Asia's Emerging Nuclear Era:

Climate Strategies & Implications for U.S. Policy

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Task Force: 2011

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Task Force Report 2011

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Policy Brief

Background:

Earth's climate is changing rapidly. Two centuries of burning fossil fuels have increased atmospheric concentrations of carbon dioxide and other greenhouse gases. This has led to elevated mean near-surface temperatures, rising sea levels, and acidification of the oceans. As the harmful effects of climate change become more apparent, many nations are turning to nuclear power as a viable option to meet rising demands for electricity with minimal carbon emissions. Concentrated in Asia, where hundreds of new reactors will be built in the next few decades, the new era of nuclear power expansion is underway. A nuclear power plant has not been built in the U.S. in over 30 years, suggesting America may be falling behind in nuclear technology. The American public has a largely negative perception of nuclear power due to past accidents at Chernobyl and Three-Mile Island. In the post 9/11 world, Americans are also particularly concerned about national security and the threat of nuclear terrorism.

Critical Issues:

Critics of nuclear power argue that the U.S. should focus its efforts on renewable energy sources such as wind and solar, but these are decades away from providing sufficient baseload power. Although nuclear energy does not produce significant greenhouse gas emissions, nuclear power plants do generate highly toxic radioactive waste that must be stored for centuries to avoid harmful effects on humans and the environment. A variety of geologic storage facilities have proven safe and effective but they lack political support in the U.S. due to unfounded fears about the safety of nuclear energy. Nuclear power has an outstanding safety record, but a thriving domestic industry will depend on reversing misguided public perception.

While nuclear power is an efficient means of generating large amounts of power, it is also relatively expensive when compared with coal and other fossil fuels. However, government intervention to standardize and regulate the nuclear industry has proven effective in reducing economic costs. Furthermore, the cost of nuclear power includes the expense of waste storage and decommissioning, whereas the price of fossil fuels, particularly coal, does not internalize these and other environmental costs. Such inclusion, through a carbon pricing scheme for instance, would make nuclear power fully competitive or even cheaper. Meanwhile, lower costs for nuclear plants are now being achieved in East Asia, as a result of well-planned designs and financial arrangements. Fuel resources are abundant and the price of nuclear power is not dependent to a significant degree on rising costs of uranium; electricity from coal, gas, and oil is much more sensitive to the costs of these fuels, all of which are expected to rise in the coming decades.

Possibly the most pressing concern regarding the recent increase in nuclear power is the issue of coupling; the same technologies used to produce fuel for power plants can also make fuel for nuclear weapons. Many fear that an expansion in nuclear power will lead to further weapons proliferation to potentially dangerous rogue states and terrorists. The Nuclear Non-Proliferation Treaty (NPT) and the International Atomic Energy Agency (IAEA) have proven effective in securing nuclear materials and reversing weapons programs, but the treaty is currently in crisis due to the unfulfilled commitments of signatory states. The nuclear weapon states have not fulfilled their commitment to disarm, and the non-nuclear weapon states have used this as justification to ignore the treaty or withdraw from it entirely, as in the case of North Korea. Furthermore, some states argue that the nuclear power states have not fulfilled their commitment to provide peaceful nuclear technology to states seeking nuclear power. Some states have used this as justification to acquire technologies such as reprocessing, which expand the energy efficiency of uranium, but which are economically inadvisable and which produce weapons-grade materials and are a danger to the non-proliferation regime. The future success of non-proliferation efforts hinges on the non-discriminatory and universal application of the NPT.

Recommendations:

Given these realities, this report recommends the following:

- The U.S. should support the development of peaceful nuclear programs at home and abroad through increased cooperation between the government and the private sector; the U.S. government can learn from the Asian example by increasing standardization and streamlining licensing procedures domestically. The government should work to educate the public about nuclear power to improve the domestic industry and to establish a long-term waste depository. Furthermore, the government should support research on new nuclear technologies which may improve the safety and efficiency of nuclear energy, reduce the possibility of proliferation, and benefit the U.S. economically as the world turns to nuclear power to reduce greenhouse gas emissions.
- The U.S. should work to establish an international fuel center controlled by the IAEA to provide a stable fuel supply and to prevent the spread of proliferation-prone technologies such as reprocessing.
- The U.S. should work to strengthen the non-proliferation regime by encouraging universality among treaty signatories. The U.S. should start leading by example; it should ratify the Comprehensive Test Ban Treaty; commit to further disarmament; increase transparency by opening U.S. military facilities to IAEA inspections; and end nuclear weapons research and plans to modernize its nuclear fleet. These unilateral efforts should be followed by U.S. led multilateral efforts to do the same worldwide. The U.S. should also increase funding to the IAEA and other organizations that work to increase nuclear security and prevent the spread of fissile materials to rogue states and terrorists.

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Glossary of Acronyms

ABWR – Advanced Boiling Water Reactor
AECL – Atomic Energy Canada Limited
AEO – Annual Energy Outlook
AERB - Atomic Energy Regulatory Board
AGR – Advanced Gas Cooler Reactor
Am – Americium
AP1000 – Advanced Passive 1000
AP600 – Advanced Passive 600
APR1400 – Advanced Power Reactor 1400
APWR – Advanced Pressurized Water Reactor
ASBM – Surface-to-Air Ballistic Missile
BCG – Boston Consulting Group
BHAVINI – Bharatiya Nabhikiya Vidyut Nigam Ltd.
BJP – Bharatiya Janata Party
BP – British Petroleum
Btu – British Thermal Unit
BWR – Boiling Water Reactor
CAEA – China Atomic Energy Authority
CANDU – Canada Deuterium Uranium Reactor
CBO – Congressional Budget Office
CCGT – Combined Cycle Gas Turbine
CCS – Carbon Capture and Storage
CERN – European Organization for Nuclear Research
CGNPC – China Guangdong Nuclear Power Corporation
CH_4 - Methane
CIGI – Center for International Governance Innovation
Cm – Curicium
CNNC – Chinese National Nuclear Corporation
CO_2 – Carbon Dioxide
CPPNM – Convention on the Physical Protection of Nuclear Material
CTBT – Comprehensive Test Ban Treaty
CTBTO – Comprehensive Test Ban Treaty Office
DOE – Department of Energy
DPRK – Democratic People's Republic of Korea (North Korea)
EIA – United States Energy Information Agency
EPCC – Engineering, Procurement and Construction Cost
EU – European Union
EURATOM – European Atomic Energy Agency
FBR – Fast Breeder Reactor
FMCT – Fissile Material Cut-off Treaty
FNR – Fast Neutron Reactor
g CO_2 eq/kW h – Grams of Carbon Dioxide Equivalent per Kilowatt Hour
GDP – Gross Domestic Product
GFR – Gas Cooled Fast Reactor

GHG – Greenhouse Gas
GIF – Generation IV International Forum
GNEP – Global Nuclear Energy Partnership
GNNPR – Global Nuclear Non-Proliferation Regime
Gt CO_2 eq – Gigatonne of Carbon Dioxide Equivalent
GWe – Gigawatt Electrical
HEU – Highly Enriched Uranium
HTGR – High Temperature Gas Reactor
IAEA – International Atomic Energy Agency
IAEC – Indian Atomic Energy Commission
ICBM – Intercontinental Ballistic Missile
IEA – International Energy Agency
IEO – International Energy Outlook
IFC – International Fuel Center
IFR – Integral Fast Reactor
IIASA – International Institute for Applied Systems Analysis
INERI – International Nuclear Energy Research Initiative
INF – Intermediate-Range Nuclear Forces
INMM – Institute of Nuclear Materials Management
IPCC – Intergovernmental Panel on Climate Change
ISI – Inter-Services Intelligence
ITDB – Illicit Trafficking Database
IUEC – International Uranium Enrichment Center
JPY – Japanese Yen
KAERI – Korea Atomic Energy Research Institute
KEPCO – Korea Electric Power Company
kgU – Kilograms of Uranium
KHNP – Korean Hydro and Nuclear Power Company
KSNP – Korean Standard Nuclear Plant
kW - Kilowatt
LCA – Life Cycle Assessment
LCOE – Levelized Costs of Electricity
LEU – Low Enriched Uranium
LFR – Lead Cooled Fast Reactor
LFTR – Liquid Thorium Fluoride Reactor
LPG – Liquefied Petroleum Gas
LWR – Light Water Reactor
mb/d – Millions of Barrels a Day
METI – Ministry of Economy, Trade and Industry
MIRV – Multiple Independent Reentry Vehicle
MIT – Massachusetts Institute of Technology
MITI – Ministry of International Trade and Industry
MOx – Mixed Oxide Fuel
MSR – Molten Salt Reactor
MW – Megawatt
MWe –Megawatt Electrical

MWt – Megawatt Thermal
NATO – North Atlantic Treaty Organization
NEA – Nuclear Energy Agency
NNSA – National Nuclear Security Administration
NNWS – Non Nuclear Weapon States
Np - Neptunium
NPT – Nuclear Non-Proliferation Treaty
NRC – Nuclear Regulatory Commission
NSG – Nuclear Suppliers Group
NSOI – Nuclear Smuggling Outreach Initiative
NTI – Nuclear Threat Initiative
NWFZ – Nuclear Weapon Free Zones
NWS – Nuclear Weapon States
O&M – Operations and Maintenance
OECD – Organization for Economic Cooperation and Development
OPR – Optimized Power Reactor
NPCIL – Nuclear Power Corporation of India Ltd.
P&T – Partitioning and Transmutation
PAEC – Pakistan Atomic Energy Commission
PHWR – Pressurized Heavy Water Reactor
PPB – Parts Per Billion
PPM – Parts Per Million
PRC – People's Republic of China (Mainland China)
PSI – Proliferation Security Initiative
Pu - Plutonium
PUREX – Plutonium and Uranium Extraction
PV – Photovoltaic
PWR – Pressurized Water Reactor
RAO UES – Unified Energy Systems (Russia)
RBMK – Reaktro Bolshoy Moshchnosti Kanalniy
RDD – Radiological Dispersal Device
ROC – Republic of China (Taiwan)
ROK – Republic of Korea (South Korea)
SALT – The Strategic Arms Limitation Talks
SFR – Sodium Cooled Fast Reactor
SLBM – Submarine-Launched Ballistic Missile
SLD – Second Line of Defense Program
SMART – System-Integrated Modular Advanced Reactor
SMR – Small Modular Reactor
SNPTC – Chinese State Nuclear Power Technology Company
START – Strategic Arms Reduction Treaty
SWCR – Supercritical Water-Cooled Reactor
SWR – Supercritical Water Reactor
TBP – Tri-n-butyl Phosphate
tU – Tonnes of Uranium
U - Uranium

UAE – United Arab Emirates
UN – United Nations
UNODA – United Nations office of Disarmament Affairs
UO_2 – Uranium Oxide
VHTR – Very High Temperature Reactor
VVER – Vodo-Vodyanoi Energetichesky Reactor
WANO – World Association of Nuclear Operators
WMD – Weapon of Mass Destruction
WNA – World Nuclear Association

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Cover photo courtesy of Chris Buchman 2011.

Introduction

Christan Leonard and Darren Levin

During the Cold War, Americans built bomb shelters for fear of nuclear attack. With the collapse of the Soviet Union, this fear disappeared, but now there is new cause for alarm. The frightening image of global war and nuclear winter has been replaced by the looming threat of a warming planet. Although periods of climatic shift have occurred innumerable times in earth's history, never before have these variations been so clearly the result of human activity, so relevant to human well-being, and so preventable through human action. Though American politicians continue to debate the reality of global warming, the scientific community is united in accepting its overwhelming evidence and identifying fossil fuels as the main cause.

Ironically, one part of the solution to the present danger may reside in the technology of the former global threat. The same power that destroyed Hiroshima and Nagasaki now lights the houses of Japanese citizens. Rising costs of fossil fuels, both economic and environmental, have triggered a "nuclear renaissance" in much of the world and particularly in Asia. Although the mention of "nuclear power" continues to stir mixed reactions in many developed nations, conjuring images of Hiroshima, Chernobyl, and Three Mile Island, advances in technology and regulation have improved the safety record and operational performance of nuclear facilities. Overall, nuclear power has an outstanding safety record, which exceeds that of all other energy sources. Nuclear plants do not emit greenhouse gases, and the nuclear fuel cycle releases very few of these gases compared to any fossil fuel source. For countries with little indigenous energy resources, investing in nuclear power helps cultivate energy security and diversifies electricity production by reducing dependence on imported fuels from unstable regions of the globe although currently, nuclear energy generates a small percentage of the world's electricity. Only 30 countries use commercial nuclear power, and as of early 2011, there are 443 commercial reactors worldwide.

RISING ENERGY DEMANDS AND THE BENEFITS OF NUCLEAR POWER

In the first decades of the 21st century, the world faces twin challenges of surging energy demand and climate change. These challenges are directly related. Fossil fuels, the source of emissions that contribute most to global warming, currently constitute the overwhelming majority of global energy production, and are the main sources used to meet growing demand. Climate change, which has increasingly global impacts, can only be mitigated long-term by a transition to low-carbon systems. Forecasts now show that nearly all major growth in energy demand will come from developing countries, led by Asia. Asia is where economies are industrializing and it will soon become the origin of most carbon emissions. Electricity generation, the largest source of emissions, is also the most rapidly expanding energy use in this region. Many Asian countries have chosen to invest in nuclear power in order to mitigate the effects of their industrialization on carbon emissions.

As of February 2011, there were no fewer than 62 new reactors under construction, 156 more planned, and a stunning 322 more proposed--a total of 540, which would more than double the current global reactor fleet during the next three to four decades. Over half of this expansion will occur in only four Asian nations; China, India, Japan, and South Korea, with the remainder primarily in Russia and developing states of Africa, Asia, and South America. In recent years, 40 countries have expressed interest in nuclear power and 20 states are actively considering nuclear power programs. These numbers suggest an average of 10 to 15 new reactors built per year over the next several decades. Each new nuclear plant can be said to replace a fossil fuel plant, which, in high energy consuming nations such as China and India, will translate to a particularly significant reduction in carbon emissions.

CHALLENGES TO IMPLEMENTATION

While this report argues that the benefits of nuclear power expansion outweigh the disadvantages, it acknowledges that obstacles do exist. The challenges of nuclear power development and expansion include a high level of nuclear waste, the health effects of a potential power plant accident, and construction costs and delays. Another challenge is the competition from businesses that assert that wind and solar power are the best alternatives to fossil fuels. While it is important to employ a variety of alternative resources and not discount potential solutions, nuclear power is superior to wind and solar sources on a number of counts, including reliability and cost.

The greatest obstacle to the widespread implementation of nuclear energy is the issue of coupling; the same materials and technologies used to produce electricity are also used to produce nuclear weapons. National and international security risks from proliferation are delicate matters that spark ongoing debate, especially regarding the Nuclear Non-proliferation Treaty. Proliferation risks worsen due to increasing globalization. As proven by the A.Q. Khan network and by revelations about North Korea, there are illicit trade networks that involve nuclear materials. Nuclear technology is made in one part of the world and sold in another by way of concealed shadow networks. In the past ten to twenty years, Islamic fundamentalist terrorist networks and changing terrorist strategies have caused extra caution surrounding nuclear power plants and their relationship to nuclear weapons. However, with proper regulations and safeguards these challenges are surmountable. This report will consider what risk reduction measures may be needed for a nuclear energy revival.

DEFINING U.S. INTERESTS

These realities offer a mix of opportunities and challenges to the United States, as a technological leader and as the world's sole superpower deeply concerned about the spread of nuclear weapons. The first priority of the United States government must always be the security of its citizens. U.S. nuclear policy must therefore address the three complex and overlapping issues of climate security, energy security, and national security. While climate change is a global phenomenon, it has localized effects, which jeopardize the physical and economic security of Americans. These effects must be mitigated and nuclear power, as a low-carbon energy source, can aid in this effort. A safe and reliable source of power is absolutely necessary to ensure the continued prosperity of the American people, particularly as oil prices rise and violence continue to plague the Middle East. Though nuclear power cannot realistically replace oil in the near-term, increased use of nuclear power, at home and abroad, can ease the upward pressure on oil prices and provide a domestically produced form of power, increasing energy security. Finally, the U.S. government must ensure the safety of its citizens. In accordance with established U.S. policy, this report assumes the proliferation of nuclear weapons is undesirable. Further proliferation will only increase the chances of nuclear weapons falling into the hands of rogue states or terrorist groups which, as evidenced by 9/11, are viable threats to national security. An increase in nuclear power must be met with a proportionate increase in security efforts to ensure that this technology is not used for clandestine purposes or weapons production.

ORGANIZATION OF THE REPORT

The aforementioned issues will be discussed in further detail in the following chapters. Part One gives an overview of the current state of affairs. Chapter One explains the science of global warming and the negative effects of continuing greenhouse gas emissions. Chapter Two looks at the increasing demand for energy in Asia and the potential effects of Asia's industrialization on carbon dioxide emissions as well as Asia's increasingly large investments in nuclear energy. Chapter Three compares the carbon emissions of different energy technologies, namely, nuclear, renewables, natural gas, and coal. This research indicates that nuclear energy is an efficient method for reducing carbon emissions.

Given nuclear energy's efficiency in reducing carbon emissions, Part Two analyzes the economics of nuclear power. Chapter Four compares the economic costs of nuclear energy production and compares these costs across countries and with other forms of energy production. Chapter Five discusses the interaction between governments and the private sector in shaping the world's nuclear industry. Chapter Five asserts that centralized management and planning in the East has allowed for rapid expansion of nuclear power in Asia, while deregulation has left the nuclear industry in the West struggling to compete against coal. Following this discussion, Chapter Six explains the process of mining resources for nuclear energy generation and claims that resource availability to fuel nuclear power expansion is abundant and capable of supporting growth.

Part Three addresses the human and environmental safety concerns regarding nuclear power. Chapter Seven explores new nuclear technologies, which are safer and more efficient. Chapter Eight takes up the issues of human safety and disposal, which have plagued the nuclear industry. Chapter Nine examines opposing arguments for an open versus closed fuel cycle and indicates that an international fuel center may be the best option for securing fuel supplies and for preventing states from seeking reprocessing technologies which are a threat to non-proliferation.

Part Four addresses concerns over the safety of nuclear power, considering its inextricable coupling to nuclear weapons. Chapter Ten examines the current status and future viability of the Nuclear Non-Proliferation Treaty, which has been the cornerstone of the non-proliferation regime. Chapter Eleven examines nuclear "hot spots" and lessons from their history that can be employed in a post-Cold War era. Chapter Twelve addresses the threat of the ultimate catastrophe, nuclear terrorism, but finds that such a disaster can be avoided with the proper safeguards and security measures. The controversial U.S.-India deal is discussed in detail in Chapter Thirteen. This analysis reveals that bilateral agreements such as the U.S.-India deal may weaken the Nuclear Non-Proliferation Treaty, but in the short term may be essential to securing nuclear facilities around the globe. Chapter Fourteen gives a detailed history of disarmament efforts and gives insight into the implications of past efforts for further disarmament. Chapter Fifteen addresses the safety and security of civilian nuclear facilities.

This report concludes with recommendations for U.S. policy. If these recommendations are followed, the U.S can be confident that nuclear power expansion will mitigate climate change and meet national and global energy demand in a safe, efficient, and cost effective manner.

Part I

The Current State of Affairs

Chapter One

THE CURRENT STATE OF THE EARTH'S CLIMATE AND THE FUTURE EFFECTS OF GLOBAL WARMING

Andrew Kim

Abstract:

Fossil fuels have led to an increase in atmospheric carbon dioxide, which has and will continue to raise the near-surface temperature of the earth and its oceans. This increase has already begun a variety of responses that will greatly impact all of the planet's ecosystems and human societies. Specific impacts include higher sea levels, accelerated warming of the Artic, loss of ice mass and glaciers, an increase in the strength and frequency of natural disasters, and warmer, more acidic oceans. The scientific community is united in their assertion that the burning of fossil fuels is the primary cause of these changes and has also concluded that these changes will increase with time. This paper analyzes the possible effects of this earth's warming and concludes that climate change is a real threat that must be addressed and considered in all policies going forward. This paper ends with a discussion of alternative methods to mitigate climate change and finds that nuclear energy is a viable option for reducing carbon emissions in the near future.

INTRODUCTION

Since the Industrial Revolution, mankind has utilized fossil fuels to produce and sustain unprecedented growth in population, technology, and living standards. Combustion, a natural chemical reaction, has facilitated the creation of energy from fossil fuels for human use but has also had the unintended consequence of unleashing large volumes of carbon dioxide (CO_2). Carbon dioxide is a naturally occurring compound but is of particular importance due its function as a greenhouse gas in the atmosphere. Carbon dioxide is the second largest greenhouse gas after water vapor but because it remains in the atmosphere much longer and impacts the thermal content of the atmosphere at a consistent level, it plays a particularly important role in the climate system. An increase in the amount of atmospheric carbon dioxide will result in a gradual but steady rise in temperature. The use of fossil fuels since the Industrial Revolution has led to unprecedented levels of CO_2 and will undoubtedly lead to the rise of global temperatures. The reality of climate change is no longer in doubt but the actions to mitigate it have not yet been determined. Society today has a number of options to consider in this regard and must make decisions about how to reduce greenhouse gas emissions, especially carbon dioxide. Due to the serious nature of the impacts involved, climate change is an issue that cannot be ignored and must be addressed immediately.

The first section of this paper will explore the current scientific consensus regarding global warming. This section will include an explanation of the basics of the greenhouse gas effect and the feedbacks of the climate system. The second section will explain the potential forecasts for the future and the impact climate change will have on the earth. Lastly, the third section will briefly discuss the different approaches for the mitigation of global warming. This discussion of the alternative methods of mitigation will highlight nuclear energy as a viable method of reducing emissions.

THE CURRENT SCIENTIFIC CONSENSUS

The use of coal, oil, and natural gas as the main sources of energy has led to a dramatic increase in the amount of CO_2 present in the atmosphere. The volumes of CO_2 released during the past two centuries surpass those that can easily be absorbed by the earth's natural carbon cycle and thus have accumulated in the atmosphere affecting the climate of the earth. This paper will explore the impact of CO_2 by examining scientific models of the climate system and the effects of greenhouse gases.

The Earth's Climate System: Basic Concepts

The earth's climate is a complex system that incorporates a number of different processes. Understanding climate involves knowledge and application of soil science, forestry, atmospheric and ocean physics, biology, geology, meteorology, and more. Due to the complex and interrelated nature of the climate system components, a slight change in the system can result in large consequences via processes known as feedbacks. A feedback is an internal process that acts to amplify changes (positive feedback) or moderate changes (negative feedback) in the climate system.[1] Feedbacks play a large role in understanding climate change as well as the consequences that result from it. To understand their importance, it is necessary to discuss, in simplified fashion, the basic components of the climate system.

In total, the system is composed of five interacting components: atmosphere, ice, ocean, land surface, and vegetation.[2] Acting upon one or more of these are "external forcings", which are processes or agents able to induce change. The three external forcings in nature are the sun's energy, the earth's orbit, and plate tectonics.[3] Every climate change episode in earth's history has been a result of a change in one or more these forcings. Recently, human activity has joined this list. One important factor to keep in mind is that each of the components of the climate system has different response times to any forcing. For example, an external forcing, such as a decrease in the amount of solar radiation reaching earth, can result in a rapid change to the atmosphere but has a much slower effect on the oceans. In the sections to follow, the impact of CO_2 and human activity on the climate system and the resulting responses of each of the components will help identify the future effects and the potential consequences for mankind.

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[1] William Ruddiman, *Earth's Climate: Past and Future* (W.H. Freeman, 2007), 8-10.
[2] Ibid.
[3] Ibid.

Temperature and Greenhouse Gases

The temperature of the earth is determined by an energy budget. On the positive side of the budget is solar insulation, as well as heat that emanates from the earth's interior and reaches the surface.[4] On the negative side of the budget is the heat that escapes and is reflected from the earth's surface. If it were not for the atmosphere, all the heat at the surface of the earth would radiate out into space resulting in an uninhabitable average temperature of -16 degrees Celsius.[5] Greenhouse gases such as CO_2, methane (CH_4), and water vapor help amplify the positive side of the budget by absorbing the heat and re-radiating it back toward the surface of the earth. This is known as the greenhouse gas effect. This process raises the temperature significantly to the current global average temperature of 15 degrees Celcius.[6] The relationship between greenhouse gases and the temperature of the earth is closely linked. In the earth's history, changes to the greenhouse gas concentration have directly led to temperature changes. In particular, the abundance of CO_2 has been especially evident in the correlation between greenhouse gas levels and variation in the global average temperature. As Figure 1.1 demonstrates, the level of CO_2 and temperature has been very closely linked. Figure 1.1 also exhibits the alarmingly high levels of CO_2 that are currently present in the atmosphere, approximately 90 parts per million (ppm), higher than it has ever been in the past eight hundred thousand years.[7]

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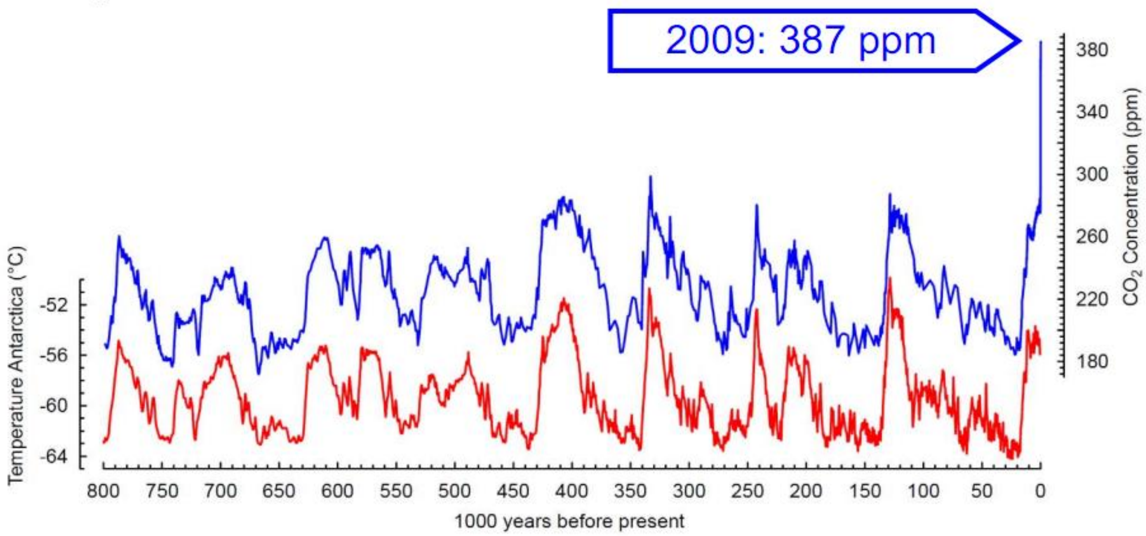
[4] David Archer, *The Long Thaw* (Princeton: Princeton University Press, 2009), 16-18.
[5] William Ruddiman, *Earth's Climate: Past and Future* (W.H. Freeman, 2007), 13.
[6] Ibid.
[7] Susan Soloman et al., *Climate Change 2007: The Physical Science Basis*, IPCC – Intergovernmental Panel on Climate Change, http://www.ipcc.ch/publications_and_data/publications_pcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm (accessed Jan. 19, 2011).

Figure 1.1. Carbon Dioxide and Temperature



Source: Susan Soloman et al., Climate Change 2007: The Physical Science Basis, IPCC – Intergovernmental Panel on Climate Change, http://www.ipcc.ch/publications_and_data/publications_pcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm (accessed Jan. 19, 2011).

In the last 200 years, CO_2 levels have risen 35 percent above pre-industrial levels and currently stand at 391 ppm, increasing at the rate of approximately 3 ppm per year.[8, 9] In addition to the high CO_2 concentration, measurements of the atmosphere have also detected increasing levels of CH_4 since the Industrial Revolution. Prior to the 19th century, CH_4 concentrations were stable, averaging around 700 parts per billion (ppb). In 2005, CH_4 reached 1774 ppb, an increase of over 150 percent, and after several years of little change, began rising again in 2008.[10] Methane is an important factor because although it remains in the atmosphere a much shorter time than CO_2, it has 20 times the

[8] U.S. Energy Information Administration, *EIA - 2010* International Energy Outlook - Energy-Related Carbon Dioxide Emissions, http://www.eia.doe.gov/oiaf/ieo/emissions.html (accessed Feb. 8, 2011).
[9] NOAA Earth System Research Laboratory, *Trends in Carbon Dioxide*, http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo (accessed February 8, 2011).
[10] Susan Soloman et al., *Climate Change 2007: The Physical Science Basis*, IPCC – Intergovernmental Panel on Climate Change, http://www.ipcc.ch/publications_and_data/publications_pcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm (accessed Jan. 19, 2011).

greenhouse gas potential. In total, the level of greenhouse gas concentrations in the earth's atmosphere has risen to over 60 percent above pre-industrial levels.[11]

Fossil Fuel Emissions and Energy

The rise in carbon dioxide concentration is directly a result of the use of fossil fuels as an energy source. Given the alarming levels of carbon dioxide, many policymakers have adopted the goal of preventing a mean global temperature rise by more than 2 degrees Celsius above pre-industrial levels.[12] However, in order to achieve this goal, scientists have predicted using climate models and historical evidence that carbon dioxide concentrations would have to be limited to less than 450 ppm.[13] Figure 2.1 highlights the current carbon dioxide emissions from fossil fuels and projections for the future. These projections give an estimate of how many "wedges" would be needed in order to maintain current levels of emissions. Each wedge, by definition, is 25 gigatons of avoided carbon emissions. In this case, by the year 2060, assuming business as usual emission rates of growth, emissions will reached the upper limit of 450 ppm carbon dioxide concentration. In order to avoid this scenario, 7 "wedges" would be needed to curb emissions. These 7 wedges are equivalent to 30 carbon-neutral terawatts of power by mid-century.[14]

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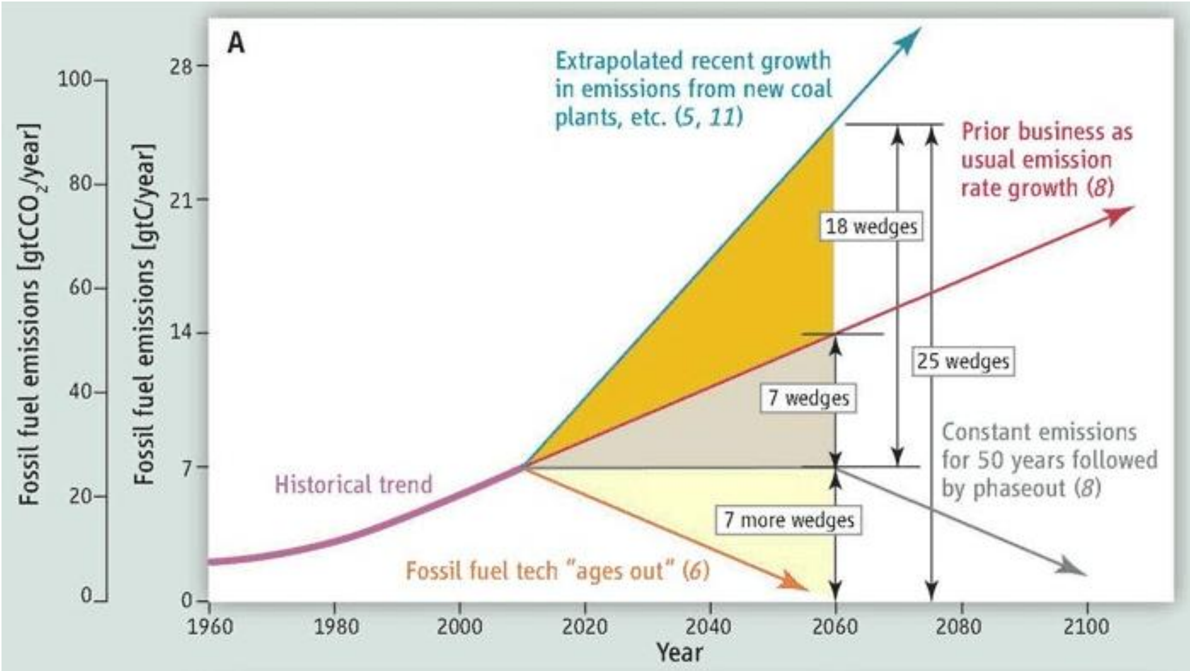
[11] David Archer, *The Long Thaw* (Princeton: Princeton University Press, 2009), 16-18.
[12] James Hansen, *Storms of My Grandchildren: The Truth About the Coming Climate Catastrophe and Our Last Chance to Save Humanity*, (New York: Bloomsbury USA, 2010).
[13] Martin Hoffert, "Farewell to Fossil Fuels?." *Science* 329, no. 5997 (2010): 1292-1294, http://www.sciencemag.org.offcampus.lib.washington.edu/content/329/5997/1292.full (accessed Feb. 15, 2011), 1292.
[14] Ibid.

Figure 1.2. Current Carbon Emissions and Future Projections



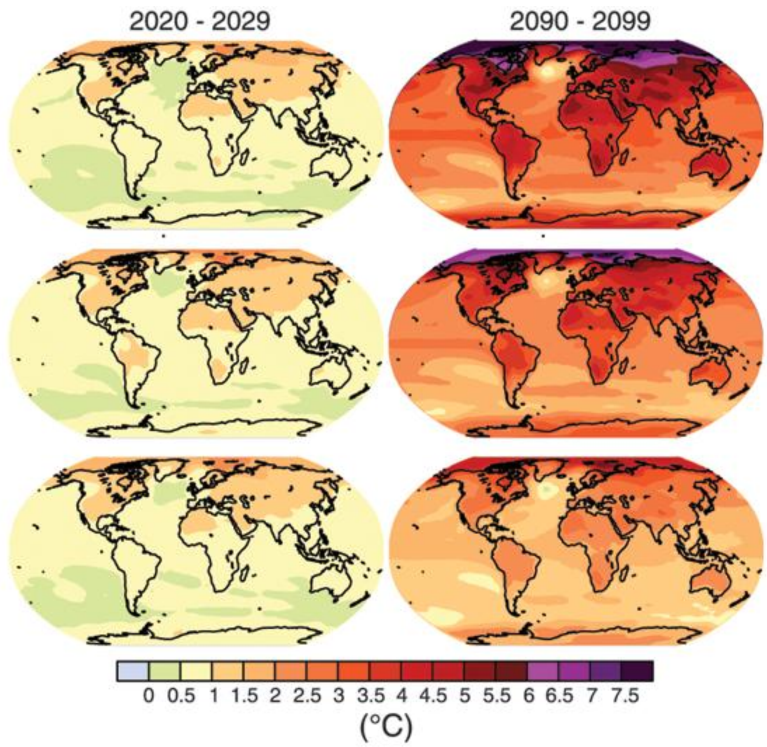
Source: Martin Hoffert, "Farewell to Fossil Fuels?." *Science* 329, no. 5997 (2010): 1292-1294, http://www.sciencemag.org.offcampus.lib.washington.edu/content/329/5997/1292.full (accessed Feb. 15, 2011).

PRESENT AND FUTURE EFFECTS OF GLOBAL WARMING

Forecasts

In order to understand some of the implications for the earth and for humans, scientists have devised a variety of models to forecast future climate changes. The most widely accepted source for these models is the Intergovernmental Panel on Climate Change (IPCC). The IPCC is an international organization that comprises the work of thousands of scientists from all over the world and provides rigorous and balanced information representing the state of knowledge, data collection, and modeling in climate-related disciplines. In 2007, the IPCC released its report and assessed future climate changes based on a variety of different models. All the models projected increased average temperatures. Figure 3.1 depicts an estimate for predicted temperature changes in the next century.

Figure 1.3. Temperature Forecasts



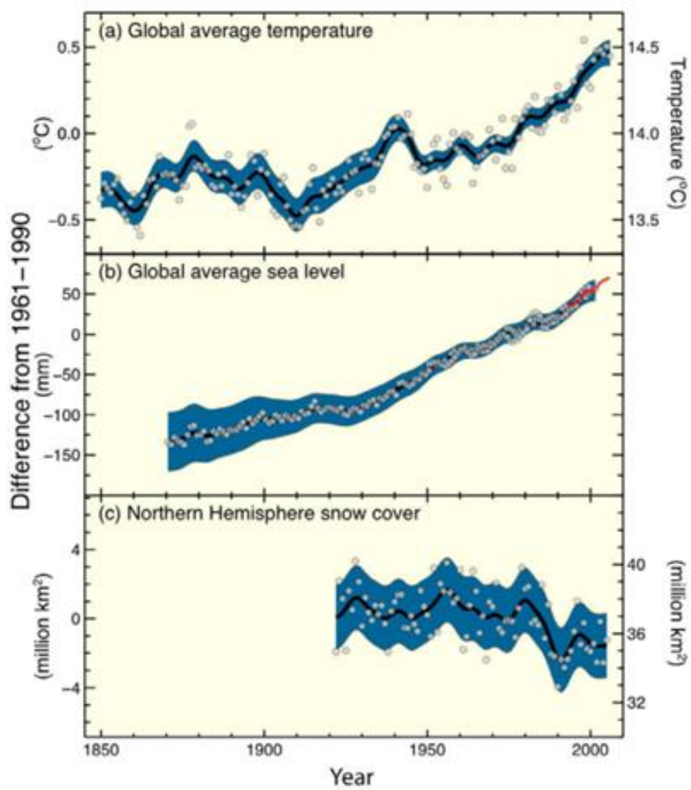
Source: Susan Soloman et al., *Climate Change 2007: The Physical Science Basis,* IPCC – Intergovernmental Panel on Climate Change, http://www.ipcc.ch/publications_and_data/publications_ pcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm (accessed Jan. 19, 2011).

In addition to warmer temperatures, global average evaporation and precipitation levels are projected to increase, resulting in a higher intensity of precipitation in some areas.[15] However, due to the temperature rise, other areas will experience higher risk of drought.[16] The amount of snow cover, glaciers, ice caps, and ice sheets are all projected

[15] Susan Soloman et al., *Climate Change 2007: The Physical Science Basis,* IPCC – Intergovernmental Panel on Climate Change, http://www.ipcc.ch/publications_and_data/publications_pcc_fourth_assessment_report_wg1_ report_the_physical_science_basis.htm (accessed Jan. 19, 2011).
[16] Ibid.

to decrease, resulting in a loss of stored fresh water and a global rise in sea level.[17] The average model predicts a sea level rise of about 3.26 mm per year and by the end of the century, predicts a rise of 1 meter or more.[18] One consideration to note about sea level rise is that there will not be an equal rise throughout the world and that many areas will experience higher sea level rise than other regions will. Figure 1.4 highlights the link between the warmer temperatures, rising sea levels, and declining snow cover.

Figure 1.4. Temperature, Sea Level, and Snow Cover



Source: Susan Soloman et al,. *Climate Change 2007: The Physical Science Basis*, IPCC – Intergovernmental Panel of Climate Change, http://www.ipcc.ch/publications_and_data/publications_pcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm (accessed Jan. 19, 2011).

[17] Susan Soloman et al., *Climate Change 2007: The Physical Science Basis,* IPCC – Intergovernmental Panel on Climate Change, http://www.ipcc.ch/publications_and_data/publications_pcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm (accessed Jan. 19, 2011).

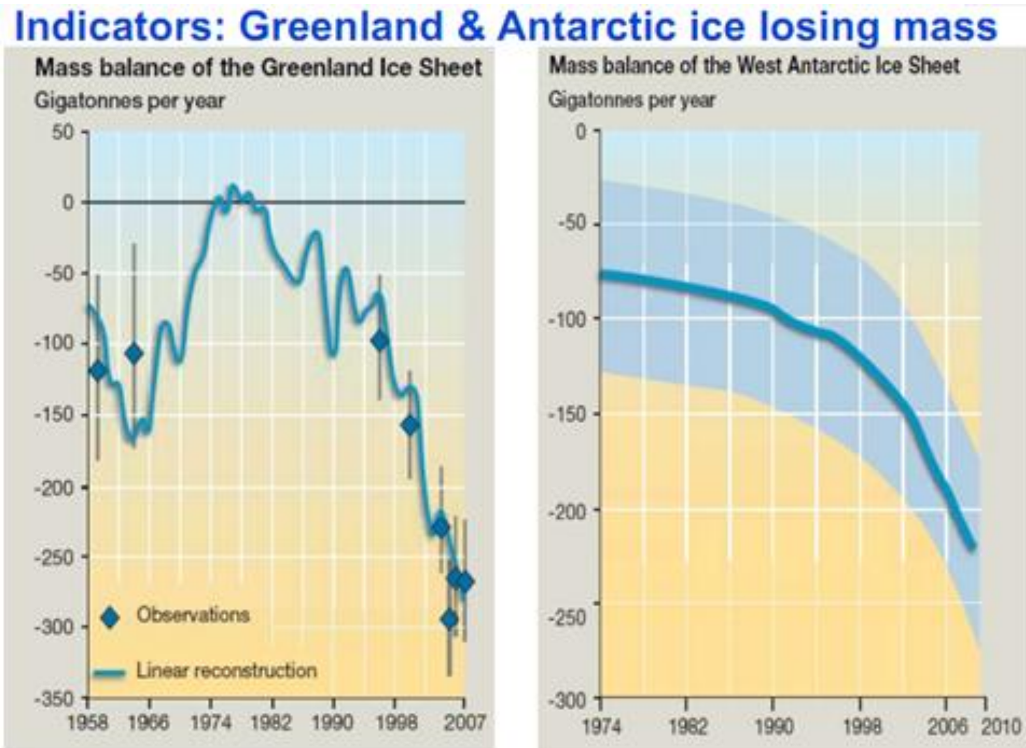
[18] Robert Nichols and Anny Cazenave, "Sea-Level Rise and Its Impact on Coastal Zones," *Science* 328, no. 5985 (2010): 1517-1520, http://www.sciencemag.org.offcampus.lib.washington.edu/content/328/5985/151 (accessed Feb. 10, 2011), 1518.

The oceans will also become increasingly acidic due to higher concentrations of carbonic acid, resulting from an increased abundance of carbon dioxide.[19] One of the results of an increasingly acidic ocean is the death of coral reefs and the ecosystems that they support. It is estimated that nearly 25 percent of all coral reefs are dead and another 20 percent are dying.[20] Nearly one billion people depend on the fish that live in coral reefs for their main source of protein.[21] This example highlights predicted changes that will have an enormous regional impact and the different events the world will experience due to global warming. This is important to note as the following descriptions on the impact of global warming are general and many areas will experience conditions that are far worse. The polar regions are notable, in that they will continue to experience the biggest changes due to global warming. Figure 1.5 demonstrates the loss in ice and snow cover over Antarctica and Greenland. The diminishing area of ice and snow cover reveals land and water surfaces that absorb more of the solar insulation compared to the ice and snow.[22] This results in a positive feedback that causes more warming and thus more melting in a self-reinforcing cycle.

Another dangerous feedback is the potential melting of permafrost throughout the world. Permafrost is a type of soil that has been frozen, typically in the northern hemisphere. The melting of permafrost is considered a strong feedback because

[19] Ove Hoegh Guldber and John Bruno, "The Impact of Climate Change on the World's Marine Ecosystems," *Science* 328, no. 5985 (2010): 1523-1528, http://www.sciencemag.org.offcampus.lib.washington.edu/ content/328/5985/1523.full (accessed Feb. 1, 2011), 1525.
[20] Victoria J. Fabry, et al, "Impacts of Ocean Acidification on Marine Fauna and Ecosystem Processes," *ICES Journal of Marine Science* 65 (2008): 414-432, (accessed February 20, 2011), 425.
[21] Ibid.
[22] William Ruddiman, *Earth's Climate: Past and Future* (W.H. Freeman, 2007), 44.

