India, Pakistan, and North Korea seem to support Hymans belief. Thus, the SQ/no-SQ standard may not apply to other proliferant states.
2. The SQ/no-SQ standard allows a much wider range of potential interpretations and political misinterpretations due to the difficulty in observing the measure in states.
3. The SQ/no-SQ standard underestimates the political and technical obstacles that must be overcome between achieving SQ and producing operational nuclear weapons.
4. The SQ/no-SQ standard may possibly encourage proliferation by reducing the barriers of entry into nuclear weapons states club.

---

[24] Jacques E.C. Hymans, "When Does a State Become a 'Nuclear Weapons State'? An Exercise in Measurement Validation," in *Forecasting Nuclear Proliferation in the 21st Century: Volume 1. The Role of Theory*, ed. William C. Potter and Gaukhar Mukhatzhanova (Stanford, CA: Stanford University Press, 2010), 102-103.

[25] Hymans, "When Does a State Become a 'Nuclear Weapons State'?" 111-112.

What makes this argument relevant to this study is that a state's acquisition or development of ENR technology would give that state the capability to produce fissile materials and allow that state to surpass the SQ standard. According to the SQ/no-SQ standard, this would make that state a de facto nuclear weapons state. However, the SQ/no-SQ standard does not say much about a state's intentions. Purely civilian development of ENR technology thus could unfairly dub that state a nuclear weapons state, when in fact that state had no intentions of ever developing nuclear weapons. Hymans is right to point out the problems associated with moving to a SQ/no-SQ standard for determining the difference between nuclear weapons state and non nuclear weapons states. Maintaining the test/no-test standard is good from a technical viewpoint, but the real test should lie in analyzing the intentions, motivations, and decisional factors behind a state's decision to pursue or not pursue fuel cycle technology development. That is precisely the goal of this study.

2.2 Prospect Theory

Prospect theory first appeared in the late 1970s in the work of social psychologists Daniel Kahneman and Amos Tversky, who were seeking to create a new theory to explain experimental results that were inconsistent with expected-utility theory. In essence, Kahneman and Tversky found that people tend to be risk averse in choices among gains but risk acceptant with respect to losses.[26] For

---

[26] Rose McDermott expounds on risk by writing, "Risk is inherent in any situation where there is uncertainty, and even more so when the stakes are high or the prize is big," and she defines decisions as "…the times when people are forced by the demands of time constraints, the complexity of the task, or the dimension of the stakes to stop, take conscious stock of the available

example, their experimental results showed that if people were presented with a choice between a 50/50 chance of getting $0 or $100 and a certain $40, then about 70 percent would choose the certain $40. On the other hand, if people are given a choice between a certain $40 loss and a 50/50 chance of losing $0 or $100, then roughly 70 percent would choose the 50/50 gamble. Thus, people are more willing to take risks to avoid losses and less willing to take risks for gains.[27]

Prospect theory would argue that people "…overvalue losses relative to comparable gains…" and that "…the pain of losses exceeds the pleasure from gains…," which Jack Levy defines as loss aversion.[28] Levy writes that loss aversion then leads to the endowment effect, which says that "…people tend to value what they have more than comparable things that they do not have, and the psychological cost of relinquishing a good is greater than the psychological benefit of acquiring it."[29] These two phenomena lead to a core analytic assumption of prospect theory, reference dependence. This means that "…people appear to be more sensitive to changes in assets than to net asset levels, to gains and losses from a reference point rather than to levels of wealth and welfare."[30]

---

options, and make a best guess as to which choice will lead to the most desired outcome." These considerations are important for this study because, as McDermott notes, "Virtually every important decision involves some element of risk. When confronted with a problem of what to do in a given situation, a decision maker is first faced with the problem of deciding which factors should influence his choice." Rose McDermott, *Risk-Taking in International Politics: Prospect Theory in American Foreign Policy* (Ann Arbor, MI: University of Michigan Press, 2001), 3.

[27] Jack S. Levy, "Loss Aversion, Framing Effects, and International Conflict: Perspectives from Prospect Theory," in *Handbook of War Studies II*, ed. Manus I. Midlarsky (Ann Arbor, MI: University of Michigan Press, 2000), 195.

[28] Levy, 194.

[29] There is also an instant endowment effect, in which people "…'renormalize' their reference points after gains but not after losses, and they do so very quickly." The result is that people adjust to gains more rapidly than to losses. See Levy, 195.

[30] Levy, 194.

The reference point that people make for themselves is called their frame,[31] and "…a change in preference and choice as a result of a change in frame is a framing effect."[32] Additionally, Jeffrey Berejekian points out, "…there is a diminishing value from continual increases in gains."[33]

Kahneman and Tversky went on to spell out two phases that people go through in the decision making process. The first phase is the editing phase, where a person "…identifies the reference point, the available options, the possible outcomes, and the value and probability of each of these outcomes."[34] Second is the evaluation phase during which a person "…combines the values of possible outcomes…with their weighted probabilities…and then maximizes over the product (the 'prospective utility')."[35,36]

2.2.1 Prospect Theory in National Decision Making and International Relations

Throughout the previous section, prospect theory was described in terms of individuals. Indeed, prospect theory was first developed as "a descriptive

---

[31] The action of selecting a frame is called framing, and this action should be considered a variable. "…[M]ost important prospect theory hypotheses involve the explanation of variations in outcomes as a function of variations in the framing of the reference point." See Levy, 197.

[32] Levy, 195.

[33] Jeffrey Berejikian, "The Gains Debate: Framing State Choice," *American Political Science Review* 91, no. 4 (December 1997): 790.

[34] Levy, 198-199.

[35] Levy, 199.

[36] It is worth noting that Kahneman and Tversky modified standard prospect theory with cumulative prospect theory. The major changes in cumulative prospect theory are: "1) the carriers of value are gains and losses, not final assets; and 2) the value of each outcome is multiplied by a decision weight, not by an additive probability." The result is a theory that states that individuals have "…risk-averse and risk-seeking preferences, respectively, for gains and for losses of moderate or high probability…" and favor "…risk seeking for small probabilities of gains and risk aversion for small probabilities of loss, provided the outcomes are not extreme." See Amos Tversky and Daniel Kahneman, "Advances in Prospect Theory: Cumulative Representation of Uncertainty," *Journal of Risk and Uncertainty* 5 (1992): 299-306.

model of individual decision making under risk."[37] This leads to three of the biggest concerns regarding the application of prospect theory to national decision making or international relations. First, Robert Jervis noted that replicating Kahneman and Tversky's experimental results in national decision making situations will be difficult because the risks and utility of various options are often vague. Second, Levy pointed out that national policy decisions are made under conditions of uncertainty, rather than in prospect theory where decisions are made under risk. Third, Eldar Shafir made the observation that prospect theory is a model of individual decision making, but national policy decisions are typically made by groups.[38,39]

Expanding on the first and second points of criticism mentioned in the above paragraph, William Boettcher comments that analysts are left with the difficult task of determining risk and utility based on non-numerical data. In the realm of international relations, an analyst must often "…interpret verbal expressions of probability that are known to be quite variable."[40,41]

---

[37] William A. Boettcher, III, "Context, Methods, Numbers, and Words: Prospect Theory in International Relations," *The Journal of Conflict Resolution* 39, no. 3 (September 1995): 562.

[38] Boettcher, 566.

[39] Jervis adds that "…units composed of many individuals appear more irrational than individual decision makers for several reasons: governments or coalitions that pursue contradictory goals, organizational or institutional incapacity in strategy choice, alternation of different groups (with different preference orderings) in power, and the possibility of cycling." See Miles Kahler, "Rationality in International Relations," *International Organization* 52, no. 4 (Autumn 1998): 930.

[40] Boettcher, 566.

[41] Boettcher even proposes a hypothesis related to this issue that demonstrates the potential problems associated with assigning numerical value to verbal indicators of risk. "The framing of a foreign policy problem will affect numerical estimates of verbal probabilities: in the domain of gains, the decision maker will tend to deflate numerical estimates of the verbal probabilities associated with the potential success of risky options; in the domain of losses, the decision maker will tend to deflate numerical estimates of the verbal probabilities associated with the potential failure of risky options." See Boettcher, 569.

Related to the third point of criticism, many scholars have pointed out that individuals can vary in their decision making behavior. With regard to framing, Levy challenges the assumption that framing is exogenous and states that "…under some circumstances framing might be endogenous…one's preference for a certain outcome might influence how one frames the choice problem."[42] In addition to preference, differences in personality can influence decision making. Rose McDermott, James Fowler, and Oleg Smirnov state, "Bold individuals take the risky choice…[i]n contrast, meek individuals always choose the safe option, which nets them a sure-thing increase in their payoff."[43]

Paul Kowert and Margaret Hermann's research concluded that there are at least four types of ways that people respond to risk. Individuals can:

1. be risk averse in the face of gains and risk acceptant in the face of losses,
2. be both risk and frame invariant,
3. be willing to take risks, primarily when one has something to gain, or
4. be risk averse in general, especially when facing a loss.[44]

Kowert and Hermann also state that some individuals may "…set unusually low reference points such that most of their decisions occur in the domain of gains," yet others "…may tend to set high or ambitious reference points. Their risk acceptant behavior in what seems to be the domain of gains may actually reflect a

---

[42] Levy, 213.

[43] They also assert that prospect theory "…represents a comprehensive module of human preference concerning risk…and would prove highly resistant to change or learning through experience or education over time." In other words, prospect theory describes behavior that is difficult to alter but could be manipulated by policymakers and leaders. See Rose McDermott, James H. Fowler, and Oleg Smirnov, "On the Evolutionary Origin of Prospect Theory Preferences," *The Journal of Politics* 70, no. 2 (April 2008): 342-347.

[44] Paul A. Kowert and Margaret G. Hermann, "Who Takes Risks? Daring and Caution in Foreign Policy Making," *The Journal of Conflict Resolution* 41, no. 5 (October 1997): 625.

perceived failure to meet these ever-higher new standards. As a result, "…behavior that appears to run counter to the predictions of prospect theory…may be indicative of subjects whose reference points place them in the opposite frame."[45]

Also with regard to the third point of criticism, Barbara Vis counters Shafir's implication that it would be problematic to apply prospect theory to decision making by groups. The problem of analyzing collective decision making is called the *aggregation problem*, but in her analysis of collective decision making in welfare state reform, Vis cites studies that demonstrate that "…organizations facing losses take larger risks, just as individuals facing losses do."[46] Based on her meta-analysis, Vis concludes that there is "…a high degree of correspondence between the results for studies in which the individual is the unit of analysis or those in which a group is."[47] Vis also points out that the aggregation problem can be circumvented in cases where "…an individual decision is so dominant in decision-making that the collective decision is in effect an individual decision."[48] Thus, the aggregation problem may not be a significant problem.

Even with these acknowledged concerns, scholars have utilized prospect theory to analyze national and foreign policy decision making and come to some general conclusions about state behavior. Vis offers an argument for why prospect theory can serve as a theoretical alternative to rational choice theory.

---

[45] Kowert and Hermann, 631-632.
[46] Barbara Vis, *Politics of Risk-taking: Welfare State Reform in Advanced Democracies* (Amsterdam: Amsterdam University Press, 2010), 120.
[47] Vis, 110.
[48] Vis, 119.

Prospect theory has a micro-foundation because it assumes that individuals are self-interested actors, but the theory also assumes that the environment around decision makers shapes their perception of alternatives and decision making. Thus, prospect theory "…offers a micro-foundation but allows preferences to be shaped by factors…at the macro-level as well…"[49] This departs from expected utility theory's principle of methodological individualism.

Vis also states that prospect theory differs from rational choice or other international relations theories in that prospect theory's predictions are dynamic and adjust to a changing environment. She writes, "When the external environment and hence the domain changes, prospect theory would predict a different outcome."[50] For example, prospect theory is able to deal with changes like escalating commitments and sunk costs.

Regarding political leaders, Levy writes that they may seek to prevent a decline in national or personal reputation than to increase reputation by a comparable amount, and political leaders sometimes frame around expectations or aspirations, rather than the status quo, which creates reference point bias.[51] Likewise, McDermott, Fowler, and Smirnov claim that "…leaders are reluctant to accept a sure loss to their own political power and thus are willing to take risky actions such as war to avoid such a loss."[52] Even in the economic realm, while examining economic restructuring in Latin America, Kurt Weyland concluded that Latin American presidents implemented risky shock programs over gradual,

---

[49] Vis, 117.
[50] Vis, 122.
[51] Levy, 201-202.
[52] McDermott, Fowler, and Smirnov, 346.

less costly reform strategies because "…newly elected presidents cannot let economic deterioration continue without endangering their political survival."[53] How political leaders and nations frame themselves seems to the key starting point to using prospect theory for assessing national and foreign policy decision making.

Unlike neorealism that claims countries pursue relative gains or neoliberalism that assumes countries pursue absolute gains,[54] prospect theory states that a country's preference for relative or absolute gains is not predetermined but is determined by how a country frames its current condition, which can vary for different issues.[55] According to Jeffrey Berejekian, determining a country's frame for a particular issue, such as nuclear fuel cycle policy, is crucial for also ascertaining a country's preference for relative or absolute gains. This is because he states that a country in a gains frame pursues absolute gains and is risk averse, but a country in a losses frame pursues relative gains and is risk acceptant.[56] This postulate is really just an extension of prospect theory from individuals to countries, but it demonstrates the importance of determining a country's frame and reference point.

---

[53] Kurt Weyland, "Risk Taking in Latin American Economic Restructuring: Lessons from Prospect Theory," *International Studies Quarterly* 40 (1996): 186.

[54] Additionally, Tversky and Kahneman point out that prospect theory differs from traditional theories that assume rationality in that prospect theory "…is proposed as a descriptive, not a normative theory." They conclude that their research shows that, contrary to traditional rational economic theory, "…people can spend a lifetime in a competitive environment without acquiring a general ability to avoid framing effects or to apply linear decision weights" and that "…human choices are orderly, although not always rational in the traditional sense of the word." See Tversky and Kahneman, 317.

[55] Jeffrey Berejikian and John Dryzek assert that any general theory of state choice, be it realist or liberalist, must establish preference prior to choice, unlike prospect theory, because such theories "…deduce preferences from characteristics argued to be inherent and permanent features of anarchic systems." See Jeffrey Berejikian and John S. Dryzek, "Reflexive Action in International Politics," *British Journal of Political Science* 30, no. 2 (April 2000): 197-198.

[56] Berejikian, 795.

Also similar to prospect theory for individuals, Berejekian and John Dryzek propose a theory of state behavior that incorporates both relative and absolute gains. First, a country evaluates the impact of any proposed change to its capacities, and second, the country makes comparisons with potential rivals. In this way, a country determines its preference for absolute or relative gains by putting itself either in a gains frame or a losses frame.[57] Also important to recognize in this model is that how a country perceives itself (e.g., great power, regional power, predator, prey, friend, etc.) and views other countries in these terms is significant in identifying that country's frame and reference point.[58]

How states' perceive themselves can also matter during negotiations and other interactions. In terms of framing effect, Peter Carnevale writes that "…with a loss frame, negotiators are risk tolerant thus making fewer concessions and risking nonagreement; with a gain frame, negotiators are risk averse thus making more concessions to get to agreement quickly."[59] Moreover, Berejekian argues that states can use their power to change the frame of other states. "…[I]t is logically possible that the application of power through rewards can also change the target state's social frame from losses to gains and, therefore, its policy goals from relative to absolute gains pursuit."[60]

A final relevant point here about prospect theory is that individuals are predicted to quickly renormalize their reference points after gains but do not

---

[57] Berejikian and Dryzek, 198.
[58] Berejikian and Dryzek, 204.
[59] Peter J. Carnevale, "Positive Affect and Decision Frame In Negotiation," *Group Decision Negotiation* 17 (2008): 52.
[60] Berejikian, 804.

renormalize after losses.[61] However, it can be assumed that, after a change has occurred that alters the status quo, the prior gains or losses frame will persist for some period of time after the change has occurred. The implication for state behavior is that a losses frame is likely to carry on longer than a gains frame after the change to the status quo has occurred, which suggests that a country will take longer to factor losses into its reference point than gains.[62]

2.3 Technical Overview of the Nuclear Fuel Cycle

While this dissertation is not a technical analysis of the nuclear fuel cycle, it is important to understand the nuclear fuel cycle and the technology used in the nuclear fuel cycle. A general understanding of the technical aspects of the nuclear fuel cycle helps one understand the decisions that can and cannot be made at each step of the nuclear fuel cycle and the technical and policy ramifications of a particular decision. In addition to prospect theory, a technical understanding of the nuclear fuel cycle provides a basis for this study's analytical framework and guides the research methodology.

The overwhelming predominance of LWRs, and PWRs specifically, in the global nuclear power industry may suggest that the same nuclear fuel cycle is used in most countries. However, there are significant differences in the nuclear fuel cycles used in countries around the world, even among those countries that mostly use PWRs, such as the United States and Japan. These differences can be found in either actual variations in the fuel cycle used for producing nuclear

---

[61] Levy, 197.
[62] Berejikian, 792-793.

power or in the steps in the fuel cycle that are performed indigenously and the steps that are purchased on the international nuclear technology market.

A clarification of this point should be made before moving into an examination of the nuclear fuel cycle. For this, suppose that Country A and Country B both have large nuclear power industries. If Country A reprocesses spent nuclear fuel in order to make new fuel and Country B does not reprocess spent fuel, then this is an obvious fuel cycle difference. Now suppose that the nuclear power reactors in Country A and in Country B employ the same nuclear fuel cycle, but Country A enriches uranium domestically and Country B buys enriched uranium on the international market. This situation will also be considered a difference in national nuclear fuel cycles, since government policymakers and industry leaders in both countries came to differing conclusions about whether to establish a domestic uranium enrichment program. Again, the high costs and dual nature of nuclear technology, particularly sensitive technologies like uranium enrichment, often force these types of nuclear fuel cycle decisions to be made at the national level with explicit and extensive government involvement.

Regardless of differences, there are certain general steps in the nuclear fuel cycle that are common to most currently used nuclear power systems: mining and milling, conversion, enrichment, fuel fabrication, electricity generation, spent fuel interim storage, and waste disposal. A major alternative step that can be added between spent fuel interim storage and waste disposal is spent fuel reprocessing, which creates a closed nuclear fuel cycle. Other alternate steps can be taken, and as explained above, most steps in the cycle can be purchased on the international market instead of being performed domestically. The only step that absolutely must be done domestically in order to have a nuclear power industry is electricity generation with nuclear power reactors. Figure 1 portrays a generic flow chart of these steps in the nuclear fuel cycle, and each step is explained in more detail in the following sections.

In Figure 1, the large block arrows represent the civilian nuclear fuel cycle used in the United States, and the thin black arrows represent alternatives to the U.S. nuclear fuel cycle. The current U.S. nuclear fuel cycle is an open once-through cycle because the fuel is used in a rector only once before being disposed of directly. A closed fuel cycle includes reprocessing spent fuel to recover remaining fissile material. The two routes to nuclear weapons, uranium enrichment or spent fuel reprocessing, were both used by the United States in its military nuclear fuel cycle. Also in Figure 1, "Natural U + D_2O" does not mean that natural uranium and heavy water are mixed together. It means that reactor designs, such as Canada Deuterium Uranium (CANDU) reactors, that use natural uranium must use heavy water as a neutron moderator.[63] CANDU reactors are classified as a type of PHWRs.

---

[63] In order to induce nuclear fission in uranium, neutrons must be slowed down to a lower energy state, called "thermal" neutrons, and a moderator is used to thermalize neutrons in a nuclear reactor.

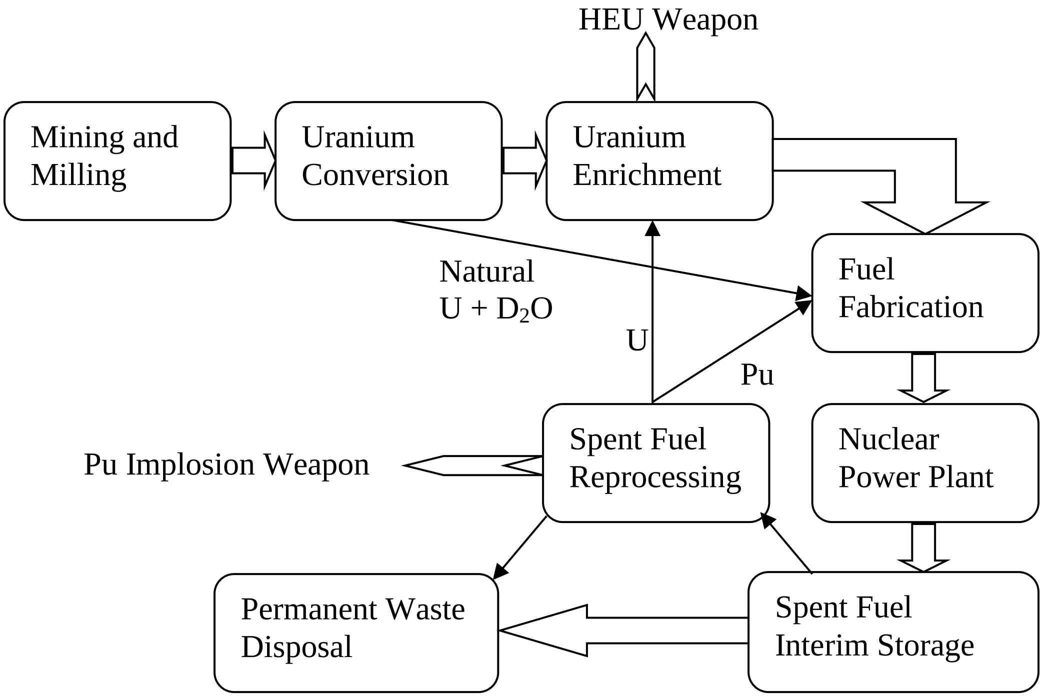

Figure 2.1 – Flow Chart of the Nuclear Fuel Cycle

Legend

D_2O = Deuterium Oxide, also written as ^2H_2O and commonly called "heavy water"[64]
HEU = Highly Enriched Uranium
U = Uranium
Pu = Plutonium

2.3.1 Mining and Milling

A nuclear reactor produces power through harnessing the thermal energy released in nuclear fission.[65] Fissile materials are isotopes[66] that naturally

---

[64] In nature, over 99 percent of hydrogen occurs as ^1H, which means the nucleus consists of just a proton, and most water is ^1H_2O. Deuterium (D) is an isotope of hydrogen that contains a proton and a neutron in the nucleus, so deuterium has roughly twice the atomic weight as hydrogen. Thus, the name "heavy water" is given to D_2O, and H_2O is termed "light water." H_2O and D_2O are chemically similar, but the difference in atomic weight results in different nuclear properties and effects in a nuclear reactor.

[65] Nuclear fission is the splitting of a nucleus into two or more nuclei. In fissile materials, fission can occur when a nucleus is struck by a neutron, and the resulting fission reaction produces new nuclei and loose neutrons and releases energy.

undergo fission, and the isotopes uranium-233 (^{233}U), uranium-235 (^{235}U), and plutoninum-239 (^{239}Pu) are the best fissile materials for use in a nuclear reactor or weapon, although ^{235}U and ^{239}Pu are the most commonly used. Uranium is a naturally occurring metallic element, and plutonium is produced through neutron bombardment and decay of the isotope uranium-238 (^{238}U),[67] which means there are only trace amounts of plutonium found in nature. Since plutonium is produced through ^{238}U decay, the only fissile material that is naturally occurring and can be mined is uranium.

Uranium is a ubiquitous metal in the earth's crust and even can be found in seawater. However, the concentration of uranium in various types of rock and locations differs widely, and depending on the cost of extraction and the price of uranium on the international market, ore must contain a certain concentration of uranium to be considered economically recoverable. High-grade uranium ore contains about 2 percent uranium, and low-grade uranium ore contains about 0.1 percent uranium. As with other metals, certain countries are endowed with more high-grade uranium than other countries. Table 2.1 lists the top five countries in terms of amounts of known recoverable resources of uranium, as of 2011.[68]

Together, these five countries account for 69 percent of the known recoverable resources of uranium, with no other country having more than a 5 percent share of global uranium resources. While the price of uranium has risen lately, the global uranium market is considered more stable than fossil fuel

---

[66] Isotopes are nuclei of the same element that contain different numbers of neutrons.
[67] Isotopes that produce fissile materials, such as ^{238}U, are known as fertile materials.
[68] "Supply of Uranium," World Nuclear Association, last modified August 2012, http://world-nuclear.org/info/inf75.html.

markets, and the large deposits of uranium ore in countries like Australia, Canada, and the United States make the uranium market perceived as more geopolitically stable than Middle Eastern fossil fuels. An effect of rising uranium prices will be that lower grade ores will become economically recoverable.

COUNTRY	TONNES OF URANIUM	WORLD SHARE
Australia	1,661,000	31%
Kazakhstan	629,000	12%
Russia	487,200	9%
Canada	468,700	9%
Niger	421,000	8%
World	**5,327,200**	**100%**

Table 2.1 – Top Known Recoverable Resources of Uranium

Clearly, there are not many choices for countries who are involved in making decisions on this fuel cycle step. Either a country has enough uranium reserves to fuel its nuclear power reactors or it does not. Although, some countries with smaller uranium reserves could still choose to buy some uranium either because buying uranium on the international market is cheaper than developing domestic uranium resources or in order to avoid quickly depleting domestic resources. There is also the choice of from which country or countries to buy natural uranium, or this step could be circumvented in a way by choosing to not perform enrichment domestically because enriched uranium does not necessarily come from the countries that mine uranium.

There is an alternative to mining uranium. The metallic element thorium occurs exclusively as the isotope thorium-232 (^{232}Th), a fertile isotope that breeds the fissile isotope ^{233}U when bombarded with neutrons, in nature. Thorium is estimated to be about three times more abundant than uranium, and there have been several research and commercial reactors that operated with at least partial loadings of thorium fuel.[69] A potential nonproliferation benefit of a thorium fuel cycle is that it does not produce plutonium, but the thorium fuel cycle has yet to be employed on a wide scale.

2.3.2 Uranium Conversion

After uranium ore is mined, it is then milled into triuranium octaoxide (U_3O_8), which is a powdery substance commonly called yellowcake. Yellowcake is not suitable for use in either a uranium enrichment plan or in a natural uranium fueled reactor, so yellowcake must be processed again in the fuel cycle step called conversion. For use in a natural uranium fueled reactor, yellowcake is converted directly into the ceramic compound uranium dioxide (UO_2) that is used for manufacturing reactor fuel. For use in a uranium enrichment facility, yellowcake is converted into a gas, uranium hexafluoride (UF_6). Since LWRs use enriched uranium for fuel, most of the conversion work done in the world is to convert yellowcake into UF_6.

Due to the fact that all uranium fueled reactors must use a fuel cycle that includes some type of conversion, this is a step that cannot be avoided. The only choice is to either convert uranium domestically or purchase UF_6 or UO_2 on the global market, depending on the requirements of a country's reactors. One

---

[69] "Thorium," World Nuclear Association, last modified August 2012, http://world-nuclear.org/info/inf62.html .

exception to this is magnox reactors that use natural uranium metal as fuel, but only the United Kingdom still operates magnox reactors and produces natural uranium metal fuel.

Currently, six countries operate commercial scale yellowcake to UF_6 conversion facilities: Canada, China, France, Russia, the United Kingdom, and the United States. Conversion from yellowcake to UO_2 or UO_3 for use in natural uranium fueled reactors is conducted in Argentina, Canada, China, India, and Romania, and the United Kingdom operates a facility for converting yellowcake to uranium metal.[70] This means that a total of nine countries perform some type of industrial scale uranium conversion domestically. If a country decided to domestically enrich uranium or fabricate fuel for natural uranium reactors but not convert uranium domestically, then it would be forced to buy converted uranium from one of these countries.

2.3.3 Uranium Enrichment

Uranium naturally occurs in two isotopes, the fertile isotope ^{238}U and the fissile isotope ^{235}U. Natural uranium consists of approximately 99.3 percent ^{238}U, with the remainder 0.7 percent being ^{235}U. In order to maintain a fission chain reaction in LWRs,[71] the isotopic ratio of the fissile ^{235}U must be increased to around 3 to 5 percent. Uranium enriched up to 20 percent is considered low-

---

[70] "Country Nuclear Fuel Cycle Profiles," 6.

[71] Loose neutrons are produced in a fission reaction, and these neutrons can cause more fission in ^{235}U or be absorbed by ^{238}U or other reactor materials. When each fission reaction leads to another fission reaction, a self-sustaining chain reaction occurs, and the reactor is said to be "critical." A supercritical state leads to the chain reaction quickly going out of control, as in a nuclear weapon, and a subcritical reactor would shut itself down due to being unable to sustain the chain reaction. Thus, nuclear power reactors are designed to operate in a critical state.

enriched uranium (LEU), and uranium enriched above 20 percent is called highly enriched uranium (HEU). Uranium weapons require enrichment of around 90 percent. Thus, nuclear power reactors use LEU and nuclear weapons use HEU. Some research reactors and naval reactors still use HEU, but most of those research reactors are being retrofitted to use LEU instead. What makes uranium enrichment so contentious is that the same technology used to produce LEU reactor fuel can be used to also produce HEU weapons material.

The two primary enrichment methods in commercial use today take advantage of the small mass difference between ^{235}U and ^{238}U. Gaseous diffusion works by passing gaseous UF_6 through a series of semi-permeable membranes that separate ^{235}U and ^{238}U. This method was used at Oak Ridge to produce most of the HEU for Little Boy during the Manhattan Project, and the Paducah Gaseous Diffusion Plant operated by the United States Enrichment Corporation (USEC) in Paducah, Kentucky, the only uranium enrichment plant in the United States, still utilizes gaseous diffusion, as does the European Gaseous Diffusion Uranium Enrichment Consortium (EURODIF) in France.

The other main method for uranium enrichment is gas centrifuge. In this process, a large number of rotating cylinders are connected in series and parallel formations, called the centrifuge cascade. Gaseous UF_6 is passed through the cascade, and the spinning of the cylinders separates ^{235}U and ^{238}U. This method uses far less energy than gaseous diffusion, so it has become the method of choice for countries seeking to enrich uranium domestically. The European company the Urenco Group uses gas centrifuges to enrich uranium for customers around the world. Other enrichment methods, such as electromagnetic isotope separation and atomic vapor laser isotope separation, have been proven scientifically but are not currently commercially viable.

Uranium enrichment is conducted by six organizations on a commercial scale: the China National Nuclear Corporation (CNNC), EURODIF, RosAtom (Russia's Federal Atomic Energy Agency), Japan Nuclear Fuel Limited (JNFL), the Urenco Group (operating in Germany, the Netherlands, and the United Kingdom), and USEC Inc.[72] In addition, smaller scale uranium enrichment plants can be found in Argentina, Brazil, India, Iran, and Pakistan[73].

Similar to uranium conversion, the biggest choice for a country to make here is whether to enrich uranium domestically or purchase enriched UF_6 or UO_2 for fuel fabrication. Of course, using a natural uranium reactor design, such as CANDU, would bypass the enrichment step altogether, but given that most reactors in the world are LEU fueled LWRs, enrichment is a step used in most fuel cycles. Developing a domestic uranium enrichment capability has become particularly contentious because the same technology used to produce LEU reactor fuel can produce HEU for weapons. Nuclear programs in Iran, Iraq, North Korea, and Pakistan have all created controversy due to domestic enrichment programs.

2.3.4 Fuel Fabrication

---

[72] "Country Nuclear Fuel Cycle Profiles," 7.

[73] "Uranium Enrichment Facilities," WISE Uranium Project, last modified December 10, 2012, http://www.wise-uranium.org/efac.html#ENR.

After UF_6 is enriched to between 3 and 5 percent ^{235}U for use in LWRs, it is converted to UO_2 powder and formed into pellets. The pellets are then stacked inside metal tubes called fuel rods, which are then sealed at both ends and placed in fixed parallel arrays called assemblies. The fuel assemblies are then loaded into the reactor core.

Since all nuclear power reactors must use nuclear fuel, variations on this step mainly stem from using different types of fuel. Natural uranium fuel has already been discussed, and the natural UO_2 would be formed into pellets and assemblies in a fashion similar to enriched UO_2. PuO_2 and UO_2 can be combined in fuel assemblies in mixed oxide (MOX) fuel that is made from reprocessing spent nuclear fuel. MOX fuel is already being used in Belgium, France, Germany, and Switzerland, and there are plans to use MOX in Japan, Russia, and the United States.[74] Other nuclear fuels, such as thorium or metallic uranium, can also be fabricated for use in a reactor, but natural UO_2 and low enriched UO_2 used in PHWRs and LWRs, respectively, are the dominant fuel types in most of the world.

The use of MOX fuel has been controversial because it requires that plutonium is separated out from spent nuclear fuel, which is as a weapons proliferation concern. The United States and Russia decided to limit the use of MOX in commercial power reactors to the disposal of plutonium recovered from dismantled nuclear weapons.[75] Additionally, the use of MOX fuel does change

---

[74] "Country Nuclear Fuel Cycle Profiles," 8.

[75] "Country Nuclear Fuel Cycle Profiles," 8.

the operating characteristics of a reactor, so most reactors need to be adapted to be able to accept MOX fuel.

Currently, 17 countries domestically fabricate nuclear fuel: Argentina, Belgium, Brazil, Canada, China, France, Germany, India, Japan, Pakistan, Romania, Russia, South Korea, Spain, Sweden, the United Kingdom, and the United States.[76] Clearly, many countries have chosen to fabricate some or all of their nuclear fuel domestically. Current world nuclear fuel fabrication capacity exceeds demand, so fuel also can be easily purchased on the global market.

2.3.5 Nuclear Power Plant

Once uranium or plutonium has been fabricated into fuel, then it is ready to be loaded into a nuclear reactor to generate electricity. There are obviously many kinds of reactor types in commercial use, with the most common being PWRs, but other types includes BWR, PHWR, FBR, Magnox, and LWGR. The type and design of a reactor[77] strongly influences the power output, fuel burnup, refueling time, and other operation parameters. There are also advanced reactor designs presently under development that should improve on the safety, efficiency, and proliferation resistance of current reactor designs in use. There are

---

[76] "Country Nuclear Fuel Cycle Profiles," 11-12.

[77] There are various ways to classify nuclear reactors (e.g., by neutron speed, moderator material, coolant), but one distinction is by comparing the breeding ratio, which is the ratio of final to initial fissile material content. Burner reactors have a breeding ratio of less than one, consuming more fissile material than they produce, and breeder reactors have a breeding ratio of more than one. Breeder reactors are necessary to create a closed fuel cycle.

over 430 civilian power reactors in operation by 30 countries around the world,[78] and this step is a necessity to having a nuclear power program.

Most reactor materials other than the fuel, such as things like light water, carbon, zirconium, and graphite, are fairly standard industrial materials that do not require special nuclear facilities to manufacture. However, a note should be made about natural uranium reactors because they require the use of heavy water for neutron moderation. Due to the relative scarcity of deuterium in nature, heavy water must be industrially produced for natural uranium reactors. Distillation, electrolysis, and chemical methods have all been developed to produce water with a higher concentration of deuterium, and water containing greater than 99 percent deuterium nuclei is considered reactor grade.[79] Currently, the major producers of heavy water are Argentina, China, India, and Romania.[80] Reactors using heavy water are better at breeding plutonium than light water reactors, and most nuclear weapons states have used heavy water reactors to produce plutonium for weapons, which makes some countries consider heavy water a proliferation concern.

2.3.6 Spent Fuel Interim Storage

All nuclear fuel requires interim storage after being discharged from the reactor due to high levels of thermal heat and radioactivity. Regardless of fuel cycle, the spent fuel assemblies must be at least temporarily stored in spent fuel

---

[78] The 30 countries with civilian nuclear power reactors are Argentina, Armenia, Belgium, Brazil, Bulgaria, Canada, China, Czech Republic, Finland, France, Germany, Hungary, India, Japan, Lithuania, Mexico, Netherlands, Pakistan, Romania, Russia, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Ukraine, the United Kingdom, and the United States. In addition, Taiwan operates civilian nuclear power reactors.

[79] "Heavy Water Production," Federation of American Scientists, last modified October 21, 1998, http://www.fas.org/nuke/intro/nuke/heavy.htm.

[80] "Country Nuclear Fuel Cycle Profiles," 9.

pools, below a minimum of 20 feet of water in the United States,[81] in order for the fuel to cool and for some short-lived fission products to decay. Due to the necessity of pool storage, spent fuel pools are typically located on-site at power reactors.

With many countries struggling to find a way of permanently disposing of spent fuel, spent fuel pools are rapidly filling up, so an alternative interim storage method called dry cask storage has been developed. The casks are typically steel cylinders equipped with radiation shielding and are stored above-ground. Spent fuel must have been cooled for at least one year in a spent fuel pool before being placed in dry cask storage. Most dry cask storage facilities are at reactor sites, but there are some off-reactor sites in use.[82]

All countries operating nuclear power reactors must use interim storage for their spent fuel. The sensitivity and controversy surrounding managing spent nuclear fuel means that finding another country to accept spent fuel for storage is unlikely, which leaves countries with little choice but to find ways to store their own spent fuel.

2.3.7 Spent Fuel Reprocessing

After spent nuclear fuel has sufficiently cooled in a pool, it can be chemically reprocessed, mainly through a process called PUREX (Plutonium and Uranium Recover by Extraction) to separate the leftover uranium, plutonium, and

---

[81] "Spent Fuel Pools," U.S. Nuclear Regulatory Commission, last modified December 21, 2012, http://www.nrc.gov/waste/spent-fuel-storage/pools.html.

[82] "Dry Cask Storage," U.S. Nuclear Regulatory Commission, last modified December 21, 2012, http://www.nrc.gov/waste/spent-fuel-storage/dry-cask-storage.html.

fission products that will be present in all spent fuel from uranium-fueled reactors.[83] The recovered uranium can then be re-enriched and re-fabricated to produce new fuel assemblies, and the plutonium can be fabricated into new nuclear fuel. MOX fuel is an example of fuel that can be produced from reprocessing. The other fission products are waste and must be disposed of.

Spent fuel reprocessing occurs on a large scale in France and the United Kingdom and on smaller scales in India, Japan, and Russia.[84] In addition to recovering usable fissile materials and creating a closed fuel cycle, countries that reprocess spent nuclear fuel can also benefit by reducing both the amount of material to be disposed of as high-level waste and the long-term radioactivity levels of nuclear waste. However, reprocessing methods and breeder reactors that would be required to close the nuclear fuel cycle completely have yet to become truly economically viable.

The fissile isotope of plutonium that can be recovered from spent fuel, plutonium-239 (^{239}Pu), can be used for either fabricating new reactor fuel or making weapons material. This dual nature led the United States to decide in the 1970s not to reprocess spent fuel as part of its nonproliferation policy, but other countries decided to either reprocess or leave the reprocessing option open.

From a proliferation perspective, uranium enrichment and spent fuel reprocessing are the most sensitive steps in the nuclear fuel cycle because these are the only two methods of producing fissile materials, which are necessary for both nuclear reactors and weapons. Regardless of fuel cycle selection, one of

---

[83] "Processing of Used Nuclear Fuel," World Nuclear Association, last modified May 2012, http://www.world-nuclear.org/info/inf69.html.
[84] "Country Nuclear Fuel Cycle Profiles," 20.

these steps can come into play. Uranium enrichment can be avoided by using natural uranium reactors, but the option of reprocessing is always available as long as a country keeps spent fuel from any type of uranium fueled reactor.

2.3.8 Permanent Waste Disposal

The operation of nuclear power reactors inevitably leads to the production of radioactive wastes, including low level waste (LLW), intermediate level waste (ILW), high level waste (HLW), and transuranic waste (TRUW). Even closed nuclear fuel cycles using breeder reactors and spent fuel reprocessing would produce HLW. LLW is relatively simple to handle and dispose of, and ILW can be placed in geological repositories. The United States currently operates an underground facility near Carlsbad, New Mexico, called the Waste Isolation Pilot Plant (WIPP), to store TRUW below certain levels of radioactivity.[85]

To handle HLW and spent nuclear fuel, most countries have decided that deep geological disposal is the best option. The United States has been studying and preparing a repository at Yucca Mountain in Nevada since 1978 that is intended to accept HLW and spent nuclear fuel from civilian and military nuclear facilities around the country.[86] However, the Yucca Mountain project has been plagued by legal disputes and public opposition, and it is uncertain when the repository will begin accepting waste. Other countries are in similar situations with their geological repositories. Sweden anticipates opening its geological

---

[85] "Waste Isolation Pilot Plant," U.S. Department of Energy, accessed December 29, 2012, http://www.wipp.energy.gov.

[86] "Fact Sheet on Licensing Yucca Mountain," U.S. Nuclear Regulatory Commission, last modified March 29, 2012, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-yucca-license-review.html.

repository around 2015, but most other countries project opening repositories not before 2020.[87]

As with spent fuel interim storage, it seems unlikely that any country would be willing to accept HLW and spent nuclear fuel from another country due to the high costs and public opposition. Thus, this is another step that countries must handle on their own, although cooperation on technology development and establishing international safety regulations could be in the interest of all countries with nuclear power plants.

---

[87] "Radioactive Waste: An International Concern," U.S. Department of Energy Office of Civilian Radioactive Waste Management, accessed December 29, 2012, http://web.archive.org/web/20090515021337/http://www.ocrwm.doe.gov/factsheets/doeymp0405.shtml.

3. ANALYTICAL FRAMEWORK AND METHODOLOGY

This study employs prospect theory to examine the decision making behind national nuclear fuel cycle policy. It will focus on how a country's reference point determines how a country views itself in the international setting and how that guides nuclear fuel cycle policy. Other factors will be used to help determine reference points and explain a country's decision making environment. A qualitative approach will be used throughout the study. After using prospect theory to create an analytical framework, three country case studies will be examined. The three case studies will be analyzed individually, and then the three will be compared through a structured, focused comparison. The ability of prospect theory to explain nuclear fuel cycle decision making will be compared with alternative explanations provided by existing theories of nuclear weapons proliferation.

3.1 Prospect Theory Framework for Nuclear Fuel Cycle Decision Making

When using prospect theory to analyze nuclear fuel cycle decision making, it is important to first determine a country's reference point. Barbara Vis claims that, for an individual, the reference point is often likely to be the status quo.[1] If that individual is satisfied with the status quo, then he or she tends to be in a gains domain. Dissatisfaction with the status quo likely puts that individual in the losses domain. Determining whether the status quo is acceptable could be a straightforward way to determine the frame in which an actor is. Keeping in mind

---

[1] Barbara Vis, *Politics of Risk-taking: Welfare State Reform in Advanced Democracies* (Amsterdam: Amsterdam University Press, 2010), 118.

the concerns about applying prospect theory to collective decision making and the aggregation problem, determining a country's reference point (possibly that country's status quo) similarly can help determine whether a country is in a gains or losses frame.

This study uses the same variables as Rose McDermott did in her study of U.S. foreign policy decision making. The independent variable is the domain, namely either a domain of gains or losses. The dependent variable is risk-propensity or relative riskiness of an option.[2] Thus, starting off by determining the reference point will also ascertain the independent variable for a particular decision.

This study assumes that nuclear fuel cycle decision making is not done in isolation from other national concerns, which means that the reference point here should refer to the general reference of point of a country. Thus, some general points must be considered in order to establish a baseline reference for a country. It is important to note that a country's reference point can change over time, so the reference point for each particular decision must be determined. After determining individual points, a general trend of decision making can be determined. Considering a series of questions about a country and its policy can help to determine the reference point.

- How does the country portray itself in the international system?
- How does the country place itself among regional neighbors?
- How does the country view its relations with major nuclear powers (e.g., the United States, Japan, France, and the United Kingdom)?

---

[2] Vis, 121.

- How do other countries view the country and their relationships with the country?
- What is the country's overall view on energy policy, and how does nuclear power fit into this?
- With regards to the nuclear fuel cycle, what are the country's capabilities and potential for the future?
- For each step of the nuclear fuel cycle, what are the options and risks associated with that step, and how does the country value each step of the cycle in relation to its energy and nuclear policies?
- How would a certain change in the international or domestic nuclear power industry affect the country's nuclear industry?

Other questions may arise, but the first step is to gather the data needed to answer these types of questions, which will provide insights into determining a country's reference point. With this reference point identified, a change in the status quo can be translated into whether a country is in a gains or losses frame and thus whether it will seek relative or absolute gains. Of course, the main reason to go through this analytic process is to answer a puzzle that has not satisfactorily been answered by other theories, such as why has Japan chosen to reprocess spent nuclear fuel but South Korea uses a once-through fuel cycle?

As stated before, a country's domain is the independent variable, and risk propensity is the dependent variable. Determining the independent variable, the domain, will thus allow for determining the dependent variable, the risk propensity. When applying prospect theory to national decision making, the domain determines how a country perceives, or frames, the riskiness of policy options. A country in a domain of gains is risk averse and pursues the less risky policy options, and a country in a domain of losses is risk acceptant and selects the more risky policy options. Thus, after the domain is determined, the next step is to frame the various policy options based on their perceived risk propensity. The test for prospect theory will be whether the actual decisions made were in line with these tenets of the theory.

It is also crucial to understand what relative gains and absolute gains mean in national nuclear fuel cycle policy. Absolute gains would seem to be the development of new nuclear fuel cycle capabilities, such as creating a domestic uranium enrichment program. Relative gains would seem to be expanding the scale of a country's existing nuclear fuel cycle without significantly modifying capabilities. Per Berejekian's description of countries in domains of gains or losses, a country in a domain of gains pursues absolute gains, and a country in a domain of losses pursues relative gains.[3] Without understanding relative and absolute gains in the nuclear fuel cycle, it would be difficult to definitively conclude that a country is acting according to the tenets of prospect theory.

In summary, the model for using prospect theory to analyze national decision making proceeds as thus: 1) determine reference point, 2) determine domain of gains or losses, 3) frame risk propensity of policy options based on domain, and 4) determine which policy option(s) would best fit the domain

---

[3] Jeffrey Berejikian, "The Gains Debate: Framing State Choice," *American Political Science Review* 91, no. 4 (December 1997): 795.

framing. This model for analyzing decision making using prospect theory is summarized visually in Figure 3.1.

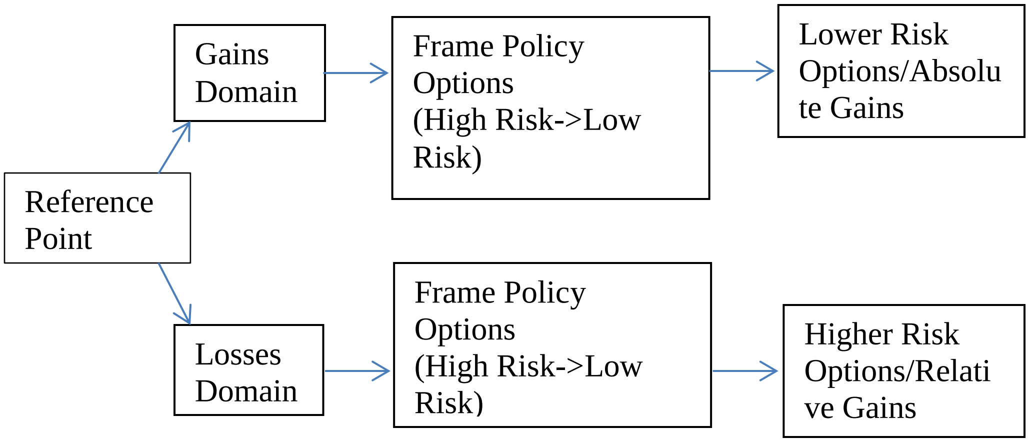

Figure 3.1 – Flow Chart of Decision Making Analysis Using Prospect Theory

3.2 Case Study Selection

Four principal criteria will be used to select cases for this study. The first criterion is that a country operates large civilian nuclear power industry (more than ten civilian nuclear power reactors) with indigenous capability in multiple steps of the nuclear fuel cycle. Countries that operate only research reactors or only employ nuclear energy for nuclear weapons, medical isotope production, or other purposes will not be considered. Additionally, countries that only operate a handful of reactors (less than ten) will not be considered. Nuclear energy may be important to such countries but, when compared to countries with large civilian nuclear power industries, likely has not played a significant role in meeting the country’s national goals.

The second criterion is that a country began its civilian nuclear program while still a developing country. This is done to be able to analyze more clearly the connections between nuclear power and a particular country's economic and development goals. If a country began its civilian nuclear power program as a developed country, then the link between developing nuclear power and overall economic development would not be as clear.

The third criterion is that a country is not a nuclear weapons state under the NPT. Article IX of the NPT defines a nuclear weapon state as "one which has manufactured and exploded a nuclear weapon or other nuclear explosive device prior to 1 January, 1967."[4] Thus, the United States, Russia, the United Kingdom, France, and the People's Republic of China are the only nuclear weapon states under the NPT and also are the five permanent members of the United Nations Security Council (collectively known as the P5). The considerations that would have influenced nuclear fuel cycle decision making for these five countries are significantly different than for other countries, which would make comparisons between these five countries and other countries difficult.

The fourth criterion is that a country faces or faced significant external security threats, particularly regional nuclear threats. In this context, security threats refer to traditional threats to national security posed by another nation-state. This is necessary in order to test this study's third hypothesis that security concerns are a primary driver of the decision to start and maintain a nuclear program.

---

[4] "Treaty on the Non-Proliferation of Nuclear Weapons," United Nations Office for Disarmament Affairs, accessed on December 28, 2012, http://www.un.org/disarmament/WMD/Nuclear/NPTtext.shtml.

Based on a review of countries that fit these four criteria, India, Japan, and South Korea have been selected as case studies. Table 4 summarizes the nuclear industries and other relevant factors in these three countries.[5]

	INDIA	JAPAN	SOUTH KOREA
Installed Nuclear Capacity (MWe)	4,385	44,396	20,787
% of Electricity from Nuclear	4	18	35
Operational Reactors	20	50	23
First Reactor	1969	1963	1977
Open/Closed Cycle	Closed	Closed	Open
Indigenous Fuel Cycle Steps	Mining and Milling; Conversion; Fabrication; Reprocessing; Waste Storage	Enrichment; Fabrication; Reprocessing; Waste Storage	Fabrication; Waste Storage
Military Nuclear Program	Yes	No	No
Nuclear Warheads	80-100	N/A	N/A
NPT Status	Non-party	Deposited 1976	Deposited 1975
Regional Nuclear Threats	China, Pakistan	China, North Korea	China, North Korea

Table 3.1 – Summary of Case Study Factors

---

[5] Data in Table 4 is compiled from International Atomic Energy Agency, *Country Nuclear Fuel Cycle Profiles*, 2nd ed. (Vienna: International Atomic Energy Agency, 2005), 47-56, http://www-pub.iaea.org/MTCD/publications/PDF/TRS425_web.pdf; "Nuclear Power in India," World Nuclear Association, last modified September 2012, http://www.world-nuclear.org/info/inf53.html; "Nuclear Power in Japan," World Nuclear Association, last modified October 22, 2012, http://www.world-nuclear.org/info/inf79.html; "Nuclear Power in South Korea," World Nuclear Association, last modified December 2012, http://www.world-nuclear.org/info/inf81.html; "Power Reactor Information System," International Atomic Energy Agency, last modified December 28, 2012, http://www.iaea.org/PRIS/; "Status of the Treaty," United Nations Office for Disarmament Affairs, accessed December 29, 2012, http://disarmament.un.org/treaties/t/npt; "Status of World Nuclear Forces," Federation of American Scientists, last modified December 18, 2012, http://www.fas.org/programs/ssp/nukes/nuclearweapons/nukestatus.html.

Other than the four factors listed above, these three countries provide a good contrast among themselves. Economically, both Japan and South Korea are robust, developed industrial economies (with Japan being the wealthier and less recently developed of the two), but India is still a developing economy. However, the situation is the opposite in terms of military use of nuclear energy. India conducted its first nuclear test in 1974, conducted a second round of nuclear tests in 1998, and possesses over 100 nuclear warheads with corresponding delivery systems. South Korea had a covert nuclear weapons program until it was exposed by the United States in the mid-1970s, but some suspicious research since then has generated lingering questions about South Korea's military nuclear ambitions to this day. Japan, despite being the wealthiest of these three countries, has never been suspected of having a nuclear weapons program and has been a strong advocate of strengthening the international nuclear nonproliferation regime.

In terms of nuclear fuel cycle use and capability, South Korea does not possess any fissile material production capability, although it did have plans to develop spent nuclear fuel reprocessing technology until the mid-1970s. Japan possesses uranium enrichment and spent nuclear fuel reprocessing technology (ENR technology), which it uses only for civilian purposes. India also possesses ENR technology and uses it for both civilian and military purposes. Thus, these three cases provide a broad spectrum of nuclear fuel cycle decisions to analyze, and for these reasons, these three cases provide a basis for testing the hypotheses proposed in this study.

This study is not meant to provide a comprehensive analysis of nuclear fuel cycle decision making in the world, and there are potential selection biases in the case study selection process. Other than the exclusion of the United States, Russia, United Kingdom, France, and China, there is no case study of a country that never considered developing ENR technology for any purpose. Such cases likely are countries with smaller nuclear industries. Therefore, the two ends of a spectrum of nuclear technology use, with the P5 at the top and countries with small-scale nuclear industries at the bottom, are not included. The cases included in this study could be considered representative of the middle section of a spectrum of nuclear technology use.