Figure 1.5. Ice Mass Loss



Source: Susan Soloman et al., *Climate Change 2007: The Physical Science Basis,* IPCC – Intergovernmental Panel on Climate Change, http://www.ipcc.ch/publications_and_data/publications_ pcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm (accessed Jan. 19, 2011).

permafrost contains high levels of methane estimated at over 1,700 Gt of carbon.[23] The melting of permafrost releases the methane into the atmosphere resulting in further warming. These are some examples of the more prominent feedbacks that result due to global warming. However, information on feedbacks is not complete and the data that scientists collect each year suggests that the feedbacks are stronger than predicted. This

[23] Susan Soloman et al., *Climate Change 2007: The Physical Science Basis,* IPCC – Intergovernmental Panel on Climate Change, http://www.ipcc.ch/publications_and_data/publications_pcc_fourth_assessment_report_wg1_ report_the_physical_science_basis.htm (accessed Jan. 19, 2011).

means that the climate is even more sensitive to change than estimated and past predictions of climate change have been found to underestimate the rate of change.[24]

The impact of these forecasted events will vary depending on the degree to which the climate changes. However, scientists maintain "high confidence that climate change will result in the extinction of many species and reduction in the diversity of ecosystems."[25] At high risk are the polar and tundra ecosystems, which will experience the highest change in temperature.[26] The rise in temperatures will also allow pests and diseases to spread further.[27] Other areas of high risk include coral reefs and if the warming was to reach 3 degrees Celsius, it is likely that over one-fifth of ecosystems will be transformed and up to 30 percent of known species will become extinct.[28]

Impact on Human Life

Perhaps the most important aspect of climate change is the impact on human life. Humans are the actors who caused climate change and our ability to innovate is the only opportunity to reverse or mitigate the result. The greater impact that climate change has on human lives, the larger the incentive will become for humans to find solutions to climate change. In particular, due to the lack of infrastructure and resources, the areas that will be hit hardest are developing countries. The major concerns regarding climate change and the impact it will have on humans are as follows: the increasing heat and

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[24] Susan Soloman et al., *Climate Change 2007: The Physical Science Basis*, IPCC – Intergovernmental Panel on Climate Change, http://www.ipcc.ch/publications_and_data/publications_pcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm (accessed Jan. 19, 2011).
[25] Ibid.
[26] William Ruddiman, *Earth's Climate: Past and Future* (W.H. Freeman, 2007), 348-350.
[27] Ibid.
[28] Susan Soloman et al., *Climate Change 2007: The Physical Science Basis*, IPCC – Intergovernmental Panel on Climate Change, http://www.ipcc.ch/publications_and_data/publications_pcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm (accessed Jan. 19, 2011).

humidity will become worse and affect the availability of water; stronger and more frequent natural disasters will destroy human lives and infrastructure; certain diseases may become more widespread; sea level rise will impact a number of coastal cities; the number of environmental refugees will likely increase; and food security may be jeopardized.[29] These environmental events have the risk of increasing social disorder and conflict in countries as health services and other civic institutions struggle to deal with higher demands for their services.[30] Despite the seemingly dire circumstances and risk of high impact events, there are still opportunities to mitigate and adapt to the changes that will occur.

POTENTIAL SOLUTIONS: A GENERAL STATEMENT

Climate change is slowly building toward a potentially bleak future with the potential to disrupt ecosystems as well as human societies. However, the opportunity to innovate and reverse human dependence on fossil fuels is not yet lost.

Energy Solutions

The biggest short term and long term issues are fossil fuels and energy. Energy consumption is the biggest producer of greenhouse gases and demands for energy are growing due to the development of countries such as China, India, and other non-OECD countries. There are a variety of strategies that can be utilized to reduce the dependence on fossil fuels or the emissions they produce in the short and long term. For example, more efficient vehicles, energy efficient homes and buildings, and an increased reliance on and innovation of renewables are all strategies that are being employed and should

[29] Susan Soloman et al., *Climate Change 2007: The Physical Science Basis,* IPCC – Intergovernmental Panel on Climate Change, http://www.ipcc.ch/publications_and_data/publications_pcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm (accessed Jan. 19, 2011).
[30] Ibid.

continue to be a large part of the mitigation process. Improving energy efficiency in as many domains of generation and consumption as possible has been defined as a major goal in this context.[31] The ultimate impact of efficiency upgrades is difficult to predict, in part due to what is called the "Jevons Paradox" or "rebound effect," whereby efficiency gains can lead to some level of increased energy consumption. Conservation is another potential approach to reducing fossil fuel use, but is unlikely to play a major role in developing countries like China and India, whose emissions must be reduced over time.

Within the global energy system, several major options exist. Carbon capture and storage (CCS) would allow for continued use of fossil energy with reduced emissions. Expanding the use of renewables worldwide offers another approach. Unfortunately, neither of these two options has yet been proven on a large scale. CCS remains at an early stage of development, while renewables cannot yet supply power on a reliable, 24-hour basis. This may well change in the decades ahead, as technologies for storing energy develop. In the meantime, nuclear power is a low-carbon source of electricity that is proven and reliable, though one that comes with its own set of issues and limitations. In short, no single option will be able to fully address the reality of carbon emissions and therefore climate change but among the energy possibilities that do exist, efficiency improvements and nuclear power are the two that stand out with a proven track record relevant to the next two or three decades.

CONCLUSION

Climate change is a real threat to the current way of life for humans and the sustainability of ecosystems around the earth. The dependence on fossil fuels is an

[31] "Improving Energy Efficiency," *United Nations Foundation,* http://www.unfoundation.org/global-issues/climate-and-energy/improving-energy-efficiency.html (accessed Feburary 21, 2011).

enormous burden that will be difficult to overcome but each year of intense fossil fuel usage results in gigatons of carbon released into the atmosphere. The increased abundance of carbon will and already has increased temperatures on the earth and positive feedbacks have begun to amplify these changes. Some of the threats include rising sea levels, water security, and more natural disasters. Each prediction put forth by the scientific community continues to forecast worsening conditions and many of the worst-case scenarios predicted years ago have become current best-case scenarios. The rate of change continues to raise alarms and the understanding of the impact of climate change on ecosystems has only scratched the surface.

The largest contribution to carbon emissions, and therefore man-made climate change, comes from the burning of fossil fuels. It is clear that if the world seeks to reduce the long-term negative impacts of global warming, it must reduce emissions from these sources of energy. Nuclear power remains the single major source of electricity that is low-carbon, economically affordable, and reliable on a mass scale. Asian countries have stated, and shown, their intention to use the nuclear option as a means to reduce their emissions. However, there are a variety of issues with nuclear power and the rest of this report will illuminate the benefits and costs of nuclear energy. However, one thing is clear: climate change is real, the changes are happening fast, and it will impact every ecosystem and nation. There are a variety of mitigation approaches that must be considered by the leaders of every country because the alternative is adaptation to climate change at enormous costs.

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Chapter Two

THE FUTURE OF ENERGY CONSUMPTION: ENERGY TRENDS AND DEMAND IN ASIA

Alyssa Hunt

Abstract:

Climate change, driven largely by carbon emissions, puts a spotlight on world energy use, the major source of such emissions. Study of global energy realities sheds light on several main conclusions. Non-OECD countries, led by China and India, will be overwhelmingly responsible for future increases in energy demand and use. Since fossil fuels will continue to be the dominant sources of energy for at least the next few decades, these countries will also be the source of most of the world's increase in carbon emissions and thus future climate change. Rapid economic development, population growth, rising incomes and thus the uptake of modern lifestyles are major factors for growth in Asia. In contrast, OECD nations are predicted to see their energy demand rise slightly and then plateau, or even shrink, while their economies continue to grow and benefit from long-term innovations in energy efficiency. Thus, the future of global energy now belongs to non-OECD Asia. With global warming a real concern for the future, it is becoming increasingly important for the world to move towards low-carbon sources of energy, among which nuclear energy must be considered a proven and viable option. Since the most rapidly growing demand for energy is in the power sector, nuclear seems well positioned to expand significantly in this region.

INTRODUCTION

The year 2030 may seem like the setting for the latest science-fiction movie, but it is closer to reality than we might imagine. The world is on a path to major changes both environmentally and developmentally that may cause future generations to grapple with consequences of actions today. Forecast models are predicting upward trends in worldwide energy demand in the coming decades, and for economies that primarily rely on fossil fuels, this means grave consequences for the state of the earth's climate. This investigation analyzes energy consumption primarily in East and South East Asia, and includes a discussion of past trends that helped analysts make forecast models to drive current policy. China and India, countries critical to determining future needs for Asia as a whole, are expected to have the most growth in both industry and population, and thus will lead to the most increase in energy demand and consequently, in carbon emissions. Future growth predictions indicate that many countries will increase their dependence on coal and other fossil fuels, while alternatives such as nuclear, wind, or solar power are expected grow as well, but at a slower rate. This report will examine the energy trends and demand in Asia, and provide context for comparison using countries that adhere to the Organization for Economic Cooperation and Development (OECD) and those that do not.

OECD and non-OECD countries are forecasted to experience radically different trends in their energy consumption. The OECD was founded on September 30, 1961 and currently has 34 members, led primarily by the United States and the United Kingdom. In Asia, the principal members are Japan and South Korea. The roots of the organization can be traced to post-WWII Europe, when the founding countries were determined to avoid the mistakes of their predecessors and create a lasting peace through the encouragement of cooperation and reconstruction of intricately linked economies. Spectacular progress has been made by member states. The United States, for example, saw its national wealth triple in the last five decades.[32]

The calculation of energy use of an entire country or even region is highly intricate, and there is not a single agency that can complete the task alone due to the gargantuan nature of the task. Thus, much of the data comes from self-reporting from analysts who assemble it using methodology that may not be uniform. Also, the domestic situation may not allow data to be collected sufficiently. For example, in times of war or

[32] "History," *OECD: Better Policies for Better Lives,* http://www.oecd.org/document/25/0,3746,en_36734052_36761863_36952473_1_1_1_1,00.html (accessed Jan. 17, 2011).

political breakdown, the country or region could be in too much disarray to allow for accurate energy consumption analysis. Honest approximations are necessary to construct political and economic policy, but do unavoidably rely on today's trends and can make the future seem reliant on the present.[33] This vision may undermine the possibility of the growth of nuclear energy, renewables, or new technology. Further, sources may report data that slightly differs. Nevertheless, despite the slightly differing data and methodology that goes into collection, a consensus on trends exists because analysts are dealing with generally similar sources of data, also referred to as "energy indicators."[34] The forecast models explored in this study are representative of trends that have been consented on by accepted and reputable sources.

CONSUMPTION OF ENERGY

Total World Consumption Growth Estimates

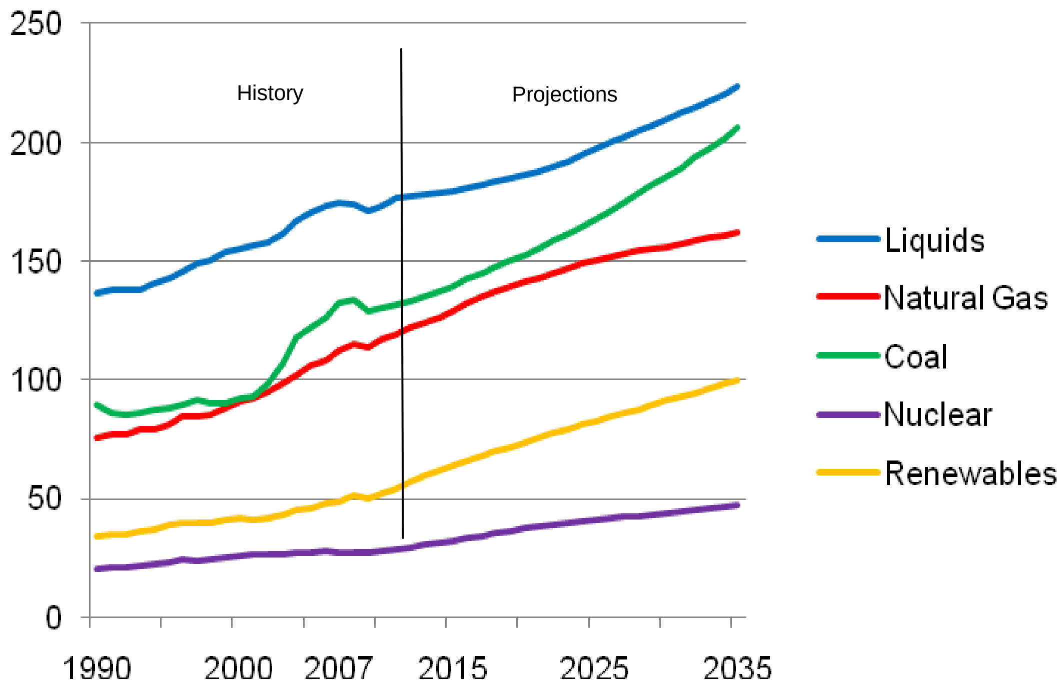
Population and income growth are the two most powerful forces behind the increasing demand for energy. The British Petroleum (BP) Energy Outlook 2030 found that since 1900, world population has more than quadrupled, real income has grown by a factor of 25, and primary energy consumption has multiplied by a factor of 22.5. While population growth is trending downward, with a projected increase of 1.4 billion people over the next 20 years compared to 1.6 billion over the last 20 years, there is no such trend predicted for real income. Over the past 20 years, income has risen 87 percent and is likely to rise by 100 percent over the next 20 years.[35] These increases in population

[33] Scott L. Montgomery, *The Powers That Be: Global Energy for the Twenty-First Century.* (USA: The University of Chicago Press, 2010), 31.
[34] Ibid.
[35] "BP Energy Outlook 2030: London, January 2011." *British Petroleum.* http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistic

and incomes mean that total world consumption of energy is inevitably going to rise, and considering present trends, fossil fuels will principally foster that rise, as shown by Figure 2.1. As the projections show, the ratios between the types of fuel stay relatively the same, while the absolute values all rise.

Figure 2.1. World Marketed Energy Use by Fuel Type (2010)

Quadrillion Btu



	Liquids	Natural Gas	Coal	Nuclear	Renewables
1990	136.4	75.4	89.2	20.4	33.9
2000	155.5	91	92.3	25.7	41.6
2010	172.9	117.3	130.26	27.64	52.05
2030	210.03	155.77	185.65	43.86	91.23

Source: "International Energy Outlook 2010 – Highlights," *U.S. Energy Information Administration,"* http://www.eia.doe.gov/oiaf/ieo/highlights.html (accessed Feb. 17, 2011).

The United States Energy Information Administration's (EIA) predictions on the international energy outlook for 2010 expect that the total world consumption of marketed energy will increase by 49 percent between 2007 and 2035, with growth broken

al_energy_review_2008/STAGING/local_assets/2010_downloads/2030_energy_outlook_booklet.pdf (accessed Feb. 17, 2011), 9.

down into an average of 1.4 percent per year. The EIA also states that the largest projected increase in energy demand will take place in non-OECD economies.[36] Since the 2008 global economic recession, recovery rates have been uneven, though developing Asian nations have led the recovery. Japan, an essential Asian member of the OECD, has shown lagging recovery rates compared to their non-OECD neighbors, such as China. The year 2007 marked the beginning of an energy use discrepancy between OECD and non-OECD countries; previously, OECD countries accounted for the largest share of worldwide energy consumption, but this has since changed and the gap is expected to widen considerably.[37]

Energy consumption patterns used to be driven by the OECD countries until relatively recently. In the post-war era, the OECD countries showed massive spikes in growth, which began to slow down around 1990 as their then-maturing economies shifted away from heavy industry and manufacturing.[38] World energy consumption took a pause and revamped a few decades later, this time due to economic growth in the developing world. China, with the largest population of any country, has entered "not just the Industrial Age, but the Age of Electrification, Motorization, mass consumerism and communication, the Nuclear Age, the Information Age, all at the same time."[39] From 2000 on, China began rapidly industrializing, focusing on infrastructure such as roads, railways, skyscrapers, suburbs, airports, power plants, and factories. From 2000 to 2008,

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[36] "International Energy Outlook 2010: World Energy Demand and Economic Outlook," *U.S. Energy Information Administration Independent Statistics and Analysis,* http://www.eia.doe.gov/oiaf/ieo/world.html (accessed Jan. 18, 2011).
[37] Ibid.
[38] Scott L. Montgomery, *The Powers that Be: Global Energy for the Twenty-First Century.* (USA: The University of Chicago Press, 2010), 32.
[39] Ibid, 34.

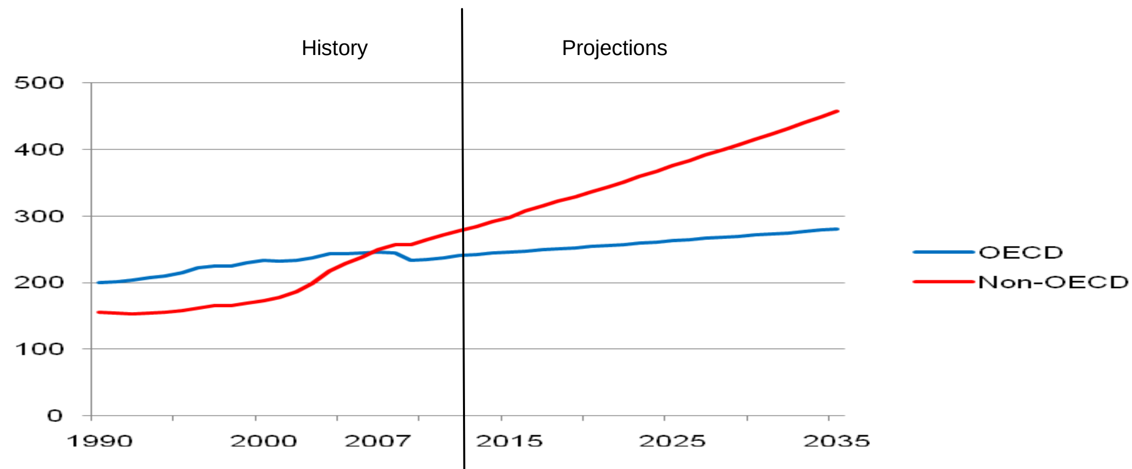
their energy consumption went up more that 100 percent.[40] India is experiencing overall trends similar to those in China, but at a slower pace. As the second most populous country (currently), the growing demand for infrastructure requires more power. As gross domestic product (GDP) grows, people overall become more affluent, and desire consumer goods such as cars, houses, and modern conveniences. Non-OECD countries are working toward raising the standard of living for their citizens, and while this is undeniably positive in a humanitarian sense, it is imperative to explore ways in which this growth can be fostered by cleaner-burning fuels, renewables, and nuclear energy.

Segmenting the world into two groups – the OECD and non-OECD countries – provides a clear comparison tool, as affiliation with the OECD assumes levels of industrialization and similar future goals of members. Figure 2.2 shows the relationship between OECD and non-OECD countries in terms of energy consumption. These rates of growth are what will drive government policy in the years to come. Forecast models are based partially on current trends which indicate a growth in the energy share of both coal and oil (petroleum). Many OECD countries have already set goals to reduce emissions. For example, President Barack Obama pledged to reduce emission output in the United States to 1990 levels by 2020, and further reduce them 80 percent by 2050.[41] Non-OECD countries have focused on industrialization and modernity and less on the harmful effects that fossil fuels have on the environment. Forecast models are unable to take into account specific future international accords, and so only time will tell how the extraordinary growth shown in Figure 2.2 will affect the global perception of climate change.

[40] Scott L. Montgomery, *The Powers that Be: Global Energy for the Twenty-First Century.* (USA: The University of Chicago Press, 2010),, 44.
[41] Ibid, 47.

Figure 2.2. World Marketed Energy Consumption: OECD and non-OECD (1990-2035)

Quadrillion Btu



	1990	2000	2007	2015	2025	2035
OECD	199.51	233.46	245.63	245.96	263.19	280.75
Non-OECD	155.87	172.51	249.47	297.51	375.52	457.98

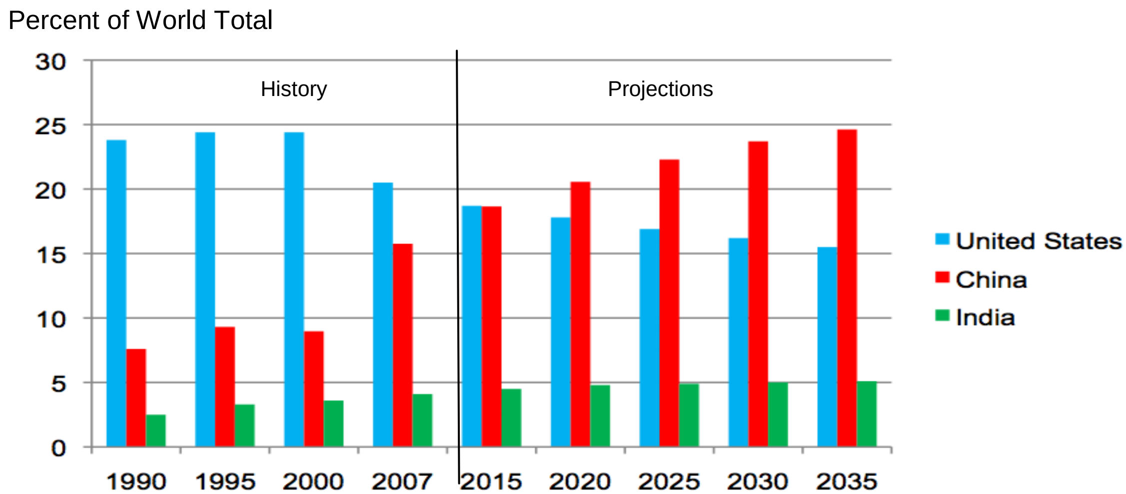
Source: adapted from EIA, International Energy Statistics database (as of November 2009), web site www.eia.gov/emeu/international. Projections: EIA, World Energy Projection System Plus (2010).

Energy Use in China and India versus the United States

Since 1990, China and India's energy consumption as a share of total worldwide energy use has increased significantly. Together, they accounted for approximately 10 percent of worldwide energy use in 1990, and 20 percent in 2007.[42] If the EIA's prediction of future energy use is correct, a 30 percent share of the world's energy use in 2035 can be expected in China and India. In contrast, the United States' share is predicted to fall from 21 percent in 2007 to 16 percent in 2035. Figure 3 shows an almost reversal of energy use between the United States and China, with India's percentage almost doubling its energy use between 1990 and 2035.

[42] "International Energy Outlook 2010: World Energy Demand and Economic Outlook," *U.S. Energy Information Administration Independent Statistics and Analysis,* http://www.eia.doe.gov/oiaf/ieo/world.html (accessed Jan. 18, 2011).

Figure 2.3. Shares of World Energy Consumption in the United States, China, and India (1990-2035)



Year	United States	China	India
1990	23.80*	7.60	2.50
1995	24.40	9.31	3.30
2000	24.40	8.97	3.60
2007	20.50	15.76	4.10
2015	18.70	18.65	4.50
2020	17.80	20.56	4.80
2025	16.90	22.29	4.90
2030	16.20	23.70	5.00
2035	15.50	24.62	5.10

Source: "International Energy Outlook 2010: World Energy Demand and Economic Outlook," *U.S. Energy Information Administration Independent Statistics and Analysis,* http://www.eia.doe.gov/oiaf/ieo/world.html (accessed Jan. 18, 2011).
*Note: numbers refer to percent of world total

China is already witnessing rises in living standards and industrialization, and Figure 2.3 shows there is little sign of the trend ending, at least in the next two decades. From 1960 to 1990, China's GDP per capita (at current prices, not adjusted for inflation) relatively did not change, hovering between $100 and $200. In 1990, an exponential trend began occurring, leading to per capita GDP levels of $946 (in 2000) and $1,731 (in

2005). In 2009, per capita GDP was $3,744.[43] This type of rise can be attributed to increasing living standards and therefore a greater need for consumer products and infrastructure. In addition, the expansion of commercial services goes in tandem with rising living standards. Examples of services are hospitals, businesses, and retail locations. In OECD countries, these infrastructures are more mature and population growth is slower, which explains the relatively slow rate of change. Increased efficiency in appliance technology, cars, and building designs helps to explain the reason for the declining energy share of the United States. The presence of efficient technology during the period may prove beneficial for China as it embarks on its period of rapid industrialization.

Current Energy Sources in Use

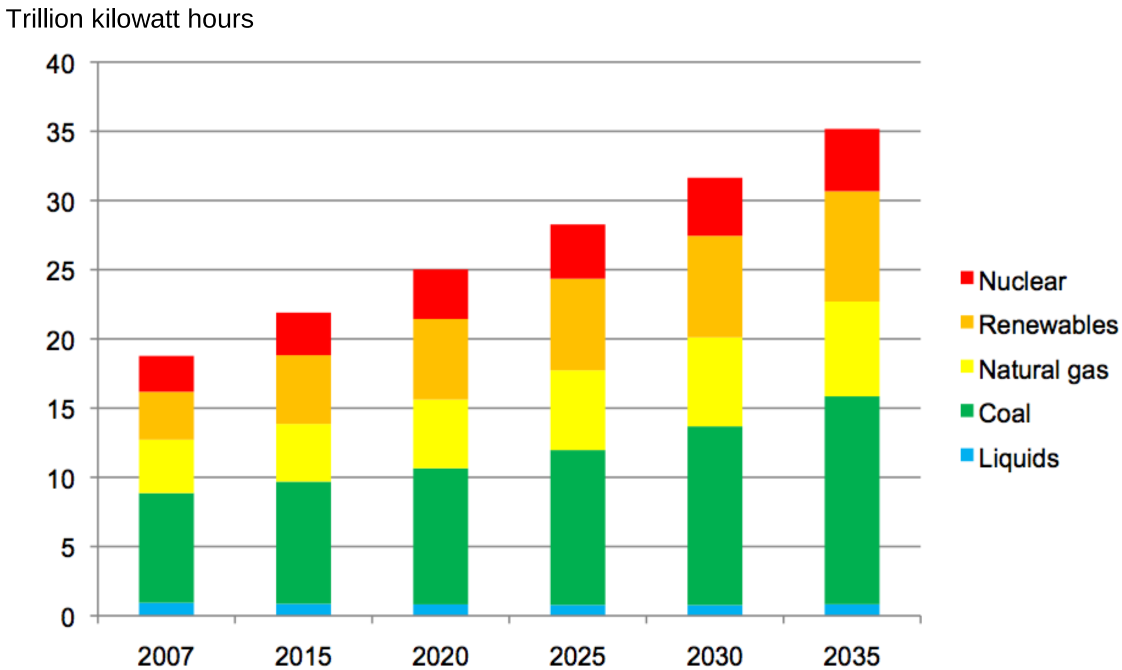
Today, fossil fuels remain the primary source of energy. In 2007, coal supplied 42 percent of the world's energy demand, and this share will increase slightly to 43 percent in 2035. Modern infrastructure and industry have been integrated into the global market for coal, oil, and natural gas, and the transition from these fossil fuels to renewables and nuclear energy would require a worldwide effort and trillions of dollars. Another reason for the predicted continued reliance on coal in the face of irrefutable global warming evidence is the price of coal. After 2003, a rise in energy prices made coal cheaper compared to natural gas, a cleaner-burning fossil fuel.[44] Use of coal has accelerated in developing countries such as China and India, both of which have large domestic coal reserves. Both countries want to use their reserves to exercise self-

[43] "GDP per Capita at Current Prices." *Google Public Data.* http://www.google.com/publicdata?ds=wbwdi&met=ny_gdp_pcap_cd&idim=country:CHN&dl=en&hl=en&q=china%27s+gdp+per+capita (accessed Feb. 17, 2011).

[44] Scott L. Montgomery, *The Powers That Be: Global Energy for the Twenty-First Century.* (USA: The University of Chicago Press, 2010), 8.

sufficiency. Coal currently accounts for more than two-thirds of electricity generation in all of non-OECD Asia, and considering the forecasted industrial development of China and India, most of the carbon dioxide emissions that the world will face in the coming decades will be a result of their industrialization.

Figure 2.4. World Electricity Generation by Fuel Type (2007-2035)



Source: "International Energy Outlook 2010: World Energy Demand and Economic Outlook," *U.S. Energy Information Administration Independent Statistics and Analysis,* http://www.eia.doe.gov/oiaf/ieo/world.html (accessed Jan. 18, 2011).

Petroleum is a crucial energy source to explore because of its vital importance in the personal and military transportation industry. According to the United States Energy Information Administration's International Energy Outlook for 2010, the use of all energy sources will increase over the given time period. If oil prices remain relatively high during the same period, liquid fuels and other petroleum products will grow slowly at an average rate of 0.9 percent per year.[45] Given that total energy demand is predicted to grow at 1.4 percent per year, the energy share of oil and related sources will decrease. However, petroleum in the transportation sector rises due to increasing number of vehicles, notably in China. Considering standard growth, car ownership is predicted to rise from 27.42 million in 2004 to 200-300 million in 2030, nearly twice the size of the United States' fleet today.[46]

A viable alternative to petroleum that can overcome the rapidly growing demand for transportation has yet to be found. In the United States, hybrid cars are predicted to constitute a larger percentage of sales (approximately 15 percent by 2030), and improvements in aircrafts and aviation biofuels could save 1.6 md/d (millions of barrels a day) of oil demand by 2030. [47,48] Increases in efficiency not just in the transportation sector vessels, but buildings and appliances, are accounting for much of the plateau shape of energy consumption in OECD countries.

Renewables as a group are the fastest growing sector, with consumption increasing at an average of 3 percent per year.[49] This assumes that the world continues on a business-as-usual case, also referred to as the Reference case. More specifically, in non-OECD countries, strong growth in hydroelectric power generation in mid- to large-

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[45] "International Energy Outlook 2010: World Energy Demand and Economic Outlook," *U.S. Energy Information Administration Independent Statistics and Analysis,* http://www.eia.doe.gov/oiaf/ieo/world.html (accessed Jan. 18, 2011).

[46] Zhidong Li and Kokichi Ito, "Energy Demand and Supply Outlook in China for 2030 and a Northeast Asian Community – The Automobile Strategy and Nuclear Power Strategy of China," http://eneken.ieej.or.jp/en/data/pdf/300.pdf (accessed Feb. 17, 2011), 16.

[47] "Outlook for Energy: A View to 2030," *Exxon Mobil,* http://www.exxonmobil.com/Corporate/files/news_pub_eo_2009.pdf (accessed Feb. 1, 2011), 17.

[48] "World Energy Outlook 2009: Executive Summary," *International Energy Agency,* http://www.worldenergyoutlook.org/docs/weo2009/WEO2009_es_english.pdf (accessed Feb. 1, 2011), 9.

[49] "International Energy Outlook 2010," *U.S. Energy Information Administration: Independent Statistics and Analysis,* http://www.eia.doe.gov/oiaf/ieo/electricity.html. (accessed Feb. 3, 2011).

scale power plants is expected predominantly in China and India.[50] China is also predicted to experience high growth rates in wind-powered energy generation. While renewable energy sources have positive environmental and energy security impacts, they are typically not able to compete economically or substantially with fossil fuels. Diversification of the energy portfolio is important for countries expecting high future growth rates because of the uncertainty of certain resource availability and international goals to combat global warming.

The Exxon Mobile Outlook for 2010 released forecast data that shows trends similar to the growth of renewables. Natural gas is predicted to experience the most growth by 2030, with a proposed 55 percent increase in demand compared with 2005 levels.[51] With concerns about fossil fuel burning becoming an issue of global importance, many countries are turning to natural gas as a less carbon-dioxide-intense alternative. Demand for renewables (solar, wind, hydro) and nuclear energy are expected to increase for the same environmental reason. By 2030, approximately 40 percent of the world's electricity is forecasted to be generated by nuclear and renewable sources.[52]

GROWTH IN CHINA – POPULATION AND ECONOMY

As a leading non-OECD country, China's current and future growth is imperative to determining energy trends and predictions in all of Asia. In 2009, the National Bureau of Statistics in China reported an 8.7 percent increase from the previous year's GDP. Specifically, primary industry (raw material extraction) rose 4.2 percent, secondary industry (manufactured goods) rose 9.5 percent, and tertiary industry (service industry)

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[50] "International Energy Outlook 2010," *U.S. Energy Information Administration: Independent Statistics and Analysis,* http://www.eia.doe.gov/oiaf/ieo/electricity.html. (accessed Feb. 3, 2011).
[51] "Outlook for Energy: A View to 2030," *Exxon Mobil,* http://www.exxonmobil.com/Corporate/files/news_pub_eo_2009.pdf (accessed Feb. 1, 2011), 25.
[52] Ibid, 23.

rose 8.9 percent.[53] The OECD collection of statistics (Figure 2.5) presents a slightly varied set of data points, but the trend of growth being experienced in China is the same – high and rapid growth.

Figure 2.5. OECD's Report of China's Real GDP Growth 2008-2012

Real GDP Growth (%)	2008	2009	2010	2011	2012
	9.6	9.1	10.5	9.7	9.7

Source: "China – Economic Outlook 88 Country Summary," *OECD: Better Policies for Better Lives,* http://www.oecd.org/document/31/0,3746,en_ 33873108_36016481_45 274719_1_1_1_1,00.html (accessed Jan. 18, 2011).
Note: The figures given for GDP are percentage changes from the previous year.

A country experiencing GDP growth of 8 percent per annum can expect to see GDP double in a mere ten years. A growth rate of 2.5 to 3.5 percent is generally accepted to constitute a stable growth rate that can be sustained without unmanageable negative consequences. For comparison, as of 2010, the United States' GDP is growing at approximately 2.8 percent, fitting in the stable growth rate range.[54] With growth rates nearing the double-digits, China's current growth patterns cannot be sustained in the coming decades without suffering pollution problems and a lack of markets to keep up with production.

In addition, the population growth rates in China for 2010 were estimated to be 0.494 percent.[55] The world's population is around 6.7 billion, and China constitutes about 20 percent of that at just over 1.3 billion people.[56] While China's fertility rate is

[53] "Statistical Communiqué of the People's Republic of China on the 2009 National Economic and Social Development," *National Bureau of Statistics of China,* http://www.stats.gov.cn/was40/gjtjj_en_detail.jsp?searchword=energy+consumption&channelid=9528&record=5 (accessed Feb. 4, 2011).
[54] "China – Economic Outlook 88 Country Summary." *OECD: Better Policies for Better Lives.* http://www.oecd.org/document/31/0,3746,en_33873108_36016481_45274719_1_1_1_1,00.html (accessed Jan. 18, 2011).
[55] "The World Factbook: China," *Central Intelligence Agency,* https://www.cia.gov/library/publications/the-world-factbook/geos/ch.html (accessed Jan. 18, 2011).
[56] "China Population: The Population Growth of the World's Largest Country." *About.com Geography.* http://geography.about.com/od/populationgeography/a/chinapopulation.htm (accessed Feb. 15, 2011).

1.7 children per woman, less than the 2.1 rate necessary to maintain a stable population, the population is still expected to grow due to immigration and a decrease in the death rate as health care improves. A peak population of 1.5 billion is anticipated for 2030, after which it is predicted to begin declining.[57] An increased population thus requires more infrastructure and electricity at a rapid pace. As populations rise, not only does the populace require more energy for personal needs, such as fuel for cars and electricity for homes, but the demand for 'indirect' energy rises.[58] Indirect energy is what is used to serve the broader society and economy, including public works and retail establishments.

It should be noted that India is experiencing even more rapid population growth than China. In 2010, the growth rate was estimated to be 1.376 percent.[59] Currently, India's population is second to China's, but demographers expect it to surpass China's by 2030. At that time, India may be home to more than 1.53 billion people, while China's population will be on the decline.[60] Therefore, much indirect energy growth will stem from India as well as China.

In 2009, consumer sales rose 15.5 percent in China from the previous year, indicating more availability of consumer goods. This was due to a 4-trillion yuan (equal to 568 billion U.S. dollars) economic stimulus package launched in November of 2008. The goals of this stimulus were to boost China's domestic consumption and fixed asset investment, and therefore improve industry value chains and decrease dependence on

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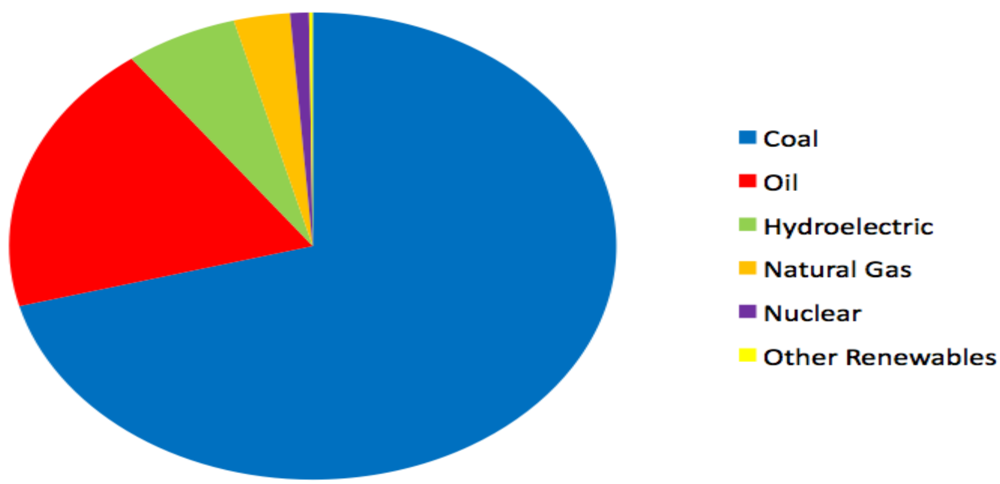
[57] "China Population: The Population Growth of the World's Largest Country." *About.com Geography.* http://geography.about.com/od/populationgeography/a/chinapopulation.htm (accessed Feb. 15, 2011).
[58] "Outlook for Energy: A View to 2030," *Exxon Mobil,* http://www.exxonmobil.com/Corporate/files/news_pub_eo_2009.pdf (accessed Feb. 1, 2011). 10.
[59] "The World Factbook: India," *Central Intelligence Agency,* https://www.cia.gov/library/publications/the-world-factbook/geos/in.html (accessed Feb. 20, 2011).
[60] "India's Population: India Likely to Surpass China in Population by 2030," *About.com Geography,* http://geography.about.com/od/obtainpopulationdata/a/indiapopulation.htm (accessed Feb. 20, 2011).

their export-driven economy.[61] Through various measures such as tax reductions, rebates, fiscal subsidies, improved access to credit, and direct government expenditures, almost all sectors of the economy were targeted.

In 1993, China became a net oil exporter, but since 2006 it has become the world's third largest net importer of oil.[62] China alone accounted for approximately a third of the world's oil consumption growth in 2009, in part due to increases in personal automobile ownership as a result of growing standards of living and per capita income. As shown in Figure 2.6, coal supplied almost three-quarters of China's 85 quadrillion

Figure 2.6. China's Energy Use by Source (2008)



Oil	Coal	Natural Gas	Nuclear	Hydroelectricity	Other Renewables
71%*	19%	3%	1%	6%	0.2%

Source: "China: Background," *U.S. Energy Information Administration: Independent Statistics and Analysis,* http://www.eia.doe.gov/emeu/cabs/China/Background.html (accessed Feb. 7, 2011).

*Represents percent of total energy production

[61] "China: Background," *U.S. Energy Information Administration: Independent Statistics and Analysis,* http://www.eia.doe.gov/emeu/cabs/China/Background.html (accessed Feb. 7, 2011).
[62] Ibid.

Btu of total energy consumption in 2008. By 2020, coal demand is expected to roughly double.[63] As coal is the largest source of environmentally harmful carbon dioxide emissions, its use at this magnitude is causing international accords such as the Kyoto Protocol to lose clout. However, in recent years China has expressed interest in expanding its natural gas, nuclear, and renewables sectors, measures that will help the global effort to fight climate change. In 2010, China announced plans to reduce the amount of energy consumed per unit of GDP by 31 percent, and to increase the use of non-fossil fuel energy to a total of 15 percent of the energy mix from the period 2010 to 2020.[64]

OECD ASIA – JAPAN AND SOUTH KOREA

The two main players in OECD Asia are Japan and South Korea. Both countries are heavily dependent on imports to meet their domestic energy needs. Japan is only 16 percent energy self-sufficient, while South Korea has to import 97 percent of its energy resources.[65] Due to this high level of dependence, both countries have placed energy security as top priorities for the coming years. Japan is the third largest net importer of oil in the world, (behind the United States and China), and South Korea is the fifth or sixth, depending on sources.

Figure 2.7 shows that from 2002 to 2030, both Japan and South Korea are expected to experience patterns of energy demand growth similar to the United States and the rest of the OECD members. Future increases in energy will be in the form of

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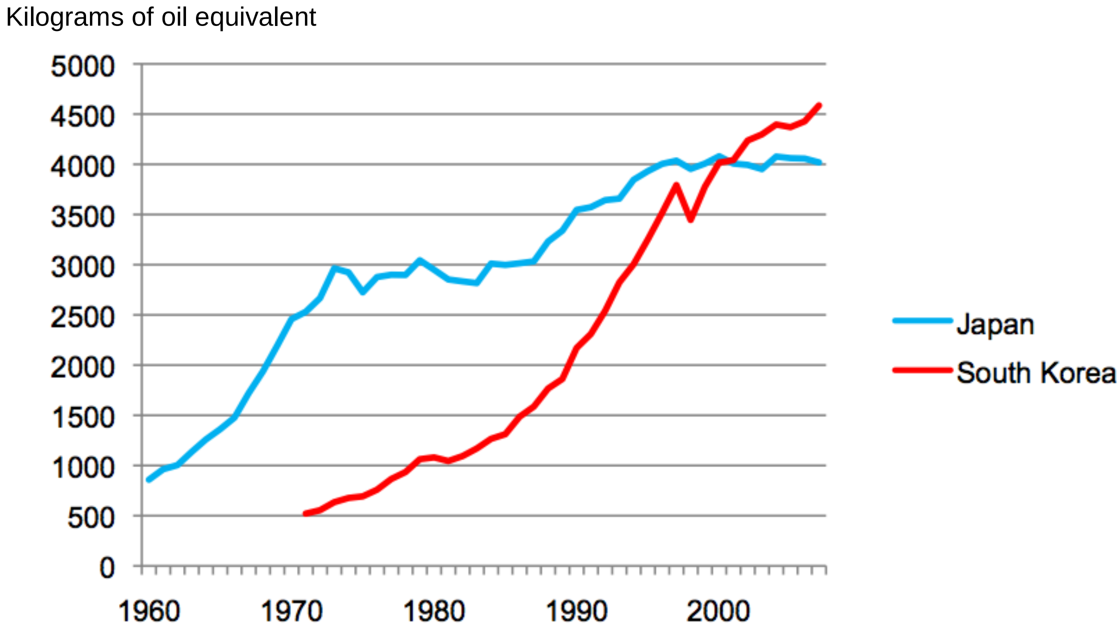
[63] "Country Analysis Briefs: China," *U.S. Energy Information Administration,* http://www.geni.org/globalenergy/library/national_energy_grid/china/china_country_analysis_brief.shtml (accessed Feb. 17, 2011).
[64] "China: Background," *U.S. Energy Information Administration: Independent Statistics and Analysis,* http://www.eia.doe.gov/emeu/cabs/China/Background.html (accessed Feb. 7, 2011).
[65] "Renewable Energy South Korea," *Global Impact Consulting*, http://globalimpactconsulting.com/55/5/2/hot_sectors/renewable_energy/south_korea_.html (accessed Feb. 4, 2011).

Figure 2.7. Energy Use Per Capita in Japan and South Korea (end date: 2007)



Source: "Energy Use per Capita: Japan and South Korea," *Google Public Data,* http://www.google.com/publicdata?ds=wb-wdi&met=eg_use_pcap_kg_oe&idim=country:JPN&dl=en&hl=en&q=japan%27s+energy+consumption#met=eg_use_pcap_kg_oe&idim=country:JPN:KOR (accessed Feb. 7, 2011).

electricity, at the rate of 1.3 percent per year from 2002 to 2030 (Japan and Korea combined).[66] Total primary energy demand is expected to rise at an average of one percent per year.[67] This growth had been approximately 1.7 percent until 2010, and is expected to fall to 0.5 percent in the 2020s, creating a plateau shape. This plateau is primarily due to energy-efficient technologies, as well as a decline in population. In addition, new policies are geared toward stabilizing emission levels in the 2010s and driving them back to 2002 levels by 2030.[68] Natural gas, as a lower carbon dioxide-emitting energy source, is forecasted to become more important in the future. In Japan, demand is expected to grow 1.9 percent per year, and in South Korea the rate of growth is

[66] Kenji Kobayashi, "Forecasting Supply and Demand Up to 2030," *8th Annual Victoria Power 2005*, (22-24 February 2005) 1-14. http://www.iea.org/speech/2005/kk_melbourne_notes.pdf (accessed Feb. 18, 2011).
[67] Ibid.
[68] Ibid.

3.9 percent per year. Nuclear energy is also on the rise at an average of 1.7 percent per year. This means that nuclear energy's share in the fuel mix of OECD Asia is expected to rise from 15 percent in 2005 to 18 percent in 2030.

Japan – Energy Trends and Nuclear Goals

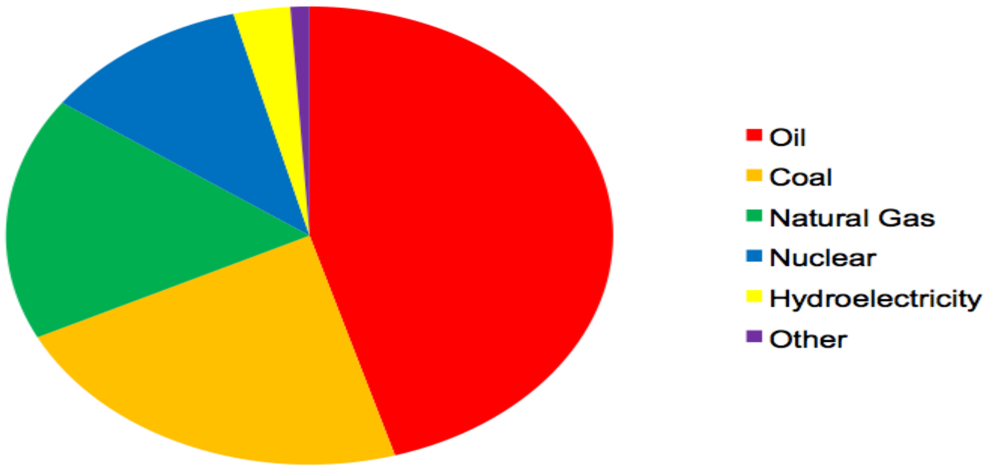
In addition to losing many industrial centers during WWII, Japan was considered a late developer, but had the path to industrialization illuminated by the United States, an early developer. The Japanese began to experience rapid industrialization after World War II under the occupation of the United States, who wished to make Japan a strong democratic ally in the Pacific. The Japanese were given access to modern western technology and ideas that rebuilt the war-torn country into an important economic competitor. This meant that Japan did not have to go through the typical stages of development – it was able to begin with modern technology after many pre-war factories in the industrial centers were destroyed by firebombing.

As shown by Figure 2.7, Japan's growth in energy demand has risen over time, but appears to begin to even out in the mid-1990s. The 1990s was known as the "Lost Decade" because the Japanese period of high growth ended when the economic bubble caused by enormous speculation burst, and the Japanese saw trillions of yen worth of wealth evaporate. The following period of economic stagnation corresponded with a declining birth rate. According to the National Institute of Population and Social Security Research, by the year 2055, Japan's population will shrink 30 percent to 90 million, the same population as in 1955, the year that marked the beginning of the high growth period.[69] Another reason Japan can expect a decrease in energy consumption is because

[69] Jeff Kingston, "Contemporary Japan: History, Politics, and Social Change Since the 1980s." (UK: Wiley-Blackwell Publishing, 2011), 41-2.

of efficiency in technology and infrastructure. During the high growth period, the Japanese made a name for themselves as frontrunners in research and technology, and this trend continues to this day.

Figure 2.8. Japan's Energy Use by Source (2007)



Oil	Coal	Natural Gas	Nuclear	Hydroelectricity	Other
45%*	22%	17%	11%	3%	1%

Source: "Japan: Background," *U.S. Energy Information Administration: Independent Statistics and Analysis,* http://www.eia.doe.gov/cabs/Japan/Background.html (accessed Feb. 3, 2011).
* Represents percent of total energy production

Japan has a strong nuclear research and development program that is supported by the government. These programs are designed to serve three goals: promote energy efficiency, increase energy security, and reduce carbon dioxide and other greenhouse gas emissions.[70] As reported by the Ministry of Economy, Trade and Industry (METI), the share of energy derived from nuclear power accounted for 24 percent in 2008. Figure 2.8 reports nuclear as having an 11 percent share in 2007, and while differing data collection methodology may have taken place, the significant rise parallels Japan's nuclear goals.

[70] "Japan: Background," *U.S. Energy Information Administration: Independent Statistics and Analysis,* http://www.eia.doe.gov/cabs/Japan/Background.html (accessed Feb. 3, 2001).

The current goal is to raise that share to 40 percent by 2017, and reach 50 percent by 2030.[71]

Japan is currently the third largest producer of nuclear power. The first plant was built by the Japan Atomic Power Company in 1961, and the company currently operates four of the 54 plants in operation. Japan also has its own domestic enrichment and reprocessing plants. This means that soon Japan can have control over the fuel cycle, and will not have to rely on foreign companies for nuclear fuel for their reactors, which will increase feelings of energy security. Energy security is a top priority for Japan's future, and the energy diversification opportunity is another reason the Japanese government promotes nuclear energy. In local communities, where the electricity demand is not as high, hydroelectric power is being significantly explored as a sustainable and low carbon-emitting energy option.[72] Nuclear power would be more suitable for large cities, such as Tokyo or Osaka, as the economic cost of construction is a large investment.

South Korea – Energy Trends and Nuclear Goals

Power demand in South Korea has been on a steep upward slope since 1990, at more than 9 percent per year, but has been slowing since around 2006.[73] Compared to Japan, South Korea's projected electricity demand growth is high at 2.1 percent per year to 2030, and this is due to expectations of more robust economic and population growth.[74] South Korea is also reliant on imports for almost all energy needs, and therefore nuclear is an attractive choice because of its enhanced energy security.

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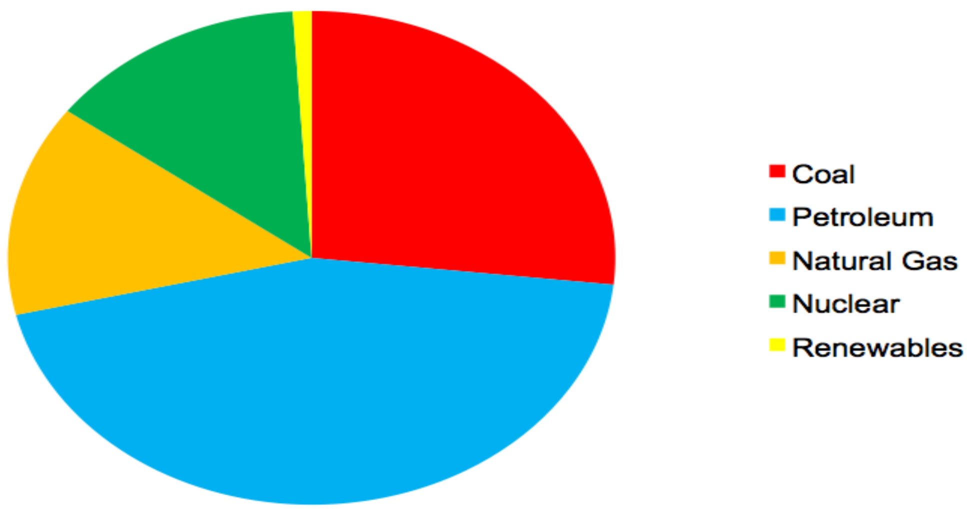
[71] "Japan: Electricity," *U.S. Energy Information Administration: Independent Statistics and Analysis,* http://www.eia.doe.gov/cabs/Japan/Electricity.html (accessed Feb. 3, 2011).
[72] Ibid.
[73] "Nuclear Power in South Korea," *World Nuclear Association,* http://www.world-nuclear.org/info/inf81.html (accessed Feb. 5, 2011).
[74] "International Energy Outlook 2010," *U.S. Energy Information Administration: Independent Statistics and Analysis,* http://www.eia.doe.gov/oiaf/ieo/electricity.html (accessed Feb. 3, 2011).

Petroleum, which makes up the majority share, has been on the decline since the mid 1990s, when the share was at a peak of 66 percent.[75] As of 2008, South Korea had about 80 million kilowatts of installed generating capacity, and Figure 2.9 shows that 64 percent of energy generated in that year came from conventional thermal sources (fossil fuels), 34 percent came from nuclear power, and less than two percent was generated by renewable sources.[76]

Figure 2.9. South Korea's Total Primary Energy Consumption by Type (2008)



Coal	Petroleum	Natural Gas	Nuclear	Renewables
27	45	14	14	1

Source: "South Korea: Background," *U.S. Energy Information Administration: Independent Statistics and Analysis,* http://www.eia.doe.gov/emeu/cabs/China/Background.html (accessed Feb. 7, 2011).

South Korea's first nuclear plant was completed in 1978, and the country has been allocating resources toward development of the industry ever since. Korea Hydro & Nuclear Power Company operates the four nuclear power stations with 20 individual

[75] "South Korea: Background," *U.S. Energy Information Administration: Independent Statistics and Analysis*, http://www.eia.doe.gov/emeu/cabs/China/Background.html (accessed Feb. 7, 2011).
[76] "South Korea: Electricity," *U.S. Energy Information Administration: Independent Statistics and Analysis,* http://www.eia.doe.gov/cabs/South_Korea/Electricity.html (accessed Feb. 7, 2011).

power reactors in total.[77] Scheduled plans to have 12 new reactors completed by the year 2022 will help South Korea fulfill their goal of generating nearly half of their energy supply from nuclear sources. South Korea's research and development program, equivalent to $U.S. 1 billion, aims to produce commercial nuclear heat around the year 2020.[78] South Korea is set to become a major nuclear energy country by exporting technology. Korea Electric Power Company (KEPCO) won a contract worth $20 billion in December 2009 to build four 1,400 megawatt nuclear reactors in the United Arab Emirates. The first reactor is expected to be ready for operation by 2017. The South Korean Ministry of Knowledge Economy said in January 2010 that, "nuclear power-related business will be the most profitable market after automobiles, semiconductors and shipbuilding…We will promote the industry as a major export business."[79]

CURRENT AND FUTURE NUCLEAR PRESENCE IN ASIA

The energy demand trends in Asia cannot be met with a business-as-usual approach to energy production. The world stockpiles of fossil fuels may last a few centuries into the future, but the transition to reliance on more sustainable and less environmentally costly forms of energy should be put into place before it becomes too costly to make such a transition. China and India, the main Asian non-OECD countries, are exploring nuclear power as a means to diversify their energy portfolio and handle the extremely high rates of expected growth in both economy and population.[80] South Korea and Japan, the main Asian OECD countries, are turning increasingly to nuclear power for

[77] "South Korea: Electricity," *U.S. Energy Information Administration: Independent Statistics and Analysis,* http://www.eia.doe.gov/cabs/South_Korea/Electricity.html (accessed Feb. 7, 2011).
[78] "Asia's Nuclear Energy Growth," *World Nuclear Association,* http://www.world-nuclear.org/info/inf47.html (accessed Jan. 9, 2011).
[79] "Nuclear Power in South Korea," *World Nuclear Association,* http://www.world-nuclear.org/info/inf81.html (accessed Feb. 5, 2011).
[80] "Asia's Nuclear Energy Growth," *World Nuclear Association,* http://www.world-nuclear.org/info/inf47.html (accessed Jan. 9, 2011).

energy security since both must currently import the overwhelming majority of their energy needs. The exact number of nuclear reactors in operation, under construction, planned, and proposed in most Asian countries, the U.S. and the world can be seen in Figure 2.10.

Figure 2.10. Nuclear Power Plants Worldwide (as of January 19, 2011)

Country	PR in Operation	PR under construction	PR planned	PR Proposed
United States	104	1	9	23
China	13	27	50	110
Taiwan	6	2	0	1
India	20	5	18	40
Japan	55	2	12	1
South Korea	21	5	6	0
North Korea	0	0	0	1
Malaysia	0	0	0	1
Bangladesh	0	0	0	2
Pakistan	2	1	2	2
Vietnam	0	0	2	12
World Total →	443	62	156	322

Source: "World Nuclear Power Reactors & Uranium Requirements," *World Nuclear Association.* http://www.world-nuclear.org/info/reactors.html (accessed Feb. 14, 2011)
* This table includes only those future reactors envisaged in specific plans and proposals and expected to be operating by 2030.

Many of the reactors being built in Asia are newer models, typically second or third generation light-water reactors.[81] This means that they come equipped with better safety features and efficiency features that together will influence the public perception of nuclear power. Also, they will last longer – perhaps up to sixty years, in comparison to the plants built in the 1970s and 1980s that last thirty to forty years. The new generation of reactors will be smaller in size, consume less fuel, and generate less radioactive waste.[82] Currently, the world's energy capacity is about 37,000 gigawatts (Gwe) of

[81] Scott L. Montgomery, *The Powers That Be: Global Energy for the Twenty-First Century.* (USA: The University of Chicago Press, 2010), 129.
[82] Ibid.

which only 370 Gwe is generated through nuclear means. Through the new plants, the projected new generating capacity from 2010 to 2020 would rise 56 Gwe a year, which equates to about 36 percent of the world's new capacity.

CONCLUSION

The rapid industrialization and integration of economies that the world has witnessed in the last century is arguably an astounding human accomplishment, but has produced negative externalities such as widespread pollution and the buildup of climate-altering greenhouse gases in the atmosphere. While the earth is only recently beginning to suffer the effects of this man-made phenomenon, the effects will be much larger in the years to come. The EIA has predicted that worldwide, total consumption of marketed energy will increase approximately 1.4 percent per year between 2007 and 2035, a total of 49 percent. The majority of this growth will be in non-OECD Asian countries, led by China and India, the two with the most predicted population and economic growth, and, without major changes, it will continue to be dominated by fossil fuel sources. OECD countries, led by the United States and the United Kingdom, industrialized earlier, allowing them to shift their main focus away from heavy industry. Their mature economies, while still reliant on fossil fuels, are not expected to experience intense growth associated with a spike in energy consumption. In fact, OECD countries' total share of energy consumption is predicted to reverse with non-OECD countries.

While a great amount of data exists corroborating these trends and forecasts, the predictions for the coming decades hinge critically on government policies and action, and the result of these actions on technology and prices of energy services. In addition, end-user behavior is paramount.[83] Today, there are approximately 1.5 billion people, a fourth of the world's total population, who lack access to electricity, and in an effort to expand the modern lifestyle comforts to every person, it is to be expected that the total amount of energy consumption will rise.[84] However, this does not necessarily have to spell disaster for the environment or human civilization. Cleaner burning, less carbon dioxide-emitting energy sources exist, and there are practical alternatives to help mitigate the crisis of global warming. China, India, Japan, and South Korea are leading Asia in nuclear energy production, and each have plans for expansion. Economies all over the globe may very well be comfortable with the use of fossil fuels, but as technology develops and economies mature, it would be beneficial to build up significant sectors for nuclear and renewable forms of generation in the energy portfolio. It is important for the world to collectively move toward low-carbon sources of energy in the future.

[83] "World Energy Outlook 2009: Executive Summary." *International Energy Agency.* http://www.worldenergyoutlook.org/docs/weo2009/WEO2009_es_english.pdf (accessed Feb. 1, 2011), 4.
[84] "Outlook for Energy: A View to 2030," *Exxon Mobil,* http://www.exxonmobil.com/Corporate/files/news_pub_eo_2009.pdf (accessed Feb. 1, 2011), 1.

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"BP Energy Outlook 2030: London, January 2011." *British Petroleum.* http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2010_downloads/2030_energy_outlook_booklet.pdf (accessed Feb. 17, 2011).

"China: Background." *U.S. Energy Information Administration: Independent Statistics and Analysis.* http://www.eia.doe.gov/emeu/cabs/China/Background.html (accessed Feb. 7, 2011).

"China – Economic Outlook 88 Country Summary." *OECD: Better Policies for Better Lives.* http://www.oecd.org/document/31/0,3746,en_33873108_36016481_45274719_1_1_1_1,00.html (accessed Jan. 18, 2011).

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"South Korea: Electricity." *U.S. Energy Information Administration: Independent Statistics and Analysis.*http://www.eia.doe.gov/cabs/South_Korea/Electricity.html (accessed Feb. 7, 2011).

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Chapter Three

NUCLEAR ENERGY'S ENVIRONMENTAL ADVANTAGE: A COMPARISON OF EMISSIONS AND CLIMATE CHANGE MITIGATION POTENTIAL FOR DIFFERENT ENERGY TECHNOLOGIES

Emilia Jones

Abstract:

Energy decisions for the future must take into account climate impacts, energy security, and increasing demand for fuel and power. This chapter focuses on the first of these three considerations, comparing life cycle greenhouse gas emissions from fossil fuels (oil, natural gas, and coal), renewables (wind, solar, and hydropower), and nuclear energy. While emissions from fossil fuels are very high despite emerging technologies to improve efficiency, emissions from renewables and nuclear energy are low. Renewable and nuclear energy currently contribute to reducing emissions but only nuclear energy is likely to do so on a truly global scale in the next several decades, a crucial period with regard to preventing the worst impacts of climate change. Renewables' contribution is likely to be more limited due to unsolved problems of reliability associated with wind and solar power and environmental and social impacts from hydropower. Nuclear energy continues to be the only low-carbon source of large-scale baseload electricity. As such, it will continue to offer a much-needed option in any multidimensional approach to climate change mitigation.

INTRODUCTION

Can climate change realistically be mitigated in the context of rapidly increasing global energy use? Energy decisions for the future must take into account the consequences of both climate impacts and rapidly increasing energy demand. The main energy source options for the next few decades, when greenhouse gas (GHG) emissions most need to begin a decline, are fossil fuels, renewables, and nuclear power. Fossil fuels - oil, natural gas, and coal - continue to satisfy 80 percent of global energy use, and emit large amounts of carbon dioxide (CO_2) into the atmosphere.[85] Modernization in many countries has contributed to a rise in the use of fossil fuel for energy generation. At

[85] Shinzo Saito, "Role of Nuclear Energy to a Future Society of Shortage of Energy Resources and Global Warming," *Journal of Nuclear Materials* 398, no. 1 (2010): 1, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/1430549588984.

current rates of increased use, coal, the source of the highest volume of carbon emissions, could become the world's main fossil fuel in the 21st century.[86] One alternative energy source, the world's newest energy option, is renewable energy, mainly hydropower, wind, and solar power. Renewables have become popular in the environmental community for their ability to provide energy with low GHG emissions. Most renewable energy technology is fairly new but the use of renewables worldwide has dramatically increased in recent years and will likely continue to rise. Yet the use of renewables on a large scale is problematic due to the inadequate reliability of wind and solar power and the environmental concerns associated with hydropower.

Nuclear energy is a viable low-carbon option for both the present and future. Nuclear power technology has existed for decades and several countries have extensive experience producing electricity from this source. As a low-emissions source of energy, nuclear power could significantly contribute to the global energy supply in the next several decades. It is almost certain that future global energy supply will consist of some combination of fossil fuels, renewables, and nuclear power. However, nuclear has more mitigation potential and lower costs than other low-emissions technologies.[87] Public perception of nuclear power has varied significantly and generally included a strong measure of skepticism, particularly in the West. However, nuclear energy is beginning to undergo what has been described as a "renaissance," led by non- Organization for Economic Cooperation and Development (OECD) Asian countries such as China, which

[86] "International Energy Outlook 2010: Energy-Related Carbon Dioxide Emissions," *U.S. Energy Information Administration Independent Statistics and Analysis*, http://www.eia.doe.gov/oiaf/ieo/emissions.html (accessed Jan. 30, 2011).
[87] "Judge Nuclear on its Merits," *International Atomic Energy Agency*, http://www.iaea.org/OurWork/ST/NE/judge-nuclear.html (accessed Feb. 2, 2011).

will likely continue for several decades.[88] The amount of emissions avoided by nuclear energy in the future will depend on the scale of the nuclear renaissance, improvements in nuclear technology, and the future contribution of other energy sources to meet the global demand. In light of the realities of global energy demand and global warming, nuclear power has the potential to contribute significantly to climate change mitigation by providing low-emissions baseload energy on a large scale.

This chapter will compare emissions levels for different types of energy production. Then it will evaluate the potential of both nuclear and renewable energy as low-emissions power sources and examine their viability for large-scale energy generation. The final section will conclude by discussing the future of nuclear energy and the potential for nuclear and renewable energy to work in conjunction with each other.

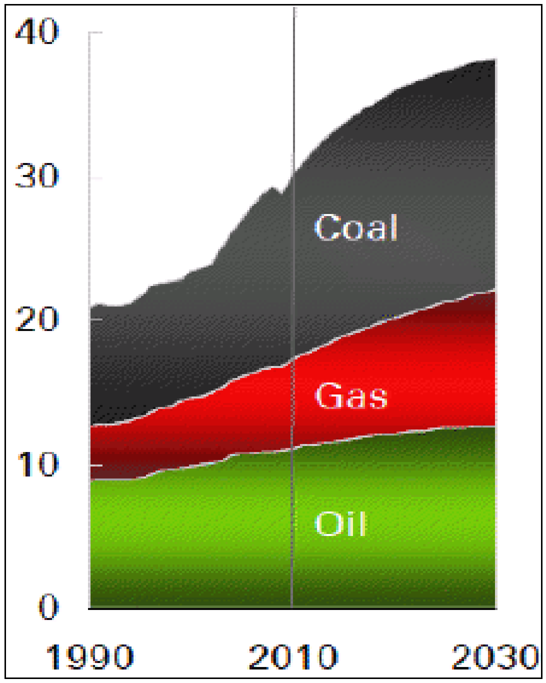
EMISSIONS DATA

Fossil Fuel Emissions

Global energy production is dominated by fossil fuel sources, which emit significant amounts of carbon dioxide; 80 percent of CO_2 emissions currently come from burning fossil fuels.[89] In 2005, global concentration of carbon had risen 35 percent from pre-industrial levels, and emissions have continued to grow.[90] Figure 3.1 shows the rising global emissions of fossil fuels.

[88] "Plans for New Reactors Worldwide," *World Nuclear Association*, http://www.world-nuclear.org/info/inf17.html (accessed Feb. 7, 2011).
[89] "Climate Change 101," *Pew Center*, 3, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006eb5903e68651015ce7c7a808911483f66?inline=1 (accessed Jan. 19, 2011).
[90] Ibid.

Figure 3.1. CO_2 Emissions from Energy Use by Fuel Type (billion metric tons)



Source: "Energy Outlook 2030," *BP*, http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2010_downloads/2030_energy_outlook_booklet.pdf (accessed Feb. 19, 2011).

Oil has been a major energy source and a cause of GHG emissions for many years. In the past two decades, global CO_2 emissions from oil have increased as global consumption of oil-fueled energy has risen, but the percentage of total global CO_2 emissions from oil has modestly decreased as the use of coal has increased faster than oil.[91] Emissions from oil power plants primarily come from the operation of the plant but additional emissions occur during exploration, extraction of oil, transportation, and refinement.[92]

[91] "International Energy Outlook 2010: Energy-Related Carbon Dioxide Emissions," *U.S. Energy Information Administration Independent Statistics and Analysis*, http://www.eia.doe.gov/oiaf/ieo/emissions.html (accessed Jan. 30, 2011).
[92] Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1550, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.

Natural gas is also a widely used fossil fuel with significant emissions. Its emissions are much lower than coal and significantly less than oil. Consequently, natural gas is preferred by many experts to other fossil fuels.[93] As with oil, the majority of emissions from natural gas occur during plant operation. Additional emissions arise from gas processing and from leakage during transportation. Natural gas combustion has consistently contributed to about 20 percent of global CO_2 emissions and will likely continue to do so.[94]

Coal is forecast to play a leading role in shaping the energy outlook of the next several decades. In recent years, the use of coal has increased rapidly, from 89.2 quadrillion British thermal units (Btu) in 1990 to 130.26 quadrillion Btu in 2010.[95] While coal use is declining in the West and in OECD countries overall, most energy forecasts agree that the total global use of coal for energy will dramatically rise in the near future, led by Asian non-OECD countries. Coal consumption could reach 206.06 billion Btu by 2035, with China and India alone consuming 112.37 and 15.46 quadrillion Btu respectively.[96] As the most carbon-intensive fossil fuel, a large increase in coal power use would greatly increase CO_2 emissions.[97] Most GHG emissions from coal occur

[93] Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1550, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.
[94] "International Energy Outlook 2010: Energy-Related Carbon Dioxide Emissions," *U.S. Energy Information Administration Independent Statistics and Analysis*, http://www.eia.doe.gov/oiaf/ieo/emissions.html (accessed Jan. 30, 2011).
[95] Ibid.
[96] Ibid.
[97] Ibid.

during the operation of coal-fired plants with additional emissions coming from mining and transport.[98]

Technologies to Reduce Emissions

As the large-scale use of fossil fuels cannot be expected to disappear in the near future, new technologies are emerging with the goal of reducing the share of fossil fuel energy in the global mix and replacing future use of oil and coal particularly. As discussed in Chapter One, carbon capture and storage (CCS) is often cited as a key component of future strategies to reduce carbon emissions. CCS is a new technology, primarily applicable to coal, in which CO_2 that would otherwise be emitted from power plants into the atmosphere is removed and stored, for example in depleted oil/gas reservoirs underground.[99] While individual components of this process have been successfully tested, CCS is still in the early stages of development and a large commercial demonstration of a full CCS system is not expected until 2020.[100] Additionally, cost estimates indicate that CCS will be highly expensive in the near future, and political issues surrounding CCS systems, such as responsibility for sequestered carbon, are yet to be settled. CCS therefore is marked by a high degree of uncertainty. While it may prove to be a valuable technology, it does not yet appear to be practical for use on a significant scale.

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[98] Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1550, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.

[99] "International Energy Outlook 2010: Will Carbon Capture and Storage Reduce the World's Carbon Dioxide Emissions?," *U.S. Energy Information Administration Independent Statistics and Analysis*, http://www.eia.doe.gov/ oiaf/ieo/wcde.html (accessed Feb. 5, 2011).

[100] "Integrated Sustainability Analysis," *University of Sydney*, 18, https://catalyst.uw.edu/workspace/file/download/ 94ccf2154b61861151978042a842006eb094ca37f4847aec237b251b7b2ec058?inline=1 (accessed Jan. 19, 2011).

In addition to specific technological advances such as CCS, many proposals for emissions reductions include improvements in energy efficiency. While emissions from fossil fuel use are expected to increase, technological improvements in energy efficiency could lead to less overall energy use, thereby offsetting rising emissions.[101] However, this assumption that increased energy efficiency will lead to less energy use is challenged by the "Jevons paradox," an economic theory originally proposed by William Jevons in the 19th century.[102] The theory posits that increased energy efficiency will make energy cheaper, more abundant, and readily available, which in turn will induce people to use more energy. If this principle proves accurate in the current context of energy use, improvements in efficiency will lead to more energy use and consequently more GHG emissions. A possible solution to this problem is a carbon tax or similar government measure that prevents efficiency improvements from lowering the price of energy. However, technological improvements in efficiency to reduce fossil fuel emissions do not currently appear to be viable for widespread use. Emissions reductions are more likely to come from alternative sources of energy.

Renewables

The use of renewable energy as an alternative to fossil fuels is increasing worldwide.[103] As low-emissions energy sources, renewables have the potential to lower global emissions by replacing fossil fuels to some extent. Wind, solar, and hydropower are three types of renewable energy that appear most viable for the next several decades.

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[101] "International Energy Outlook 2010: Highlights," *U.S. Energy Information Administration Independent Statistics and Analysis*, http://www.eia.doe.gov/oiaf/ieo/highlights.html (accessed Feb. 5, 2011).
[102] Blake Alcott, "Jevons' Paradox," *Ecological Economics* 54, no. 1 (2005): 11, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/352704625.
[103] "International Energy Outlook 2010: Highlights," *U.S. Energy Information Administration Independent Statistics and Analysis*, http://www.eia.doe.gov/oiaf/ieo/highlights.html (accessed Feb. 5, 2011).

The use of wind and solar power on a notable scale is fairly recent, but public support for these energy sources and new technologies to improve their efficiency and applicability are increasing. In order to determine the total emissions from energy sources such as renewables, researchers conduct life cycle assessments (LCAs), which take into account direct and indirect emissions from construction to decommissioning of a power system. LCAs have determined that the majority of emissions from renewable energy generally come from the construction of the power systems.[104] However, wind and solar power systems are intermittent, depending on the availability of wind and sunlight. They therefore often require a backup energy generator, which relies on fossil fuels. While emissions from backup fossil fuel generators are usually excluded from LCAs, they are a notable source of indirect emissions from wind and solar power.

Wind power is generally considered to have some of the lowest levels of GHG emissions among energy sources. GHG emissions from wind power are mainly concentrated in the production of turbines and construction of the power plant, which involve the use of fossil fuel energy.[105] Emissions from wind power plants vary with the type, size, and location of the plant. A particularly important factor is whether a plant is offshore or on-shore; offshore plants require much more steel and concrete for foundation construction and therefore tend to have higher emissions. A study of multiple LCAs of wind power plants found the range of emissions from offshore plants to be between 9 and 19 grams of carbon dioxide equivalent per kilowatt-hour of electricity (g CO_2 eq/kW h),

[104] Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1552, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.
[105] Ibid.

while emissions from on-shore plants range from 8 to 30 g CO_2 eq/kW h.[106] As wind power is a new energy source, technological improvements are expected to lower wind power emissions in the future.

Photovoltaic (PV) solar power is similar to wind power in that most emissions come from upstream of the plant operation stage. Solar power's emissions, while small compared to those of fossil fuels, are not insignificant. Construction of the modules for PV systems can account for up to 80 percent of emissions in a solar power plant's lifespan.[107] The carbon emissions from a 3 kW rooftop PV system were estimated to be 53.4 g CO_2 eq/kW h, with over 75 percent of emissions coming from construction.[108] As with other forms of renewable energy, the quality and type of a PV system affects its overall emissions. Generally, lifetime emissions are estimated to be between 43 and 73 g CO_2 eq/kW h, surpassing the typical emissions levels of both wind and hydropower.[109] However, technological advances continue to improve emissions levels.

There is a notable ambiguity in the scientific community concerning GHG emissions from hydropower. The size, type, and location of hydropower plants significantly affect a plant's overall emissions and the main sources of emissions in the plant's life. Generally, traditional large hydroelectric plants have higher emissions levels

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[106] Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1552, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.
[107] Ibid.
[108] Hiroki Hondo, "Life Cycle GHG Emission Analysis of Power Generation Systems: Japanese Case." *Energy: Technologies, Resources, Reserves, Demands, Impact, Conservation, Management, Policy* 30, no. 11-12 (2005): 2052, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/1430108750848.
[109] Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1552, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.

than run-of-river plants, which have much smaller reservoirs.[110] For run-of-river plants, emissions come mainly from the production of concrete and steel used in the plant's construction.[111] For traditional plants, emissions come from plant construction, deforestation of the reservoir area, decaying of organic matter in the reservoir (especially in tropical climates), and decommissioning.[112] Organic decay in a hydroelectric reservoir is especially important, as it emits both CO_2 and the much more potent GHG methane. When the entire life cycle of a large hydropower plant is considered in its entirety, emissions levels can reach up to 200 g/kW h when widespread anaerobic decay of submerged plant matter occurs.[113] While emissions from renewables are much lower than those of fossil fuels, they are not negligible.

Nuclear

Nuclear energy, like renewables, is a low-emissions power source and is increasingly viewed as a realistic way to lower GHG emissions. While nuclear is not a renewable source of power, the earth's abundant uranium supply ensures a reliable supply of fuel for nuclear energy.[114] The use of nuclear energy has so far been mainly

[110] Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1553, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.
[111] Hiroki Hondo, "Life Cycle GHG Emission Analysis of Power Generation Systems: Japanese Case." *Energy: Technologies, Resources, Reserves, Demands, Impact, Conservation, Management, Policy* 30, no. 11-12 (2005): 2051, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/1430108750848.
[112] Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1553, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.
[113] "Integrated Sustainability Analysis," *University of Sydney*, 74, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006eb094ca37f4847aec237b251b7b2ec058?inline=1 (accessed Jan. 19, 2011).
[114] Ibid, 46.

concentrated in OECD countries, and has not increased significantly in recent years.[115] Mixed public perceptions of nuclear energy in the West have served as a barrier against the widespread use of nuclear power. However, an expected non-OECD Asian led "nuclear renaissance" in the next decade is forecast to reassert nuclear power as a major energy source.[116] Unlike wind, solar, and CCS, nuclear energy is a well-established technology. Nuclear energy has been commercially produced for approximately 50 years and 30 countries currently use nuclear power.[117] Consequently, nuclear technology has the advantage of being time-tested on a large scale and emissions from nuclear power can be estimated with more accuracy than those of new renewables. Like renewable energy technology, however, nuclear technologies that improve efficiency and effectiveness are rapidly being developed as nuclear energy becomes more widespread.[118] New technologies will likely decrease emissions from nuclear energy in the future.

Estimates of emissions from nuclear reactors vary, although they tend to agree that emissions levels are low, particularly during the actual operation of nuclear plants. A survey of multiple LCAs of light water reactors (LWRs), the most common nuclear reactor type, concluded that lifetime emissions ranged from 2.8 to 24 g CO_2 eq/kW h.[119] A separate survey of LCAs for nuclear reactors, however, places emissions between 10

[115] Luis Echávarri, "Climate Change: The Case for Nuclear Energy." *Organization for Economic Cooperation & Development, The OECD Observer* 278, (2010): 42, http://uwashington.worldcat.org.offcampus.lib.washington.edu/ oclc/660805989.
[116] "Plans for New Reactors Worldwide," *World Nuclear Association*, http://www.world-nuclear.org/info/inf17.html (accessed Feb. 7, 2011).
[117] Robert H. Socolow and Alexander Glaser, "Balancing Risks: Nuclear Energy & Climate Change," *Daedalus* 138, no. 4 (2009): 35, https://catalyst.uw.edu/workspace/file/download/ 94ccf2154b61861151978042a842006e9a4ff41a1b48741af1f672c3cde5f9a9?inline=1.
[118] Luis Echávarri, "Climate Change: The Case for Nuclear Energy." *Organization for Economic Cooperation & Development, The OECD Observer* 278, (2010): 42, http://uwashington.worldcat.org.offcampus.lib.washington.edu/ oclc/660805989.
[119] Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1552, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.

and 130 g/kW h.[120] As with wind and solar power, emissions from the operation of nuclear power plants are negligible; LWRs emit between 0.74 and 1.3 g CO_2 eq/kW h during their operation.[121] Emissions from decommissioning of reactors and waste management and disposal are also small, ranging from 0.46 to 1.4 g CO_2 eq/kW h according to studies of LWRs.[122] Most emissions from nuclear power reactors occur upstream of their operation. Lower uranium ore grades tend to be correlated with higher CO_2 emissions from uranium mining.[123] As is the case for renewables, a notable fraction of a reactor's emissions comes from the use of fossil fuels to construct the reactor facilities.[124] Additionally, while power from nuclear reactors is stable during reactor operation, LWRs must be shut down one to two times each year to refuel.[125] During these downtimes, backup fossil fuel generators are generally required to maintain stable energy production, increasing the indirect emissions of reactors.

The uranium enrichment process can also contribute significantly to a reactor's lifetime emissions. For LWRs, enrichment using diffusion technology causes higher

[120] "Integrated Sustainability Analysis," *University of Sydney*, 53, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006eb094ca37f4847aec237b251b7b2ec058?inline=1 (accessed Jan. 19, 2011).
[121] Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1551, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.
[122] Ibid.
[123] "Integrated Sustainability Analysis," *University of Sydney*, 45, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006eb094ca37f4847aec237b251b7b2ec058?inline=1 (accessed Jan. 19, 2011).
[124] Luis Echávarri, "Climate Change: The Case for Nuclear Energy." *Organization for Economic Cooperation & Development, The OECD Observer* 278, (2010): 42, http://uwashington.worldcat.org.offcampus.lib.washington.edu/ oclc/660805989.
[125] "Nuclear Power Reactors," *World Nuclear Association,* http://www.world-nuclear.org/info/inf32.html (accessed Jan. 20, 2011).

emissions than centrifuge technology.[126] Diffusion technology requires large amounts of electricity, which is generally provided by fossil fuels, particularly coal.[127] An analysis of emissions from a typical Japanese boiling water reactor assumed that 89 percent of the reactor's uranium was enriched using diffusion technology. The analysis found that enrichment emitted 15 g CO_2 /kW h, accounting for 62 percent of the reactor's lifetime emissions.[128] However, centrifuge technology is forecast to largely replace diffusion technology, indicating that emissions from the enrichment process will likely decrease.

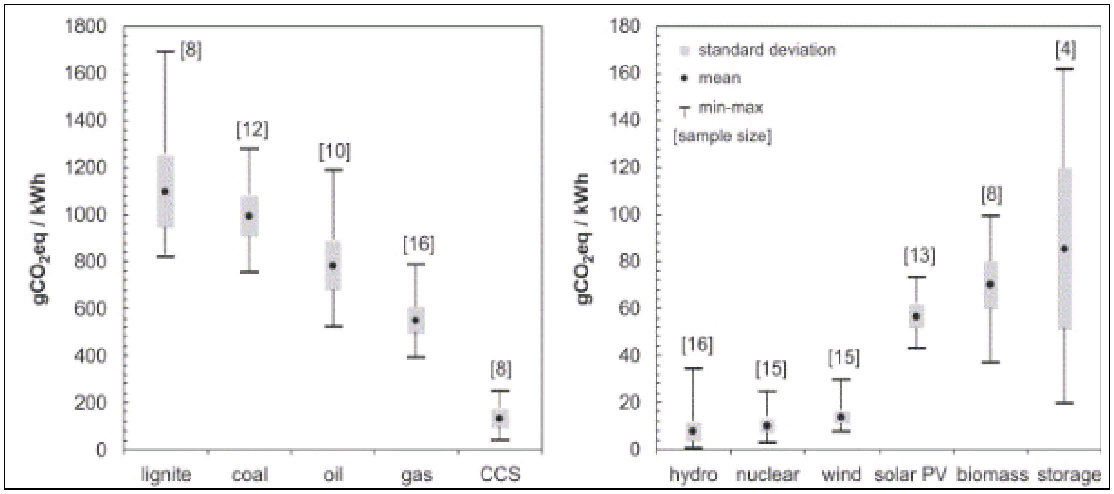
Reprocessing of spent fuel does not appear to be a source of carbon emissions. The Japanese reactor's total lifetime emissions were 24.2 g CO_2 /kW h.[129] A hypothetical case in the same analysis examined the emissions effects of reprocessing used fuel. Although reprocessing contributed a small emissions increase of 0.7 g CO_2 /kW h, the substitution of some uranium and plutonium extracted from the spent fuel for primary uranium offset this increase, and the reprocessing reactor's total emissions were estimated to be 22.2 g CO_2 /kW h.[130]

Emissions Comparison

The following graph represents a compilation of data from LCAs of fossil fuels, renewables, and nuclear power, comparing current emissions from each energy source.

[126] Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1552, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.
[127] Hiroki Hondo, "Life Cycle GHG Emission Analysis of Power Generation Systems: Japanese Case." *Energy: Technologies, Resources, Reserves, Demands, Impact, Conservation, Management, Policy* 30, no. 11-12 (2005): 2050, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/1430108750848.
[128] Ibid.
[129] Ibid.
[130] Ibid.

Figure 3.2. Life Cycle Emissions of Energy Sources



Source: Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1549, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.

When the entire life of an energy system is considered, no source is truly emissions-free. Both renewables and nuclear power emit substantially less GHGs than fossil fuels, and nuclear has the lowest maximum estimated emissions of any energy source. Emerging technologies for all of these energy sources will likely increase their efficiency and reduce emissions. In the near future, however, it appears that fossil fuels' emissions levels are unsustainably high. Renewables and especially nuclear power present potential alternatives.

CLIMATE CHANGE MITIGATION POTENTIAL

Current and Future Emissions Reductions from Energy Technologies

Nuclear power represents only a modest percentage of world energy use, yet it has made definite contributions to emissions reductions. Nuclear energy currently supplies approximately 14 percent of the world's electricity, and over 20 percent of electricity in

OECD countries.[131,132] In 2007, worldwide use of nuclear energy totaled 27.1 quadrillion Btu.[133] By supplying energy that would otherwise almost certainly be provided by fossil fuels, nuclear power has been lowering emissions since its initial commercial deployment. According to one calculation, cumulative CO_2 emissions saved due to the use of nuclear instead of coal power are approximately 60 gigatonnes of carbon dioxide equivalent (Gt CO_2 eq), and the use of nuclear energy instead of fossil fuels for electricity currently saves 2 Gt CO_2 eq per year.[134] 10 percent of world CO_2 emissions are saved from nuclear power plants.[135] If all nuclear power plants in OECD countries were replaced by fossil fueled plants, emissions from the energy sector would rise by up to a third.[136] Figure 3.3 compares actual power sector emissions with emissions avoided by the use of nuclear, hydropower, and other renewables.

In order to raise the contribution of nuclear energy to CO_2 emissions reduction from today's level of about 10 percent to 20 percent in 2030, one analysis estimates that global nuclear capacity must increase by approximately 700 gigawatts electrical

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131 "Integrated Sustainability Analysis," *University of Sydney*, 44, https://catalyst.uw.edu/workspace/file/download/ 94ccf2154b61861151978042a842006eb094ca37f4847aec237b251b7b2ec058?inline=1 (accessed Jan. 19, 2011).

132 Luis Echávarri, "Climate Change: The Case for Nuclear Energy." *Organization for Economic Cooperation & Development, The OECD Observer* 278, (2010): 42, http://uwashington.worldcat.org.offcampus.lib.washington.edu/ oclc/660805989.

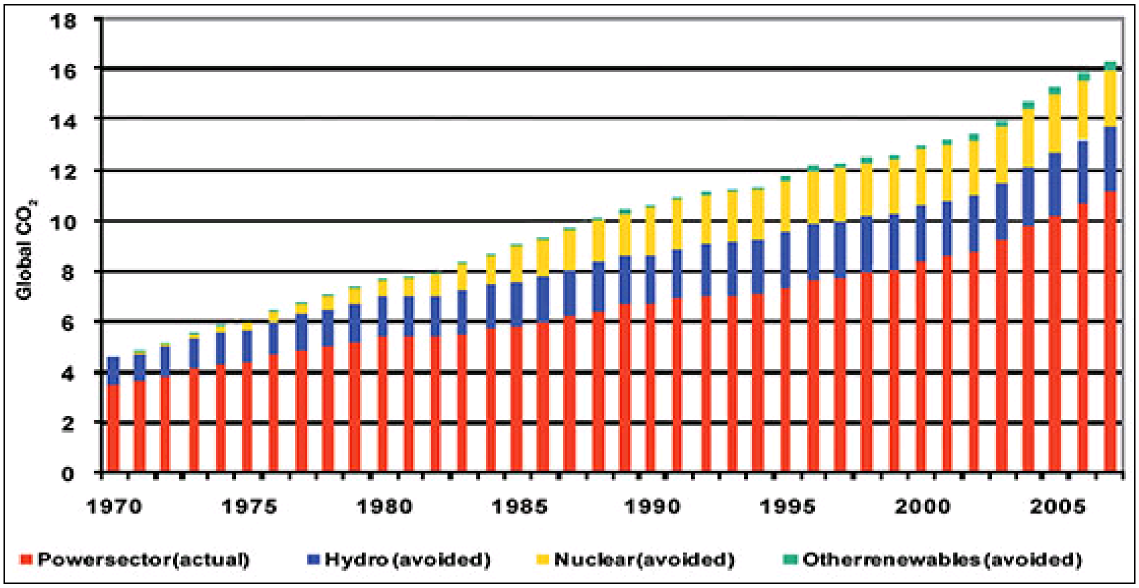
133 "International Energy Outlook 2010: Highlights," *U.S. Energy Information Administration Independent Statistics and Analysis*, http://www.eia.doe.gov/oiaf/ieo/highlights.html (accessed Feb. 5, 2011).

134 Luis Echávarri, "Climate Change: The Case for Nuclear Energy." *Organization for Economic Cooperation & Development, The OECD Observer* 278, (2010): 42, http://uwashington.worldcat.org.offcampus.lib.washington.edu/ oclc/660805989.

135 Nicholas Apergis, James E. Payne, Kojo Menyah, and Yemane Wolde-Rufael, "On the Causal Dynamics between Emissions, Nuclear Energy, Renewable Energy, and Economic Growth." *Ecological Economics* 69, no. 11 (2010): 2256, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/687611206.

136 Ibid.

Figure 3.3. Emissions Avoided by Low-Emissions Energy Sources (Gt)



Source: "Judge Nuclear on its Merits," *International Atomic Energy Agency,* http://www.iaea.org/OurWork/ ST/NE/judge-nuclear.html (accessed Feb. 2, 2011).