3.3 Case Study Comparison

In order to systematically compare the three case studies, the method of structured, focused comparison is employed after each case study is analyzed individually. This methodology was described by Alexander George and Andrew Bennett. First, the method is "structured" in that the same research questions are asked in each case study to guide and standardize data collection. Second, the method is "focused" in that it only certain aspects of the case studies examined.[6]

Along these lines, two groups of questions were formulated to conduct a structured, focused comparison of Indian, Japanese, and South Korean nuclear fuel cycle policy decision making. The first group of questions is technical in

---

[6] Alexander L. George and Andrew Bennett, *Case Studies and Theory Development in the Social Sciences* (Cambridge, MA: MIT Press, 2005), 67.

nature. These questions represent decisions made to pursue a technology or capability.

1. Did the country decide to utilize nuclear energy to produce electricity? If so, to what extent has nuclear power been utilized?
2. Did the country decide to pursue uranium enrichment and spent nuclear fuel reprocess (ENR) technology? If so, was ENR technology acquired?
3. Did the country decide to indigenize nuclear reactor designs, and has the country achieved technological independence in nuclear power plant technology (i.e., capable of designing, constructing, operating nuclear power plants)?
4. Did the country decide to develop nuclear weapons? If so, were nuclear weapons acquired?
5. Did the country decide to test a nuclear explosive device? If so, was a test conducted?
6. Did the country decide to develop civilian nuclear technology as a hedge for future military use?

This group of questions can be further divided into civilian and military technology or capability categories. Table 3.2 summarizes the technical group of questions and divides them into civilian and military categories. In the nuclear realm, there is not always a clear line between civilian and military, but this group of questions explores both capabilities and intents to make the line between civilian and military clearer.

CIVILIAN	MILITARY
Electric Power Generation	Acquire/Develop Nuclear Weapons
Acquire/Develop Enrichment and Reprocessing (ENR) Technology	Test Nuclear Explosive Device
Achieve Nuclear Power Plant Independence	Nuclear Weapons Hedging

Table 3.2 – Technological Comparison Categories

The second group of questions categories is political in nature, both domestic politics and geopolitics. This group of questions investigates the factors or influences on nuclear fuel cycle decision making, not necessarily actual decisions.

1. Are there bureaucratic actors with vested interests in pursuing or maintaining a nuclear sector that drove decision making?
2. Is decision making centralized in the head of government, and how strong is the national leader?
3. How sensitive is the country to energy security?
4. What is the nature of the governing regime or national leader?
5. What is the relationship between the country and the United States?
6. Does the country face significant regional security threats, particularly regional nuclear weapons states?
7. What is the country's access to international energy markets like?
8. How does the country view and adhere to international nonproliferation norms?

Table 3.3 summarizes these questions and divides them into either domestic politics or geopolitical factors.

DOMESTIC	**GEOPOLITICAL**
Bureaucratic Interests	U.S. Relationship
Centralization of Power/Strength of Leader	Security Threats
Energy Security Sensitivity	Access to International Energy Markets
Nature of Regime/Leader	Nonproliferation Norms Adherence

Table 3.3 – Political Comparison Categories

While the set of questions summarized in Table 3.2 gauges the technical capabilities and intent of each case study, the questions in Table 3.3 will bring to light the primary factors that drove each country to make the technology decisions in Table 3.2. This also will provide a test for the existing theories of nuclear weapons proliferation described in the literature review in Chapter 2. The set of political questions was derived, in part, from the factors that drive a country to develop nuclear weapons cited in those theories. By examining the same factors, whether these existing nuclear weapons proliferation theories also can describe nuclear fuel cycle decision making will be tested, and this will provide potential alternative explanations to this study's hypotheses.

4. CASE STUDY: INDIA

Figure 4.1 – Political Map of India

India is one of the oldest civilizations on the planet. The Indus Valley Civilization, the first major civilization in South Asia, dates back some 5,000 years. However, what is now the modern nation-state of India was ruled by various kingdoms and empires during much of its history. The United Kingdom unified India under colonial rule in the 19th century, and the current borders of the Republic of India were established when India achieved independence from British rule in 1947 (see Figure 4.1 for India's current borders).[1] The first few years of independence were marked by the bloody partition of British India into the modern states of India and Pakistan.

---

[1] "India," Central Intelligence Agency, accessed January 4, 2013, https://www.cia.gov/library/publications/the-world-factbook/geos/in.html.

Since independence, Indian political thought was dominated by prominent independence leaders, principally Mahatma Gandhi and Jawaharlal Nehru. New Delhi strove to forge its own path on the international scene by leading the Non-Aligned Movement (NAM), which sought not to join either the American or Soviet side of the Cold War. Despite being rich in natural resources and population, India economically lagged behind the industrialized world. In addition, the security of India faced frequent challenges from neighboring Pakistan and the People's Republic of China.

4.1 Historical Economic and Energy Data for India

After achieving independence in 1947, India recorded modest economic growth during the ensuing decades. More rapid growth in the Indian economy began to occur in the mid-1990s. India's population also grew significantly in the second half of the twentieth century. The Indian population doubled in just over 30 years between 1960 and 1992, going from about 450 million to 900 million, and the population eclipsed one billion in 1997.[2] India's annual population growth rate gradually increased until 1977, and since the late 1970s, the annual population growth rate has declined steadily.[3]

---

[2] "India | Data," World Bank, accessed August 3, 2012, http://data.worldbank.org/country/india.

[3] Ibid.

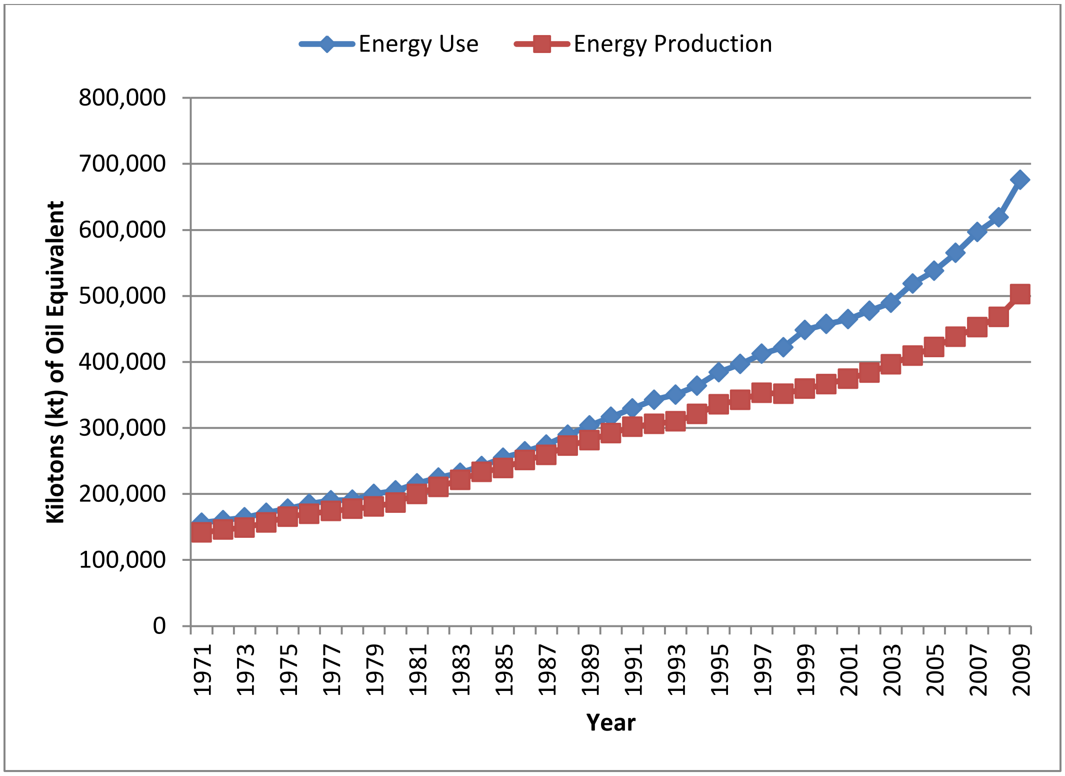

Figure 4.2 – Energy Use and Production in India (1971-2009)

Obviously, a growing economy and population will result in increased energy demand, and Figure 4.2 graphs the growth in energy use and production in India from 1971 to 2009.[4] Going back a bit further, India's total demand for energy was 25.5 million tons of oil equivalent (mtoe) in 1953, and energy demand grew over tenfold to 270.6 mtoe by 1997.[5] However, before the Indian economy began to grow rapidly in the 1990s, the country's energy demand growth was not as high as seen in other parts of the world. For example, Indian energy demand grew at an annual average rate of 4.5 percent during the 1960s, but the average world annual growth rate was over 5 percent. In addition, the per capita energy consumption growth rate between 1960 and 1980 (2.2 percent per year) was lower

---

[4] Ibid.

[5] Shebonti Ray-Dadwal, *Rethiking Energy Security in India* (New Delhi: Knowledge World), 110.

than the population growth rate (2.4 percent per year) during the same time period.[6]

As Figure 4.2 shows, India met nearly all of its energy demand until about 1990. Since then, India has had to increasingly rely on energy imports to meet growing energy demand, but the country still meets a significant portion of its energy demand with domestic sources.

4.1.1 Historical Electric Power Sector Data in India

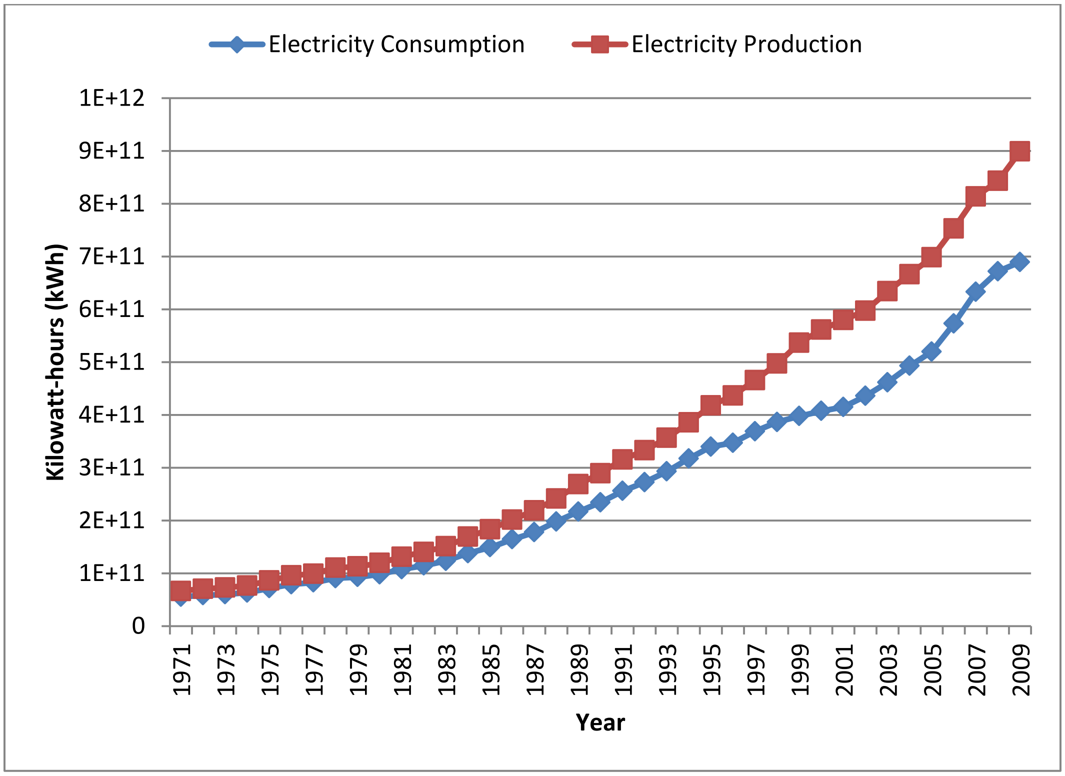

Figure 4.3 – Electricity Consumption and Production in India (1971 to 2009)

---

[6] Vijay G. Pande, "Towards an Increased Concern with Energy Research and Development in India," in *Energy Policy for India: An Interdisciplinary Analysis*, ed. Rajendra K. Pachauri (New Delhi: MacMillan Company of India, Ltd.: 1980), 162.

Since nuclear power is used primarily to generate electricity, the most relevant portion of India's energy sector to analyze is the electric power sector. Figure 4.3 shows the increase in electricity consumption and production from 1971 to 2009.[7] As with overall energy demand, electricity demand grew steadily, and demand has increased more rapidly since the early 1990s. Figure 4.3 also shows that India has met domestic electricity demand with domestic electricity production, and surplus electricity production has increased since the mid-1990s.

Figure 4.4 and Figure 4.5 break down the electric power sector by source from 1971 to 2009.[8] Figure 4.5 displays the dominance of coal and hydropower in the Indian electricity sector, with those two sources providing around 90 percent of India's electricity during the time period covered. Figure 4.4 displays how particularly important coal is to India's electricity sector, as use of coal to generate electricity has sharply increased since the late 1970s. On the other hand, hydropower has seen modest growth in absolute production (see Figure A.6 in the Appendix) but has declined in relative production since the late 1970s.[9] The two figures show that coal has been the main source used to meet growing electricity demand in India since the late 1970s. Among the other sources of electricity, natural gas has become an increasingly important source since the mid-1990s. Nuclear, oil, and renewable sources remain small, marginal sources of electricity.

---

[7] "India | Data."

[8] "India | Data."

[9] "Statistical Review of World Energy 2011: Historical Data," BP, accessed June 10, 2012, http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/spreadsheets/statistical_review_of_world_energy_full_report_2011.xls.

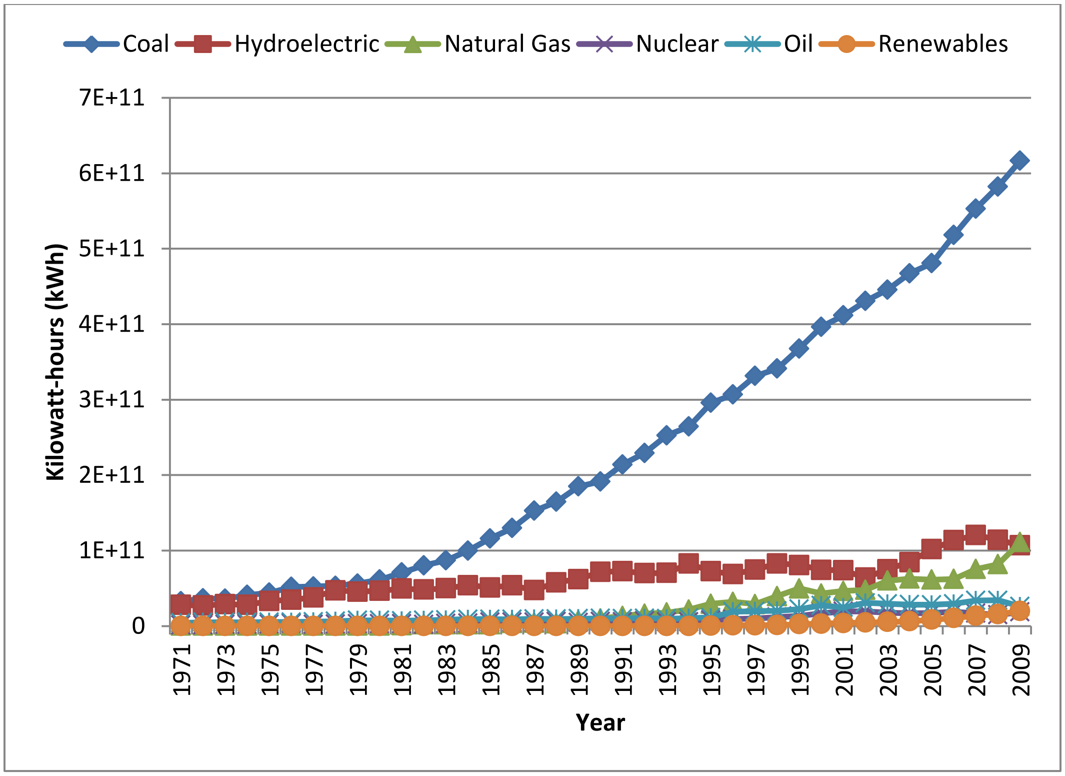

Figure 4.4 – Electricity Production by Source in India (1971-2009)

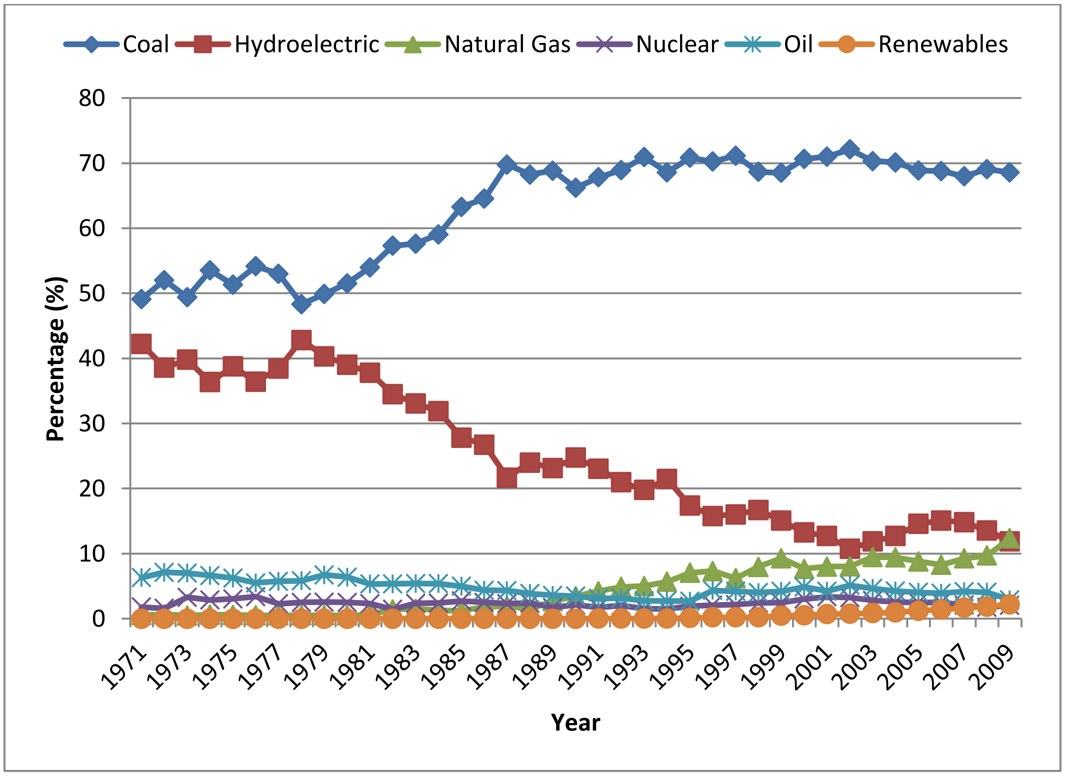

Figure 4.5 – Share of Electricity Production by Source in India (1971-2009)

India was able to meet its growing electricity demand with coal mostly by utilizing the country's large domestic reserves of coal. India did not start consuming more coal than the country produces until the 1990s, and still today, the majority of India's coal demand is met with domestic reserves (see Figure A.5 in the Appendix).[10]

India also has increased domestic oil production in order to meet growing demand for oil, but the increase in demand has far outpaced the increase in production (see Figure A.7 in the Appendix).[11] Figures 4.4 and 4.5 show that oil is not a significant source of electricity for India; thus, the increase in oil consumption and production likely has been for transportation. Similarly, India has met increasing demand for natural gas mostly with domestic reserves, with production meeting demand until 2003 (see Figure A.8 in the Appendix).[12] Interestingly, none of the data related to Indian GDP or energy show much effect related to the oil crises of the 1970s. India's domestic energy reserves, structure of the energy sector, and relations with Middle Eastern countries are likely explanations for this.

4.2 Nuclear Sector Development in India

India showed an early interest in the promise of nuclear energy, and the country's domestic nuclear energy research program dates back to the mid-1940s, before even independence from British rule. However, India did not begin producing electricity from nuclear energy until 1969, and the nuclear power

---

[10] Ibid.
[11] Ibid.
[12] Ibid.

program has only provided around 3 to 5 percent of India's electricity since that first nuclear power plant (NPP) went online. Figure 4.6 charts the growth in installed nuclear power capacity since 1969.[13] Figure 4.7 displays the growth in consumption of nuclear power since 1969.[14] The two figures show that significant growth in nuclear capacity and consumption has occurred mostly from 1990 onward.

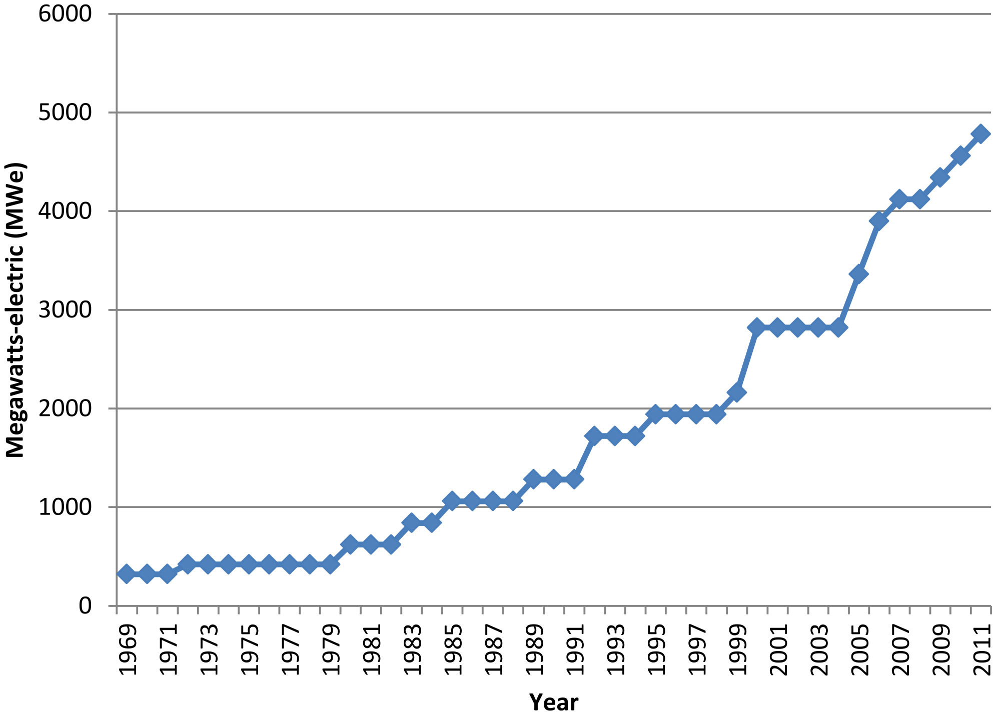

Figure 4.6 – Installed Nuclear Capacity in India (1969-2011)

---

[13] "Reactor Database," World Nuclear Association, accessed June 27, 2012, http://world-nuclear.org/NuclearDatabase/.

[14] "Statistical Review of World Energy 2011: Historical Data."

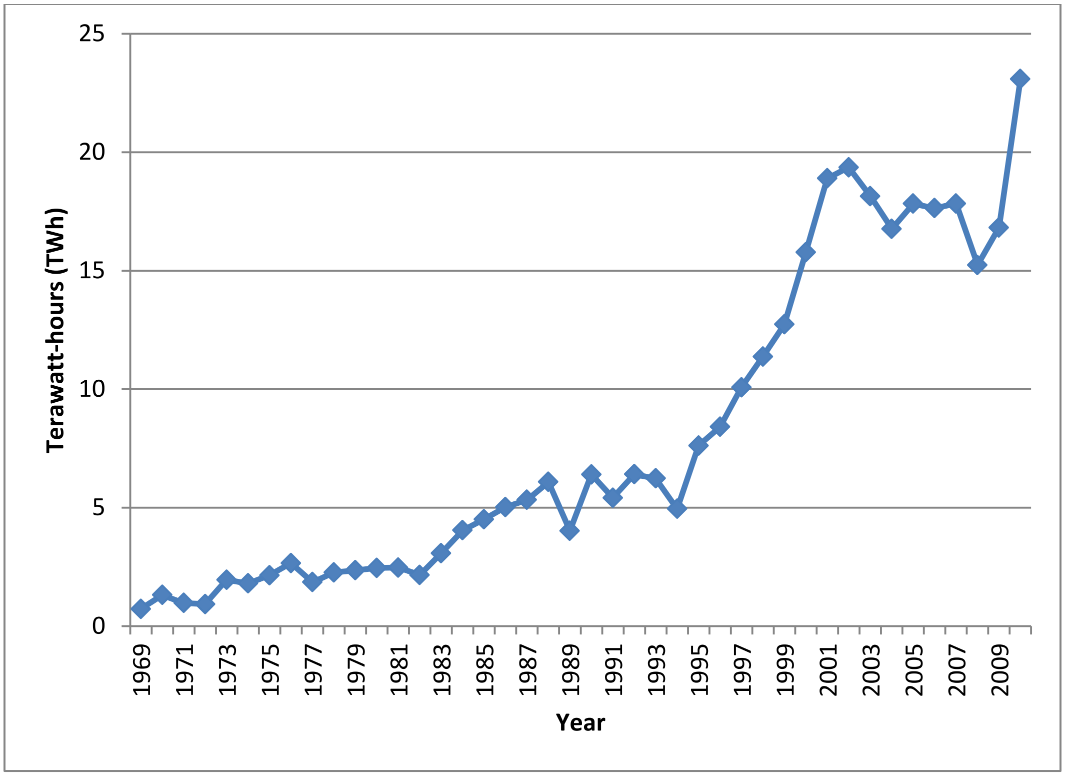

Figure 4.7 – Nuclear Power Consumption in India (1969-2010)

The time frame for this case study of India's nuclear fuel cycle decision making is from 1948 to 1990. This includes the Pokhran-I nuclear explosive test in 1974 but not the Pokhran-II nuclear weapon tests in 1998. The case study divides India's nuclear development into three phases. The first phase is the initial research and development under Jawaharlal Nehru and Homi J. Bhabha between 1948 and 1966. The second phase covers 1967 to 1973 and includes New Delhi's response to the Non Proliferation Treaty (NPT) and India's first NPPs. The third phase covers 1974 to 1990 and describes India's decision to develop and test a nuclear explosive in 1974 and the country's subsequent isolation from the global nuclear market.

4.2.1 Nehru, Bhabha, and the Start of India's Nuclear Program (1948-1966)

The early stages of India's nuclear program were defined, in large part, by two men: Jawaharlal Nehru and Homi Jehangir Bhabha. Nehru was the first prime minister of independent India and held that office from 1947 to 1964. Bhabha was the leading nuclear scientist in India and eventually came to hold four of the top posts in India's nuclear program: Chairman of the Atomic Energy Commission (AEC), Secretary of the Department of Atomic Energy (DAE), Director of the Atomic Energy Establishment, Trombay (AEET)[15], and the Director of the Tata Institute of Fundamental Research (TIFR).[16]

Nehru was a strong supporter of science and wrote, "No country can do without science, of which the West has been the pioneer. That science and the scientific spirit and method are the basis of life today and there lies in science the search for truth on the one hand and the betterment of humanity on the other."[17] Generally, Nehru believed that India's path to modernization and parity with the West was through science. Nuclear science, being one of the cutting edge technologies of the twentieth century, was of particular importance, and in Bhabha, Nehru had a close compatriot who believed strongly in the potential of nuclear energy.

Bhabha was an early proponent of nuclear energy. In 1944, he wrote a letter to the Sir Dorabji Tata Trust and stated, "When nuclear energy has been successfully applied for power production, in, say, a couple of decades from now,

---

[15] Following Bhabha's death in 1966, AEET was renamed the Bhabha Atomic Research Centre (BARC) in his honor.

[16] B. Banerjee and N. Sarma, *Nuclear Power in India: A Critical History* (New Delhi: Rupa & Co., 2008), 18-19.

[17] R. Rama Rao, *India and the Atom* (New Delhi: Allied Publishers Pvt Ltd, 1982), 60.

India will not have to look abroad for its experts, but will find them ready at hand."[18] This statement also reflected Bhabha's and India's ultimate goal for nuclear energy, to achieve self-sufficiency. Bhabha received funding from Tata to establish the Tata Institute of Fundamental Research (TIFR) in Mumbai in 1945, which marked the beginning of nuclear research in India.

Also in 1945, Bhabha was appointed chairman of an Atomic Energy Committee that was tasked with searching for nuclear-usable raw materials in India, proposing methods to employ domestic resources of nuclear materials, and establish ties with nuclear organizations in other countries.[19] Three years later, the Atomic Energy Act was passed and the Atomic Energy Commission (AEC) was formed with Bhabha as the chairman. The AEC also was tasked with searching for nuclear-usable raw materials in India but was given the additional tasks of developing a nuclear research infrastructure and ensuring the Indian government maintain control over nuclear energy-related matters.[20]

In 1954, the AEC formed the Atomic Energy Establishment, Trombay (AEET) and the Department of Atomic Energy (DAE), both of which were led by Bhabha. The DAE was placed directly under the Prime Minister and located in Mumbai, away from the rest of the bureaucracy in New Delhi.[21] These moves effectively gave Bhabha control over the nuclear program, and Bhabha reportedly directly to Nehru.

---

[18] Raja Ramanna, "Raja Ramanna on Development of Nuclear Energy 1947-73," in *The Indian Atom: Power & Proliferation*, ed. Dhirendra Sharma (New Delhi: Committee for a Sane Nuclear Policy, 1986), 61.
[19] Banerjee and Sarma, 9.
[20] Ramanna, 62.
[21] G.G. Mirchandani and P.K.S. Namboodiri, *Nuclear India: A Technological Assessment* (New Delhi: Vision Books, 1981), 27.

Later that same year, Bhabha outlined his three stage nuclear program at a conference in New Delhi. India has modest uranium reserves, only on the order of 1 percent of the world's uranium reserves, and around one third of its uranium reserves are of low uranium concentration. India does have large thorium reserves, around 30 percent of the world's thorium reserves.[22] Thus, Bhabha declared, "The aim of a long range atomic power programme in India must…be to base the nuclear power generation as soon as possible on thorium rather than uranium."[23] Bhabha's three stage program is designed to take advantage of India's thorium reserves and proceeds as follows.[24]

1. Natural uranium is burned in reactors that use heavy water as moderator and coolant. These reactors are called pressurized heavy water reactors (PHWRs) and produce both power and fissile plutonium-239.
2. Plutonium-239 is separated out of the spent fuel from the PHWRs. This plutonium, along with natural uranium and thorium, are used in fast breeder reactors (FBRs) to produce both power and fissile uranium-233.
3. Thermal breeder reactors fueled with uranium-233 and thorium produce power and more uranium-233.

With this plan in place, India set out on building up its nuclear infrastructure. The United Kingdom agreed to assist India build a research reactor. Indian scientists and engineers constructed the reactor at AEET, and the United Kingdom provided enriched uranium fuel. This reactor, named Apsara,

---

[22] R.G. Bucher, "India's Baseline Plan for Nuclear Energy Self-sufficiency," Argonne National Laboratory, January 2009, 1, http://www.ipd.anl.gov/anlpubs/2010/05/67057.pdf.
[23] Jagdish P. Jain, *Nuclear India, Volume 1* (New Delhi: Radiant Publishers, 1974), 5.
[24] Banerjee and Sarma, 27.

attained criticality on 4 August 1956, making it the first research reactor in Asia outside of the Soviet Union.[25] With an operating research reactor, a training school for nuclear scientists and engineers was established at AEET in 1957 in order to develop the human infrastructure necessary for India's nuclear program.[26]

Also in 1956, India began construction on the 40 Megawatt-thermal CIRUS (Canada-India-Reactor-US) natural uranium-fueled, heavy water-moderated research reactor. The reactor was called CIRUS because Canada supplied the materials and design, India funded the construction, and the United States provided the heavy water moderator. CIRUS attained criticality in 1960.[27] France also assisted India's nuclear development with a zero-energy research reactor named ZERLINA, which went into operation in 1961.[28]

In 1962, the Indian government updated the 1948 Atomic Energy Act. A key provision of the 1962 Atomic Energy Act was Section 3, which gives the central government sole authority over nuclear activities in India. It says the central government has the authority "…to produce, develop, use and dispose of atomic energy either by itself or through any authority or corporation established by it or a government company and carry out all research into all matters connected therewith."[29] This effectively barred any private sector participation in India's nuclear sector.

---

[25] P.K. Iyengar, *Briefings on Nuclear Technology in India* (New Delhi: Rupa & Co., 2009), 93.
[26] Iyengar, 89.
[27] Banerjee and Sarma, 31.
[28] Ibid.
[29] IDSA Task Force, *Development of Nuclear Energy Sector in India: IDSA Task Force Report* (New Delhi: Institute for Defence Studies and Analyses, 2010), 47.

With firm legal control over the nuclear sector in place, the Indian government next made its first serious attempt to formulate a national energy plan. The Energy Survey of India Committee was assembled in 1963 to advise the central government on meeting India's energy needs until 1981. The committee recommended discouraging the consumption of oil through fiscal measures and developing nuclear energy. In particular, the committee believed that nuclear energy would be most useful for locations far from cheap coal supplies and where hydropower is not available.[30]

Despite the progress being made at AEET in research reactor construction and operation, Bhabha decided to jump start the nuclear power program by importing two light water reactors from the United States. General Electric was selected as the reactor vendor in 1962, a nuclear cooperation agreement with Washington was signed in 1963.[31] Under this agreement, the U.S. government agreed to supply low enriched uranium fuel for the thirty year nominal life of the reactors, and India agreed to safeguards that would ensure no diversion of spent fuel for nuclear weapons purposes.[32] Construction work on these reactors, dubbed the Tarapur Atomic Power Station (TAPS), began in 1964. In the same year, Canada signed an agreement with India to build PHWRs similar to the Canadian Deuterium Uranium Reactor (CANDU).[33] This project would become

---

[30] Vijay G. Pande, "Towards an Increased Concern with Energy Research and Development in India," in *Energy Policy for India: An Interdisciplinary Analysis*, ed. Rajendra K. Pachauri (New Delhi: MacMillan Company of India, Ltd., 1980), 168-169.

[31] Mirchandani and Namboodiri, 136.

[32] Banerjee and Sarma, 34-35.

[33] Banerjee and Sarma, 37.

the Rajasthan Atomic Power Station (RAPS). India appeared on its way to making nuclear power a major source of electricity.

Bhabha's three stage program employed natural uranium, so India did not work on developing a uranium enrichment capability during this time period. However, spent fuel reprocessing is part of the three stage program, and a chemical reprocessing plant for separating plutonium out of spent nuclear fuel went into operation in Trombay in 1965. By 1966, several kilograms of plutonium had been produced, and Bhabha declared that India could make a nuclear weapon in 18 months.[34]

Whether it was India's intention from the beginning to build nuclear weapons is a matter of contention. Nehru made several statements to the Indian Parliament that indicated his opposition to nuclear weapons. In 1957, Nehru said, "We have declared quite clearly that we are no interested in making atom bombs, even if we have the capacity to do so, and that in no event will we use atomic energy for destructive purposes."[35] Nehru reiterated this stance to the parliament in 1960 when he said, "So far as we are concerned, we are determined not to go in for making atomic bombs and the like."[36]

Nehru died in May 1964, shortly before the People's Republic of China conducted its first nuclear test in October 1964. China had defeated India in a border war in 1962, and China's nuclear test represented a major challenge to India. In 1965, Lal Bahadur Shastri, who succeeded Nehru as prime minister,

---

[34] Iyengar, 30.
[35] "Indian Prime Ministers on Nuclear Strategy: 1957-1974," in *The Indian Atom: Power & Proliferation*, ed. Dhirendra Sharma (New Delhi: Committee for a Sane Nuclear Policy, 1986), 78.
[36] Ibid.

held Nehru's line and said to the parliament, "Despite the continued threat of aggression China which has developed nuclear weapons, Government have continued to adhere to the decisions not to go infor nuclear weapons but to work for their elimination instead."[37]

According to P.K. Iyengar, a former head of the Bhabha Atomic Research Center (BARC), Bhabha "…did not venture to have a programme for atomic bomb but was keen to build up the infrastructure for India to make the bomb when needed."[38] Iyengar also wrote that Nehru would tell Bhabha to "…come and tell him [Nehru] when ready, rather than asking for early approval."[39] At most, it appears that Bhabha and the nuclear establishment in Trombay had in mind that they could prepare a nuclear weapon if or when the political leadership in New Delhi gave the order, but for the time being, Nehruvian India was opposed to nuclear weapons, even in the face of a nuclear-armed rival across the border in China.

Bhabha would not have the chance to oversee a potential nuclear weapons program or see his three stage nuclear program produce any electricity, as he died in an airplane crash in January 1966. Thus, at the end of this period, India had lost the two giants pushing nuclear science forward in India, Bhabha and Nehru. However, the legacy they left was carried on by the nuclear establishment in Trombay.

4.2.2 First Nuclear Power Plants and the NPT (1967-1973)

---

[37] Ibid.
[38] Iyengar, 27.
[39] Iyengar, 28.

After Bhabha died in 1966, Dr. Vikram Sarabhai took over as the head of the AEC. Prime Minister Shastri also died in 1966, and Indira Gandhi, Nehru's daughter, was elected as prime minister. Thus, the Indian nuclear program experienced a large turnover in leadership within a two year time span, but the legacy of Nehru and Bhabha endured.

The era of nuclear power in India began in 1969 when the two U.S.-supplied boiling water reactors at Tarapur entered operation. Both TAPS units are rated at 160 megawatts-electric. Relatively small compared to modern Western reactors, but in addition to generating electricity, these reactors provided Indian engineers with experience operating commercial nuclear power reactors. Construction on the two PHWR units at RAPS also had commenced by 1969, and RAPS-1 began supplying electricity to the grid in 1972.

Despite this progress, the AEC expressed displeasure with the nuclear power program in its development plan for the 1970s. The plan stated that the program "…has slipped badly in relation to targets that were contemplated in the early 1960s" and cited several reasons for the program's lack of progress.[40] The ten year plan, referred to as the Sarabhai Plan, outlined a bold expansion plan for the nuclear sector. The main points of this plan were the following.

- Commission 2700 megawatts of nuclear power by 1980
- Design and construct 500 MW advanced thermal reactors and 500 MW prototype FBR
- Increase heavy water production

---

[40] Atomic Energy Commission, *Atomic Energy and Space Research: A Profile for the Decade 1970-80* (New Delhi: Atomic Energy Commission, 1970), 3.

- Develop gas centrifuge technology for uranium enrichment
- Develop uranium mines
- Complete Nuclear Fuel Complex for nuclear fuel production[41]

The decision to develop uranium enrichment was the most significant departure from Bhabha's planning. According to the Sarabhai Plan, India planners previously disregarded developing uranium enrichment plants due to "…their high costs as well as their enormous consumption of electric power," but the advent of cheaper and more efficient gas centrifuges made uranium enrichment more appealing.[42] Accordingly, the Sarabhai Plan said the "…use of slightly enriched uranium in thermal reactors will result in savings both in capital and fuelling costs."[43] The AEC also may have felt pressure from the central government. In 1970, the Indian Parliament's Estimates Committee stated that TAPS did not advance India's goal of self-reliance in the nuclear field because the plant was dependent on foreign supplies of enriched uranium fuel.[44] With these considerations in mind, the Sarabhai Plan called for the development of uranium enrichment technology.

India also made progress on indigenous PHWR designs, as construction started on the two PHWR units at the Madras Atomic Power Station (MAPS) in the southeastern state of Tamil Nadu in 1971 and 1972. The MAPS units were indigenously designed but very similar to the CANDU reactors supplied by

---

[41] Birla Institute of Scientific Research, Economic Research Division, *India and the Atom* (New Delhi: Allied Publishers Pvt Ltd, 1982), 65-66.
[42] Atomic Energy Commission, 10.
[43] Ibid.
[44] Mirchandani and Namboodiri, 36.

Canada at RAPS.[45] However, one of the challenges facing the PHWR program was the supply of heavy water. Canada initially agreed to provide the 230 tons of heavy water needed to start RAPS-1 but ended up providing only 130 tons due to problems with heavy water production in Canada. The Soviet Union agreed to supply the remaining 100 tons of heavy water, which allowed RAPS-1 to start in 1972.[46]

To address the heavy water production issue, India signed an agreement with France to build a heavy water plant at Baroda in the western state of Gujarat in 1969.[47] Construction on the Baroda plant began in 1970, and the plant was scheduled to commence operation in 1973. However, the plant did not start operating until 1977 due to equipment procurement delays, a labor strike, and a leak in the ammonia condenser.[48]

Decisions regarding uranium enrichment and heavy water were not the only significant ones facing the Indian nuclear program. On 1 July 1968, the Soviet Union, the United States, and the United Kingdom signed the Nuclear Non-Proliferation Treaty (NPT), and the treaty came into effect in 1970. New Delhi decided to not sign the NPT because Indian leaders viewed the treaty as discriminatory and did not support universal disarmament. A DAE memo from 1974 explains this "…refusal is not because she [India] has any desire to become a nuclear weapons power but because the Treat [NPT] is discriminatory…it

---

[45] Banerjee and Sarma, 40.
[46] Banerjee and Sarma, 38.
[47] Mirchandani and Namboodiri, 143.
[48] Banerjee and Sarma, 50.

allows nuclear weapons powers to continue testing nuclear weapons."[49] In 1970, Prime Minister Gandhi reiterated her government's stance on peaceful nuclear development to the Rajya Sabha, the upper house of the Indian Parliament. She said, "Government believe that the present policy of developing our scientific and technology capability in expanding our program for the peaceful uses of atomic energy…is in the best overall interest of the nation."[50]

However, P.K. Iyengar wrote that the "…non-aligned countries showed little interest in signing the NPT and resisted losing the sovereign right to develop a new technology which has changed the nature of political security in the world," which suggests that at least some in India had nuclear weapons ambitions at the time of the NPT's signing.[51] Indeed, some Indian nuclear scientists had been conducting nuclear explosives-related research, despite Sarabhai's personal opposition to the research.[52] Indian policymakers' opposition to developing nuclear weapons, including by Mrs. Gandhi and Sarabhai, limited the scientists' research activities, but other events in South Asia would soon change the direction of the nuclear program.

In 1971, U.S. President Richard Nixon decided to send a U.S. Navy flotilla into the Bay of Bengal during the Indo-Pakistani War. The war ended in Indian victory, and Bangladesh broke away from Pakistan. Yet, Mrs. Gandhi perceived that Washington had supported Pakistan from the beginning of the war.

---

[49] Department of Atomic Energy, "India's Nuclear Policy," in *The Indian Atom: Power & Proliferation*, ed. Dhirendra Sharma (New Delhi: Committee for a Sane Nuclear Policy, 1986), 51.
[50] "Indian Prime Ministers on Nuclear Strategy: 1957-1974," 79.
[51] Iyengar, 41.
[52] Jacques E.C. Hymans, *The Psychology of Nuclear Proliferation: Identity, Emotions, and Foreign Policy* (New York: Cambridge University Press, 2006), 182.

More troubling, Indian intelligence learned in 1972 that Pakistani leader Zulfiqar Ali Bhutto had "…called a meeting of eminent scientists in Multan in January 1972 an announced his desire and decision to make Pakistan a nuclear weapon state."[53]

In September 1972, Mrs. Gandhi visited Trombay and discussed conducting a nuclear explosive test with DAE nuclear scientists. According to Iyengar, Mrs. Gandhi was shown a model of the nuclear device and asked how much it would cost, and then AEC chairman Homi Sethna replied "…by saying that we don't ask for money." Mrs. Gandhi then authorized DAE to develop a device and notify her when ready.[54]

4.2.3 Pokhran-I and Nuclear Isolation (1974-1990)

India's quest to construct and test a nuclear explosive device successfully culminated on 18 May 1974. On that day, India conducted its first nuclear test at Pokhran (thus giving the test the formal name of Pokhran-1) in the northwestern state of Rajasthan. British seismic sensors indicated a yield of 8 kilotons, while the Indian seismic indicated a yield of 10 kilotons.[55] The device used plutonium recovered from spent fuel from CIRUS in an implosion design.[56]

After the test, AEC declared that the test was "…part of the program to keep India abreast of developments in underground explosions technology, particularly with reference to its use in the field of mining and earthmoving

---

[53] Hymans, 185.
[54] Iyengar, 78.
[55] Iyengar, 36.
[56] Carey Sublette, "India's Nuclear Weapons Program – Smiling Buddha: 1974," last modified November 8, 2001, http://nuclearweaponarchive.org/India/IndiaSmiling.html.

operations."[57] In a letter to the Canadian prime minister on 1 June 1974, Mrs. Gandhi wrote, "India remains firmly committed to a policy of nuclear energy for peaceful purposes. We have no intention of production nuclear weapons. India has opposed and will continue to oppose military use of nuclear energy as a threat to humanity."[58] In this way, the Indian government tried to characterize Pokhran-I as a peaceful nuclear explosion (PNE).

Despite these assertions, India's test was met with condemnation from around the world, most notably by Canada and the United States. India's refusal to sign the NPT already had unsettled Ottawa, and Canada decided to end all nuclear cooperation with India after the Pokhran-I test.[59] This significantly slowed down work on the second unit at RAPS and on both units at MAPS. Construction on all of these units began before Pokhran-I, but all of them took over ten years to complete. RAPS-2 did not go online until 1980, which was 12 years after construction began and 8 years after RAPS-1 went online. The construction time for MAPS-1 was from 1971 to 1983, and MAPS-2 took from 1972 to 1985.

Washington also ended all nuclear cooperation with India in response to Pokhran-I. This included shipments of fuel to TAPS. The U.S. Nuclear Non-Proliferation Act of 1978 requires all recipients of U.S.-origin nuclear material or technology to be subject to full-scope safeguards, and this legally barred the United States from shipping fuel for TAPS or any other nuclear cooperation with

---

[57] Department of Atomic Energy, 51.
[58] "Indian Prime Ministers on Nuclear Strategy: 1957-1974," 79.
[59] Mirchandani and Namboodiri, 140.

India. France agreed to supply fuel for TAPS until 1993, but the loss of U.S. cooperation was a significant setback for India's nuclear power program.[60]

In addition, Washington led the formation of the Nuclear Suppliers Group (initially known as the London Group) in 1974. In addition to the United States, the NSG included Canada, France, West Germany, Japan, the Soviet Union, and the United Kingdom, and the group agreed to conduct nuclear commerce only with states that implemented full-scope safeguards.[61] This effectively isolated India's nuclear sector from the rest of the world. Former Managing Director of the Nuclear Power Corporation of India Limited V.K. Chaturvedi summed up the effect of Pokhran-I as thus. "The tests stopped technical aids for setting up nuclear power plants and purchases of reactors. We were forced to prepare everything on our own. It significantly delayed our projects. Financial institutions like the International Monetary Fund and the World Bank did not give us aid. So our projects went into doldrums."[62]

Of course, another major energy-related world event was occurring at the same time as India was preparing for Pokhran-I. The oil crisis of 1973 and subsequent price increase in crude oil in 1974 affected India, as well. India's oil import bill increased from US$414 million in 1973 to US$900 by 1975, which was twice the amount of the country's existing foreign exchange reserves.[63]

---

[60] Banerjee and Sarma, 35.

[61] "History of the NSG," Nuclear Suppliers Group, accessed August 26, 2012, http://www.nuclearsuppliersgroup.org/Leng/01-history.htm.

[62] Banerjee and Sarma, 109-110.

[63] Bhupendra Kumar Singh, *India's Energy Security: The Changing Dynamics* (New Delhi: Pentagon Energy Press, 2010), 27.

However, the impact of the oil crisis was felt disparately across Indian society. As energy analyst Vijay Pande wrote in 1980, “The new energy crisis has primarily affected the higher income deciles of the Indian population…The other 60 percent of the Indian population below and just above the poverty line continue to survive now, as for a long, long time, with a *permanent* energy crisis” (emphasis original).[64] The lower income portion of India’s population relied on non-commercial fuels for energy and was thus not significantly impacted by the increase in crude oil prices. Pande continued by writing, “Many of the current problems of the energy sector are internal to India, and arise in connection with the supply and distribution of indigenous fuels.”[65]

Nevertheless, the Indian economy slowed considerably after the oil crisis. National income grew only 1 percent in 1975, and agricultural production registered only a 1.5 percent growth rate. In response, the Indian government decided to increase domestic oil exploration and reformulate standing national energy policy.[66] The Fuel Policy Committee, which was formed by the government in 1970, recommended making coal the primary source of energy and reducing the rate of growth of oil consumption, in addition to increasing the use of alternative energy sources and increasing energy conservation.[67] Nuclear remained a solution for the long-term energy crisis, but the nuclear industry was not ready to deal with the energy crisis of the mid-1970s, especially in the wake of Pokhran-I.

---

[64] Pande, 153.
[65] Ibid.
[66] Pande, 155.
[67] Pande, 170.

One of the biggest obstacles facing India's nuclear program in the mid-1970s was the lack of heavy water, which is required to operate the indigenously designed PHWRs (i.e., all of India's commercial NPPs except TAPS). India already had experienced this problem with RAPS-1, and RAPS-2 faced a similar situation. As with RAPS-1, the Soviet Union agreed to supply heavy water for RAPS-2. In 1976, Moscow agreed to supply 200 tons of heavy water, under safeguards, to India, and another agreement for 256 tons was made in March 1980. The first shipment of heavy water occurred in May 1980, and RAPS-2 finally went online in November 1980. Indo-Soviet nuclear agreement did not go much beyond these shipments of heavy water, as Moscow was a member of the NSG.[68]

Domestic development of heavy water production was not proceeding smoothly, either. As mentioned in the previous section, the Baroda plant started operating in 1977 but faced a series of shut downs and capacity reductions due to accidents and inadequate feed materials. The plant did not return to full capacity until 1998. Including the Baroda plant, India planned to have four heavy water plants online by 1974 but did not have all four operational until 1985.[69]

Combined with being cut-off from the global nuclear technology market, heavy water shortages led to long construction times for new nuclear reactors. For example, RAPS-1 took seven years from initial construction to grid connection. The next five units (RAPS-2, MAPS-1, MAPS-2, and both units at the Narora Atomic Power Station [NAPS]) all took over ten years from initial

---

[68] Mirchandani and Namboodiri, 142.
[69] Banerjee and Sarma, 51.

construction to grid connection, which was over twice as long as the original estimates of four to five years.[70] By 1990, India had seven operating nuclear reactors, two LWRs and five PHWRs, with an installed capacity of 1,280 megawatts. The delays in commissioning reactors led to nuclear power's share of electricity generation in India dropping from 3.3 percent in 1973 to 2.1 percent in 1990.

India did make some progress on research and development for the three-stage program. In 1977, plutonium-uranium mixed-oxide (MOX) fuel was fabricated at Trombay. MOX fuel would be used in the second stage to power FBRs, and these FBRs would be used to breed uranium-233 for the third stage. Along those lines, the Fast Breeder Test Reactor (FBTR) at the Indira Gandhi Center for Atomic Research (IGCAR) attained criticality in 1985. India utilized the PURNIMA (Plutonium Reactor for Neutron Investigations in Multiplying Assemblies) series of small, low-power research reactors to study the use of uranium-233 fuel, and PURNIMA-I, II, and III achieved criticality in 1972, 1984, and 1990, respectively. Finally, the 100 megawatt, heavy water Dhruva research reactor began operating in 1985 at Trombay and provided India with another plutonium production reactor, in addition to CIRUS.[71]

4.3 Prospect Theory and India's Nuclear Fuel Cycle Decision Making

To summarize the history of India's nuclear development given in Section 4.2, Figure 4.8 displays the nuclear fuel cycle under development in India. India

---

[70] Ibid.

[71] Iyengar, 90-91.

is developing a closed nuclear fuel cycle, which means that spent nuclear fuel is reprocessed to produce new nuclear fuel that is loaded back into reactors. India's closed nuclear fuel cycle differs from other closed nuclear fuel cycles, such as the one employed in Japan, in that India's fuel cycle is based on thorium and heavy water reactors and not on uranium and light water reactors. The three stages of India's nuclear fuel cycle are displayed in Figure 4.8.[72]

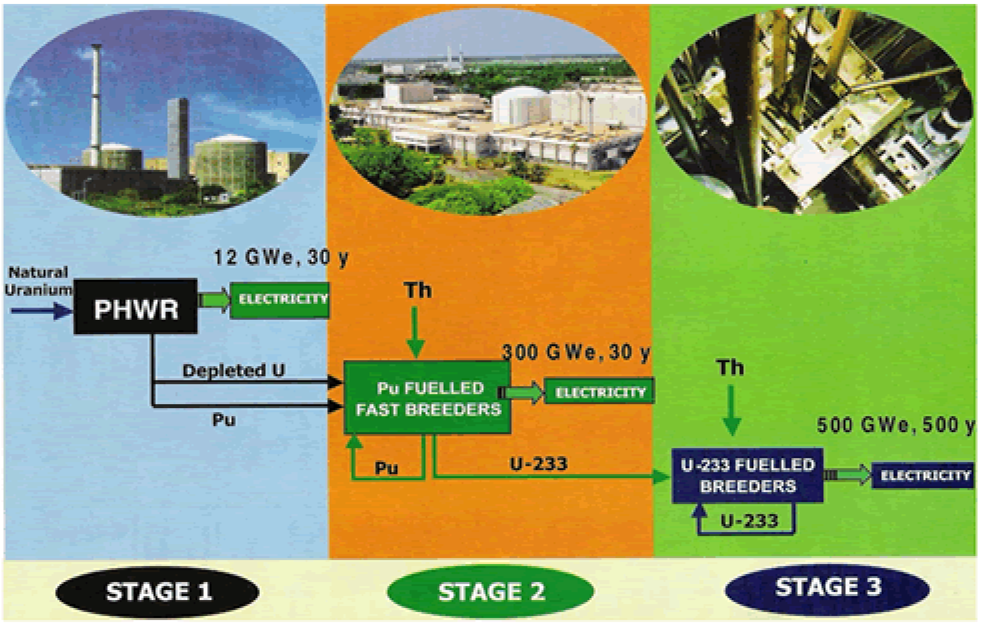

Figure 4.8 – India's Nuclear Fuel Cycle

Not included in Figure 4.8 are the two LWRs operating at TAPS. Those two reactors require low enriched uranium (LEU). Currently, India sends natural uranium to China to be enriched and then reimports the LEU to make fuel for

---

[72] "Thorium Fuel Cycle," Bhabha Atomic Research Centre, accessed September 10, 2012, http://www.barc.ernet.in/reactor/tfc_3sinpp.html.

TAPS.[73] Enrichment for TAPS fuel is the only external assistance that India receives for its nuclear fuel cycle. All other steps of India's nuclear fuel cycle, including everything shown in Figure 4.8, are performed domestically. This is due largely to the isolation of India's nuclear industry from the global nuclear market after Pokhran-I.

India has remained committed to developing the three stage nuclear program, including reprocessing and FBRs, since the initial stages of the program. Thus, the general question to examine with prospect theory is why India chose this particular fuel cycle to develop, and three more specific questions arise out of the historical review of India's nuclear sector.

1. Why did India decide to develop a nuclear fuel cycle based on natural uranium and thorium?
2. Why did India not sign the NPT?
3. Why did India conduct a nuclear test in 1974 and accept isolation of its nuclear industry?

4.3.1 India's Nuclear Fuel Cycle Decision Making

A summary of the technical decisions made in India during the development of its nuclear sector is presented in Table 4.1. This list of decisions certainly does not include every decision made. Other decisions, including nuclear reactor design, are important, but Table 4.1 represents the major nuclear

---

[73] International Atomic Energy Agency, *Country Nuclear Fuel Cycle Profiles*, 2nd ed. (Vienna: International Atomic Energy Agency, 2005), 49, http://www-pub.iaea.org/MTCD/publications/PDF/TRS425_web.pdf.

fuel cycle decisions that were made, principally whether to develop ENR technology for civilian and/or military use.

CIVILIAN TECHNOLOGY	RESULT
Electric Power Generation	Yes. 20 NPPs provided 3.7 percent of electricity in 2011.[74]
Acquire/Develop Enrichment and Reprocessing (ENR) Technology	Yes. Indigenously developed enrichment and reprocessing, but neither capability is at commercial scale yet.
Achieve Nuclear Power Plant Independence	Yes. Domestic firms able to design, construct, and operate NPPs.
MILITARY TECHNOLOGY	**RESULT**
Acquire/Develop Nuclear Weapons	Yes. Decided to develop nuclear explosive in early 1970s.
Test Nuclear Explosive Device	Yes. Pokhran-I and Pokhran-II demonstrated nuclear weapons capability.
Nuclear Weapons Hedging	No.

Table 4.1 – Civilian and Military Nuclear Technology Decision in India

With this summary in mind, the three questions presented above will be analyzed in order to determine the main factors influencing Japan's nuclear fuel cycle decision making and how this decision making fit into Japan's overall strategy.

Why did India decide to develop a nuclear fuel cycle based on natural uranium and thorium?

Bhabha and Nehru often echoed each other in presenting their reasoning for developing nuclear energy in India. Former AEC chairman M.R. Srinivasan

---

[74] "India," International Atomic Energy Agency, last modified December 29, 2012, http://www.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=IN.

wrote, “Our politicians constantly reminded us that we had missed the Industrial Revolution and that we should not miss the atomic revolution,” and “Nehru often reminded his audiences how societies in the West had progressed by putting science and technology to work on problem solving and wealth creation, but many of us had no clear idea of how science and technology would transform our society.”[75] Bhabha expressed similar sentiments in 1961 by stating that underdeveloped countries were some 20 to 50 years behind in modern technology as compared to industrialized nations. To avoid a similar fate with nuclear technology, Bhabha then advocated for India to train scientists and engineers and build facilities for nuclear research.[76] Thus, Bhabha and Nehru believed that developing science and technology, particularly nuclear technology, was the path to India’s modernization and competing with other world powers, especially the West.

Bhabha and Nehru accordingly viewed that India must develop nuclear energy on a principle of self-reliance. The building of the Apsara reactor in the mid-1950s by Indian scientists and engineers at Trombay was exemplary of this principle. One of Bhabha’s close associates, Raja Ramanna, reminisced about the experience of building the Apsara reactor during a talk in 1974. “…[T]here were still many people not willing to believe that we could establish a modern technology in the country by ourselves. The country seemed to be covered in a cloak of non-self-reliance. People in general felt that every thing had to be imported from abroad, be it ideas or equipment. We realized that to cash in on the

---

[75] M.R. Srinivasan, *From Fission to Fusion: The Story of India’s Atomic Energy Programme* (New Delhi: Viking, 2002), 14.
[76] Jain, 1.

success of Apsara we had to take a series of steps to make ourselves not only self-sufficient in quantity but in quality also."[77] Training Indian scientists and building facilities, such as the Aspara reactor in Trombay, were in line with a principle of self-reliance, but that was not the only aspect of the nuclear energy program in which India strived to be self-reliant.

Before the Lok Sabha in 1957, Nehru said, "If we depend too much on others for fissionable materials, then inevitably that dependence may affect us in the sense that other people may try to influence our foreign policy or any other policy through that dependence." Given India's thorium deposits, Bhabha formulated the three stage program that utilized natural uranium and thorium. In this way, India would breed its own fissile material, namely uranium-233 and plutonium-239, and not be dependent on imports of enriched uranium or other fissile materials. Iyengar wrote that Bhabha "…strongly believed that a self-reliant nuclear program can only be based on indigenous resources, and hence formulated the three-phase program: natural uranium, plutonium, and then on to thorium," and Bhabha had "…a strong belief that sustainability and security of energy sources can come only through the natural resources of that country."[78]

All of this reasoning was included in the central government's acceptance of Bhabha's three stage program in 1960. In endorsing the launching of a nuclear power program for India, the central government cited the following factors, among others:[79]

---

[77] Ramanna, 65.
[78] Iyengar, 181.
[79] Atomic Energy Commission, 6.

1. A core of talented, trained, and devoted scientists and engineers at Trombay who had acquired experience through the construction of the Apsara, ZERLINA, and CIRUS reactors;
2. Uranium reserves in Bihar and thorium reserves in Kerala;
3. Indian scientists ability to fabricate uranium fuel, demonstrated through fabricating fuel for CIRUS;
4. Inadequacy of and uneven distribution of India's coal and oil reserves;
5. Low fueling cost of nuclear power plants;
6. Avoiding developing nuclear technology too late.

These factors encapsulated the vision of Bhabha and Nehru to utilize India's indigenous human and natural resources to develop nuclear power, and they set India down a path toward nuclear self-reliance based on Bhabha's three stage program.

Of course, an exception to the three stage program was India's first NPP, TAPS. Bhabha took this step to demonstrate both the economic viability of nuclear power in India and to justify the research and development work of the AEC.[80] After TAPS, India's nuclear power efforts focused on indigenously developing the three stage program.

Why did India not sign the NPT?

The Treaty on the Non-Proliferation of Nuclear Weapons, commonly referred to as the Non-Proliferation Treaty (NPT), was signed on 1 July 1968 by the Soviet Union, the United States, and the United Kingdom. The NPT divided

---

[80] Banerjee and Sarma, 33-34.

parties to the treat into nuclear weapon states and non-nuclear weapon states. Nuclear weapon states were defined as a state "…which has manufactured and exploded a nuclear weapon or other nuclear explosive device prior to 1 January, 1967."[81] The grand bargain of the NPT is that the "…non-nuclear-weapon states agree never to acquire nuclear weapons and the NPT nuclear-weapon states in exchange agree to share the benefits of peaceful nuclear technology and to pursue nuclear disarmament aimed at the ultimate elimination of their nuclear arsenals."[82] After being ratified by enough governments, the NPT came into force on 5 March 1970. One of the countries conspicuously absent from the NPT was and still is India. New Delhi's refusal to sign the NPT was a matter of much concern for the other world powers, as India had a burgeoning nuclear program and was a leader of the Non-Aligned Movement.

India's opposition to the NPT had its roots in the country's concerns over the creation of the International Atomic Energy Agency (IAEA) in 1957. After U.S. President Dwight D. Eisenhower announced the Atoms for Peace program in 1953, the United Nations convened negotiations to create the IAEA, which would facilitate and monitor international trade in nuclear technology. Early on, India's ambassador to the United Nations, Krishna Menon, emphasized that the "…newly-independent countries…could not permit the proposed Agency to be of such a character that the resources for the development of atomic energy were

---

[81] "Treaty on the Non-Proliferation of Nuclear Weapons," United Nations Office for Disarmament Affairs, accessed December 28, 2012, http://www.un.org/disarmament/WMD/Nuclear/NPTtext.shtml.

[82] Thomas Graham Jr., "Avoiding the Tipping Point," *Arms Control Today*, November 2004, http://www.armscontrol.org/act/2004_11/BookReview.

utilized in the contest of colonial exploitation."[83] Menon wanted to ensure that each country was able to achieve self-reliance in technological development and that each country's interests were reflected in the negotiations. Making a statement that could be seen as a prelude to the NPT, Menon said, "We are not prepared to accept the position that because the Soviet Union agrees with the United States, all problems of the world are solved."[84]

India's principal objections to the negotiations were regarding the safeguards provisions in the proposed IAEA Statute. Bhabha was deeply concerned with proposed safeguards that would be applied to countries receiving nuclear materials and technology, while the supplier countries would not be subject to the same safeguards. Bhabha believed that this would discriminate against under-developed countries that would require more IAEA assistance and create a situation where "…a large part of the world is subject to controls and the other free from them, we will stand on the brink of a dangerous era sharply dividing the world in atomic haves and the have-nots dominated by the Agency."[85] Bhabha believed that the safeguards could be used to restrain developing countries and warned that the IAEA should not put "…a new-born infant into chains in order to ensure that it will never grow up into a criminal."[86]

India ratified the Statute of the IAEA in 1957, but the concerns of Menon and Bhabha were reflected in India's instrument of ratification. India included the following statement with its ratification, "If safeguards are applied by the Agency

---

[83] Jain, 26.
[84] Jain, 19.
[85] Jain, 34.
[86] Jain, 35.

only to those States which cannot further their atomic development without the receipt of aid from the Agency or the other Member States, the operations of the Agency will have the effect of dividing Member States into two categories, the smaller and less powerful States being subject to safeguards, while the Great Powers are above them. This will increase rather than decrease tensions."[87] These sentiments and objections would arise again concerning the NPT.

After the creation of the IAEA, India went on to be a strong advocate for nuclear disarmament and supported the Partial Test Ban Treaty of 1963. In fact, Nehru, Indira Gandhi, and Rajiv Gandhi all made proposals for universal nuclear test bans and disarmament. Yet, from Indira Gandhi forward, Indian leaders refused to sign the NPT. Hymans explains this stance as such, "…the principle of non-discrimination mattered to Nehruvian India, and this is what kept it from supporting the NPT while promoting a universal test ban."[88]

This principle was expressed clearly during the negotiations to create the IAEA and was reiterated during the NPT negotiations. A poll of Indian elites at the time found that they both opposed India developing nuclear weapons and the discriminatory NPT.[89] Even after conducting the Pokhran-I nuclear test in 1974, the DAE reiterated India's position concerning the NPT. India's refusal to sign the NPT was "…not because she has any desire to become a nuclear weapons power but because the Treaty is discriminatory while it allows nuclear weapons

---

[87] Jain, 41-42.
[88] Hymans, 174.
[89] Hymans, 175.

power to continue testing nuclear weapons, it prevents others from even developing underground nuclear explosions technology for peaceful purposes."[90]

Iyengar goes deeper into the Indian psyche to explain his country's opposition to the NPT. "This situation is a direct result of centuries of colonial rule and our subjugation to the diktats of foreign power…We cannot forsake our right to be able to do independent research, add to the technologies that we need to develop and the freedom to pursue an independent nuclear policy both for strategic as well as civil uses."[91] He continues to write that the attempt to restrict trade in and development of nuclear technology through sanctions or safeguards is "…contrary to human dignity, especially for a nation with an ancient history and which has propelled Buddhism and other philosophical ideas throughout the globe."[92]

Thus, India opposed the NPT on the grounds that it was discriminatory and restricting. In particular, the NPT was discriminatory and restricting to a country like India. Under the NPT, India's burgeoning nuclear energy program would have been completely subject to IAEA safeguards, and India would be denied the right to make nuclear weapons. This would prevent India's nuclear program from achieving its principle goals of technological self-reliance and equity with the industrialized powers. Acquiescing to the conditions of the NPT was not acceptable to Indian leaders.

---

[90] Ramanna, 59.
[91] Iyengar, 45.
[92] Ibid.

Why did India conduct a nuclear test in 1974 and accept isolation of its nuclear industry?

As with India's decision not to sign the NPT, the decision to conduct a test nuclear explosion in 1974, dubbed Pokhran-I, was not a simple decision and has an important backstory to it. The test came as quite a surprise to outside observers, both from technical and political perspectives. Pokhran-I also resulted in harsh sanctions imposed on India, which effectively isolated India's nuclear program from the global nuclear market.

Iyengar claims that the decision in the 1950s to build the CIRUS heavy water reactor, which is a type of reactor that is relatively efficient at producing plutonium, shows that Bhabha "…had in mind perhaps priority for being able to produce plutonium as fast as possible and thus the raw material for making the atom bomb."[93] Nuclear scientists in Trombay also conducted research related to nuclear explosives, such as on forming a plutonium pit and triggers for an implosion weapon, in the 1960s and early 1970s, before receiving the order from Indira Gandhi in 1972 to assemble a nuclear explosive. Despite what may have been nuclear hedging on the part of Bhabha and the AEC, Indian prime ministers resisted giving authorization to develop nuclear weapons until 1972.

This political opposition to nuclear weapons was defined by Nehruvian thought. Hymans explains, "For the Nehruvians, nuclear weapons represented the fundamental corruption of Western modernity, which India should not merely reject itself but also teach all humanity to spurn."[94] Nehru desired to modernize

---

[93] Iyengar, 27.
[94] Hymans, 176.

Indian society through indigenous development of science and technology, but not to the extremes of developing nuclear weapons. Again, Hymans writes, "…Nehru set a clear path for India: for autonomous nuclear technology, but against nuclear weapons."[95]

Nehru's successors, Shastri and Indira Gandhi, followed this thinking, even after the Chinese nuclear test in 1964. In response to a nuclear-armed China, Shastri and Mrs. Gandhi both sent envoys in search of a security guarantee from the United States, the Soviet Union, and the United Kingdom, but this effort failed. However, both leaders sought a guarantee from Washington, Moscow, and London to protect all non-nuclear weapon states from a nuclear attack, in line with New Delhi's policy of non-alignment. Shastri and Mrs. Gandhi both viewed autonomous economic development and a foreign policy of friendship with all countries as the best way to guarantee Indian security, and building nuclear weapons would decrease Indian security.[96] When asked in 1968 about the ability of nuclear weapons to preserve Indian security, Menon reflected this attitude by responding, "You are saying that the nuclear bomb is a weapon of security. I deny that this is so even for the United States or the USSR." Menon added, "China gains politically from that damn bomb because it obtains for her an entry into international circles. We don't need that."[97] Indian leaders questioned the utility of nuclear weapons and strove not to get caught up in Cold War nuclear politics.

---

[95] Hymans, 177.

[96] Hymans, 177-181.

[97] "Krishna Menon's View on Nuclear Policy: 1968," in *The Indian Atom: Power & Proliferation*, ed. Dhirendra Sharma (New Delhi: Committee for a Sane Nuclear Policy, 1986), 27-28.

As with the decision not to sign the NPT, New Delhi asserted independence in its nuclear policy by deciding not to pursue nuclear weapons, even in the face of a nuclear-armed China. Then what happened to push Indira Gandhi, Jawaharlal Nehru's daughter, to authorize the AEC in 1972 to build and test a nuclear explosive? Certainly, the 1971 war that ended with Bangladesh breaking away from Pakistan and saw the United States send an aircraft carrier into the Bay of Bengal, perceived as Washington supporting Islamabad in the war, was unsettling to Mrs. Gandhi. What seems to have been the tipping point was Bhutto declaring in Multan in 1972 that he intended to make Pakistan a nuclear weapons state. Shortly after Mrs. Gandhi learned of Bhutto's declaration, she confided to a friend that India needed to conduct a nuclear test to demonstrate the country's ability to the rest of the world.[98]

Mrs. Gandhi viewed Bhutto's declaration at Multan as a sign of what the great powers were allowing Pakistan to do. Hymans writes that Mrs. Gandhi came to view an Indian nuclear test as a reminder that India was a great power, too, and that the other great powers needed to restrain Pakistan. She then decided to authorize a one-off nuclear test, which would demonstrate both India's power and self-restraint.[99] Once again, this showed Indian leaders' desire to be technologically self-reliant and equal to the great powers.

In the immediate aftermath of the Pokhran-I test, the AEC and Mrs. Gandhi emphasized that it was a peaceful nuclear explosion (PNE). The AEC proclaimed that the test "…was part of the program to keep India abreast of

---

[98] Hymans, 185.
[99] Hymans, 186-187.

developments in underground explosions technology," and in an interview with *Newsweek*, Mrs. Gandhi said, "We don't intend to use this knowledge or this power for any other than peaceful purposes."[100] A DAE memo defending the peaceful nature of India's nuclear program, including the Pokhran-I test, claimed that India "…made no secret of her intention to develop…" underground nuclear explosive technology.[101] The memo cited two statements made by Mrs. Gandhi made to the Indian parliament that included intentions to develop peaceful nuclear explosives, but the statements are dated November 1972 and November 1973, after Mrs. Gandhi decided to conduct a nuclear test in order to demonstrate Indian power.[102] These brief political statements aside, Pokhran-I came as a surprise to the world, and Iyengar attributes this to the preparations being a "…small deviation from the normal work carried out by many scientists and engineers at Trombay."[103] The unauthorized research conducted in Trombay in the late 1960s and early 1970s combined with the nuclear program's policy of self-reliance paid off in keeping preparations for Pokhran-I secret.

The potential use of PNEs had been conducted by the IAEA and other countries, but the reaction from world powers to sanction and isolate India's nuclear program suggest that most outside observers did not view Pokhran-I as a PNE. Isolation certainly slowed the development of India's nuclear power program, but India's nuclear scientists saw this as a necessary cost in order to maintain independence and self-reliance in nuclear affairs. As Iyengar writes,

---

[100] Department of Atomic Energy, 55.
[101] Department of Atomic Energy, 56.
[102] Ibid.
[103] Iyengar, 33.

"Fifty years of managing the nuclear program while suffering humiliation of discrimination in the international fora has not weakened this country's scientists from upholding a tradition."[104] Indira Gandhi also expressed this sentiment, "A nation's strength ultimately consists in what it can do on its own, and not in what it can borrow from others."[105] The result of this stand for self-reliance is a nuclear industry, except for TAPS and RAPS, and nuclear arsenal that are entirely indigenous. This is viewed as carrying out the vision set for India's nuclear program by Nehru and Bhabha.

4.3.2 Indian Policy Drivers

By 1990, nuclear power was generating about 2.1 percent of India's electricity, placing it well behind coal and hydropower and only above renewables in terms of percentage of electricity generated. Natural gas production also surpassed nuclear production by 1990, and natural gas has steadily increased since. Nuclear power, on the other hand, has generated between 1 and 4 percent of India's electricity ever since TAPS went online. Progress had been made on stages 2 and 3 of Bhabha's three stage program, but only stage 1, generating electricity and plutonium in PHWRs, had attained commercial viability (this still holds true today). India had developed the ability to design, construct, and operate all the facilities necessary for its nuclear program, partly out of a principle of self-reliance and partly due to the isolation imposed after Pokhran-I.

---

[104] Iyengar, 45.
[105] Iyengar, 78.

Of course, Pokrhan-I proved India was capable of building an indigenous nuclear explosive, but a moratorium on further testing after Pokhran-I left India's nuclear weapons status somewhat ambiguous.[106] As Iyengar writes, "A country can declare itself a weapon country when it has an arsenal in which all the devices are certified as for its yield is concerned."[107] Thus, Pokhran-I proved India could produce nuclear weapons, not that the country possessed an arsenal of nuclear weapons.

On the diplomatic front, India forged its own path by leading the NAM and refusing to sign the NPT. The refusal to sign the NPT reflected earlier concerns expressed during the creation of the IAEA. New Delhi viewed the NPT as the major powers (i.e., the United States and the Soviet Union) attempting to control the nuclear policies of under-developed countries. This was not acceptable to Indian leaders and went against their principle of self-reliance and independence.

A review of the history of nuclear development and of the decision making presented in sections 4.2 and 4.3.1 reveals that a desire to be self-reliant and equal to the major powers drove much of India's nuclear decision making. Becoming self-reliant in the nuclear sector was a principal goal for Bhabha, and Nehru emphasized using science and technology to secure India's place among the great powers. Even after Bhabha's and Nehru's deaths, these themes dominated Indian thinking in nuclear and foreign policy making.

---

[106] This moratorium abruptly ended in May 1998 when India conducted a series of nuclear weapons tests dubbed Pokhran-II. This series of tests affirmed that India had an active nuclear weapons arsenal, not merely the capability to produce nuclear weapons.

[107] Iyengar, 37.

Certainly, India's colonial legacy left a lasting mark on Indian leaders. India has a history of being one of the world's great civilizations, but British colonial rule lowered India's standing in the world. After achieving independence in 1947, Indian leaders sought to restore India's place among the world powers, and they sought to do this in a self-reliant and independent fashion. India's independence came just as the nuclear age was dawning, so it only made sense that developing nuclear energy became a strategic imperative for India. Other factors certainly influenced Indian decision making, and Table 4.2 summarizes these factors.

DOMESTIC	**INFLUENCE**
Bureaucratic Interests	Nehru gave Bhabha nearly complete control of the nuclear program, and after Bhabha's death, DAE continued to control program. However, nuclear explosives development and testing was done at the order of the prime minister.
Centralization of Power/Strength of Leader	Power over the nuclear program was centralized in the DAE. Nehru defined Indian science and foreign policy, and his legacy was carried out by his daughter, Indira Gandhi.
Energy Security Sensitivity	Moderate sensitivity. Domestic reserves of coal, natural gas, thorium, and uranium mitigated concerns over energy imports.
Nature of Regime/Leader	India has been democratic since achieving independence from the United Kingdom in 1947. **Nehru and other leaders have been nationalistic in their desire to maintain and demonstrate a strong, independent India.**
GEOPOLITICAL	**INFLUENCE**
U.S. Relationship	U.S. support of Pakistan has caused

	tension in the U.S.-India relationship, particularly during the early 1970s. India’s leadership in the NAM and desire to remain outside of Cold War politics led to disputes with Washington, such as over the NPT.
Security Threats	China was the principal security threat during the Cold War era, particularly after losing a border war with China in 1962 and China’s nuclear test in 1964. Pakistan also has been an enduring source of conflict and instability.
Access to International Energy Markets	Good. Ties with the Middle East, leadership of developing countries, and not being aligned with Washington reduced impact of oil shocks of the 1970s. Domestic energy reserves insulates India somewhat from external energy shocks.
Nonproliferation Norms Adherence	India has supported universal nuclear test bans and disarmament but did not accept norms imposed by other great powers, namely the NPT. **Independence and self-reliance in nuclear and foreign policy making was more important than accepting nonproliferation norms as defined by the great powers.**

Table 4.2 – Political Factors Influencing Indian Decision Making

Using self-reliance and equity as the primary driver, India’s nuclear fuel cycle decision making from the 1950s until 1990 is in line with the tenants of prospect theory. Nehru made developing science and technology part and parcel of India’s strategy to achieve self-reliance and equality, and he gave Bhabha the authority to develop the latest and most powerful field in science, nuclear energy. As India built nuclear facilities, including research reactors and a reprocessing facility at Trombay, Indian leaders placed high value on these facilities (endowment effect) and became risk averse in the nuclear field. The NPT was the first real threat to Indian policies of self-reliance and equality in nuclear affairs. Indian leaders perceived that they could either: 1) sacrifice self-reliance and equality in exchange for guaranteed nuclear assistance from the great powers, or 2) not sign the NPT to preserve self-reliance, despite pressure from the great powers. Risk-averse Indian leaders perceived the latter as less risky and chose not to sign the NPT.

Interestingly, it does not seem that China's nuclear test in 1964, coming two years after India lost a border war with China, pushed Indian leaders into a losses frame. The Indian response to China's nuclear test was to conduct a "…half-hearted search for a generic UN guarantee covering all non-nuclear states, and a few theoretical studies of nuclear explosions."[108] Neither Shastri nor Mrs. Gandhi desired to be covered by the U.S. of Soviet nuclear umbrella because that would risk Indian self-reliance, and as stated earlier, Indian leaders believed that developing an Indian nuclear deterrent in response to China would decrease Indian security.

India's response to Pakistan's desire to develop nuclear weapons was different, but it was not necessarily a Pakistani nuclear weapons capability that Indian leaders feared at the time. In his Multan speech, Bhutto said that Pakistan would acquire nuclear weapons even if it required Pakistanis to eat grass. P.N. Haskar, Mrs. Gandhi's chief secretary, said in response, "If by eating grass one can produce atom bombs, then by now cows and horses would have produced them. But, of course, the people of Pakistan under the great and charismatic

---

[108] Hymans, 180.

leadership to which they are now exposed might produce a bomb on a diet of grass."[109] In the early 1970s, AEC head Homi Sethna also advised Mrs. Gandhi that it would take Pakistan at least ten years to produce a nuclear weapon.[110] Mrs. Gandhi and her advisers simply did not view Pakistan as one of India's peers, and Pakistan was still reeling from the war that split the country, into what is now Pakistan and Bangladesh, in 1971.

What Mrs. Gandhi viewed as a threat was U.S. support of Islamabad. She believed that Pakistan could acquire nuclear weapons only if the great powers let it happen, and what Pakistan was being allowed to do was a serious problem. Mrs. Gandhi then decided to "…send a strong signal to the great powers to rein in Pakistan before things got out of hand," and she believed that demonstrating that India, too, was a great power would prevent the situation from getting worse.[111] Mrs. Gandhi seemed to be in a losses frame with regards to India's international standing and acted risk acceptant by authorizing preparations for Pokhran-I. However, she may not have grasped how risky the idea of conducting a one-off nuclear test was, since she did not think that "…any 'unprejudiced observers' could believe that India – her country, the country of Gandhi and Nehru, a beacon of peace and non-violence throughout the world – wanted nuclear weapons."[112]

Regardless, Mrs. Gandhi was compelled to accept the risks in order to prove India's equity with the great powers. This decision led to the isolation of India's nuclear program, and India was faced either with rolling back their new

---

[109] Hymans, 186.
[110] Ibid.
[111] Hymans, 187.
[112] Hymans, 188.

capacity to produce nuclear explosives or continuing to move forward with all phases of their nuclear program. Losing foreign assistance and access to the global nuclear market was risky for India's technology development, but risk acceptant Indian leaders in a losses frame were willing to accept isolation for the sake of preserving self-reliance in nuclear affairs.

4.4 Alternative Explanations

In the literature review in Chapter 2, several theories of nuclear proliferation and of fuel cycle technology development are reviewed. The two theories of ENR technology development, James Acton's received wisdom and William Walker's technology entrapment, do not apply to India. Bhabha's three stage nuclear program significantly differed from the LWR-based fuel cycle promoted by the United States, and India has been committed to developing the three stage nuclear program rather than being entrapped by it. In addition, India had not reached commercial operation of any fuel cycle facility by 1990, so technology entrapment does not seem to apply.

Of the theories of nuclear weapons proliferation, Scott Sagan's domestic politics model is based on the Indian nuclear weapons program, and Hymans uses India as a case study for his National Identity Conception (NIC) theory. Obviously, these models are focused on India's nuclear weapons program, not necessarily India's nuclear fuel cycle program. It would be most relevant to examine how prospect theory compares with these models' explanation of the decision to conduct Pokhran-I.

In sum, Sagan's domestic politics model states that the acquisition of nuclear weapons can "…serve the parochial bureaucratic or political interests of at least some individual actors within the state, and these actors "…create the conditions that favor weapons acquisition by encouraging extreme perceptions of foreign threats, promoting supportive politicians, and actively lobbying for increased defense spending."[113] Sagan starts his analysis of India's nuclear weapons program first by dismissing his own security model, which would predict that India would have started a crash nuclear weapons program after the first Chinese nuclear test in 1964. His reasons for this are: 1) India did not initiate a concerted nuclear weapons effort after 1964, and 2) India would not accept bilateral security guarantees from either Moscow or Washington because that would have violated India's non-alignment policy. Instead, India's leadership was divided between those who wanted to develop nuclear weapons as soon as possible and those who supported global nuclear disarmament.[114] Sagan then states three factors that suggest domestic political concerns influenced Mrs. Gandhi's decision to conduct Pokhran-I more than international security threats: 1) Mrs. Gandhi was advised by a small number of nuclear scientists, not defense officials, on the matter, 2) The lack of a systematic program for nuclear weapons development and shock over international condemnation means the decision was made in haste, and 3) Domestic support for Mrs. Gandhi's government was very low due to an economic recession (support for the government increased by one

---

[113] Scott D. Sagan, "Why Do States Build Nuclear Weapons? Three Models in Search of a Bomb," *International Security* 21, no. 3 (Winter 1996/97): 63-73.

[114] Sagan, 65-66.

third after Pokhran-I).[115] For these reasons, Sagan concludes that Pokhran-I was conducted for domestic political, rather than international security, reasons.

While this explanation sounds potentially compelling for explaining Pokhran-I, it cannot explain the broad sweep of India's nuclear fuel cycle decision making. Domestic politics do not explain why India pursued the three stage nuclear program. Also, when Indian leaders felt nuclear self-reliance and India's international standing were threatened by the NPT and by a Pakistani nuclear weapons program, they acted according to prospect theory in order to preserve these two aspects of Indian strategy. Mrs. Gandhi's decision to conduct Pokhran-I was not a simple reaction to domestic politics and bureaucratic influence but a reflection of Indian strategy.

Hymans directly addresses the bureaucratic influence proposition by pointing out that Sethna advised Mrs. Gandhi not to worry too much about a Pakistani nuclear weapons program because it would take at least ten years for Pakistan to develop nuclear weapons.[116] Thus, the AEC commissioner passed on an opportunity to advocate for nuclear weapons development. Hymans explain Mrs. Gandhi's decision by examining her NIC. The NIC is a leader's "…sense of *what the nation naturally stands for* and of *how high it naturally stands*, in comparison to others in the international arena [emphasis in original]."[117] He identifies Mrs. Gandhi's NIC as sportsmanlike nationalist. Sportsmanlike leaders are not driven by fear and "…nest the us-them distinction within a broader,

---

[115] Sagan, 67-68.
[116] Hymans, 186.
[117] Hymans, 18.

transcendent identity conception,"[118] and nationalists believe "…the nation can hold its head high in dealings with its key comparison other(s)…"[119] Hymans summarizes Mrs. Gandhi's decision to conduct Pokhran-I as a paradox between "…her sportsmanlike desire to avoid a nuclear arms race…" and "…her inflamed nationalist pride that caused her to misjudge badly the potential international reaction to such a blast."[120]

Hymans also wrote that sportsmanlike nationalists would be unlikely to pursue nuclear weapons or superpower nuclear guarantees but likely to pursue nuclear technology autonomy and resist the nuclear nonproliferation regime.[121] He characterizes Indian prime ministers from Nehru through to 1990 as sportsmanlike nationalists, and his description of a sportsmanlike nationalist's tendencies in the nuclear field seems to fit Indian leaders during this time.

Both Hymans and the prospect theory explanation focus on India's strategy to attain self-reliance in the nuclear field and prove the country's status as a great power. Hymans focuses on the individual prime ministers, whereas the prospect theory explanation has the advantage of being able to cover the prime minister and the broader nuclear enterprise. In the end, Hymans and his NIC theory offer a compelling alternative to the prospect theory explanation given here.

Solingen offers another model of domestic politics guiding nuclear decision making, but in a different way than Sagan proposed. Solingen

---

[118] Hymans, 22-23.
[119] Hymans, 24.
[120] Hymans, 188.
[121] Hymans, 38.

summarized her model thus, “whereas inward-looking models might have regarded nuclear weapons programs as assets in the arsenal of building a regime’s legitimacy and prestige, outward-oriented ones thwarted such latent utility.”[122] India was not an export-driven economy to the scale of Japan or South Korea, but neither was India an inward-looking country. Indian leaders’ desire to demonstrate great power status on the global stage suggests that India was more outward-oriented, so Solingen’s model likely would predict that India would shun nuclear weapons development.

Indeed, Nehru put India on a path of not developing nuclear weapons, and even Mrs. Gandhi did not demonstrate a desire to build a nuclear weapons arsenal, just demonstrate India’s capability. Prospect theory explains why Mrs. Gandhi was driven to demonstrate this capability with Pokrhan-I, and Solingen acknowledges that prospect theory explains why India never relinquished this capability. “…[I]t seems far more costly politically for leaders and ruling coalitions to eliminate their existing nuclear weapons entirely than it would be for those who have not yet acquired such weapons to abandon steps in that direction. This would be the case even for internationalizers and most particularly for those surrounded by inward-looking neighbors, such as India…”[123] The endowment effect described by prospect theory explains why Indian leaders could not relinquish a nuclear weapons capability after demonstrating it with Pokhran-I.

---

[122] Etel Solingen, “Domestic Models of Political Survival: Why Some Do and Others Don’t (Proliferate),” in *Forecasting Nuclear Proliferation in the 21st Century: Volume 1. The Role of Theory*, ed. William C. Potter and Gaukhar Mukhatzhanova (Stanford, CA: Stanford University Press, 2010), 41.

[123] Solingen, 46.

Thus, prospect theory offers more explanatory power regarding Indian nuclear fuel cycle decision making than Solingen's model.

5. CASE STUDY: JAPAN

Figure 5.1 – Political Map of Japan

Japan is an island nation that has a history as a unified polity reaching back thousands of years. The Japanese archipelago lies at the eastern edge of continental Asia and stretches from the island of Hokkaido in the north to the island of Kyushu in the south (see Figure 5.1 for a map of Japan).[1] The Ryukyu Islands, including Okinawa, extend Japan's territory nearly to Taiwan. While Japan does not share borders with any other countries, Korea, Russia, and China all lie in close proximity to Japan, and Japan has deep historical ties with its neighbors in Northeast Asia, particularly China.

---

[1] "Japan," Central Intelligence Agency, accessed January 4, 2013, https://www.cia.gov/library/publications/the-world-factbook/geos/ja.html.

Japan's modern era began in 1854 when Commodore Matthew Perry of the U.S. Navy ended Japan's isolation and forced the country to open up to the outside world, and Japan's feudal government ended during the ensuing Meiji Restoration. Imperial Japan aggressively expanded through and colonized parts of Northeast and Southeast Asia from the late 19th century until being defeated by Allied forces at the end of World War II in 1945. World War II left Japan in ruins, with much of the country's industry and infrastructure destroyed, and the country's military and political systems were dismantled. Allied forces, led by the United States, occupied Japan from the end of World War II until 1952. The United States has maintained a military presence in Japan since 1945 and is principally responsible for ensuring Japanese security. This has made the United States the most dominant external player in Japanese foreign policy, with significant impact on Japan's nuclear sector.

5.1 Historical Economic and Energy Data for Japan

Beginning in the Meiji period, Japan adopted Western economic policies and grew to become the biggest economic power in East Asia during the first half of the 20th century, but as stated above, much of Japan's industry and infrastructure was destroyed during World War II. However, Japan recovered from the ruins of war to record impressive economic growth during the 1950s, which is referred to as the Japanese post-war economic miracle. This growth set the stage for the Japanese economy to really take off in the 1960s, and Japan's gross domestic product (GDP) grew steadily until the early 1990s before growth slowed down during the 1990s in what is now termed the Lost Decade. The post-war economic miracle notably was interrupted by negative growth in 1973 due to the oil crisis of that year.[2] Japan's population growth rate generally decreased as the country's GDP increased and has declined to very low levels since the beginning of the 1990s. Unlike some of Japan's neighbors in Northeast Asia, the country did not experience a population boom during second half of the 20th century (see Figure A.9 through Figure A.12 in the Appendix).[3]

As would be expected with the high economic growth rate experienced in Japan from 1960 to 1990, the country also saw a large increase in energy demand. Between 1960 and 1973, Japan experienced a near four-fold increase in energy demand. This constant increase in energy demand was broken by the effects of the 1973 oil crisis. Energy demand leveled out for about the next ten years before starting to gradually increase again in the mid-1980s and has been fairly constant since the mid-1990s. Figure 5.2 displays the growth in energy use.[4]

The gap in energy use and energy production demonstrates Japan's dependence on imports for meeting energy demand, as the country has little in terms of domestic energy resources. Domestic energy production was nearly constant between 1960 and the mid-1980s, even experiencing a dip in energy production in the mid-1970s, and has increased slightly since the late 1980s. As energy demand grew, this meant that Japan became increasingly dependent on energy imports.

---

[2] "Japan | Data," World Bank, accessed July 19, 2012, http://data.worldbank.org/country/japan.
[3] Ibid.
[4] Ibid.

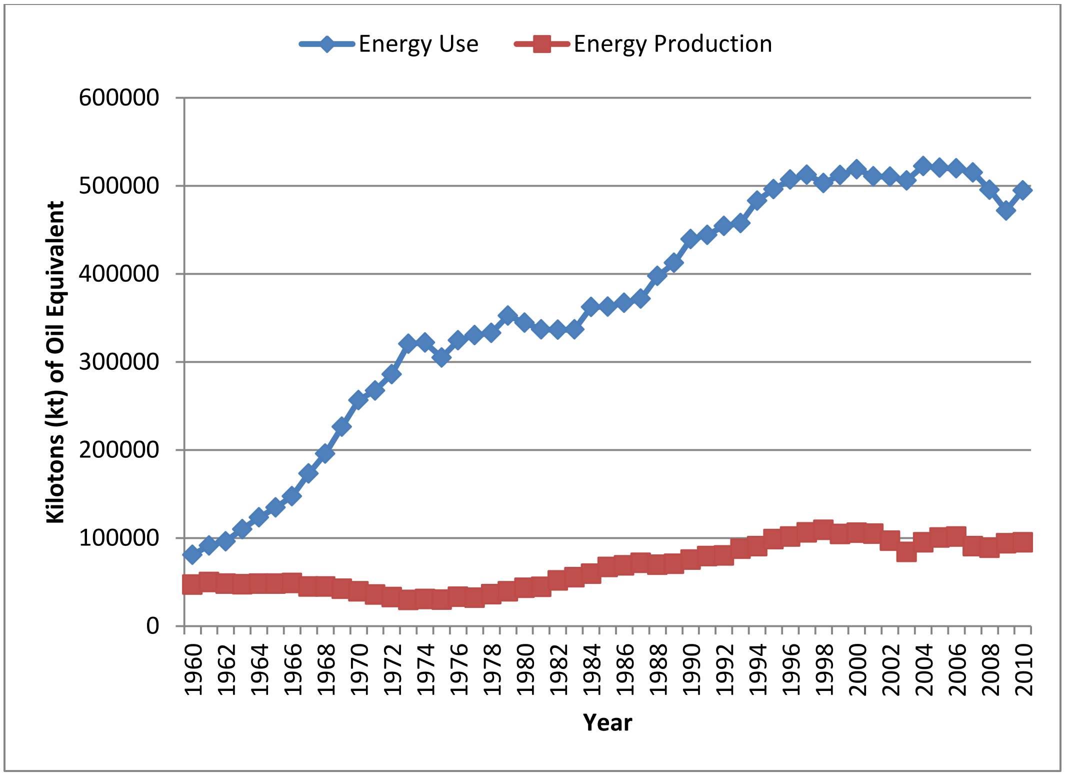

Figure 5.2 – Energy Production and Use in Japan (1960-2010)

5.1.1 Historical Electric Power Sector Data in Japan

Since nuclear power is used primarily to generate electricity, the most relevant portion of Japan's energy sector to analyze is the electric power sector. As with overall energy, Japan experienced tremendous growth in electricity demand after the post-war economic boom started. Figure 5.3 shows the growth in electricity consumption and production.[5] As can be seen in the figure, electricity consumption and production grew steadily, with brief periods of leveling out after the 1973 and 1979 oil crises. Clearly, meeting the growth in demand for electricity became a policy priority for the Japanese government.

---

[5] Ibid.

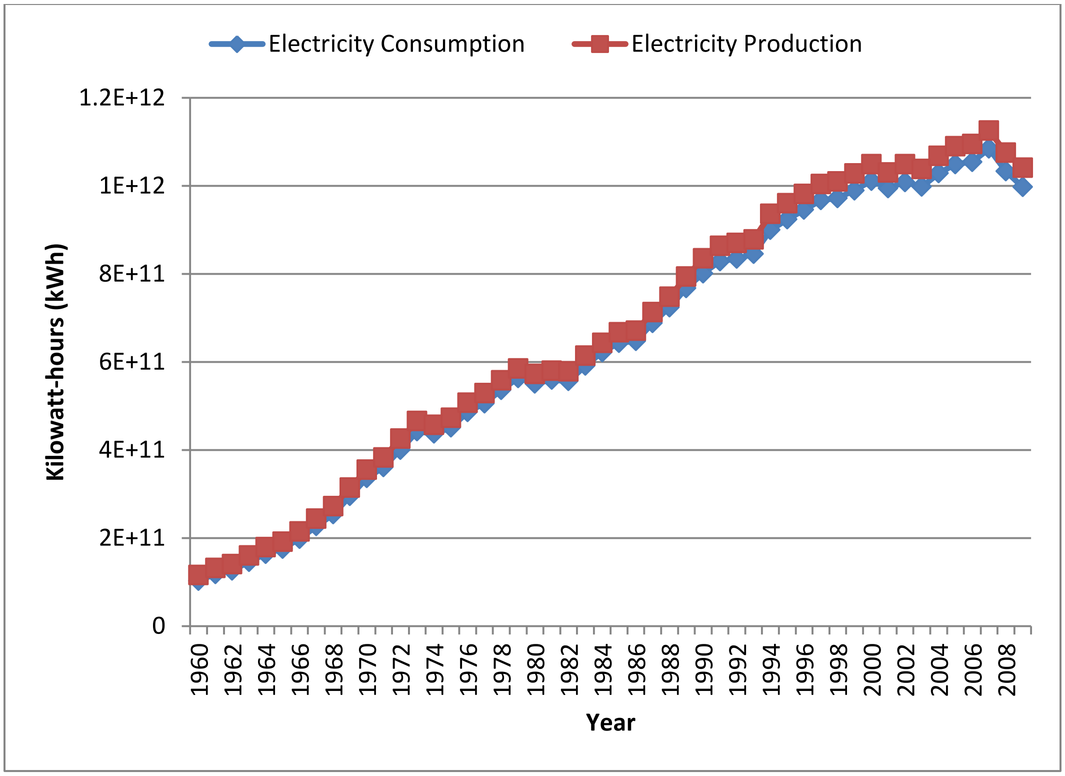

Figure 5.3 – Electricity Consumption and Production in Japan (1960-2010)

Figure 5.4 and Figure 5.5 break down the electric power sector by source.[6] Up until the early 1960s, hydropower generated the majority of Japan's electricity, but oil was used to meet the growth in electricity demand in the 1960s. By 1969, oil generated the majority of Japan's electricity and peaked at 73 percent of Japan's electricity in 1973. With negligible domestic oil reserves, this meant that Japan imported much of the fuel used to meet the country's booming demand for electricity. After the oil crisis, Japan began to reduce its use of oil to generate electricity, and nuclear, coal, and natural gas all increased in output. Since 2000, those three sources each have provided just under 30 percent of Japan's electricity. Use of hydropower has remained roughly the same since the mid-1960s, meaning that hydropower's share of Japan's electricity market has

---

[6] Ibid.

gradually decreased (see Figure A.13 in the Appendix for the steady consumption of hydropower in Japan since 1960).[7] Renewable sources of energy have remained a minor source of electricity, providing between 1 to 2 percent of Japan's electricity. Oil mainly is used as a marginal source of electricity to meet peak load demand.

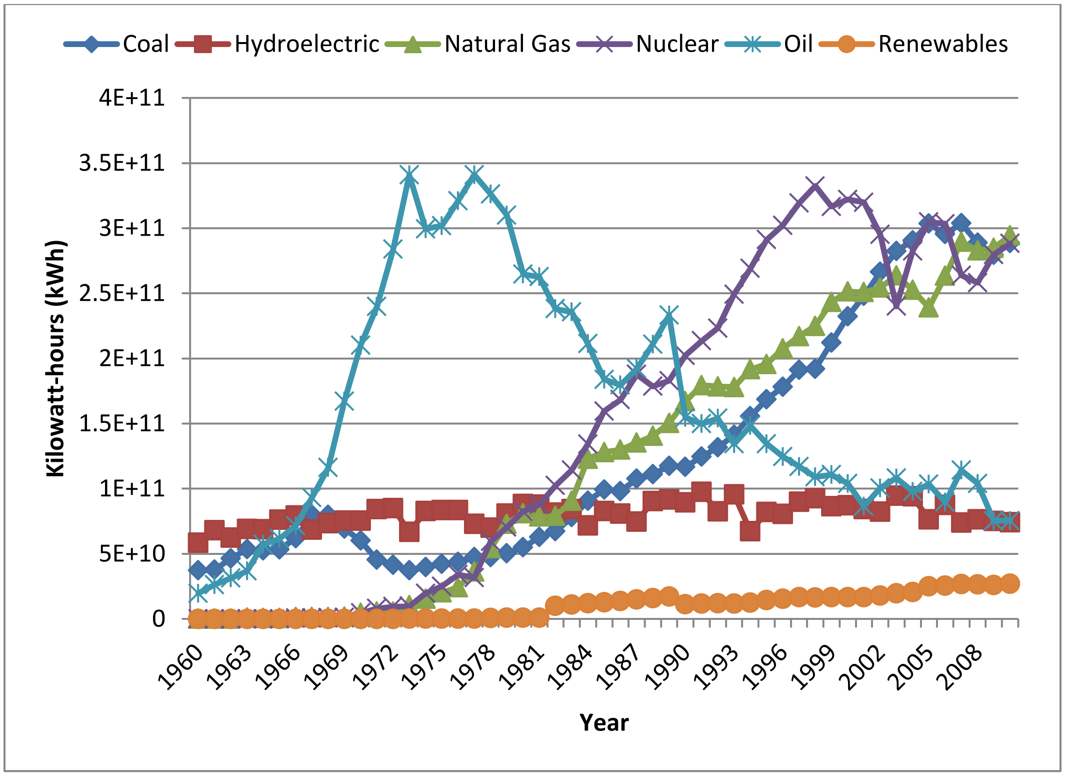

Figure 5.4 – Electricity Production by Source in Japan (1960-2010)

---

[7] "Statistical Review of World Energy 2011: Historical Data," BP, accessed June 10, 2012, http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/spreadsheets/statistical_review_of_world_energy_full_report_2011.xls.

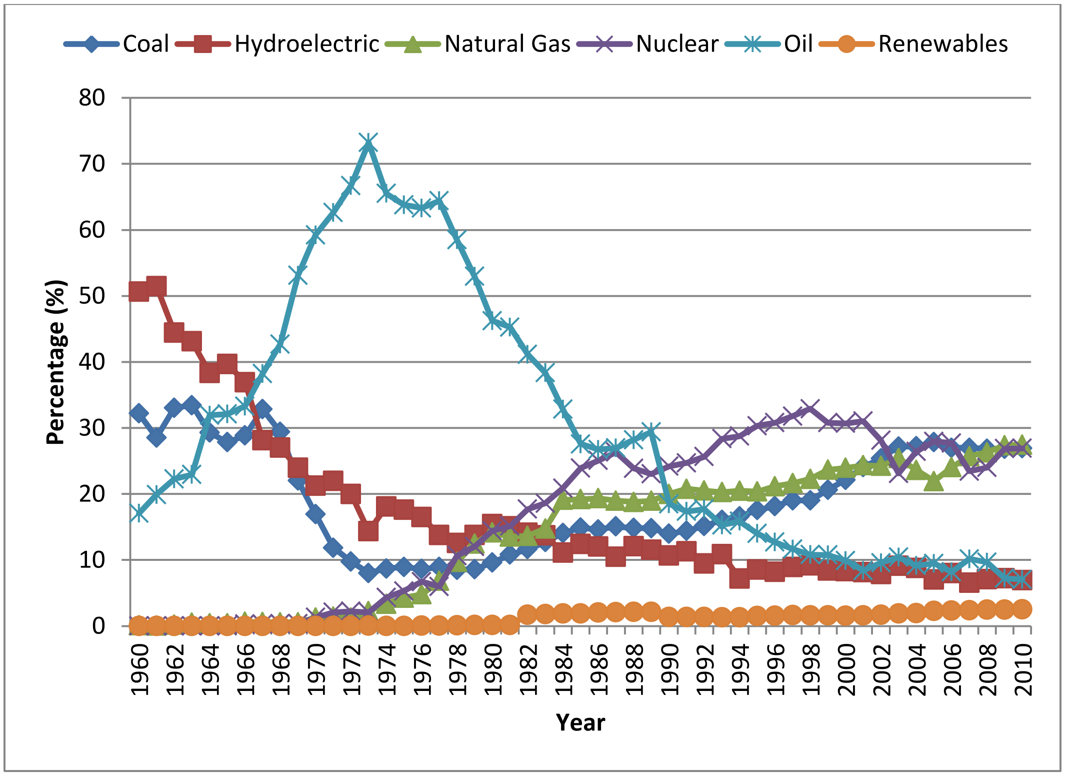

Figure 5.5 – Share of Electricity Production by Source in Japan (1960-2010)

It can be gleaned from Figure 5.5 that use of hydropower is nearly maximized in Japan and has been since the 1960s. Domestic coal production has always been well below consumption, meaning most coal is imported, and has declined to negligible levels (see Figure A.14 in the Appendix).[8] Japan virtually has no oil or natural gas reserves, so renewable energy sources, such as wind and solar, are Japan's only domestic sources of energy.

Aware of the energy situation in their country, Japanese planners saw nuclear energy as a way to create a "semi-national" fuel. A closed nuclear fuel cycle that utilizes spent nuclear fuel reprocessing and plutonium fuel creates fuel while generating electricity. Thus, Japan set out to develop a closed nuclear fuel cycle to alleviate the country's dependence on energy imports.

---

[8] Ibid.

5.2 Nuclear Sector Development in Japan

Japan formally began its nuclear energy program in the mid-1950s and aggressively developed the sector in the following decades. The first reactor to provide power the electric grid, the Japan Power Demonstration Reactor (JPDR), went online in 1963, and the first commercial, Tokai-1, opened in 1966.[9] Japan steadily built nuclear power plants (NPPs) throughout the 1960s, 1970s, and 1980s, and installed nuclear capacity correspondingly grew until leveling off in the mid-1990s (see Figure 5.6).[10] Figure 5.7 shows nuclear power consumption.[11]

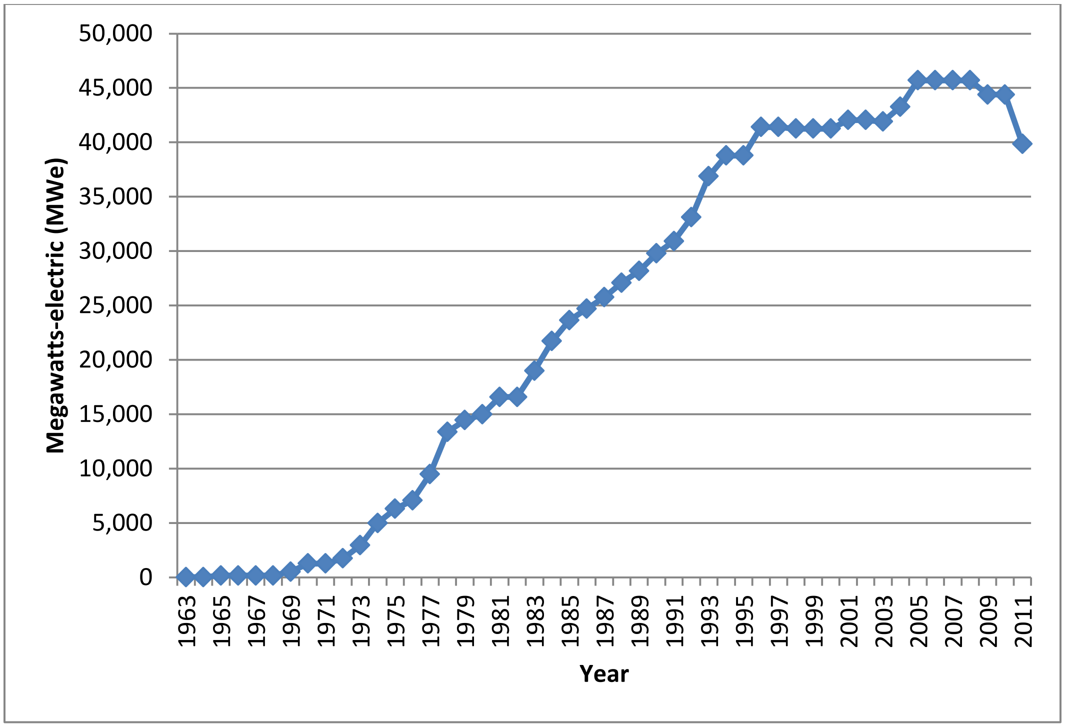

Figure 5.6 – Installed Nuclear Capacity in Japan (1963-2011)

---

[9] "Nuclear Power in Japan," World Nuclear Association, last modified October 22, 2012, http://www.world-nuclear.org/info/inf79.html.