(GWe).[137] This is a major increase from the current net capacity of 376 GWe and it is unlikely to be achieved by 2030.[138] However, a recent International Atomic Energy Agency (IAEA) estimate places world nuclear capacity in 2030 between 546 and 803 GWe, and the Nuclear Energy Agency estimates that by 2050, capacity could be between 540 and 1400 GWe.[139,140] If the low scenario for 2050 proves correct, annual CO_2 emissions savings from nuclear energy will be approximately 0.5 Gt CO_2 eq. In the high scenario, however, world nuclear capacity would increase by over 1000 GWe and nuclear energy would save 4.5 Gt CO_2 eq annually.[141] Considering the expected increase in

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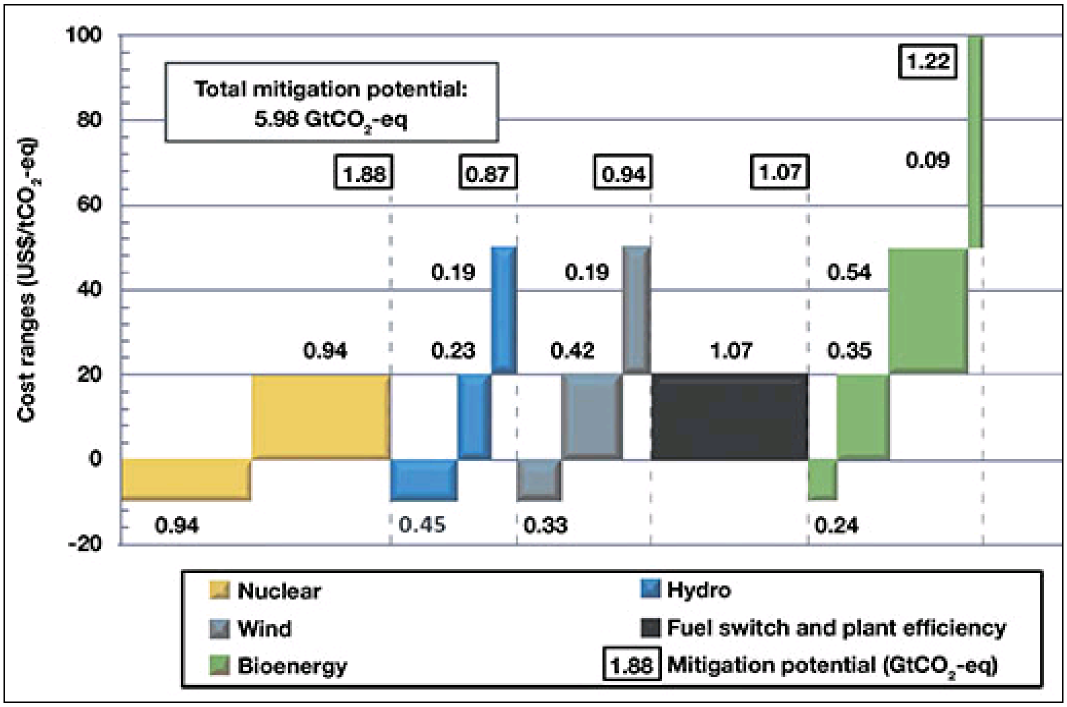
[137] Shinzo Saito, "Role of Nuclear Energy to a Future Society of Shortage of Energy Resources and Global Warming," *Journal of Nuclear Materials* 398, no. 1 (2010): 6, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/1430549588984.
[138] "Plans for New Reactors Worldwide," *World Nuclear Association*, http://www.world-nuclear.org/info/inf17.html (accessed Feb. 7, 2011).
[139] Ibid.
[140] Luis Echávarri, "Climate Change: The Case for Nuclear Energy." *Organization for Economic Cooperation & Development, The OECD Observer* 278, (2010): 43, http://uwashington.worldcat.org.offcampus.lib.washington.edu/ oclc/660805989.
[141] Ibid.

nuclear energy use, one analysis has estimated that nuclear energy could avoid 180 Gt CO_2 emissions until 2100.[142] Figure 3.4 shows the potential of several low-emissions energy sources to reduce emissions in 2030. In this analysis, nuclear power is the most viable energy option in terms of both mitigation potential and cost.

Figure 3.4. Mitigation Potential and Cost of Energy Technologies in 2030



Source: "Judge Nuclear on its Merits," *International Atomic Energy Agency,* http://www.iaea.org/OurWork/ST/NE/judge-nuclear.html (accessed Feb. 2, 2011).
Note: The width of each rectangle represents the mitigation potential of each technology for the corresponding carbon cost range on the vertical axis.

Renewables, like nuclear power, are a growing energy source and have also contributed to lowering GHG emissions. In 2007, global use of renewable energy was 48.83 quadrillion Btu.[143] Although one analysis suggests that "renewable energy supply

[142] "Integrated Sustainability Analysis," *University of Sydney*, 44, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006eb094ca37f4847aec237b251b7b2ec058?inline=1 (accessed Jan. 19, 2011).

[143] "International Energy Outlook 2010: Highlights," *U.S. Energy Information Administration Independent Statistics and Analysis,* http://www.eia.doe.gov/oiaf/ieo/highlights.html (accessed Feb. 5, 2011).

has to account for 8.39 percent of total energy supply before any impact on mitigating CO_2 emissions is observed," Figure 3.3 shows that hydropower has been responsible for significant emissions reductions for a longer period of time than nuclear.[144] Almost all emissions reductions that can be attributed to renewables have so far come from hydropower. Hydropower has been in use for much longer than new technologies such as wind and solar, and has been widely used for large-scale electricity generation in developed and some developing countries. While the role of wind and solar power in reducing emissions is expected to grow as these technologies become established, hydropower will remain the major renewable contributor for some time. Figure 3.4 estimates the future mitigation potential of both hydropower and wind to be important, but not comparable to other technologies. As the graph shows, emissions reductions from the use of hydropower and wind power are expected to be more costly than those of nuclear in the future.

Renewable Energy on a Large Scale

Renewables, like nuclear power, are expected to experience significant growth in the next several decades. However, it is not certain that a large increase in renewables is realistic in the near future. Wind and solar power are newly emerging energy technologies. While their efficiency is rapidly increasing, wind and solar power lack the technology required to be applicable on a large scale. These power sources are disadvantaged by their inability to store energy and provide baseload electricity.[145] Both

[144] Nicholas Apergis, James E. Payne, Kojo Menyah, and Yemane Wolde-Rufael, "On the Causal Dynamics between Emissions, Nuclear Energy, Renewable Energy, and Economic Growth." *Ecological Economics* 69, no. 11 (2010): 2258, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/687611206.
[145] Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1552, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.

are intermittent energy sources, relying on the immediate availability of wind and sunlight to generate energy. They are unreliable for use as a source of baseload electricity because a prolonged lack of wind or sun could effectively cut off the energy supply. Efforts to store energy generated by wind and solar systems generally add to emissions and costs themselves.[146] While wind and solar are able to provide low-emissions energy, on a large scale they are currently only suitable as a supplement to a baseload source, not as primary power providers.

Unlike wind and solar energy, hydropower has been produced on a large scale for decades. Hydropower has the potential to grow as a major energy source in the next several decades, but its growth will be concentrated in certain regions. Many Western countries have already exploited their most cost-effective sites and run out of large rivers to dam.[147] Future hydropower growth, therefore, will come mainly from the developing world, particularly from Asia, which has more unexploited economic and technical hydropower potential than any other region.[148] However, hydropower faces serious and growing criticism for its negative environmental and social impacts. While small-scale run-of-river hydropower plants have very few negative impacts, the large hydropower plants that dominate world hydroelectricity production are criticized for their "displacement of residents from flooded areas, transformation of traditional land use, disturbance and fragmentation of faunal habitat, obstruction of fish passage, [and]

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[146] Daniel Weisser, "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies," *Energy* 32, no. 9 (2007): 1552, http://uwashington.worldcat.org.offcampus.lib.washington.edu/oclc/442681067.
[147] "Integrated Sustainability Analysis," *University of Sydney*, 75, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006eb094ca37f4847aec237b251b7b2ec058?inline=1 (accessed Jan. 19, 2011).
[148] Ibid.

thermal pollution."[149] One of the most widely criticized hydropower stations is China's Three Gorges Project on the Yangtze River, the largest hydroelectric project in the world. Completed in 2009, the project's total capacity is 22,500 megawatts (MW).[150] Although the project is intended to benefit China by providing low-emissions electricity, controversy has arisen over the relocation of approximately 1.4 million rural residents by the Chinese government to clear land for the dam and reservoir.[151] In addition, the project's reservoir has become highly polluted and the reservoir's high water levels have caused deadly landslides.[152] Such consequences become important in light of China's plans for many more large-scale hydropower dams; hydro plants currently under construction total over 50 GW.[153] The future of hydropower will largely depend on whether its environmental and social impacts can be successfully reduced.

Nuclear Energy on a Large Scale

The "nuclear renaissance" expected in the next decade includes plans for new reactors in many countries, indicating a large increase in nuclear energy use worldwide. While many of these plans are ambitious, it is likely that such an increase is realistic. Nuclear power has already been proven as a large-scale source of energy in many OECD countries. The "renaissance," however, is expected to be based mainly in Asian non-

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149 "Integrated Sustainability Analysis," *University of Sydney*, 75, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006eb094ca37f4847aec237b251b7b2ec058?inline=1 (accessed Jan. 19, 2011), 82.
150 Ibid.
151 Shai Oster, "Three Gorges Drama: Why Chinese Dam is Forcing Yet another Mass Exodus; Pollution, Poverty Spur Relocation of 4 Million; Death in a Demolition," *Wall Street Journal* (2007): A1, http://proquest.umi.com.offcampus.lib.washington.edu/pqdweb?did=1377951331&sid=1&Fmt=4&clientId=2302&RQT=309&VName=PQD.
152 Ibid.
153 "Integrated Sustainability Analysis," *University of Sydney*, 79, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006eb094ca37f4847aec237b251b7b2ec058?inline=1 (accessed Jan. 19, 2011).

OECD countries, many of which are building or planning their first nuclear reactors. While their short-term contribution to the world's nuclear renaissance is expected to be small, some of these countries such as Vietnam, Turkey, and Iran already have committed plans for nuclear reactors.[154] However, most of the new reactors expected in the next several decades will be built in countries such as China and India that are well experienced in using nuclear technology and can afford the up-front costs associated with new nuclear reactors.[155] Currently, there are 117 operating nuclear reactors in Asia, with 42 more under construction, 90 more planned, and proposals for another 170.[156]

Nuclear energy's ability to provide reliable baseload electricity makes it practical for large-scale use. Nuclear power's output is fairly inflexible which hinders its ability to meet varying electricity demands but also makes nuclear electricity reliable and well suited to large electricity grids.[157] Nuclear power's fuel supply is stable, and nuclear technologies have proven their ability to produce constant, reliable electricity supplies on a large scale. Furthermore, nuclear energy is highly efficient, requiring small amounts of uranium or plutonium to produce large amounts of energy. Only one ton of uranium is required to produce 1000 MW of power for a year, compared to three million tons of coal, and uranium supplies are abundant.[158] Nuclear energy's low input levels and abundant fuel supply ensure that a large-scale increase in nuclear power production will

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[154] "Emerging Nuclear Energy Countries," *World Nuclear Association*, http://www.world-nuclear.org/info/inf102.html (accessed Feb. 8, 2011).
[155] "Plans for New Reactors Worldwide," *World Nuclear Association*, http://www.world-nuclear.org/info/inf17.html (accessed Feb. 7, 2011).
[156] "World Nuclear Power Reactors & Uranium Requirements," *World Nuclear Association.* http://www.world-nuclear.org/info/reactors.html (accessed Feb. 14, 2011).
[157] Robert H. Socolow and Alexander Glaser, "Balancing Risks: Nuclear Energy & Climate Change," *Daedalus* 138, no. 4 (2009): 35, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006e9a4ff41a1b48741af1f672c3cde5f9a9?inline=1.
[158] Ibid.

be possible without concerns about fuel shortages or inefficiencies. Additionally, nuclear power generation does not use much land, an advantage over renewables.[159]

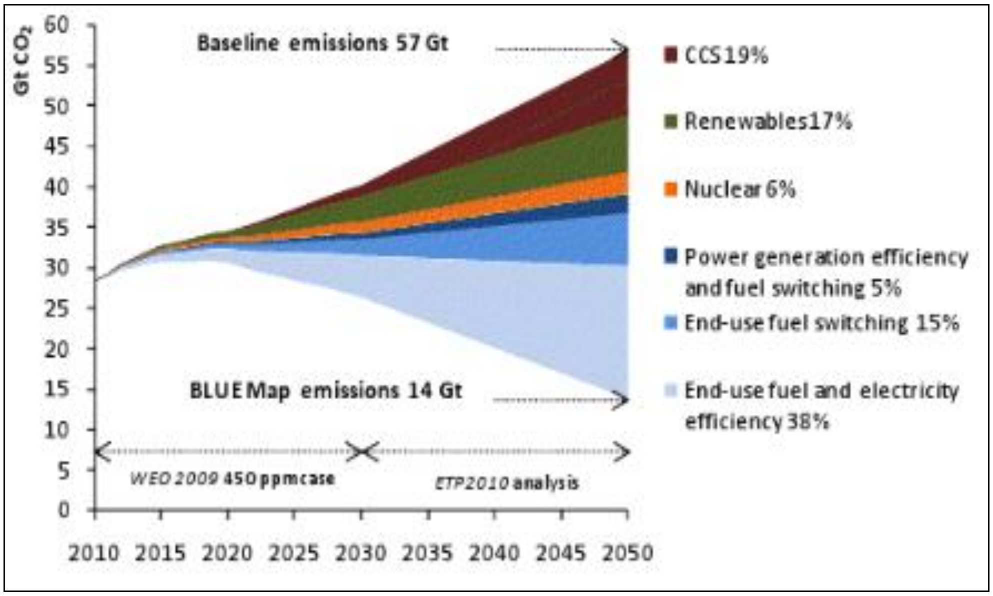
Energy and Emissions Outlook

The next several decades will most likely see important changes in the main sources of global energy. A prominent and often cited energy forecast is the International Energy Agency's (IEA) Energy Technology Perspectives 2010. The report analyses and compares two likely scenarios for world energy use through 2050. The first is the Baseline scenario, which assumes that governments do not implement any new energy or climate policies, and the second is the BLUE Map scenario, which presents the least expensive path to halving world energy-related CO_2 emissions by 2050 compared to 2005 levels.[160] Figures 3.5 and 3.6 illustrate the potential contributions of low-emissions technologies towards achieving the BLUE Map emissions levels.

In this scenario, the overall contribution of nuclear power in reducing global CO_2 emissions is fairly small, only six percent, while the annual contribution of nuclear power in reducing CO_2 emissions specifically from the electricity sector is considerably larger, at nineteen percent. However, nuclear energy's contribution may prove larger than these models predict; as has been discussed earlier, nuclear power has the potential to contribute significantly to global energy supply and emissions reductions, and the viability of nuclear energy technology is more reliable than many of the other technologies in the BLUE Map scenario. CCS is expected to play a large role in

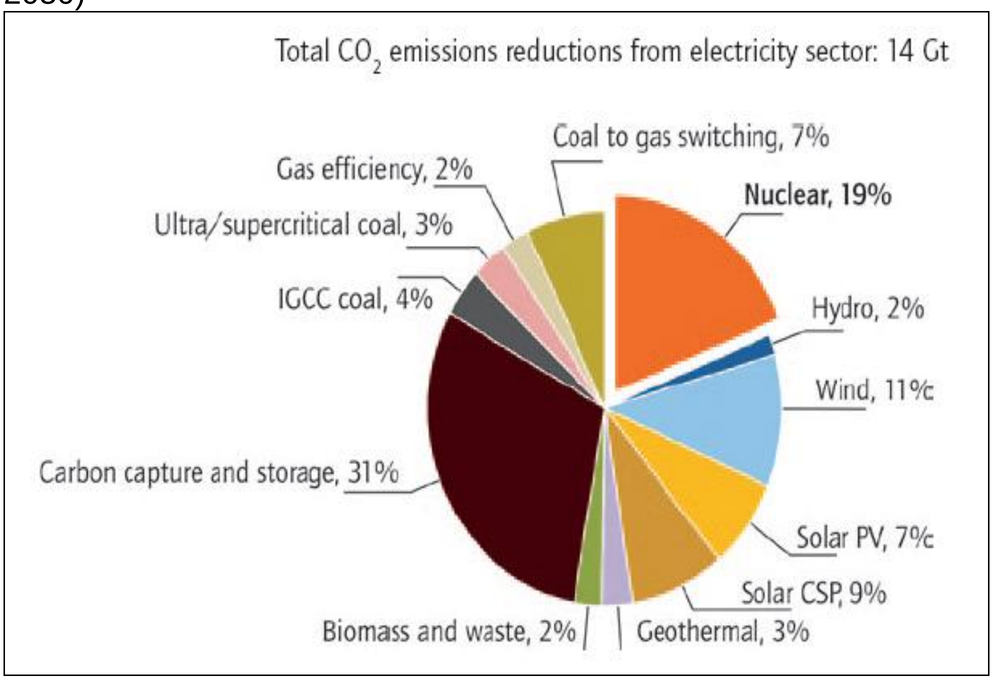
[159] "Integrated Sustainability Analysis," *University of Sydney*, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006eb094ca37f4847aec237b251b7b2ec058?inline=1 (accessed Jan. 19, 2011).
[160] "Technology Roadmap: Nuclear Energy," *International Energy Agency*, 5, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006ec64dc36cb042e71265aedfc9d7be9db8?inline=1 (accessed Jan. 19, 2011).

Figure 3.5. Energy Technologies for Reducing Global CO_2 Emissions



Source: "Energy Technology Perspectives 2010," *International Energy Agency*, http://www.iea.org/speech/2010/Tanaka/etp2010_berlin.pdf (accessed Jan. 29, 2011).

Figure 3.6. Annual Electricity Sector CO_2 Emissions Reductions (BLUE Map 2050)



Source: "Technology Roadmap: Nuclear Energy," *International Energy Agency*, 6, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006ec64dc36cb042e71265aedfc9d7be9db8?inline=1 (accessed Jan. 19, 2011).

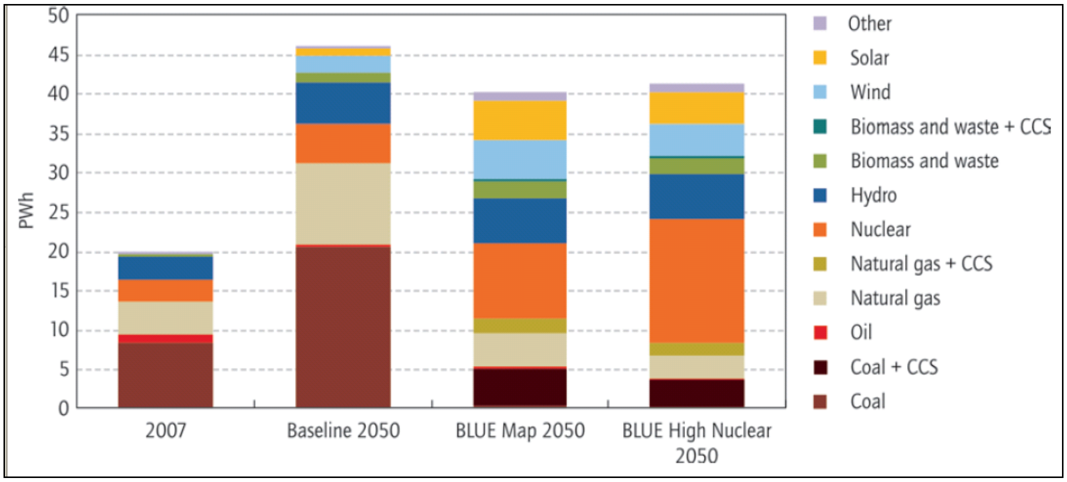
emissions reductions, but it has not yet proven its ability to function on a large scale. Electricity efficiency's contribution is expected to predominate in reducing overall CO_2 emissions, but the problems of the Jevons paradox may render improvements in efficiency ineffective. Renewables are expected to contribute substantially as well but there are significant uncertainties involved in scaling up the use of renewables. Nuclear, however, is well suited to large-scale energy production and could be scaled-up significantly in the next several decades. If any of the IEA scenario's "key technologies" fail to fulfill their expected contributions to emissions reductions, nuclear energy use could most likely be increased to reach the emissions target and nuclear power's total contribution would likely become much greater.

The IEA's electricity sector scenarios highlight the importance of nuclear energy in the coming decades. Nuclear energy has the potential to play a large role in reducing emissions because it is expected to become the largest source of electricity by 2050 under the BLUE Map scenario.[161] Under this scenario, world nuclear capacity would reach 1200 GW in 2050, providing 9,600 terawatt-hours of electricity (24 percent of the world total). Figure 3.7 shows the contribution of various technologies to world electricity supply in 2007 and in several scenarios for 2050. The BLUE Map High Nuclear scenario places world nuclear capacity at 2,000 GW, dominating electricity supply and emissions reductions.[162] Even in the baseline scenario in which nuclear power is not emphasized, its capacity is expected to increase.

[161] "Technology Roadmap: Nuclear Energy," *International Energy Agency*, 17, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006ec64dc36cb042e71265aedfc9d7be9db8?inline=1 (accessed Jan. 19, 2011).

[162] Ibid.

Figure 3.7. Global Electricity Production by Source (Petawatt Hours)



Source: "Technology Roadmap: Nuclear Energy," *International Energy Agency*, 17, https://catalyst.uw.edu/workspace/file/download/94ccf2154b61861151978042a842006ec64dc36cb042e71265aedfc9d7be9db8?inline=1 (accessed Jan. 19, 2011).

CONCLUSION

The information presented in this chapter has compared the GHG emissions of fossil fuels, renewables, and nuclear energy and examined the potential for low-emissions energy sources to be used on a large scale. While fossil fuels currently dominate global energy production, their high emissions levels are unsustainable if severe climate change consequences are to be avoided. Methods of reducing emissions from fossil fuels exist, including CCS and increasing electricity efficiency, but there is significant uncertainty concerning their emissions reducing capacity. Renewables, namely hydropower, wind, and solar power, present a low-emissions alternative to fossil fuels. However, using renewables on a large scale may not be feasible in the case of wind and solar, and often has negative social and environmental impacts in the case of hydropower. Nuclear power is the other major alternative to fossil fuels. Nuclear power is a low-emissions energy source and it is known to be successful on a large scale. The current nuclear "renaissance" is expected to largely increase the role of nuclear energy in providing electricity and reducing emissions worldwide.

Nuclear energy has the potential to contribute significantly to global emissions reductions. Depending on the scale of nuclear power use in the next several decades, it could play a leading role in mitigating climate change. However, this chapter has also shown that nuclear energy alone is not sufficient to achieve the required emissions reductions described in Chapter One. As the IEA scenarios demonstrate, future energy demand will be met with a combination of sources. Under the current capacity constraints of low-emissions sources, fossil fuels will still provide a large share of global energy, but both renewables and nuclear power will play an increasing role. Despite the common public perception of a conflict between nuclear and renewables, these two low-emissions sources are undoubtedly compatible with each other. Indeed, neither source alone can completely eliminate emissions, but renewable and nuclear energy can work in tandem to lower emissions significantly in the next several decades. Nuclear power has the potential to be an important component of a multidimensional approach to mitigating climate change.

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"Energy Technology Perspectives 2010." *International Energy Agency*. http://www.iea.org/ speech/2010/Tanaka/etp2010_berlin.pdf (accessed Jan. 29, 2011).

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Part II

The Economics of Nuclear Power

Chapter Four

THE COST OF POWER: AN ECONOMIC COMPARISON OF ENERGY TECHNOLOGIES

Sandy Yi-hsuan Lee

Abstract:

The economics of nuclear power is a major factor that will impact growth of the industry and thus its role in reducing carbon emissions. Compared to fossil fuel energy, nuclear power plants are expensive to build yet cheap to run. There are a number of individual cost factors that determine the ultimate expense for any nuclear plant, including design, land, insurance, interest on investment, construction, with fuel and maintenance accounting for a very small proportion of the total cost. The discount rate can also be very important, given the length of time that plants operate. Costs tend to be higher in the U.S. and Europe and lower in Asia, particularly in China and South Korea. The economic benefits of standardization can be seen in the nuclear program of France and are equally demonstrated by the current programs in Asia. Standard designs have led to shorter construction times, more efficient use of materials, and reduced labor needs. To guarantee the economic competitiveness of its own nuclear power, the U.S. should learn from the experience of East Asia. Countries here are setting the pace for lower cost plants of the future.

INTRODUCTION

The economics of nuclear power is a core determinant for the growth of the industry and thus its role as an option to lower global carbon emissions. Economic considerations differ significantly for nuclear compared to other major sources of baseload electricity, such as coal and natural gas. Nuclear plants are expensive to build and cheap to run, with costs directly affected by the scale of construction and regulation. The Americas and Europe have relatively mature nuclear industries and have thus created a more complex regulatory framework. The Three Mile Island disaster in 1979 and Chernobyl accident in1986 launched programs and regulatory interventions to secure operational safety.[163] These regulations helped cause delays in plant construction and

[163] H-Holger Rogner and A. McDonald. "The Future of Nuclear Power: A Global and Regional Outlook." IAEA, 2009, 25.

cost overruns in the West. Thus, high costs of building a nuclear power plant are often said to be the Achilles heel of this technology. However, this has not been the case in Asia, center of the so-called "nuclear renaissance," which has benefited from advantages in the post-Chernobyl era. Today, both the West and the East are motivated to reduce overall costs and improve efficiency by developing new reactor technologies but it is in Asia where actual construction is happening and therefore where the economic realities for new plants are becoming apparent.

The economics of nuclear power are unique compared to that of other forms of energy production. Overall, nuclear power has very high capital, or start-up costs, that "front load" the total investment. Yet, nuclear power plants have comparative advantages after construction is completed. The operation and maintenance costs of plants and fuel are both low and consistent compared to fossil fuel power plants. Thus, cost reductions are a main priority for both the West and Asia in order to secure a more economically feasible expansion of nuclear power. Cost differences in nuclear power between the West and the East are due to technological innovations and particularly the deployment of plant standardization. The U.S. built its plants decades ago, without standardization, while Asian nations, inspired in part by the example of France, have applied more standardized policies in design and construction. This report will argue that innovations and improvements could indicate a new era for nuclear power and enable the technology to become economically competitive. The U.S., which has not built a nuclear plant for some time, can investigate and learn from the Asian experience.

This report will be divided into four parts. First, economic costs of nuclear and its comparison with other forms of energy production will be presented. Basic knowledge of nuclear costs and characteristics of each cost will be discussed. Then, the report will present the cost comparisons between the U.S., China, Japan, and South Korea. Third, economic benefits of standardization will be discussed based on a comparison of France and the U.S. Lastly, cost trends of energy resources and future technology will be presented to give a global perspective on the possibility of making nuclear power more economically competitive.

ECONOMIC COSTS OF NUCLEAR POWER

Categorization

A standard categorization of the costs is necessary for effective assessment of nuclear economics today.[164] There are four components to the economic costs of nuclear power: capital costs, operations and maintenance (O&M) costs, fuel costs, and back-end costs. Capital costs are incurred during the planning, preparation and construction of new nuclear power plants.[165] O&M costs are those related to administration, management support and upkeep of a power station. Fuel costs reflect the price of uranium. Finally, back-end costs include the expenses incurred due to decommissioning, long-term management, and waste disposal. There are two specific calculations devised for convenient comparison of nuclear costs. The "overnight capital cost" equals the engineering-procurement and construction cost (EPCC) that excludes financing and escalation due to increased costs of material and labor, and inflation. The "levelized costs of electricity" (LCOE) are the average costs of all these elements in terms of

[164] "The Economics of Nuclear Power." The World Nuclear Association. http://www.world-nuclear.org/info/inf02.html (accessed Feb. 10, 2011).
[165] Paul Joskow. The Future of Nuclear Power in the United States: Economic and Regulatory challenges. Working Paper06-019. (MIT Center for Energy and Environmental Policy Research, 2006) 11-12.

produced electricity.[166] The calculation is generalized so that there is a base for comparisons of costs both among different nuclear plants and with other types of plants.

Economic Costs: Detailed Breakdown

The economic costs of nuclear power are evaluated based on accumulative data collection from past and future projections. The IAEA has a good definition of what critically determines the economics of nuclear power; the economics depend on national and regional conditions, which include the costs of capital, land, labor and materials, insurance, the regulatory environment, and the availability and costs of alternative generating technologies.[167] Most of these are included in capital cost. The capital costs may account for 60 percent or more of the levelized cost of electricity (LCOE).[168] In the pursuit of short-term profit returns, nuclear power's high front-loaded cost structure is a disadvantage. Yet construction costs per kW for nuclear plants have fallen considerably over the past few decades due to standardized design, shorter construction times, and more efficient generating technologies. A major factor is the length of time required for construction. Time-related charges, such as interest on investment debt and escalation of costs (e.g. for raw materials, labor, etc.) during the period of construction can add significantly to the overall expense of building a plant. The ability to shorten this period has proven to be very important. Further benefits are expected as nuclear technology becomes even more standardized around a few globally accepted designs.[169]

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[166] "The Economics of Nuclear Power." The World Nuclear Association. http://www.world-nuclear.org/info/inf02.html (accessed Feb. 10, 2011).
[167] IAEA. Financing of New Nuclear Power Plants. No. NG-T-4.2. Vienna, 2008. 4
[168] IAEA , *Issue to Improve the Prospects of Financing Nuclear Power Plants*, No. NG-T-4.1, Vienna, 2009, 4.
[169] "The New Economics of Nuclear Power," *WNA Report*, http://www.world-nuclear.org/reference/pdf/economics.pdf (accessed Feb. 15 2011).

Financial costs are related to the uncertainty embedded in the regulatory infrastructure and are cited as one of the main deterrents to private investment in new nuclear power plants. Governments can have a major impact in this realm by establishing a stable legal infrastructure and set of policies for risk management, which can help drive down costs. Financial supports such as funding and loan guarantees would mitigate the high level of risk. Uncertainties, meanwhile, can delay construction time and greatly lower the confidence in investment.[170] Financial costs are expected to fall as new approaches are developed and tested to increase certainty and to lower investor risk. Meanwhile, in many countries, licensing procedures are being streamlined. This will retain rigorous standards but reduce regulatory cost and uncertainty by establishing predictable technical parameters and scheduling, from design certification to construction and granting of operating licenses.[171]

Operating costs of nuclear power plants are directly related to the level of know-how of the utilities that operate the plants. A pooling of sufficient knowledge and experience can minimize the costs.[172] Over the last twenty years, as such experience has grown, operating costs have fallen steadily due to the increase in capacity factors, which have squeezed much more output (up to 35 percent more) from the same generating capacity. Owners of nuclear plants have found it worthwhile to invest in nuclear plant refurbishment and capacity upgrades. Nuclear power's low marginal cost and its high

[170] IAEA. *Financing of New Nuclear Power Plants*, No. NG-T-4.2, Vienna, 2008, 3
[171] The New Economics of Nuclear Power. WNA Report. http://www.world-nuclear.org/reference/pdf/economics.pdf (accessed Feb. 15, 2011).
[172] "Everything You Want to Know about Nuclear power." http://nuclearinfo.net/Nuclearpower/WebHomeCostOfNuclearPower (accessed Feb. 3, 2011).

degree of price stability and predictability have also encouraged nuclear plant owners to seek operating license extensions for nearly all reactors.[173]

Fuel costs, including used fuel management and waste disposal, are relatively minimal.[174] Decommissioning of a nuclear plant involves removing it from service, dismantling it, and reducing residual radioactivity to a level that permits termination.[175] Waste and decommissioning costs, represent a tiny fraction of the lifetime costs of a reactor's operation. Nuclear plant economics are greatly insensitive to these costs and will become more so as fuel efficiency increases and as waste and decommissioning costs are spread over longer reactor lifetimes.[176]

Future projections of overnight costs of nuclear generating technology range from 1,600 to 5,900 U.S. dollars per kilowatt electricity (USD/kWe). Yet, at a 5 percent discount rate, the LCOE varies between 29 to 82 USD/megawatt (Mwh). Investment costs account for the largest share, around 60 percent, while O&M costs account for 24 percent and fuel cycle costs for 16 percent. These calculations are based on a 60-year plant lifetime. At a 10 percent discount rate, the LCOE ranges from 42 to 137 USD/Mwh. In this case, investment costs comprise 75 percent of the total, O&M for 15 percent, and fuel costs for 9 percent.[177] The breakdown of operating costs is shown in Figure 4.1.

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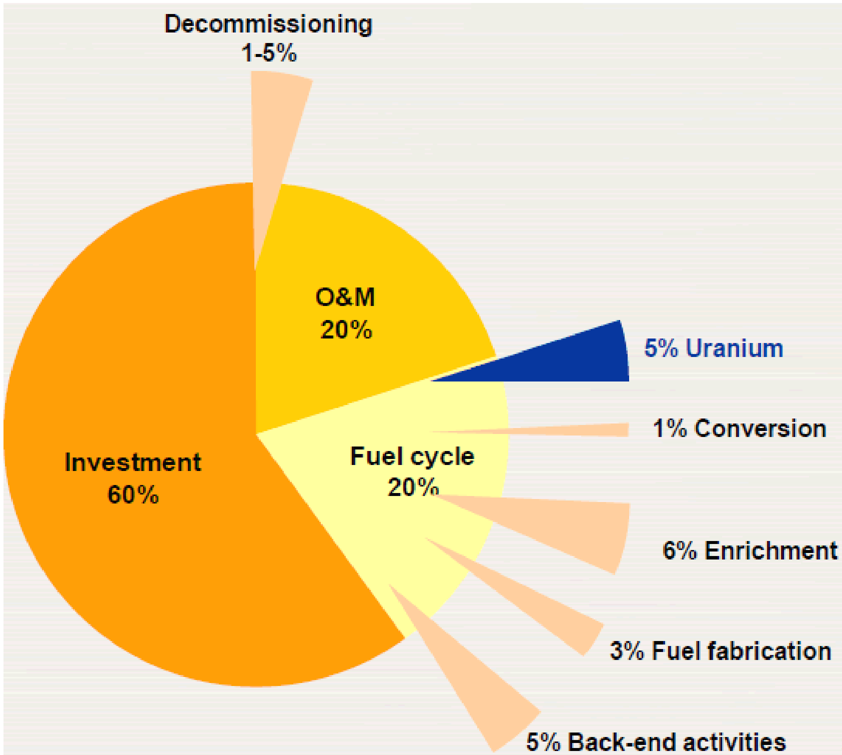
[173] The New Economics of Nuclear Power. WNA Report. http://www.world-nuclear.org/reference/pdf/economics.pdf (accessed Feb. 15, 2011).
[174] Ibid.
[175] "Fact Sheet on Decommissioning Nuclear Power Plant." U.S. Nuclear Regulatory Commission. http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.html (accessed Feb. 15, 2011).
[176] The New Economics of Nuclear Power. WNA Report. http://www.world-nuclear.org/reference/pdf/economics.pdf (Accessed Feb. 15, 2011).
[177] IEA (Paris), Projected Costs of Generating Electricity – 2010 Edition, Executive Summary, 2010, 9.

Figure 4.1. Typical Nuclear Electricity Generation Cost Breakdown



Source: IAEA, H-Holger Rogner, *The Economics of Nuclear Power,* 2010.

Economics of Other Major Forms of Energy Production

The economics of fossil fuels and renewable energy are important to consider in relation to those of nuclear power. The International Energy Agency (IEA) (Paris) conducts projections of the economics of major energy production technologies and compares them with projections of nuclear power. Important to its calculations are the assumed real discount rates, 5 percent and 10 percent, and for the first time, a carbon price of USD 30 per tonne of carbon dioxide (CO_2). The addition of the carbon price into the calculations is a projection of future policy since there has not yet been deployment of carbon pricing on a major international scale. The study reaches two important conclusions. First, in the low discount rate case, nuclear energy is the most competitive option compared to coal-fired and gas-fired plants. Coal is also globally competitive with or without carbon capture. Second, in the high discount rate case, coal-fired electricity generation is the most competitive. This study highlights the importance of the discount rate in cost calculations. Higher discount rates penalize more heavily capital-intensive, low-carbon technologies such as nuclear and renewables due to their high upfront investment costs. On the other hand, a higher discount rate comparatively favors fossil-fuel technologies with higher operating costs. These comparisons are based on figures from OECD countries.

The strength of coal is its economic competitiveness without carbon pricing and the neglect of environmental costs (negative externalities). This applies to the areas where coal is an abundant resource. Thus, in areas without reserves of coal the advantage would be reduced greatly by transport and transaction costs. In places where carbon costs are included, the economic competitiveness of coal may be eliminated entirely. Coal-fired power plants have overnight investment costs ranging between 3,223 to 6,268 USD/kWe with carbon capture. Construction time averages four years for a large-sized plant, eg. a one gigawatt (GWe) plant. At a 5 percent discount rate, investment costs and fuel costs each approximately accounts for 28 percent of total cost, O&M costs for 9 percent, and carbon costs for 30 percent of the total. At a 10 percent discount rate, investment costs account for 42 percent, fuel costs for 23 percent, O&M costs for 8 percent, and carbon costs for around 27 percent of the total.[178] Thus, even at a relatively low price (USD 30/tonne), carbon costs become a significant factor. In other words, the

[178] International Energy Agency (Paris), Projected Costs of Generating Electricity – 2010 Edition, Executive Summary, 2010, 9.

competitiveness of coal vis a vis nuclear depends to a large degree on the presence or absence of a price on carbon.

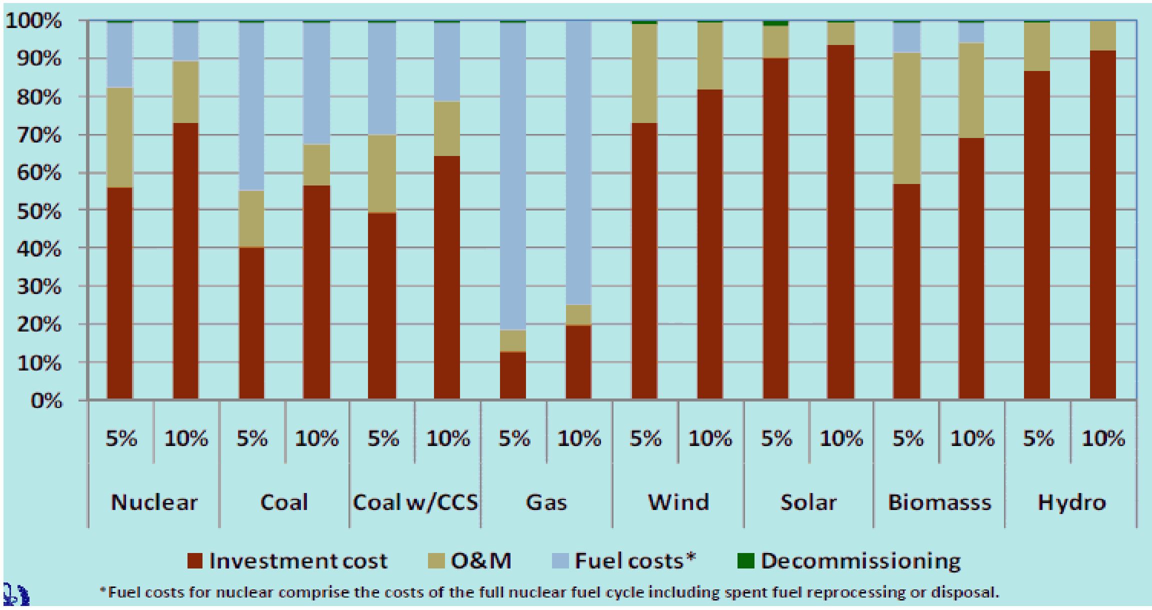
Gas-fired generating technologies have overnight construction costs ranging from 520 to 1,800 USD/kWe. Gas-fired plants are built quickly, within two to three years. At a 5 percent discount rate, investment costs represents 12 percent, O&M costs 6 percent, carbon costs 12 percent, and fuel costs represent 70 percent of the total cost.[179] For gas-fired power the difference due to 5 percent and 10 percent discount rates is limited due its low investment costs and short construction periods.

As for the renewable technologies, costs are country and site-specific. Most renewable energy plants face the problem of intermittency of supply and the need for a large amount of land per kW of capacity. The share of investment costs varies from 70 percent to 80 percent for either discount rate.[180] Price of land, labor, and materials comprises the major cost, but these obviously depend on the scale of an individual project, its location and access, and other local factors.

Comparison of the above energy sources with nuclear power, in terms of cost percentages, is shown in Figure 4.2. This figure does not include carbon pricing. Notably, it indicates the importance of discount rate levels as well as the very high dependence of renewables on upfront investment. Nuclear power and renewables share two characteristics: low fuel and very low decommissioning costs. This seems important, as both types of plants, when dismantled, yield toxic waste material.

[179] International Energy Agency (Paris), Projected Costs of Generating Electricity – 2010 Edition, Executive Summary, 2010, 9.
[180] Ibid, 10.

Figure 4.2. Generating Cost Structure (Including IDC)



Source: IAEA, H-Holger Rogner, *The Economics of Nuclear Power,* 2010.

Comparisons

Since 2003, construction costs for all types of large-scale engineering projects have increased drastically due to the rising prices for materials, fuels, and labor, as well as tight manufacturing capacity. Nuclear power costs may rise disproportionately due to economic downturn and increasing demand in Asia.[181] Currently, most developed countries and several developing countries are implementing deregulation of electricity markets. This means that utilities can no longer guarantee high prices or pass cost increases on to customers. Private investors and electricity utilities base their decisions on projected levelized costs and rates of return compared to other alternatives. However, no new nuclear power plant has yet been built and operated in a liberalized electricity market. The influence of deregulation has yet to be fully determined.

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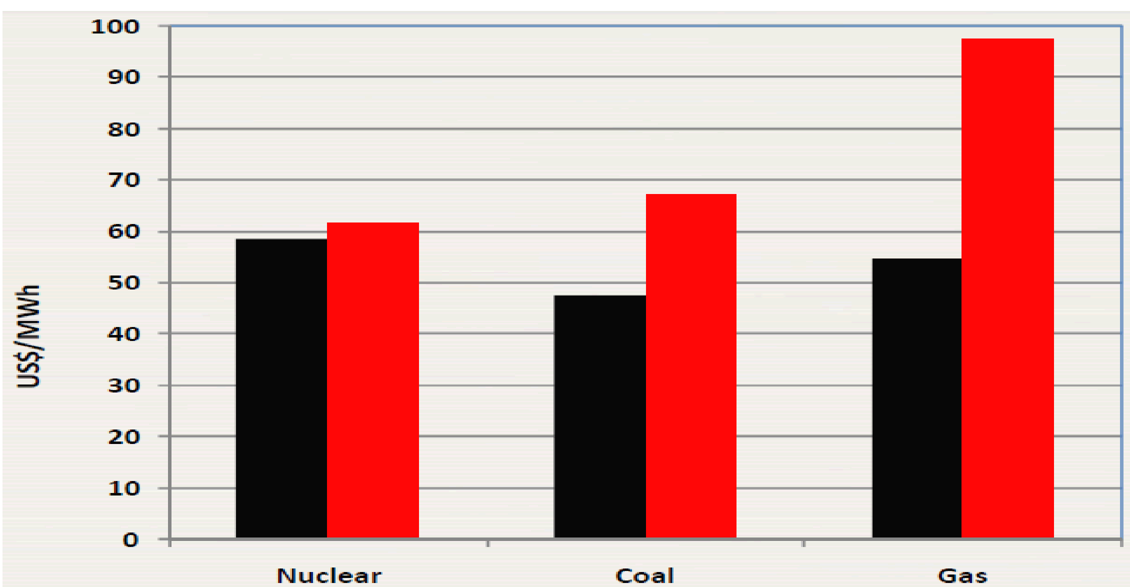
[181] CIGI, *The Future of Nuclear Energy to 2030 and its Implications for Safety, Security and Nonproliferation Overview: Nuclear Energy Futures Project*, 2010, 5.

The relative costs of nuclear power can vary substantially around the globe considering the competition between combined-cycle gas turbines and coal-based power plants for base-load power generation.[182] Comparatively, nuclear power generation technology possesses both economic advantages and disadvantages. The low fuel costs of uranium have been a major attraction of nuclear energy compared to coal, oil, and gas fired plants. In addition, fuel costs are one area of increasing advantage. A doubling of uranium prices only increases nuclear generating costs by 5-10 percent. For coal, a price doubling raises electricity costs by 35- 45 percent, and for gas by 70-80 percent.[183] This is shown in Figure 4.3. For the U.S., a doubling of fuel prices would result in 9 percent rise in the cost of electricity while for coal energy, the price would rise 31 percent, and for gas 66 percent.[184]

Figure 4.3. Impact of a Doubling of Resource Prices on Generating Costs



Source: IAEA, H-Holger Rogner, *The Economics of Nuclear Power,* 2010.

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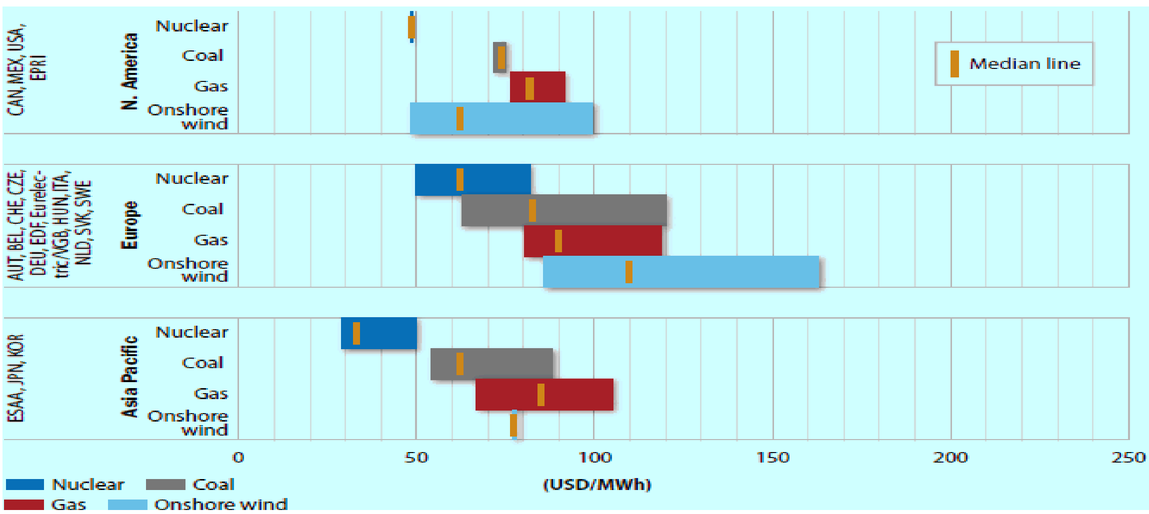
[182] IAEA, *Revisiting Nuclear Renaissance*, Bulletin 49/I, 2007, 1-2.
[183] IAEA, *Issue to Improve the Prospects of Financing Nuclear Power Plants*, No. NG-T-4.1, Vienna, 2009, 4.
[184] "The Economics of Nuclear Power." The World Nuclear Association. http://www.world-nuclear.org/info/inf02.html (accessed Feb. 5, 2011).

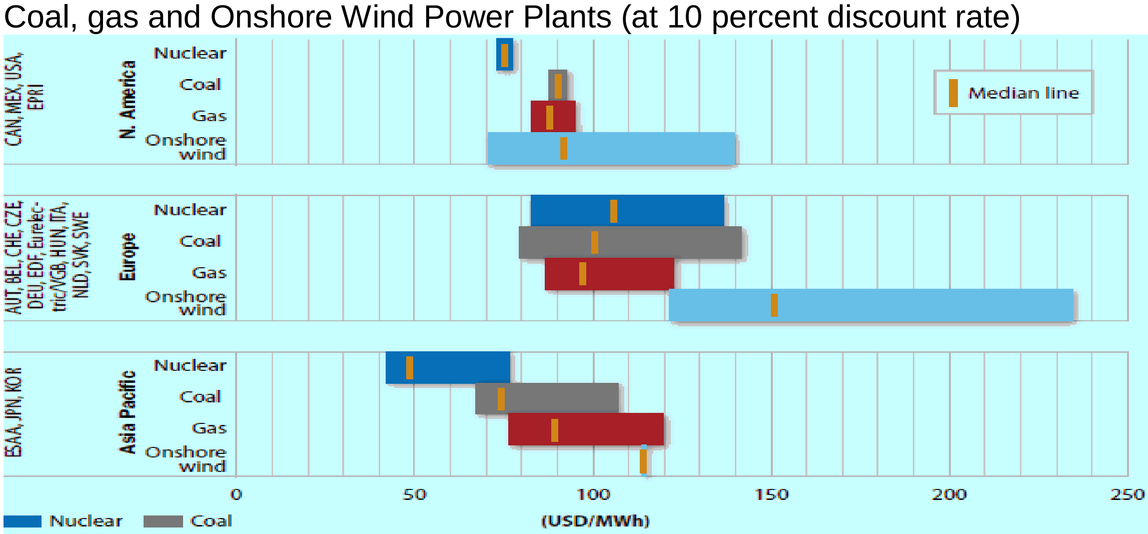
Figures 4.4 and 4.5 show a comparative perspective of North America, Europe, and Asia, of how the different discount rates can influence the LCOE of nuclear power and other types of power generation. The commonality shared throughout the globe is that at a higher discount rate, 10 percent, the LCOE of nuclear power is higher than at a 5 percent discount rate.

Figure 4.4. Regional Ranges of Levelized Cost of Electricity (LCOE) for Nuclear, Coal, gas and Onshore Wind Power Plants (at 5 percent discount rate)



Source: IAEA, *Projected Costs of Generating Electricity – 2010 Edition*, 2010, 18.

Figure 4.5. Regional Ranges of Levelized Cost of Electricity (LCOE) for Nuclear, Coal, gas and Onshore Wind Power Plants (at 10 percent discount rate)



Source: IAEA, *Projected Costs of Generating Electricity – 2010 Edition*, 2010, 18.

Nonetheless, a 2003 study by the Massachusetts Institute of Technology (MIT), updated in 2009, concluded that nuclear energy is not an economically competitive choice in the U.S. at the present time. It is more expensive than coal and Combined Cycle Gas Turbine (CCGT) generation, even at high natural gas prices. Figure 4.6 presents the results. The study emphasized, however, that a price on carbon, either through a carbon tax or a cap-and-trade system, would significantly alter the situation and make nuclear instantly competitive with these other sources.

Figure 4.6. Costs of Electric Generation Alternatives

	Over-night Cost	Fuel Cost	Base Case	With carbon charge \$25/ton CO_2	With same cost of capital as coal/gas
	\$/kW	\$/million BTU	¢/kWh	¢/kWh	¢/kWh
2003 (2002 USD)					
Nuclear	2,000	0.47	6.7	n/a	5.5
Coal	1,300	1.20	4.3	6.4	n/a
Gas	500	3.5	4.1	5.1	n/a
2009 (2007 USD)					
Nuclear	4,000	0.67	8.4	n/a	6.6
Coal	2,300	2.60	6.2	8.3	n/a
Gas	850	7.00	6.5	7.4	n/a

Source: MIT, *Update of the MIT 2003 Future of Nuclear Power Study*, Boston, MA: MIT, 2009.

A report by the Center for International Governance Innovation (CIGI) also indicates challenges for the future of nuclear power in OECD countries.[185] Coal and natural gas plants are cheaper to build with lower capital costs, they win regulatory approval more easily, and are more flexible in terms of electricity generation, as they can

[185] CIGI, *The Future of Nuclear Energy to 2030 and its Implications for Safety, Security and Nonproliferation Overview: Nuclear Energy Futures Project*, 2010, 5-7.

build many different sizes and their power output can be adjusted rapidly to meet changing cycles in demand. Nuclear plants by comparison take up to a decade to plan, win regulatory approval and be completed. They are inflexible generators which need to be kept operating at full power to be economically feasible. Also nuclear energy has to cope, economically speaking, with its alternatives' volatility of prices. For example, since the MIT 2009 update, natural gas prices have plummeted due to newly accessible reserves in shale. CIGI's report also agrees with the IEA report in suggesting that nuclear power projects need to attract a discount rate below 10 percent, though it can rise as high as 15 percent, due to the risk involved compared with other energy technologies. Even in accounting for currency conversion distortions, the range of cost estimates is enormous, further illustrating the complexity of the decisions facing potential investors in nuclear energy.

Importance of the Discount Rate

Projections of any future costs or investments are dependent on the choice of the discount rate. The level of uncertainty depends on the time horizons, which are highly sensitive to the choice of discount rate. The discount rate is used to evaluate future expenses at their current values. Thus, the discounting procedure takes into account the value of time in economic analysis. The methodology of the application of the discount rate can help to conduct a technical and economic database. The discount rate is a key parameter in the economic evaluation, which is based on a mean value between the individual preferences for the present time, the average capital cost, and the growth rate of the economy. Recently in 2005, the French General Planning Commission revised its reference macroeconomic discount rate towards a lower value, from 8 percent to 4 percent. The revision takes into account not only the social and environmental effects on investment but also the constraint of public finance. The precautionary principle and attitude are necessary due to the fact that investors are generally more risk adverse toward cost rising than cost decreasing.[186]

COMPARING COSTS BETWEEN COUNTRIES

Technology can overcome the bottleneck of current economic constraints on energy. The comparison of nuclear costs between the U.S. and Asia illustrates this statement above. This report will focus on China, Japan, and South Korea as they have the most ambitious nuclear programs.

The OECD in 2010 projected costs of generating electricity for coal and nuclear technology at discount rates of 5 and 10 percent. Figure 4.7 shows that with a 5 percent discount rate, the U.S., Japan, and South Korea all have lower LCOE in nuclear power while China has similar figures for nuclear and coal costs. Figure 4.8 reveals that with a 10 percent discount rate, the LCOE difference between nuclear power and coal are lessened yet for the U.S., Japan, and South Korea, nuclear power is still more competitive. However, for China, LCOE of nuclear power is higher than coal due to the fact that China has more coal reserves. In relation to other countries, the costs of fuel and carbon are comparatively lower in China. Even so, there are still uncertainties based on changes in future policies and price fluctuations of other energy sources.

[186] Aude le Darsa and Christine Loaecb, "Economic Comparison of Long-Term Nuclear Fuel Cycle Management Scenarios: The Influence of the Discount Rate." *Energy Policy*, no.35 (2006): 3000-3002.

Figure 4.7. Country-by-country Data on Electricity Generating Costs for Mainstream Technologies (at 5 Percent Discount Rate)

Nuclear*					Coal				
Technology	Invest. costs	O&M	Fuel & carbon	LCOE	Technology	Invest. costs	O&M	Fuel & carbon	LCOE
	USD/MWh					USD/MWh			
UNITED STATES									
Adv Gen III+	26.53	12.87	9.33	**48.73**	Bk PCC	17.73	8.76	46.00	**72.49**
					Bk IGCC	20.46	8.37	46.03	**74.87**
					Bk IGCC w/CC(S)	29.96	11.31	26.76	**68.04**
JAPAN									
ABWR	23.88	16.50	9.33	**49.71**	Bk	22.53	10.06	55.49	**88.08**
KOREA									
OPR-1000	14.61	10.42	7.90	**32.93**	Bk PCC	8.59	4.25	55.57	**68.41**
APR-1400	12.20	8.95	7.90	**29.05**	Bk PCC	7.74	3.84	54.28	**65.86**
CHINA									
CPR-1000	13.55	7.10	9.33	**29.99**	Bk USC PCC	5.29	1.64	23.06	**29.99**
CPR-1000	13.44	7.04	9.33	**29.82**	Bk SC	4.86	1.51	23.06	**29.42**
AP-1000	17.70	9.28	9.33	**36.31**	Bk SC	5.42	1.68	23.06	**30.16**

Source: OECD, *Projected Costs of Generating Electricity: 2010 edition,* 2010, 90, Chapter 4, Table 4.1a.

Figure 4.8. Country-by-country Data on Electricity Generating Costs for Mainstream Technologies (at 10 Percent Discount Rate)

Nuclear*					Coal				
Technology	Invest. costs	O&M	Fuel & carbon	LCOE	Technology	Invest. costs	O&M	Fuel & carbon	LCOE
	USD/MWh					USD/MWh			
UNITED STATES									
Adv Gen III+	55.20	12.87	9.33	**77.39**	Bk PCC	33.09	8.76	46.00	**87.85**
					Bk IGCC	38.20	8.37	46.03	**92.61**
					Bk IGCC w/CC(S)	55.85	11.31	26.76	**93.92**
JAPAN									
ABWR	50.63	16.50	9.33	**76.46**	Bk	41.49	10.06	55.49	**107.03**
KOREA									
OPR-1000	30.07	10.42	7.90	**48.38**	Bk PCC	14.42	4.25	55.57	**74.25**
APR-1400	25.24	8.95	7.90	**42.09**	Bk PCC	13.00	3.84	54.28	**71.12**
CHINA									
CPR-1000	27.57	7.10	9.33	**44.00**	Bk USC PCC	9.47	1.64	23.06	**34.17**
CPR-1000	27.34	7.04	9.33	**43.72**	Bk SC	8.69	1.51	23.06	**33.26**
AP-1000	36.01	9.28	9.33	**54.61**	Bk SC	9.69	1.68	23.06	**34.43**

Source: OECD, Projected Costs of Generating Electricity: 2010 edition, 2010, 90, Chapter 4, Table 4.1b.

China Versus the West

Regarding its relatively low costs, China has comparative national and industrial advantages in nuclear construction. China has a less strict and more rapid approval process for plant construction. In contrast, the U.S.'s environmental and regulatory framework has lengthened the time of actual construction, which increases financing and capital costs. The overnight cost of nuclear is $5,335 per kilowatt but inclusion of the permit process adds $8,000 to $10,000 per kilowatt. Financing and capital are available through state ownership in China. The Chinese nuclear programs are ambitious; they aim to produce more power in 2030 than the United States and at a much lower cost. Zhao Chengkun, vice-president of the China Nuclear Energy Association said that "nuclear is recognized as the only energy source" that can achieve the global priority of developing clean and low-carbon energy. Thus, the Chinese have $511 billion in-hand dedicated to the construction of 245 nuclear reactors.

Low-cost labor is also a factor in China's construction of major infrastructure.[187] It is common, for example, for 9,000 people to work 10-hour shifts, seven days a week. Thus, to build a western-designed reactor, it would cost China about $4 billion, 40 percent less than the price of an identical reactor in France. The Chinese reactor could also be completed in 46 months versus 71 months, according to Areva, the French company that sold two third-generation reactors to China.[188] Experience and technology transfer also play a crucial role in cost reduction in Asia. The United States and France are both helping China to build nuclear reactors through the transfer of technical training and related information. China will soon be self-sufficient in reactor design and has abundant sources of fuel due to its innovative reprocessing technology, which can meet China's fuel needs for at least 3,000 years.[189]

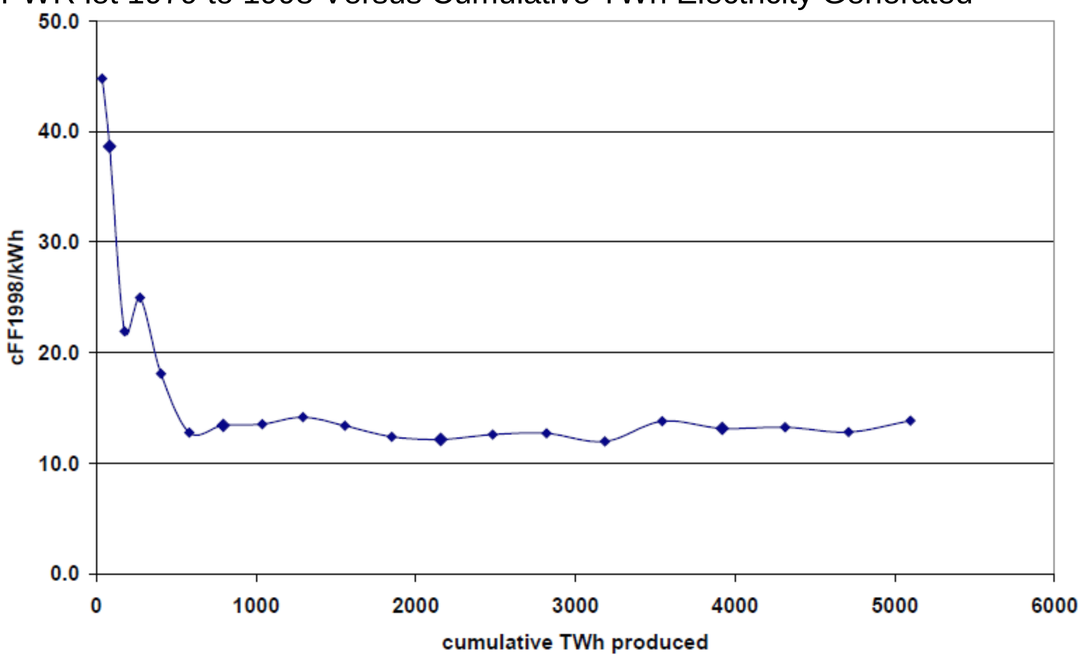
ECONOMIC BENEFITS OF STANDARDIZATION

Standardization refers mainly to the use of a single design, or small number of chosen designs, plus a consistent set of management and operational practices that ensure

[187] "Construction Schedule on Chinese Third-Generation Nuclear Plants Races Ahead of European Models," *Guardian Weekly*, http://www.guardian.co.uk/environment/2010/dec/28/china-areva-taishan-nuclear-thibault (accessed Feb. 12, 2011).
[188] "China's Nuclear Program: Fast and Relatively Inexpensive," Canada Free Press, http://www.canadafreepress.com/index.php/article/31864 (accessed Feb. 13, 2011).
[189] "China Claims New Nuclear Technology," *Guardian. CO. UK*., http://www.guardian.co.uk/world/2011/jan/03/china-claims-new-nuclear-technology (accessed Feb. 17, 2011).

quality, safety, and predictable cost.[190] The French nuclear pressurized water reactor (PWR) program is arguably the most successful nuclear-scale up experience in an industrialized country. The factor of success was a unique institutional framework that allowed for centralized decision-making, a high degree of standardization, and regulatory stability that resulted in relatively short reactor construction time.[191] The total cost of the French PWR program was 230 billion Euros (2008), equivalent to $330 billion (2008) for 56 reactors.[192] France's PWR program also demonstrates the stable and low operation costs of accumulative nuclear electricity generation. As shown in Figure 4.9 since 1984, operating costs have remained essentially flat, averaging $30 (2008)/MWh: not exactly "too cheap to meter" but certainly very competitive.

Figure 4.9. Average Operating Costs (in Centimes FF98 per kWh) of French PWR let 1979 to 1998 Versus Cumulative TWh Electricity Generated



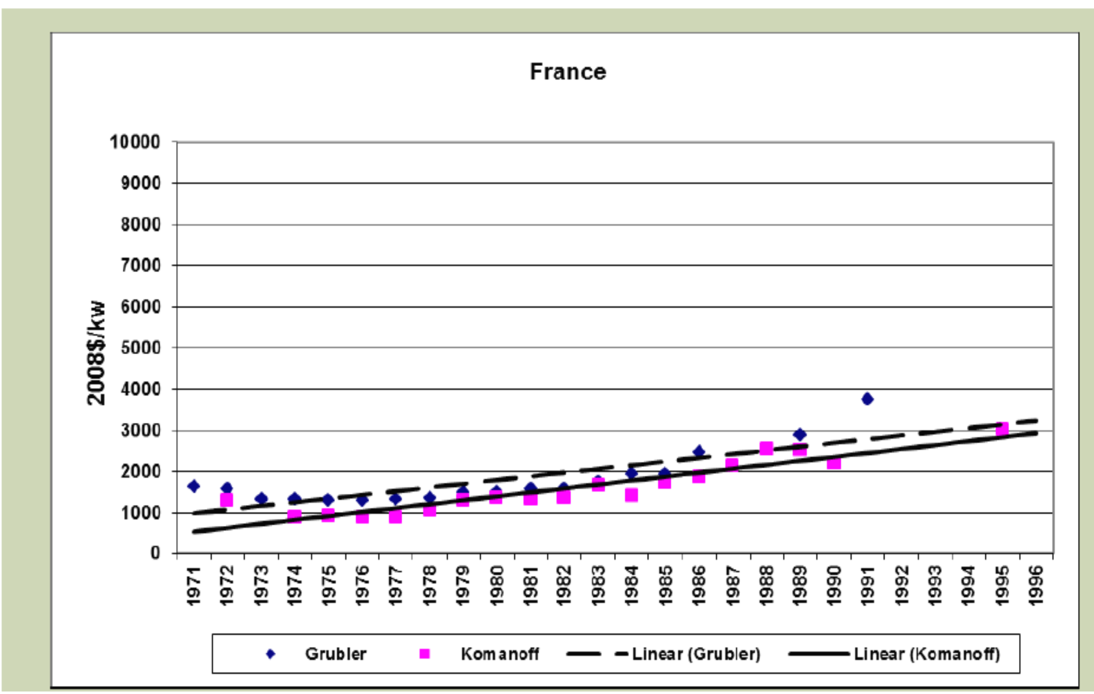
Source: IIASA, Arnulf Grubler *, An Assessment of the Costs of the French Nuclear PWR Program 1970-2000*, Interim Report IR-09-036, 2009, 28.

[190] IAEA, *Nuclear Safety Review for the year 2009*, July 2010.
[191] IIASA, Arnulf Grubler *, An Assessment of the Costs of the French Nuclear PWR Program 1970-2000*, Interim Report IR-09-036, 2009, 1.
[192] Ibid, 19.

The United States Versus France

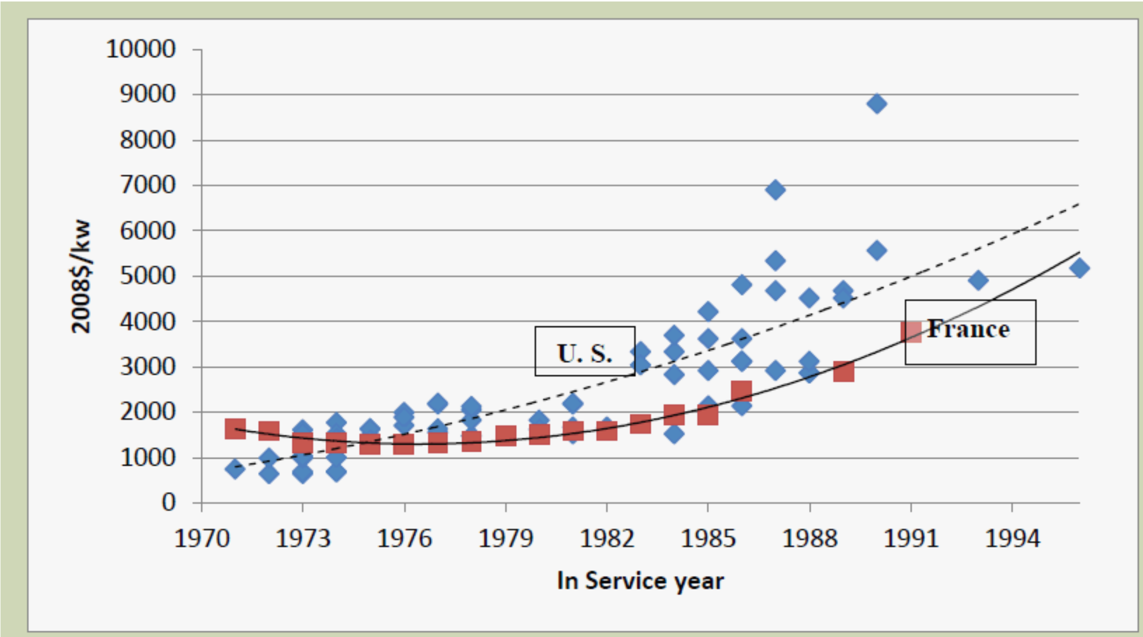
As Figure 4.10 illustrates, nuclear construction programs in both the U.S. and France continue to rise in cost. However, the French trend is more consistent than the U.S. data. This is due to the fact that in France, there was a single monopoly company in contrast to over a dozen companies operating in the U.S.. In France, from the low-cost end in the mid-1970s to the high-cost end in early 1990s, costs for new reactors have more than tripled from just under $1,000/kW to $3,000/kW. The projected costs for the reactors currently under construction are in the range of $4,500 to $5,000/kW. In the same time frame, U.S. costs escalated from about $1,000 to $3,600/kW. The projected

Figure 4.10. French Nuclear Reactor Overnight Costs (2008$)



Source: Mark Cooper, "Policy Challenges of Nuclear Reactor Construction, Cost Escalation and Crowding Alternatives: Lessons from the U.S. and France for the Effort to Revive the U.S. Industry with Loan Guarantees and Tax Subsidies, September 2010, 6.

Figure 4.11. Overnight Costs of Pressurized Water Reactors (2008$)



Source: Mark Cooper, "Policy Challenges of Nuclear Reactor Construction, Cost Escalation and Crowding Alternatives: Lessons from the U.S. and France for the Effort to Revive the U.S. Industry with Loan Guarantees and Tax Subsidies, September 2010, 7.

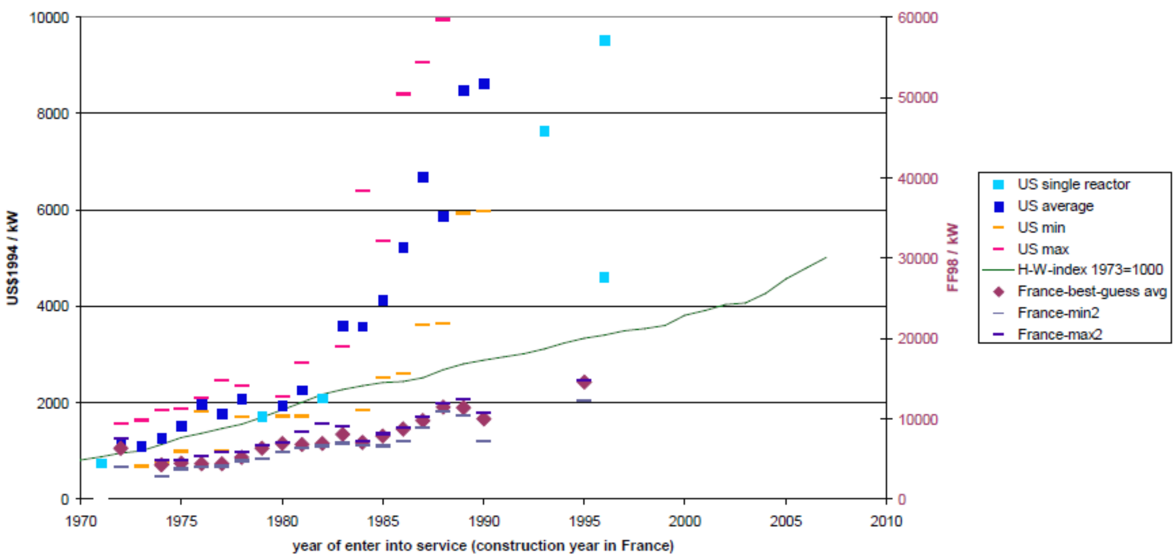
costs range from $4,000 to $6,000/kW and even up to $10,000/kW.[193]

Figure 4.11. illustrates some of the differences between the French and the U.S. experiences. It suggests that part of the difference in cost escalation between the two countries can be explained by the standardized technology in France. Approximately two-thirds of the U.S. reactors used PWR technology, while all the French reactors used this technology. In fact, the French PWR industry was launched by a U.S. licensed design that France tried to make its own. The cost escalation trends in the two countries are similar when a single technology is evaluated. By the end of 1988, French reactors were consistently in the range of $2,000 to $3,000/kW while the U.S. reactors were significantly higher, at $3,000 to $6,000/kW.

[193] Mark Cooper, "Policy Challenges of Nuclear Reactor Construction, Cost Escalation and Crowding Alternatives: Lessons from the U.S. and France for the Effort to Revive the U.S. Industry with Loan Guarantees and Tax Subsidies," September 2010, 37.

Standardization in France also enabled accuracy in cost projections. As Figure 4.12 shows, the construction costs of France and the U.S. are compared based on the Handy-Whiteman U.S. nuclear construction cost index (1973= 1000). During 1975-1990, French nuclear construction costs followed quite closely the trends of cost escalation as estimated by the H-W index. The "central planning" model of France with its regulatory stability and standardization appeared economically more successful, even with substantial but moderated real cost escalation, than the uncertain U.S. system.[194]

Figure 4.12. U.S. and France Reactor Construction Costs with Interest (U.S. Maxima Beyond Scale: 1989:13807 $/kW, 1990=12412$/kW)



Source: IIASA, Arnulf Grubler , *An Assessment of the Costs of the French Nuclear PWR Program 1970-2000*, Interim Report IR-09-036, 2009, 31.

Nuclear power plant standardization has also been deployed in Asia and the benefits are shared simultaneously with the expansion of this technology. In Figure 4.13, the levelized costs of electricity show stark comparisons between the U.S., China, Japan,

[194] IIASA, Arnulf Grubler, *An Assessment of the Costs of the French Nuclear PWR program 1970-2000*, Interim Report IR-09-036, 2009, 31.

and South Korea. Asia has lower costs compared to those of the U.S. due to the standardization of nuclear plants.

Figure 4.13. Nuclear Power Plants: Levelized Costs of Electricity in US Dollars per MWh

Country	Technology	Net capacity	Overnight costs[1]	Investment costs[2]		Decommissioning costs		Fuel Cycle costs	O&M costs[3]	LCOE	
				5%	10%	5%	10%			5%	10%
		MWe	USD/kWe	USD/kWe		USD/MWh		USD/MWh	USD/MWh	USD/MWh	
United States	Advanced Gen III+	1 350	3 382	3 814	4 296	0.13	0.01	9.33	12.87	**48.73**	**77.39**
Japan	ABWR	1 330	3 009	3 430	3 940	0.13	0.01	9.33	16.50	**49.71**	**76.46**
Korea	OPR-1000	954	1 876	2 098	2 340	0.09	0.01	7.90	10.42	**32.93**	**48.38**
	APR-1400	1 343	1 556	1 751	1 964	0.07	0.01	7.90	8.95	**29.05**	**42.09**
China	CPR-1000	1 000	1 763	1 946	2 145	0.08	0.01	9.33	7.10	**29.99**	**44.00**
	CPR-1000	1 000	1 748	1 931	2 128	0.08	0.01	9.33	7.04	**29.82**	**43.72**
	AP-1000	1 250	2 302	2 542	2 802	0.10	0.01	9.33	9.28	**36.31**	**54.61**

Source: OECD, *Projected Costs of GeneratingEelectricity: 2010 edition*, p. 59, Chapter 3, Table 3.7a.

The Republic of Korea

The benefits of standardization and construction in series are being realized in South Korea, mainly based on two next-generation (Generation III) type reactors. They are the Optimized Power Reactor (OPR) units and the Advanced Power Reactor 1400 (APR-1400) which focus on improving capacity and reducing costs.[195] In the mid-1980s, the Korean nuclear industry embarked upon a plan to standardize the design of nuclear plants and achieve much greater self-sufficiency in building them. A further step of standardization was the Korean Standard Nuclear Plant (KSNP). In 2005, KSNP/KSNP+ was re-branded into OPR-1000 for export to the Asian market. The Korean government reportedly put the overnight cost of APR-1400 at the end of 2009 at $2,300/kW and construction times as short as 48 months. Cost is expected to be 10-20 percent less than for KSNP/OPR-1000 reactors.[196]

[195] "Nuclear Power Technology Development Section: Light Water Reactors," IAEA, http://www.iaea.org/NuclearPower/WCR/LWR/ (accessed Feb. 2, 2011).
[196] The New Economics of Nuclear Power. WNA Report. http://www.world-nuclear.org/reference/pdf/economics.pdf (accessed Feb. 15, 2011).

According to a 2010 OECD report on costs of power generation, South Korean reactors are among the least expensive in the world, with overnight costs of $1,700 - $2,000/kW compared to nearly twice that amount in the U.S. and Europe.[197] South Korean firms are also developing standardized power plant designs for export.[198] This is significant, as these firms have announced plans to export as many as 80 power reactors worth $400 billion by 2030, capturing at least 20 percent of the global market.[199] Korean firms have already won a major contract for new reactors the United Arab Emirates and have been in negotiations with other countries, both for future power plant construction and training of nuclear engineers. The deal with the UAE is said to involve $18.6 billion for the four reactors and which will cost $3,400/kW.[200]

Japan

In 1975, the Ministry of International Trade and Industry (MITI) launched the light water reactor (LWR) Improvement & Standardization Program based on three phases. In the most recent, third phase of the program, design changes were made to increase the reactor capacity to 1,300-1,400 MWe.[201] There were to be the Advanced BWR (ABWR) and Advanced PWR (APWR). As Figure 4.13 shows, Japan's costs of ABWR are just slightly below that of the U.S. Future ABWRs are expected to achieve substantial

[197] OECD 2010, *Projected Costs of Generating Electricity:2010 edition*, 2010, 90, Chapter 4, Table 4.1a.
[198] "KHNP Aims for Global Market," *World Nuclear News*, http://www.world-nuclear-news.org/newsarticle.aspx?id=14302&LangType=2057 (accessed Feb.20, 2011).
[199] "Nuclear Plant Construction Up; South Korean Challenging Market," *The Japan Times*, http://search.japantimes.co.jp/cgi-bin/eo20100201mr.html (accessed Feb.20, 2011).
[200] "South Korea-UAE Nuclear Deal: Future Lies in Low Cost Advanced Nuclear Reactors," *Gerson Lehrman Group*, http://www.glgroup.com/News/South-Korea-UAE--Nuclear-Deal-Future-Lies-in-Low-Cost-Advanced-Nuclear-Reactors-45677.html (accessed Feb. 20, 2011).
[201] The New Economics of Nuclear Power. WNA Report. http://www.world-nuclear.org/reference/pdf/economics.pdf (accessed Feb. 15 2011).

reductions in generation costs from the first ABWRs.[202] This cost reduction is related directly to standardization and design changes with all the current operation plants. In addition, a development program was started in 1991 for an ABWR-II reactor, which aimed to significantly reduce the cost of power generation relative to a standardized ABWR. The benefits of economies-of-scale are expected as well.[203] With the exception of South Korea, Japan's overnight costs are among the lowest of any nation in the OECD, at about $3,000/kW in 2010.

Like South Korea, Japan is interested in exporting its nuclear technology. In early 2011, the government secured for Japanese companies a deal with Vietnam for two reactors and related services, including radioisotopes, worth $14.4 billion. Japan in 2010 entered into talks with Turkey for a second set of reactors to follow the four that Turkey has contracted with Russia to build at a total cost of $20 billion.[204] Exact projected cost information for these new reactors is not yet available; however, Japan is aiming to build its new plants to operate for up to 80 years.

China

Two designs, the CPR1000 and APR 1000, are currently predominant in China's construction plans. These designs are adaptations of French and U.S. (Westinghouse AP1000) originals that China plans to build much more cheaply. The cost of the first four APR1000 is expected to be less than $2,000/kW, and would reduce to $1,600 for further units. This is the lowest cost level for a large-scale nuclear plant that has yet been

[202] "Nuclear Power Technology Development Section: Light Water Reactors," IAEA, http://www.iaea.org/NuclearPower/WCR/LWR/ (accessed Feb. 2, 2011).
[203] Ibid.
[204] "Turkey, Japan in Exclusive Talks of Nuclear Plant," *Bloomberg Businessweek*, http://www.businessweek.com/news/2010-12-24/turkey-japan-in-exclusive-talks-for-nuclear-plant.html (accessed Feb. 19, 2011).

attempted. If achieved, it will possibly set a new standard for plants to strive for elsewhere. What matters as well are China's plans to export its technology to other portions of Asia and Africa, putting it in direct competition with Japan and South Korea and promising cost benefits for new nuclear states.

The standardization program for the CPR1000 has established a nearly complete domestic supply chain, pursued by the China Guangdong Nuclear Power Corporation (CGNPC).[205] Self-reliance and local participation can also result in cost savings in materials, construction, training and labor. For example, China's Qinshan-II plant's construction cost is less than those imported large-size plants due to localization of design and equipment procured from domestic organizations.[206]

COST TRENDS

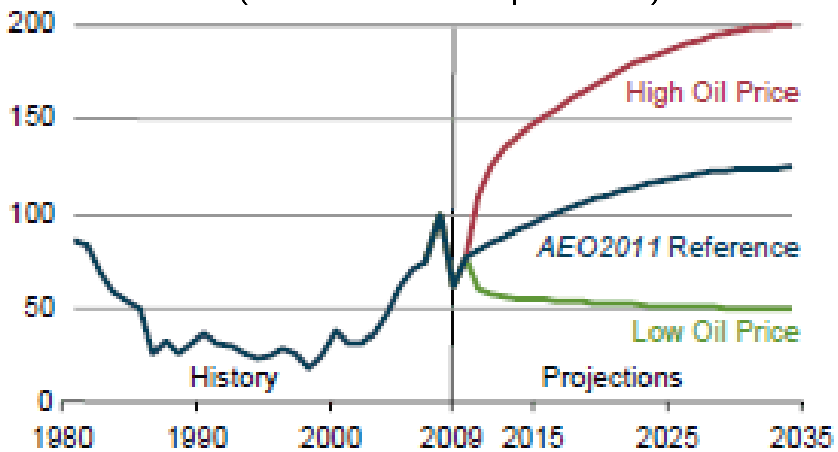
Prices of Energy

Cost trends of energy are influenced by total energy demand. Based on projections of the International Energy Outlook 2010 (IEO 2010) by the EIA, world energy demand is increasing and so are prices. Particularly, total energy demand between 2010 and 2035 in non-OECD countries will increase by 84 percent while demand in OECD countries will increase 14 percent.[207] Liquid products account for the largest portion of energy use.[208] Average oil prices increased strongly from 2003 to mid-July 2008 after which the price collapsed as a result of the deepening recession.[209] The 2008 peak was in part due

[205] The New Economics of Nuclear Power. WNA Report. http://www.world-nuclear.org/reference/pdf/economics.pdf (accessed Feb. 15 2011).
[206] IAEA, *Competitiveness of Nuclear Energy: IAEA's Perspective and Study Results for Europe*, Romania, 2008, 7.
[207] EIA, *International Energy Outlook 2010- Highlights*, Report#: DOC/EIA-0484, May 2011, 1.
[208] Ibid.
[209] Ibid, 2.

to an increase in demand for transportation by non-OECD countries.[210] In the early release overview, the real price of oil trended upward and remained generally in a range between $70 and $80 per barrel in 2010, as shown in Figure 4.14.[211] Global demand for oil, and for most other energy sources, is expected to rise again from 2011 on, as recovery from the global economic recession advances.

Figure 4.14. World Crude Oil Prices, 1980-2035. Annual Average Price of Low-Sulfur Crude Oil (Real 2009 Dollars per Barrel)



Source: EIA, Annual Energy Outlook 2011 Early Release Overview, 2011, 3.

Recovery will also impact global demand for natural gas.[212] In projections of the U.S. Department of Energy's Annual Energy Outlook 2011 (AEO, 2011), energy prices in several sectors have trended upward in annual percentage, reflected in Figure 4.15. Rapid increase in world energy prices from 2003 to 2008 has shifted interests to other energy alternatives particularly nuclear power and renewables.[213]

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[210] EIA, *International Energy Outlook 2010- Highlights*, Report#: DOC/EIA-0484, May 2011, 2.
[211] EIA, *Annual Energy Outlook 2011 (AEO2011)*,Report number: DOC/EIA-0383ER(2001), December 2011, 3.
[212] Ibid.
[213] EIA, *International Energy utlook2010- Highlights*, Report number: DOC/EIA-0484, May 2011, 6.

Figure 4.15. Energy Prices by Sector and Source (2009 Dollars per million Btu, Unless Otherwise Noted)

Sector and Source	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Average Price to All Users[10]								
Liquefied Petroleum Gases	20.51	17.43	23.68	28.86	33.70	38.32	42.64	3.5%
E85[4]	35.03	20.50	28.81	34.76	39.14	44.10	49.28	3.4%
Motor Gasoline[5]	26.63	19.23	28.36	34.04	39.20	44.07	49.19	3.7%
Jet Fuel	23.09	12.59	20.68	26.64	31.18	35.87	40.41	4.6%
Distillate Fuel Oil	26.28	17.51	23.89	30.32	35.34	39.90	44.68	3.7%
Residual Fuel Oil	14.75	10.53	14.32	18.08	21.71	24.71	26.88	3.7%
Natural Gas	10.46	7.28	7.18	8.52	10.43	12.15	14.43	2.7%
Metallurgical Coal	4.49	5.43	6.60	7.66	8.56	9.45	10.53	2.6%
Other Coal	2.10	2.25	2.38	2.67	3.02	3.41	3.88	2.1%
Coal to Liquids	- -	- -	1.97	2.31	2.40	2.89	3.37	- -
Electricity	28.38	28.69	28.73	31.44	34.62	38.22	43.09	1.6%

Source: IEA, AEO 2011 Early Release Overview, Table A3.

Cost Impacts of New Technology

Generation III advanced reactors can address the cost issue in a number of ways. First, it is claimed that these reactors will remain in service for more years, so construction costs will be spread over a longer operating time. Second, the new plants are also designed to be simpler and faster to build, reducing financing costs. Recent cost estimates for Generation III plants range from $4,000 to $6.700 per kilowatt. Alternatively, for plants ranging from 1,100 to 1,600 megawatts in size, the estimates are $4.4 billion to $11 billion.[214] The Generation III (3+) have a standardized design for each type in order to expedite licensing, reduce capital costs and reduce construction time. A simpler and more rugged design is employed which makes it easier to operate and less vulnerable to operational upsets.[215]

[214] "The New Nukes," *The Wall Street Journal*, http://online.wsj.com/article/SB10001424052970204409904574350342705855178.html (accessed Feb.19, 2011).
[215] IAEA , *Issue to Improve the Prospects of Financing Nuclear Power Plants*, No. NG-T-4.1, Vienna, 2009, 29.

Small modular reactors (SMRs) for power generation are generally expected to have greater simplicity of design and economy of mass production, and reduced sitting costs.[216] SMRs have some advantages over large-scale facilities. First, relatively small size and modularity means lower initial capital expenditures, shorter manufacturing lead-times, and potentially less risk of cost overruns.[217] A prototypical 100 MW SMR costs $500 million to manufacture.[218] The modular approach allows for great standardization of components and process compared to large nuclear power plants. The evaluations of the capital outlay and O&M costs prove that the lack of initial economies of scale would be counterbalanced by the modular ad integral design approach of SMRs.[219] In the U.S., both the costs and production techniques for SMR manufacturing and construction are proprietary. Published sources give cost estimates for SMRs ranging from $3,000-$7,000 per kilowatt with an average of $5,000/kW, or $500 million per SMR.[220] They are economically competitive but still have relatively high capital costs, compared to thorium reactors.[221]

The liquid-fluoride thorium reactor (LFTR) is a Generation IV reactor. It has comparative advantages in design, operation, safety, waste management, costs, and proliferation resistance.[222] The favorable cost structure is based on the following factors: simpler fuel handling, smaller components, markedly lower fuel costs and significantly

[216] "Small Nuclear Reactors," *World Nuclear Association*, http://www.world-nuclear.org/info/inf33.html (accessed Feb.20, 2011).
[217] The Energy Policy Institute, *Economic and Employment Impacts of Small Modular Nuclear Reactors*, 2010, 5.
[218] Ibid, 6.
[219] Ibid, 7.
[220] Ibid, 28.
[221] "The New Nukes," *The Wall Street Journal*, http://online.wsj.com/article/SB10001424052970204409904574350342705855178.html (Accessed Feb.19, 2011).
[222] Ibid.

higher energy efficiency.[223] A plant of this type would avoid the cost of fabricating fuel elements and also the expense and lost revenue of periodic shutdowns to replace them. In the MIT study *The Future of Nuclear Power,* updated in 2009, the capital costs of coal plants are shown at $2.3 per watt versus $4 for a light-water nuclear. A principal reason why the capital costs of LFTR plant could close this gap is that it operates at atmospheric pressure without pressurized water.[224] The most compelling idea for pushing thorium-based power into the mainstream is mass production to drive rapid deployment in the U.S. and export elsewhere. The commercialization of any technology leads to lower costs as the number of units increases. Increasing experience also offers benefits in refined production processes, product standardization and efficient product design.[225] Given the diminished scale of LFTRs, the estimate costs for a 100 megawatt plant can be produced for a cost of around $200 million.[226]

CONCLUSION

The main features of the economics of nuclear power are high start-up costs, a long construction period, and a long period of return on investment compared to other energy sources. While this will not disappear with new, standardized reactor designs, it will be considerably softened by lower overall expenses, reduced operational and maintenance costs, and by longer terms of operation. As shown by Asia, the new era of nuclear expansion could bring a significant improvement in the overall economics of nuclear power during the next 15-20 years. Meanwhile, such economics will also benefit from the worldwide trends of high fossil fuel prices and the increasing attention paid to

[223] Robert Hargraves and Ralph Moir, "Liquid-Fluoride Thorium Reactors: an old idea in nuclear power gets reexamined," *American Scientist*, Volume 98, Number 4, (July-August 2010): 311.
[224] Ibid, 310.
[225] Ibid, 311.
[226] Ibid.

reducing carbon emissions. Although the West has been caught in the ambivalence of nuclear accidents and stagnation, it has started to revive its nuclear programs. Technology and policy innovations are both required to improve nuclear energy's economic competitiveness.