[10] "Reactor Database," World Nuclear Association, accessed June 27, 2012, http://world-nuclear.org/NuclearDatabase/.

[11] "Statistical Review of World Energy 2011: Historical Data."

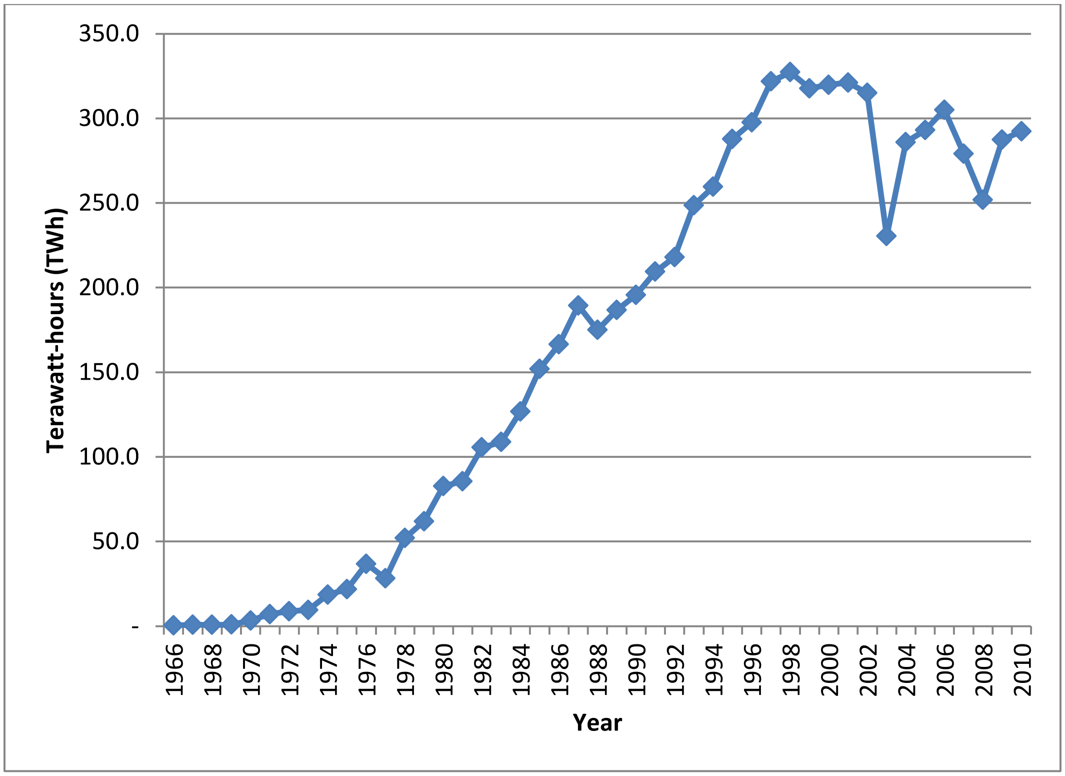

Figure 5.7 – Nuclear Power Consumption in Japan (1966-2010)

The large drop in installed capacity in 2011 is the result of the Fukushima Daiichi Nuclear Power Plant being shut down after the Great East Japan Earthquake and tsunami on March 11, 2011 caused a major accident at that site. Currently, Japan has fifty operational nuclear reactors with an installed capacity of over 44,000 megawatts-electric (MWe).[12] Nuclear power provided roughly 30 percent of Japan's electricity prior to the Great East Japan Earthquake.[13] In addition to this large fleet of nuclear reactors, Japan has several fuel cycle facilities, including uranium enrichment and spent fuel reprocessing, and operates

---

[12] "Nuclear Power in Japan,"

[13] While these nuclear reactors remain operational, all of Japan's nuclear reactors were gradually shut down after the Great East Japan Earthquake to undergo safety inspections and tests. Only two of Japan's NPPs presently provide electricity to the grid.

two experimental fast breeder reactors. Until the Great East Japan Earthquake, Japan was developing indigenously a closed nuclear fuel cycle.

The time frame for this case study of Japan's nuclear fuel cycle decision making is from 1955 to 1987, so the accident at the Fukushima Daiichi Nuclear Power Plant and its effect on Japanese nuclear policy are not included. The case study divides Japan's nuclear development into three phases. The first phase is the initial research and development between 1955 and 1966. The second phase covers 1967 to 1974 and includes Japan's response to the Non Proliferation Treaty (NPT) and the oil shock of 1973. The third phase covers 1975 to 1987 and describes Japan's reaction to Washington's nuclear nonproliferation policy change in the mid-1970s and Tokyo's commitment to developing reprocessing technology.

5.2.1 Initial Research and Development (1955-1966)

Japan's nuclear program got its start in the early 1950s, and the most strident early supporter of nuclear power for Japan was Yasuhiro Nakasone. As a young member of the Diet (Japan's legislature) in 1951, Nakasone petitioned John Foster Dulles to permit Japan to develop nuclear technology.[14] That was just the beginning of Nakasone's advocacy for nuclear power in Japan. Nakasone strove to return Japan to its former great power status and "…believed that mastery of the nuclear fuel cycle was necessary to that end."[15] He used his influence in the

---

[14] Richard J. Samuels, *The Business of the Japanese State: Energy Markets in Comparative and Historical Perspective* (Ithaca, NY: Cornell University Press, 1987), 234.
[15] Jacques E.C. Hymans, "Veto Players, Nuclear Energy, and Nonproliferation: Domestic Institutional Barriers to a Japanese Bomb," *International Security* 36 (2011): 163.

Diet to push the Japanese government to start funding nuclear development in 1954, and when the Joint Diet Atomic Energy Committee was formed in 1955, Nakasone was appointed as chairman.[16]

Also in 1955, the Atomic Energy Basic Law was passed. This law formed the core of Japan's nuclear legal structure. In particular, the law stipulates that Japan's nuclear program must be peaceful and transparent in nature. It states: "…the research, development, and utilization of atomic energy shall be limited to peaceful purposes, aimed at ensuring safety and performed independently under democratic management, the results therefrom shall be made public to contribute to international cooperation."[17]

In the private sector, Matsutaro Shoriki, president of the newspaper *Yomiuri Shimbun*, was an early supporter of nuclear power and established the Committee for the Peaceful Use of Atomic Power in 1954. This committee effectively lobbied the Japanese government to sign a nuclear cooperation agreement with the U.S. government. In the agreement, Washington agreed to supply nuclear fuel for an experimental nuclear reactor, and Japan would form a nuclear energy research agency.[18] Shoriki also was instrumental in forming an association of several hundred relevant private firms called the Japan Atomic Industrial Forum (JAIF). JAIF would turn into one of the most powerful entities that shaped the early direction of nuclear policy in Japan.[19]

---

[16] Ibid.
[17] Emma Chanlett-Avery and Mary Beth Nikitin, "Japan's Nuclear Future: Policy Debate, Prospects, and U.S. Interests," *Congressional Research Service*, February 19, 2009, 8, http://www.fas.org/sgp/crs/nuke/RL34487.pdf.
[18] Samuels, 235.
[19] Samuels, 236.

In 1956, the Japanese Atomic Energy Commission (JAEC) and the Science and Technology Agency (STA) both were established within the office of the prime minister.[20] The JAEC was given authority to formulate broad nuclear policy, and the STA focused on nuclear energy research policy.[21] In the same year, the Japan Atomic Energy Research Institute (JAERI), tasked with conducting nuclear research and development, and the Atomic Fuel Corporation, which carried out mining, smelting, and administration of nuclear fuel materials, were established.[22] The head of the JAEC and of the STA were the same, and Shoriki was appointed as the first head of both agencies.[23]

The basic structure of the government's nuclear policy making was thus formed in the mid-1950s, and it was a top-down approach, as envisioned by Nakasone. The JAEC, reporting directly to the prime minister, would formulate broad, long-term nuclear policy, and the STA would translate JAEC policy into specific research and development objectives that would be carried out by JAERI. The results of JAERI research would then be transferred to the private sector.[24]

Shoriki moved quickly to develop Japan's nuclear industry and proclaimed on 5 January 1956 that Japan would build and operate a nuclear reactor within five years. Given the low level of nuclear technology in the country at the time, this meant that Japan's first reactor would have to be imported from abroad. The only commercial nuclear reactor in operation in the

---

[20] Ibid.
[21] Hymans, 164.
[22] Ichiro Ishikawa, "Present Status of the Development of Atomic Energy in Japan (Especially of Nuclear Power Developments)," in *Proceedings of the Anglo-Japanese Nuclear Power Symposium*, Tokyo, March 1963, 8.
[23] Hymans, 165.
[24] Hymans, 164-165.

world at the time was the Calder Hall NPP in the United Kingdom. Calder Hall was a gas-cooled, graphite-moderated "Magnox" style reactor, and Shoriki selected this design to import for Japan's first reactor. The Japan Atomic Power Company (JAPC) was established in 1957 in order to import Magnox reactors from the United Kingdom.[25]

This project eventually resulted in the Tokai-1 reactor, which was Japan's first commercial NPP. Tokai-1 came online in 1966, three years late (five years after Shoriki's proclaimed timeframe) and 50 percent over the initial budget because of major design and safety problems.[26] Speaking at the Anglo-Japanese Nuclear Power Symposium in Tokyo in March 1963, a member of the JAEC, Ichiro Ishikawa, said that the government did not regret the decision to import a Magnox reactor because it gave Japan "…valuable experience on the construction and operation of nuclear power plant [sic]…"[27]

Japanese power utilities, however, seemed to have disagreed with Ishikawa. The troubles with the Tokai-1 reactor were compounded with JAERI's struggles to develop indigenous nuclear technology. Before Tokai-1 even came online, JAPC announced in May 1963 that Japan's second nuclear reactor would be a U.S.-designed light water reactor (LWR). Following this decision by JAPC, Tokyo Electric Power Company (TEPCO) and Kansai Electric Power Company (KEPCO) both announced plans to import U.S.-designed LWRs, and the other power utilities soon followed suit.[28] With the Japanese economy rapidly growing

---

[25] Ishikawa, 10.
[26] Samuels, 240.
[27] Ishikawa, 10.
[28] Samuels, 240.

in the early 1960s, the Ministry of International Trade and Industry (MITI)[29] sought to maximize electricity production and increase Japan's energy independence. On these points, the utilities sided with MITI, and JAPC was effectively sidelined. The scene was set for Japan to begin large-scale importation and indigenization of U.S.-designed LWRs.

In addition to the struggle to select an appropriate nuclear reactor design for the country, Japan initiated development of its fuel cycle programs during this time. The "Long-Term Program for Development and Utilization of Atomic Energy" was released in 1956 by the JAEC and stated, "…it is our basic policy to conduct reprocessing using domestic technology as much as possible…[for] effective utilization of nuclear fuel resources, [the] breeder reactor is the most appropriate type of reactor for Japan, thus it is our basic goal to develop such type of reactor…"[30] The long-term plan was revised in 1961 and called for the first reprocessing plant to be built by 1971. Thus, from the very beginning, Japan planned to develop reprocessing technology and fast breeder reactors (FBRs) as part of a closed nuclear fuel cycle.

Uranium enrichment technology was not included in the initial long-term plans since Magnox reactors used natural uranium fuel, but the decision to import U.S.-designed LWRs would necessitate that Japan also develop uranium enrichment technology in order to produce low-enriched uranium (LEU) fuel. The 1961 long-term plan called for Japan to begin importing and indigenizing

---

[29] MITI was transformed into the Ministry of Economy, Trade, and Industry (METI) in 2001.
[30] Eugene Skolnikoff, Tatsujiro Suzuki, and Kenneth Oye, "International Responses to Japanese Plutonium Programs," *Center for International Studies* (August 1995), 2, http://ia600507.us.archive.org/23/items/InternationalResponsesToJapanesePlutoniumPrograms/1995-08IntlResponseToJpnsPlutoniumProgram.pdf.

U.S.-designed LWRs and stated, "…it is advisable to construct this type of reactor with a view to acquiring construction technique, propelling home production and training scientists and engineers, etc."[31] Considering that LWRs required enriched uranium, the 1961 plan then called for "…some of enriched uranium required to be manufactured at home during the later half of the second ten-year period [1975-1980]."[32] By the early 1960s, Japan had committed itself to indigenous development of uranium enrichment, spent fuel reprocessing, and FBRs as part of a closed fuel cycle.

There also was some debate in Tokyo about the legality of developing or possessing nuclear weapons. The current Japanese constitution came into effect in 1947, and Article 9 of the constitution proclaims, "…the Japanese people forever renounce war as a sovereign right of the nation and the threat or use of force as means of settling international disputes..."[33] Japan's Cabinet Legislative Bureau (CLB) has interpreted this article to mean that Japan cannot possess offensive military capabilities but can maintain a defensive military capability, and the director of the CLB also testified on the legality of nuclear weapons to a committee of the upper house of the Diet in 1965.[34] In April 1958, Prime Minister Nobusuke Kishi told the upper house of the Diet that Japan would not possess any nuclear weapons, even though Japan's constitution did not prohibit the possession of nuclear weapons for strictly defensive purposes. Kishi followed

---

[31] Japan Atomic Energy Commission, *Long-Range Program on Development and Utilization of Atomic Energy* (Tokyo: Japan Atomic Energy Commission, 1961), 16.

[32] Japan Atomic Energy Commission, 23.

[33] "The Constitution of Japan," Prime Minister of Japan and His Cabinet, accessed June 27, 2012, http://www.kantei.go.jp/foreign/constitution_and_government_of_japan/constitution_e.html.

[34] Llewelyn Hughes, "Why Japan Will Not Go Nuclear (Yet): International and Domestic Constraints on the Nuclearization of Japan," *International Security* 31 (2007): 83.

this with a statement to the lower house of the Diet in April 1960, "Japan will not arm itself with nuclear weapons, nor will it allow the introduction of nuclear weapons [into its territory]."[35] Despite this statement by Kishi and the Atomic Energy Basic Law's requirement that nuclear research be peaceful in nature, there was some speculation on Japan's nuclear intentions.

The nuclear weapons issue became of higher importance after China conducted its first nuclear weapons test in October 1964. China's test shocked Japanese leaders, and two months later, Prime Minister Eisaku Sato made the following bold statement to the Diet, "If the other fellow has nuclear weapons, it is only common sense to have them oneself. The Japanese public is not ready for this, but would have to be educated…Nuclear weapons are less costly than is generally assumed, and the Japanese scientific and industrial level is fully up to producing them."[36] Sato expressed similar sentiments to U.S. Ambassador Edwin Reischauer and U.S. President Lyndon Johnson in the months following China's test in an effort to gain reassurance that Washington would extend its nuclear umbrella to Japan.[37] Sato and Johnson addressed this issue in a joint communiqué in January 1965 that proclaimed, "…the President reaffirmed the United States' determination to abide by its commitment under the treaty to defend Japan against any armed attack from the outside."[38] Sato added to the communiqué by

---

[35] Matake Kamiya, "Nuclear Japan: Oxymoron or Coming Soon?" *The Washington Quarterly* 26 (2002): 65.
[36] Yuri Kase, "The Costs and Benefits of Japan's Nuclearization: An Insight into the 1968/70 Internal Report," *The Nonproliferation Review* (2001): 58-59.
[37] Hughes, 86.
[38] Kase, 63.

declaring that "…as long as a U.S. nuclear deterrent remained viable, no country would dare to attack Japan."[39]

5.2.2 The Non Proliferation Treaty, Oil Crisis, and Nuclear Growth (1967-1974)

After the failure of the Magnox reactor project at Tokai, Japan moved forward with importing U.S.-designed LWRs and developing indigenous reactor designs. U.S. firms had both major LWR variants, boiling water reactors (BWRs) from General Electric and pressurized water reactors (PWRs) from Westinghouse, available for export. Neither the Japanese government nor the private industry expressed a strong preference for one LWR design over the other, and licensing agreements were settled not based on LWR design preference but based on existing ties between American and Japanese companies. Hitachi and Toshiba selected BWR technology from General Electric, and Mitsubishi selected PWR technology from Westinghouse.[40]

In 1965, the JAEC issued a report that tasked the industry with indigenizing LWR technology and the government with guaranteeing safety and fuel supply. This report also called for research and development on advanced thermal reactors (ATRs) and FBRs, but there was no consensus on who would be responsible for these projects. After more than a year of negotiations between industry and government leaders, it was decided that a new entity, jointly funded by public and private capital, would take responsibility for ATR and FBR

---

[39] Ibid.

[40] Richard K. Lester, "U.S.-Japanese Nuclear Relations: Structural Change and Political Strain," *Asian Survey* 22, no. 5 (May 1982): 419.

development, and the Power Reactor and Nuclear Fuel Corporation (PNC) was established in 1967 for this purpose. PNC soon became the primary nuclear technology development entity in Japan, with PNC's budget exceeding JAERI's budget by 1969.[41]

The private sector gained more control over the nuclear industry when the JAEC legalized private ownership of spent fuel and fissile materials in 1968.[42] Despite this move, Japan did not have uranium refining or enrichment facilities at that time and was still dependent on U.S.-supplied nuclear fuel. To address this issue, the U.S.-Japan nuclear cooperation agreement was revised in 1968, and JAIF leaders believed the revised agreement guaranteed a thirty year supply of enriched uranium.[43] The utilities also were concerned about guaranteeing access to uranium ore, as American and European firms were actively acquiring uranium mining rights around the world. Tokyo responded by forming the Metal Mining Public Corporation (MMPC) in 1971. Japanese mining companies could receive government loans from the MMPC that were redeemable only if uranium deposits were discovered, which encouraged Japanese companies to acquire uranium mining rights.[44]

These moves worked to address Japanese concerns about the front end of the nuclear fuel cycle (i.e., uranium mining and enrichment) and electricity generation, but the back end of the fuel cycle (i.e., reprocessing) also was a topic of concern for Japan during this time period. From the outset, Japanese nuclear

---

[41] Samuels, 241-243.
[42] Hymans, 169-170.
[43] Samuels, 244.
[44] Samuels, 244-245.

planning placed high importance on developing reprocessing technology, and in the mid-1960s, Washington encouraged Japan and other consumers of U.S.-origin nuclear fuel to reprocess spent nuclear fuel in order to reduce the demand for enriched uranium. The 1967 long-term development program issued by the JAEC identified FBRs as the main goal of the Japanese domestic nuclear development program but acknowledged that delays in FBR commercialization would lead to plutonium first being used in LWRs and ATRs. The Japan Atomic Fuel Public Corporation (JAFC) was responsible initially for reprocessing, and the private sector eventually would take over reprocessing.[45]

In 1966, JAFC contracted with SGN of France to supply the technology for a pilot reprocessing plant at Tokai.[46] In addition, JAFC contracted with the American company Nuclear Materials and Equipment Corporation (NUMEC) for the design of a mixed-oxide (MOX) fuel fabrication plant that would produce nuclear fuel using uranium and plutonium. MOX fuel fabrication lines were completed for the Joyo test FBR and Fugen test ATR in 1970 and 1972, respectively.[47]

While original plans projected that reprocessing would be necessary to supply plutonium for FBRs, the accumulation of spent fuel at operating NPPs led to demand for reprocessing before FBRs were developed commercially. To reprocess the spent fuel at the Magnox reactor at Tokai, JAPC signed a three year reprocessing contract with the UK Atomic Energy Authority in 1967. The

---

[45] Skolnikoff, Suzuki, and Oye, 3.
[46] Skolnikoff, Suzuki, and Oye, 10.
[47] Skolnikoff, Suzuki, and Oye, 4.

contract was for three years, and plutonium recovered from reprocessing would be returned to Japan. This marked Japan's first overseas reprocessing agreement.[48]

Based on the U.S.-Japan nuclear cooperation agreement amended in 1958, Tokyo needed to obtain prior consent from Washington in order to reprocess or transfer to third countries U.S.-origin spent nuclear fuel. Consent was granted on a case-by-case basis, which meant that each shipment of spent fuel required Washington's approval before being shipped to Europe. The nuclear cooperation agreement was amended again in 1972 to include a requirement for joint determination by Japan and the United States to allow the startup of a reprocessing plant in Japan.[49] This clause was relevant because Japan began construction of the Tokai pilot reprocessing plant in 1971 and would become more important after India's first nuclear test in 1974.[50]

Regarding the nuclear weapons issue, Prime Minister Sato announced the "Three Non-Nuclear Principles," which stated that Japan would not possess, produce, or permit the introduction of nuclear weapons into Japan, in 1967.[51] In early 1968, Sato and the ruling Liberal Democratic Party (LDP) announced the Four Nuclear Policies in a policy paper. The Four Nuclear Policies were:[52]

1. Promoting the peaceful use of nuclear energy
2. Working toward global nuclear disarmament
3. Relying on the U.S. nuclear umbrella

---

[48] Ibid.
[49] Skolnikoff, Suzuki, and Oye, 7.
[50] "Reprocessing Technology Development," Japan Atomic Energy Agency, accessed July 7, 2012, http://www.jaea.go.jp/english/04/tokai-cycle/02.htm.
[51] Chanlett-Avery and Nikitin, 2.
[52] Kase, 60.

4. Supporting the Three Non-Nuclear Principles

Regarding the Three Non-Nuclear Principles, the LDP's policy paper added the caveat, "…the LDP supports the Three Non-Nuclear Principles under the circumstances where Japan's national security is guaranteed by the three other policies."[53] The Three Non-Nuclear Principles were passed in a Diet resolution in 1971, but they were never formally adopted into law.[54]

At the same time that Sato and the LDP were drawing up the Three Non-Nuclear Principles and the Four Nuclear Policies, Sato's Cabinet Information Research Office commissioned four Japanese academics to analyze the costs and benefits for Japan to develop nuclear weapons. The report was issued in two parts. The first part, completed in September 1968, examined technical and economic issues, and the second part, completed in January 1970, covered strategic and political issues. Thus, the report is referred to as the 1968/70 Report.[55] The report was kept internal and distributed among members of Sato's cabinet and senior officials at various ministries and agencies.[56]

The 1968/70 Report concluded that Japan would be capable of producing a small number of nuclear weapons using plutonium in the near future, but developing nuclear weapons would be costly financially and likely to not receive the Japanese public's support. In addition, Japanese nuclearization would invite the suspicion of neighboring countries and isolate Japan in the international

---

[53] Ibid.

[54] Hughes, 85.

[55] Kase, 55-56.

[56] Kase, 58.

community.[57] In particular, the 1968/70 Report emphasized that developing nuclear weapons would harm severely Tokyo's relationship with Washington.[58] The authors concluded that Japan's security would be best guaranteed "…through a multi-dimensional approach including political and economic efforts, and not through a traditional militaristic, power-based approach."[59]

Of course, the world of nuclear politics was changed on 1 July 1968 when the Soviet Union, the United Kingdom, and the United States signed the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). The signing of the NPT sparked debate in Japan, and Tokyo did not immediately sign the NPT. The debate revolved around three major objections. First, the NPT was viewed as discriminatory in nature because it officially approved the status of the five nuclear-weapons states and did not push for global nuclear disarmament. Second, there were concerns that the NPT may allow the nuclear-weapon states to restrict the peaceful uses of nuclear energy by the non-nuclear-weapon states. Third, a small group of Japanese conservatives asserted that Japan should not forgo its nuclear option, but this sentiment was not nearly as strong as the other two.[60] Japan signed the NPT in 1970, but the Foreign Ministry voiced Tokyo's concerns by issuing a statement upon signing the treaty that said, "…the non-nuclear weapon states will not be hindered in any way whatsoever in the experimentation, development, and research on the peaceful uses of nuclear energy and will not

---

[57] Kamiya, 72.
[58] Kase, 65.
[59] Kase, 59.
[60] Kamiya, 72.
[60] Kase, 71.

accept discriminatory treatment from any source."[61] Even after signing the NPT, the debate over it led to Japan not ratifying the treaty for another six years.

Another significant shock to the Japanese nuclear sector during this time period was the oil crisis of 1973. The oil crisis hit at a time of high economic growth for Japan. To fuel this growth, Japan's energy consumption nearly doubled in the ten years that preceded the oil crisis.[62] Oil was the major energy source used to meet this growth in energy demand. Figure 5.5 and Figure 5.5 display the large increase in electricity produced by oil from the early 1960s until the oil crisis, with a peak of 73 percent of Japan's electricity coming from oil in 1973. With virtually no domestic oil reserves, Japan essentially is completely dependent on imports for its supply of oil, and the country was particularly dependent on oil imports from the Middle East, with upwards of 80 percent of Japan's oil imports coming from the Middle East.[63] The oil shock of 1973 resulted in reductions in the supply of Middle East oil and a dramatic increase in the global price of oil (prices quadrupled from US$3 per barrel to US$12 per barrel between 1973 and 1974[64]).

Eugene Skolnikoff, Tatsujiro Suzuki, and Kenneth Oye summarized the impact on Japan. "The 1973 oil crisis was perhaps the most visible of many recent events that dramatized for Japanese officials and the public at large the extent of vulnerability to outside events. The development of nuclear sources of

---

[61] Roger W. Gale, "Nuclear Power and Japan's Proliferation Option," *Asian Survey* 18, no. 11 (1978): 1120.
[62] Keichi Oshima, et al, *Future U.S.-Japanese Nuclear Energy Relations* (New York: Rockefeller Foundation, 1979), 42.
[63] Ibid.
[64] Oshima, et al, 21.

energy, using technology that could be wholly based on Japanese soil, appeared as an exciting new possibility that could over time greatly reduce that energy dependence."[65] The oil crisis made nuclear power an even more attractive technology for Japan and increased the impetus to develop nuclear power in the country. To encourage the growth of nuclear power, Prime Minister Kakuei Tanaka in 1974 established an account for the siting of new nuclear power plants that drew from electricity taxes. These funds, referred to as "cooperation money," were used to provide incentives to and win the support of local communities to host nuclear power plants.[66]

The 1973 oil crisis arguably was the most significant event that solidified Japan's commitment to generating electricity from nuclear energy. However, another significant external shock to Japan's nuclear sector came the very next year when India detonated a nuclear explosive in May 1974. While India's nuclear program posed no direct threat to Japan, India's test elicited a strong response from and a major change in nuclear nonproliferation policy by the United States, and this policy change led to tensions between Washington and Tokyo over Japan's nuclear fuel cycle programs.

5.2.3 Committing to Reprocessing (1975-1988)

From the mid-1950s to the mid-1970s, the United States had contrasting policies toward uranium enrichment and spent nuclear fuel reprocessing technologies. In general, Washington placed few obstacles on the transfer of

---

[65] Skolnikoff, Suzuki, and Oye, 1.
[66] Samuels, 246.

nuclear technologies and strongly encouraged the spread of civilian nuclear technology after the Atoms for Peace program was launched, but the transfer of enrichment technology was strictly prohibited. The United States readily provided supplies of enriched uranium to other countries but retained approval authority over where and how reprocessing of U.S.-origin fuel would be conducted. In contrast to enrichment technology, Washington did not restrict the spread of reprocessing technology, yet commercial reprocessing was never realized in the United States itself. Overall, these policies meant that the United States could provide enriched uranium fuel to a third country, such as Japan, but was unable to provide reprocessing services for that fuel, and Washington held veto power over the receiver country's reprocessing arrangements.[67]

Following India's nuclear test in 1974, the U.S. government became increasingly concerned about the further spread of nuclear weapons capabilities. The fear was that the spread of enrichment and reprocessing (ENR) technologies would remove the technical barriers and leave only political barriers against nuclear weapons proliferation. Standing U.S. policy was to prohibit the transfer of enrichment technology, and in October 1976, U.S. President Gerald Ford announced that the commercialization of reprocessing technology in the United States would be postponed and that exports of reprocessing technology also would be prohibited.[68] When Jimmy Carter assumed the U.S. presidency in 1977, he furthered Ford's announcement by indefinitely deferring the commercialization of reprocessing and FBR technology in the United States, and Carter launched the

---

[67] Skolnikoff, Suzuki, and Oye, 80-83.
[68] Lester, 421.

International Nuclear Fuel Cycle Evaluation (INFCE) program in October 1977 to study jointly with over 50 other countries alternative nuclear fuel cycle technologies and to assess proliferation risks. In addition, the Nuclear Nonproliferation Act (NNPA) of 1978 required that all receivers of U.S.-origin nuclear technology and fuel be subject to full-scope IAEA safeguards and that U.S. consent must be granted before reprocessing any U.S.-origin nuclear fuel or any nuclear fuel discharged from reactors of U.S. origin.[69]

Washington also worked to build international consensus on nonproliferation policy by forming the Nuclear Suppliers Group (NSG) to coordinate the policies of all nuclear technology and fuel supplier countries. The United States convinced the other members of the NSG to exercise “restraint” in exports of ENR technology.[70] Japan participated in the NSG from the beginning and agreed to adhere to the NSG guidelines established in 1976. By the time the Carter Administration came to power in Washington, it was clear that the United States would push other countries to not only restrict trade in ENR technology but also to suspend existing commercial reprocessing and FBR programs, as Washington had decided to do.[71] In essence, India’s nuclear test prompted the United States to abandon a plutonium economy (i.e., employing a nuclear fuel cycle that utilizes plutonium in nuclear fuel), and Washington pressed other countries to do the same.

This reversal in U.S. policy was not welcomed in Japan and led to tensions between Washington and Tokyo. Japan was totally dependent on imports of

---

[69] Oshima, et al, 36-39.
[70] Lester, 421.
[71] Lester, 421.

enriched uranium to fuel its fleet of LWRs and placed high emphasis on developing reprocessing and FBRs in order to alleviate the country of this dependence. Thus, the new U.S. policy challenged the basic fundamentals of Japan’s nuclear program, and Tokyo pushed back in defense of its reprocessing and FBR programs.

The conflict between Tokyo and Washington over the reprocessing issue focused on two actions: shipments of Japanese spent nuclear fuel to Europe for reprocessing and the reprocessing plant at Tokai. Per the U.S.-Japan nuclear cooperation agreement signed in 1972, both Japan and the United States had to approve these actions before they could occur. Starting in late 1976, Japan faced lengthy delays in receiving approval for spent nuclear fuel shipments to Europe, and the United States balked at approving the start up of the Tokai reprocessing plant.[72] The Tokai plant was completed in 1975, and a cold test run of the plan was conducted in 1976. Tokai’s operator, PNC, needed U.S. approval before conducting a hot test in 1977, but the Carter Administration requested that Japan change Tokai’s process so that plutonium would not be completely separated. Japan refused to accept this request, which would have required significant modifications to the plant, and a compromise was reached that allowed the plant to operate at a limited capacity (99 tons of fuel per year instead of 140 tons per year).[73]

After Ronald Reagan became U.S. President in 1981, his administration reviewed Carter’s nonproliferation policies and took a softer stance. In July 1981,

---

[72] Oshima, et al, 101.

[73] Skolnikoff, Suzuki, and Oye, 9.

Reagan reiterated Washington's commitment to preventing the proliferation of nuclear weapons but also stated "…(t)he Administration will also not inhibit or set back civil reprocessing and breeder reactor development abroad in nations with advanced nuclear power programs where it does not constitute a proliferation risk."[74] This seemed to speak to the situation in Japan. Acting on this new stance, Japan was able to negotiate a new agreement with the United States that allowed the Tokai plant to operate at full capacity.[75]

Japan then undertook long negotiations with the Reagan Administration in order to modify the 1972 U.S.-Japan nuclear cooperation agreement. A new agreement was ratified in 1988, and Japan won programmatic approval from the United States for reprocessing. Article 11 of the agreement stated that prior consent could be given at one time for all programs Japan submits for plutonium use and that this programmatic consent would be in effect for 30 years. Thus, Japan did not have to apply for case-by-case approval of spent fuels shipments to Europe, starting the Tokai reprocessing plant, FBR development, MOX fuel fabrication, or other activities that produce or use plutonium.[76] Japan became the only non-nuclear-weapons state to be granted programmatic consent from the United States.[77] This was a major diplomatic victory for Tokyo and allowed Japan to push ahead with its nuclear fuel cycle research and development plans.

---

[74] Lester, 423.

[75] Skolnikoff, Suzuki, and Oye, 9.

[76] Skolnikoff, Suzuki, and Oye, 7.

[77] The United States also granted programmatic consent to the European Atomic Energy Community (Euratom), which has nuclear weapons states and non-nuclear weapons states among its membership.

The U.S. policy reversal on reprocessing not only led to Japan confronting and challenging its ally but also helped guide Japanese policy. In 1976, a JAEC study group recommended that the country construct a commercial scale reprocessing plant, and until this plant was completed, Japan would have to ship spent fuel overseas for reprocessing. After the U.S. decision to halt commercial reprocessing in 1976, Japanese utilities chose to sign larger reprocessing contracts with French and British companies. In 1979, the Diet passed a law that allowed private companies to engage in reprocessing, and the utilities and other private companies established the Japan Nuclear Fuel Service (JNFS) in 1980 to build and operate a commercial reprocessing plant. The private sector's reprocessing plans were included in the JAEC long term nuclear development plan released in 1982.[78] Thus, despite the Carter Administration's requests to suspend reprocessing plans, Tokyo pushed forward with its reprocessing program while negotiating for programmatic consent.

As Japan was moving forward with its reprocessing program, FBR development made progress during this time period, too. The experimental FBR, Joyo, began operations in 1977,[79] and initial site preparations and licensing began on the prototype FBR, Monju, in the late 1970s and early 1980s.[80] Both sites were being built and operated by PNC, and approximately one-sixth of the Japanese government's total nuclear budget went to the FBR program.[81]

---

[78] Skolnikoff, Suzuki, and Oye, 4-5.

[79] Skolnikoff, Suzuki, and Oye, 3.

[80] "Development of Monju," Japan Atomic Energy Agency, accessed July 12, 2012, http://www.jaea.go.jp/04/monju/EnglishSite/1_Overview%20of%20Monju/History%20of%20Monju.pdf.

[81] Skolnikoff, Suzuki, and Oye, 3.

Japan also made progress on its uranium enrichment program during the dispute with the Carter Administration over reprocessing. In August 1977, PNC broke ground on a pilot enrichment plant at Ningyo-toge.[82] The first enriched uranium from this plant was then produced two years later in December 1979.[83]

Regarding the weapons issue, the internal debate in Japan over the NPT ended in June 1976 when Tokyo ratified the treaty. Japanese officials view this as the moment when Japan officially relinquished the option of ever developing nuclear weapons.[84] Opposition party members of the Diet requested that the government restate the view that developing nuclear weapons is not against the Japanese constitution in February 1978, and Foreign Minister Sonoda Sunao responded by stating that, while nuclear weapons were not constitutionally prohibited, party membership to the NPT and the Atomic Energy Basic Law limited Japan's nuclear development to peaceful uses.[85]

By the end of 1987, Japan had 37 operational NPPs that accounted for 25,700 megawatts of installed electric capacity. The country also has successfully indigenized LWR technology and was operating experimental or pilot scale uranium enrichment and reprocessing plants, MOX fuel fabrication lines, and FBRs. The country appeared on the path toward developing an indigenous closed nuclear fuel cycle.

5.3 Prospect Theory and Japan's Nuclear Fuel Cycle Decision Making

---

[82] Gale, 1129.
[83] "Brief History of JNC," Japan Atomic Energy Agency, accessed July 12, 2012, http://www.jaea.go.jp/jnc/jncweb/01intro/history.html.
[84] Hughes, 73.
[85] Gale, 1121.

To summarize the history of Japan's nuclear development given in section 5.2, Figure 5.8 displays the nuclear fuel cycle employed in Japan.[86] Japan is developing a closed nuclear fuel cycle, which means that spent nuclear fuel is reprocessed to produce new nuclear fuel that is loaded back into reactors.

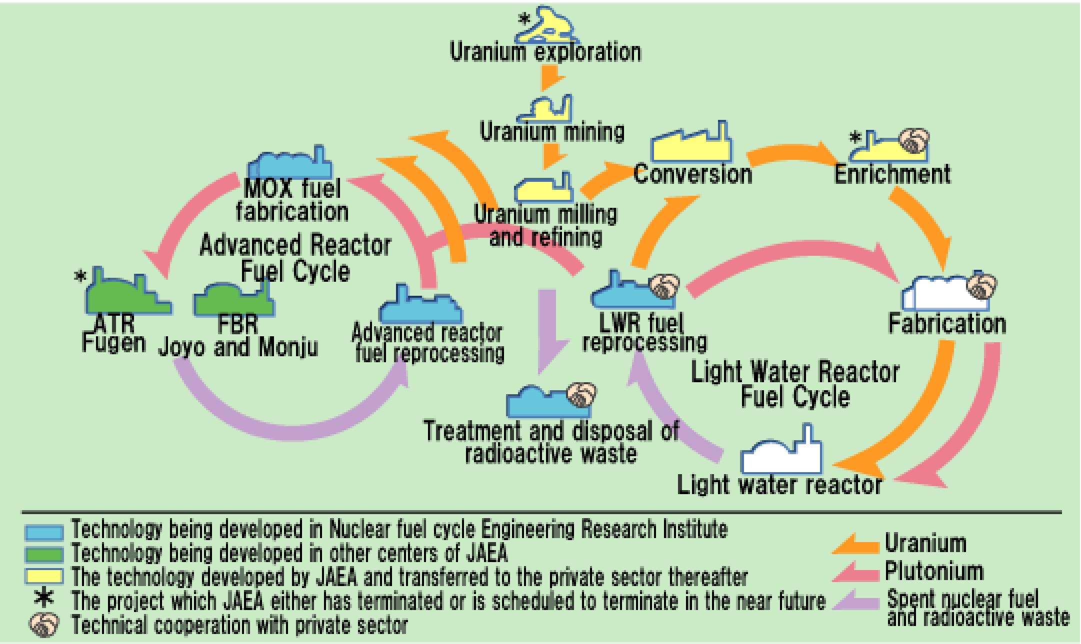

Figure 5.8 – Japan's Nuclear Fuel Cycle

Japanese planners intended to develop each step in Figure 5.8 indigenously, except for uranium mining and conversion. Since Japan has little domestic uranium reserves, the country has no choice but to import the uranium needed to power its fleet of LWRs. The critical steps on the front end of the nuclear fuel cycle are uranium enrichment and fuel fabrication, so Japan decided to develop each step of the fuel cycle in Figure 5.8 after uranium enrichment.

---

[86] "Outline of Nuclear Fuel Cycle Engineering Laboratories," Japan Atomic Energy Agency, accessed July 19, 2012, http://www.jaea.go.jp/english/04/tokai-cycle/01.htm.

On the front end, Japan imports uranium in yellowcake form (triuranium octoxide, U_3O_8) Australia, Canada, China, France, Niger, South Africa, and the United States. Conversion services (converting yellowcake to uranium hexafluoride, UF_6) are provided by firms in Canada, France, the United States, and the United Kingdom. The uranium enrichment plant operated by Japan Nuclear Fuel Limited at Rokkasho does not have enough capacity to meet total domestic demand for enriched uranium, so enrichment services also are provided by firms in Europe and the United States. On the back end of the cycle, Japan does not yet have an operational commercial reprocessing facility, and Japan has shipped its spent fuel to companies in France and the United Kingdom for reprocessing.[87]

Japan has remained committed to developing a closed nuclear fuel cycle, including uranium enrichment, reprocessing, and FBRs, since the initial stages of the program. Thus, the general question to examine with prospect theory is why Japan chose this particular fuel cycle to develop, and three more specific questions arise out of the historical review of Japan's nuclear sector.

1. Why did Japan make such a strong commitment to developing nuclear power and a closed nuclear fuel cycle?
2. Why did Japan not pursue a nuclear weapons program?
3. Why did Japan oppose U.S. policy in the mid-1970s and continue developing reprocessing technology?

---

[87] International Atomic Energy Agency, *Country Nuclear Fuel Cycle Profiles*, 2nd ed. (Vienna: International Atomic Energy Agency, 2005), 51, http://www-pub.iaea.org/MTCD/publications/PDF/TRS425_web.pdf.

These questions will be analyzed using prospect theory and the analytical framework outlined in Chapter 3.

5.3.1 Japan's Nuclear Fuel Cycle Decision Making

CIVILIAN TECHNOLOGY	RESULT
Electric Power Generation	Yes. 54 NPPs provided between 25-30% of electricity (before 2011).
Acquire/Develop Enrichment and Reprocessing (ENR) Technology	Yes. Indigenously developed enrichment technology and imported French reprocessing technology. Operates ENR facilities at Tokai and Rokkasho
Achieve Nuclear Power Plant Independence	Yes. Domestic firms able to design, construct, and operate NPPs (current reactor fleet all derived from U.S.-designed LWRs).
MILITARY TECHNOLOGY	**RESULT**
Acquire/Develop Nuclear Weapons	No. Explored nuclear weapon option in late 1960s but concluded political costs would be too high. Strong legal and social norms block weapons development.
Test Nuclear Explosive Device	No. Never constructed nuclear explosive.
Nuclear Weapons Hedging	No.

Table 5.1 – Civilian and Military Nuclear Technology Decision in Japan

A summary of the technical decisions made in Japan during the development of its nuclear sector is presented in Table 5.1. This list of decisions certainly does not include every decision made. Other decisions, including nuclear reactor design, are important, but Table 5.1 represents the major nuclear fuel cycle decisions that were made, principally whether to develop ENR technology for civilian and/or military use.

With this summary in mind, the three questions presented above will be analyzed in order to determine the main factors influencing Japan's nuclear fuel cycle decision making and how this decision making fit into Japan's overall strategy.

Why did Japan make such a strong commitment to developing nuclear power and a closed nuclear fuel cycle?

The JAEC summed up Japan's intentions for developing nuclear power in its annual report from 1981. "Japan has promoted nuclear power generation to be free from a weak, foreign-country-dependent energy-supplying structure."[88] This was not a new view of nuclear power, as this thinking had been present in Japan since the beginning of the country's nuclear program in the 1950s.

In the early 1950s, Japan was struggling to rebuild from the devastation of World War II but faced some significant economic challenges. In particular, the Japanese economy was heavily dependent on imports for raw materials and food, and the country was still experiencing regular power outages and shortages.[89] Due to Japan's lack of significant reserves of coal, oil, or natural gas, hydropower was the major domestic source of energy and accounted for over 60 percent of installed capacity.[90] The JAEC expressed skepticism about hydropower's potential for future expansion by saying that the number of economically viable

---

[88] Japan Atomic Energy Commission, *Advances in the Field of Research, Development, and Utilization of Nuclear Energy in Japan* (Tokyo: Japan Atomic Energy Commission, December 1981), 19.

[89] Michael Sapir and Sam J. Van Hyning, *The Outlook for Nuclear Power in Japan* (Washington, DC: National Planning Association, 1956): 8, 36.

[90] Sapir and Van Hyning, 8, 24.

sites was limited and being exhausted.[91] This would lead to a greater emphasis on developing thermal power, and the JAEC also frankly stated that "Japan cannot but rely on overseas sources of supply for the time being since her domestic resources have not yet been developed sufficiently."[92] Yet, the JAEC also justified the need for developing nuclear power by stating, "…since there should be limitation to the development of petroleum resources in the future, it is necessary to start the development and utilization of atomic energy right now in order to ensure the long-range stability of supplying energy resources."[93] The Suez Crisis of 1956 also provided early warning to Japanese leaders as to the vulnerability in relying on Middle Eastern oil supplies.[94]

Thus, Japanese leaders viewed domestic energy resources, including hydropower, were too limited to meet domestic demand, and they believed that relying on imported oil also was not a sustainable economic growth policy. Nuclear power was the only source of power that could produce large amounts of electricity and alleviate Japan's dependence on energy imports. Nakasone and other high level policy makers shared these views expressed by the JAEC.[95]

Japanese policy makers did not desire to just build nuclear power plants to generate electricity. Nakasone and others were attracted to the potential of a self-sustaining plutonium economy, involving reprocessing and FBRs in a closed fuel cycle, which would reduce Japan's dependence on uranium imports and free the country from foreign influence over electricity supplies. The United States played

---

[91] Japan Atomic Energy Commission, *Long-Range Program*, 12.
[92] Japan Atomic Energy Commission, *Long-Range Program*, 22.
[93] Japan Atomic Energy Commission, *Long-Range Program*, 5.
[94] Lester, 419.
[95] Hymans, 163.

a role in Japanese thinking by encouraging Japan and other countries to develop reprocessing and promoting a closed fuel cycle as ideal.[96]

On top of the strategic importance given to ensuring energy security through developing a closed nuclear fuel cycle, Japanese cultural beliefs influenced policy makers. Skolnikoff, Suzuki, and Oye state that there is "…a cultural view that it is wrong, or worse, to waste resources..." and that there is a "…strong appeal to the argument that the maximum value should be realized from all resources, in this case uranium."[97] Thus, Japanese leaders were compelled by these beliefs to pursue development of a closed fuel cycle.

The JAEC also believed that developing nuclear power would have other benefits on the domestic economy. It called for "…epoch-making improvement of the nation's technical skill and improvement of the industrial structure…" in order to realize "…sound economic growth and enhance the welfare of the people…"[98] The JAEC argued that developing nuclear power would spur innovation and accelerate development across many sectors of the economy.[99]

Overall, Japanese policy makers have viewed nuclear power and a closed nuclear fuel cycle as the best and least risky energy source for the country. This view was reinforced by the oil shocks of the 1970s. Up until 1973, Japan was heavily dependent on oil for generating electricity, but the 1973 oil crisis triggered Japan to drastically reduce the use of oil-fired power plants and speed up the siting and construction of NPPs. In 1973, economic planners were in a

---

[96] James Acton, "Nuclear Power, Disarmament and Technological Restraint," *Survival* 51, no. 4 (August-September 2009): 105-106.
[97] Skolnikoff, Suzuki, and Oye, ix.
[98] Japan Atomic Energy Commission, *Long-Range Program*, 6.
[99] Japan Atomic Energy Commission, *Long-Range Program*, 7.

gains frame due to the high GDP growth rates experienced over the past 15 years, and the oil crisis made continuing to rely on oil for electricity seem too risky from an energy security perspective. Thus, Japan’s commitment to nuclear power was reinforced and nuclear development was accelerated.

Why did Japan not pursue a nuclear weapons program?

Japan’s first prime minister after World War II ended, Shigeru Yoshida, laid out a strategic vision for his country that is known as the Yoshida Doctrine. Per this doctrine, Japan would focus on economic development in order to restore the country’s status as a major world power and rely on the United States to provide the country’s security.[100] The U.S. nuclear umbrella has been critical to Washington’s security guarantee and removes some impetus that could drive Japan to develop nuclear weapons; however, this requires that Japanese leaders are confident the U.S. commitment to defend Japan against conventional and nuclear threats.

During the Cold War era, the biggest moment of insecurity regarding the U.S. security commitment came after the first Chinese nuclear test in 1964. While Sato’s first reaction to the test was to gain reassurance from Washington, his other reaction was to commission a study of the costs and benefits to Japan acquiring nuclear weapons. This report was composed of two sections, technical considerations and political considerations. The technical section was completed in 1968, and the political section was completed in 1970. This so-called “1968/70 Report” clearly concluded that “…Japan should continue to rely on the U.S.

---

[100] Hughes, 75.

security guarantee and that development of nuclear weapons would threaten that relationship."[101]

Damaging the relationship with Washington would not only have affected the U.S. security commitment but also commercial relations with the United States. Given that Japan was nearly completely reliant on the United States for enriched uranium and LWR technology, pursuing nuclear weapons would have threatened Japan's nuclear power sector as well. For Sato and other Japanese leaders in the mid and late 1960s, the benefits of developing a native nuclear deterrent clearly were outweighed by the costs.

Sato also had received reassurance from the Lyndon Johnson administration that the United States would honor its security commitment to Japan against all threats. Combined with the booming economy of the 1960s, this put Sato and other Japanese leaders in a gains frame. Pursuing nuclear weapons was a greater risk than relying on the U.S. security guarantee, so Tokyo elected to stick with the principles of the Yoshida Doctrine by focusing on economic development and relying on the United States for security.

Sato's Three Non-Nuclear Principles were adopted in a Diet resolution a year after the 1968/70 Report was released internally, and Japan signed and ratified the NPT in 1970 and 1976, respectively. These measures were in addition to Article 9 of the constitution, the Atomic Energy Basic Law, safeguards agreements with the International Atomic Energy Agency, and the provisions of the U.S.-Japan nuclear cooperation agreement. When challenged by the threat of a nuclear-armed China, Japan's leaders concluded that developing nuclear

---

[101] Chanlett-Avery and Nikitin, 2.

weapons was not worth the risk from a political and economic standpoint, and within twelve years of China's first nuclear test, Japan was bound by domestic law, international law, and bilateral agreement with its most important ally to use nuclear energy for peaceful purposes only.

Another constraint withholding Japan from developing nuclear weapons is the strong anti-nuclear sentiment of the Japanese public. Polling conducted by the *Asahi Shimbun*, a leading Japanese newspaper, demonstrates that this sentiment has held steady over time. In 1968, 21 percent of those polled believed that Japan should obtain nuclear weapons. In 1978, support for acquiring nuclear weapons fell to 15 percent, and support rose only to 16 percent in 1981.[102] Given that Japan is the only country to ever have been attacked with nuclear weapons, this public sentiment is not surprising and is a domestic political constraint on any Japanese leader considering the development of nuclear weapons.

Overall, Japan's national security was never threatened enough to put its leaders in a losses frame and become acceptant of the risks involved with developing nuclear weapons. Tokyo made economic development its top priority, and developing a closed nuclear fuel cycle was considered essential to ensuring a supply of electricity to power that economic development. Japan concluded that developing nuclear weapons would not have furthered the strategic priority of energy security

Why did Japan oppose U.S. policy in the mid-1970s and continue developing reprocessing technology?

---

[102] Hughes, 89.

As described in Section 5.2.3, Washington reversed its policy regarding reprocessing and FBR technology in response to India's nuclear test in 1974 and decided to neither develop domestically nor trade internationally these technologies. The Carter Administration, in particular, was particularly adamant in pursuing stricter nonproliferation policies and pushed other countries to suspend development and trade in these technologies. This included pressuring Japan to not separate plutonium at the pilot reprocessing plant at Tokai that began testing in the mid-1970s.

At the time, Japan was already uneasy about being completely dependent on the United States for enriched uranium. In the early 1970s, the United States changed the commercial terms and conditions of its enriched uranium supply contracts, and Japan became concerned about the U.S. ability to deliver on existing and future uranium enrichment contracts. Thus, the U.S. call to suspend reprocessing operations compounded Tokyo's concerns about its front end fuel supply with new concerns about its back end reprocessing.

Richard Lester wrote this conflict "…pitted the fundamental Japanese objective of nuclear energy self-sufficiency and self-determination against Washington's readiness to use its residual influence over Japanese domestic nuclear policy…"[103] Japan also was worried about the stagnation of the U.S. civilian nuclear industry in the late 1970s, as new plant construction slowed and fuel cycle technology research was suspended. Even though Japan had indigenized NPP design and construction capability, the country was still dependent on U.S. nuclear vendors for technical support. A Japanese energy

---

[103] Lester, 420.

specialist expressed the concerns over the direction of the U.S. nuclear industry, "…it is desirable that the United States should recognize its position…as the leading political power in the free world and resume positive nuclear policies to encourage the use of nuclear power within the country, not only for reducing its dependence on imported oil but also for facilitating the Japanese and European nuclear programs."[104]

The main effect of the Carter administration's nonproliferation policies was to strengthen Japan's desire to achieve nuclear fuel cycle independence, and Tokyo pushed forward with its plans to indigenously develop a closed nuclear fuel cycle while negotiating with the Carter administration. In addition to pursuing the country's ambition of achieving energy security through a closed nuclear fuel cycle, Japanese utilities were facing limitations for on-site storage of spent fuel at NPPS in the late 1970s.[105] Japan felt it had little choice but to continue sending spent fuel to Europe for reprocessing while developing a domestic reprocessing capability. Japan's desire to develop a closed nuclear fuel cycle free of foreign influence was expressed in the JAEC's annual report released in 1981. The report directly addressed the need for enrichment, reprocessing, and FBR technologies.

- Regarding enrichment, the report said, "Japan…has to promote domestic production of enriched uranium to push the program forward smoothly with a view to freeing from dependence on foreign countries…"[106]

---

[104] Lester, 428.

[105] Frans Berkhout, Tatsujiro Suzuki, and William Walker, "The Approaching Plutonium Surplus: A Japanese/European Predicament," *International Affairs* 66, no. 3 (July 1990): 527.

[106] Japan Atomic Energy Commission, *Advances in the Field of Research*, 22.