The current development in East Asia can serve as an example for the U.S. to follow. In the experience of France and East Asia, nuclear reductions can be achieved in several steps. Firstly, nuclear plants should use higher-capacity reactors due to economies of scale. Standardization of reactors and construction in series can also yield substantial savings. Lastly, a predictable licensing process can avoid unexpected costs.[227] The U.S. should take these three steps into consideration for its development of new nuclear power plants. By following this approach, it would guarantee the economic competitiveness of nuclear power.

[227] The New Economics of Nuclear Power, *World Nuclear Association*. http://www.world-nuclear.org/reference/pdf/economics.pdf (accessed Feb. 15, 2011).

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"The Economics of Nuclear Power." The World Nuclear Association. http://www.world-nuclear.org/info/inf02.html (accessed Feb. 10, 2011).

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Trevor Findlay. The Future of Nuclear Energy to 2030 and its Implications for Safety, Security and Nonproliferation Overview. Nuclear energy futures project. The Centre for International Governance Innovation (CIGI), 2010.

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Wang, Jone-Lin and Hansen Christopher J.. "Nuclear Renaissance." IAEA Bulletin 49.2007.

Chapter Five

POWER, PURPOSE, AND THE EMERGING NUCLEAR MARKET: THE ROLE OF GOVERNMENTS AND THE PRIVATE SECTOR

Brandon Skyles

Abstract:

This chapter discusses the interaction between governments and the private sector in shaping the world's nuclear industry. Because government regulation is central to the use of nuclear technology, policymakers are able to create strong incentives and barriers to development. This analysis begins with an overview of regulatory environments in emerging nuclear powerhouses in Asia and contrasts government policy in these states with the increasingly stagnant nuclear power scene in the West. This report places a special emphasis on energy businesses with significant operations in Asia. It examines U.S. government involvement in the energy industry in Asia, as well as foreign involvement in the U.S. energy industry. Significant differences exist in the level of government involvement in nuclear power development between Asian nations, the United States, and other Western nations. Centralized management and planning in the East have allowed for a rapid expansion of nuclear power in Asia while deregulation has left the nuclear industry of the West struggling to compete against coal.

INTRODUCTION

As nuclear power becomes a more and more viable option in East Asia, U.S. policy makers are in a position to greatly influence the development of these technologies and the industry that forms around them. Asian countries have looked to the West in developing their nuclear facilities and have relied on American and European businesses to provide key technologies in the industry. Because nuclear has long been placed under careful government supervision and stringent policy controls, the emerging global energy market has and will continue to be strongly influenced by national and international regulatory environments. Governments can create both strong barriers and powerful incentives for private sector investment in nuclear power. For this reason, the relationship between national and international governing bodies and the private sector is critical to the future of the global energy market—from nuclear to renewable to fossil fuels.

This section will serve to critically analyze the roles of the government and the private sector in achieving success with nuclear energy generation by evaluating the following four main axes of interaction. First, an overview of the nuclear industry will give country specific information and serve to illustrate the most pressing international issues. Second, regulatory policy will be considered by evaluating both incentive and restrictive programs. Third, financing options will be laid out by looking at specific companies engaged in the construction and operation of nuclear facilities. And, fourth, the role of the U.S. as a global leader in nuclear technology will be addressed through a brief glance at U.S. domestic and foreign policy pertaining to nuclear and its impact on the rest of the world. In the next century, energy is likely to become a key determinant of a country's economic success; the U.S. is no exception. As new energy sources emerge, the U.S. is poised to make important choices which are likely to affect its posturing in the international community. The interrelation between the sections above will be further explained in the conclusion and serve as basis for decisions that will be critical to the position of the United States as the global superpower now and in the future.

NUCLEAR MARKET STRUCTURE

The decision of whether or not to do business in the nuclear industry is a serious one for energy providing institutions to make. Both private companies and government-sponsored entities must consider cost, efficiency, and existing energy infrastructure in order to make important financial decisions on power production. This section is intended to provide an overview of the industry as a whole and, particularly, describe the barriers to entry, both for governments and private industry. Specifically this section will focus on startup issues, what share of the market nuclear currently accounts for, and whether or not governments and companies have an incentive to join the industry based on a strict cost benefit analysis. In these respects, several fundamental differences exist between the management of a stagnant nuclear industry in the West and the emerging nuclear powerhouses of the East. To these ends, each of the following subsections will provide a brief illustration of various nuclear markets by creating a portfolio of growing nuclear energy operations in Asian nations. These examples were chosen because of their prominence in nuclear energy development and their gross nuclear energy production. From East to West and North to South they include: Japan, Russia, China, North Korea, South Korea, Taiwan, and India. In the conclusion of this section, parallels will be drawn to compare these nations with the West by differentiating them with respect to the nuclear energy industry in the United States.

Japan

Because of its unique location and island status, Japan is extremely resource dependent for standard energy sources (coal, natural gas, etc.) and imports 80 percent of its energy resources. In an attempt to reduce its reliance on foreign supplies, the Japanese Atomic Energy Commission was established in 1953 and has since worked to develop a long-term plan for nuclear energy. Since the oil crises of the 1970s, the Japanese government has made nuclear energy a strategic national priority.[228] Japan is, as of January 2011, the third largest generator of nuclear energy in the world with a 47,348 megawatt electrical (MWe) net capacity, which provides 28.9 percent of domestic

[228] Japan's Nuclear Program, *Federation of Electric Power Companies of Japan (FEPC)*, http://www.japannuclear.com/nuclearpower/program/ (accessed Feb. 6, 2011).

electricity production.[229] Japan's nuclear strategy has relied in large part on government leadership despite numerous attempts and calls for deregulation and the creation of incentives for private involvement in nuclear energy development. Since the early 2000s, the Diet has passed several regulatory reforms to allow a less restricted market, which have been implemented progressively. According to Paul Scalise, an energy expert at Sophia University in Tokyo,

> The result is that, today, real competition does not exist in the Japanese electricity market. Despite widespread market liberalization, new entrants have captured less than 2 percent of the contestable market. Prices are still high yet profits continue to fall. The goals of the Japanese electricity industry were clear in 1995. Greater transparency was called for; it has not yet materialized. Lower electricity prices, or else a breakup of the vertically-integrated industry were demanded; neither happened. By Japanese standards, deregulation of the electricity industry has been a failure, not reaching any of its 1995 goals.[230]

Currently, Japan is served by what was once a highly regulated consortium of 10 electric power companies and an emerging private power sector (although, there is only one private company operating nuclear power facilities as of February 2011). Japan's end goal is to allow more freedom for private enterprise to develop nuclear power, but the government still plays a strong role in energy production. In 2002, the Ministry of Economy, Trade, and Industry (METI) implemented a coal power plant tax, which provided an additional 10 billion Japanese yen (JPY) annually to METI's special energy account. This was meant to compliment preexisting oil, gas, and liquefied petroleum gas (LPG) taxes along with a JPY 50 billion per year (or 15.7 percent of LPG taxes at 2002

[229] "World Nuclear Power Reactors & Uranium Requirements," *World Nuclear Association*, January 6, 2011, http://www.world-nuclear.org/info/reactors.html (accessed Feb. 5, 2011).
[230] Paul Scalise, "Whatever Happened to Japan's Energy Deregulation?" *RIETI*, 2009, http://www.rieti.go.jp/en/events/bbl/09062401.html (accessed Feb. 7, 2011).

levels) reduction in its power source development tax for nuclear projects.[231] At that time, Japan hoped to introduce a comprehensive carbon tax in 2005; this did not happen and repeated attempts to introduce legislation to create a carbon tax in Japan have failed, met by relentless political resistance. Because of staunch opposition to this type of a measure by the business community, recent attempts to pass a carbon tax have been seen as publicity stunts designed to garner popularity from specific voter bases without being politically viable.[232] Japan hopes to create a self-sustaining closed nuclear fuel cycle and currently reprocesses spent uranium and plutonium. The U.S. has maintained a strong relationship with Japan in terms of collaboration on nuclear efforts. Several agreements have been signed between the two governments, most recently in 2007 the U.S.-Japan Nuclear Energy Action Plan was signed by President Bush and Prime Minister Koizumi.[233] Between December 2010 and February 2011, the time of this writing, the U.S. has been rushing to sign a number of nuclear deals with foreign countries including South Korea, Vietnam, India, Turkey, and Saudi Arabia.[234]

In Japan, there is a significant activist movement against nuclear energy, which includes citizen lobbyist groups, and ongoing hunger strikes against proposed reactors, but these have had a limited effect on the political viability of the industry (as of January 2011).[235] Japan's sensitivity to seismic activity and earthquakes has been the cause of

[231] "Nuclear Power in Japan," *World Nuclear Association*, January 21, 2011, http://www.world-nuclear.org/info/inf79.html (accessed Feb. 7, 2011).
[232] Tom Young, "Japan Sets Out Domestic-focused Low Carbon Action Plan," *Business Green*, April 21, 2010, http://www.businessgreen.com/bg/news/1802477/japan-sets-domestic-focused-low-carbon-action-plan (accessed Feb. 19, 2011).
[233] "United States-Japan Join Nuclear Energy Action Plan," Ministry of Foreign Affairs of Japan, June, 29, 2006, http://www.mofa.go.jp/policy/un/disarmament/arms/action0704.pdf (accessed Feb. 5, 2011).
[234] "News Watch 140." *CNIC-Citizens' Nuclear Information Center*, February, 2011. http://cnic.jp/english/newsletter/nit140/nit140articles/nw140.html#enrich (accessed Feb. 5, 2011).
[235] "Five Japanese in Hunger Strike Against Kaminoseki Nuclear Power Plant," *PanOrient News*, January 29, 2011, http://www.panorientnews.com/en/news.php?k=716 (accessed Feb. 5, 2011).

several incidents involving nuclear facilities. Geologists recently warned that a controversial spent fuel reprocessing plant at Rokkasho, which holds about 3,000 tons of spent nuclear fuel, may be built on an active fault line about 10 miles long.[236] A 6.8 earthquake in 2008 forced a Tokyo nuclear facility to temporarily shut down for inspection. Additionally, the Tokaimura nuclear accident in September 1999 is known as the "world's worst nuclear accident since Chernobyl."[237] This incident involved the inappropriate handling of nuclear materials by improperly trained personnel, which resulted in one death and radiation exposure to hundreds of others. By contrast, an earthquake in July 2007 that rattled Japan's Kashiwazaki-Kariwa Nuclear Power Station did much less damage than expected given the magnitude of the seismic event. After a four-day comprehensive physical inspection, IAEA officials concluded that no damage to nuclear components occurred and that safety precautions had proven even more beneficial than intended.[238]

Russia

Home of the very first civilian nuclear power reactor in 1954 through the formerly centrally controlled Unified Energy Systems (RAO UES), Russia is facing a sharp rise in energy demand after decades of stagnation.[239] With a call for increased energy output on the horizon, Russia plans to close the gap by a rapid expansion of its current nuclear programs. Russia is currently the fourth largest generator of nuclear energy in the world

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[236] "Japan's Nuclear Facilities Face Quake Risk," *UPI Asia*, June 12, 2008, http://www.upiasia.com/Security/2008/06/12/japans_nuclear_facilities_face_quake_risk/3945/ (accessed Feb. 7, 2011).

[237] "Japan Cancels Nuclear Plant," *BBC News*, February 22, 2000, http://news.bbc.co.uk/2/hi/asia-pacific/652169.stm (accessed Feb. 5, 2011).

[238] "IAEA Issues Report on Kashiwazaki-Kariwa Nuclear Plant," *International Atomic Energy Agency*, August 17, 2007, http://www.iaea.org/newscenter/news/2007/kashiwazaki-kariwa_report.html. (accessed Feb. 19, 2011).

[239] "Nuclear Power in Russia," *World Nuclear Association*, January 21, 2011. http://www.world-nuclear.org/info/inf45.html (accessed Feb. 6, 2011).

with a 23,084 MWe net capacity—about half of that of Japan—which provides a 17.8 percent share of electricity production.[240] While most of its nuclear energy production capacity is in the West, Russia currently has plans to double its nuclear output by 2020 with new operations in Siberian East Asia and on the Kamchatka Peninsula.[241] Rosatom, Russia's Federal Atomic Energy Agency's 2050 vision is to phase out fossil fuels for energy generation and move, in large part, to reliance on nuclear with a closed fuel cycle. In large part, Russia's emphasis on nuclear is a strategic move to free up its own fossil fuel resources for export, namely to China and other developing Asian economies (which will be discussed in further detail below). In 2001, the government consolidated all civilian nuclear programs into Rosenergoatom, which became Energoatom in 2008. Energoatom operates with state funding for new plants and life extensions of current plants, and plans to meet the policy goal of doubling nuclear output by 2020. Current licensing processes generally allow plants to operate for 30 years with extensions adding a potential 15-25 years.[242] Russia's business model for nuclear is in part based on energy sales and foreign investment:

> In February 2007 RAO UES said that it was aiming to raise up to US$ 15 billion by selling shares in as many as 15 power generation companies, having increased its investment target by 2010 from $79 to $118 billion. Late in 2006 UES raised $459 million by selling 14.4 percent of one of its generators, OGK-5, and since then the UES sell-off has continued with investors committing to continued expansion. In mid 2008 RAO UES was wound up, having sold off all its assets. Some of these were bought by EU utilities, for instance Finland's Fortum bought at auction 76.5 percent of the small utility TGC-10, which operates in well-developed industrial regions of the Urals and Western Siberia. From July 2008,

[240] "World Nuclear Power Reactors & Uranium Requirements," *World Nuclear Association*, January 6, 2011. http://www.world-nuclear.org/info/reactors.html (accessed Feb. 5, 2011).
[241] "Nuclear Power in Russia," *World Nuclear Association*, January 21, 2011. http://www.world-nuclear.org/info/inf45.html (accessed Feb. 6, 2011).
[242] Ibid.

> 25 percent of all Russia's power is sold on the competitive market. The wholesale power market is expected to be fully liberalised by 2011.[243]

In addition to government funding and the consolidated nuclear energy production process in Russia, RAO UES has also taken advantage of regional energy opportunities, energy wholesaling, foreign investment, and used asset liquidation to finance new nuclear projects.

A recent agreement between the U.S. and Russia known as a 123 Agreement, which began on December 9th, 2010, laid the groundwork for closer collaboration between the two nations on nuclear energy research, trade, and, production.[244] Mirroring the U.S.-Japan agreement, this deal was revived after President Bush withdrew the proposal as a sanction following Russia's armed conflict with Georgia. While the 123 agreement marked at least nominal improvements in U.S.-Russia relations, it comes amid lingering Cold War animosity and tensions over Russia's relationship with governments that have an unsavory reputation in the eyes of the U.S. State Department. Notably, Russia has been involved in contentious nuclear energy agreements with Iran, a state sponsor of terrorism. In addition to billions of dollars worth of non-nuclear weapons deals with Venezuela, Russia agreed in September of 2008 to assist Venezuela in acquiring nuclear weapons to the chagrin of the U.S. and EU.[245] On August 21, 2010, Russia began loading uranium into Iran's Bushehr nuclear power station despite criticisms from U.S. Secretary of State Hilary Clinton and a fourth round of sanctions

[243] Nuclear Power in Russia," *World Nuclear Association*, January 21, 2011. http://www.world-nuclear.org/info/inf45.html (accessed Feb. 6, 2011).
[244] Ruslan Krivobok, "Civilian Nuclear Deal Enables U.S., Russia to 'Develop Nuclear Reactors,'" *RIA Novosti*, December 14, 2010. http://en.rian.ru/russia/20101214/161772852.html (accessed Feb. 7, 2011).
[245] "Venezuela Set to Develop Nuclear Power With Russia," *Fox News*, September 29, 2008. http://www.foxnews.com/story/0,2933,429441,00.html (accessed Feb. 7, 2011).

from the UN Security Council.[246] This is one billion dollar project for was provided by Tehran after a 1975 project with German companies fell through following a U.S. high-technology supplies embargo during the 1979 Islamic Revolution, and siege of the U.S. Embassy in Tehran.

Russia also has aggressive plans to carve up the Arctic and is currently in the process of developing a fleet of portable floating nuclear reactors for offshore use. Engineers at Rosatom in St. Petersburg hope to have these reactors online in the next few years as part of a plan to ramp up drilling operations. Russia sees the Arctic as its main source of oil and gas by 2020. With eyes on natural resource hungry China, Russia sees the estimated 75 billion barrels of oil in the Arctic as a tremendous opportunity.[247]

Figure 5.1. Artist's Rendering of the Academic Lomonosov, A Russian Floating Power Station

Source: Ken Stier, "In Russia, a Push for Floating Nuclear Power Plants," *Time*, November 12, 2010. http://www.time.com/time/health/article/0,8599,2031143,00.html (accessed Feb. 19, 2011).

[246] Mark Tran, "Iran to Gain Nuclear Power as Russia Loads Fuel Into Bushehr Reactor," *The Guardian*, August 13, 2010. http://www.guardian.co.uk/world/2010/aug/13/iran-nuclear-power-plant-russia (accessed Feb. 7, 2011).
[247] Richard Galpin, "Nuclear Power at Heart of Russia's Arctic Ambition," *BBC News*, September 22, 2010. http://www.bbc.co.uk/news/world-11381773 (accessed Feb. 7, 2011).

Situated on barges, Rosatom's 21.5 ton, 35 MW light water reactor (LWR) floating power stations are designed to support floating cities of up to 45,000 and support oil and gas drilling operations.[248] Figure 5.1 gives an idea of the appearance and scale of what some have called "Floating Chernobyls," which have the potential to power cities up to 200,000.[249]

China

Facing an estimated six percent loss in GDP due to pollution and predicted to expand its share of world pollution to 52 percent by 2030, China is looking to nuclear power as a way to reduce its environmental losses and become less dependent on fossil fuels.[250] With plans for the largest nuclear scale ups of any nation, China represents the fastest growing nuclear power industry in the world. It ranks as the tenth nation in terms of nuclear energy production, just behind the United Kingdom with 10,234 MWe net capacity which provides a mere 1.9 percent share of its electricity production portfolio.[251] China currently has 13 reactors and 27 under construction with plans for many more.[252] Between now and 2020, China plans on investing $10.6 billion annually into nuclear energy with hopes of reaching 86 GWe of nuclear output by that time.[253] The People's Republic of China (PRC) hopes to produce 400 GWe by nuclear by 2050, nearly 40 times the current output. With the U.S.'s 104 operable reactors and output of 101,229 MWe,

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[248] Peter Fairley, "Russia Launches Floating Nuclear Power Plant," *IEEE Spectrum*, July 2, 2010. http://spectrum.ieee.org/energywise/energy/nuclear/russia-launches-floating-nuclear-power-plant (accessed Feb. 7, 2011).
[249] Ken Stier, "In Russia, a Push for Floating Nuclear Power Plants," *Time*, November 12, 2010. http://www.time.com/time/health/article/0,8599,2031143,00.html (accessed Feb. 19, 2011).
[250] "Nuclear Power in China," *World Nuclear Association*, January 28, 2011. http://www.world-nuclear.org/info/inf63.html (accessed Feb. 7, 2011).
[251] Ibid.
[252] Ibid.
[253] "China to Boost Nuclear Power," *UPI.com*, January 26, 2011, http://www.upi.com/Science_News/Resource-Wars/2011/01/26/China-to-boost-nuclear-power/UPI-51011296055177/ (accessed Feb. 7, 2011).

China's new construction is significant but still by 2020 would not come close to U.S. levels (though with an ageing nuclear fleet and negative nuclear power replacement plan, the U.S. will likely have a lower nuclear capacity and fewer plants by 2020).[254] These reactors are mostly American engineered generation III Westinghouse APR-1000s and upgraded French "generation II+" CPR-1000s which are based on an old reactor model from France which has been modernized and standardized for cheap Chinese installation.[255] Because the generation II+ reactors are a new rendering of a somewhat outdated design of the 1990s, the Chinese National Nuclear Corporation (CNNC) and the State Council have attempted to reach out to other nations for technology trading. They have called for "Sino-foreign cooperation, in order to master international advanced technology on nuclear power and develop a Chinese third-generation large PWR."[256] Government officials have prioritized the use of generation III technology. The State Council Research Office has cautioned the State Council on going too far too fast by overdeveloping Generation II reactors, which could still be in operation in the 2070s—a time when Generation III reactors will be long surpassed and potentially replaced by nuclear fusion technologies.[257] Notwithstanding the limit to China's access to technology is its shortage of trained and skilled personnel to monitor its developing nuclear facilities.[258] Because of its quickly expanding nuclear sector, China cannot produce

[254] "World Nuclear Power Reactors & Uranium Requirements," *World Nuclear Association*, January 6, 2011. http://www.world-nuclear.org/info/reactors.html (accessed Feb. 5, 2011).
[255] "Nuclear Power in China," *World Nuclear Association*, January 28, 2011. http://www.world-nuclear.org/info/inf63.html (accessed Feb. 7, 2011).
[256] "APWR and HTR are Listed Into the National Program," *Chinese National Nuclear Corporation*, February 24, 2006. http://www.cnnc.com.cn/en/tabid/166/InfoID/6939/frtid/161/Default.aspx (accessed Feb. 7, 2011).
[257] "Maintain Nuclear Perspective, China Told," *World Nuclear News*, January 11, 2011. http://www.world-nuclear-news.org/newsarticle.aspx?id=29080&terms=China (accessed Feb. 19, 2011).
[258] "China's Nuclear Sector Faces Shortage of Specialists," *Reuters*, September 22, 2010, http://af.reuters.com/article/energyOilNews/idAFTOE68J04920100920 (accessed Feb. 7, 2011).

enough specialists on its own. Like Japan and Russia, China has worked to develop a closed fuel cycle and has recently, according to state media, come up with a method of reprocessing spent fuel.[259]

North Korea

Until November 2010, most intelligence indicated that the Democratic People's Republic of Korea (DPRK) had been shutting down nuclear power operations since 2008. However, at that time Siegfried Heckler, a former director of the Los Alamos Nuclear Laboratory, published a revealing report after a visit to North Korea that gave information on a new light water reactor construction project.[260] Indications of such a project began on May 12, 2010 when Pyongyang announced that it had carried out a nuclear fusion reaction.[261] If this is true, the DPRK will have an immediate opportunity to begin enriching uranium for nuclear power with the potential of also enriching uranium for nuclear weapons. Such claims, however, have been met with skepticism and most are hesitant to accept DPRK announcements at face value because of Pyongyang's history of deliberately misstating the facts.

The U.S. has viewed North Korea's nuclear program as a security threat since the 1990s when the Agreed Framework came about. This 1994 agreement provided for U.S. installation of two LWRs for the energy hungry DPRK. In 2003, however, North Korean leaders, fearing threats to their regime, withdrew from the NPT and the Agreed Framework. At that time, North Korea began developing a nuclear weapons program. In

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[259] Michael Bristow. "China 'In Nuclear Power Advance,'" *BBC News*, January 3, 2011. http://www.bbc.co.uk/news/world-asia-pacific-12107126 (accessed Feb. 7, 2011).
[260] "Report: N. Korea Begins Building Light-Water Reactor," *Fox News*, November 13, 2010. http://www.foxnews.com/world/2010/11/13/report-n-korea-begins-building-light-water-reactor/ (accessed Feb. 7, 2011).
[261] "North Korea Claims Nuclear Fusion Success," *The Australian*, May 12, 2010. http://www.theaustralian.com.au/news/world/north-korea-claims-nuclear-fusion-success/story-e6frg6so-1225865505827 (accessed Feb. 7, 2011).

2008, after years of unsuccessful talks and rounds of negotiating, North Korea announced that it would dismantle its nuclear program and discontinue a reactor project under construction.[262] In November 2010, former New Mexico Governor Bill Richardson traveled to Pyongyang as a non-governmental private consultant and convinced the DPRK to allow UN inspectors in their nuclear facilities. He has been in continual talks with the North Korean government since that time including a December 2010 trip with CNN's Wolf Blitzer.[263] The North Korean Institute of Physics has been the primary government entity responsible for nuclear development.

South Korea

The Republic of Korea (ROK) has 21 operational reactors, 5 under construction, and 6 in the planning phase with a current net capacity of 18,678 MWe, making it the sixth largest nuclear energy producer in the world behind Germany. Nationally, this provides a 34.8 percent share of the net electricity portfolio.[264] In December 2010, the Ministry of Knowledge Economy announced that South Korea plans to build 14 new reactors by 2024. The Korea Hydro & Nuclear Power Company (KHNP), a subsidiary of the government owned Korea Electric Power Company (KEPCO), which has a monopoly on power transmission in the ROK, will invest $30-40 billion to build 18 power plants by 2030 which will generate 59 percent of South Korea's power.

Emerging as a new global leader in nuclear development, the Republic of Korea has recently been involved in discussions about how it could become involved in

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262 Siegfried Heckler, "The Risks of North Korea's Nuclear Restart," *Bulletin of the Atomic Scientists*, May 12, 2009. http://thebulletin.org/web-edition/features/the-risks-of-north-koreas-nuclear-restart (accessed Feb. 7, 2011).

263 "Transcript: Bill Richardson on *The Situation Room* with Wolf Blitzer," *CNN Press Room*, December 15, 2010. http://cnnpressroom.blogs.cnn.com/2010/12/15/transcript-bill-richardson-on-the-situation-room-with-wolf-blitzer/ (accessed Feb. 7, 2011).

264 "World Nuclear Power Reactors & Uranium Requirements," *World Nuclear Association*, January 16, 2011. http://www.world-nuclear.org/info/reactors.html (accessed Feb. 5, 2011)..

exporting its technology and expertise, to nuclear programs in Malaysia, Turkey, Egypt, Jordan, and, most notably, the United Arab Emirates. In December 2010, ROK President Lee Myng-bak met with Malaysian Prime Minister Datuk Seri Najib Tun Razak to discuss nuclear technology sharing and assistance programs.[265] In October 2010, officials from Seoul's Ministry of Knowledge Economy traveled to Turkey to follow up on a nuclear agreement reached earlier in the year during a presidential visit to Seoul and to discuss taking on a $10 billion project to build two new nuclear reactors.[266] Turkey plans on negotiating $400 billion in nuclear plant contracts by 2030. As recently as January 23, 2011, ROK officials were in talks with Egyptian officials about offering nuclear assistance as Cairo intends on issuing a six month tender for bidding on nuclear plant construction with plans of adding 4,000 MWe by 2025.[267] At the time of this writing, there is an ongoing attempt to overthrow the government of Egypt, the outcome of which is not yet known. In January 2010, KEPCO won its most notable victory so far beating out GE Hitachi, and Areva in a bidding war for a $20 billion contract to build four of its signature APR-1400s in the United Arab Emirates (UAE).[268] The deal marked a critical turning point for South Korea and gave KEPCO a competitive edge as the leader in "some of the world's most efficient, cutting-edge plant designs."[269] According to South Korean President Lee Myung-bak, the UAE deal represented a huge

[265] Dharmender Singh, "KL and Seoul to Work Together on Nuclear Energy," *TheStar Online*, December 11, 2010. http://thestar.com.my/news/story.asp?file=/2010/12/11/nation/7604925&sec=nation (accessed Feb. 7, 2011).
[266] Koh Young-aahb. "Korea, Turkey to Discuss Nuclear Industry Cooperation., *The Korea Herald*, October 16, 2010. http://www.koreaherald.com/business/Detail.jsp?newsMLId=20101006000763 (accessed Feb. 7, 2011).
[267] Mohamed-Abel Salam, "Egypt to Seek Atomic Reactor Bids, South Korea Offers Building Help," *Bikyamasr*, January 23, 2011. http://bikyamasr.com/wordpress/?p=24550 (accessed Feb. 7, 2011).
[268] "KEPCO Wins UAE Civil Nuclear Bid," *Nuclear Engineering International*, January 4, 2010. http://www.neimagazine.com/story.asp?storyCode=2055052 (accessed Feb. 7, 2011).
[269] Lee Ho-jeong, "Why Is the U.A.E. Nuclear Plant Deal So Important?" *Korea JoongAng Daily*, January 9, 2010, accessed February 7, 2011, http://joongangdaily.joins.com/article/view.asp?aid=2915051.

breakthrough: "We had been building nuclear power stations for 30 years but had failed in repeated attempts to break into international markets."[270] In the eyes of South Korea, one of the most significant pressures on its growing nuclear power potential is the fact that it is not allowed to reprocess under a 1974 agreement with the United States. Because of South Korea's ardent desire to export nuclear technology, it also desires a closed fuel cycle. Because its nuclear treaty expires in 2014, it has been pressuring the U.S. to change the terms to allow it to reprocess or pyroprocess. Seoul has most recently proposed pyroprocessing as an alternative because it reprocesses plutonium in a way that maintains a level of impurity that would not allow for direct use in weapons without further refinement.[271]

Taiwan

With a net capacity of 4,927 MWe providing a 20.7 percent share of net electricity production, the Republic of China (ROC), more commonly referred to as Taiwan, is the 14th largest nuclear energy producer behind Belgium.[272] Importing 99 percent of its energy, Taiwan has a vested interest in nuclear energy production, but, because of its size, will likely not expand as extensively as neighboring countries. The ROC has four operational boiling water reactors (BWRs), two pressurized water reactors (PWRs), and two advanced boiling water reactors (ABWRs) under construction. Taiwan also operates its own waste facility. All facilities are managed by the ROC's state power

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[270] David Adam Stott, "South Korea's Global Nuclear Ambitions," *The Asia-Pacific Journal: Japan Focus*, March 22, 2010. http://japanfocus.org/-David_Adam-Stott/3322 (accessed Feb. 6, 2011)..
[271] Choe Sang-Hun, "U.S. Wary of South Korea's Plan to Reuse Nuclear Fuel," *NY Times*, June 13, 2010. http://www.nytimes.com/2010/07/14/world/asia/14seoul.html?_r=2 (accessed Feb. 19, 2011).
[272] "World Nuclear Power Reactors & Uranium Requirements," *World Nuclear Association*, January 6, 2011. http://www.world-nuclear.org/info/reactors.html (accessed Feb. 5, 2011).

company, Taipower.[273] Thus, Taiwanese nuclear energy is entirely under government control and is executed through a small civilian power company. This parallels other models already discussed, such as that of South Korea or China, but on a much smaller scale.

India

A non-signatory to the Nuclear Non-Proliferation Treaty (NPT), India comes in just behind Taiwan as the 15th largest nuclear energy producer, with a net capacity of 4,780 MWe that provides a measly 2.2 percent of the net national electricity portfolio.[274] One of the main reasons for India's stagnation in nuclear power until now has been its status as a nuclear weapons state outside the NPT which has made it difficult for India to acquire nuclear materials for energy generation. Civil nuclear energy agreements have recently been signed with the United States, Russia, France, the UK, South Korea, and Canada, as well as Argentina, Kazakhstan, Mongolia and Namibia, which have led to increasing developments beyond prior trade restrictions.[275] India has 20 reactors, 5 under construction, and 39 proposed which should be operational within the next decade. In terms of power, the Indian Atomic Energy Commission (IAEC) is the oversight and regulatory body and the Nuclear Power Corporation of India Ltd. (NPCIL) is the vertically integrated entity responsible for design, construction, commissioning, and operation of civilian nuclear energy facilities. By law, private control of nuclear power is

[273] "Nuclear Power in Taiwan," *World Nuclear Association*, September 2010. http://www.world-nuclear.org/info/inf115_taiwan.html (accessed Feb. 7, 2011).
[274] "World Nuclear Power Reactors & Uranium Requirements," *World Nuclear Association*, January 6, 2011, http://www.world-nuclear.org/info/reactors.html (accessed Feb. 5, 2011).
[275] "Nuclear Power in India," *World Nuclear Association*, January 20, 2011. http://www.world-nuclear.org/info/inf53.html (accessed Feb. 7, 2011).

prohibited and there is no indication that this will change.[276] The private sector can only participate through the supply chain for major equipment and specialized post-installation support.[277] Likely suppliers for plant construction include GE Hitachi, Toshiba Westinghouse, Areva, and Russia's Rosatom. India aims to reach a capacity of 63,000 MWe by 2032 through 16 pressurized heavy water reactor (PHWR) plants which would be organized into "nuclear parks" of 3-4 plants each.[278, 279] Beyond 2032, NPCIL hopes to export its own technology with smaller 220, 540, and 700 MWe PHWRs and potentially thorium reactors.[280] The development of thorium technology is notable in India's quest for nuclear energy as it would represent a major breakthrough if achieved. However, there are several issues with its viability. For one, the Indian method uses plutonium to add neutrons to thorium-233 to turn it into unranium-235 while U.S. scientists believe that it would be safer and more efficient to use a particle accelerator in this process.[281] Additionally, since the thorium energy process is not well known or widely pursued, the market is not predisposed to rapidly adjust to the introduction of thorium-based reactors.

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[276] "Nuclear Power in India," *World Nuclear Association*, January 20, 2011. http://www.world-nuclear.org/info/inf53.html (accessed Feb. 7, 2011).

[277] "Slowdown Not to Affect India's Nuclear Plans," *Business Standard*, January 29, 2011. http://www.business-standard.com/india/news/slowdown-not-to-affect-indias-nuclear-plans/19/57/53400/on (accessed Feb. 7, 2011).

[278] Ibid.

[279] "India Eyeing 63,000 MW Nuclear Power capacity by 2032: NPCIL," *The Economic Times*, October 11, 2010. http://economictimes.indiatimes.com/news/news-by-industry/energy/power/India-eyeing-63000-MW-nuclear-power-capacity-by-2032-NPCIL/articleshow/6730724.cms (accessed Feb. 7, 2011).

[280] Ibid.

[281] Lisa Pham. "Considering an Alternative Fuel for Nuclear Energy," *The New York Times*, October 19, 2009. http://www.nytimes.com/2009/10/20/business/global/20renthorium.html?_r=2&adxnnl=1&pagewanted=1&adxnnlx=1297076445-pC76X32Y/vNYkuOrosMEDw (accessed Feb. 7, 2011).

Parallels

The preceding profiles in nuclear energy have given a broad overview of how the nuclear industry is managed in Asian countries with significant nuclear energy operations and goals. These centralized, active, government guided systems contrast with the nuclear stagnation of the West. Because of the intensive roles played by Asian governments in planning, funding, and operating nuclear new nuclear facilities, it is much easier to overcome legal problems, startup costs, and other financial issues which might make nuclear power unattractive or economically unfeasible to private power companies in the West. Most Asian governments also have had fewer problems with public objections to nuclear facilities. Differences in the price of natural resources, degree of energy dependence, and public demand for new sources of energy have all played a role in shaping the emerging Eastern nuclear market. The robust relationship between public policy and energy production in Asia has created a highly effective top-down system of managing and expanding nuclear power operations. This type of government leadership has distinguished the emerging nuclear future in the East from a relatively stagnant nuclear forecast the West.

DOING BUSINESS IN NUCLEAR

This section is intended to give an overview of the largest companies involved in nuclear and, specifically, provide information on American companies doing business abroad. It will also give some brief commentary about the forecast for this type of business, as well as mention significant Asian firms that will affect U.S. policy and the American energy economy. This section provides some synthesis of the preceding profiles and analysis. Then it will examine regulations pertaining to cap and trade type policies or government tax structures that would affect the energy production of private companies. Additionally, this will also address subsidies and incentive programs for developing nuclear power, structures that already provide regulations and potential future programs, as well as relations between East Asia and Western companies.

Western Firms

While much of the current nuclear development is occurring in Asia, western companies have dominated this process. U.S. giant, Toshiba-Westinghouse Electric Corp. controls 28 percent of the nuclear market, followed by France's Areva Group with 24 percent, American GE Hitachi Corp. at 20 percent, and Canada's Atomic Energy of Canada Ltd. (AECL) at 5 percent.[282] This leaves only 23 percent of the market to all other companies.[283] Strikingly, none of these major western vendors has received certification from the U.S. Nuclear Regulatory Commission (NRC) for any of their reactor designs.[284] Southern Nuclear Operating Co., Inc. which is the only company currently constructing a nuclear reactor in the United States is taking advantage of part of an $18.5 billion government loan guarantee and state laws in Florida, Georgia, and South Carolina that allow utility companies to begin charging customers a special fee for nuclear projects before even making a final commitment to build. Company spokesman David Scanzoni noted: "Without such a policy, the utilities are unlikely to be able to

[282] Lee Ho-jeong , "Why Is the U.A.E. Nuclear Plant Deal So Important?" *Korea JoongAng Daily*, January 9, 2010. http://joongangdaily.joins.com/article/view.asp?aid=2915051 (accessed Feb. 7, 2011).
[283] Note: while Westinghouse and GE both originated and are headquartered in the US, they were purchased by Japanese firms Toshiba and Hitachi, respectively—hence Toshiba-Westinghouse and GE-Hitachi.
[284] Shawn McCarthy, "Why the U.S. Nuclear Industry's Ambitions are at Risk of Going Up in Smoke," *The Globe and Mail*, January 16, 2011. http://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/why-the-us-nuclear-industrys-ambitions-are-at-risk-of-going-up-in-smoke/article1872161/ (accessed Feb. 7, 2011).

proceed with the plants."[285] Overall, the lack of Western activity in nuclear power and a lull in government support in the United States has left Western nuclear companies high and dry. With no sign of these issues relenting, many are predicting a rough road ahead for Western behemoths like Westinghouse, GE Hitachi, Electricité de France, and AECL.

KEPCO-UAE Deal

Perhaps one of the most recent befuddling and confounding changes in the balance of power in nuclear came as KEPCO, South Korea's state energy company, sealed the $20 billion nuclear deal with the UAE. Historically, there was no precedent for such an unexpected gain for an Eastern nuclear firm, but many suspect that the security of KEPCO as a government-backed company may have put it ahead:

> American and Japanese nuclear firms' chances of maintaining an edge may depend on how far their governments are willing to push nuclear power at home. Mr. Obama's sudden enthusiasm has given the American firms hope. But the Department of Energy has yet to hand out any of the previous batch of loan guarantees approved in 2005. Regulators in Florida have squelched local utilities' plans to build new reactors. Recriminations about rising costs have held up another project in Texas. It is a far cry from South Korea, where six reactors are under construction and another 14 are on the drawing board.[286]

Many would adduce the ROK's strong government support for nuclear exports and production, combined with its power company, KEPCO, as the primary reasons for its emerging competitive edge. While U.S. diplomats often advocate U.S. business interests to foreign governments, these deals have primarily centered on contracts with companies that have historically had strong government support such as Boeing. Similarly, the French government, which in many respects has a much larger interest in nuclear power

[285] Shawn McCarthy, "Why the U.S. Nuclear Industry's Ambitions are at Risk of Going Up in Smoke," *The Globe and Mail*, January 16, 2011. http://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/why-the-us-nuclear-industrys-ambitions-are-at-risk-of-going-up-in-smoke/article1872161/ (accessed Feb. 7, 2011).
[286] "The Nuclear Industry: Unexpected Reaction," *The Economist*, February 4, 2010. http://www.economist.com/node/15457220 (accessed Feb. 7, 2011).

(namely, because the country relies on nuclear for more than three quarters of its power generation), has had a difficult time in selling its nuclear programs to foreign governments due to a *laissez-faire* market structure and lack of central control over power generation companies. Because the Western governments and nuclear energy have been reluctant to form a committed alliance, other priorities have taken precedence and the complicated and politically difficult issue of nuclear energy has fallen to the wayside.

Band-Aids for U.S. Nuclear

Recently the U.S. government created a $18.5 billion nuclear loan guarantee program to combat investment stagnation since Three Mile Island in 1979. This amount of money is enough to cover about three nuclear reactor projects and is potentially a first step in making a concerted effort to send a message about nuclear energy to the private sector and investors on Wall Street. The Department of Energy sees four likely contenders: Southern Co., Constellation Energy, NRG Energy, and SCANA Corp.[287] A good example of an innovative company on that list is NRG, a company that is making progress on the U.S. front. NRG is seeking to "revive the faltering nuclear renaissance" by establishing a creative portfolio of investors for its nuclear project in Bay City, Texas, including the U.S. government, the government of Japan, and the plant's builder Toshiba. While a series of setbacks have made nuclear seem relatively more expensive in the short term than coal and natural gas, and a carbon tax and cap and trade seem unlikely in the near future, another U.S. government incentive has been created for new plants: "The first 6 gigawatts of new nukes in the U.S. get a bonus: a tax credit of 1.8 cents per

[287] Ayesha Rascoe, "U.S. Loans to Boost Nuclear Industry Seen Soon," *Reuters*, December 28, 2009. http://www.reuters.com/article/2009/12/28/us-usa-nuclear-loans-idUSTRE5BR39H20091228 (accessed Feb. 7, 2011).

kilowatt-hour for the first eight years of production, to a maximum of $125 million a year. Assuming the first of NRG's twin plants (each 1.35 gigawatts) makes the cut, that's $1 billion."[288] These types of tax credits and loan programs are great incentives, but have a limited audience and the extent to which these can encourage growth in the industry is extremely limited. A loan program that can only help build three plants is not going to spur the kind of growth in nuclear power that is occurring in Asia.

When considering tackling the issue of climate change as a whole, there is the domestic possibility of a carbon tax or cap and trade system that would also incentivize nuclear power. Most economists believe that a carbon tax would be more effective and less detrimental on the economy as a whole as it would not set a definite "cap" on emissions like cap and trade proposals. However, most believe that a cap and trade system would be the most politically viable at a time when raising taxes is not a wise choice from the standpoint of an elected official. As Al Gore wrote,

> For more than 20 years, I have supported a CO_2 tax offset by an equal reduction in taxes elsewhere. However, a cap-and-trade system is also essential and actually offers a better prospect for a global agreement, in part because it is difficult to imagine a harmonized global CO_2 tax. Moreover, I have long recognized that our political system has special difficulty in considering a CO_2 tax even if it is revenue neutral.[289]

A cap and trade bill died in Congress in March of 2010 and 2009, with notable political fallout.[290,291] While discussing the issue with great zeal in his initial proposal earlier in

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[288] Jonathan Fahey, "How NRG Energy Wants to Revive Nuclear Industry," *Forbes*, November 25, 2009. http://www.forbes.com/forbes/2009/1214/energy-power-nrg-energy-wants-revive-nuclear-industry.html (accessed Feb. 7, 2011).

[289] John M. Broder, "House Bill for a Carbon Tax to Cut Emissions Faces a Steep Climb," *NY Times*, March 6, 2009. http://www.nytimes.com/2009/03/07/us/politics/07carbon.html (accessed Feb. 7, 2011).

[290] "Cap and Trade News," *The New York Times*, March 26, 2010. http://topics.nytimes.com/topics/reference/timestopics/subjects/g/greenhouse_gas_emissions/cap_and_trade/index.html (accessed Feb. 7, 2011).

[291] "Barack Obama's Cap and Trade Program Is a Tax on the Working Class," *The Wall Street Journal*, March 9, 2009. http://online.wsj.com/article/SB123655590609066021.html (accessed Feb. 7, 2011).

2010, President Obama dropped all mention of the proposal by March after considerable political backlash. A lack of political leadership and public education on the issue at a time when budgets are tight makes nuclear (and, more broadly, the environment as a whole) a tough subject in Washington.

Asian Firms

Never before has the East presented such a significant challenge to the western nuclear industry and it has done this because, in reality, the West still outpaces Asia in nuclear technology and in total market share. However, the East is engaging in nuclear and will soon surpass western activity and competitive advantage. Individual Asian governments have created their own power companies and are developing their own reactors. The biggest players are Russia's Rosatom, which controls 10 percent of the global market and Korean Electric Power Company with considerably less. Growth is expected from CNNC and CPNIL and therefore Asia's nuclear power market is expected to become 80 percent localized during the coming decade.[292] Despite public funding issues and supply bottlenecks from companies controlling large portions of the market, this means that a significant share of the market for new power reactors is forecasted to move away from western companies and into more centralized national operations.

An emerging player in the Asia power market, Japan is looking to consolidate its national nuclear energy market in response to an ageing population and losses in deals like the KEPCO-UAE agreement.[293] In response, the Japanese government is merging

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[292] Mohammed Hadi and Andrew Peaple, "Nuclear Power's Asian Fallout," *The Wall Street Journal*, June 28, 2010. http://online.wsj.com/article/SB10001424052748703964104575334523878549304.html (accessed Feb. 7, 2011).
[293] J. Soble,"Japan's Nuclear Industry Turns Focus Abroad," *The Financial Times*, August 10, 2010. http://www.ft.com/cms/s/0/9aaca542-8b19-11df-a4b4-00144feab49a.html#axzz1DG6r8T2R (accessed Feb. 7, 2011).

companies together to look abroad for business. The Japanese government began planning in June 2010 for a public-private consortium of six companies to include Hitachi (who owns American GE), Mitsubishi Heavy Industries (which has been involved with GE and Areva of France), Toshiba (who owns Westinghouse), and three of the largest local power companies, Tokyo Electric, Chubu Electric, and Kansai Electric. According to Hirofumi Kawachi, an analyst with Mizuho Investors Securities Corporation, Japan's private-public marriage "is a reasonable step, given that the nuclear-related business needs government involvement to prevent [weapons] proliferation, including cooperation between governments."[294] Japan hopes that such a framework will give it a competitive export edge over industries in countries like France where Electricité de France, Areva, Alstrom, GDF Suez, and Total work together without any formal organization.

It is known that the Chinese National Nuclear Corporation is attempting to develop its own independent nuclear technology to be used on its vast domestic energy expansion project. When these efforts are realized, this will represent a huge transition in the market structure in East Asia where Chinese nuclear power contracts are the most numerous and centralized. At present, China has contracts for advanced pressurized reactors with Westinghouse, Vodo-Vodyanoi Energetichesky reactors with Atomstroyexport (Russia's export arm), among others, and is engaged in cooperative efforts with its own nuclear research bodies and engineering divisions.[295-296]

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[294] Mari Iwata, "Six Japan Firms Team Up to Sell Nuclear-Power Technology," *The Wall Street Journal*, July 10, 2010. http://online.wsj.com/article/SB10001424052748704862404575350511096532110.html (accessed Feb. 7, 2011).

[295] "Chinese Government Approves Reactor Projects," *World Nuclear News*, January 5, 2011. http://www.world-nuclear-news.org/NN-Chinese_government_approves_reactor_projects-0501114.html (accessed Feb. 7, 2011).

CONCLUSION

This chapter is intended to be considered in other chapters of the report in the context of the considerations policymakers face when it comes to nuclear power and global issues that impact U.S. domestic policy. It is also intended to illustrate how the United States' leadership role in global politics will have a large effect on the development of nuclear policy abroad. To conclude, it is important to note several things about the progress of nuclear energy in Asia and what this means for industry leaders in the West like the United States. The biggest takeaway is in noting the differences in government and corporate structures for nuclear power between Asia and the West. Governments have the most power of any player in incentivizing, restricting, or promoting nuclear power.

As Asian nations push for nuclear energy and work to centralize companies in which governments have a stake and improve national research facilities and technologies, western companies can be expected to fall behind due to a lack of government interest in nuclear power and a move toward localized markets and closed nuclear production cycles in the East. Little has been done to encourage or promote what is, to the private sector, a more costly source of power in deregulated economies. In the East, governments have attached a high priority to nuclear power, their energy independence, and, ultimately, their national security. For these countries, energy supply is too valuable to be left to the market which will likely not have the sophistication to develop the technology or create the forward-looking infrastructure necessary for a 21st century power supply alone. For the West, especially in countries like the U.S. that are

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[296] "Nuclear Power in China," *World Nuclear Association*, January 28, 2011. http://www.world-nuclear.org/info/inf63.html (accessed Feb. 7, 2011).

rich in natural resources, the energy issue is not as imminent, especially when it pertains to nuclear which is strongly opposed by segments of the public and economically inefficient for private industry. The policy side difficulties created by a lack of public knowledge and concern combined with the question of cost have created a gap that could leave countries like the U.S. behind if, as resources become scarcer, the energy infrastructure for the future is not built. As energy becomes one of the most powerful and valuable global commodities, the role of government in fostering involvement in nuclear energy will continue to grow.

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Chapter Six

MINING FOR POWER: DISTRIBUTION, EXTRACTION, AND IMPLICATIONS OF THE GLOBAL URANIUM RESOURCE

Alexandra Sawyer

Abstract:

Escalating East Asian investment in nuclear power, coupled with the likelihood of civilian nuclear programs emerging in a number of other states, raises the issue of uranium availability. Uranium is broadly distributed throughout the world in a variety of geologic settings, but is concentrated for productive extraction in only a handful of countries. Economic resources in these states, most notably Australia, Kazakhstan, Canada, Russia, and South Africa, are sufficient to meet forecasted power generation needs for many decades. Identified resources are likely to increase further in the near future with favorable market prices and expanded exploration. Conventional uranium extraction is achieved through either open pit or under ground mining, or increasingly by in situ leaching. While significant health and environmental impacts result from uranium extraction, these can be mitigated with appropriately strict and well-enforced regulations. Uranium prices are expected to stabilize in the near future, having come down from the 2007-2008 spike. Nuclear fuels are cheaper by orders of magnitude than fossil fuels, whose volatile prices and energy security difficulties seem destined to make nuclear energy an increasingly attractive alternative.

INTRODUCTION

Escalating East Asian investment in nuclear power for electricity generation necessitates a discussion of uranium resource availability. Countries that pursue domestic production of nuclear power must secure access to uranium ore to drive electricity generation. Although uranium is broadly dispersed throughout the world, its existence in concentrations high enough to warrant productive extraction is limited to a relatively small but geographically diverse group of countries. Global identified uranium resources are sufficient to meet power generation needs for the near future, and favorable market prices that drive exploration will increase uranium resources for decades to come. Although there are significant health and environmental impacts associated with uranium mining, they are negligible when juxtaposed with the impacts associated with fossil fuel extraction and can be effectively mitigated through stricter application of and adherence to existing regulations.

This chapter will address the issues surrounding availability of uranium ore for nuclear power generation purposes. In exploring these issues, first two fundamental terms will be defined: "uranium resources" and "uranium reserves." The following section will address the distribution of uranium ore, and based on this information provide current estimates and future projections of available uranium resources. The next section will deconstruct the process of uranium extraction and the health and environmental impacts that stem from extraction activities. Following this discussion, information regarding the specificities of the uranium market and uranium imports and exports will be presented. Finally, this report will address the challenges associated with continued global reliance on fossil fuel energy sources, and explore the energy security implications associated with use of fossil fuels and nuclear power.

RESOURCE TERMINOLOGY

To understand the issues pertinent to nuclear materials resource availability, it is first necessary to establish a basic understanding of resource terminology. *Uranium resources* are divided into two categories: identified resources and undiscovered resources. *Identified resources* have been measured sufficiently to warrant the conduct of a pre-feasibility or feasibility study. Identified resources are split into two groups: reasonably assured resources are those characterized by high confidence in tonnage and grade, which aligns them with mining standards, while inferred resources require further measurement to determine their mining suitability.[297] *Undiscovered resources* are expected to exist based on established geological knowledge, but require significant

[297] NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 160.

further exploration to confirm and characterize their grade and tonnage. Like identified resources, undiscovered resources are split into two groups: prognosticated resources are presumed to exist (generally with some evidence) in known uranium areas, while speculative resources are presumed to exist in areas that may contain uranium reserves.[298]

The term *reserves* is used to indicate the identified resources that are recoverable using current technology and under current economic conditions. Reserves exclude known deposits whose extraction is not economically feasible, or those whose exact geologic location relative to other well-mapped deposits is uncertain. As such, reserves represent only a small portion, a "snapshot", of the total uranium resource available on earth, and are not demonstrative of the total quantity of uranium available for future use.[299,300] Reserves are categorized into four cost production categories, based on the cost of resource recovery: <\$40/kilogram of uranium (kgU), <\$80/kgU, <\$130/kgU, and <\$260/kgU.[301]

URANIUM RESOURCE

Distribution of Uranium Ores

Uranium ore is broadly distributed throughout the world, and is found in low concentrations in rock, soil, and water.[302] Extractable deposits are found in a variety of geological settings, the most common of which are unconformity-related deposits that arise from geological changes occurring close to major unconformities. Less common sandstone deposits are comprised of fluvial or marine sedimentary environments where

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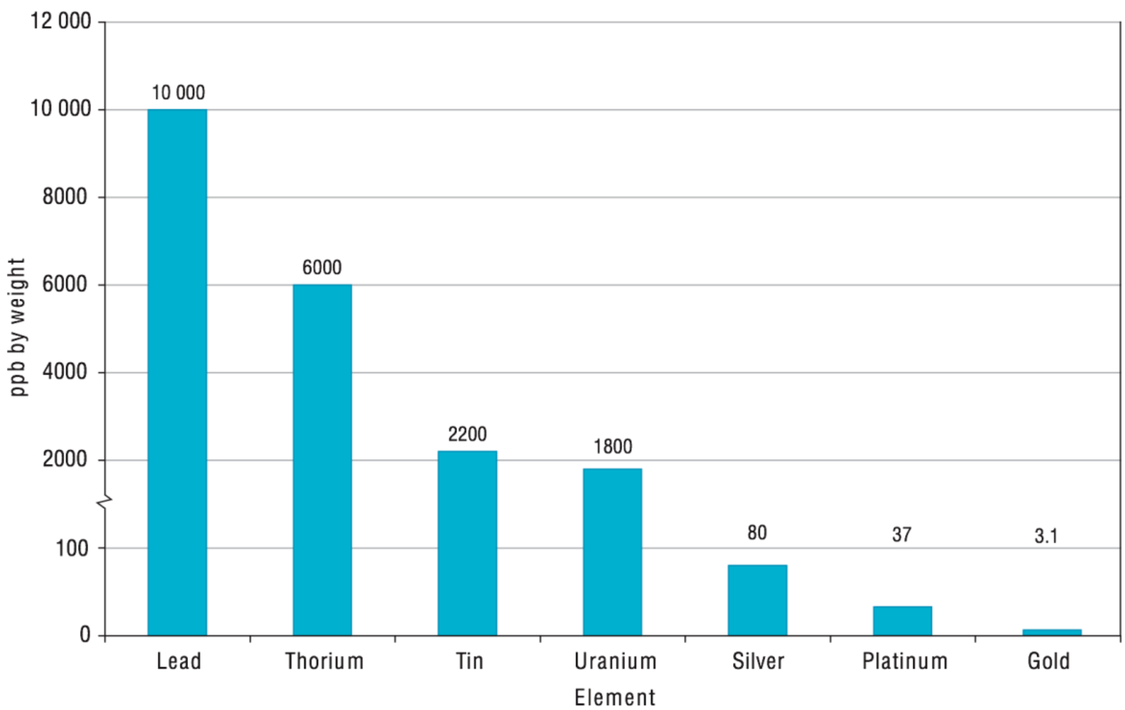
[298] NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 160.
[299] MIT, *The Future of Nuclear Power* (Boston, MA: MIT, 2003), 152.
[300] NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 159.
[301] Ibid, 160.
[302] Australia, *Uranium Mining, Processing and Nuclear Energy: Opportunities for Australia?* (Department of the Minister and Cabinet: 2006), 22-23.

uranium is precipitated through medium to coarse-grained sandstones. Surficial deposits are those in which uranium is present in sediments and soils near the surface. Vein deposits are those in which uranium fills existing cavities in the earth's crust, such as cracks, veins, and fissures, while volcanic deposits arise from faults and shear zones related to volcanic activity.[303] These major types of geologic deposits and their broad global distribution make uranium more abundant that gold or silver, as demonstrated in Figure 6.1.[304]

Figure 6.1. Abundance of Various Economic Metals in the Earth's Crust



Source: Australia, *Uranium Mining, Processing and Nuclear Energy: Opportunities for Australia?* (Department of the Minister and Cabinet: 2006).

Despite the broad distribution of uranium, most ore deposits are found in concentrations of about 0.01-0.02 percent, or 100-200 grams per tonne of rock.[305] As such, the majority

[303] "Geology of Uranium Deposits," *World Nuclear Association*, http://www.world-nuclear.org, January 2010 – (accessed 19 February 2011).
[304] Australia, *Uranium Mining, Processing and Nuclear Energy: Opportunities for Australia?* (Department of the Minister and Cabinet: 2006), 22-23.
[305] Jon Hughes, "Uranium Mining and Milling," *The Ecologist* 36 (2006): 44.

of earth's uranium resources, both identified and undiscovered, contains one percent or less of natural uranium and is classified as low grade.[306] Those reserves that contain 2-20 percent natural uranium are classified as high grade, and attract the majority of exploration and extraction activity because their extraction leaves behind fewer tailings (the waste byproduct of uranium mining) than low grade ore, and as such is more cost effective.[307,308]

Since 1965, the Nuclear Energy Agency (with the help of the International Atomic Energy Agency since the mid-1980s) has compiled a biennial report on the global uranium industry entitled *Uranium [respective year]: Resources, Production, and Demand*. Commonly called "the Red Book" due to its red cover, this report has emerged as the primary source of uranium industry information from 107 participating countries. To date 23 editions have been published, the most recent in 2009.[309] As demonstrated by information obtained from the 2009 edition of the Red Book in Figure 6.2, uranium resources are located in a globally diverse array of countries, though resource share does not always indicate production share[310,311]

Although uranium ore is common throughout the earth's crust, the majority of its productive extraction is limited to a handful of countries. Australia has historically been a primary producer of uranium, and has the world's largest quantity of identified

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306 MIT, *The Future of Nuclear Power* (Boston, MA: MIT, 2003), 152.
307 "Supply of Uranium," *World Nuclear Association*, http://www.world-nuclear.org. December 2010 – (accessed Feb. 19, 2011).
308 NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 160.
309 "Joint NEA/ IAEA Uranium Group," *Nuclear Energy Agency*, http://www.oecd-nea.org/ndd/uranium, 3 June 2008, (accessed Jan. 20, 2011).
310 NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 160.
311 "Supply of Uranium," *World Nuclear Association*, http://www.world-nuclear.org, December 2010 – (accessed Feb. 19, 2011).

Figure 6.2. Identified Resources of Uranium Recoverable at <$130/kgU, 2009

Country	Tonnes Uranium	Percent of World Resources
Australia	1,673,000	31.0
Kazakhstan	651,000	12.0
Canada	485,000	9.0
Russia	480,000	9.0
South Africa	295,000	5.0
Namibia	284,000	5.0
Brazil	279,000	5.0
Niger	272,000	5.0
US	207,000	4.0
China	171,000	3.0
Jordan	112,000	2.0
Uzbekistan	111,000	2.0
Ukraine	105,000	2.0
India	80,000	1.5
Mongolia	49,000	1.0
Other	150,000	3.0
World total	5,404,000	

Source: "Supply of Uranium," *World Nuclear Association*, http://www.world-nuclear.org, December 2010 – (accessed Feb. 19, 2011).

resources extractable at low cost (<$40/kgU) with an estimated 1.2 million tonnes, which is approximately 38 percent of the global low cost resources.[312] In addition to low cost resources, Australia has 27 percent of the global share of identified resources extractable at <$80/kgU, and 22 percent of the global share of identified resources extractable at <$130/kgU.[313] Although resource share alone does not determine production share, Kazakhstan, Australia and Canada (the three countries with the most identified resources) together produce 63 percent of global uranium (see Figure 6.3).[314] Global uranium

[312] Australia, *Uranium Mining, Processing and Nuclear Energy: Opportunities for Australia?* (Department of the Minister and Cabinet: 2006), 22.
[313] Greg Baker, *Australia's Uranium* (Canberra: Parliamentary Library, 2009), 3.
[314] "World Uranium Mining," *World Nuclear Association*, http://www.world-nuclear.org, May 2010, (accessed Feb. 19, 2011).

production totaled approximately 51,000 tU in 2009, amounting to a 16 percent increase from 2008 levels.[315]

Figure 6.3. Uranium Production from Mines (tU)

Country	2003	2004	2005	2006	2007	2008	2009
Kazakhstan	3300	3719	4375	5279	6637	8521	14020
Canada	10457	11597	11628	9862	9476	9000	10173
Australia	7572	8982	9516	7593	8611	8430	7982
Namibia	2036	3038	3147	3067	2879	4366	4626
Russia	3150	3200	3431	3262	3413	3521	3564
Niger	3143	3282	3093	3434	3153	3032	3243
Uzbekistan	1598	2016	2300	2260	2320	2338	2429
US	779	878	1039	1672	1654	1430	1453

Source: "World Uranium Mining," *World Nuclear Association*, http://www.world-nuclear.org, May 2010 – (accessed Feb. 19, 2011).

Despite continued extraction, the total uranium resource base continues to grow as a result of increasing exploration. In short, resources are increasing faster than consumption depletes them.[316] As of 2009, total identified resources were quantified at approximately 796,400 tonnes of uranium (tU) in the <$40/kgU category, 3,741,900 tU in the <$80/kgU category, 5,404,000 tU in the <$130/kgU category, and 6,306,3000 tU in the <$260/kgU category. Although identified resources fell in the lower cost production categories, a drastic increase in the <$260/kgU category elevated total identified resources in 2009 to 837,000 tU higher than 2007 levels, equating to a 13 year increase in supply.[317] Total undiscovered resources were quantified at 10,400,000 tU, representing a slight decrease from 2007 levels. However, some countries, Australia and Namibia included, do not report undiscovered resources and thus quantities are likely significantly higher.[318]

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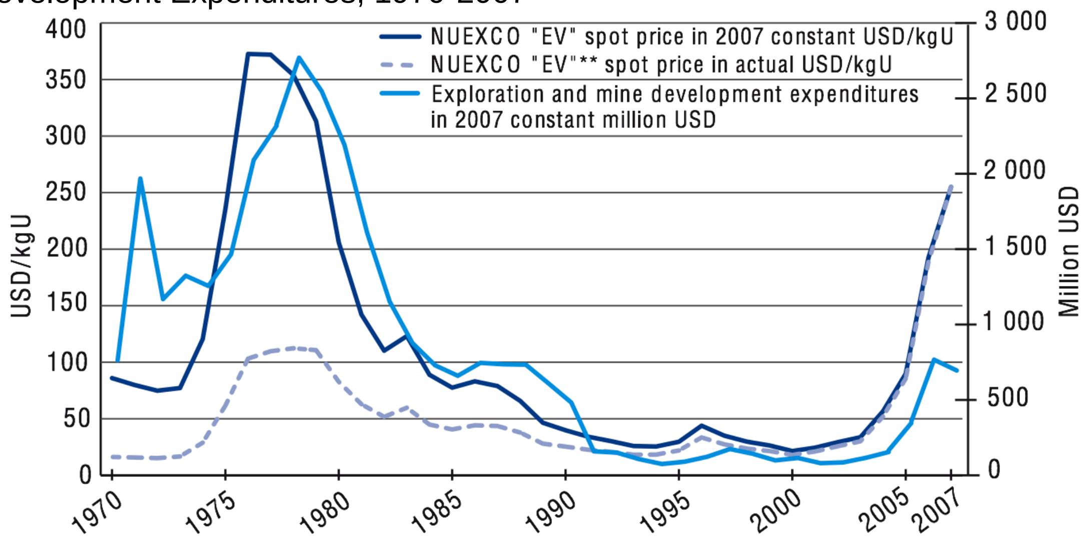
[315] NEA and IAEA, *Uranium 2009: Resources, Production, and Demand* (Paris: Nuclear Energy Agency, 2010), 44.
[316] MIT, *Update of the 2003 MIT Future of Nuclear Power* (Boston, MA: MIT, 2009), 12.
[317] NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 159.
[318] NEA and IAEA, *Uranium 2009: Resources, Production, and Demand* (Paris: Nuclear Energy Agency, 2010), 15-18.

Projections abound as to the future availability of uranium resources for nuclear power use. Favorable market conditions drive exploration, and in the short term are predicted to prolong the trend of increasing uranium resources.[319] A recent increase in uranium prices has spurred a rapid increase in global exploration and mining. Global exploration and mining expenditures rose to $705 million in 2006, $1.33 billion in 2007, and $1.64 billion in 2009, which indicates a likely increase in identified uranium resources.[320,321] Figure 6.4 demonstrates the relationship between the uranium spot market price (the global market for one-time sales of small quantities of uranium ore) and the level of exploration and mining.[322]

Figure 6.4. Average Annual Uranium Market Price, Exploration and Mine Development Expenditures, 1970-2007



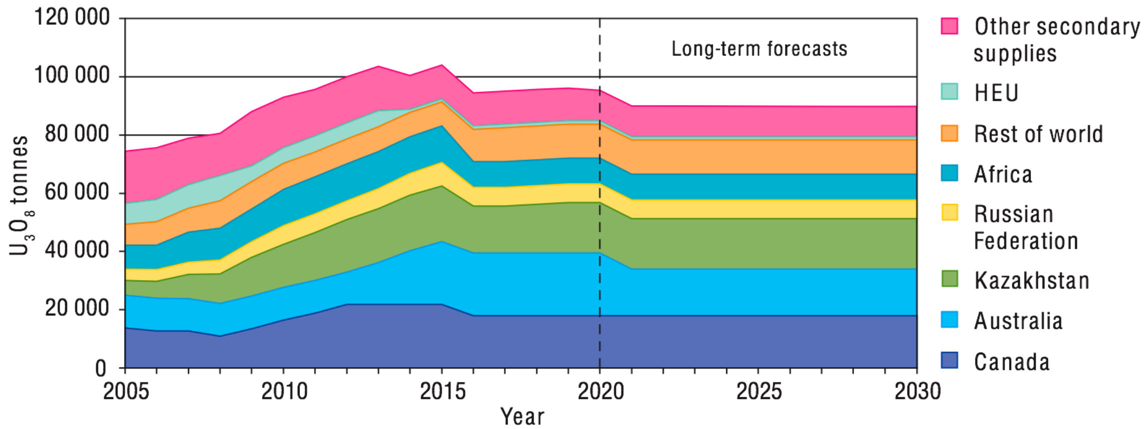
Source: NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 158.

Future increase in uranium production is largely projected in Australia and Canada, but Kazakhstan, Namibia, Russia, and the United States are also projected to

[319] NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 156.
[320] "Supply of Uranium," *World Nuclear Association*, http://www.world-nuclear.org, December 2010, (accessed Feb. 19, 2011).
[321] NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 158.
[322] Ibid, 159.

play a significant role (see Figure 6.5).[323] In Australia alone, exploration and mining expenditures have showed a rapid increase in line with favorable market prices, jumping from $3 million in 2002 to $10 million in 2004, $34 million in 2005, $60 million in 2006, and over $70 million in 2007.[324] Moreover, continued technological advances in exploration techniques increase efficiency and thus make exploration both more thorough and less costly.[325] In particular, current production centers will experience the most rapid expansion because their existing infrastructure allows newly discovered reserves to be brought into production quickly.[326]

Figure 6.5. Projected Uranium Supply by Country, 2005-2030



Source: Australia, *Uranium Mining, Processing and Nuclear Energy: Opportunities for Australia?* (Department of the Minister and Cabinet: 2006), 27.

Based on the 2006 global annual uranium use of 66,500 tU and assuming a once-through fuel cycle, identified resources are already sufficient to fuel at least 85 years of energy generation. If current favorable market trends continue and exploration and mining expenditures follow in the predictable fashion to convert known undiscovered

[323] Australia, *Uranium Mining, Processing and Nuclear Energy: Opportunities for Australia?* (Department of the Minister and Cabinet: 2006), 27.
[324] NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 159.
[325] Australia, *Uranium Mining, Processing and Nuclear Energy: Opportunities for Australia?* (Department of the Minister and Cabinet: 2006), 24.
[326] Ibid, 27.

resources into identified resources, it is projected that reserves would be sufficient to fuel over 300 years of energy generation.[327]

Distribution of Thorium Ores

In considering the current and future status of resource availability for nuclear power production, it is important to include a brief discussion of thorium. Although commercial nuclear power is driven by uranium, major research efforts are underway in India to develop nuclear power reactors that generate electricity using thorium. Lesser efforts have been conducted in China, Germany, Japan, Russia, the United Kingdom, and the United States, but were largely abandoned in the 1980s.[328] Thorium is a potentially attractive alternative to uranium for several reasons, including its relative abundance, high neutron yield, resistance to proliferation, and lessened production of nuclear waste. Like uranium, thorium is broadly distributed in low concentrations throughout the earth's crust in rock, soil, and water. However, as demonstrated in Figure 6.1, thorium is approximately three times as abundant as uranium.[329,330] Current identified resources indicate that there are 2.5 million tonnes of thorium extractable at <$80/kgTh.[331] The fact that India's monazite deposits are thought to contain two thirds of the estimated 12 million tonne global thorium resource incentivizes India's continued research into the

[327] NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 159-160.
[328] Ibid, 414.
[329] "Thorium," *World Nuclear Association*, http://www.world-nuclear.org, July 2010 – (accessed Feb. 19, 2011).
[330] Australia, *Uranium Mining, Processing and Nuclear Energy: Opportunities for Australia?* (Department of the Minister and Cabinet: 2006), 22-23.
[331] NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 414.

development of thorium-driven nuclear power plants.[332] Additional sizeable thorium resources can be found in Australia, Brazil, Egypt, Turkey, and the United States.[333]

Uranium Mining

The economic recoverability of uranium ore is driven by the uranium spot market. Historically, the spot market has made uranium mining economical when ores are present in concentrations of at least 0.1 percent.[334] There are various methods with which to recover uranium ores; these methods vary in their implementation based on the geologic specificities of the ore body, such as the quality of the terrain and the size, grade, and depth of the deposit. Based on these characteristics, conventional uranium extraction is achieved via one of two techniques: open pit mining or underground mining. Open pit mining is the preferred technique when uranium deposits are less than 100 meters below the surface, and beneath an overburden that can be removed without undue expense or effort. Open pit mining requires approximately 25 square hectares of land and removal of 10 million tonnes of waste rock per 200 tU produced annually, but this figure is expected to decrease as lower grade mines are depleted and higher grade mines are developed.[335] Underground mining is the preferred technique when uranium deposits are located more than 100 meters below the surface. Underground mining requires minimal land use, and produces significantly less waste rock than open pit mining.[336]

In addition to the aforementioned conventional mining techniques, various other non-conventional mining techniques are employed to a lesser degree in uranium ore

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[332] "Thorium," *World Nuclear Association*, http://www.world-nuclear.org, July 2010 – (accessed 19 February 2011).

[333] Australia, *Uranium Mining, Processing and Nuclear Energy: Opportunities for Australia?* (Department of the Minister and Cabinet: 2006), 30.

[334] NEA and IAEA, *Environmental Activities in Uranium Mining and Milling: A Joint Report* (Paris: Nuclear Energy Agency, Organization for Economic Cooperation and Development, 1999), 21-22.

[335] Ibid.

[336] Ibid.

recovery. For example, a process called in situ leaching requires pumping a leaching solution into an intact porous ore body to dissolve uranium ores and recover the resultant uranium-bearing solution.[337] If planned extraction projects in Kazakhstan, Russia, the United States, and Uzbekistan manifest as planned, in situ leaching is predicted to overtake open pit and underground mining as the principal method of uranium extraction in the near future.[338] Another non-conventional technique similar to in situ leaching is called heap leaching, which involves percolation of a leaching solution through a "heap" of broken ore and recovery of the resultant uranium-bearing solution.[339] When uranium is present in grades of 0.01-0.1 percent, it is typically recovered as a byproduct of other mineral ores such as phosphates, gold, and copper.[340]

Impacts of Uranium Mining

Impacts of uranium mining vary with mining technique, intensity, and duration. However, regulations established to control these impacts vary in their implementation and efficacy. This section will detail the impacts of uranium mining on the surrounding communities and environs through the lens of human health and the natural environment.

Despite the possibility of direct radioactive exposure for those working in uranium mines, uranium tailings represent the most significant mining-related risk to human health. Tailings contain radioactive materials and other heavy metals that remain after uranium ore has been recovered.[341,342] The extraction of uranium from mined ore

[337] NEA and IAEA, *Environmental Activities in Uranium Mining and Milling: A Joint Report* (Paris: Nuclear Energy Agency, Organization for Economic Cooperation and Development, 1999), 21-22.
[338] NEA and IAEA, *Uranium 2009: Resources, Production, and Demand* (Paris: Nuclear Energy Agency, 2010), 52.
[339] NEA and IAEA, *Environmental Activities in Uranium Mining and Milling: A Joint Report* (Paris: Nuclear Energy Agency, Organization for Economic Cooperation and Development, 1999), 22.
[340] Ibid.
[341] NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 162.

can leave up to ten percent unrecovered, and tailings retain approximately 85 percent of the ore's initial radioactivity.[343] Typically, tailings are disposed of over large areas of surface terrain near their origin in specialized ponds or piles, where they are subsequently abandoned. Depending on the duration and quantity of mining performed, these piles can grow to be massive in size: the largest piles in the US and Canada exceed 30 million tonnes, while the largest piles in Germany exceed 80 million tonnes.[344] Beyond the sheer quantity of waste material present in uranium tailings, their method of disposal puts radioactive rock and heavy metals in direct contact with both surface air and water. Historically, this practice has resulted in the dispersal of these materials from the mine site to surrounding communities.[345] As such, people living in close proximity to uranium mines may face radioactive exposure from a variety of sources, including the mine itself, the transport of mined ore, and contaminated air and water.[346]

In addition to its effects on human health, uranium mining has measurable impacts on the natural environment. Environmental impacts are largely derivative of acute and chronic failures in tailings containment structures. Numerous problems can affect these structures and lead to their failure, such as leakages from earthquake-induced instability, breaching from weakness of embankments, dispersal of residue from erosion, overflow of materials, or collapse from heavy rainfalls.[347] On a slower (but no less damaging) timescale, tailings containment structures can release radioactive dust, seep

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[342] IAEA, *Environmental Contamination from Uranium Production Facilities and their Remediation* (Vienna: International Atomic Energy Agency, 2005), 6.
[343] Jon Hughes, "Uranium Mining and Milling," *The Ecologist* 36 (2006): 44.
[344] Ibid.
[345] IAEA, *Environmental Contamination from Uranium Production Facilities and their Remediation* (Vienna: International Atomic Energy Agency, 2005), 6.
[346] Ibid.
[347] Ibid, 5.

acid drainage through the floors and/or walls of the structure, and produce contaminated surface runoff that drains into natural waterways.[348]

Contaminated water is one of the most worrisome consequences of uranium mining. In addition to contaminated runoff water from tailings piles, water is used and contaminated in the process of mining itself. Water used in mining is mixed with radioactive substances such as uranium, thorium, radium, and lead, and is further mixed with heavy metals such as arsenic, selenium, and nickel.[349] Nitrates, nitrites, and ammonia from the blasting of ore further contaminate water. In combination with the surface runoff from mine sites and tailings piles, this represents a substantial quantity of water use and subsequent water contamination. Accidental breach of the groundwater table below mines can lead to further radioactivity and heavy metals contamination of a region's water supply as a whole.[350]

The progression and expansion of uranium mining has several terrestrial impacts as well. Long-term buildup of radionuclides in sediments, plants, and animals has been demonstrated in the immediate vicinity of uranium mining operations. Concentrations increase as radionuclides move up the food chain, and as such pose a direct risk to humans that may consume contaminated plants or animals.[351] Ecosystem contamination and radionuclide concentration stem from the failure to contain radioactive materials released in uranium mining. Additionally, chemical residues resulting from uranium mining pose further environmental risks that can often outweigh those posed by

[348] IAEA, *Environmental Contamination from Uranium Production Facilities and their Remediation* (Vienna: International Atomic Energy Agency, 2005), 5.
[349] NEA and IAEA, *Environmental Activities in Uranium Mining and Milling: A Joint Report* (Paris: Nuclear Energy Agency, Organization for Economic Cooperation and Development, 1999), 23.
[350] IAEA, *Environmental Contamination from Uranium Production Facilities and their Remediation* (Vienna: International Atomic Energy Agency, 2005), 4.
[351] Ibid, 7.

radioactivity, largely stemming from the chemical toxicity of radionuclides, heavy metals, and compounds used in uranium extraction and processing.[352] If environmental exposure to such risks occurs in a chronic fashion, it can poison organisms and in the process compromise their growth, reproduction, behavior, and disease resistance.[353]

Extensive regulations exist to prevent the negative health and environmental impacts of uranium mining. However, effective enforcement of these regulations is not the norm. While the International Atomic Energy Agency has published several guides regarding mining safety and best practices, their enforcement is complicated by the sheer global scope of uranium extraction and the long-term nature of the impacts in question. Enforcement is further complicated by the profusion of country-specific and state-specific mining legislation. The regulations enshrined in such publications and bodies of legislation stipulate best practices in mining safety, radiation safety, equipment safety, mine ventilation, water quality, and environmental protection. Further regulations exist to manage hazardous wastes and contaminated materials associated with uranium extraction.[354] In accordance with regulations, tailings acids should be neutralized and made insoluble, mine floors should be sealed, the excavated overburden should be replaced, and the entire area should be replanted with indigenous vegetation.[355] Processes such as these reflect proper planning, development, operation, and decommissioning of uranium extraction sites, and in theory should minimize health and

[352] IAEA, *Environmental Contamination from Uranium Production Facilities and their Remediation* (Vienna: International Atomic Energy Agency, 2005), 6-7.
[353] Ibid, 8.
[354] World Nuclear Association, *Sustaining Global Best Practices in Uranium Mining and Processing* (London: World Nuclear Association, 2008), 3-5.
[355] Jon Hughes, "Uranium Mining and Milling," *The Ecologist* 36 (2006): 44.

environmental impacts.[356,357.] However, these impact mitigation processes are time consuming and expensive, and as such are commonly deemphasized.[358]

URANIUM MARKET

Exporters and Importers

The uranium market is characterized by certain peculiarities that differentiate it from other global mineral commodities. In large part, uranium is not an exchange-traded commodity, but rather is traded between countries in three to seven year contracts that take into account capital investments in mines, diplomatic links, uranium quality, and duration of the contract.[359] The spot market, which consists of one-time sales of small quantities of uranium ore, accounts for only about 20 percent of global uranium trade.[360,361.] Moreover, uranium is sold in varying forms and levels of enrichment based on the capabilities and treaty responsibilities of importer and exporter countries.[362].

Due to its abundance of uranium resources and its dominance in uranium production, Australia is the principal supplier in the global uranium market. As of 2005, Australia exported uranium to ten countries, of which the United States (36 percent) and the European Union (31 percent) were the primary importers, followed by Japan (22 percent) and South Korea (9 percent). All of these countries have been and will likely

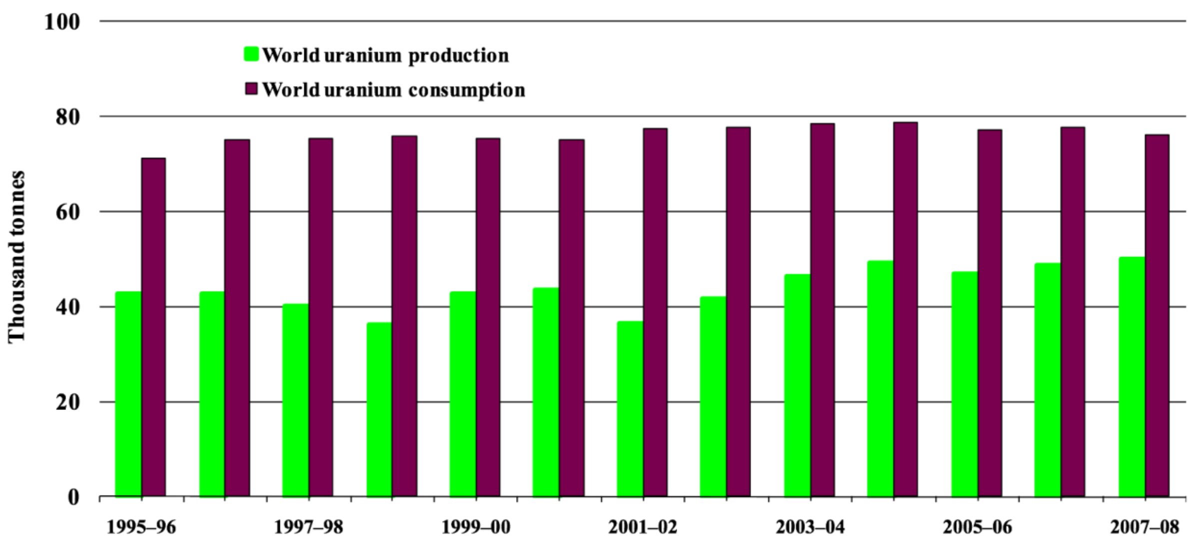
356 World Nuclear Association, *Sustaining Global Best Practices in Uranium Mining and Processing* (London: World Nuclear Association, 2008), 6.
357 NEA and IAEA, *Environmental Activities in Uranium Mining and Milling: A Joint Report* (Paris: Nuclear Energy Agency, Organization for Economic Cooperation and Development, 1999), 28.
358 Jon Hughes, "Uranium Mining and Milling," *The Ecologist* 36 (2006), 44.
359 Gabrielle Hecht, "The Power of Nuclear Things," *Technology & Culture* 51 (2010), 14.
360 Ibid.
361 Devika Sharma, "Uranium Trade and its Security Implications for India," *South Asian Survey* 17 (2010), 99.
362 Ibid.

continue to be long-term importers of uranium.[363] India, Russia, and China are projected to increase their roles as primary uranium importers in the coming years.[364] This increased demand reflects projections for growth in the nuclear energy industry in terms of power plant construction, increased power plant capacity, and reduction in stocks of retired warheads from which to derive previously enriched uranium.[365]

Price Considerations and Trends

As previously discussed, economic recovery of uranium reserves is limited by the uranium spot market.[366] Currently, the rate of global uranium consumption exceeds the rate of global uranium production, despite abundance of global resources (see Figure 6.6).[367,368.] However, due to favorable market prices and increased exploration, supply is

Figure 6.6. World Uranium Production and Consumption, 1995-96 to 2007-08



Source: Greg Baker, *Australia's Uranium* (Canberra: Parliamentary Library, 2009), 5.

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363 Australia, *Uranium Mining, Processing and Nuclear Energy: Opportunities for Australia?* (Department of the Minister and Cabinet: 2006), 22.
364 Ibid, 26.
365 Ibid.
366 NEA and IAEA, *Environmental Activities in Uranium Mining and Milling: A Joint Report* (Paris: Nuclear Energy Agency, Organization for Economic Cooperation and Development, 1999), 21-22.
367 Greg Baker, *Australia's Uranium* (Canberra: Parliamentary Library, 2009), 4-5.
368 MIT, *Update of the 2003 MIT Future of Nuclear Power* (Boston, MA: MIT, 2009), 12.

forecast to meet demand over the medium term.[369]

As demonstrated, there exists a persistent imbalance between uranium supply and demand.[370] The shortage of uranium production is currently mitigated via decommissioning of retired warheads.[371] Specifically, the Megatons to Megawatts Program has both maintained uranium supply and kept uranium prices relatively low. Initiated in 1993, the Megatons to Megawatts Program decommissions retired nuclear warheads in accordance with the nuclear disarmament treaties between the United States and Russia, and converts the highly enriched uranium recovered into low enriched uranium fuel for use in civilian nuclear power plants.[372] To date, 16,494 warheads have been decommissioned to convert 412 tonnes of highly enriched uranium to 11,905 tonnes of low enriched uranium for civilian power.[373] This program, combined with slow growth in generating capacity and expansion of mine productivity, kept uranium prices relatively low until 2004. In 2004, prices began to rise, reaching a peak in 2007-2008 as a result of heightened demand coupled with uncertainty about future supply. Since then, uranium prices have decreased, though not to their previous levels (see Figure 6.7).[374,375.] At of February 2011, the uranium spot market price is $159.28/kgU.[376] Forecasts predict

[369] Australia, *Uranium Mining, Processing and Nuclear Energy: Opportunities for Australia?* (Department of the Minister and Cabinet: 2006), 27.
[370] Greg Baker, *Australia's Uranium* (Canberra: Parliamentary Library, 2009), 4-5.
[371] Ibid.
[372] "Military Warheads as a Source of Fuel," *World Nuclear Association*, http://www.world-nuclear.org, January 2010, (accessed Feb. 19, 2011).
[373] "Nuclear Nonproliferation - Megatons to Megawatts," *USEC Inc. - A Global Energy Company*, http://www.usec.com/megatonstomegawatts.htm. 31 December 2010 – (accessed Feb. 21, 2011).
[374] Greg Baker, *Australia's Uranium* (Canberra: Parliamentary Library, 2009), 4-5.
[375] "Steel Exports," *AdvisorAnalyst.com*, http://advisoranalyst.com/glablog/tag/steel-exports, 6 December 2010 – (accessed Feb. 19, 2011).
[376] "UxC: Ux Prices," *UxC: Ux Consulting-The Nuclear Fuel Price Reporter*, http://www.uxc.com/review/uxc_Prices.aspx. 14 February 2011 – (accessed Feb. 19, 2011).

that uranium prices will even out in the short term when the uncertainties surrounding global supply and decommissioning of retired warheads have stabilized.[377]

Figure 6.7. World Uranium Prices, 1990-2010

Source: "Steel Exports," *AdvisorAnalyst.com*, http://advisoranalyst.com/glablog/tag/steel-exports, 6 December 2010 – (accessed Feb. 19, 2011).

In addition to driving exploration, the spot market price of uranium plays an important role in the issue of reprocessing. Low uranium prices, as experienced through 2004, mean that uranium is cheaply attainable and hence provide a low incentive for countries to pursue reprocessing of spent nuclear fuel. However, the rise in uranium prices after 2004 and the spike that occurred in 2007-2008 reversed this trend, making the reprocessing of spent fuel a more attractive option for countries without sufficient resources to meet growing demand at a higher price. Although prices have fallen somewhat since the 2007-2008 spike, their failure to come down to pre-2004 levels means that at present there is still a significantly higher incentive to reprocess spent fuel than existed in previous years.

[377] Australia, *Uranium Mining, Processing and Nuclear Energy: Opportunities for Australia?* (Department of the Minister and Cabinet: 2006), 27.

ENERGY SECURITY AND GEOPOLITICAL SHIFTS

Diversification of Energy Supply

Although global demand for uranium is increasing and the nuclear power industry is on the rise, fossil fuel energy sources continue to dominate the global energy supply. Continued reliance on fossil fuels, namely coal, oil, and natural gas, is problematic for a variety of reasons: fossil fuels are dangerous to extract, pose environmental hazards in their mining and production, emit airborne pollutants, and are finite in nature.[378] The geopolitical circumstances surrounding their use further complicate the efficacy of continued reliance on fossil fuel energy sources.[379] Since the 1970s, industrialized countries' reliance on fossil fuel resources has been marked with instability stemming from oil crises, wars, price volatility, and natural disasters. When coupled with the burgeoning demand for energy on a global scale, the instability surrounding fossil fuels has consequently become a substantial security concern.[380]

Given the known instabilities and uncertainties inherent to the current mix of energy consumption, countries necessarily take a multitude of factors into account when devising an energy strategy, including the domestic availability of energy resources, the present and future energy demand, and the affordability of energy imports.[381] The state of international affairs also plays a pertinent role in a country's domestic energy strategy, particularly in regard to the geopolitical situation of energy sources and concern for the effects of energy use on climate change.[382] However, uneven distribution of energy

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378 Udo W. Schroeder, "Energy Realpolitik: Towards a Sustainable Energy Strategy," (2010): 4.
379 Jose Goldemberg, "Energy Choices Toward a Sustainable Future," *Environment* 49 (2007): 14.
380 NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 154.
381 Devika Sharma, "Uranium Trade and its Security Implications for India," *South Asian Survey* 17 (2010): 91.
382 Ibid, 92.

resources and the realities of energy interdependence pose persistent challenges to the maintenance of stability on both domestic and international scales. In short, there exists a delicate balancing act between maintenance of energy supply and maintenance of energy security.[383]

Questions concerning limits to fossil fuel supply and fossil fuel security difficulties have led many countries to pursue a diversified mix of energy sources. Diversification of energy sources simultaneously increases supply and security. As the demand for and price of fossil fuels increase, the price of uranium-fueled nuclear power will become increasingly competitive with coal, oil, and natural gas.[384,385] Nuclear power is in many cases attractive because it addresses the shortcomings and challenges inherent to fossil fuel use. Unlike fossil fuels, uranium is highly energy dense and as such requires less material for equivalent energy production; one tonne of uranium can produce as much energy in a once-through fuel cycle as is produced from 14,000-23,000 tonnes of coal.[386] In addition, the majority of nuclear power production can be accomplished domestically once uranium is acquired on the global spot market or through long-term contracts, thus bolstering energy independence for nuclear power producers.[387]

Moreover, the geopolitical situation of identified uranium resources is more diverse and more stable than that of fossil fuels, thus enhancing the energy security

[383] Devika Sharma, "Uranium Trade and its Security Implications for India," *South Asian Survey* 17 (2010): 92.
[384] Charles Ebinger and Kevin Massy, "Security Implications of the Expansion of Nuclear Energy," *South Asian Survey* 17 (2010): 77.
[385] Jose Goldemberg, "Energy Choices Toward a Sustainable Future," *Environment* 49 (2007): 14.
[386] NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 155.
[387] Ibid.

benefits inherent to nuclear power.[388] The majority of fossil fuel production is concentrated in specific regions, which manifests in a problematic geographic disconnect between energy supply and energy demand.[389] For example, much of the industrialized world is heavily reliant on Middle Eastern and Russian oil to fuel burgeoning energy needs in transportation and power generation.[390,391] The same disconnect is evident with natural gas, as just three countries control 56 percent of the global identified resources: Iran, Qatar, and Russia.[392,393.] In contrast, the geographic diversity characteristic of uranium ore distribution makes nuclear power one of the few viable options with which to combat the lopsided energy supply-demand structure perpetuated by fossil fuel reliance. As demonstrated in Figure 6.8, the global uranium resource is dispersed in countries as geographically far apart as Australia and Ukraine, Kazakhstan and Canada, and Russia and Brazil.[394]

Reorganization of the Geopolitical Energy Hierarchy

Concerns about energy security have already led to a manifest increase in and diversification of resource-based diplomacy, wherein energy consumers are actively expanding the network of energy producers on whom they rely. This expansion is already evident in the developing world, and is especially pertinent to fast-industrializing East Asian countries such as India and China that are simultaneously driving global

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388 NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 154.
389 NEA and IAEA, *Uranium 2009: Resources, Production, and Demand* (Paris: Nuclear Energy Agency, 2010), 17.
390 MIT, *The Future of Nuclear Power* (Boston, MA: MIT, 2003), 20.
391 NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 154.
392 MIT, *The Future of Nuclear Power* (Boston, MA: MIT, 2003), 20.
393 NEA, *Nuclear Energy Outlook, 2008* (Paris: Nuclear Energy Agency, 2008), 155.
394 NEA and IAEA, *Uranium 2009: Resources, Production, and Demand* (Paris: Nuclear Energy Agency, 2010), 17.