- Regarding reprocessing, the report said, "...part of the spent fuels are being reprocessed at the Tokai Reprocessing Facility…but most of them at overseas reprocessing facilities. These circumstances surrounding reprocessing are extremely unstable to meet increasing requirements for reprocessing of spent fuels, necessitating the construction and operation of a domestic reprocessing plant with enough capacity."[107]
- Regarding FBRs, the report said, "…Japan has developed fast breeder reactor…since 1967 as national projects, aiming at freeing itself from the dependency on imported technology…completion of these projects has a great significance not only in ensuring Japan's energy resources, but also in developing its nuclear industry by enhancing technological improvement and strengthening international competitive power."[108]

Overall, Tokyo bitterly resented this policy reversal by Washington, especially since Japan previously had crafted its nuclear fuel cycle development policies in concert with the United States. Tokyo felt that the United States did not understand Japan's sensitivity to energy security and how a closed nuclear fuel cycle was the key to achieving Japanese energy security. On the other hand, Lester also notes that Japan did not appreciate Washington's desire to achieve a universal suspension in reprocessing on nonproliferation grounds. As a U.S. ally and party to the NPT, Tokyo felt that Washington should allow Japan to continue developing reprocessing and FBR technology.[109]

---

[107] Japan Atomic Energy Commission, *Advances in the Field of Research*, 24.
[108] Japan Atomic Energy Commission, *Advances in the Field of Research*, 15.
[109] Lester, 422.

Japan eventually won the diplomatic confrontation with the United States and got programmatic consent for reprocessing in 1988. In a way, Tokyo did this by waiting out the Carter administration. The Japanese government initially pushed back at the Carter administration and pressed forward with its reprocessing and FBR development. The Reagan administration then took a softer stance toward Japan's reprocessing program. Reagan and Japanese Prime Minister Zenko Suzuki meet in May 1981, and Reagan "…endorsed the view of the Prime Minister that reprocessing is of particular importance to Japan."[110] In July 1981, Reagan announced that his administration would not inhibit civilian reprocessing or FBR development in countries with low proliferation risks. The JAEC "…welcomed the statement as a reasonable approach."[111]

In October 1981, Tokyo won Washington's approval to allow the Tokai reprocessing plant to operate at its designed capacity until 1984 and continue construction on a second reprocessing plant. The JAEC believed "…no time limit should have been imposed on the operation of the Tokai Reprocessing Facility..." but recognized that the Reagan administration needed time to formulate new nonproliferation policies.[112] The JAEC also said it was "…necessary for both parties to endeavor to work out a long-term solution to this question at the earliest possible date."[113] This long-term solution came in 1988 with Washington's programmatic consent of Japan's reprocessing program.

---

[110] "Joint Communique Following Discussions With Prime Minister Zenko Suzuki of Japan," Ronald Reagan Presidential Library, accessed July 22, 2012, http://www.reagan.utexas.edu/archives/speeches/1981/50881b.htm.
[111] Japan Atomic Energy Commission, *Advances in the Field of Research*, 42.
[112] Japan Atomic Energy Commission, *Advances in the Field of Research*, 42-43.
[113] Japan Atomic Energy Commission, *Advances in the Field of Research*, 43.

Japan clearly felt threatened by the Carter's administration policies, and Tokyo believed it had to fight not just to save Japan's nuclear program but the country's overall economic viability. One particular postulate of prospect theory, the endowment effect, is useful in explaining Japan's behavior here. According to Jack Levy, the endowment effect means "…people tend to value what they have more than comparable things that they do not have, and the psychological cost of relinquishing a good is greater than the psychological benefit of acquiring it."[114]

By 1977, Japan had completed construction of plutonium fuel production lines, a pilot reprocessing plant, and an experimental FBR. The endowment effect led Japanese leaders to value these facilities more than any alternative nuclear fuel cycle technologies proposed by the Carter administration in the INFCE project, nor was acceding U.S. demands merely to gain the Carter administration's favor highly valued. Gaining these fuel cycle facilities also put Japanese leaders in a gains frame, thus making them risk averse.

Therefore, the options facing Tokyo were: 1) oppose its closest ally and guarantor of its security by continuing with reprocessing and FBR development, or 2) accede to the Carter administration's demands and suspend reprocessing and FBR development. Given the high value of Japan's nuclear fuel cycle facilities produced by the endowment effect, the first option was less risky or potentially less painful. In a gains frame, Japanese leaders then acted risk averse by opposing Washington and pressing ultimately to gain programmatic consent.

---

[114] Jack S. Levy, "Loss Aversion, Framing Effects, and International Conflict: Perspectives from Prospect Theory," in *Handbook of War Studies II*, ed. Manus I. Midlarsky (Ann Arbor, MI: University of Michigan Press, 2000), 195.

5.3.2 Japanese Policy Drivers

By 1990, nuclear power was generating about 25 percent of Japan's electricity and had surpassed oil as the top source of electricity in the country. Japan had developed the domestic capability to design, construct, and operate LWRs and was viewed as a global leader in nuclear reactor technology. In addition, Japan appeared to be on its way to commercial operation of a closed nuclear fuel cycle, with experimental or pilot level facilities for uranium enrichment, spent fuel reprocessing, MOX fuel fabrication, and FBRs (problems in development led to later delays in all of these technologies). This was the result of a concerted effort in Japan to develop a closed nuclear fuel cycle that was capable of producing fuel while generating electricity and reducing foreign influence over Japan's supply of electricity. Japan was not completely independent from foreign influence, as the country was still largely dependent on the United States for enriched uranium and sent most spent fuel to France and the United Kingdom for reprocessing. U.S. firms also provided key technical support services for Japan's fleet of nuclear power plants.

On the diplomatic front, Japan became the first nonnuclear weapons state (other than the nonnuclear weapons states included in EURATOM) to be granted programmatic consent by the United States for reprocessing. Tokyo won this consent after initially opposing calls from the Carter administration for universal suspension of reprocessing and FBRs and then entering into decade long negotiations with the Carter and Reagan administrations. This reflected Japan's commitment to developing a closed fuel cycle and sensitivity to the issues of energy security and technology independence.

A review of the history of nuclear development and of the decision making presented in sections 5.2 and 5.3.1 reveals that energy security concerns drove much of Japan's nuclear decision making. This sensitivity toward energy security is not surprising when considering Japan's energy situation. The country has little in terms of domestic energy sources, is unable to import electricity due to being an island nation, and has a history of problems related to securing oil imports.

One of the drivers for Imperial Japan's military expansionism in the first half of the Twentieth Century was a quest to secure oil in other parts of East Asia. Of course, this quest ultimately ended in Imperial Japan's defeat by Allied Forces during World War II, and that war left Japan devastated. The total surrender imposed by the Allies also brought about an end to Imperial Japan's system of government, the dismantlement of Japan's military, and the occupation of Japan by Allied Forces. This traumatic experience certainly was on the minds of Japanese policy makers in the 1950s, and the damaging economic effects of the oil shocks of the 1970s acted as reminders of the perils of relying foreign imports of oil. Richard Samuels wrote that postwar Japan's "…energy pregnability is matched by its military impotence," but the U.S. alliance "…abetted policy planners in their benign neglect of military security."[115] Thus, Japanese policy makers were left to focus on ensuring energy security.

---

[115] Samuels, 228.

Samuels also wrote that Japan made energy and industrial policy central to discussions of national security, in what he terms as Japan's "comprehensive security." Japan's goal was to develop "…commercially viable energy technologies that might also enhance Japan's international competitiveness."[116] Samuels went on to write, "Energy security, narrowly defined, may be the 'push' for an active search for alternative energies, but national security, broadly constituted and inclusive of commercial considerations, acts as the 'pull'."[117]

When these factors are considered, Japan's focus on energy security is understandable, and developing a closed nuclear fuel cycle has been viewed by Japanese planners since the 1950s as the key to the country's energy security. Other factors certainly influenced Japanese decision making, and Table 5.2 summarizes these factors.

DOMESTIC	INFLUENCE
Bureaucratic Interests	JAPC, MITI, STA, and private utilities all fought for control over nuclear sector development or for particular projects, but initiative for fuel cycle policy came from central government leadership. All factions seemed to support ENR and FBR development.
Centralization of Power/Strength of Leader	A few individual leaders were influential, but power was generally spread out among the prime minister's office, MITI, STA, and the private sector. JAEC and the prime minister's power diminished relative to MITI and other bureaucrats after the 1950s.
Energy Security Sensitivity	**Ensuring energy security has been one of post-war Japan's top priorities and closely related to the**

---

[116] Samuels, 229.
[117] Ibid.

	main strategic goal of economic development. A lack of domestic energy resources and high dependence on energy imports makes Japan highly sensitive to energy security, and the oil shocks of the 1970s had a major impact on energy planning.
Nature of Regime/Leader	The LDP held power for nearly all of the post-World War II period, but Japan has been democratic and not particularly nationalist. Leadership was decentralized, and consensus building was vital for policy making.
GEOPOLITICAL	**INFLUENCE**
U.S. Relationship	Treaty ally and host to U.S. troops. Ensuring the U.S. security guarantee is a high priority since U.S. forces were principally responsible for Japan’s security.
Security Threats	Chinese nuclear test in 1964 was biggest security threat of Cold War period. No security threat ever surpassed the importance of energy security.
Access to International Energy Markets	Good access, but alignment with United States made oil shocks of 1970s worse.
Nonproliferation Norms Adherence	Strong adherence to global nonproliferation norms. Anti-nuclear public sentiment and repeated public statements by government reinforce commitment to norms.

Table 5.2 – Political Factors Influencing Japanese Decision Making

Using energy security as the primary driver, Japan’s nuclear fuel cycle decision making from the mid-1950s until the late 1980s is in line with the tenants of prospect theory. Japan made energy security part and parcel of its perception of national security, which made developing a closed nuclear fuel cycle a strategic imperative for the country. Postwar Japan’s energy insecurity drove Nakasone and other top policy makers to invest heavily in nuclear power research and development. When Japan's economy was growing rapidly in the late 1950s and 1960s, Japanese policy makers moved into a gains frame and acted risk averse. They did not want to take any actions, such as developing nuclear weapons in response to China's nuclear test in 1964, that may have upset economic growth or slowed development of the nuclear sector. After several nuclear fuel cycle facilities were constructed in the early and mid-1970s, Japanese policy makers placed high value on these facilities, an endowment effect, and again acted risk averse by pushing back on U.S. calls for suspending reprocessing and FBRs.

5.4 Alternative Explanations

In the literature review in Chapter 2, several theories of nuclear weapons proliferation and of nuclear fuel cycle technology development are given. The two theories of fuel cycle technology development, James Acton's received wisdom and William Walker's technology entrapment, were both proposed with Japan in mind and are applicable because Japan did develop uranium enrichment, reprocessing, FBR, and other fuel cycle technologies. Of the theories of nuclear weapons proliferation, Scott Sagan's and Etel Solingen's models of proliferation potentially apply to Japan. The national identity conception model developed by Jacques Hymans does not apply due to the more collective, bureaucratic decision making style in the Japanese government and lack of individual, strong Japanese leaders to which to apply the model.

Acton defines received wisdom as "…the assumed belief, often based on the actions of other states, that a given nuclear technology is too lucrative to be missed."[118] Acton claims that received wisdom can explain the shift in norms related to ENR technology in the mid-1970s. Prior to 1976, the United States promoted the development of ENR technology, and all U.S.-aligned states during that time had plans to develop ENR technology. However, when Washington changed its policy in 1976 and began to oppose the spread of ENR technology, then many states dropped their ENR technology development plans, with a notable exception of Japan. Acton quotes Japanese diplomats as saying, "…'our belief in the necessity of the plutonium cycle is based on American teaching'…" and says that countries like Japan did not select a closed fuel cycle based on an economic analysis.[119] While Japan's early nuclear planning was conducted with U.S. assistance, the pursuit of a closed nuclear fuel cycle in Japan was based on energy security, not purely economics. Received wisdom also does not explain why Japan stuck with reprocessing and FBR development after the United States abandoned those programs. It then would seem like Japan did not receive the new wisdom from Washington.

Walker's entrapment theory states that complex products and infrastructures that take long periods of time to development "…attract huge investment and can survive long after they should have been sent to the grave."[120] The very decision to develop a complex system like a closed nuclear fuel cycle

---

[118] Acton, 105.

[119] Acton, 106.

[120] William Walker, "Entrapment In Large Technology Systems: Institution Commitment and Power Relations," *Research Policy* 29 (August 2000): 834.

can entrap a state and make the political, bureaucratic, and economic costs of withdrawal from that system very high. This may explain in part Japan's commitment to developing a closed nuclear fuel cycle from the 1990s onward, when many of the fuel cycle facilities experienced problems and delays, but entrapment certainly does not explain the initial decision making of the 1950s and 1960s. It also does not seem convincing that Tokyo opposed the Carter administration's nonproliferation policies in the 1970s because Japan was entrapped into developing reprocessing.

Applying prospect theory with Japanese perceptions of energy security provides more explanatory power to Japanese nuclear fuel cycle decision making from the mid-1950s to 1990 than these two theories of nuclear fuel cycle technology development. What about the models of nuclear weapons proliferation?

Solingen stated, "…leaders advocating economic growth through integration in the global economy ('internationalizing models' henceforth) had incentives to avoid the costs of embarking on nuclear weapons programs."[121] Japan has employed an export-driven economy and certainly qualifies as one of Solingen's "internationalizing models." This model would predict that Japan would not embark on a nuclear weapons program, which is correct. The authors of the 1968/70 Internal Report also stated that pursuing nuclear weapons would damage Japan's international economic standing and relations with other

---

[121] Etel Solingen, "Domestic Models of Political Survival: Why Some Do and Others Don't (Proliferate)," in *Forecasting Nuclear Proliferation in the 21st Century: Volume 1. The Role of Theory*, ed. William C. Potter and Gaukhar Mukhatzhanova (Stanford, CA: Stanford University Press, 2010), 40.

countries, principally the United States. The Japanese public's strong anti-nuclear sentiment also constrains any potential nuclear weapons ambitions among the leadership, but Solingen's model does seem to apply to Japanese decision making regarding nuclear weapons, particularly in the 1960s and 1970s. However, Solingen's model does not explain Japan's decision to pursue a closed nuclear fuel cycle. Prospect theory provides explanatory power on why a closed nuclear fuel cycle became directly tied to ensuring Japanese energy security.

Sagan's three models of proliferation are: 1) security model, 2) domestic politics model, and 3) norms model. The security model predicts that strong states "…can pursue a form of internal balancing by adopting the costly, but self-sufficient, policy of developing their own nuclear weapons" and that weak states "…can join a balancing alliance with a nuclear power, utilizing a promise of nuclear retaliation by that ally as a means of extended deterrence."[122] Japan allies with a nuclear power, the United States, and certainly was a weaker state during the 1950s. After Japan's strength grew through its booming economy, though, Japan showed no real signs of developing its own nuclear weapons. In addition, postwar Japan has not derived national strength and prestige from nuclear weapons or military power, so the security model fails to explain the nuance behind Japanese decision making regarding nuclear weapons or nuclear fuel cycle.

Sagan's domestic politics model states that the acquisition of nuclear weapons can "…serve the parochial bureaucratic or political interests of at least

---

[122] Scott D. Sagan, "Why Do States Build Nuclear Weapons? Three Models in Search of a Bomb," *International Security* 21, no. 3 (Winter 1996/97): 57-63.

some individual actors within the state," and security threats are "…not the central cause of weapons decisions…they are merely windows of opportunity through which parochial interests can jump."[123] Certainly, MITI and STA were strong bureaucratic institutions that supported developing a closed nuclear fuel cycle. However, there was strong support throughout the various factions in the government and private sector for developing a closed nuclear fuel cycle in Japan, and there was opposition to nuclear weapons throughout the government and private sector. No one organization pushed for or created the conditions for these policies. The sensitivity toward energy security and opposition to nuclear weapons was prevalent throughout Japanese society.

Sagan's norms model claims that state behavior is determined "…by deeper norms and shared beliefs about what actions are legitimate and appropriate in international relations."[124] Simply, this model focuses on the shift in global norms concerning nuclear weapons before and after the signing of the Non-Proliferation Treaty (NPT) in 1968. Before 1968, developing and testing nuclear weapons were viewed as sources of state power, legitimacy, and prestige, but after 1968, norms started to shift to shunning the development and testing of nuclear weapons. Japan has historically shunned the development and testing of nuclear weapons, but this strong anti-nuclear sentiment is due to the nuclear bombings of Hiroshima and Nagasaki, not due to the passage of the NPT. In essence, Japan has adhered to its own domestic norm against nuclear weapons. This model does not explain Japan's decision making regarding nuclear weapons

---

[123] Sagan, 63-73.
[124] Sagan, 73-85.

or nuclear fuel cycle. Prospect theory offers explanatory power on Japan's decision making regarding nuclear fuel cycle and nuclear weapons.

6. CASE STUDY: SOUTH KOREA

Figure 6.1 – Political Map of South Korea

After Japan surrendered in World War II in 1945, Japanese colonial rule of Korea ended, and the Korean Peninsula was split along the 38th parallel, with the Soviet Union administering the northern half of the peninsula and the United States administering the southern half of the peninsula. The U.S.-backed Republic of Korea (ROK, otherwise referred to as South Korea) was established in the southern half of the Korean Peninsula on August 15, 1948, exactly three years after the Japanese surrender in World War II, and Syngman Rhee was named the first president of the new republic.[1]

---

[1] "Background Note: South Korea," U.S. Department of State, last modified December 17, 2012, http://www.state.gov/r/pa/ei/bgn/2800.htm.

Figure 6.1 is a current political map of South Korea.[2] The country is surrounded by larger regional powers, namely Japan, China, and Russia, but South Korea shares a land border with only one other country, North Korea. North Korea and South Korea fought a bitter war from 1950 to 1953, and the current border between the two was fixed after an armistice suspended the Korean War on July 27, 1953.[3] However, the armistice did not officially end the war, and South Korea remains technically at war with its northern neighbor. While there has been no major military confrontations between North and South Korea since the end of the Korean War, tensions have often ran high between the two, and the occasional border skirmish has occurred in the subsequent decades.[4] There also is almost no cross-border commerce, communication, or travel between North Korea and South Korea, which effectively makes South Korea an island.

The military threat presented by North Korea has largely defined South Korea's security posture for its entire existence. Exacerbating the state of unresolved war is the fact that South Korea's capital, Seoul, lies within range of North Korean artillery and short range missiles amassed along the demilitarized zone (DMZ) that encapsulates the border between the two Koreas. Of course, this is in addition to the fact that North Korea has pursued nuclear weapons for several decades and conducted nuclear tests in October 2006 and May 2009.[5]

---

[2] "Korea, South," Central Intelligence Agency, accessed January 4, 2013, https://www.cia.gov/library/publications/the-world-factbook/geos/ks.html.
[3] Ibid.
[4] Daniel P. Bolger, "Scenes from an Unfinished War: Low-Intensity Conflict in Korea, 1966-1968," *Leavenworth Papers*, no. 19 (July 1991), http://www.cgsc.edu/carl/download/csipubs/ScenesFromanUnfinishedWar.pdf.
[5] "Statement by the Office of the Director of National Intelligence on the North Korea Nuclear Test," Office of the Director of National Intelligence, October 16, 2006, http://www.dni.gov/announcements/20061016_release.pdf; "Statement by the Office of the

6.1 Historical Economic and Energy Data for South Korea

Other than the conflict with North Korea, the aspect that has defined South Korea in the international community over the last fifty years has been remarkable economic growth, measured in terms of gross domestic product (GDP). After gaining independence from Japan in 1945, South Korea was a poor, agrarian country with little industry. However, the country experienced explosive economic growth beginning in the mid-1960s during the authoritarian presidency of Park Chung-hee. High GDP growth rates continued through the 1970s, 1980s, and to the latter part of the 1990s. GDP growth rates have declined a bit since the end of the 1990s, but they remain stable and relatively high for an industrialized country. Large drops in annual GDP growth occurred in 1979 and 1997. The dip in 1979 could probably be attributed to the assassination of Park Chung-hee and the ensuing political turmoil that ended with Chun Doo-hwan taking control of the South Korean government through a military coup d'état. In 1997, the dip can be explained by the fact that South Korea was hit hard by that year's Asian Financial Crisis (see Figure A.15 and Figure A.16 in the Appendix).[6]

South Korea's population also has grown significantly since the end of the Korean War. Overall, the population nearly doubled from about 25.1 million in 1960 to about 48.9 million in 2010 (see Figure A.17 and Figure A.18 in the Appendix). South Korea's population growth rate has decreased steadily as the

---

Director of National Intelligence on North Korea's Declared Nuclear Test on May 25, 2009," Office of the Director of National Intelligence, June 15, 2009, http://www.dni.gov/press_releases/20090615_release.pdf.

[6] "Korea, Rep. | Data," World Bank, accessed April 29, 2012, http://data.worldbank.org/country/korea-republic.

country's GDP output grew. After being fairly stable from the mid-1980s to the end of the 1990s, South Korea's population growth rate has declined continually since 2000.[7]

Corresponding to economic and population growth, energy and electricity consumption has grown dramatically in South Korea since the end of the Korean War. Figure 6.2 graphs the growth in energy consumption and domestic production, and Figure 6.3 shows the growth in electricity consumption and domestic production.[8]

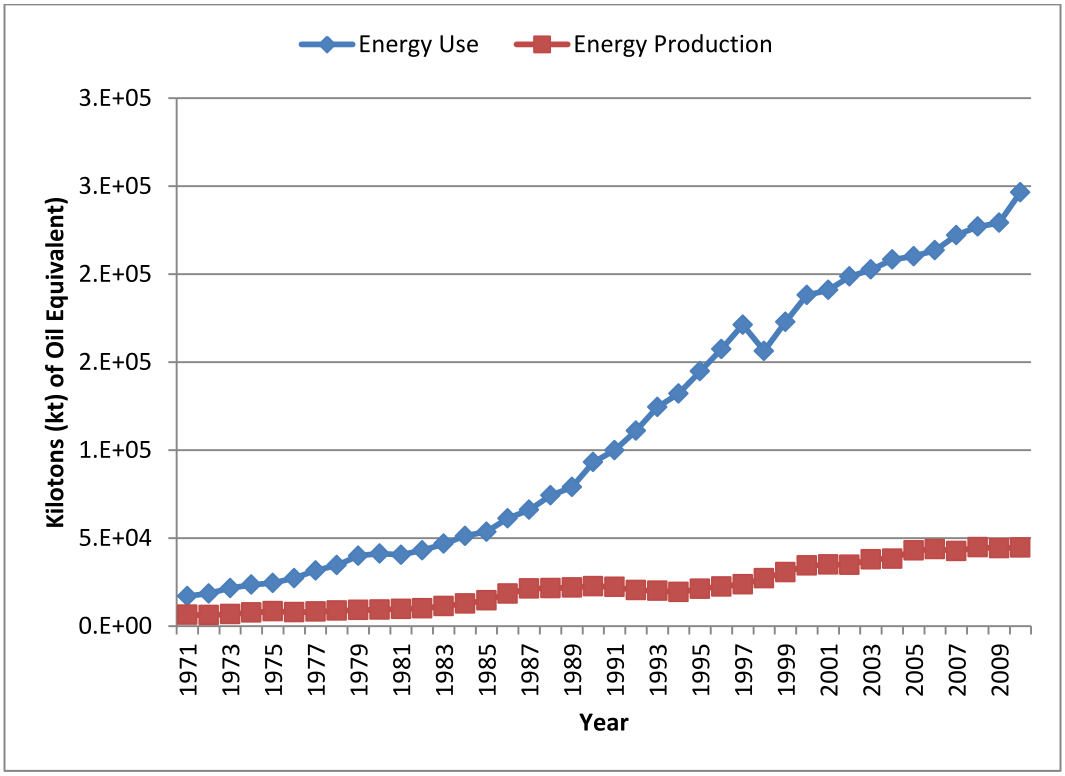

Figure 6.2 – Energy Production and Use in South Korea (1971-2010)

---

[7] Ibid.
[8] Ibid.

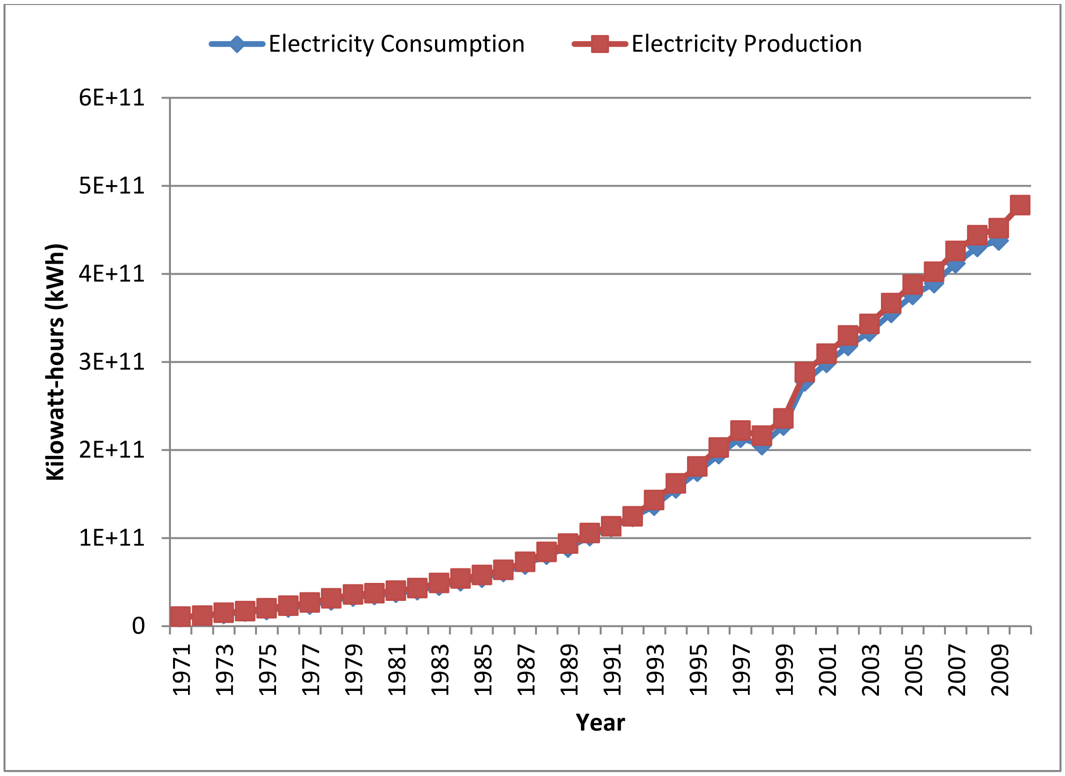

Figure 6.3 – Electricity Consumption and Production in South Korea (1971-2010)

Prior to the beginning of South Korea's industrialization, agriculture was the biggest sector of the country's economy and main consumer of energy, and during this period, energy was provided primarily by domestically available resources, such as anthracite coal, firewood, and hydropower. The utilization of domestic energy resources is displayed in Figure 6.2. In the early 1970s, South Korea was not heavily dependent on energy imports, but energy use quickly outpaced energy production after the early 1970s. In numerical terms, the share of energy provided by imports increased from 17 percent to 94.6 percent between 1962 and 1993. Much of this increase in dependence on imports can be attributed to the rise in the use of oil in the South Korean economy. The share of oil in primary energy sources increased from 9.8 percent in 1962 to 62 percent in 1993.[9]

Once again, the effects of the Asian Financial Crisis are seen by the dips in energy and electricity consumption in the late 1990s. Otherwise, both Figures 6.2 and 6.3 show how energy and electricity use has grown sharply in South Korea in the last few decades. Both figures also appear parabolic in shape, which means that energy and electricity use is increasing at an increasing rate. Thus, South Korea will continue to be faced with meeting exponential growth in energy and electricity demand into the future.

6.1.1 Historical Electric Power Sector Data in South Korea

Since nuclear power is primarily used for electricity generation, a breakdown of just the electric power sector, instead of the entire energy sector, is more appropriate when analyzing nuclear fuel cycle policy. Figure 6.4 displays the annual production of electricity by source between 1971 and 2004, and Figure 6.5 shows the year-to-year share of total electricity production by source during the same time frame.[10]

---

[9] Jae-In Shin and Tae-Yoon Eom, "The Role of Nuclear Power in the Republic of Korea," in *The Nuclear Power Option: Proceedings of an International Conference on the Nuclear Power Option Organized by the International Atomic Energy Agency and Held in Vienna, 5-8 September 1994* (Vienna: International Atomic Energy Agency, 1995), 153-162.

[10] "Korea, Rep. | Data."

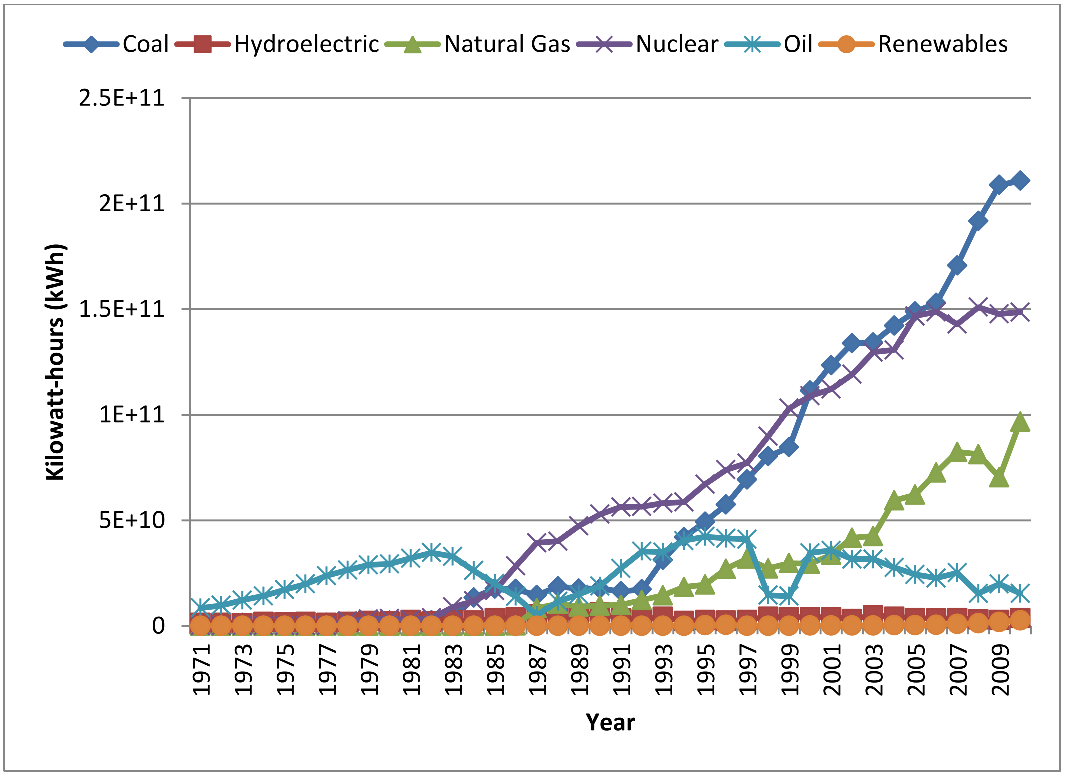

Figure 6.4 – Electricity Production by Source in South Korea (1971-2010)

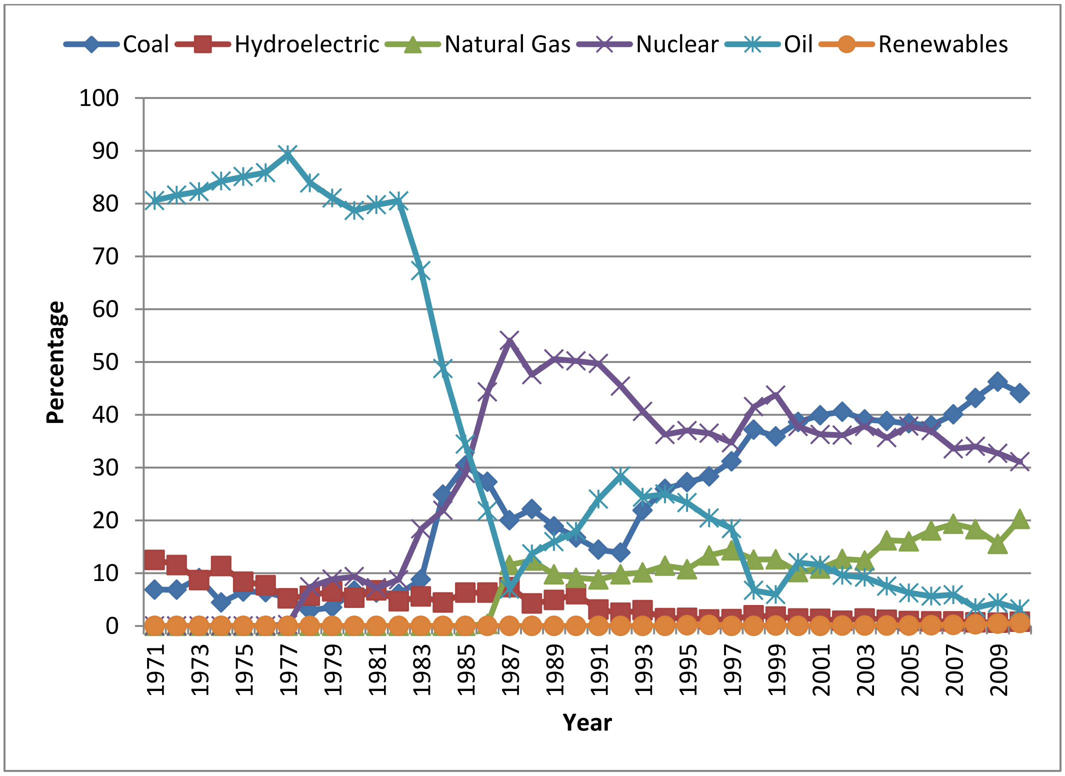

Figure 6.5 – Share of Electricity Production by Source in South Korea (1971-2010)

In 1962, oil generated just 9 percent of South Korea's electricity but rose quickly to become the dominant source of electricity by the 1970s.[11] Oil was South Korea's dominant electricity-generating fuel until the early 1980s, but the oil shocks of the 1970s and increased use of coal and nuclear power led to a sharp decline in oil's share of total electricity generation. Interestingly, the number of terawatt-hours generated by oil has remained fairly steady since the early 1980s. Natural gas usage also has increased gradually in terms of terawatt-hours since the mid-1980s, but natural gas's share of total production has remained around 10 to 15 percent since the early 1990s. Hydropower has not seen much growth in terms of terawatt-hours since the 1970s, and its share of total electricity generation actually has declined since the late 1980s. All of this seems to indicate that that South Korea chose to meet its booming electricity demand mostly with coal and nuclear power.

South Korea is not blessed with abundant natural resources that can be used to generate electricity, but coal, hydropower, and wood can be considered the major indigenous sources of energy. Obviously, wood is not a practical source of energy for large-scale electricity generation, and hydropower is limited to only certain geographic sites. Even though hydropower consumption has roughly doubled since the early 1980s, the relative contribution of hydropower to total electric generation remains marginal (see Figure A.19 in the Appendix).[12]

---

[11] Shin and Eom, 155.

[12] "Statistical Review of World Energy 2011: Historical Data," BP, accessed June 10, 2012, http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/sta

British energy company BP estimates that, at the end of 2006, South Korea had 80 million tons of proven sub-bituminous and lignite coal reserves and produced 2.8 million tons in 2006. If South Korea were to continue annual coal production at its 2006 rate, proven coal reserves would be exhausted within roughly 25 years, by the mid-2030s.[13] South Korea's meager coal reserves have not been nearly sufficient for meeting domestic demand, so coal imports must be relied upon to meet the gap between demand and domestic supply (see Figure A.20 in the Appendix).

The South Korean government knew early on that it would not be able to rely on indigenous resources in order to meet domestic electricity demand. In the late 1960s, a government task force, the Review Committee on the Nuclear Power Generation Plan, stated that South Korea had 400 million tons of anthracite coal reserves, and these reserves would be depleted within 25 years, or around the early 1990s.[14] BP's numbers do not list any anthracite coal reserves in South Korea, so it seems like the country has already exhausted these reserves and is left with its few remaining tons of sub-bituminous and lignite coal.[15] The same government review also expressed skepticism about hydropower ever being able to provide more than a marginal proportion of the total electricity demand.[16] Therefore, a commitment was made to develop nuclear power and use it to provide a significant proportion of South Korea's growing demand for electricity.

---

tistical_energy_review_2011/STAGING/local_assets/spreadsheets/statistical_review_of_world_energy_full_report_2011.xls.

[13] Ibid.

[14] Young-Sun Ha, "Republic of (South) Korea," in *Nuclear Power in Developing Countries: An Analysis of Decision Making*, ed. James Everett Katz and Onkar S. Marwah (Lexington, MA: Lexington Books, 1982), 224.

[15] "Statistical Review of World Energy 2011: Historical Data."

[16] Ha, 224.

6.2 Nuclear Sector Development in South Korea

In response to U.S. President Dwight Eisenhower's Atoms for Peace policy, South Korea and the United States signed an "Agreement for Cooperation between the Government of the United States of America and the Government of the Republic of Korea Concerning Civil Uses of Atomic Energy" on 3 February 1956, which thus marked the official beginning of South Korea's nuclear policy.[17] Twenty-two years later, South Korea's first civilian nuclear power reactor, Kori-1 near the southern port city of Busan, went into commercial operation in 1978. Eight nuclear plants were connected to the grid in the 1980s, seven came online during the 1990s, and seven plants have begun operating since 2000. Today, a total of 23 nuclear reactors, 19 PWRs and four PHWRs, in operation at four sites across South Korea have a total installed capacity of 19,948 megawatts (MW). In 2011, South Korea's fleet of nuclear plants generated about 147,700 gigawatt-hours of electricity, which accounted for nearly 35 percent of the country's total electricity generation.[18] South Korea's nuclear reactors have an impressive performance record in the world, recording a fleet wide average capacity factor of up to 96.5 percent in recent years.[19] Figure 6.6 displays the growth in nuclear power consumption in South Korea since Kori-1 first went online, and South

---

[17] "Agreement for Cooperation between the Government of the United States of America and the Government of the Republic of Korea Concerning Civil Uses of Atomic Energy," National Nuclear Security Administration, accessed June 10, 2012, http://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/Korea_South_123.pdf.

[18] "Korea, Republic of," International Atomic Energy Agency, accessed December 30, 2012, http://www.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=KR.

[19] "Nuclear Power in South Korea," World Nuclear Association, last modified December 2012, http://www.world-nuclear.org/info/inf81.html.

Korea has not developed any fissile material production capability, such as uranium enrichment or spent nuclear fuel reprocessing technology.

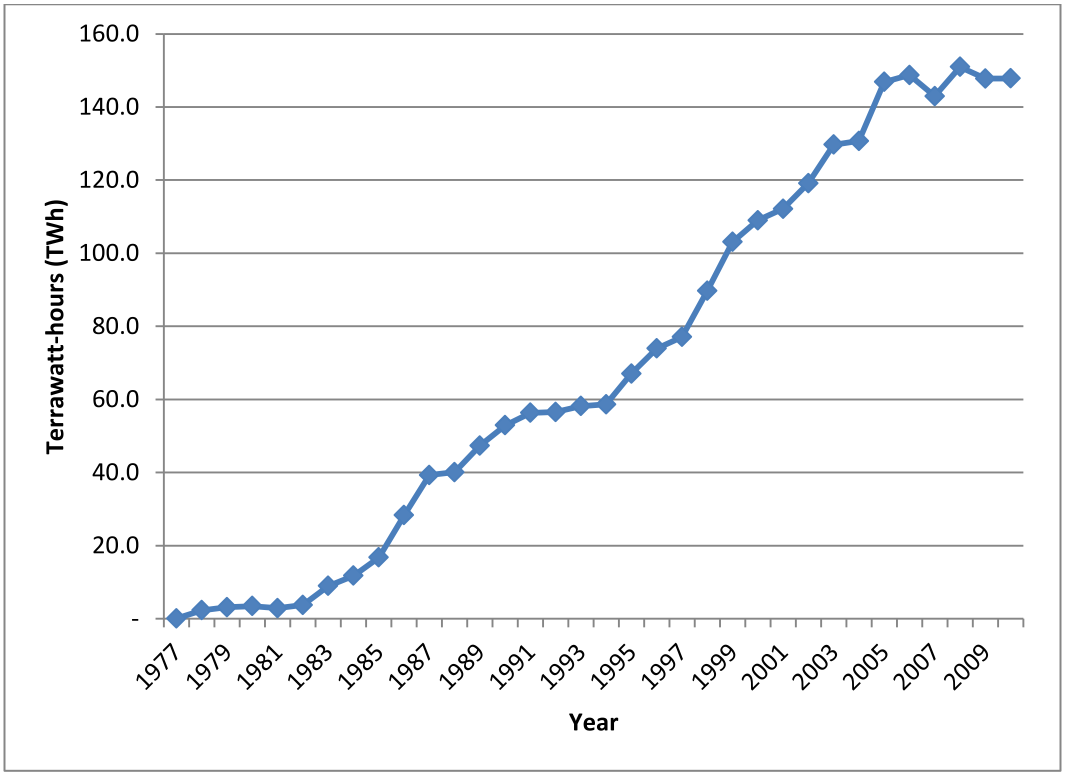

Figure 6.6 – Nuclear Power Consumption in South Korea (1977-2010)

6.2.1 Phase I: Turnkey Approach and Weapons R&D (1958-1977)

South Korea set the initial legal and research framework for its nuclear power program in the late 1950s. The Atomic Energy Act was passed by the National Assembly in 1958, and in accordance with this act, the Office of Atomic Energy (OAE) and the Korea Atomic Energy Research Institute were established in 1959.[20] Other developments in the 1950s included signing a contract with the

---

[20] Korea Atomic Energy Research Institute, *Energy Sourced from the Brain: 50 Years of Nuclear Energy, 50 Years of Prosperity* (Seoul, South Korea: Korea Atomic Energy Research Institute, 2009), 40-41.

General Atomic Division of General Dynamics Corporation for the purchase of a 100 kilowatt (kW) research reactor in 1958. Activity during the late 1950s and early 1960s was mostly focused on exploring what would be needed in terms of technical and human infrastructure and fostering international partnerships. In 1959, a visiting International Atomic Energy Agency (IAEA) delegation expressed concern that South Korea's early nuclear efforts were being conducted in haste[21], but the OAE was convinced that, due to a lack of indigenous resources, South Korea would need to eventually utilize nuclear power to meet electricity demands.[22]

South Korea's civilian nuclear power program began in earnest in 1962 when the research reactor supplied by General Atomics began operating.[23] In the same year, the Survey Committee on Nuclear Power Generation was formed and wrote "A Plan for the Promotion of Nuclear Power Generation." This plan stated the need to develop nuclear power on the grounds that South Korea would exhaust all indigenous energy resources within twenty to thirty years, and it called for construction of a 150 MW plant to begin in the early 1970s.[24] Additionally, nuclear power was justified as the most promising source to "meet the 'urgent' energy needs of 'rapid' economic development in the near future."[25]

The Council on the Nuclear Power Generation Plan was established in 1965, and this council set up a Review Committee on the Nuclear Power

---

[21] Korea Atomic Energy Research Institute, 52.
[22] Ha, 222-223.
[23] Korea Atomic Energy Research Institute, 70-71.
[24] Ha, 223.
[25] Jong-dall Kim and John Byrne, "The Asian Atom: Hard-Path Nuclearization in East Asia," in *Governing the Atom: The Politics of Risk*, ed. John Byrne and Steven M. Hoffman (New Brunswick, NJ: Transaction Publishers, 1996), 282.

Generation Plan in 1967. The Review Committee recommended the construction of two 500 MW nuclear plants during the 1970s for the following reasons: 1) total energy demand in South Korea would double in the next ten years, 2) demand for electricity would increase six fold by 1976, 3) the economic costs of nuclear power had been decreasing since the early 1960s, and 4) the operating reliability and safety of nuclear reactors had been improving since the early 1960s. South Korea then financially committed itself to nuclear power by signing a contract for a turnkey nuclear power plant, which turned out to be Kori-1, with Westinghouse Electric International Company in 1969.[26]

It was also during the 1960s that the South Korean government began to integrate *chaebeol*[27] companies into the government's nuclear plans. This resulted in forming a strong public-private alliance that firmly committed the country to developing nuclear power. On top of *chaebeol* participation, the government tasked the state-owned Korea Electric Power Company (KEPCO) with engineering, construction and operation of plants, gave responsibility for research and development of nuclear technology to the Korea Atomic Energy Research Institute (KAERI), and assigned the Economic Planning Board (EPB) with coordinating the nuclear program, negotiation of foreign loans, and preparation of feasibility studies.[28]

---

[26] Ha, 224-226.

[27] *Chaebol* (also spelled *Jaebeol*) are large, family-owned South Korean conglomerates that were favored by the South Korean government to aid economic development. Some of these companies, such as Samsung, Hyundai, LG, Daewoo, and Doosan, are now among the world's largest and most well-known companies.

[28] Kim and Byrne, 283.

The initial phase of South Korea's nuclear program was marked by the construction of turnkey power plants. Between 1972 and 1977, South Korea initiated construction on three nuclear power plants: Kori-1 in 1972, Kori-2 in 1977, and Wolsong-1 in 1977. The prime contractor for Kori-1 and Kori-2 was Westinghouse Electric Company, and the prime contractor for Wolsong-1 was Atomic Energy of Canada Limited (AECL). Domestic South Korean companies had minimal participation in the construction of these power plants, and the government focused on building up the "legal, institutional, and organizational bases necessary for the development of nuclear power and technology transfer."[29]

The opening of Kori-1 in 1978 marked a major milestone in the development of South Korea's economy. With Kori-1, South Korea became the twenty-first country to operate a nuclear power plant, and the plant provided a significant new source of electricity to meet the country's growing demand. However, South Korea's nuclear program in the early and mid-1970s had intentions other than civilian use of nuclear energy.

When the United States and South Korea negotiated their nuclear cooperation agreement in the early 1970s, South Korea's potential as a nuclear weapons proliferant state was not well understood. As Miles Pomper write, "South Korea did not have a single operating nuclear power plant let alone piles of spent nuclear fuel…" and "U.S. nuclear nonproliferation efforts remained in

---

[29] Ho-Tak Kim, "Technology Transfer Strategy for Nuclear Power Development in Korea," *Energy R&D* 14 (1992): 155.

their infancy."[30] By the late 1970s, though, the full scope of South Korea's nuclear intentions became clear to the U.S. government.

A June 1978 report by the Central Intelligence Agency (CIA) concluded that South Korean President Park Chung-hee authorized a program to develop nuclear weapons technology in late 1974 under a projected designated "890" but that Park had not decided whether to actually build nuclear weapons.[31] Sung Gul Hong puts the start date for South Korea's nuclear weapons program as November 1971, when Park instructed his adviser for developing defense-related heavy and chemical industries, Oh Won-chul, to create plans for developing nuclear weapons technology. South Korea's Agency for Defense Development (ADD) then was tasked with research and development on nuclear weapons design, delivery systems, and explosion technologies, and KAERI attempted to import reprocessing technology and facilities from abroad. KAERI scientists, though, were not informed of the potential military application of their work, and Park kept information about the military nuclear program closely guarded.[32]

Initially, Park envisioned developing fissile material production capability as a hedge and to give South Korea the option of also developing an indigenous nuclear deterrent. South Korea's cabinet already approved a nuclear research plan by KAERI in 1968 that included plans to construct nuclear fuel fabrication,

---

[30] Miles A. Pomper, "Stakes Rise for U.S.-ROK Nuclear Energy Talks," *Center for U.S.-Korea Policy Newsletter*, February 2010, http://cns.miis.edu/other/pomper_miles_100200_cuskp_newsletter_2-2.pdf.

[31] "South Korea: Nuclear Developments and Strategic Decisionmaking," Central Intelligence Agency, June 1978, http://www.foia.cia.gov/docs/DOC_0001254259/DOC_0001254259.pdf, 6.

[32] Sung Gul Hong, "The Search for Deterrence: Park's Nuclear Option," in *The Park Chung Hee Era: The Transformation of South Korea*, ed. Kim Byung-Kook and Ezra F. Vogel (Cambridge, MA: Harvard University Press, 2011), 483.

uranium refinement, and reprocessing facilities by 1981.[33] Park's decision to develop nuclear technology for military purposes in the early 1970s accelerated KAERI's efforts to acquire nuclear technology from abroad. In 1972, France agreed to sell fuel fabrication and reprocessing technology to South Korea, and KAERI set about developing the human capital necessary for this technology.

Since KAERI believed that it was unlikely that South Korea would be allowed to reprocess fuel from the U.S.-supplied Kori-1 reactor, they also entered negotiations with Canada in 1973 to acquire a heavy water CANDU reactor, and Park received a plan from the ADD to develop nuclear weapons in the same year. According to declassified South Korean government documents, South Korean Ambassador to Canada Kim Young-ju referenced being able to produce fissile material for weapons with CANDU reactors in a letter to Park in 1975, but Kim mentioned that production would be impossible if South Korea were subject to international controls on uranium.[34]

Also in 1975, South Korea made a deal with Belgium for the purchase of a research-scale mixed-oxide (MOX) nuclear fuel[35] fabrication facility[36], and the ADD developed a workable nuclear weapon design.[37] France and South Korea

---

[33] Hong, 489.
[34] Won-sup Yoon, "Park Sought to Develop Nuclear Weapons," *Korea Times*, January 15, 2008, http://www.koreatimes.co.kr/www/news/nation/nation_view.asp?newsIdx=17354.
[35] MOX nuclear fuel contains a mixture of plutonium oxide and uranium oxide. Plutonium recovered from spent nuclear fuel reprocessing can be used in making MOX fuel. This is a key step in creating a closed nuclear fuel cycle and can reduce the need for imports of enriched uranium.
[36] "South Korea: Nuclear Developments and Strategic Decisionmaking,"5-6.
[37] Hong, 491.

even signed a safeguards agreement in September 1975,[38] and France notified South Korea that it was ready to provide $20 million for the facility.[39] Thus, by the mid-1970s, KAERI had plans in place to acquire the technology to domestically produce the fissile material needed to fuel ADD's weaponization efforts.

After India conducted a nuclear test in 1974, the U.S. nuclear nonproliferation policy became much stricter, and other nuclear programs came under stronger U.S. scrutiny. As the United States found out about South Korea's nuclear negotiations with Canada and France, Washington moved to prevent South Korea from developing a nuclear weapons capability by pressuring Ottawa and Paris to end negotiations, and the United States, France, and Canada began to push for Seoul to ratify the NPT. The U.S. Embassy in Seoul also began to confront Park directly, but Park denied having any intentions to develop nuclear weapons. U.S. government pressure also included a Congressional resolution calling for deferral of Export-Import Bank loans that were intended for the construction of the Kori-2 reactor. South Korea responded by ratifying the NPT in April 1975.[40]

The United States sought to not only stop South Korea from acquiring nuclear weapons but also from acquiring the technological capability to produce nuclear weapons, and U.S. officials made it clear to Park that there would be significant consequences if South Korea continued to pursue nuclear reprocessing

---

[38] International Atomic Energy Agency, Treaty No. 14581, "International Atomic Energy Agency, France, and Republic of Korea: Agreement for the application of safeguards," September 22, 1975., http://treaties.un.org/doc/publication/unts/volume%20996/volume-996-i-14581-english.pdf.
[39] Ha, 237.
[40] Hong, 496-499.

technology. Along those lines, the U.S. ambassador to South Korea in the mid-1970s, Richard L. Sneider, stated in a cable that "…far more than our nuclear support is at stake here…[the] whole range of security and political relationships between [the United States] and ROK will be affected…" In addition, there were hints from the U.S. government about terminating further military sales to South Korea.[41] This pressure led to Park cancelling the reprocessing plant deal with France and suspending all activities related to Project 980 in 1976.[42] In addition, Canada suspended talks on the sale of a NRX-style research reactor in 1976, and a contract with Belgium to provide a plutonium reprocessing facility was cancelled in 1977.[43]

Park's nuclear fuel cycle ambitions did not completely end there. After Jimmy Carter was elected U.S. president in November 1976, Park instructed Oh Won-chul to pursue full development of the nuclear industry (i.e., with reprocessing capability) but "…in a manner not inviting foreign pressure."[44] South Korea sought to develop reprocessing and fuel fabrication technology indigenously, and the Korea Nuclear Fuel Development Institute (KNFDI) was established in December 1976 to develop these technologies.[45] The United States kept a close watch on the activities of KNFDI, and little progress was made on developing reprocessing technology. By 1978, major nuclear research efforts

---

[41] Ha, 237.
[42] "South Korea: Nuclear Developments and Strategic Decisionmaking," 7.
[43] Seung-Young Kim, "Security, Nationalism and the Pursuit of Nuclear Weapons and Missiles: The South Korean Case, 1970-82," *Diplomacy & Statecraft* 12, no. 4 (2001): 66.
[44] Seung-Young Kim, 67.
[45] Hong, 509.

were reoriented to focus on uranium mining and ore conversion, LWR fuel fabrication, and power reactor components.[46]

6.2.2 Phase II: Component Approach (1978-1986)

After Park Chung-hee suspended South Korea's work on nuclear weapons and reprocessing technology, South Korea's nuclear sector focused on boosting the country's nuclear reactor construction capability. In this phase, South Korea moved away from importing turnkey reactors and expanded the role of domestic companies in reactor construction. South Korean firms took over construction work, while foreign companies still were contracted to provide reactor design and supply of the primary systems.[47] The main objective of this approach was to "…facilitate technology transfer and localization of equipment supply through direct management of project implementation by KEPCO and through providing more opportunities to domestic companies and local manpower to participate more actively in the project."[48]

The South Korean government set a goal of attaining 30 percent self-sufficiency in the areas of nuclear power plant equipment and fuel by 1981.[49] Subsequent contracts with Westinghouse also had clauses in them to require more participation in plant design, construction and management by South Korean firms and personnel, and Westinghouse was obligated to train South Korean

---

[46] "South Korea: Nuclear Developments and Strategic Decisionmaking," 8.
[47] Mark Holt, "U.S. and South Korean Cooperation in the World Nuclear Energy Market: Major Policy Considerations," *Congressional Research Service*, January 21, 2010, http://www.fas.org/sgp/crs/row/R41032.pdf, 2.
[48] Ho-Tak Kim, 157-158.
[49] Ha, 231.

personnel.[50] Major South Korean heavy-industry conglomerates also began to form business relationships with the global nuclear industry in accordance with the government's ambitions.[51]

South Korea also further diversified its nuclear suppliers by contracting with the French company Framatome to supply the primary systems for Ulchin-1 and Ulchin-2. This meant that South Korea was working with American, Canadian, and French nuclear suppliers while increasing domestic firm capabilities. However, the United States still dominated much of South Korea's economics and foreign relations, and South Korea was obliged to sign contracts with U.S. firms for other planned nuclear power plants after U.S. President Jimmy Carter visited South Korea in 1979.[52]

With KEPCO in charge of project management and South Korean firms more involved in reactor construction, the ratio of work conducted domestically (the localization ratio) increased to 46 percent for design and engineering services and 41.5 percent for construction equipment manufacturing. During this phase, construction began on six units: Kori-3, Kori-4, Yonggwang-1, Yonggwang-2, Ulchin-1, and Ulchin-2. Wolsong-1, Kori-2, Kori-3, Kori-4, Yonggwang-1, and Yonggwang-2 were connected to the electricity grid during this time period, adding over 5,400 MW of capacity to power South Korea's booming economy.

In addition to boosting domestic firms' nuclear power plant construction capacity, South Korea began to develop domestic nuclear fuel production capacity during this time period. On 31 December 1980, the Ministry of Science and

---

[50] Kim and Byrne, 288.
[51] Ha, 231.
[52] Kim and Byrne, 287.

Technology (MOST) decided to lead a project to develop domestic supply of fuel for pressurized heavy water reactors (PHWRs), namely South Korea's CANDU style reactors at Wolsong.[53] KAERI signed a contract with AECL for fuel verification, and facilities for testing nuclear fuel were installed at KAERI in 1982. South Korean-developed fuel was sent to Canada for in-reactor testing in January 1983 and received approval by MOST a year later in January 1984. The first batch of test fuel was loaded in the Wolsong NPP in September 1984. After successful test runs, Canada agreed to transfer technology for the mass production of PHWR fuel, and South Korea began mass production of PHWR fuel in 1987. This gave South Korea the ability to produce domestically all of the fuel needed for the Wolsong NPP.[54]

South Korea experienced a major shock when Park Chung-hee was assassinated by the chief of South Korea's Central Intelligence Agency (KCIA) in October 1979, and Chun Doo-hwan took power in a coup d'état in 1980. Chun sought to win the favor of the United States and reassure the U.S. security commitment to Seoul, and for the sake of good relations with Washington, he froze all nuclear weapons-related research and scaled back South Korea's missile program. Subsequent research during Chun's presidency focused on peaceful uses of nuclear energy.[55] However, interest in reprocessing resurfaced in 1983 with KAERI performing a joint study with Atomic Energy of Canada, Ltd (AECL) on a TANDEM fuel cycle, in which spent PWR fuel would be fabricated to be used in CANDU reactors. The U.S. government again opposed this study

---

[53] Korea Atomic Energy Research Institute, 144.
[54] Korea Atomic Energy Research Institute, 148-153.
[55] Seung-Young Kim, 69-70.

out of opposition to any South Korean ability to reprocess spent nuclear fuel, and the study ended the year it started.[56]

6.2.3 Phase III: Complete Indigenization and Standardization (1987-1999)

In 1987, KEPCO set out to create a standard Korean nuclear reactor design, and South Korean firms took the role of primary contractor in all major phases of reactor construction and component supply, with foreign firms acting as subcontractors. U.S. firm Combustion Engineering (C-E) agreed to full technology transfer of its System 80 reactor design, so KEPCO made System 80 the basis of the Korean standard design. Other U.S. firms, including General Electric and Sargent & Lundy, also agreed to transfer technology related to turbine generators and architect/engineering services. Under these terms, construction began on the units Yonggwang-3, Yonggwang-4, Ulchin-3, and Ulchin-4 in the late 1980s and early 1990s. A similar agreement was made with AECL, which led to construction starting on Wolsong 2-4 in the early 1990s.[57] All six of these units came online by the end of the 1990s, adding some 6,400 MW to South Korea's total electricity generating capacity.

KAERI scientists worked with C-E engineers in order to design the Korea Standard Nuclear Power Plant (KSNP) during the mid and late 1980s. The result of this effort was put into practice with the completion of the Ulchin-3 and Ulchin-4 units, which were the first KSNP, in 1998. After designing Ulchin-3

---

[56] Jungmin Kang and H.A. Feiveson, "South Korea's Shifting and Controversial Interest in Spent Fuel Reprocessing," *The Nonproliferation Review*, Spring 2001, 72, http://cns.miis.edu/npr/pdfs/81kang.pdf.

[57] Holt, 2-4.

and Ulchin-4, C-E transferred core technology to South Korea, and construction began on the next wave of KNSP, Yonggwang-5, Yonggwang-6, Ulchin-5, and Ulchin-6, in the late 1990s. With the successful design, construction, and operation of these KSNP units, South Korea became the first developing country capable of designing and producing nuclear reactors.[58] In addition, the development of the KSNP increased the localization ratio of South Korean nuclear plants from a mere 8 percent with Kori-1 to 95 percent with Ulchin-3 and 4. Figure 6.7 illustrates the increase in localization ratio over this twenty year period.[59]

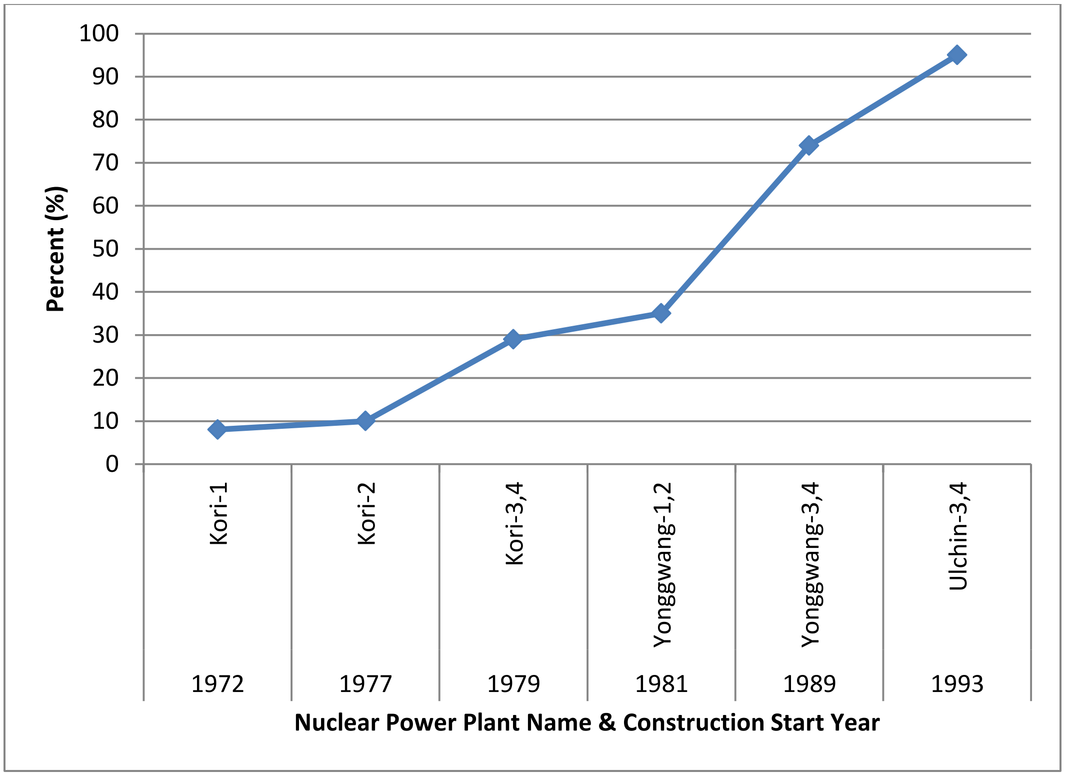

Figure 6.7 – Increase in the Localization Ratio in South Korean NPP Construction

---

[58] Korea Atomic Energy Research Institute, 166-170.
[59] Korea Atomic Energy Research Institute, 138, 164-165.

Soon after KAERI began developing and testing heavy water reactor fuel, the development of domestic supply of light water reactor fuel began. KEPCO initially was skeptical of the need for a domestic supply of LWR fuel, but President Chun Doo-hwan made LWR fuel production a priority.[60] In 1986, South Korea partnered with Siemens of Germany to transfer LWR fuel production technology to South Korea, and the Korea Nuclear Fuel Company (KNF) set up a facility for producing LWR fuel was set up near KAERI. For the first time, KAERI engineers conducted the nuclear fuel design work for Kori-2 in 1989, and KNF produced the Korea Fuel Assembly (KOFA) in 1990, which was then loaded into Kori-2. KOFA was replaced soon after due to a fuel incident in Kori-2, and Westinghouse was contracted to supply and transfer nuclear fuel technology in place of KOFA.[61] By the end of the 1990s, KNF (then called KEPCO Nuclear Fuel) took over nuclear fuel design operation from KAERI and was capable of producing nuclear fuel for all of South Korea's NPPs.[62]

The fuel fabrication plants were the only fuel cycle facilities[63] that South Korea developed during this era (and still are the only fuel cycle facilities), but even after Chun Doo-hwan suspended research on reprocessing technology, there was lingering talk in the 1990s of South Korea acquiring or otherwise developing reprocessing technology. In 1992, South Korea signed the Joint Declaration of the Denuclearization of the Korean Peninsula with North Korea, which mandates,

---

[60] Korea Atomic Energy Research Institute, 154-158.

[61] Korea Atomic Energy Research Institute, 162-163.

[62] "History," KEPCO Nuclear Fuel Company, accessed June 10, 2012, http://www.knfc.co.kr/main/?en_skin=intro03.html&left=3.

[63] "Fuel cycle facilities" would include facilities for mining, uranium conversion, uranium enrichment, fuel fabrication, spent fuel reprocessing, and waste disposal, which is essentially everything other than power plants.

"The South and the North shall not possess nuclear reprocessing and uranium enrichment facilities."[64] Despite this agreement, a South Korean official reacted to Japanese plans to use plutonium as a reactor fuel by telling *Nuclear Fuel*, "If Japan now forces ahead with industrial-scale plutonium use, the pressures on us to be next will be very great."[65] Another *Nuclear Fuel* article reported in 1999 that officials at KEPCO were planning on keeping open the option of reprocessing spent fuel offshore and then using MOX fuel in KEPCO reactors.[66]

Two factors that arose in the 1990s led to South Korean officials revisiting the reprocessing option. First, a 1997 analysis concluded that spent fuel storage pools at the Kori NPP would be full by 2005, and the storage pools at the Yonggwang and Ulchin NPPs would be full by 2009. With no long-term waste storage facilities, South Korea faced growing pressure to deal with this mounting stockpile of spent nuclear fuel. However, a reanalysis showed that through re-racking of pools, intra-site transshipment of spent fuel, and dry-storage facilities can be used to make spent fuel pools last until 2016. After 2016, the government plans to open a centralized, away from reactor interim storage facility.[67]

Second, Japan signed a bilateral agreement with the United States in 1988 that allows Japan to reprocess, either domestically or overseas, U.S.-origin spent nuclear fuel. The nuclear fuel agreement between the United States and South Korea, which lasts until 2013, gives the United States consent rights to all U.S.-

---

[64] "Joint Declaration of South and North Korea on the Denuclearization of the Korean Peninsula," Center for Nonproliferation Studies, accessed June 10, 2012, http://cns.miis.edu/inventory/pdfs/aptkoreanuc.pdf.

[65] Mark Hibbs, "Japan Bristles In Advance of Expected U.S. Meddling In Plutonium Use Program," *Nuclear Fuel* 19, no. 9 (1994): 9.

[66] Mark Hibbs, "Chang's Successor Will Reopen Reprocessing Option, Officials Say," *Nuclear Fuel* 24, no. 13 (1999): 8.

[67] Kang and Feiveson, 72-73.

origin fuel. This means that South Korea cannot reprocess the fuel without U.S. permission. Japan had a similar agreement to this prior to 1988, so some South Korean officials were unhappy with the change in U.S. policy toward Japan but not toward South Korea. In 1997, the South Korean government hired a U.S. law firm, Hogan & Hartson, to intercede on its behalf in order to obtain U.S. consent to reprocessing South Korean spent fuel. However, Washington did not relent, and Seoul eventually decided it would not try to reprocess U.S.-origin or even non-U.S.-origin spent fuel without U.S. consent.[68]

Despite the reprocessing debate, South Korea's nuclear industry took a major step forward by gaining nuclear power plant independence through this localization effort, meaning that South Korean firms could be responsible for subsequent reactor design, construction, and component supply nearly independent of foreign firms. Some key components still are supplied by foreign firms, but these components constitute a small portion of a nuclear reactor's total cost.[69] Thus, in a span of about 30 years, South Korea went from a poor country purchasing turnkey nuclear reactors from somewhat skeptical vendors to a developed country capable of designing and building nuclear reactors on its own.

In the military realm, there are reports that South Korea's Joint Chiefs of Staff were drawing up plans for a clandestine nuclear weapons program in the late 1980s and early 1990s during the administration of President Roh Tae-woo but agreed to pull back in exchange for the United States shelving troop withdrawal

---

[68] Kang and Feiveson, 73-75.
[69] Holt, 4.

plans.[70] It also was revealed that South Korean scientists carried out laboratory-scale experiments on uranium enrichment and reprocessing in the early 1980s and in 2000. Despite being required to report these activities per its safeguards agreement with the IAEA, South Korea did not report these experiments to the IAEA until 2004. A subsequent IAEA investigation of the matter found no link to a nuclear weapons program and concluded that the experiments ceased in 2000.[71]

6.3 Prospect Theory and South Korea's Nuclear Fuel Cycle Decision Making

To summarize the history of South Korea's nuclear development given in Section 6.2, Figure 6.8 displays the nuclear fuel cycle employed in South Korea. South Korea uses an open nuclear fuel cycle, which means that spent fuel is disposed of after use in a reactor and is not reprocessed. As can be seen in the Figure 6.8, South Korea receives front end fuel cycle services from a number of foreign entities, including Australia, Canada, the European Union, Russia, the United Kingdom, and the United States. The only front end service performed in South Korea is fuel fabrication, and all of South Korea's nuclear fuel is fabricated domestically by KEPCO Nuclear Fuel.

---

[70] Mark Hibbs, "ROK military said to have begun nuclear weapons plan in 1980s," *Nucleonics Week* 45, no. 47 (2004): 14; Mack, Andrew, "Potential, not Proliferation," *The Bulletin of the Atomic Scientists* 53, no. 4 (July-August 1997): 49.

[71] "Implementation of the NPT Safeguards Agreement in the Republic of Korea."

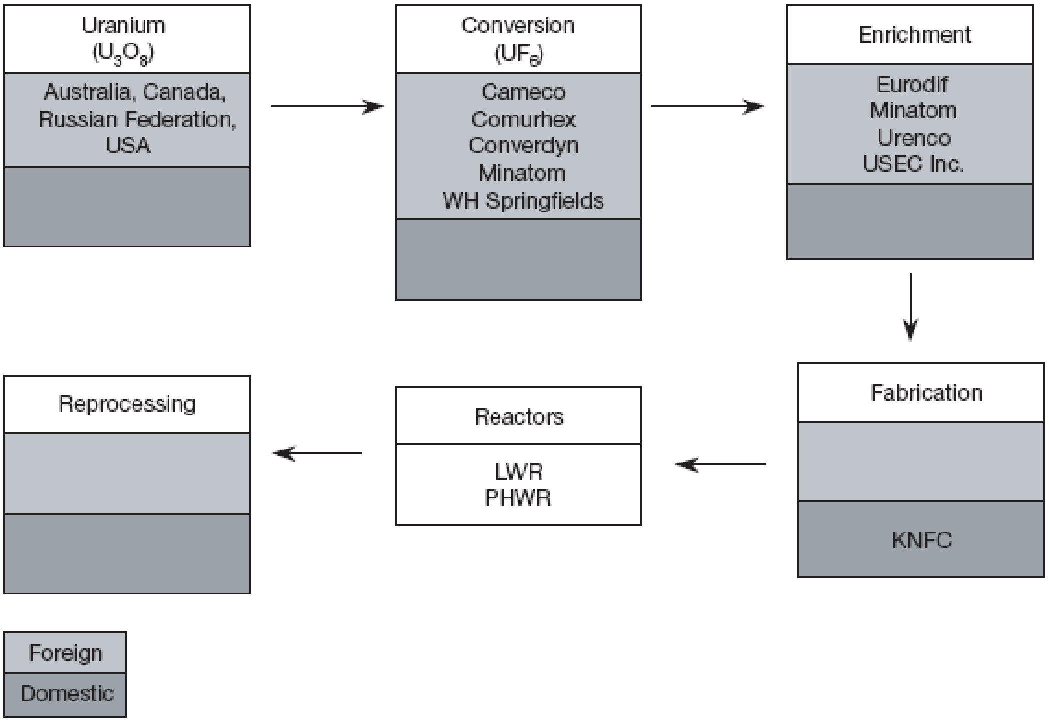

Figure 6.8 – South Korea's Current Nuclear Fuel Cycle[72]

It should be noted that the only changes in South Korea's nuclear fuel cycle since the beginning of its nuclear program in the early 1970s are the addition of South Korean fuel fabrication and a diversification of vendors in the other front end steps. Essentially, South Korea has employed the same fuel cycle since the beginning of its nuclear program, which is an open cycle with no fissile material production capabilities. Thus, the general question to examine with prospect theory is why South Korea chose this particular fuel cycle to develop, and three more specific questions arise out of the historical review of South Korea's nuclear sector.

---

[72] Foreign companies involved in South Korea's nuclear fuel cycle: Cameco (Canada), Comurhex (France), Converdyn (USA), Eurodif (Belgium, France, Italy, Spain), Minatom (Russian Federation), Urenco Ltd (Germany, Netherlands, UK), USEC Inc. (USA), WH Springfields (UK). See International Atomic Energy Agency, *Country Nuclear Fuel Cycle Profiles*, 2nd ed. (Vienna: International Atomic Energy Agency, 2005), 54, http://www-pub.iaea.org/MTCD/publications/PDF/TRS425_web.pdf.

1. Why did South Korea make such a strong commitment to developing nuclear power?
2. Why did Park Chung-hee pursue and abandon nuclear weapons program, and why did Chun Doo-hwan and subsequent South Korean governments not pursue nuclear weapons?
3. Why did South Korea not develop ENR technology for civilian use?

These questions will be analyzed using prospect theory and the analytical framework outlined in Chapter 3.

6.3.1 South Korea's Nuclear Fuel Cycle Decision Making

CIVILIAN TECHNOLOGY	RESULT
Electric Power Generation	Yes. 23 NPPs provide over 34% of electricity as of 2011.
Acquire/Develop Enrichment and Reprocessing (ENR) Technology	No. Attempted to acquire reprocessing technology in 1970s but abandoned due to U.S. pressure.
Achieve Nuclear Power Plant Independence	Yes. Domestic firms able to design, construct, and operate NPPs (but no domestic FISMAT production).
MILITARY TECHNOLOGY	**RESULT**
Acquire/Develop Nuclear Weapons	No. Clandestine nuclear weapons program in 1970s stopped before developing weapons capability.
Test Nuclear Explosive Device	No. Never constructed nuclear explosive.
Nuclear Weapons Hedging	No.

Table 6.1 – Civilian and Military Nuclear Technology Decision in South Korea

A summary of the technical decisions made in South Korea during the development of its nuclear sector is presented in Table 6.1. This list of decisions certainly does not include every decision made. Other decisions, including nuclear reactor design, are important, but Table 6.1 represents the major nuclear fuel cycle decisions that were made, principally whether to develop ENR technology for civilian and/or military use.

With this summary in mind, the three questions presented above will be analyzed in order to determine the main factors influencing South Korea's nuclear fuel cycle decision making and how this decision making fit into South Korea's overall strategy.

Why did South Korea make such a strong commitment to developing nuclear power?

The Korean Peninsula is not blessed with an overabundance of energy resources. Making matters worse for South Korea was that 88 percent of the power plants on the Korean Peninsula were located in North Korea after World War II ended, and North Korea's power plants produced 96 percent of the Korean Peninsula's electricity. In May 1948, North Korea cut off power supply to South Korea, leading to severe power shortages in South Korea. In the 1950s, South Korean planners viewed hydropower as insufficient to meet future electricity demand and projected South Korean coal reserves would be depleted within 30 years.[73] Thus, Seoul decided to develop nuclear power as an alternative energy source.

South Korea's first president, Syngman Rhee, was an enthusiastic supporter of nuclear power, and the technology represented more than a source of electricity to him. At South Korea's first Academic Conference on Nuclear

---

[73] Korea Atomic Energy Research Institute, 91-93.

Energy in July 1959, President Rhee stated, "The so-called least developed countries will be able to usher in a new ear, banking on the unlimited potential of nuclear energy. However, if we fail to overcome the hardships facing us, we will never see the new era."[74] In the crisis that faced South Korea after the devastation of the Korean War, nuclear power represented the promise of an abundant energy source that would drive economic growth. This type of sentiment toward nuclear energy was common in the 1950s, but South Korea was particularly strong in its belief in the benefits of nuclear energy.

However, South Korea could have chosen to rely simply on fossil fuels, namely coal, natural gas, or oil, or attempted to develop renewable sources of energy, such as solar power, in order to meet growing electricity demands. Daniel Poneman offers a thought on why nuclear power is particularly appealing to developing countries, "Large projects often appeal to developing country governments as a means to demonstrate their ability. Because of its complexity, perhaps, even its mystery, the mastery of nuclear technology can instill popular pride as well as enhance the legitimacy of a central government."[75] Jong-dall Kim and John Byrne add to this by writing, "Nuclear power signaled the transition from underdevelopment in the minds of South Korean leaders."[76]

While South Korea did build many fossil fuel-fired power plants to meet electricity demand, Seoul invested heavily in developing nuclear power from the start. In the early years of South Korea's nuclear program of the late 1950s, the nuclear program's budget grew rapidly, and "…funds set aside for nuclear energy

---

[74] Korea Atomic Energy Research Institute, 58.
[75] Kim and Byrne, 285.
[76] Ibid.

took up a significant portion of the national budget."[77] Construction of the Kori-1 NPP between 1972 and 1977 cost over 150 billion won, which "…represented the biggest ever single project of its kind in Korea" at the time.[78]

After the oil shock of 1973 caused crude oil to quadruple in price, Seoul "…judged that construction of nuclear power plants was the only alternative energy source that would substitute for oil."[79] The oil shock reaffirmed the South Korean government's belief in nuclear power as an answer to the country's energy needs and increased the urgency to build more reactors. In response to the oil shock, plans to build Kori-2 and Wolsong-1 were made in 1973,[80] and in 1974, KAERI began preparations to secure nuclear technology independence.[81] As a result of the increased pace of construction activity, "…nuclear power plants were constructed…nearly every year in the late 1970s and nuclear power became a major source of electricity generation in the 1980s."[82]

The second oil crisis in 1979 caused a greater than expected drop in electricity demand in South Korea, and nuclear power plant construction halted after 1981. The reserve margin of electricity rose to 60 percent in 1986 due to the decreased electricity demand, but nuclear power plant constructed resumed in 1989 after the reserve margin of electricity dropped to 19 percent. In the 1990s, the South Korean government decided to diversify electricity sources in order to stabilize the country's electricity market and enable the government to react to

---

[77] Korea Atomic Energy Research Institute, 52.
[78] Korea Atomic Energy Research Institute, 114.
[79] Korea Atomic Energy Research Institute, 115.
[80] Korea Atomic Energy Research Institute, 116-119.
[81] Korea Atomic Energy Research Institute, 134.
[82] Shin and Eom, 157.

changes in world energy markets. Nuclear power was selected as the preferred source for the base load, and coal and natural gas would meet middle and peak loads.[83]

In summary, South Korea, under the Rhee Syngman presidency, made an initial decision in the 1950s to invest heavily in nuclear technology out of a belief that nuclear power could meet the country's electricity demands and vault the country into the ranks of the advanced nations. After taking office in 1961, Park Chung-hee continued with this thinking and strongly supported South Korea's nuclear energy program. While South Korea was experiencing double digit growth rates in the late 1960s and early 1970s, the first oil shock of 1973 made nuclear power seem less risky than oil or other fossil fuels to South Korean policy makers. From an economic point of view, South Korea was in a gains frame in 1973; therefore, nuclear power was selected as the less risky source of electricity to power the country's economic growth. With this decision, nuclear power became South Korea's base load electricity source and committed the country to nuclear power.

Why did Park Chung-hee pursue and abandon nuclear weapons program, and why did Chun Doo-hwan and subsequent South Korean governments not pursue nuclear weapons?

Given the importance that South Korean policy makers placed on nuclear power, it is somewhat surprising that Park Chung-hee pursued a nuclear weapons program that ended up jeopardizing South Korea's nuclear energy program. The

---

[83] Shin and Eom, 157-158.

answer to why Park desired nuclear weapons lies in how he viewed South Korea's overall security situation during the 1970s.

For Park, national security and guarding South Korea from another North Korean invasion were of utmost importance, and the military alliance with the United States was critical to preserving South Korea's security. In order to win the favor of Washington, Park decided to send combat troops to Vietnam in 1964 to support the U.S. war effort in Southeast Asia. Between 1964 and 1973, over 300,000 South Korean troops fought in Vietnam.[84] Park thought that sending South Korean forces to an unpopular war would be worth the risk, but events that unfolded during the late 1960s and early 1970s made him doubt Washington's commitment to South Korea.

With the United States becoming increasingly committed to the war in Vietnam, North Korean leader Kim Il Sung decided to test the mettle of the U.S.-ROK alliance in the late 1960s and launched a series of provocations along the demilitarized zone (DMZ) that separates North and South Korea. These provocations included three high profile attacks. In January 1968, a group of North Korean commandos attempted to assassinate Park during a raid on the Blue House, the South Korean presidential compound in Seoul. Two days later, North Korea seized the *USS Pueblo*, a U.S. Navy intelligence ship, in the Sea of Japan and held the crew for eleven months. Then in April 1969, North Korean fighter aircraft shot down a U.S. Navy reconnaissance aircraft over the Sea of Japan, killing all 31 crew members. Washington took no military retaliation against

---

[84] Paull Shin, "Korean Vietnam War Veterans Honored by Senate," *Senate Democrats Blog*, February 12, 2010, http://blog.senatedemocrats.wa.gov/shin/korean-vietnam-war-veterans-honored-by-senate/.

North Korea for these provocations, making Park doubt the will of the United States to take action against North Korea.

The real shock to Park came with the announcement of the Nixon Doctrine in 1969. In a speech in Guam, President Nixon declared that the United States would honor treaty commitments and extend the U.S. nuclear umbrella to treaty allies, but he also said, "…we shall look to the nation directly threatened to assume the primary responsibility of providing the manpower for its defense." [85] The next year, Nixon unilaterally decided to withdraw the U.S. Seventh Infantry Division from Korea, reducing the U.S. troop presence in South Korea from 63,000 to 42,000. Washington's ensuing rapprochement with the People's Republic of China further troubled Park, and made South Korea worry that the United States would move to deal directly with Pyongyang.[86]

The decision to withdraw the Seventh Infantry Division, despite repeated pleas to reconsider the withdrawal, seems to have been the tipping point for Park. Given the conventional military superiority North Korea held in the early 1970s, Seoul concluded that a conventional military buildup was not enough to deter North Korean attacks and that only U.S. military presence in South Korea could deter North Korea. His daughter, Park Geun-hye, recalled that Park launched the nuclear weapons program in response to the withdrawal of the Seventh Infantry Division.[87] The Nixon Doctrine, combined with weak U.S. responses to North Korean provocations in the 1960s, made Park question whether he could rely on

---

[85] "President Nixon's Speech on 'Vietnamization,' November 3, 1969," Vassar College, accessed June 19, 2012, http://vietnam.vassar.edu/overview/doc14.html.

[86] "South Korea: Nuclear Developments and Strategic Decisionmaking," 2.

[87] Hong, 488.

the United States for South Korea's security, so Park decided to guarantee South Korea's security by pursuing nuclear weapons.

Sung Gul Hong succinctly summarized Park's feelings at the time. "Park feared that the United States could remove its nuclear umbrella as unilaterally and abruptly as it had decided to withdraw the Seventh Infantry Division,"[88] and "Distrusting U.S. intentions, Park thought that he had to opt for nuclearization in order to make the North give up any thoughts of waging a total or a limited war."[89] Park clearly was in a losses frame, making him risk acceptant. Park accepted the risk of damaging relations with the United States by pursuing nuclear weapons because he came to view Washington as an unreliable and unfaithful partner.

Threatening negative repercussions to all aspects of the U.S.-South Korea relationship, Washington made Park suspend his nuclear weapons program by raising the stakes to an unacceptable level. However, Park remained suspicious of Washington and ordered a resumption of nuclear weapons research after newly-elected U.S. President Jimmy Carter pushed for the withdrawal of all U.S. ground troops and nuclear weapons from South Korea. The U.S. Department of Defense opposed Carter's plans, but that did little to ease Park's concerns. Only U.S. intelligence and dominating presence in South Korean politics hampered Seoul's nuclear weapons ambitions for the rest of Park's presidency.

The assassination of Park Chung-hee in 1979 and the coup d'état that brought Chun Doo-hwan to the South Korean presidency in 1980 marked a new

---

[88] Hong, 503.
[89] Hong, 504.

chapter in U.S.-South Korean relations. Chun's defense policy centered on maintaining good relations with the United States, and he sought reassurance from Washington. After taking office in 1981, the new administration of Ronald Reagan strongly backed Seoul and strengthened military relations by equipping U.S. forces in South Korea with more advanced weaponry.[90] With Washington demonstrating its commitment to defending South Korea and backing Chun, South Korean leaders, from Chun down, moved into a gains frame and became risk averse. Chun viewed continuing with Park Chung-hee's nuclear weapons program as too risky and ordered a halt to nuclear weapons research. The military officers surrounding Chun agreed with this approach, as they believed that Park pursued an overly nationalistic line and risked the U.S.-South Korea alliance. The leadership in Seoul deemed "strengthening the deterrence capability against North Korea quickly by importing the U.S. weapons…more important than the time consuming development of weapon systems in [South] Korea."[91]

The United States remained strong in its commitment to defending South Korea throughout the 1980s and 1990s, and South Korea continued to grow in strength relative to North Korea. These factors kept South Korean leaders in a gains frame. Maintaining good relations with the United States was viewed as the best way to guarantee South Korean security, and an indigenous nuclear weapons program was viewed as too risky because such a program would once again jeopardize good relations with Washington.

---

[90] Seung-Young Kim, 69.
[91] Seung-Young Kim, 70.

Why did South Korea not develop ENR technology for civilian use?

Per the existing U.S.-South Korea nuclear cooperation agreement signed in 1973, South Korea is required to obtain U.S. consent before reprocessing any U.S.-origin nuclear fuel.[92] After India's first nuclear explosive test in 1974, Washington grew increasingly concerned about limiting the spread of enrichment and reprocessing technologies to other countries. This included South Korea's interest in acquiring reprocessing technology, and the fact that South Korea's attempts to acquire reprocessing technology in the 1970s were linked to a clandestine nuclear weapons program made Washington more concerned. Thus, the United States took strong diplomatic measures in order to stop South Korea from acquiring reprocessing technology, and Washington never granted consent to reprocess U.S.-origin fuel to Seoul.

In response to India's nuclear test, the U.S. Nuclear Non-Proliferation Act of 1978 was passed. This act requires that all new nuclear cooperation agreements with the United States would require U.S. consent in order to reprocess U.S.-origin nuclear fuel or nuclear fuel processed in U.S.-origin nuclear reactors, and it requires U.S. consent to enrich U.S.-origin uranium.[93] These stipulations are stricter than the 1973 U.S.-South Korea nuclear cooperation agreement and demonstrate how serious Washington was about restricting the spread of ENR technology.

In line with Chun Doo-hwan's policy of ensuring South Korea's security through good relations with the United States, South Korea chose not to pursue

---

[92] Seongho Sheen, "Nuclear Sovereignty Versus Nuclear Security: Renewing the ROK-U.S. Atomic Energy Agreement," *The Korean Journal of Defense Analysis* 23, no. 2 (June 2011): 278.

[93] Sheen, 278.

reprocessing technology after Park Chung-hee's assassination in 1979. Doing so would have only upset relations with Washington, and South Korean leaders, in a gains frame after receiving reassurance from the Reagan administration in the early 1980s, were not willing to take that risk. In addition, nuclear power became a major source of electricity for South Korea, so Seoul did not want to jeopardize the nuclear industry by once again upsetting Washington over a reprocessing program.

In 1992, South Korea and North Korea signed the Joint Declaration of South and North Korea on the Denuclearization of the Korean Peninsula as part of Washington's effort to stop North Korea's nuclear weapons program. One of the clauses of this declaration stated, "South and North Korea shall not possess nuclear reprocessing and uranium enrichment facilities."[94] Despite North Korea's flagrant violation of the declaration, the United States still expects Seoul to hold to the declaration, so as to not give Pyongyang a legal excuse to abandon the declaration and proceed with its nuclear program.

South Korean interest in reprocessing did not completely go away (see section 6.2.3 for a brief discussion of why interest in reprocessing came up again in the 1990s), but all of the above cited factors contributed to make South Korea not develop or acquire reprocessing technology for civilian purposes. Again, risk averse governments in Seoul in the 1980s and 1990s did not feel that potentially upsetting the United States was worth the benefits to South Korea's nuclear industry that reprocessing would represent.

---

[94] "Joint Declaration of South and North Korea on the Denuclearization of the Korean Peninsula."

6.3.2 South Korean Policy Drivers

By the end of 1999, South Korea had come to rely on nuclear power to supply a significant portion of the country's electricity but the only indigenous nuclear capability outside of nuclear reactor construction and operation was nuclear fuel fabrication. South Korea had not developed uranium enrichment, spent fuel reprocessing, or any other means of fissile material production. Paul Joskow described such a situation as, "Any country which makes a large commitment to nuclear energy via a strategy of purchasing nuclear generating facilities or technology, but not fuel cycle facilities, finds itself in the position of being dependent on the internal political situation of the country or countries from which it contracts to purchase fuel cycle services."[95] The United States was the principal supplier of nuclear technology and nuclear fuel to South Korea, and accordingly, South Korea's nuclear sector has been dependent on and largely shaped by U.S. politics. What factors led to South Korea crafting and accepting such a policy?

A review of the history of nuclear development and of the decision making presented in sections 6.2 and 6.3.1 reveals that national security concerns drove much of South Korea's nuclear decision making. Given South Korea's situation through the Cold War era, this is not surprising and shows how the nuclear program fit into South Korea's overall strategy during this time frame.

After the Korean War ended in 1953, South Korea was one of the poorest countries in the world and heavily dependent on the United States for security and

---

[95] Paul L. Joskow, "The International Nuclear Industry Today: The End of the American Monopoly," *Foreign Affairs* 54, no. 4 (July 1976): 791.

economic aid. The principal threat to Seoul was the rival Korean state to the north in Pyongyang. Since the mid-1940s, Seoul and Pyongyang have been locked in a bitter ideological battle and pan-Korean competition for legitimacy, and the presence of a rival, aggressive Korean state made national security the top priority for South Korean policy makers.

South Korea has been reliant on the United States for its security since 1950, particularly during the Cold War when the Soviet Union supported North Korea. South Korea was also extremely poor and underdeveloped after the Korean War, and the alliance with the United States helped to bring much economic development and prosperity. Overall, the United States has been far and away the most dominant player in South Korean foreign relations, which can be seen in how the United States has influenced South Korea's nuclear dealings with France, Canada, and other leading providers of nuclear technology. Not that South Korea has always been pleased with all aspects of its relationship with the United States, but sacrificing some self-determination for the sake of good relations with the United States was seen as necessary to guarantee South Korean security and prosperity.

Other factors certainly influenced South Korean decision making, and Table 6.2 summarizes these factors.

DOMESTIC	INFLUENCE
Bureaucratic Interests	KAERI, KEPCO and the nuclear science community influenced technology development but did not press strongly for ENR technology.
Centralization of Power/Strength of	Power was highly centralized under

Leader	Park Chung-hee and less centralized under Chun Doo-hwan. After first democratic elections in 1987, power became more decentralized.
Energy Security Sensitivity	A lack of domestic energy resources makes South Korea highly sensitive to energy security, and the oil shocks of the 1970s had a major impact on energy planning.
Nature of Regime/Leader	Park Chung-hee was authoritarian and nationalistic. Nationalism remained high during 1980s and 1990s, but South Korea fully democratized by the 1990s.
GEOPOLITICAL	**INFLUENCE**
U.S. Relationship	Treaty ally and host to U.S. troops. **Ensuring U.S. security guarantee is top priority.**
Security Threats	North Korea was existential threat during Cold War, but threat reduced as South Korea became stronger economically and militarily.
Access to International Energy Markets	Good access, but alignment with United States made oil shocks of 1970s worse.
Nonproliferation Norms Adherence	Became strong adherent to nonproliferation norms pushed by United States by 1980s, but shadow of nuclear weapons program in 1970s lingers.

Table 6.2 – Political Factors Influencing South Korean Decision Making

Concerns over energy security initially drove South Korea's decision to invest heavily in nuclear energy research in the 1950s and 1960s. Energy security also was tied to national security, as South Korean decision makers knew that a strong economy would help greatly in the competition with North Korea. National security then clearly drove Park Chung-hee's decision making in the 1970s. Park had already concentrated power into his hands, so he was able to initiate a high risk clandestine nuclear weapons program when fears of U.S.

abandonment put him in a losses frame in the 1970s. Park also was able to suspend South Korea's nuclear program after the U.S. applied strong pressure on him.[96]

Power gradually decentralized after Park's assassination, particularly when South Korea fully transitioned to democracy in the late 1980s. Under Chun Doo-hwan and proceeding administrations, national security was the top priority, and reassurance from Washington put South Korean leaders in a gains frame and unwilling to accept the risks of pursuing nuclear weapons or ENR technology. Accordingly, Seoul adhered to U.S. nonproliferation policies and focused on developing nuclear power as South Korea's main source of base load electricity. Using national security as the primary driver, South Korea's nuclear fuel cycle decision making from the late 1960s until the late 1990s is in line with the tenants of prospect theory.

6.4 Alternative Explanations

In the literature review in Chapter 2, several theories of nuclear proliferation and of ENR technology development are given. The two theories of ENR technology development, James Acton's received wisdom and William Walker's technology entrapment, do not apply to South Korea since the country did not develop ENR technology. Of the theories of nuclear weapons proliferation, Scott Sagan's domestic politics and norms models do not appear to apply, either. Sagan's security model and Etel Solingen's model potentially

---

[96] Hong, 505.

appeal for explaining why South Korea did not ultimately obtain nuclear weapons.

In his security model, Sagan states that weak states "…can join a balancing alliance with a nuclear power, utilizing a promise of nuclear retaliation by that ally as a means of extended deterrence."[97] Certainly, this appears to apply to South Korea, since Seoul has been covered under the U.S. nuclear umbrella since the end of the Korean War. However, this model fails to explain Park Chung-hee's decision to initiate a nuclear weapons program in the 1970s. North Korea did not have nuclear weapons at that point, and there was no withdrawal of the U.S. security guarantee. It was Park's perception of U.S. intentions and move into a losses frame that caused him to desire to ensure South Korea's security through an indigenous nuclear weapons program. Prospect theory provides more explanatory power than Sagan's security model for Park's decision making.

Solingen stated "…leaders advocating economic growth through integration in the global economy ('internationalizing models' henceforth) had incentives to avoid the costs of embarking on nuclear weapons programs."[98] South Korea established an export-driven economy and certainly qualifies as one of Solingen's "internationalizing models." This model would predict that South Korea would not embark on a nuclear weapons program, but Park Chung-hee did just that. Park ultimately abandoned the program under U.S. pressure, partly so

---

[97] Scott D. Sagan, "Why Do States Build Nuclear Weapons? Three Models in Search of a Bomb," *International Security* 21, no. 3 (Winter 1996/97): 57-63.

[98] Etel Solingen, "Domestic Models of Political Survival: Why Some Do and Others Don't (Proliferate)," in *Forecasting Nuclear Proliferation in the 21st Century: Volume 1. The Role of Theory*, ed. William C. Potter and Gaukhar Mukhatzhanova (Stanford, CA: Stanford University Press, 2010), 40.

that South Korea would not be cut off from the U.S. and other world markets. However, the primary driver for Park was national security, not necessarily an internationalizing economic model. Chun Doo-hwan and subsequent South Korean presidents followed Solingen's model, but again, prospect theory provides more explanatory power throughout the history of South Korea's nuclear fuel cycle decision making.

7. COMPARATIVE ANALYSIS

Chapters 4, 5, and 6 individually analyze the nuclear fuel cycle decision making of India, Japan, and South Korea, respectively. All three chapters demonstrated the explanatory power that prospect theory offers for analyzing nuclear fuel cycle decision making. This chapter is a comparative analysis of these three cases. As described in Chapter 3, the methodology employed in this chapter is structured, focused comparison, and the purpose of this exercise is to draw out the broader themes from the three individual case studies and comment on the general ability of prospect theory to explain nuclear fuel cycle decision making.

7.1 Comparison of Technical Decisions

CIVILIAN	MILITARY
Electric Power Generation -India: Yes (not significant source) -Japan: Yes (significant source) -SK: Yes (significant source)	**Develop Nuclear Weapons** -India: Yes (developed nuclear explosive in 1970s) -Japan: No -SK: Yes/No (started in 1970s, ended by 1980)
Acquire/Develop ENR Technology -India: Yes (developed reprocessing in 1960s) -Japan: Yes (developed ENR in 1970s) -SK: Yes/No (started in 1970s, ended by 1980)	**Test Nuclear Device** -India: Yes (1974: Pokhran-I, 1998: Pokhran-II) -Japan: N/A -SK: N/A
Achieve NPP Independence -India: Yes (achieved in 1980s) -Japan: Yes (achieved in 1980s) -SK: Yes (achieved in 1990s)	**Nuclear Weapons Hedging** -India: N/A -Japan: No -SK: No

Table 7.1 – Comparison of Civilian and Military Nuclear Technology Decisions in India, Japan, and South Korea

To begin a structured, focused comparison of Indian, Japanese, and South Korean nuclear fuel cycle decision making, Table 7.1 summarizes the technical decisions made by India, Japan, and South Korea. This table is a summary of the individual country technical decisions tables that are in the respective case study chapters.

As Table 7.1 shows, all three countries share key similarities and differences regarding their technical decision making. All three countries decided to utilize nuclear energy for electric power generation and developed an indigenous capability to design, construct, and operate nuclear power plants. However, the nuclear power industries in Japan and South Korea came to be significant sources of electricity, but in India, nuclear power has remained a minor source and failed to provide more than 5 percent of the country's electricity. India and Japan both have some capability to produce fissile material, either through spent nuclear fuel reprocessing or uranium enrichment, but South Korea's interest in acquiring reprocessing was quashed by U.S. pressure in the 1970s.

On the military side, only India decided to develop a nuclear weapons capability and followed through with that decision. Former South Korean President Park Chung-hee initiated a nuclear weapons program in the 1970s, but again, U.S. pressure stopped the program. Seoul has not revived a nuclear weapons program since then. Japan conducted a study of the costs and benefits of nuclear weapons in the late 1960s and decided a nuclear weapons program would be too costly. Tokyo never made a decision to pursue nuclear weapons.

The spectrum these technical decisions represent is noteworthy and telling. During the time period of analysis (approximately 1950 to 1990), the most advanced economically and technologically among the three countries was Japan, and Japan developed the largest and most advanced civilian nuclear sector of the three. India, on the other end of the spectrum, was the least advanced economically and technologically, and India's civilian nuclear power sector contributed the least in terms of electricity generation. However, India had the most advanced military nuclear program, and Japan never had a nuclear weapons program. Economically and technologically, South Korea lay in between India and Japan. South Korea's nuclear power sector produces more electricity than India's but has no fissile material production capability, and South Korea's nuclear weapons program was stopped in a nascent stage.

This suggests that economic power or technological capability is not necessarily related to what types of nuclear fuel cycle decisions that a country will make. Decisions on whether to develop nuclear power plants, enrichment and reprocessing technology, or nuclear weapons stem from a country's deeper rooted political and strategic interests. These factors will be explored more in the next section comparing the political and strategic influences that affected nuclear fuel cycle decision making in India, Japan, and South Korea.

7.2 Political Comparison

To continue with a structured, focused comparison of Indian, Japanese, and South Korean nuclear fuel cycle decision making, Table 7.2 summarizes the domestic politics and geopolitical factors that influenced nuclear fuel cycle decision making in those countries. The table is a summary of the individual political influence tables that are in each respective case study chapter.

DOMESTIC	GEOPOLITICAL
Bureaucratic Interests -India: Autonomous DAE; PM has final say -Japan: MITI, STA, utilities; consensus -SK: KAERI, KEPCO not decision makers	**U.S. Relationship** -India: NAM leader, tense in 1970s -Japan: Ensure U.S. security guarantee -*SK: Ensure U.S. security guarantee*
Centralization of Power/Strength of Leader -India: Nehru, Mrs. Gandhi, Bhabha/DAE -Japan: Dispersed bureaucratic power -SK: Park→Chun→Democracy	**Security Threats** -India: China, Pakistan -Japan: Energy security, China -SK: North Korea
Nature of Regime/Leader -*India: Democratic, nationalistic PMs* -Japan: Democratic (LDP), consensus rule SK: Authoritarian Park and Chun, nationalistic	**Access to International Energy Market** -India: Good, not embargoed in 1973 -Japan: Good -SK: Good
Energy Security Sensitivity -India: Moderate (domestic energy sources) -*Japan: High (history with fossil fuels)* -SK: High	**Nonproliferation Norms Adherence** -*India: Did not accept externally-defined norms* -Japan: Norms champion, anti-nuclear public -SK: Eventual adherent to norms by 1980

Table 7.2 – Comparison of Domestic and Geopolitical Factors Influencing Nuclear Fuel Cycle Decision Making in India, Japan, and South Korea

Starting with the domestic politics categories, all three countries had bureaucratic interests that influenced their respective nuclear programs, yet the bureaucratic interests in all three countries were not the drivers of major nuclear fuel cycle decisions. Decisions on whether to develop ENR technology or nuclear weapons were made by the top leadership in all cases. The bureaucratic interests were more of a sustaining influence than an initiating influence. For example, some in India's nuclear science bureaucracy may have desired nuclear weapons, including Bhabha, but India did not commit to weaponization until Indira Gandhi finally gave the order to do so in 1972. After India demonstrated the capability to produce nuclear explosives in 1974, the nuclear science bureaucracy played a role by maintaining the civilian and military aspects of India's nuclear program. South Korea's nuclear bureaucracy did not press for ENR technology or nuclear weapons out of fears of losing U.S. support for South Korea's nuclear power program, but the decisions to initiate and abandon a nuclear weapons effort were made by Park Chung-hee. Again, the bureaucracy pushed for sustaining the program, but the top leadership made the decisions that guided the direction of the nuclear program. The direction of Japan's nuclear program, too, was set by the top leadership early on in the program and then collectively sustained.

Given the limited power of the nuclear bureaucracies in making major nuclear fuel cycle decisions, the centralization of power and nature of regime categories appear more relevant. Among the three cases, South Korea under Park Chung-hee and Chun Doo-hwan had the highest degree of centralization, although Chun held less power than Park. India also had relatively high degree of centralization, as Nehru and Bhabha defined the early direction of the program. India's DAE ran the nuclear program mostly independent from the rest of the government, but the Indian prime minister made the major decisions, namely on developing nuclear weapons. The Indian and Japanese governments were democratic during the period of analysis, while South Korea experienced authoritarian leadership for most of the time. Both India and South Korea also had high degrees of nationalism. Japan had the lowest degree of centralization and nationalism.

It is interesting that the cases with higher degrees of centralization and nationalism, India and South Korea, initiated nuclear weapons programs. Jacques Hymans wrote to this point, "…when the nuclear policymaking arena contains a large number of entrenched veto players, they all need to agree before a nuclear weapons project can be set in motion….the more veto players, the less likely the decision to seek nuclear weapons."[1] The converse of this theory would say that the less veto players, the more likely the decision to seek nuclear weapons. Of course, having fewer veto players can make prospect theory analysis more straightforward, since the analyst can focus on the behavior of the key decision maker, such as the South Korean president or the Indian prime minister.

Even though the Japanese government was less centralized than the other two cases, the collective leadership of Japan's nuclear program was quite cohesive. Unlike in India or South Korea, there does not appear to have been conflicting parties in Japan's nuclear fuel cycle decision making. The central government and private sector both supported developing a closed fuel cycle and opposed developing nuclear weapons. These two basic policy principles were consistent throughout the period of analysis. Prospect theory applies to this

---

[1] Jacques E.C. Hymans, "Veto Players, Nuclear Energy, and Nonproliferation: Domestic Institutional Barriers to a Japanese Bomb," *International Security* 36, no. 2 (Fall 2011): 155.

collective's pursuit of Japanese national interests, not just a single leader or a small group of leaders.

The takeaway from this is not that a particular style of regime or leader tends to pursue nuclear weapons or ENR technology but that decision making analysis must focus on the key decision maker or collective group of decision makers. A highly centralized, nationalistic government may be more likely than a decentralized leadership to pursue nuclear weapons because there are fewer veto players, but only if pursuit of nuclear weapons aligns with the leadership's perception of national interests.

Park Chung-hee and Indira Gandhi initiated nuclear weapons programs to pursue national interests, national security and national prestige, respectively, and Park abandoned his nuclear weapons program when he felt the program threatened South Korea's national security. The Japanese government decided a nuclear weapons program was not in the national interest but made developing a closed fuel cycle a top national priority.

Japan pushed for a closed nuclear fuel cycle because it supported an even higher national priority, energy security. Japan's sensitivity to energy security is the highest among the three cases, but South Korea's energy security sensitivity is a close second. Neither Japan nor South Korea possesses much domestic energy reserves, and both saw nuclear power as an answer to their energy needs. This explains the commitment to and strong belief in nuclear power in both countries, and in Japan's case, energy security sensitivity explains the country's commitment to a closed fuel cycle even in the face of U.S. pressure to abandon reprocessing and fast breeder reactor development. India, on the other hand, has domestic reserves of fossil fuels, uranium, and thorium, which lessened the country's sensitivity to energy security.

Moving to the geopolitical categories, all three countries faced security threats during the period of analysis, but the threats facing India and South Korea were more serious. India's primary threat was China, and North Korea was South Korea's primary threat. North Korea represented an existential threat to South Korea, which made ensuring national security the primary strategic goal for Seoul. The threat from North Korea drove Park Chung-hee to desire nuclear weapons, and only U.S. pressure and reassurance led to South Korea abandoning its nuclear weapons and ENR development efforts. China defeated India in a border war in 1962 and tested a nuclear weapon two years later. China also supported India's other adversary, Pakistan. Japan also felt threatened by China's nuclear test in 1964, but neither India nor Japan was driven to initiate a nuclear weapons program because of the Chinese nuclear threat.

All three countries also had good access to international energy markets and likely could have elected to use fossil fuels instead of nuclear power to meet their electricity needs. It should be noted that Japan and South Korea were affected more than India by the 1973 oil crisis due to their alignment with the United States, and India had domestic energy reserves upon which to rely. Yet, none of the three countries ever faced a situation of being completely shut off from imports of fossil fuels or other energy resources, so the selection of nuclear power was not something forced upon them by the international market.

The two categories in which the cases differ significantly are their relationships with the United States and adherence to nonproliferation norms, and these two categories certainly are related. Japan and South Korea have been treaty allies of the United States and hosted U.S. troops since the end of World War II, and the United States has been the most dominant external actor in those two countries. For both, maintaining good relations with Washington and preserving the U.S. security guarantee has been of paramount importance, and both made decisions to not pursue nuclear weapons for the sake of preserving good relations with the United States. For the most part, Japan and South Korea followed the nonproliferation norms that were advocated by Washington, too. Park Chung-hee's ENR technology and nuclear weapons programs obviously went against these norms, but by 1980, Seoul mostly fell in line with the norms. Japan has often championed U.S.-led nonproliferation norms, with the major exception of opposing U.S. requests to suspend reprocessing and FBR development. Developing a closed fuel cycle was too important to Japanese energy security strategy to give up, but Japan has a strong nonproliferation record.

India's relationship with the United States and adherence to international nonproliferation norms was quite different. India led the Non-Aligned Movement during the Cold War, and Washington upset New Delhi in the 1970s by supporting Pakistan and establishing relations with Beijing. In general, India felt that it was a great power that did not need to align itself with the United States, the Soviet Union, or any other major power, and New Delhi strove to establish and maintain its stature among the world's great powers. This reflected India's desire to maintain self-sufficiency and decision making autonomy, and this led to India not following the nonproliferation norms established by Moscow and Washington in the International Atomic Energy Agency and in the Non-Proliferation Treaty. Thus, India's nuclear fuel cycle policies included utilizing domestic energy reserves in the three-stage nuclear program and demonstrating nuclear explosives capability with Pokhran-I.

7.3 Three Questions

In the analysis of each of the case studies, three questions about particular decisions were asked after a review of the history of nuclear technology development in each case. Those three questions were specific to each case, but they all addressed similar themes. The three questions for each case are presented again below.

India

1. Why did India decide to develop a nuclear fuel cycle based on natural uranium and thorium?
2. Why did India not sign the NPT?
3. Why did India conduct a nuclear test in 1974 and accept isolation of its nuclear industry?

Japan

1. Why did Japan make such a strong commitment to developing nuclear power and a closed nuclear fuel cycle?

2. Why did Japan not pursue a nuclear weapons program?
3. Why did Japan oppose U.S. policy in the mid-1970s and continue developing reprocessing technology?

South Korea

1. Why did South Korea make such a strong commitment to developing nuclear power?
2. Why did Park Chung-hee pursue and abandon nuclear weapons program, and why did Chun Doo-hwan and subsequent South Korean governments not pursue nuclear weapons?
3. Why did South Korea not develop ENR technology for civilian use?

To compare the three cases, these individual sets of questions can be rewritten to address the general themes addressed. These three general questions are the following.

1. Why was nuclear energy viewed as a strategic energy source?
2. How did internal factors guide nuclear fuel cycle decision making?
3. How did external nonproliferation policies or norms influence domestic nuclear fuel cycle decision making?

All three countries shared the view that nuclear energy could help achieve strategic aims, and answering this question illuminates the key variable for analyzing nuclear fuel cycle policy decision making. For Japan, nuclear power utilizing a closed fuel cycle would provide the energy security that was a pillar of the country's economic strategy, and after being demilitarized after World War II, economic strategy became the main element of Japanese national strategy. Internally, Japanese leaders from the government and private sector believed in the utility of a closed nuclear fuel cycle, and the country had maintained a strong opposition to nuclear weapons. Externally, the oil shocks of the 1970s confirmed their belief in nuclear power, and Japan the U.S. alliance has removed any other incentives to develop nuclear weapons. The country's belief in nuclear power's ability to deliver energy security also explains why Japan resisted U.S. pressure to abandon developing a closed nuclear fuel cycle in the 1970s.

South Korean leaders viewed national security and defending against the North Korean threat as the country's top priorities, and the alliance with the United States guaranteed South Korean security. Internally, Park Chung-hee dominated South Korean decision making in the 1960s and 1970s, and the United States was the primary external influence. When Park believed that Washington was wavering on its commitment to defend South Korea in the early 1970s, he thought nuclear energy could help power a growing economy and provide an indigenous nuclear deterrent. After it became clear that South Korea's nuclear weapons program threatened the alliance with the United States, Park and subsequent leaders abandoned the reprocessing and nuclear weapons programs and focused on utilizing nuclear energy to generate electricity.

After gaining independence from the United Kingdom, India sought to restore the country's place among the world's great powers and achieve self-sufficiency. Indian leaders believed that developing the three stage nuclear program laid out by Bhabha would achieve both ends. Internally, the closeness of the prime minister to the nuclear program created programmatic cohesion, and India's domestic energy reserves insulated the country to some extent from external pressures. Externally, India strove not to be swayed by pressure from the major powers, which explained the decisions not to sign the NPT and pursue nuclear weapons.

When applying prospect theory to these cases, the key was first to understand why nuclear power was strategically important. Be it energy security, national security, or self-sufficiency, the respective key factor drove decision making, and leaders in each country framed policy choices in light of their key strategic interest. Secondary factors, such as decision making centralization or alliance with a nuclear weapons state, can comprise a list of indicators that a country may tend to make certain nuclear fuel cycle policy decisions, but none of those factors have strong explanatory or predictive power. What prospect theory offers is a way to incorporate these secondary factors into the key factor and explain how and why decision makers frame their decisions. This prospect theory analysis then reveals the key factors and explains nuclear fuel cycle decision making tendencies.

8. CONCLUSION

This study started off by asking the central question of why countries have developed different national nuclear fuel cycles. The study proposed to do this by first demonstrating that countries develop differing nuclear fuel cycle policies and that these policies are made at the national level. The second step would be to examine the factors that drove nuclear fuel cycle policy decision making, particularly strategic concerns, and that these factors would be viewed through a country's frame of reference as described by prospect theory in order to explain the decisions made.

These two steps were conducted in each of the three case studies in Chapters 4, 5, and 6 in order to explain why India, Japan, and South Korea developed differing nuclear fuel cycle policies. Chapter 7 then provided a comparative analysis of the three cases to highlight their similarities and differences. The three research questions and corresponding hypotheses given in the Introduction now will be examined to see how the hypotheses performed for the three case studies.

8.1 Evaluation of Research Questions and Hypotheses

Q1: Do countries develop and employ distinctly different national nuclear fuel cycles?

H1: Countries establish nuclear fuel cycle policy at the national government level, and different countries do develop and employ different nuclear fuel cycles based on their national policies and interests or goals.

This hypothesis was proven emphatically, since India, Japan, and South Korea decided to develop three different nuclear fuel cycles. India based its nuclear fuel cycle on the use of natural uranium and thorium. Japan and South Korea both use low enriched uranium in light water reactors. However, Japan decided to develop a closed nuclear fuel cycle that employs reprocessing and fast breeder reactors, while South Korea decided to utilize an open nuclear fuel cycle that does not use reprocessing. South Korea pursued reprocessing technology for a time in the 1970s but abandoned that effort due to U.S. pressure. Regardless, the central governments of all three countries made the major nuclear fuel cycle policy decisions, and they all made distinctly different decisions.

Q2: Does the frame of reference in which a country views itself and a country's cultural context guide the development of its nuclear fuel cycle policy?
H2: A country's decisions regarding nuclear fuel cycle policy are determined, in large part, based on that country's frame of reference (in terms of gains and losses frames described by prospect theory), while the frame of reference is determined by various factors, such as a country's strategic interests, economic and security situation, relations with major powers and status in the international community, technological capability, etc.

This hypothesis mostly held true in each case. It would be more appropriate to state that initial decisions on nuclear fuel cycle policy were made based on each country's resources and strategic interests, and the tendency for ensuing decisions was to make them based on how policy choices were framed in the context of strategic interests. India, Japan, and South Korea all began their nuclear programs in the 1950s at a time when there was much enthusiasm for nuclear energy around the world, and many countries hoped that nuclear energy would become an abundant source of energy. All three viewed nuclear energy as a means to energy security, economic development, and technological prowess, but their differing strategic interests played out as their nuclear programs advanced, particularly when their nuclear programs became intertwined with perceived threats to strategic interests.

For India, the primary strategic interests related to their nuclear fuel cycle policy were self-sufficiency and international prestige. Homi Bhabha designed India's nuclear science enterprise and three-stage nuclear program around the concept of self-sufficiency, and Jawaharlal Nehru and Bhabha saw nuclear energy as a way to boost India's standing among the world powers. The signing of the Non-Proliferation Treaty (NPT) in 1968 and perceived Western support of a Pakistani nuclear weapons program in the early 1970s were the two biggest threats to those interests during the period of analysis (1948-1990). Table 8.1 summarizes India's decision making with respect to these two situations.

Strategic Interest	Situation	Frame of Reference	Perceived Options	Decision
Self-sufficiency	1968: Signing of Non-Proliferation Treaty	Gains (endowment effect)	1. Accept NPT regime (higher risk)	Did not sign NPT to preserve self-sufficiency

			2. Continue independent development (lower risk)	
International Standing	1972-1974: Pakistani civil war and nuclear weapons program	Losses	1. Demonstrate Indian nuclear capability (higher risk)	Develop and test nuclear explosive to demonstrate power and capability
			2. Allow Western support of Pakistan (lower risk)	

Table 8.1 – Major Indian Nuclear Fuel Cycle Decisions during the Period of Analysis

As displayed in Table 8.1, major Indian nuclear fuel cycle decisions during the period of analysis were made in line with the tenets of prospect theory. Risk-averse decision makers in the late 1960s were unwilling to accept the perceived risks associated with signing the NPT, and risk-acceptant decision makers were willing to accept the perceived risks associated with developing and testing a nuclear explosive.

One decision not covered here that should be acknowledged is India’s reaction to China’s nuclear test in 1964. Indian leaders believed that developing nuclear weapons would be detrimental to Indian security and did not want to formally align the country with one of the Cold War nuclear superpowers. The Chinese nuclear test, coming two years after India lost a border war with China, could have been perceived as a blow to Indian national security and international standing, but India was not willing to accept the risks associated with nuclear weapons development or alignment with a nuclear power. India’s reprocessing plant at Trombay began operations in 1964, and it is possible that the endowment effect related to this and other nuclear research facilities put Indian leaders in a gains frame. Thus, they would have been risk averse and opted for sticking with peaceful development of the three-stage nuclear program. However, the India case study chapter simply regarded this as a case of the costs outweighing the benefits.

Japan placed utmost priority on guaranteeing energy security to power the country's economic development in the post-World War II era. Developing a closed nuclear fuel cycle seemed to be a way to provide Japan with ample electricity and alleviate the country's dependence on energy imports. Considering that energy security was Japan's primary strategic interested related to the country's nuclear program, the two major decisions that the country faced during the period of analysis (1955-1987) were: 1) whether to develop some sort of military nuclear capability after the Chinese nuclear test in 1964 and the signing of the NPT in 1968, and 2) whether to agree to U.S. demands in the late 1970s to discontinue Japanese development of reprocessing and fast breeder reactors (FBR). Table 8.2 summarizes these decisions.

Strategic Interest	Situation	Frame of Reference	Perceived Options	Decision
Energy Security	1964-1968: Chinese nuclear test and signing of NPT	Gains	1. Pursue nuclear weapons (higher risk)	Did not initiate nuclear weapons program for sake of external relations
			2. Forgo nuclear weapons option (lower risk)	

	Late 1970s: Oil shocks and U.S. pressure to abandon reprocessing and FBR development	Gains (endowment effect)	1. Acquiesce to U.S. policy not to develop closed fuel cycle (higher risk)	Continue with closed fuel cycle development and negotiate new nuclear cooperation agreement with Washington
			2. Resist U.S. demands and continue with closed fuel cycle development (lower risk)	

Table 8.2 – Major Japanese Nuclear Fuel Cycle Decisions during the Period of Analysis

As seen in Table 8.2, Japanese nuclear fuel cycle decision making during the period of analysis went according to the tenets of prospect theory. The Japanese economy grew rapidly during the 1950s and 1960s, which put Japanese leaders in a gains frame. Thus, Japan was risk averse and unwilling to accept the risks of initiating a nuclear weapons program in response to the Chinese nuclear test in 1964, and disavowing a nuclear weapons option by signing the NPT was not viewed as risky. By the late 1970s, Japan was operating several commercial nuclear power plants and research facilities related to closed nuclear fuel cycle development, and the endowment effect explains why Japanese leaders placed high value on these facilities and were not willing to cease fuel cycle research, despite U.S. demands to do so.

The oil shocks of the 1970s also were significant events for Japanese energy planners during the period of analysis. The oil shocks mostly confirmed to Japanese leaders that developing a closed nuclear fuel cycle was the best way to ensure the country’s energy security. Thus, the oil shocks led to Japan increasing the pace and scale of nuclear development and strengthening the belief in nuclear energy, and this contributed to the resolute commitment to nuclear energy that Japan demonstrated in the late 1970s by opposing U.S. requests.

South Korea’s top strategic priority during the period of analysis (1958-1999) was national security, particularly ensuring South Korea’s security against the threat posed by North Korea. Maintaining the military alliance with the United States was the cornerstone of South Korea’s national security strategy. Economic development and energy security also were important strategic goals for South Korea and were drivers for South Korea’s nuclear program, but the major nuclear fuel cycle decisions should be analyzed from the perspective of national security and the U.S. alliance. A summary of the major decisions during the period of analysis is presented in Table 8.3.

Strategic Interest	Situation	Frame of Reference	Perceived Options	Decision
National Security	Early 1970s: Wavering U.S. security commitment	Losses	1. Develop indigenous nuclear deterrent (higher risk)	Initiate reprocessing and nuclear weapons programs to guarantee national security
			2. Bolster conventional forces and/or reaffirm U.S. commitment (lower risk)	
	Mid-1970s: U.S. confrontation over nuclear weapons program	Losses	1. Continue with nuclear weapons program and risk damaging relations with Washington (higher risk)	Suspend reprocessing and nuclear weapons programs for sake of U.S. alliance

			2. Suspend reprocessing and nuclear weapons programs (lower risk)	
	Early 1980s: U.S. reaffirmation of commitment to South Korea	Gains	1. Reactivate dormant reprocessing and nuclear weapons programs (higher risk)	End reprocessing and nuclear weapons programs to ensure continued U.S. military and economic support
			2. End reprocessing and nuclear weapons programs (lower risk)	

Table 8.3 – Major South Korean Nuclear Fuel Cycle Decisions during the Period of Analysis

As demonstrated in the table, South Korean decision making was in line with prospect theory in the early 1970s and early 1980s, but there is deviation from prospect theory in the mid-1970s. In the early 1970s, South Korean leader Park Chung-hee feared that the United States was wavering in its commitment to defend South Korea, and in this losses frame, a risk-acceptant Park initiated reprocessing and nuclear weapons programs. By the early 1980s, Washington had reaffirmed its commitment to Seoul, and then South Korean leader Chun Doo-hwan ended any remaining reprocessing and nuclear weapons programs in South Korea. South Korea was thus committed to developing an open nuclear fuel cycle and focused on using nuclear energy to generate electricity for the country's booming economy.

Park's decision to suspend the reprocessing and nuclear weapons program in the mid-1970s is a deviation from what would be predicted by prospect theory. Park was still in a losses frame, as the United States had not alleviated Park's fears of abandonment. Washington made it clear to Park that continuing with the nuclear weapons program would damage significantly the entire relationship between the United States and South Korea. Faced with the potentially dire consequence of losing South Korea's security guarantee, Park backed down and suspended the reprocessing and nuclear weapons programs. In that situation, the riskier option was to continue with the nuclear weapons program, but Park chose the less risky option of agreeing to U.S. demands. This shows that, even while in a losses frame, Park's risk-acceptance had limits.

Q3: Is a large-scale nuclear program, and the related nuclear fuel cycle, ever purely civilian in nature, or is there always a military or security-related aspect to a nuclear program?
H3: Security concerns, be it defined traditionally in terms of national security or in terms of economic security, are always a primary driver of starting and maintaining a nuclear program, even if the program does not include developing nuclear weapons. This is due to the technological experience that a country gains through operating a large-scale nuclear program.

This hypothesis also proved true for each of the three case studies. India decided to develop and demonstrate a nuclear weapons capability in the 1970s and has maintained this capability ever since. Japan focused on civilian nuclear energy development, but with energy security as a top strategic priority, Tokyo viewed the nuclear program as vital to the country's national strategy. National security concerns drove South Korea's nuclear fuel cycle decision making during the 1970s and 1980s, but the military aspect of South Korea's nuclear program ended in the late 1970s. Even so, South Korea's nuclear program remained vital to the country's economic strategy and energy security.

8.2 General Observations on Prospect Theory and Nuclear Fuel Cycle Decision Making

In each of the case studies, the ability of prospect theory to explain nuclear fuel cycle decision making was compared to other theories of nuclear weapons proliferation. One of those nuclear weapons proliferation theorists, Jacques Hymans, wrote, "Ancillary nuclear decisions are less revolutionary – less 'big' – than the decision to acquire the bomb itself."[1] Hymans suggests that other conventional political science or economic theories could be used to explain these ancillary nuclear decisions. Prospect theory is employed in political science and economics and provided more explanatory power regarding nuclear fuel cycle decision making than theories of nuclear weapons proliferation, but the results of this study challenge Hymans' assertion that so-called ancillary nuclear decisions are less important.

Along those lines, James Acton wrote, "Nuclear-energy policy…necessarily involves weighing up incommensurable variables. This task can neither be avoided nor regarded as a purely economic decision to be delegated

---

[1] Jacques E.C. Hymans, *The Psychology of Nuclear Proliferation: Identity, Emotions, and Foreign Policy* (New York: Cambridge University Press, 2006), 37.

to the capital market."[2] This implies that nuclear technology brings value that goes beyond the technology's standard economic value. The strategic nature and value of nuclear technologies, both civilian and military, is emphasized throughout this study. The nuclear programs in India, Japan, and South Korea were part and parcel of those countries' national strategies, and the decision making regarding nuclear fuel cycle development and use must be understood in strategic terms.

Existing theories of nuclear weapons proliferation certainly take into account the strategic value of nuclear weapons, but they generally do not account for the strategic value of the technologies that underlie both nuclear power and nuclear weapons. The advantage prospect theory offers is to give the analyst a holistic view of a country's strategic interests, how all nuclear technologies fit into those strategic interests, and how a country's leadership's frame of reference with regard to strategic interests influences the direction of nuclear fuel cycle decision making. In this way, prospect theory on its own does not offer a model or predictor of nuclear fuel cycle technology development, but it illuminates how leaders viewed nuclear fuel cycle decisions and why certain decisions were made.

The strategic nature of nuclear technology also is demonstrated by the fact that major decisions regarding nuclear technology are made by the top leadership at the national level. Again, prospect theory does not provide a model or predictor of what type of leadership would be more or less likely to develop particularly nuclear technologies, such as enrichment and reprocessing

---

[2] James M. Acton, "Nuclear Power, Disarmament and Technological Restraint," *Survival* 51, no. 4 (August-September 1999): 104.

technologies. What matters more is how the key decision makers perceive nuclear fuel cycle decisions fitting into strategic interests. Prospect theory allows the analyst to focus on the frame of reference of the decision makers and then understand why certain policy options were selected over other policy options. Understanding a country's leadership and strategic interests is the basis of analyzing nuclear fuel cycle decision making, and prospect theory aims to understand the decision making of leaders. Prospect theory also places decisions in the temporal and situational context in which leaders make their decisions.

A final note on comparing prospect theory with the theories of nuclear weapons proliferation regards the idea of when a state is considered to have crossed the nuclear threshold. In the Literature Review in Chapter 2, two such thresholds were discussed. First, there is the idea that a state crosses the threshold when it conducts its first nuclear test (test/no-test threshold). Second, there is the idea that a state crosses the nuclear threshold when it acquires enough fissile material to construct a nuclear weapon, known as a significant quantity (SQ) of material (SQ/non-SQ). Clearly, the technological capabilities and fissile material stockpiles that a state possesses are of concern for nuclear fuel cycle decision making analysis and nuclear weapons proliferation analysis, but a state's intentions is equally important. The test/no-test threshold seems to measure a state's intentions, even though a state could argue that a nuclear test was a peaceful nuclear explosion. The SQ/non-SQ threshold does not accurately account for a state's intentions, as fissile materials can be used either for nuclear power or nuclear weapons production.

Prospect theory analysis avoids the ambiguity of such thresholds by examining the core of a state's perceptions and intentions. After Pokhran-I, India argued that the test was a peaceful nuclear explosion, but prospect theory analysis revealed that the test was conducted to demonstrate Indian capability and power. Japan is well past the SQ threshold, but prospect theory analysis showed that Japan's pursuit of fissile material production capability was intended to guarantee Japan's energy security. Whether a state has crossed a threshold to becoming a nuclear weapons state must be determined through an analysis of the technical capability and intentions of that state, and prospect theory offers a powerful tool to analyze intentions.

8.3 Analyzing New Nuclear Energy Programs

One thing not yet addressed by this study is how prospect theory could be applied to analyze the decision making of countries just embarking on a nuclear energy program or considering starting a nuclear energy program. As stated in the comparative analysis in Chapter 7, prospect theory itself does not give a specific model of nuclear fuel cycle decision making but is rather a tool to analyze decision making. Yet, generalizing the analytical framework here so that it could be applied to new nuclear energy program would be of great interest and use to academics and policy makers.

Before thinking of analyzing potential future decision making, it is important to understand the limitations of applying this historical study. The factors that influenced India, Japan, and South Korea during the second half of the twentieth century may not be applicable today, and leaders in India, Japan, and South Korea may not have similar viewpoints as leaders of new nuclear countries. Writing about creating models of nuclear weapons proliferation based on historical precedent, Scott Sagan makes this point, "Predicting the future based on such an understanding of the past will still be problematic, since the conditions that produced the past proliferation outcomes may themselves be subject to change."[3]

Countries starting nuclear energy programs today will not face things like the signing of the Non-Proliferation Treaty in 1968, the oil shocks of the 1970s, the creation of the Nuclear Suppliers Group in 1974, or other shocks that affected India, Japan, and South Korea during their nuclear programs' formative years. Yet, one could imagine energy crises, international nonproliferation regime changes, new technology breakthroughs, tests of nuclear weapons tests by new countries, and other events that would exert a similar influence on new nuclear energy programs. Thus, as Sagan added, "The challenge for scholars…is to produce theory-drive comparative studies to help determine conditions under which different causal forces produced similar outcomes."[4] As such, this comparative case study should offer lessons that can be applied to analysis of future nuclear fuel cycle decision making. Based on the comparative analysis of Chapter 7, the following three factors would seem to be of particular interest when examining the nuclear fuel cycle decision making of a new nuclear program.

---

[3] Scott D. Sagan, "Why Do States Build Nuclear Weapons? Three Models in Search of a Bomb," *International Security* 21, no. 3 (Winter 1996/97), 85.

[4] Ibid.

1. **Energy security sensitivity.** As energy resource poor countries, Japan and South Korea both were attracted to the promise of nuclear energy, and both made nuclear power pillars of their energy security and economic strategies. Countries with high levels of energy security sensitivity may be more likely to desire developing nuclear power and enrichment and reprocessing (ENR) technology. However, current nonproliferation norms and policies now discourage the spread of ENR technology, and the economic viability of closed nuclear fuel cycles is now questioned.
2. **Relations with nonproliferation norms setting countries.** For all three cases examined in this study, relations with the nuclear weapons powers, particularly the United States, was a key factor. The United States wielded enough influence over Seoul to cease the South Korean reprocessing and nuclear weapons programs. The United States attempted similarly to convince Japan to end reprocessing and FBR development, but Tokyo was able to win Washington's approval of those programs. India, not being an ally of either Moscow or Washington, sought to remain self-sufficient and balked at accepting the NPT-based international nonproliferation regime, which led India down a path of nuclear isolation but preserved decision making autonomy. Thus, the level of influence that Washington or other nuclear powers exerts on a new nuclear country can be a significant factor in determining the direction of nuclear fuel cycle decision making.

3. **Self-sufficiency.** Indian leaders, from Nehru and Bhabha, emphasized the importance of self-sufficiency and based the Indian nuclear program on the principle of self-sufficiency. India’s self-sufficiency policy was enabled in part by the country’s reserves of energy resources, including uranium and thorium for use in the three-stage nuclear program. Japan and South Korea strove for self-sufficiency in areas such as nuclear reactor design and construction, but their nuclear energy programs could not be completely self-sufficient because of their need to import uranium fuel. Countries with both the will and capability to practice self-sufficiency may be more likely to develop ENR technology.

These factors do not comprise a model for analysis, so a basic analytic process could be followed to analyze the potential direction of nuclear fuel cycle decision making in a new nuclear country.

1. Determine the key decision makers for the nuclear program. Given the inherently strategic nature of nuclear technology, the top leadership likely will be the most important decision makers.
2. Define how the leadership views the strategic interests of their country, and then determine in what frame of reference the leadership is with regard to those strategic interests.
3. Depending on the leadership’s frame of reference, determine whether they would be risk-acceptant or risk-averse.
4. Determine how the leadership views different options for nuclear technology development from the perspective of their frame of reference.

The three factors listed above could be of particular importance to consider when determining risk propensity for policy options, but there also may be other significant factors influencing policy options and risk propensity.

5. Prospect theory then predicts that for leaders in a losses frame, the higher risk policy option would be more likely, and for leaders in a gains frame, the lower risk policy option would be more likely.

8.4 Future Research

This study demonstrated the ability of prospect theory to explain nuclear fuel cycle decision making in India, Japan, and South Korea. The attractiveness of prospect theory for this type of analysis would justify expanding the case selection to cover a broader range of cases, perhaps ultimately ending in a large-n type study. Analyzing countries that never considered developing ENR technology, possess small nuclear industries, or began nuclear programs after the 1970s (thus being subject to a much stricter nonproliferation regime than those that started programs in the 1950s) all would expand the scope of this study and provide a rigorous test of the prospect theory analytical framework developed in this study. More general conclusions about nuclear fuel cycle decision making also could be drawn to create a stronger prospect theory-based model of nuclear fuel cycle decision making.

In addition, the prospect theory analysis performed in this study could be applied to decision making regarding the development of other strategically important technologies, such as space, missile, and information and communication technologies. This would help determine how states make and prioritize technology development decisions. It is likely that decision making regarding such technologies is not necessarily performed by the top leadership, so prospect theory would be tested by the decision making done by certain organizations within the state, such as the military or national laboratories.

APPENDIX

This appendix contains historical economic and energy for India, Japan, and South Korea that were referenced but not displayed in the main text.

A.1 Indian GDP, Population, and Energy Data from 1960 to 2010

India's gross domestic product (GDP) and annual percentage GDP growth from 1960 to 2010 are displayed in Figure A.1 and Figure A.2, respectively.[1] India's population and annual population growth rate from 1960 to 2010 are displayed in Figure A.3 and Figure A.4, respectively.[2] Data for consumption and production of coal, hydropower, oil, and natural gas are displayed in Figure A.5 through Figure A.8.[3]

---

[1] "India | Data," World Bank, accessed August 3, 2012, http://data.worldbank.org/country/india.

[2] Ibid.

[3] "Statistical Review of World Energy 2011: Historical Data," BP, accessed June 10, 2012, http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/spreadsheets/statistical_review_of_world_energy_full_report_2011.xls.

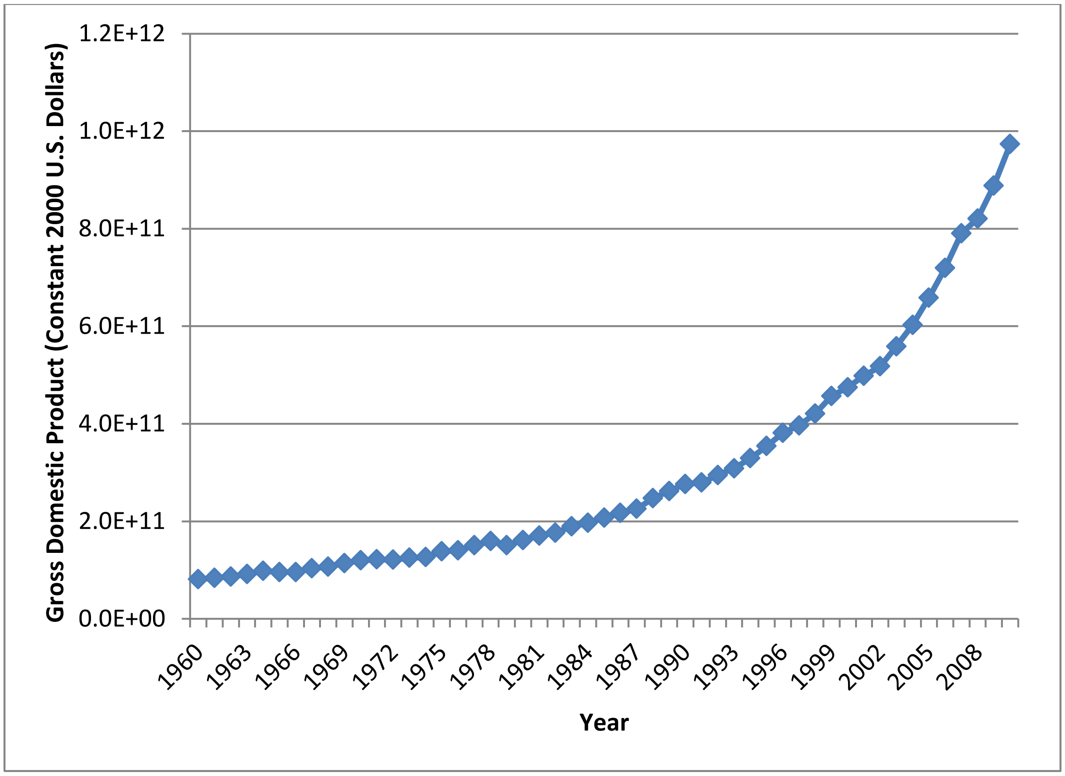

Figure A.1 – Indian GDP in Constant 2000 U.S. Dollars

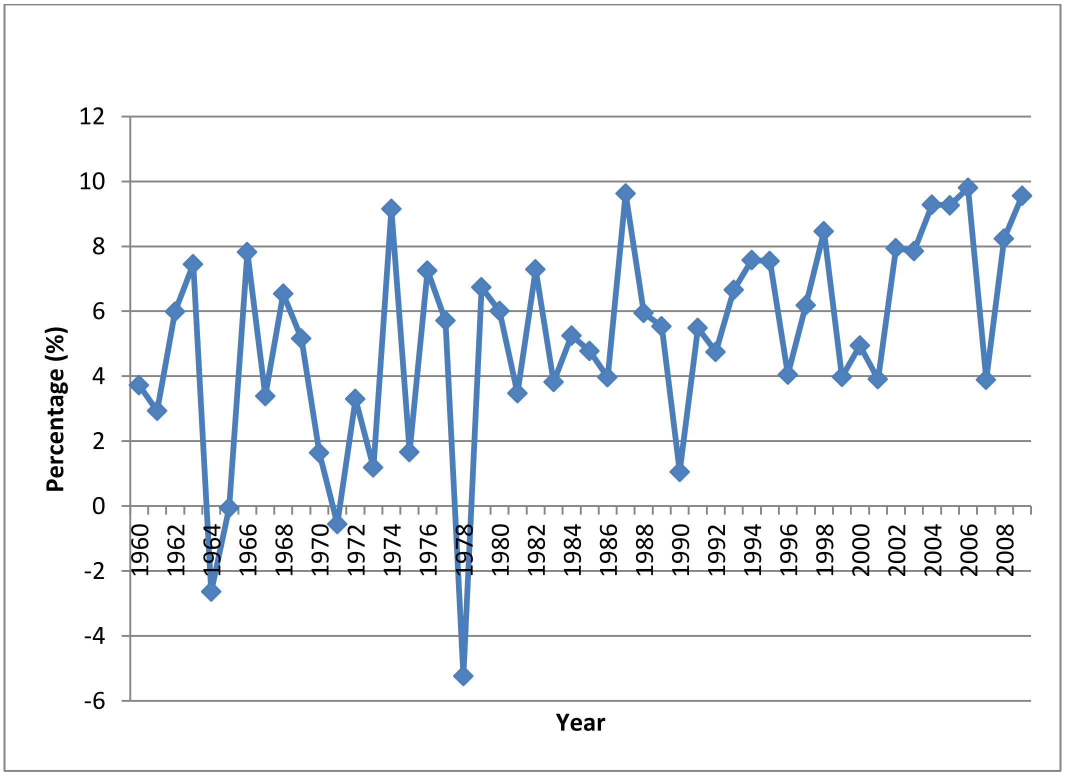

Figure A.2 – Annual Percentage GDP Growth in India

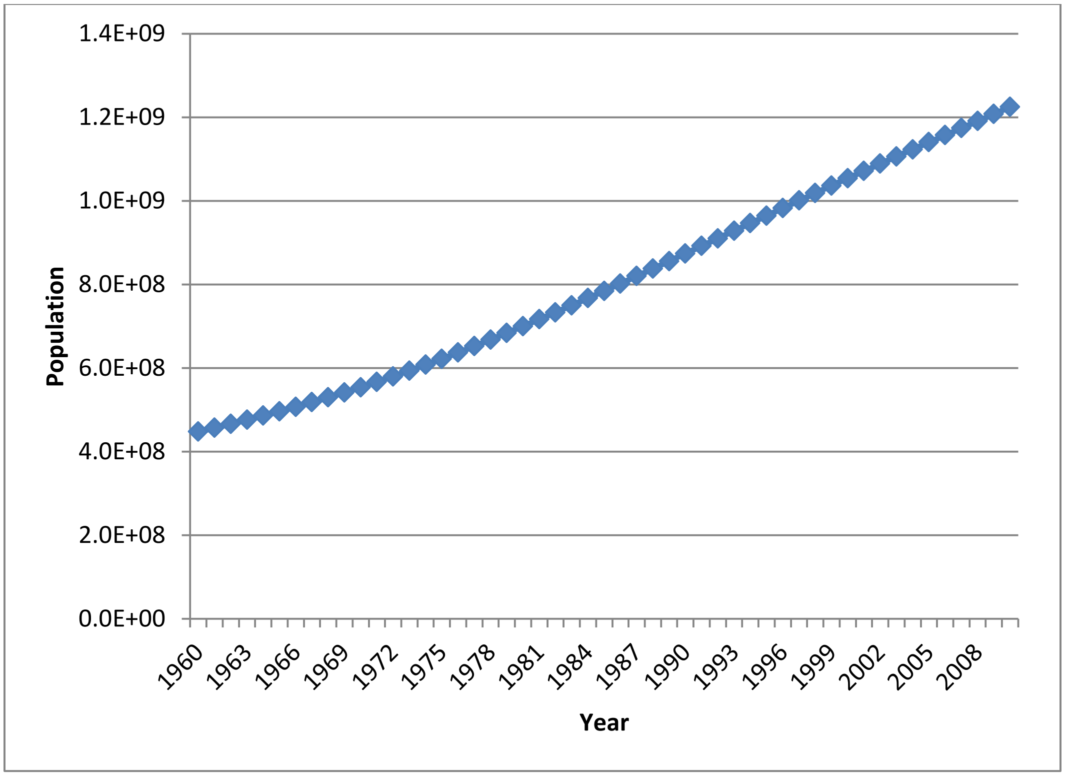

Figure A.3 – Population in India

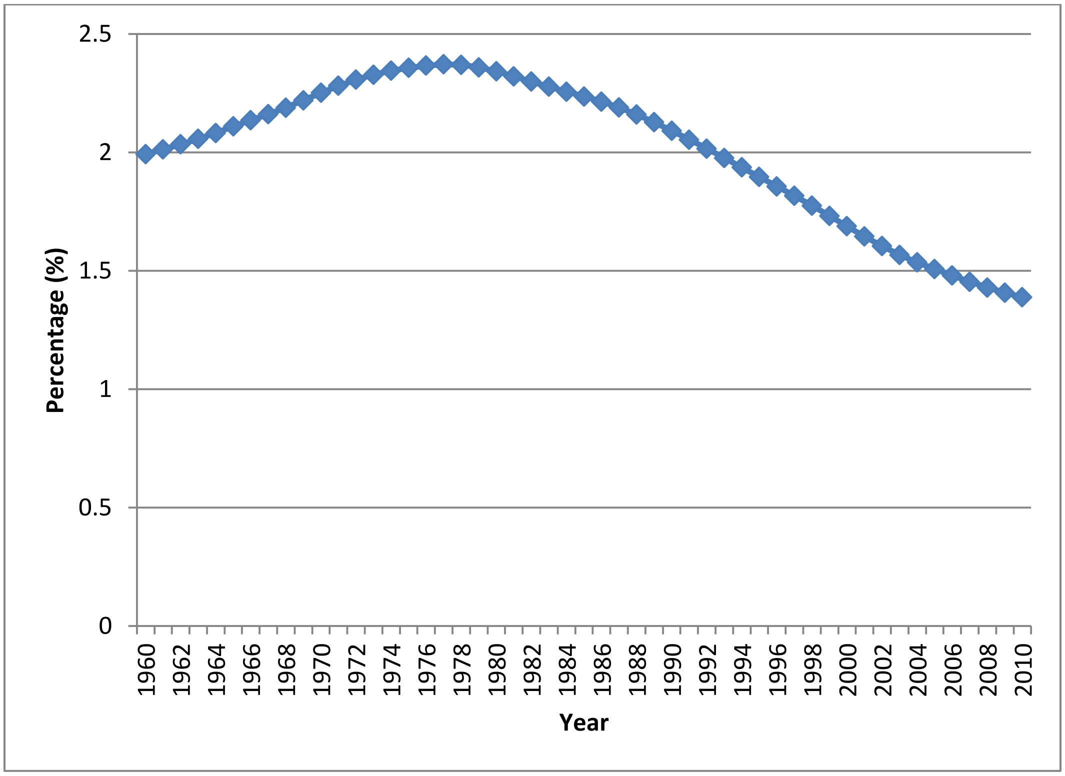

Figure A.4 – Annual Population Growth Rate in India

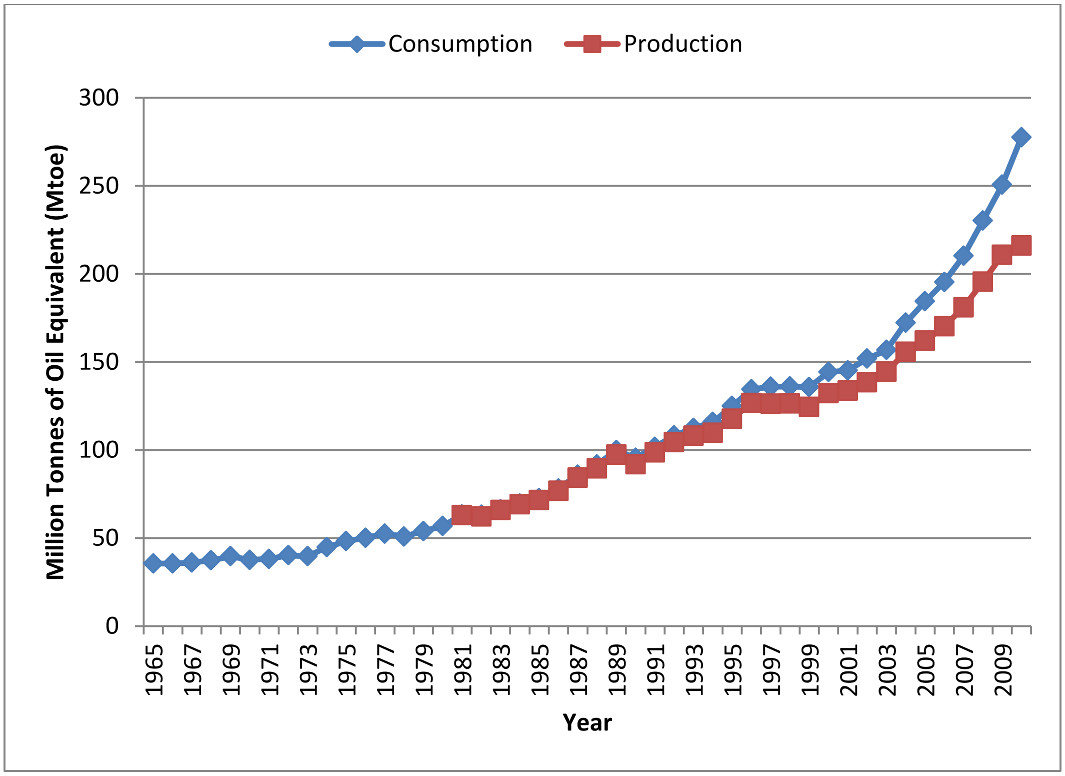

Figure A.5 – Coal Consumption and Production in India

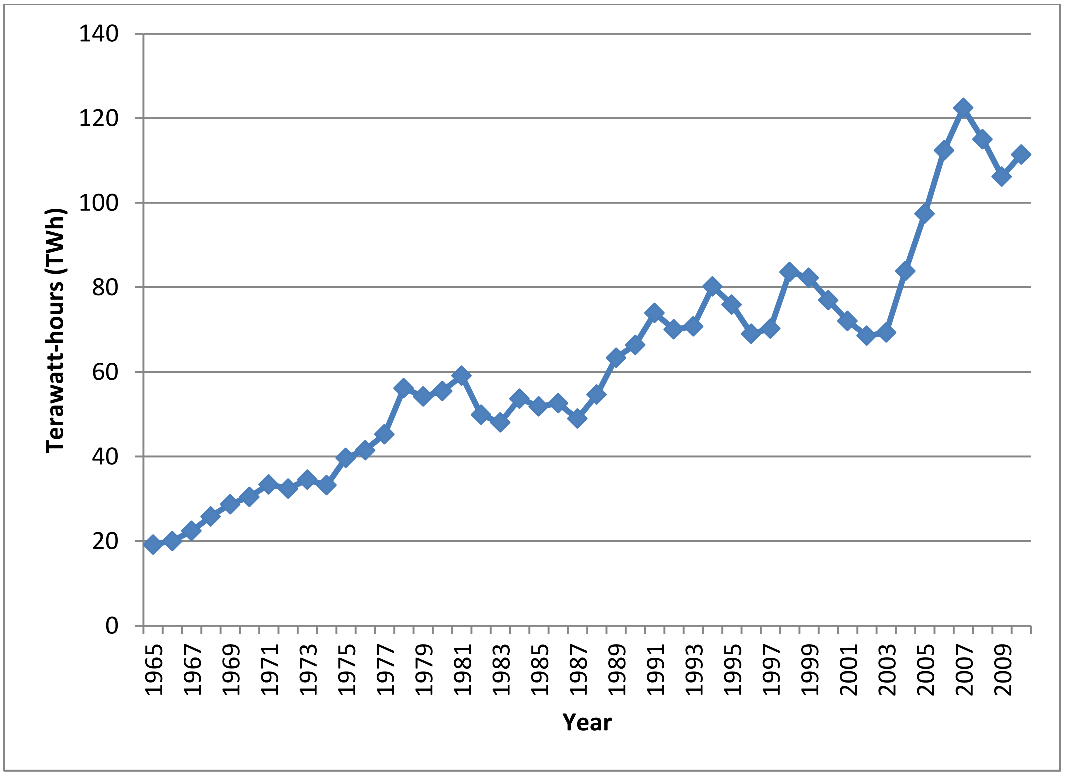

Figure A.6 – Hydropower Consumption in India

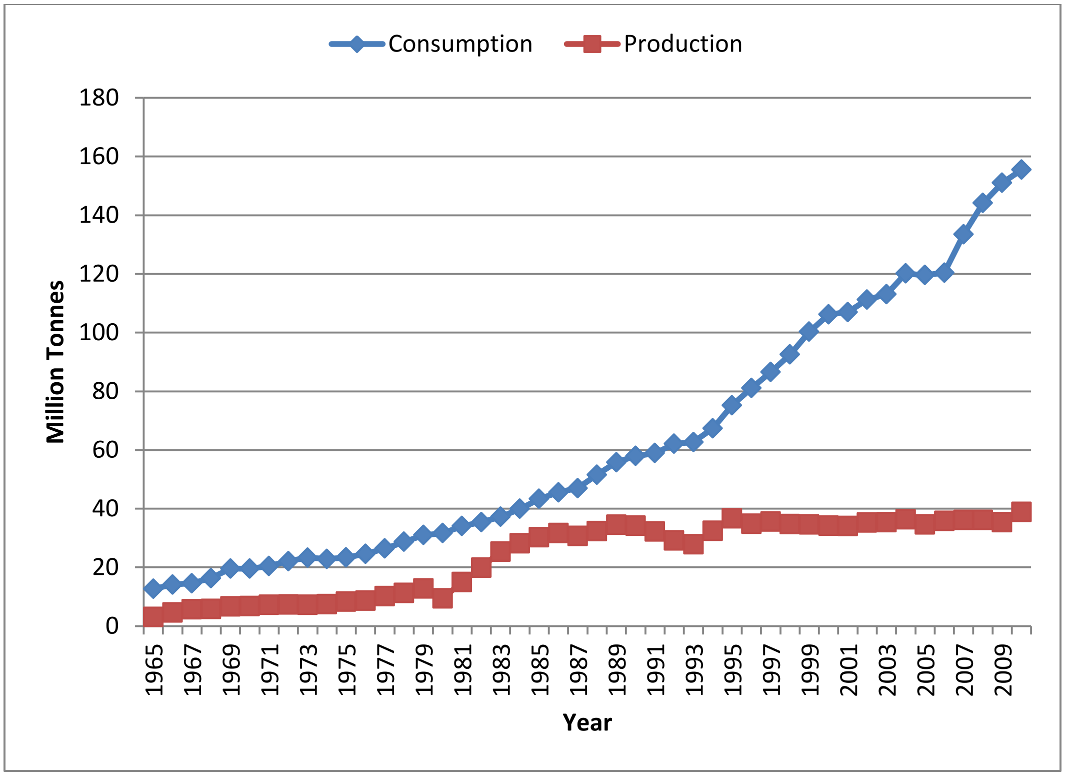

Figure A.7 – Oil Consumption and Production in India

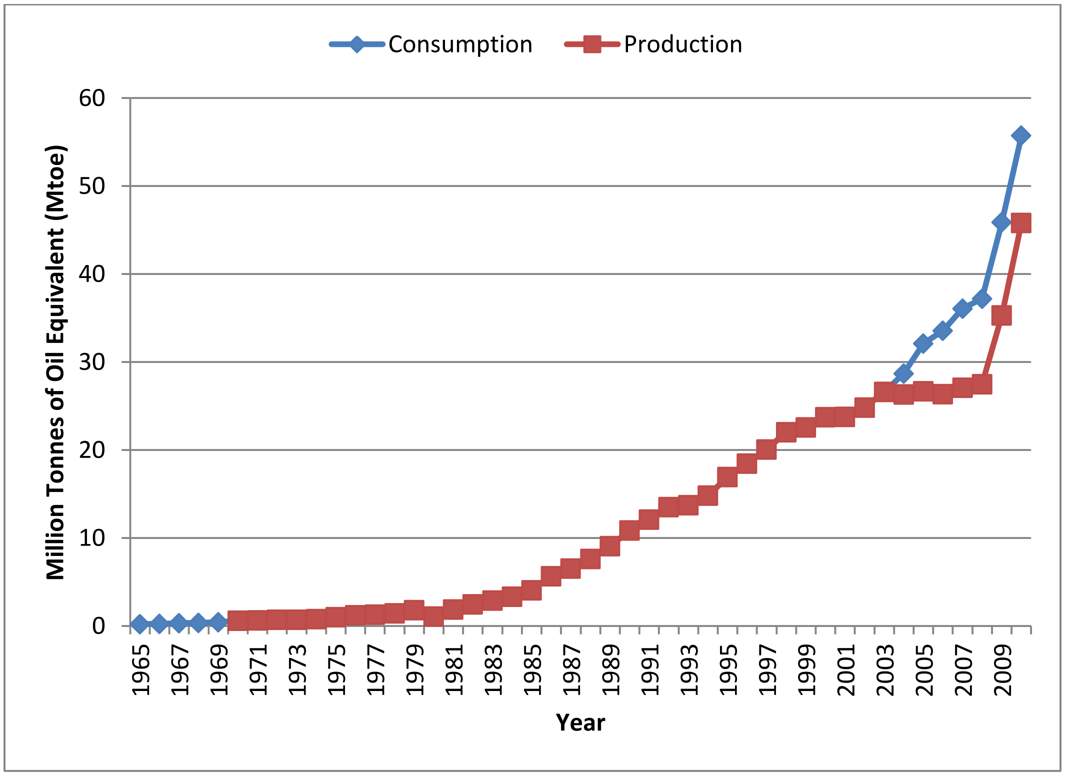

Figure A.8 – Natural Gas Consumption and Production in India

A.2 Japanese GDP, Population, and Energy Data from 1960 to 2010

Japan’s gross domestic product (GDP) and annual percentage GDP growth from 1960 to 2010 are displayed in Figure A.9 and Figure A.10, respectively.[4] Japan’s population and annual population growth rate from 1960 to 2010 are displayed in Figure A.11 and Figure A.12, respectively.[5] Data for consumption and production of hydropower and coal are displayed in Figure A.13 and Figure A.14.[6]

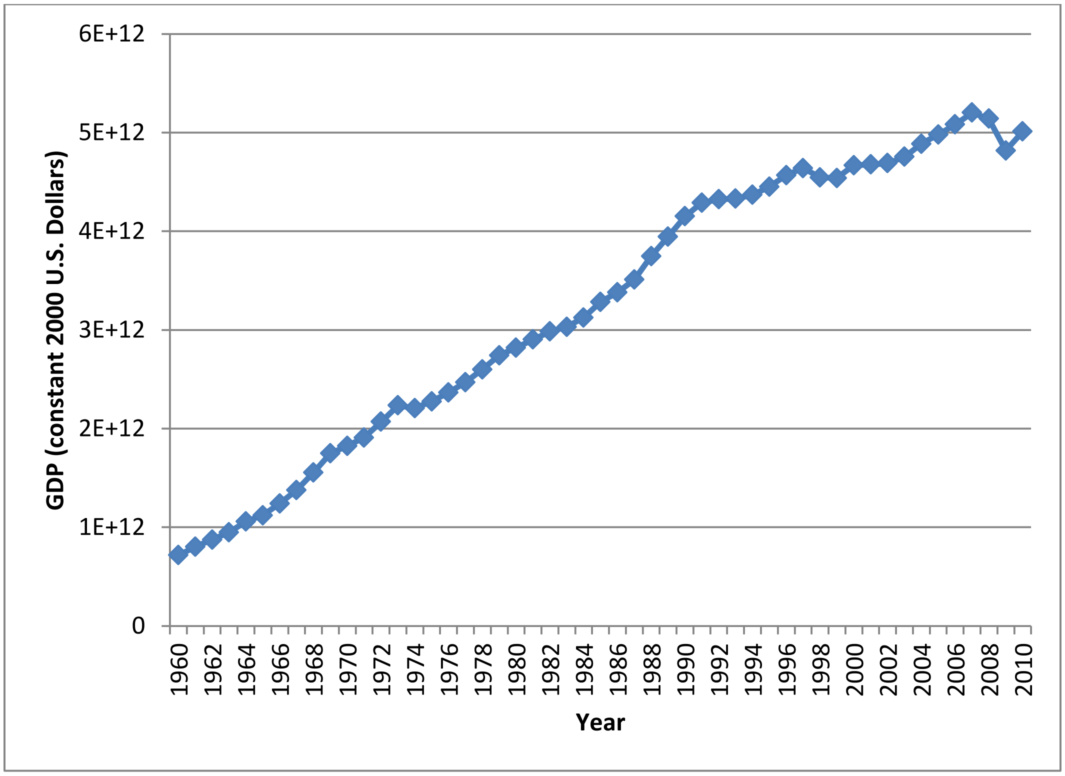

Figure A.9 – Japanese GDP in Constant 2000 U.S. Dollars

---

[4] “Japan | Data,” World Bank, accessed July 19, 2012, http://data.worldbank.org/country/japan.

[5] Ibid.

[6] “Statistical Review of World Energy 2011: Historical Data,” BP, accessed June 10, 2012, http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/spreadsheets/statistical_review_of_world_energy_full_report_2011.xls.

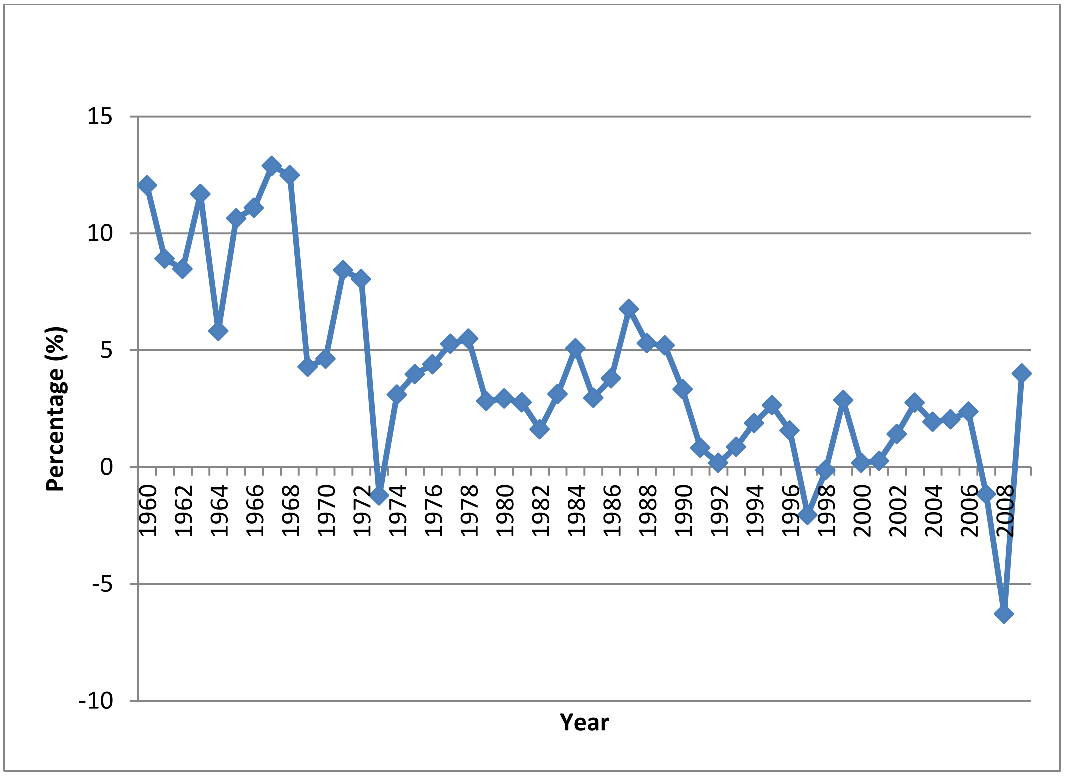

Figure A.10 – Annual Percentage GDP Growth in Japan

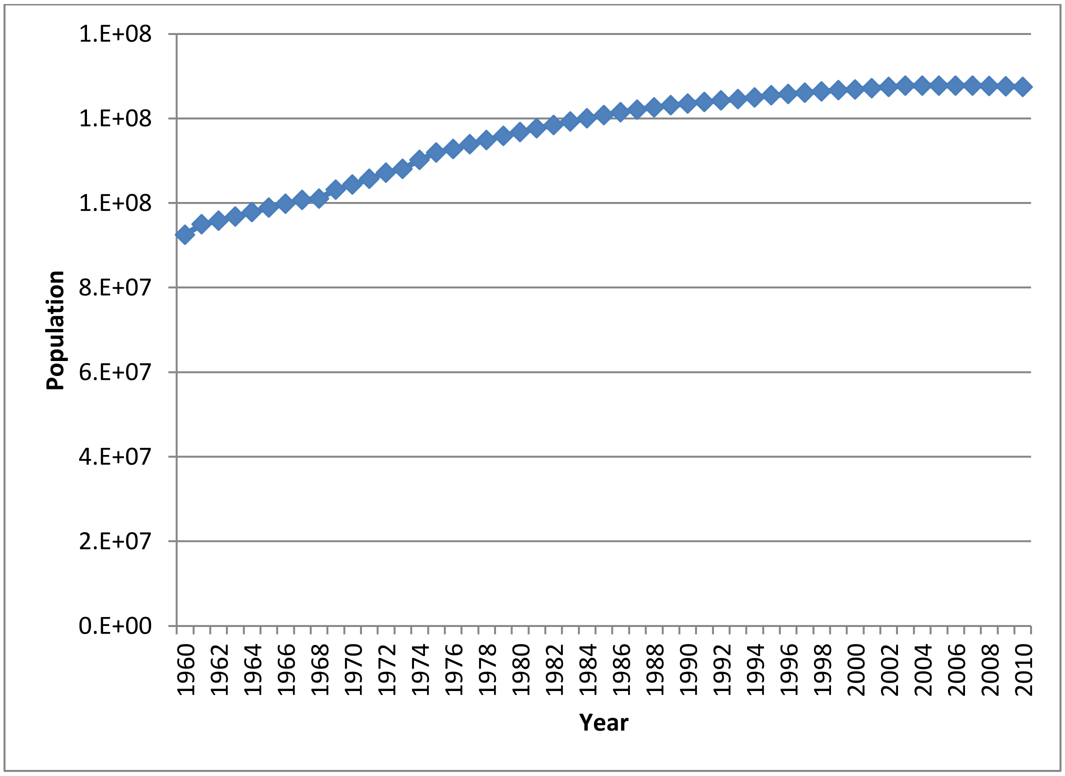

Figure A.11 – Population in Japan

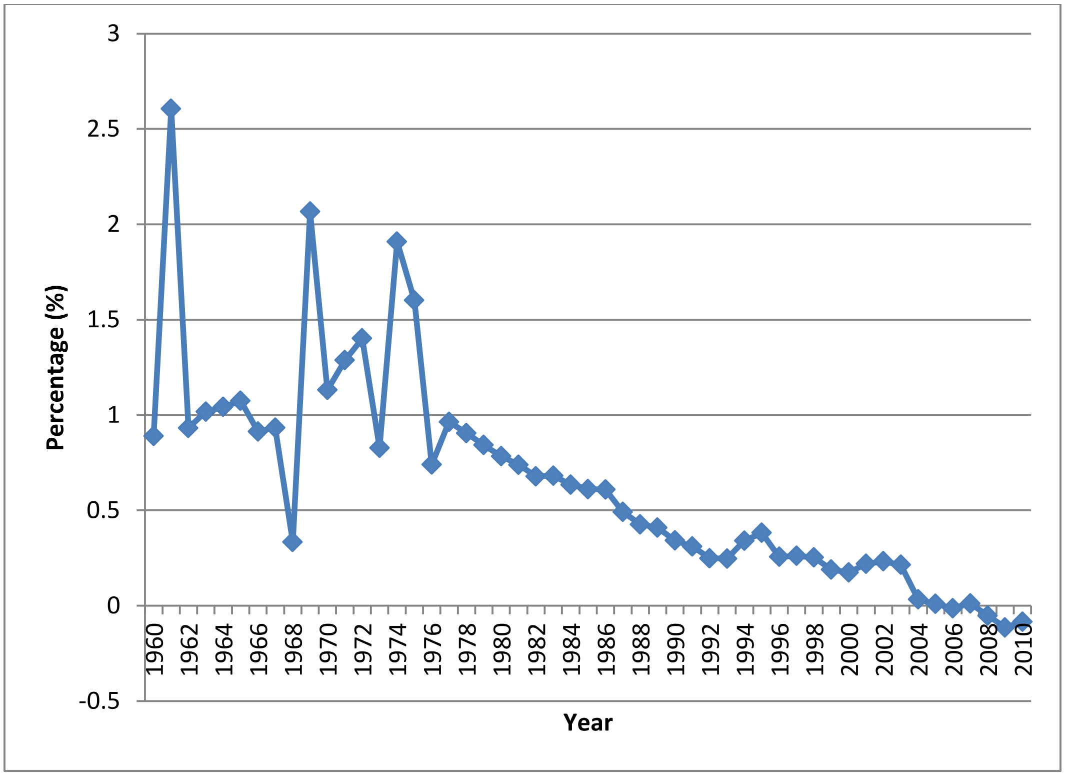

Figure A.12 – Annual Population Growth Rate in Japan

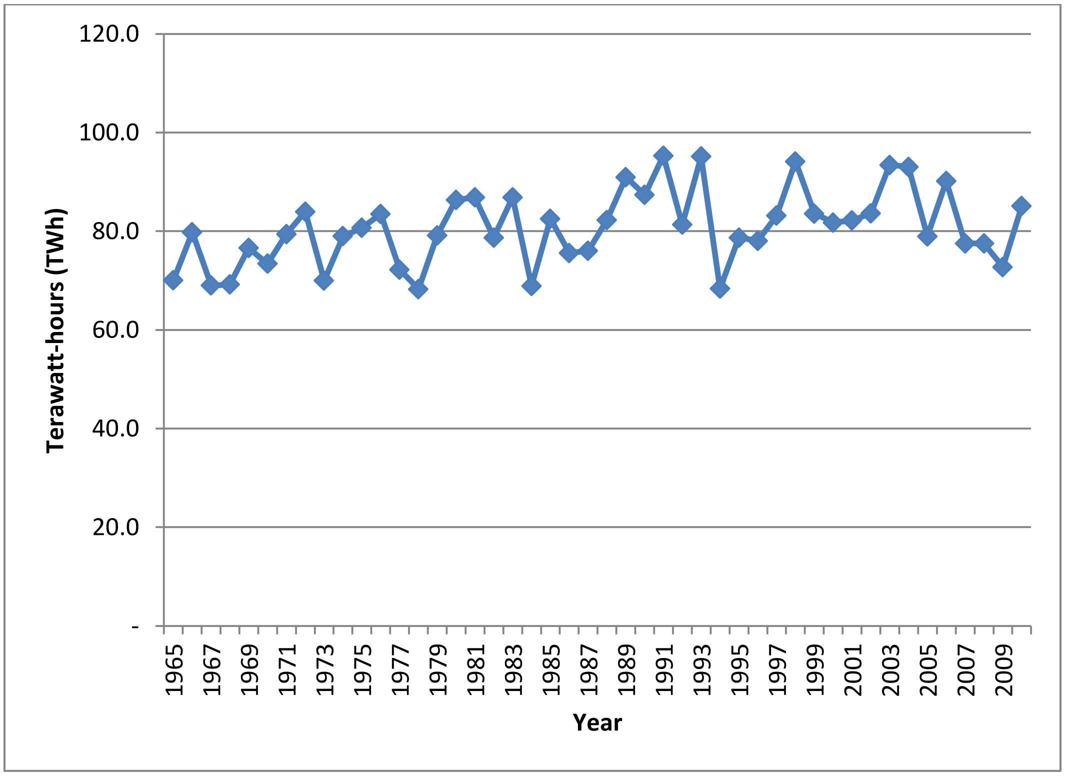

Figure A.13 – Hydropower Consumption in Japan

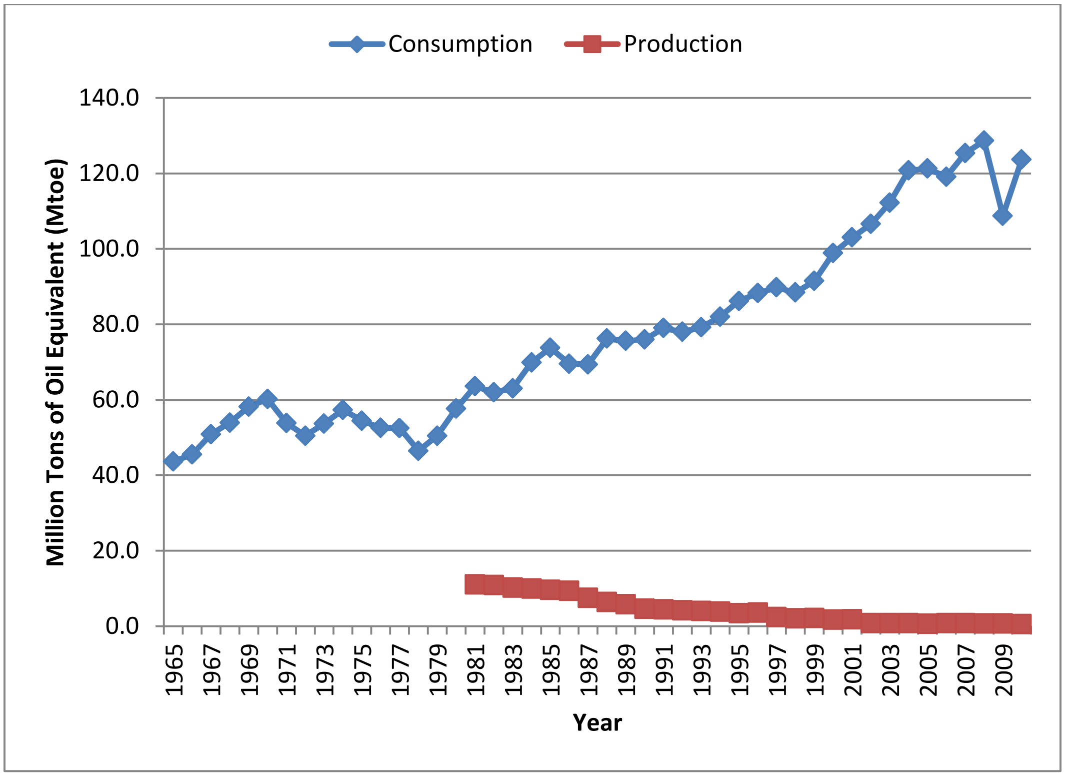

Figure A.14 – Coal Consumption and Production in Japan

A.2 South Korea GDP, Population, and Energy Data from 1960 to 2010

South Korea's gross domestic product (GDP) and annual percentage GDP growth from 1960 to 2010 are displayed in Figure A.15 and Figure A.16, respectively.[7] South Korea's population and annual population growth rate from 1960 to 2010 are displayed in Figure A.17 and Figure A.18, respectively.[8] Data for consumption and production of hydropower and coal are displayed in Figure A.19 and Figure A.20.[9]

---

[7] "Korea, Rep. | Data," World Bank, accessed April 29, 2012, http://data.worldbank.org/country/korea-republic.
[8] Ibid.
[9] "Statistical Review of World Energy 2011: Historical Data," BP, accessed June 10, 2012, http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/sta

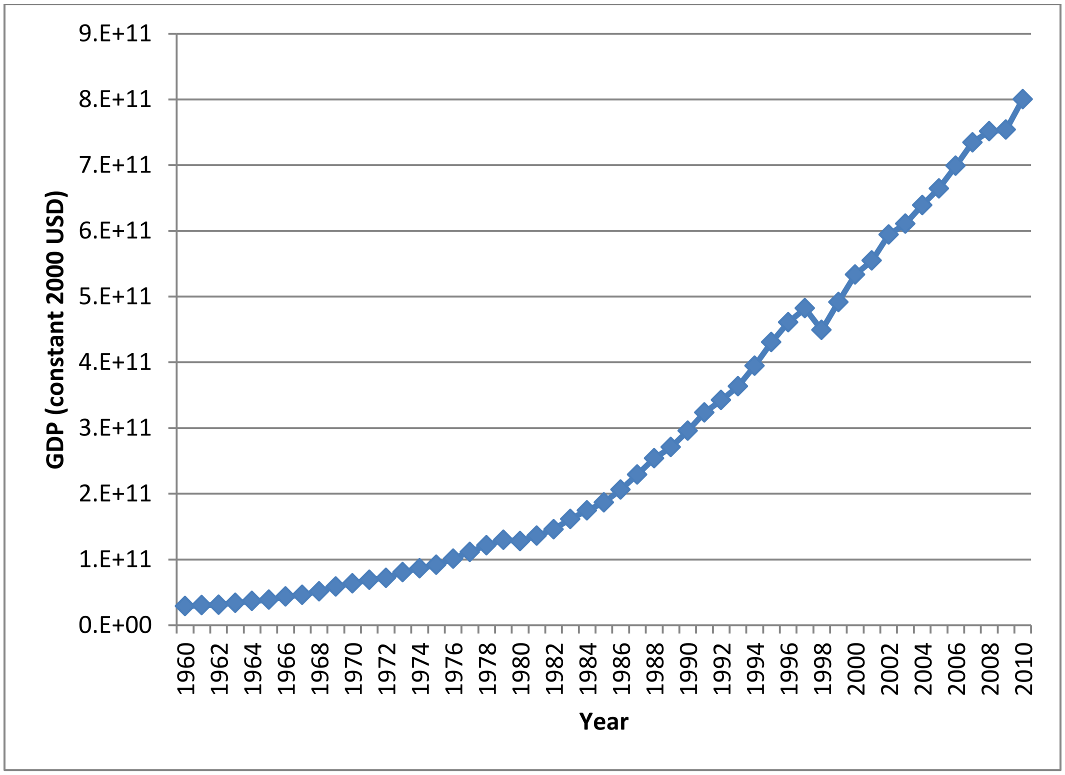

Figure A.15 – South Korean GDP in Constant 2000 U.S. Dollars

---

tistical_energy_review_2011/STAGING/local_assets/spreadsheets/statistical_review_of_world_energy_full_report_2011.xls.

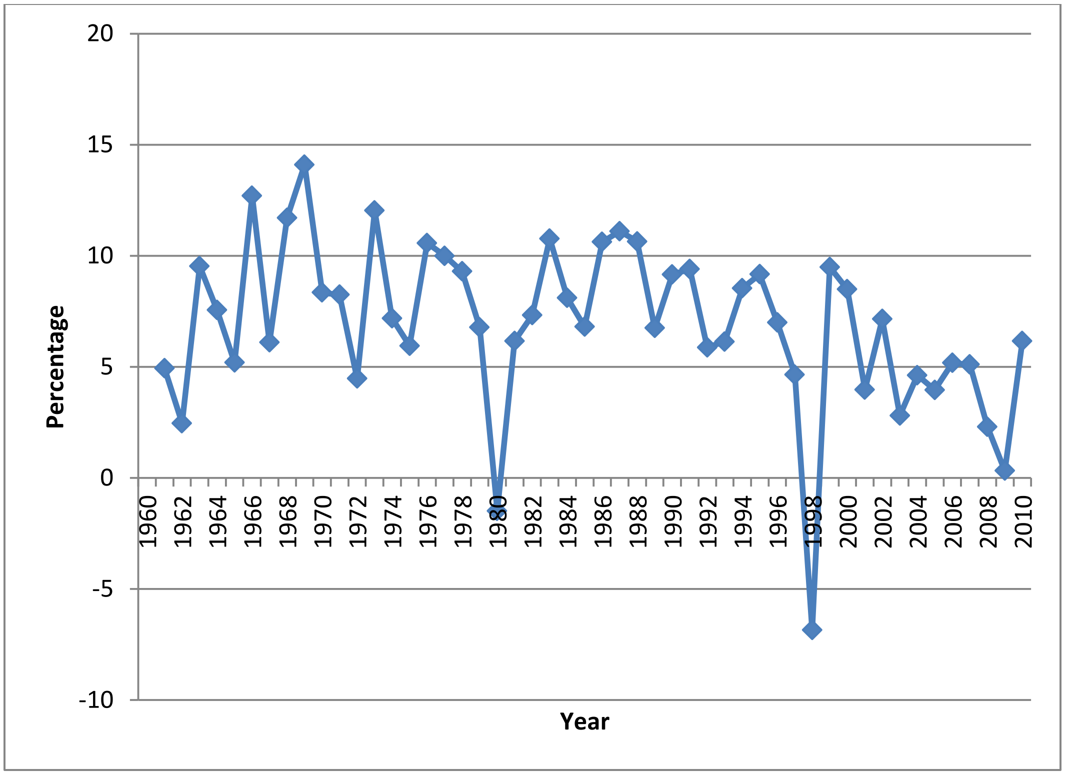

Figure A.16 – Annual Percentage GDP Growth in South Korea

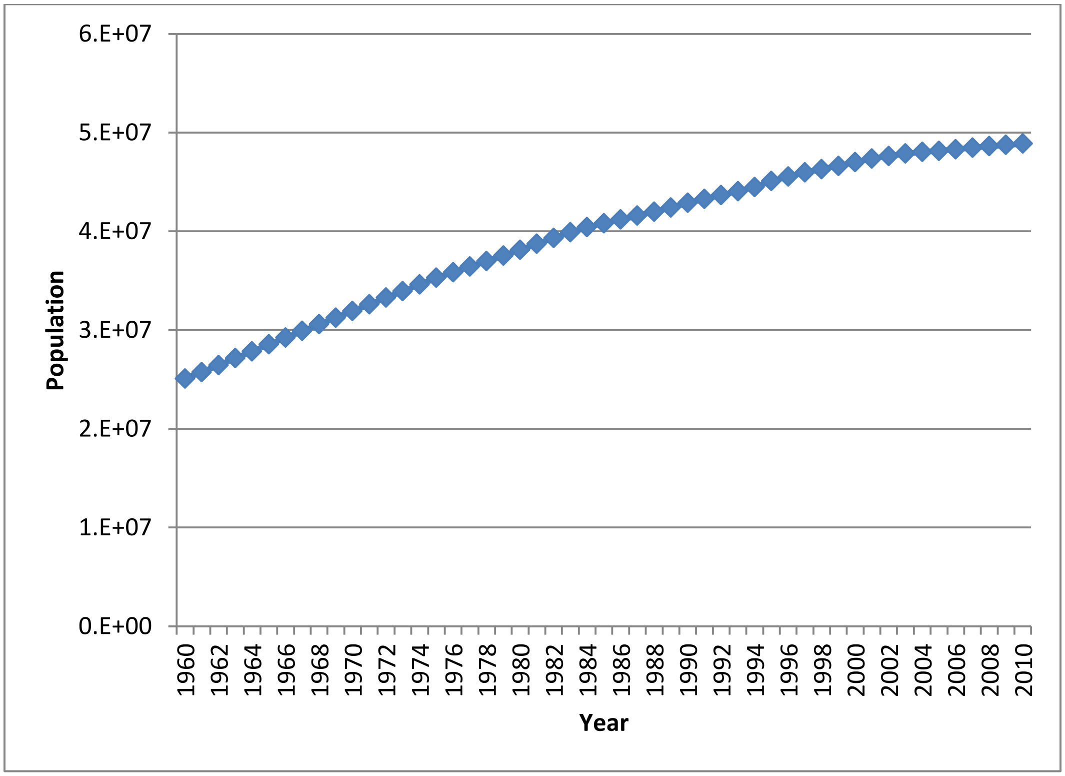

Figure A.17 – Population in South Korea

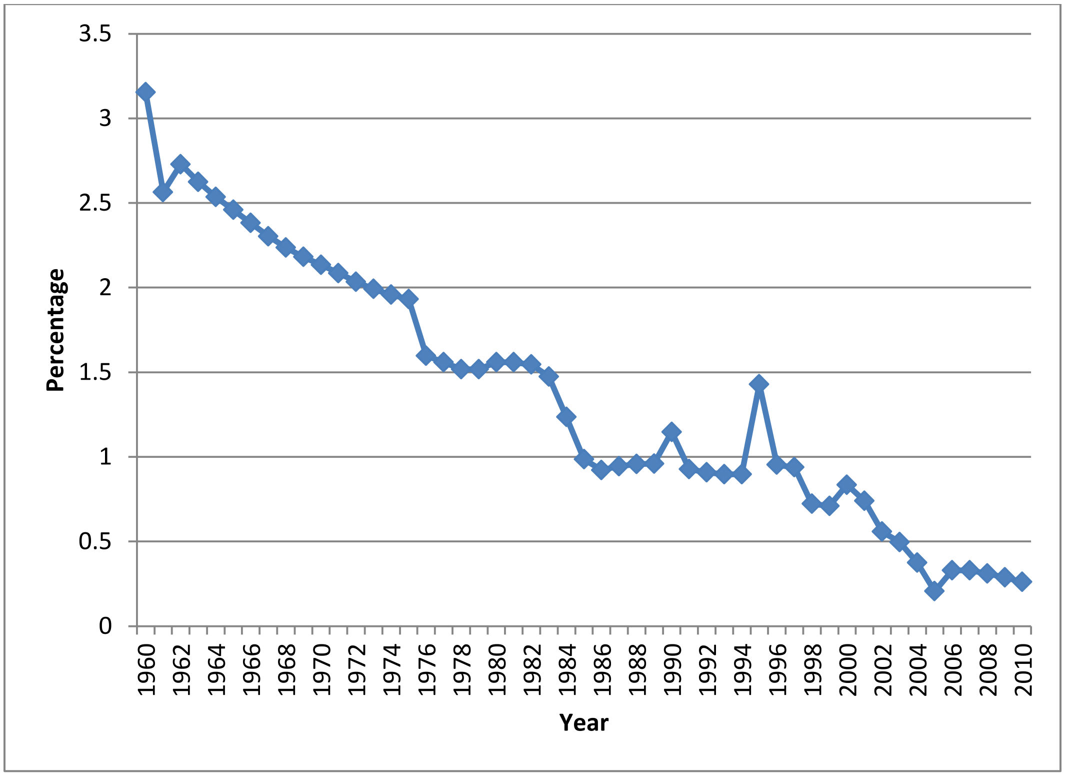

Figure A.18 – Annual Population Growth Rate in South Korea

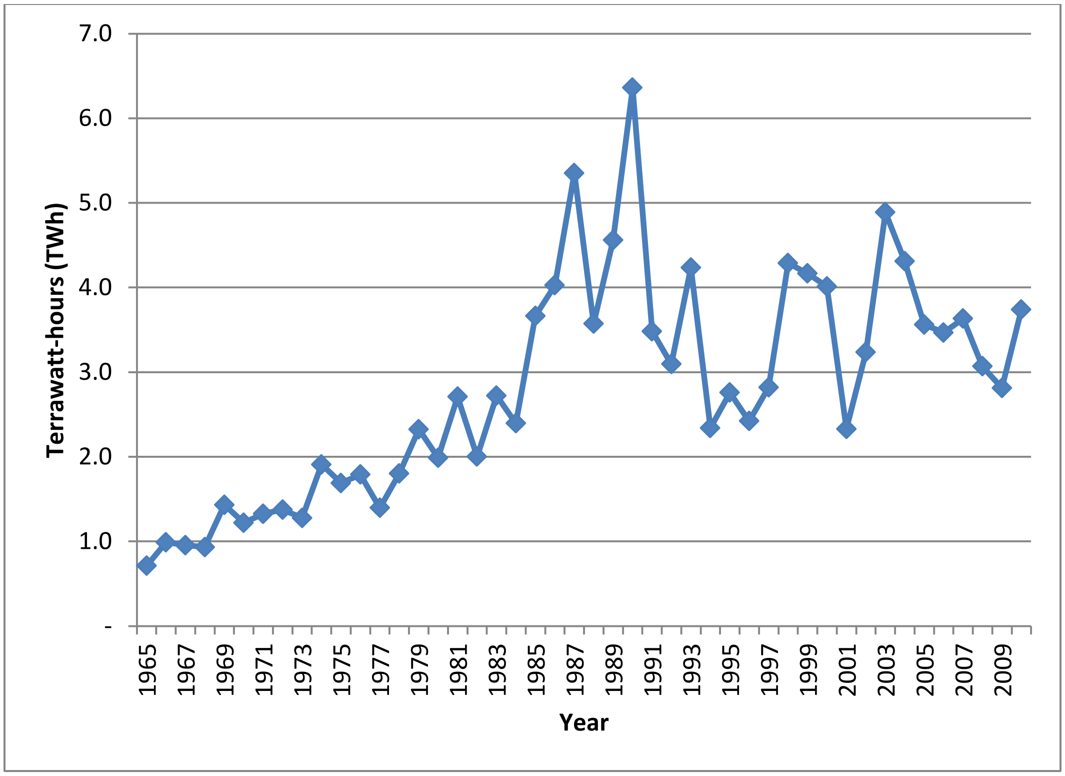

Figure A.19 – Hydropower Consumption in South Korea

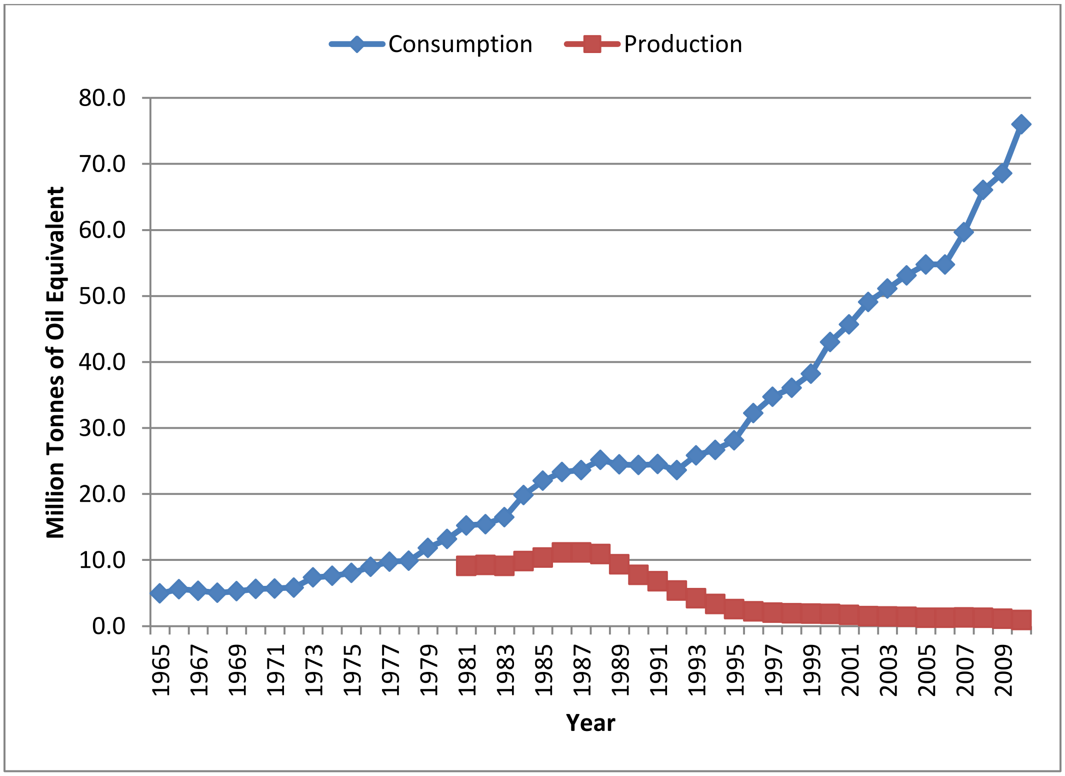

Figure A.20 – Coal Consumption and Production in South Korea

Bibliography

Acton, James M. "Nuclear Power, Disarmament and Technological Restraint." *Survival* 51, no. 4 (August-September 1999): 101-126.

American Society of Mechanical Engineers. "Historic Achievement Recognized: Shippingport Atomic Power Station, A National Historic Mechanical Engineering Landmark." Accessed December 28, 2012. http://files.asme.org/ASMEORG/Communities/History/Landmarks/5643.pdf.

Atomic Energy Commission. *Atomic Energy and Space Research: A Profile for the Decade 1970-80.* New Delhi: Atomic Energy Commission, 1970.

Atomic Weapons Establishment. "Our History." Accessed December 28, 2012. http://www.awe.co.uk/aboutus/our_history_f77a4.html.

Banerjee, B. and N. Sarma. *Nuclear Power in India: A Critical History*. New Delhi: Rupa & Co., 2008.

Berejikian, Jeffrey. "The Gains Debate: Framing State Choice." *American Political Science Review* 91, no. 4 (December 1997): 789-805.

Berejikian, Jeffrey and John S. Dryzek. "Reflexive Action in International Politics." *British Journal of Political Science* 30, no. 2 (April 2000): 193-216.

Berkhout, Frans, Tatsujiro Suzuki, and William Walker. "The Approaching Plutonium Surplus: A Japanese/European Predicament." *International Affairs* 66, no. 3 (July 1990): 523-543.

Bhabha Atomic Research Centre. “Thorium Fuel Cycle.” Accessed September 10, 2012. http://www.barc.ernet.in/reactor/tfc_3sinpp.html.

Birla Institute of Scientific Research, Economic Research Division. *India and the Atom*. New Delhi: Allied Publishers Pvt Ltd, 1982.

Boettcher, William A., III. “Context, Methods, Numbers, and Words: Prospect Theory in International Relations.” *The Journal of Conflict Resolution* 39, no. 3 (September 1995): 561-583.

Bolger, Daniel P. “Scenes from an Unfinished War: Low-Intensity Conflict in Korea, 1966-1968.” *Leavenworth Papers*, no. 19 (July 1991). http://www.cgsc.edu/carl/download/csipubs/ScenesFromanUnfinishedWar.pdf.

BP, “Statistical Review of World Energy 2011: Historical Data,” Accessed June 10, 2012, http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/spreadsheets/statistical_review_of_world_energy_full_report_2011.xls

Bucher, R.G. “India’s Baseline Plan for Nuclear Energy Self-sufficiency.” Argonne National Laboratory. January 2009. http://www.ipd.anl.gov/anlpubs/2010/05/67057.pdf.

“Calder Hall Power Station.” *The Engineer*. October 5, 1956. http://www.theengineer.co.uk/journals/pdf/21835.pdf.

Carnevale, Peter J. “Positive Affect and Decision Frame In Negotiation.” *Group Decision Negotiation* 17, no. 1 (January 2008): 51-63.

Center for Nonproliferation Studies. “Joint Declaration of South and North Korea on the Denuclearization of the Korean Peninsula.” Accessed June 10, 2012. http://cns.miis.edu/inventory/pdfs/aptkoreanuc.pdf.

Central Intelligence Agency. “India.” Accessed January 4, 2013. https://www.cia.gov/library/publications/the-world-factbook/geos/in.html.

Central Intelligence Agency. “Japan.” Accessed January 4, 2013. https://www.cia.gov/library/publications/the-world-factbook/geos/ja.html.

Central Intelligence Agency. “Korea, South.” Accessed January 4, 2013. https://www.cia.gov/library/publications/the-world-factbook/geos/ks.html.

Central Intelligence Agency. “South Korea: Nuclear Developments and Strategic Decisionmaking.” June 1978. http://www.foia.cia.gov/docs/DOC_0001254259/DOC_0001254259.pdf.

Chanlett-Avery, Emma and Mary Beth Nikitin. “Japan’s Nuclear Future: Policy Debate, Prospects, and U.S. Interests.” *Congressional Research Service*. February 19, 2009. http://www.fas.org/sgp/crs/nuke/RL34487.pdf.

Department of Atomic Energy. “India’s Nuclear Policy.” In *The Indian Atom: Power & Proliferation*, edited by Dhirendra Sharma, 55-60. New Delhi: Committee for a Sane Nuclear Policy, 1986.

Federation of American Scientists. “Heavy Water Production.” Last modified October 21, 1998. http://www.fas.org/nuke/intro/nuke/heavy.htm.

Federation of American Scientists. “Status of World Nuclear Forces,” Last modified December 18, 2012. http://www.fas.org/programs/ssp/nukes/nuclearweapons/nukestatus.html.

Gale, Roger W. “Nuclear Power and Japan’s Proliferation Option.” *Asian Survey* 18, no. 11 (November 1978): 1117-1133.

Generation IV International Forum. “GIF Membership.” Accessed December 28, 2012. http://www.gen-4.org/GIF/About/membership.htm.

George, Alexander L. and Andrew Bennett. *Case Studies and Theory Development in the Social Sciences*. Cambridge, MA: MIT Press, 2005.

Graham, Thomas, Jr. “Avoiding the Tipping Point.” *Arms Control Today*, November 2004, http://www.armscontrol.org/act/2004_11/BookReview.

Ha, Young-Sun. “Republic of (South) Korea.” In *Nuclear Power in Developing Countries: An Analysis of Decision Making*, edited by James Everett Katz and Onkar S. Marwah, 221-244. Lexington, MA: Lexington Books, 1982.

Hibbs, Mark. “Chang’s Successor Will Reopen Reprocessing Option, Officials Say.” *Nuclear Fuel* 24, no. 13 (1999): 8.

Hibbs, Mark. “Japan Bristles In Advance of Expected U.S. Meddling In Plutonium Use Program.” *Nuclear Fuel* 19, no. 9 (1994): 9.

Hibbs, Mark. “ROK military said to have begun nuclear weapons plan in 1980s.” *Nucleonics Week* 45, no. 47 (2004): 14.

Holt, Mark. “U.S. and South Korean Cooperation in the World Nuclear Energy Market: Major Policy Considerations.” *Congressional Research Service*. January 21, 2010. http://www.fas.org/sgp/crs/row/R41032.pdf.

Hong, Sung Gul. “The Search for Deterrence: Park’s Nuclear Option.” In *The Park Chung Hee Era: The Transformation of South Korea*, edited by Kim

Byung-Kook and Ezra F. Vogel, 483-512. Cambridge, MA: Harvard University Press, 2011.

Hughes, Llewelyn, “Why Japan Will Not Go Nuclear (Yet): International and Domestic Constraints on the Nuclearization of Japan.” *International Security* 31, no. 4 (Spring 2007): 67-96.

Hymans, Jacques E.C. “The Study of Nuclear Proliferation and Nonproliferation: Toward a New Consensus?” In *Forecasting Nuclear Proliferation in the 21st Century: Volume 1. The Role of Theory*, edited by William C. Potter and Gaukhar Mukhatzhanova, 13-37. Stanford, CA: Stanford University Press, 2010.

Hymans, Jacques E.C. “Veto Players, Nuclear Energy, and Nonproliferation: Domestic Institutional Barriers to a Japanese Bomb.” *International Security* 36, no. 2 (Fall 2011): 154-189.

Hymans, Jacques E.C. “When Does a State Become a ‘Nuclear Weapons State’? An Exercise in Measurement Validation.” In *Forecasting Nuclear Proliferation in the 21st Century: Volume 1. The Role of Theory*, edited by William C. Potter and Gaukhar Mukhatzhanova, 102-123. Stanford, CA: Stanford University Press, 2010.

Hymans, Jacques E.C. *The Psychology of Nuclear Proliferation: Identity, Emotions, and Foreign Policy*. New York: Cambridge University Press, 2006.

Idaho National Laboratory. “Experimental Breeder Reactor No. 1.” Accessed December 28, 2012. http://www.inl.gov/ebr/.

IDSA Task Force. *Development of Nuclear Energy Sector in India: IDSA Task Force Report*. New Delhi: Institute for Defence Studies and Analyses, 2010.

"Indian Prime Ministers on Nuclear Strategy: 1957-1974." In *The Indian Atom: Power & Proliferation*, edited by Dhirendra Sharma, 78-80. New Delhi: Committee for a Sane Nuclear Policy, 1986.

International Atomic Energy Agency, Treaty No. 14581. "International Atomic Energy Agency, France, and Republic of Korea: Agreement for the application of safeguards." September 22, 1975. http://treaties.un.org/doc/publication/unts/volume%20996/volume-996-i-14581-english.pdf.

International Atomic Energy Agency. "50 Years of Nuclear Energy." Accessed December 28, 2012. http://www.iaea.org/About/Policy/GC/GC48/Documents/gc48inf-4_ftn3.pdf.

International Atomic Energy Agency. "From Obninsk Beyond: Nuclear Power Conference Looks to Future." Last modified February 18, 2011. http://www.iaea.org/NewsCenter/News/2004/obninsk.html.

International Atomic Energy Agency. "India." Last modified December 29, 2012. http://www.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=IN.

International Atomic Energy Agency. "Korea, Republic of." Accessed December 30, 2012.

http://www.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=KR.

International Atomic Energy Agency. "Nuclear Power Capacity Trend." Last modified December 28, 2012. http://www.iaea.org/PRIS/WorldStatistics/WorldTrendNuclearPowerCapacity.aspx.

International Atomic Energy Agency. "Nuclear Share of Electricity Generation in 2011." Last modified December 28, 2012. http://www.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx.

International Atomic Energy Agency. "Operational & Long-Term Shutdown Reactors – By Country." Last modified December 28, 2012. http://www.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx.

International Atomic Energy Agency. "Power Reactor Information System." Last modified December 28, 2012. http://www.iaea.org/PRIS/.

International Atomic Energy Agency. "Under Construction Reactors." Last modified December 28, 2012. http://www.iaea.org/PRIS/WorldStatistics/UnderConstructionReactorsByCountry.aspx.

International Atomic Energy Agency. *Country Nuclear Fuel Cycle Profiles*, 2nd ed. Vienna: International Atomic Energy Agency, 2005. http://www-pub.iaea.org/MTCD/publications/PDF/TRS425_web.pdf.

International Atomic Energy Agency. *The IAEA's Safeguards System: Ready for the 21st Century*. Vienna: International Atomic Energy Agency, 1997. http://www.iaea.org/Publications/Booklets/Safeguards2/intro.html.

Ishikawa, Ichiro. "Present Status of the Development of Atomic Energy in Japan (Especially of Nuclear Power Developments)." In *Proceedings of the Anglo-Japanese Nuclear Power Symposium*. Tokyo, March 1963.

Iyengar, P.K. *Briefings on Nuclear Technology in India*. New Delhi: Rupa & Co., 2009.

Jain, Jagdish P. *Nuclear India, Volume 1*. New Delhi: Radiant Publishers, 1974.

Japan Atomic Energy Agency. "Brief History of JNC." Accessed July 12, 2012, http://www.jaea.go.jp/jnc/jncweb/01intro/history.html.

Japan Atomic Energy Agency. "Development of Monju." Accessed July 12, 2012. http://www.jaea.go.jp/04/monju/EnglishSite/1_Overview%20of%20Monju/History%20of%20Monju.pdf.

Japan Atomic Energy Agency. "Outline of Nuclear Fuel Cycle Engineering Laboratories." Accessed July 19, 2012. http://www.jaea.go.jp/english/04/tokai-cycle/01.htm.

Japan Atomic Energy Agency. "Reprocessing Technology Development." Accessed July 7, 2012. http://www.jaea.go.jp/english/04/tokai-cycle/02.htm.

Japan Atomic Energy Commission. *Advances in the Field of Research, Development, and Utilization of Nuclear Energy in Japan*. Tokyo: Japan Atomic Energy Commission, December 1981.

Japan Atomic Energy Commission. *Long-Range Program on Development and Utilization of Atomic Energy*. Tokyo: Japan Atomic Energy Commission, 1961.

Joskow, Paul L. "The International Nuclear Industry Today: The End of the American Monopoly." *Foreign Affairs* 54, no. 4 (July 1976): 788-803.

Kahler, Miles. "Rationality in International Relations." *International Organization* 52, no. 4 (Autumn 1998): 919-941.

Kamiya, Matake. "Nuclear Japan: Oxymoron or Coming Soon?" *The Washington Quarterly* 26, no. 1 (Winter 2002-2003): 63-75.

Kang, Jungmin and H.A. Feiveson, "South Korea's Shifting and Controversial Interest in Spent Fuel Reprocessing." *The Nonproliferation Review*. Spring 2001. http://cns.miis.edu/npr/pdfs/81kang.pdf.

Kase, Yuri. "The Costs and Benefits of Japan's Nuclearization: An Insight into the 1968/70 Internal Report." *The Nonproliferation Review* (Summer 2001): 55-68.

KEPCO Nuclear Fuel Company. "History." Accessed June 10, 2012. http://www.knfc.co.kr/main/?en_skin=intro03.html&left=3.

Kim, Ho-Tak. "Technology Transfer Strategy for Nuclear Power Development in Korea." *Energy R&D* 14 (1992).

Kim, Jong-dall and John Byrne. "The Asian Atom: Hard-Path Nuclearization in East Asia." In *Governing the Atom: The Politics of Risk*, edited by John Byrne and Steven M. Hoffman, 271-297. New Brunswick, NJ: Transaction Publishers, 1996.

Kim, Seung-Young. “Security, Nationalism and the Pursuit of Nuclear Weapons and Missiles: The South Korean Case, 1970-82.” *Diplomacy & Statecraft* 12, no. 4 (2001): 53-80.

Korea Atomic Energy Research Institute. *Energy Sourced from the Brain: 50 Years of Nuclear Energy, 50 Years of Prosperity*. Seoul, South Korea: Korea Atomic Energy Research Institute, 2009.

“Krishna Menon’s View on Nuclear Policy: 1968.” In *The Indian Atom: Power & Proliferation*, edited by Dhirendra Sharma, 27-28. New Delhi: Committee for a Sane Nuclear Policy, 1986.

Kowert, Paul A. and Margaret G. Hermann. “Who Takes Risks? Daring and Caution in Foreign Policy Making.” *The Journal of Conflict Resolution* 41, no. 5 (October 1997): 611-637.

Lester, Richard K. “U.S.-Japanese Nuclear Relations: Structural Change and Political Strain,” *Asian Survey* 22, no. 5 (May 1982): 417-433.

Levy, Jack S. “Loss Aversion, Framing Effects, and International Conflict: Perspectives from Prospect Theory.” In *Handbook of War Studies II*, edited by Manus I. Midlarsky, 193-221.Ann Arbor, MI: University of Michigan Press, 2000.

Mack, Andrew. “Potential, not Proliferation.” *The Bulletin of the Atomic Scientists* 53, no. 4 (July-August 1997): 48-53.

McDermott, Rose, James H. Fowler, and Oleg Smirnov. “On the Evolutionary Origin of Prospect Theory Preferences.” *The Journal of Politics* 70, no. 2 (April 2008): 335-350.

McDermott, Rose. *Risk-Taking in International Politics: Prospect Theory in American Foreign Policy*. Ann Arbor, MI: University of Michigan Press, 2001.

Mirchandani, G.G. and P.K.S. Namboodiri. *Nuclear India: A Technological Assessment*. New Delhi: Vision Books, 1981.

National Nuclear Security Administration. "Agreement for Cooperation between the Government of the United States of America and the Government of the Republic of Korea Concerning Civil Uses of Atomic Energy." Accessed June 10, 2012. http://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/Korea_South_123.pdf.

Nuclear Suppliers Group. "History of the NSG." Accessed August 26, 2012. http://www.nuclearsuppliersgroup.org/Leng/01-history.htm.

Office of the Director of National Intelligence. "Statement by the Office of the Director of National Intelligence on the North Korea Nuclear Test." October 16, 2006. http://www.dni.gov/announcements/20061016_release.pdf.

Office of the Director of National Intelligence. "Statement by the Office of the Director of National Intelligence on North Korea's Declared Nuclear Test on May 25, 2009." June 15, 2009. http://www.dni.gov/press_releases/20090615_release.pdf.

Oshima, Keichi, et al, *Future U.S.-Japanese Nuclear Energy Relations*. New York: Rockefeller Foundation, 1979.

Pande, Vijay G. "Towards an Increased Concern with Energy Research and Development in India." In *Energy Policy for India: An Interdisciplinary Analysis*, edited by Rajendra K. Pachauri, 150-187. New Delhi: MacMillan Company of India, Ltd.: 1980.

Pomper, Miles A. "Stakes Rise for U.S.-ROK Nuclear Energy Talks." *Center for U.S.-Korea Policy Newsletter*. February 2010. http://cns.miis.edu/other/pomper_miles_100200_cuskp_newsletter_2-2.pdf.

Prime Minister of Japan and His Cabinet. "The Constitution of Japan." Accessed June 27, 2012. http://www.kantei.go.jp/foreign/constitution_and_government_of_japan/constitution_e.html.

Ramanna, Raja. "Raja Ramanna on Development of Nuclear Energy 1947-73." In *The Indian Atom: Power & Proliferation*, edited by Dhirendra Sharma, 61-72. New Delhi: Committee for a Sane Nuclear Policy, 1986.

Rao, R. Rama. *India and the Atom*. New Delhi: Allied Publishers Pvt Ltd, 1982.

Ray-Dadwal, Shebonti. *Rethiking Energy Security in India*. New Delhi: Knowledge World.

Ronald Reagan Presidential Library. "Joint Communique Following Discussions With Prime Minister Zenko Suzuki of Japan." Accessed July 22, 2012. http://www.reagan.utexas.edu/archives/speeches/1981/50881b.htm.

Sagan, Scott D. “Why Do States Build Nuclear Weapons? Three Models in Search of a Bomb.” *International Security* 21, no. 3 (Winter 1996-1997): 54-86.

Samuels, Richard J. *The Business of the Japanese State: Energy Markets in Comparative and Historical Perspective*. Ithaca, NY: Cornell University Press, 1987.

Sapir, Michael and Sam J. Van Hyning. *The Outlook for Nuclear Power in Japan*. Washington, DC: National Planning Association, 1956.

Sheen, Seongho. “Nuclear Sovereignty Versus Nuclear Security: Renewing the ROK-U.S. Atomic Energy Agreement.” *The Korean Journal of Defense Analysis* 23, no. 2 (June 2011): 273-288.

Shin, Jae-In and Tae-Yoon Eom. “The Role of Nuclear Power in the Republic of Korea.” In *The Nuclear Power Option: Proceedings of an International Conference on the Nuclear Power Option Organized by the International Atomic Energy Agency and Held in Vienna, 5-8 September 1994*, 153-162. Vienna: International Atomic Energy Agency, 1995.

Shin, Paull. “Korean Vietnam War Veterans Honored by Senate.” *Senate Democrats Blog*. February 12, 2010. http://blog.senatedemocrats.wa.gov/shin/korean-vietnam-war-veterans-honored-by-senate/.

Singh, Bhupendra Kumar. *India’s Energy Security: The Changing Dynamics*. New Delhi: Pentagon Energy Press, 2010.

Skolnikoff, Eugene, Tatsujiro Suzuki, and Kenneth Oye. "International Responses to Japanese Plutonium Programs." *Center for International Studies*. August 1995. http://ia600507.us.archive.org/23/items/InternationalResponsesToJapanesePlutoniumPrograms/1995-08IntlResponseToJpnsPlutoniumProgram.pdf.

Solingen, Etel. "Domestic Models of Political Survival: Why Some Do and Others Don't (Proliferate)." In *Forecasting Nuclear Proliferation in the 21st Century: Volume 1. The Role of Theory*, edited William C. Potter and Gaukhar Mukhatzhanova, 38-57. Stanford, CA: Stanford University Press, 2010.

Srinivasan, M.R. *From Fission to Fusion: The Story of India's Atomic Energy Programme*. New Delhi: Viking, 2002.

Sublette, Carey. "France's Nuclear Weapons – Origin of the Force de Frappe." Last modified December 24, 2001. http://nuclearweaponarchive.org/France/FranceOrigin.html.

Sublette, Carey. "India's Nuclear Weapons Program – Smiling Buddha: 1974." Last modified November 8, 2001. http://nuclearweaponarchive.org/India/IndiaSmiling.html.

Sublette, Carey. "The Soviet Nuclear Weapons Program." Last modified 12 December 1997. http://nuclearweaponarchive.org/Russia/Sovwpnprog.html.

Sublette, Carey. "What Are the Real Yields of India's Tests?" Last modified November 8, 2001. http://nuclearweaponarchive.org/India/IndiaRealYields.html.

Tversky, Amos and Daniel Kahneman. "Advances in Prospect Theory: Cumulative Representation of Uncertainty." *Journal of Risk and Uncertainty* 5, no. 4 (October 1992): 297-323.

U.S. Department of Energy. "Waste Isolation Pilot Plant." Accessed December 29, 2012. http://www.wipp.energy.gov.

U.S. Department of Energy Hanford Site. "B Reactor." Last modified December 9, 2012. http://www.hanford.gov/page.cfm/BReactor.

U.S. Department of Energy Office of Civilian Radioactive Waste Management. "Radioactive Waste: An International Concern." Accessed December 29, 2012. http://web.archive.org/web/20090515021337/http://www.ocrwm.doe.gov/factsheets/doeymp0405.shtml.

U.S. Department of Energy Office of Nuclear Energy. "Our Programs." Accessed December 28, 2012. http://www.ne.doe.gov/nePrograms.html.

U.S. Department of State. "Background Note: South Korea." Last modified December 17, 2012. http://www.state.gov/r/pa/ei/bgn/2800.htm.

U.S. Nuclear Regulatory Commission. "Dry Cask Storage." Last modified December 21, 2012. http://www.nrc.gov/waste/spent-fuel-storage/dry-cask-storage.html.

U.S. Nuclear Regulatory Commission. “Fact Sheet on Licensing Yucca Mountain.” Last modified March 29, 2012. http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-yucca-license-review.html.

U.S. Nuclear Regulatory Commission. “Spent Fuel Pools.” Last modified December 21, 2012. http://www.nrc.gov/waste/spent-fuel-storage/pools.html.

United Nations Office for Disarmament Affairs. “Status of the Treaty.” Accessed December 29, 2012. http://disarmament.un.org/treaties/t/npt.

United Nations Office for Disarmament Affairs. “Treaty on the Non-Proliferation of Nuclear Weapons.” Accessed December 28, 2012. http://www.un.org/disarmament/WMD/Nuclear/NPTtext.shtml.

Vassar College. “President Nixon’s Speech on ‘Vietnamization,’ November 3, 1969.” Accessed June 19, 2012. http://vietnam.vassar.edu/overview/doc14.html.

Vis, Barbara. *Politics of Risk-taking: Welfare State Reform in Advanced Democracies*. Amsterdam: Amsterdam University Press, 2010.

Walker, William. “Entrapment In Large Technology Systems: Institution Commitment and Power Relations.” *Research Policy* 29 (August 2000): 833-846.

Weyland, Kurt. “Risk Taking in Latin American Economic Restructuring: Lessons from Prospect Theory.” *International Studies Quarterly* 40, no. 2 (June 1996): 185-207.

WISE Uranium Project. “Uranium Enrichment Facilities.” Last modified December 10, 2012. http://www.wise-uranium.org/efac.html#ENR.

World Bank, “Japan | Data.” Accessed July 19, 2012, http://data.worldbank.org/country/japan.

World Bank. “India | Data.” Accessed August 3, 2012. http://data.worldbank.org/country/india.

World Bank. “Korea, Rep. | Data.” Accessed April 29, 2012. http://data.worldbank.org/country/korea-republic.

World Nuclear Association. “Nuclear Power in India.” Last modified September 2012. http://www.world-nuclear.org/info/inf53.html.

World Nuclear Association. “Nuclear Power in Japan.” Last modified October 22, 2012. http://www.world-nuclear.org/info/inf79.html.

World Nuclear Association. “Nuclear Power in South Korea.” Last modified December 2012. http://www.world-nuclear.org/info/inf81.html.

World Nuclear Association. “Nuclear Power in the World Today.” Last modified April 2011. http://www.world-nuclear.org/info/inf01.html.

World Nuclear Association. “Plans for New Reactors Worldwide.” Last modified August 2012. http://www.world-nuclear.org/info/inf17.html.

World Nuclear Association. “Processing of Used Nuclear Fuel.” Last modified May 2012. http://www.world-nuclear.org/info/inf69.html.

World Nuclear Association. “Reactor Database.” Accessed June 27, 2012. http://world-nuclear.org/NuclearDatabase/.

World Nuclear Association. “Reactor Database.” Accessed June 27, 2012. http://world-nuclear.org/NuclearDatabase/.

World Nuclear Association. “Supply of Uranium.” Last modified August 2012. http://world-nuclear.org/info/inf75.html.

World Nuclear Association. “Thorium.” Last modified August 2012. http://world-nuclear.org/info/inf62.html.

Yoon, Won-sup. “Park Sought to Develop Nuclear Weapons.” *Korea Times*. January 15, 2008. http://www.koreatimes.co.kr/www/news/nation/nation_view.asp?newsIdx=17354.