Figure 6.8. Global Distribution of Identified Resources, 2010

Source: NEA and IAEA, *Uranium 2009: Resources, Production, and Demand* (Paris: Nuclear Energy Agency, 2010), 17.

energy demand and nuclear power generation.[395] For example, India has already secured contracts with most of the top ten uranium-producing countries. Furthermore, India also has offers of uranium supply from Canada, Brazil, South Africa, and Gabon, and in 2009 alone reached out to Tajikistan, Namibia, and Mongolia in attempt to secure access to further uranium resources.[396]

If present trends continue, the current geopolitical hierarchy and the respective roles occupied by energy producers and energy consumers is liable to witness a shift in the coming years. While the Middle East and Russia currently dominate the vast majority of energy production, an increase in nuclear power production has already borne

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[395] Charles Ebinger and Kevin Massy, "Security Implications of the Expansion of Nuclear Energy," *South Asian Survey* 17 (2010): 77.
[396] Devika Sharma, "Uranium Trade and its Security Implications for India," *South Asian Survey* 17 (2010): 96-98.

witness to the emergence of countries such as Australia, Kazakhstan, and Canada as major players in the provision of raw resource for nuclear power generation. A global shift away from fossil fuels would only enhance this hierarchical reorganization, and in theory stands to elevate the geopolitical importance of countries as varied and diverse as South Africa, Namibia, Brazil, and Uzbekistan.

CONCLUSION

Increasing East Asian investment in nuclear power, coupled with the likelihood of civilian nuclear programs emerging in a number of other states, necessitates a thorough analysis of global uranium resource availability. As demonstrated in this analysis, there exists sufficient global identified uranium resources to power electricity generation for decades to come. Uranium resources will continue to increase as attractive market prices drive further exploration. Despite recognized health and environmental impacts associated with uranium mining, their impacts relative to those of fossil fuels extraction are minor. That being said, as uranium mining expands and intensifies it will be important to ensure more stringent application of and adherence to existing regulations in order to avert preventable health and environmental impacts. If this is achieved, the high energy density and low energy security concerns associated with its use for energy generation would further establish nuclear power as an attractive alternative to continued reliance on fossil fuel energy sources.

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Part III

Human and Environmental Security

Chapter Seven

THE NEXT GENERATION OF NUCLEAR TECHNOLOGIES: MEETING SOCIAL DEMANDS

Ann Pederson

Abstract:

In order to combat growing concerns over resource availability, climate change, and the increasing energy demand in Asia, future nuclear power systems are being developed. These new nuclear technologies must address social demands and provide clean and reliable electricity, sustainability, competitive economics, recognized safety performance, and a reduction in proliferation risks. The nuclear industry has responded to these demands by developing a new generation of reactors that promises safer, cheaper, more efficient, and less waste-producing power. As the center of nuclear energy growth and development transitions to Asia, the reception of nuclear power will warm in the West, provided the industry maintains its safety record and continues to advance technologically.

INTRODUCTION

Concerns over energy resource availability, climate change, and energy security have prompted greater scientific exploration of nuclear power. The latest designs for nuclear power plants incorporate lessons learned from past experiences as well as recent technological developments to offer enhanced performance and safety. The industry has matured, offering low-carbon technology that is available today. However, future technology promises even cheaper electricity, increases in proliferation resistance and safety, sustainability, and decreases in nuclear waste. To play an essential role, future nuclear energy systems will need to provide (1) manageable nuclear waste, effective fuel utilization, and increased environmental benefits, (2) competitive economics, (3) recognized safety performance, and (4) secure nuclear energy systems and nuclear materials.

This report will begin with a review of basic nuclear reactor technology and associated technical terms in order to provide necessary background information for a more central discussion of recent and future technologies. The most common reactor types from Generations I and II are covered before the discussion moves on to recent and future generations: III, III+, and IV. In addition, because the core of this report is centered on the development of the nuclear industry in Asia, a section covering the current and planned power reactors in the region is included, as well as a look into the research and development to which each nation is devoting resources. Finally, some space is devoted to a few specific new nuclear technologies: small modular reactors, thorium reactors, fast-breeder reactors, and new reprocessing technologies.

REVIEW OF REACTOR TECHNOLOGY AND TECHNICAL TERMS

In order to discuss new nuclear technologies, it is helpful to review the basic elements and processes of nuclear power generation. Nuclear power is generated by the continuous fission of atoms in a reactor core, which is then harnessed as heat in either gas or water, and is used to produce steam. The steam in turn drives one or more turbines, which produce electricity.[397]

There are several key components common to all reactors:

- Fuel: reactor fuel is usually uranium oxide (UO_2) pellets, except for reactors that use an alternate fuel cycle. Pellets are loaded into fuel rods that are arranged into fuel assemblies in the reactor core.
- Moderator: for proper chain reaction fission, neutrons must be slowed to a velocity where they can be absorbed by the target fissioning isotope (commonly

[397] Chris Kessler, "Nuclear Fuel Cycle," (lecture, University of Washington, Seattle, WA, April 14, 2010).

uranium-235). A moderator is thus used; water (light water) is the most common but heavy water (deuterium) or nuclear grade graphite is used in some reactors.

- Control rods: these are neutron-absorbing rods, often made of cadmium, hafnium, or boron, and are inserted or withdrawn from the reactor core to control the rate of reaction or to halt it.
- Coolant: the coolant is a liquid or gas that circulates through the reactor core to transfer heat away from it. In light water reactors (LWRs) this is simply the moderator, water. In boiling water reactors (BWRs), there is also a secondary coolant circuit that produces steam.
- Pressure vessel or pressure tubes: reactors often have a robust steel vessel that contains the reactor core and moderator/coolant. Sometimes, pressure tube series are used to hold the fuel and convey the coolant through the moderator.
- Steam generator: the steam generator is a part of the cooling system where the primary coolant brings heat from the reactor to produce steam to turn the turbine.[398] These are not present in BWRs, which employ primary coolant water to generate steam.

Most reactors need to be shut down for refueling, so that the pressure vessel can be opened up. In this case, refueling occurs every 12 to 18 months and a quarter to a third of fuel assemblies are replaced with fresh ones.[399] However, some reactors have pressure tubes (rather than a pressure vessel enclosing the reactor core) and can be refueled while the reactor is still active by just disconnecting the individual pressure tube.

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[398] "Nuclear Power Reactors," *World Nuclear Association,* http://www.world-nuclear.org/info/inf32.html (accessed Jan. 25, 2011).
[399] Chris Kessler, "Nuclear Fuel Cycle," (lecture, University of Washington, Seattle, WA, April 14, 2010).

If graphite or heavy water is used as the moderator, it is possible to run a power reactor on natural instead of enriched uranium. Natural uranium fuel has the same elemental composition as when it was mined (0.7 percent U-235, over 99.2 percent U-238).[400] Enriched uranium has had the proportion of the fissile isotope (U-235) increased by enrichment, commonly to 3.5 to 5.0 percent. In this case the moderator can be ordinary water, and such reactors are called light water reactors (LWRs). Because the light water absorbs neutrons as well as slows them, it is less efficient as a moderator than heavy water or graphite.

Practically all fuel is ceramic uranium oxide (UO_2) and most is enriched. The fuel pellets (usually about 1 cm diameter and 1.5 cm long) are arranged in a long zirconium alloy tube to form a fuel rod; zirconium is hard, corrosion-resistant and permeable to neutrons.[401] Multiple rods form a fuel assembly, which is an open lattice and can be lifted into and out of the reactor core. Fuel rods are commonly between 3.5 and 5 meters long.[402]

The power output for nuclear power plants is quoted in three ways. The thermal energy output (in thermal megawatts—MWt) relates to the quantity and quality of the steam the reactor produces.[403] The gross electrical output (in electrical megawatts—MWe) indicates the power produced by the steam turbine and generator. The net electrical output (MWe) is the power available to be sent out from the plant to the power grid, after deducting the electrical power needed to run the reactor (cooling and feed-

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[400] Chris Kessler, "Nuclear Fuel Cycle," (lecture, University of Washington, Seattle, WA, April 14, 2010).
[401] Ibid.
[402] Ibid.
[403] "Nuclear Power Reactors," *World Nuclear Association*. http://www.world-nuclear.org/info/inf32.html (accessed Jan. 25, 2011).Jan. 25, 2011).

water pumps, etc.) and the rest of the plant.[404] For existing plants, the net electrical output is used to rate the plant. For planned and under construction plants, the gross electrical output is used because there is no functioning data on the reactor available.

Energy generation of all types produces waste. Nuclear power plant waste comes in the form of spent fuel; thermally hot, highly radioactive fission byproducts. The spent fuel is the used fuel pellets from a reactor that are no longer efficient in creating electricity. The waste is made up of short life radionuclides (mainly the fission products) and long life radionuclides known as actinides. Actinides are the series of radioactive elements located at the bottom of the periodic table of elements, including uranium, plutonium, neptunium, and americium. The actinide components make up the most radioactive and long-lasting portion of nuclear waste. Because it is thermally hot and highly radioactive, spent fuel is potentially very harmful. Thus, spent fuel must be handled and stored with care. Since the only way radioactive waste finally becomes harmless is through decay, which for high-level wastes can take hundreds of thousands of years, the wastes must be stored and finally disposed of in a way that provides adequate protection for a very long time.[405]

However, with emerging and current technology some amount of nuclear waste can be reused and limited in their potential for harm. Reprocessing—the process of extracting reusable elements from spent fuel such as uranium and plutonium for re-fabrication into fuel—is one avenue to reduce waste. However, as discussed in Chapter Nine of this report, reprocessing is currently not economical or politically advisable in the

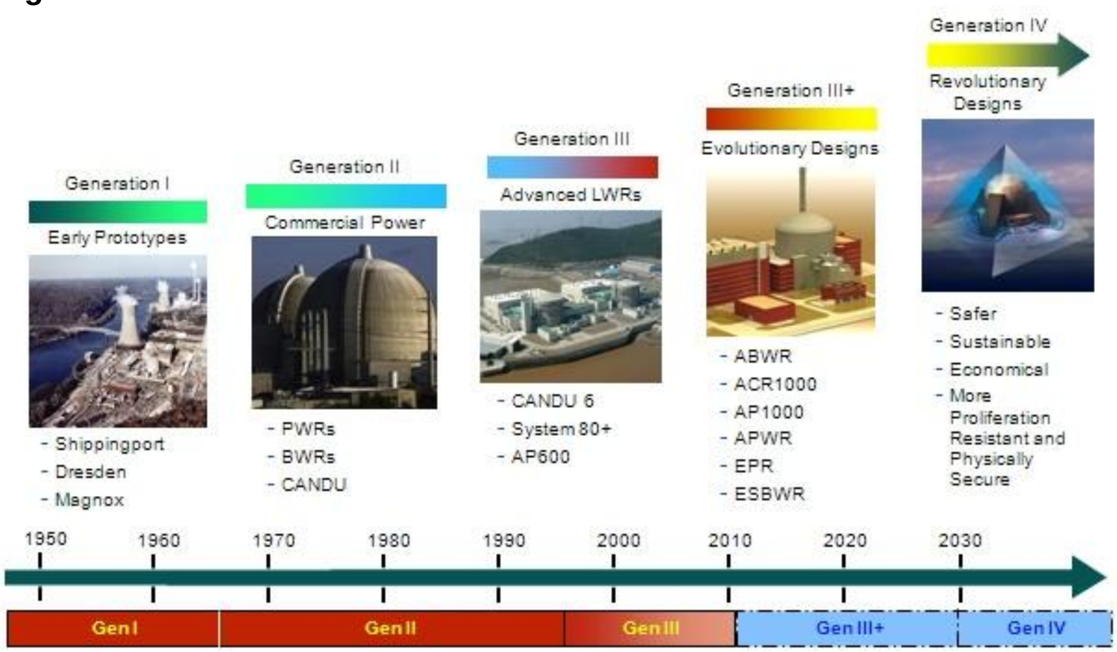
[404] "Nuclear Power Reactors," *World Nuclear Association*. http://www.world-nuclear.org/info/inf32.html (accessed Jan. 25, 2011).Jan. 25, 2011).
[405] "High-Level Waste," *United States Nuclear Regulatory Commission,* http://www.nrc.gov/waste/high-level-waste.html, (accessed Feb. 18, 2011).

United States. Another option is actinide management and recycling. Through actinide recycling, some nuclear reactors being designed are able to burn up these long-living radionuclides and reduce the volume and danger of nuclear waste.

FORMER AND CURRENT REACTOR TECHNOLOGY

The development of new nuclear technologies has steadily progressed since its creation. While all reactors share certain technologies, a preponderance of new systems exists as well. In the United States the progression of reactors is classified by generations: I, II, III, III+, and IV. This nomenclature was proposed by the Department of Energy with the creation of generation IV reactor designs. The trend of generations can be seen below.

Figure 7.1. Evolution of Nuclear Power



Source: "Generation IV Nuclear Energy Systems," *U.S. Department of Energy,* http://www.ne.doe.gov /geniv/neGenIV1.html.

Generation I/II Reactors

Nuclear power reactors have been in use since 1951 when electricity was first produced by a nuclear power reactor at the National Reactor Testing Station in Idaho.[406] Generation I reactors were developed in the 1950s and 1960s and very few are still running today. They mostly used natural uranium fuel and used graphite as a moderator. Examples of generation I reactors include the Shippingport, Pennslyvania power reactor, the Magnox reactors in Britain, and the Dresden reactors in Illinois.[407]

Generation II reactors are typified by the present U.S. reactor fleet and most in operation around the world. It is the class of commercial reactors built up to the end of the 1990s. They typically use enriched uranium fuel and are mostly cooled and moderated by water. Prototypical generation II reactors include pressurized water reactors (PWRs), the Vodo-Vodyanoi Energetichesky Reactors (VVERs), boiling water reactors (BWRs), Canada Deuterium Uranium reactors (CANDUs), and advanced gas-cooled reactors (AGRs).[408]

Boiling water reactors are one variant of LWRs; others include PWRs and super-critical water reactors (SWRs). All LWRs use normal light water as both the moderator and coolant and enriched uranium oxide fuel.[409] BWRs, as shown in Figure 7.2, contain only a single coolant circuit, which is kept at lower pressure and thus boils inside the reactor. The rising steam is separated out and turns the turbine. With 90 to 100 fuel rods

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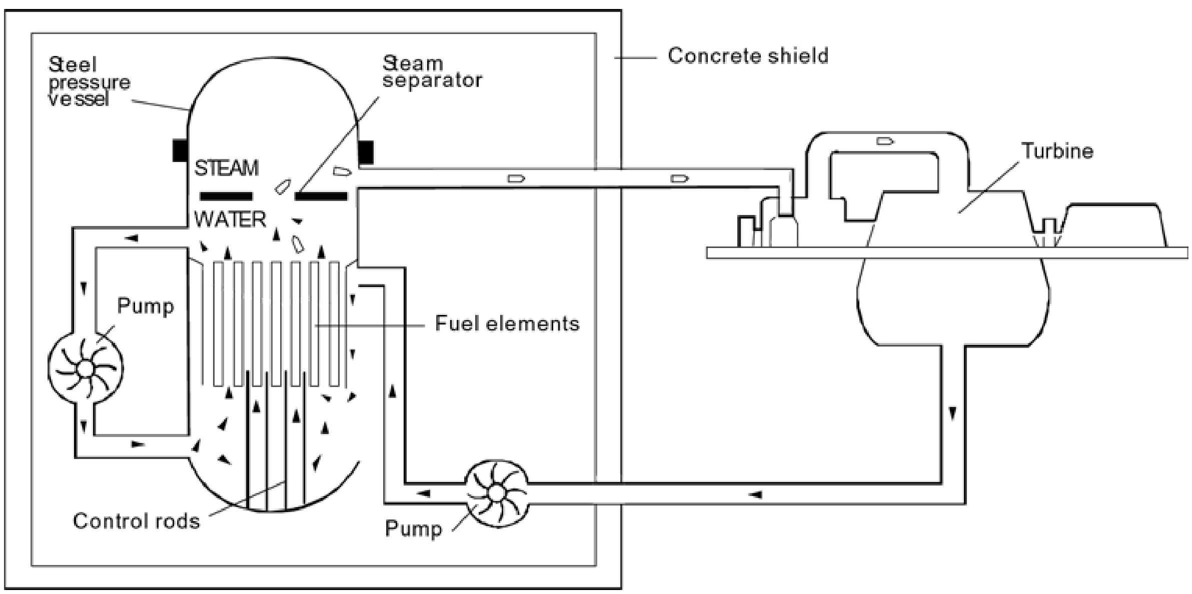
[406] "50 Years of Nuclear Energy," *International Atomic Energy Agency*, (Vienna: IAEA, 2001,) 1.
[407] "Generation IV Nuclear Energy Systems - Program Overview," *U.S. Department of Energy*, http://www.ne.doe.gov/geniv/neGenIV1.html, (accessed Jan. 26, 2011).
[408] Ibid.
[409] Chris Kessler, "Nuclear Fuel Cycle," (lecture, University of Washington, Seattle, WA, April 14, 2010).

per assembly and up to 750 assemblies per reactor, BWRs contain up to 140 tons of uranium.[410]

Pressurized water reactors are still the most common reactor type. They are very similar to BWRs. As seen in Figure 7.3, PWRs are distinguished by having both a primary and secondary cooling circuit.[411] The primary circuit flows through the reactor core under very high pressure, while the secondary circuit drives the generated steam to the turbine. PWR fuel assemblies contain between 200 and 300 fuel rods; a large reactor then contains 150 to 250 fuel assemblies and thus a total of 80 to 100 tonnes of uranium altogether.[412]

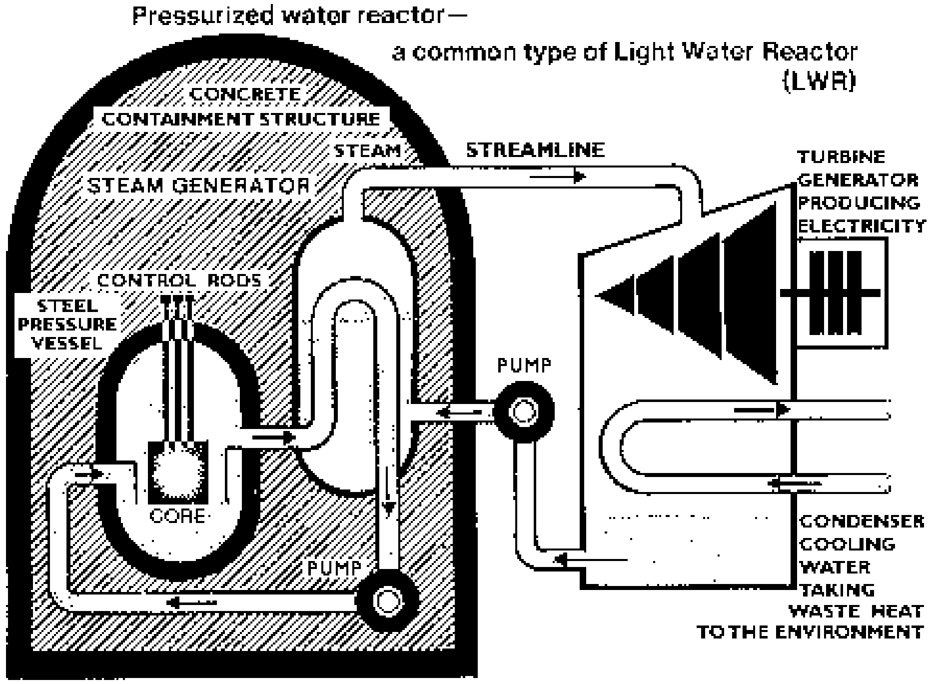
Figure 7.2. Diagram of a Boiling Water Reactor



Source: "Nuclear Power Reactors," *World Nuclear Association*, http://www.world-nuclear.org/info/inf32.html, (accessed Jan. 25, 2011).

[410] "Nuclear Power Reactors," *World Nuclear Association*, http://www.world-nuclear.org/info/inf32.html, (accessed Jan. 25, 2011).
[411] Ibid.
[412] Ibid.

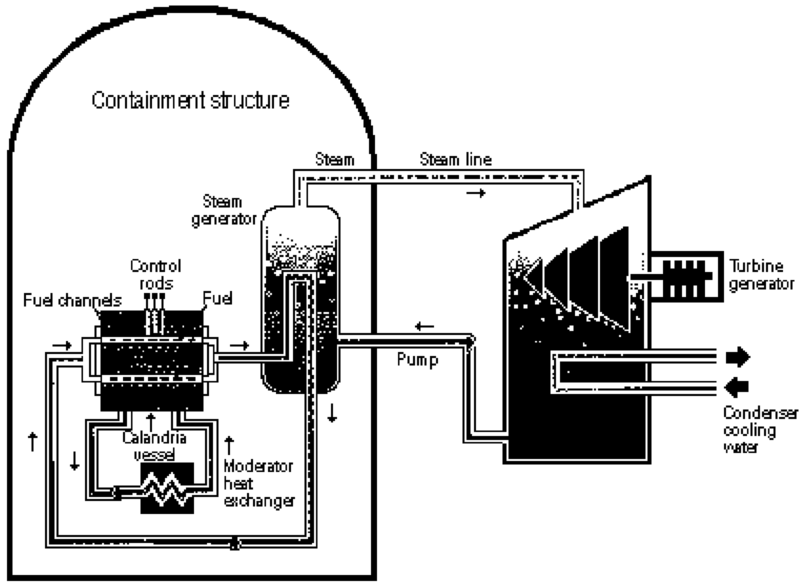
Figure 7.3. Diagram of a Pressurized Water Reactor



Source: "Nuclear Power Reactors," *World Nuclear Association*, http://www.world-nuclear.org/info/inf32.html, (accessed Jan. 25, 2011).

CANDU reactors, a diagram of which is given in Figure 7.4, are also known as pressurized heavy water reactors (PHWRs), were developed in Canada to use natural uranium oxide as fuel. Because of the lower percentage of enriched uranium, the more efficient moderator, heavy water (D_2O) is used. However, CANDU reactors can readily be run on recycled uranium from reprocessed LWR spent fuel, or a blend of this and depleted uranium left over from enrichment plants. CANDU fuel assemblies consist of 37 half-meter long fuel rods, which are considerably shorter than most in LWRs.

Figure 7.4. Diagram of a CANDU Reactor



Source: "Nuclear Power Reactors," *World Nuclear Association*, http://www.world-nuclear.org/info/inf32.html (accessed Jan. 25, 2011).

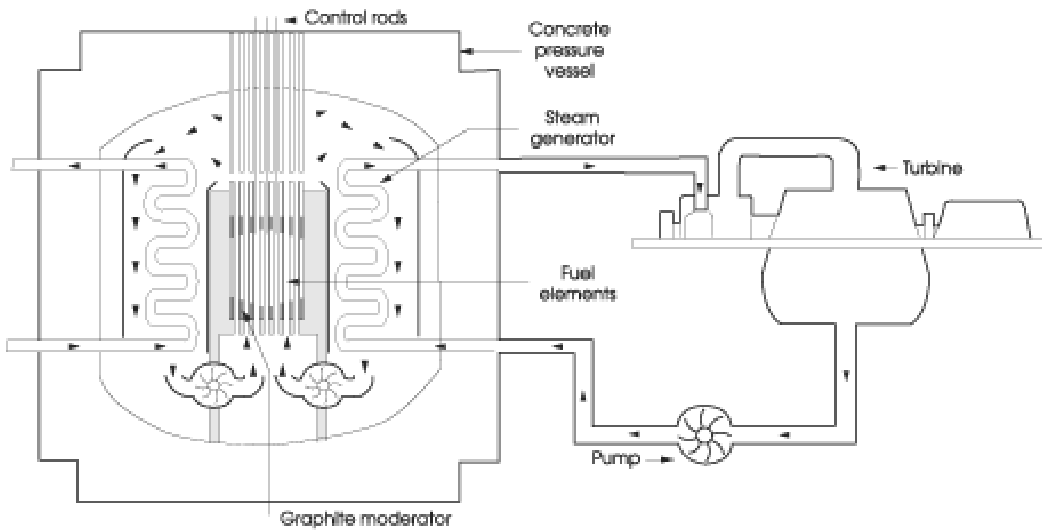
A similar Soviet design to the CANDU is a Reaktor Bolshoy Moshchnosti Kanalniy (RBMK), which means high-power channel type reactor.[413] RBMKs however use light water as the coolant and were built without any containment dome over the reactor—a profound design flaw that helped lead directly to the release of radioactivity in the Chernobyl disaster. While there are still RBMKs in use in Russia, they have largely become obsolete; there is a lot of international pressure to shut them all down.

Advanced gas-cooled reactors (AGRs), shown in Figure 7.5, are gas-cooled with carbon dioxide (CO_2), use graphite as a moderator, and use enriched uranium oxide pellets as fuel.[414] The CO_2 moves about the core, reaching 650 degrees Celsius before passing the steam generator tubes outside it, but still inside the concrete and steel

[413] "Nuclear Reactor Knowledge Base," *International Atomic Energy Agency*, http://www.iaea.org/inisnkm/nkm /aws/reactors.html, (accessed Feb. 1, 2011).
[414] Ibid.

pressure vessel. The steam in turn drives the turbines to produce electricity, as seen in the figure below.

Figure 7.5. Diagram of an Advanced Gas-Cooled Reactor



Source: "Nuclear Power Reactors," *World Nuclear Association*, http://www.world-nuclear.org/info/inf32.html, (accessed Jan. 25, 2011).

Generation III Reactors

Generation III designs were mostly created in the wake of the Chernobyl disaster and entered into use in the 1990s, the first being built in Japan in 1996. They are improvements upon second generation reactors with enhanced safety, improved fuel technology, improved thermal efficiency, and increased standardized designs for reduced maintenance and capital costs. While technology advances have been made, there are few in actual use and more than a dozen third generation designs are still in various stages of development. Most are evolutionary from the PWR, BWR, and CANDU designs above. There are three prominent third generation power reactor designs, which are discussed below.

The improvement in reactor technology between Generation II and III also increased the operational life of reactors. Generation II reactors were designed for 40 years of operation. Today's reactors have life spans of 60 operational years, with an extendable lifespan to 120 years of operation with a complete overhaul and pressure vessel replacement.

The CANDU 6 reactor, developed by Atomic Energy Canada Limited (AECL), is a third generation 700 MWe reactor. There are currently four operating in South Korea and two in China; the Qinshan plant is pictured in Figure 7.6.[415] The CANDU 6 is an improvement of the CANDU reactor, mainly with upgraded safety, shutdown, pressurized, electrical, and control systems.[416] It still operates with natural or low enriched uranium and uses heavy water for the moderator and coolant.

Figure 7.6. Chinese Qinshan Power Plant Phase III, Units 1 and 2 (CANDU 6 reactor)

Source: "CANDU 6," *AECL,* http://www.aecl.ca/Reactors/CANDU6.htm, (accessed Feb. 4, 2011).

The Westinghouse Advanced Passive 600 reactor (AP600) is a 600 MWe advanced PWR that incorporates passive safety systems (hence the name) and simplified

[415] "CANDU 6," *AECL,* http://www.aecl.ca/Reactors/CANDU6.htm, (accessed Feb. 4, 2011).
[416] Ibid.

system designs.[417] The passive systems use natural driving forces, without active pumps, diesels, and other support systems, after the reactor is running.[418] The use of redundant, non-safety-related, equipment and systems minimizes unnecessary use of safety-related systems.

The third main Generation III development is the System 80+ plant. The standardized plant design uses a 1,300 MWe PWR.[419] It is based on a Combustion Engineering 80 nuclear steam supply system (Combustion Engineering was later bought out and merged into Westinghouse). The upgraded design has safety systems that provide better emergency core cooling, as well as a safety depressurization system for the reactor, a combustion turbine as an alternate AC power source, and an in-containment refueling water storage tank to enhance the safety and reliability of the reactor system.[420]

REACTORS CURRENTLY OPERATING IN ASIA

Overall, nuclear power has not been widely dispersed across Asia. Its use is concentrated in only a few nations. The most growth is predicted to take place in China, Japan, India, and South Korea. The figure below shows the number of reactors in operation, under construction, planned, and proposed, as well as the number of research reactors and other elements of the fuel cycle a nation has.

[417] "Backgrounder on New Nuclear Plant Designs," *United States Nuclear Regulatory Commission*, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/new-nuc-plant-des-bg.html, (accessed Feb. 2, 2011).
[418] Ibid.
[419] Ibid.
[420] Ibid.

Figure 7.7. Nuclear Power in Asia

Country	Power Reactors in Operation	Power Reactors Under Construction	Power Reactors Planned	Power Reactors Proposed	Research Reactors	Other Stages of the Fuel Cycle
Australia					1	UM
Bangladesh				2	1	
China	13	27	50	110	13	UM, C, E, FF
India	19	5	18	40	5	UM, FF, R, WM
Indonesia			2	4	3	FF
Japan	54	2	12	1	17+1	C, E, FF, R, WM
South Korea	20	5	6		2	C, FF
North Korea			1	1	1	C?, FF?, R
Malaysia					1	
Pakistan	2	1	2	2	1	UM, E, FF
Philippines					1	
Thailand			2	5	1+1	
Vietnam			2	12	1	
**Total	114	40	103	177	56*	

Source: "Asia's Nuclear Energy Growth," *World Nuclear Association,* http://www.world-nuclear.org/info/default.aspx?id=386&terms=Asia, (accessed Feb. 4, 2011).

Notes: *54 operable, 2 under construction. **The total includes 6 reactors in operation, plus two under construction in Taiwan. It also has four research reactors. Taiwan has no other stages of the fuel cycle.

Key: UM-uranium mining, C-conversion, E-enrichment, FF-fuel fabrication, R-reprocessing, WM-waste management facilities for spent fuel away from reactors. In addition to those planned, there are another 180+ serious proposals for reactors.

China

China's fleet of nuclear power reactors, while currently small, is rapidly growing. With many more reactors planned, the Chinese are seeking a more than ten-fold increase in nuclear capacity to at least 80GWe by 2020, 200GWe by 2030, and 400GWe by 2050.[421] For future reactors, the Chinese are focusing on the CPR-1000 and the

[421] "Nuclear Power in China," *World Nuclear Association*. http://www.world-nuclear.org/info/inf63.html, (accessed Feb. 5, 2011).

Westinghouse AP1000 (both PWRs). They are researching high-temperature gas-cooled reactors and fast reactors as well.

There are currently eight Westinghouse AP1000 reactors planned in China, with another 30 proposed. After the initial four, Westinghouse has agreed to transfer the technology to the Chinese State Nuclear Power Technology Corp (SNPTC) so that it can build the following reactors on its own. The timeline to build the first four units is 50 months (from first pouring concrete to loading the fuel), followed by six months to grid connection. The cost will be $2,000/kW, which will be reduced to $1,600/kW for the additional units. This reduction in cost is due to cheaper Chinese labor and construction costs.

The CPR-1000 is China's own PWR design; it is a significantly upgraded French PWR from the 1980s.[422] The lifespan has been greatly extended to 60 years and vast improvements have been made with digital instrumentation and controls. The CPR-1000 is planned to take 52 months to construct and cost $1,500/kW.[423] With this design, the Chinese have managed a nearly complete domestic supply chain, thus increasing their energy security.

In July 2010 the first fast neutron reactor (FNR) developed by the Chinese, called the Chinese Experimental Fast Reactor (CEFR) went critical. For greater explanation about FNRs see the following section. According to the Chinese Atomic Energy

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[422] "Nuclear Power in China," *World Nuclear Association*. http://www.world-nuclear.org/info/inf63.html, (accessed Feb. 5, 2011).
[423] Ibid.

Authority (CAEA), it would like to develop an indigenous 1000MWe FNR for construction in 2017.[424]

Japan

Japan has the most nuclear reactors in the region. With 55 reactors Japan also has the full nuclear cycle except for natural uranium deposits: uranium conversion, uranium enrichment, fuel fabrication, reprocessing, and waste management.[425] Japan too is focusing on PWRs, but has instead decided to focus on advanced boiling water reactors (ABWRs) and advanced pressurized water reactors (APWRs). Japan has three third generation ABWRs operating, all produced by a consortium of General Electric, Hitachi, and Toshiba.[426] There are another eight ABWRs planned. In addition to China, Japan too has been researching FNRs; it has one prototype reactor as well.[427]

The Japanese company Mitsubishi has been working with Westinghouse to develop an APWR and is in the process of getting licensing for the reactor. The APWR has the advantage of being simpler than the present PWRs, and they have combined the cooling systems to a greater effect.

Finally, Japan is developing a new LWR based on both the APWR and ABWR. It promises a 20 percent reduction in construction and generating costs, a 20 percent reduction in spent fuel, and improved safety.[428] It also boasts a three-year construction time (only 36 months, compared to common 50-52 months) and an 80-year life span. The reactor will be ready for commercial use in 2020.

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[424] "Nuclear Power in China," *World Nuclear Association*, http://www.world-nuclear.org/info/default.aspx?id=344& terms=Japan, (accessed Feb. 5, 2011).
[425] "Nuclear Power in Japan," *World Nuclear Association*, http://www.world-nuclear.org/info/default.aspx?id=344& terms=Japan, (accessed Feb. 5, 2011).
[426] Ibid.
[427] Ibid.
[428] Ibid.

South Korea

Nuclear energy has become a strategic priority for South Korea; it not only plans to increase its capacity by 56 percent by 2020; the Korean business of exporting nuclear technology is booming.[429] The South Korean Minister of Knowledge Economy declared in January 2010 that, "nuclear power-related business will be the most profitable market after automobiles, semiconductors, and shipbuilding," adding that, "we will promote the industry as a major export business."[430] The Korean nuclear industry aims to be 100 percent domestic and self-sufficient by 2012, with no residual intellectual property constraints. Its policy has been driven by the need for energy security and to minimize its dependence on current imports. Plus, with growing electricity demands, the South Koreans see nuclear as a viable sector for growth.

South Korea has 21 reactors, operating at 18.7 GWe and an average of 96.4 percent capacity, one of the highest in the world.[431] Eight of South Korea's reactors are PWRs, by either Westinghouse or Framatome (now part of Areva). In addition, they operate four CANDU reactors, two System 80+ reactors, and seven South Korean designed Optimized Power Reactors (OPR-1000).

The South Korean OPR-1000 reactor is boasted as the safest, most reliable reactor in the world.[432] The Ulchin plant, shown in Figure 7.8, demonstrates the sheer size of the OPR-1000. Operated by the Korean Hydro and Nuclear Power Co. Ltd. (KHNP), it

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[429] "Nuclear Power in South Korea," *World Nuclear Association,* http://www.world-nuclear.org/info/inf81.html, (accessed Feb. 5, 2011).
[430] Ibid.
[431] Ibid.
[432] "OPR-1000 Major Design Features," *Korean Hydro and Nuclear Power Co. Ltd.,* http://www.opr1000.com /design/design01.jsp, (accessed Feb. 5, 2011).

produces 1,000 MWe, as the name implies. The reactor was South Korea's first success in its "technology self-reliance" program.

Figure 7.8. Ulchin Nuclear Power Plant, South Korea (OPR-1000s)

Source: "Images," *Korean Hydro and Nuclear* Power Co. Ltd., http://www.opr1000.com/pr/image_list.jsp, taken Nov. 6, 2006, (accessed Feb 5, 2011).

More recently, the KHNP has developed an advanced power reactor (APR-1400) with the Korean firm Doosan Heavy Industries though some components are subcontracted out to Westinghouse and Hyundai. The APR-1400 has enhanced safety systems with a seismic design to withstand ground acceleration.[433] Designed for a 60-year lifespan, the APR-1400 also costs 10 to 20 percent less than competing reactors.[434] Korean government data stated that in 2009 the APR-1400 cost $2,300/kW, compared with $3,580/kW for the GE-Hitachi-Toshiba ABWR.[435]

[433] "Nuclear Power in South Korea," *World Nuclear Association,* http://www.world-nuclear.org/info/inf81.html, (accessed Feb. 5, 2011).
[434] Ibid.
[435] Ibid.

South Korea is very constrained in its fuel cycle possibilities. The 1970s Korea-U.S. Atomic Energy Agreement constrains raw material supply and does not allow uranium enrichment or reprocessing in South Korea.[436] The South Korean government has called these restrictions “excessive” and is pushing for eased constraints, preferably before the agreement is due for renewal in 2014.

The Korea Electric Power Corporation (KEPCO) is actively marketing the OPR-1000 and APR-1400 reactors in the Middle East and North Africa. In December 2009 the APR-1400 was selected by the United Arab Emirates (UAE) to be the basis of its nuclear power program.[437] Under a $20.4 billion contract, the first four reactors are planned to begin operating by 2020 and another ten reactors are scheduled to follow.[438] The UAE stated its choice for the South Korean design over the others was on the basis of cost and reliability of building schedule. Shortly following the sale of the four reactors to the UAE, the South Korean Ministry of Knowledge Economy reported that it aims to achieve exports of 80 nuclear power reactors worth $400 billion by 2030, becoming the worlds third largest exporter of nuclear technology.[439] KHNP is also marketing its reactors to Turkey, Jordan, Romania, and Ukraine, as well as several South East Asian countries. For example, KEPCO has signed an agreement with Indonesia to conduct a feasibility study with KHNP for Indonesia's first nuclear power plant. The Indonesian government confirmed an approval of four 1,000 MWe units on the Muria peninsula, with a plan to commission them in 2016.

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[436] “Nuclear Power in South Korea,” *World Nuclear Association,* http://www.world-nuclear.org/info/inf81.html, (accessed Feb. 5, 2011).
[437] Ibid.
[438] Ibid.
[439] Ibid.

For advanced reactors, the Korea Atomic Energy Research Institute (KAERI) has been developing the SMART (System-integrated Modular Advanced Reactor) reactor. The 330 MWt PWR has integral steam generators and advanced passive safety features. It is designed for generating electricity (up to 100 MWe) and/or thermal applications such as seawater desalination. Design life is 60 years, with a 3-year refueling cycle. While the basic design is complete, the absence of any orders for an initial reference unit has stalled development.

India

India has a flourishing and largely indigenous nuclear power program. It aims to supply 25 percent of its electricity from nuclear power by 2050.[440] Because India is outside the Nuclear Non-Proliferation Treaty due to its weapons program, it was largely excluded from trade in nuclear plant or materials for 34 years, which has hampered its development of civil nuclear energy until 2009 (see Chapter Thirteen for further explanation fn the U.S.-India deal). As such, India's power reactors of the mid-1990s had some of the world's lowest capacity factors, reflecting the technical difficulties of the country's isolation. Recently, however, India's figures have improved yet they still suffer from uranium fuel shortages due to continued trade restrictions (India possesses very little indigenous uranium). With the softening of nuclear technology restrictions to India, foreign technology and fuel are expected to boost India's nuclear power plans considerably though all plants will have high indigenous engineering content.[441]

As of early 2011 India has 20 operating power reactors. In 1972 and 1980 India received two small CANDU reactors from Canada; India was then able to indigenously

[440] "Nuclear Power in India," *World Nuclear Association*, http://www.world-nuclear.org/info/inf53.html, (accessed Feb. 5, 2011).
[441] Ibid.

design and construct following PHWRs.[442] The construction costs of reactors as reported by the Indian Atomic Energy Commission (IAEC) are about $1,200/kW for their 540 MWe reactors, $1,300/kW for the 220 MWe reactors, and expected $1,700/kW for the 700 MWe PHWRs with 60-year life expectancy.[443]

In addition to its large PHWR fleet, India has a fast breeder reactor and is building a much larger one. A 500 MWe prototype fast breeder reactor (FBR) is under construction at Kalpakkam by BHAVINI (Bharatiya Nabhikiya Vidyut Nigam Ltd), a government enterprise set up to focus on FBRs. It was expected to begin operating at the end of 2010 and produce power by 2011, but this schedule has been delayed 12 to 15 months. India is also developing technology to utilize its abundant resources of thorium as a nuclear fuel (discussed more below).

GENERATION III+/IV REACTORS

The only reactors in operation that are marketed as being "evolutionary," Generation III+ models are the four General Electric/Hitachi/Toshiba advanced boiling water reactors (ABWRs) in Japan that began operations between 1996 and 2005.[444] Two more of these are under construction in Taiwan and one in Japan. Also, the first Westinghouse Advanced Passive 1000 (AP-1000) reactor began construction in China in 2009. No new Advanced CANDUs have been ordered. In addition to the ABWR, APWR, and AP-1000, there are more radical Generation III+ designs. The best-known radical new design is the pebble bed modular reactor, which uses helium as coolant, at very high temperature, to drive a turbine directly.

[442] "Nuclear Power in India," *World Nuclear Association*, http://www.world-nuclear.org/info/inf53.html, (accessed Feb. 5, 2011).
[443] Ibid.
[444] "Nuclear Power Reactors," *World Nuclear Association*, http://www.world-nuclear.org/info/inf32.html, (accessed Jan. 25, 2011).

The U.S. Department of Energy (DOE) is responsible for most of the Generation IV research. Compared to previous generations, Generation IV is being supported and researched largely through international cooperation and arenas. The DOE has three specific pathways for its Generation IV program. The first is the International Nuclear Energy Research Initiative (I-NERI), which engages the international community through bilateral agreements. The DOE has I-NERI offices in Canada, France, Japan, South Korea, and in the organization EURATOM. The second is the International Atomic Energy Agency (IAEA), which operates through Technical Working Groups and coordinated Research Projects, and has been focusing on High Temperature Gas Reactors (HTGRs). The third pathway is the Generation IV International Forum (GIF). GIF has thirteen signatories to its statute: Argentina, Brazil, Canada, China, EURATOM, France, Japan, South Korea, the Russian Federation, South Africa, Switzerland, the United Kingdom, and the United States. It is worth noting that all Asian countries expected to see the most nuclear power industry growth are a part of GIF, except for India. The DOE cites the purpose of the Generation IV reactors:

> Gen IV reactor concepts arebeing developed to use advanced fuels, fashioned from recycled reactor fuel and capable of high-burnups. The corresponding fuel cycle strategies allow for efficient utilization of domestic uranium resources while minimizing waste. Reduction of proliferation risk and improvements in physical protection are being designed into Gen IV concepts to help thwart those who would target nuclear power plants for terrorist acts or use them improperly to develop materials for nuclear weapons. Gen IV concepts will feature advances in safety and reliability to improve public confidence in nuclear energy while providing enhanced investment protection for plant owners. Competitive life-cycle costs and acceptable financial risk are being factored into Gen IV concepts with high-efficiency electricity generation systems, modular construction, and shortened development schedules before plant startup.[445]

[445] "Generation IV Nuclear Energy Systems - Program Overview," *U.S. Department of Energy*, http://www.ne.doe.gov/geniv/neGenIV1.html (accessed Jan. 26, 2011).

While this new generation pledges reductions in spent fuel, proliferation risks, costs, and construction time, and increased efficiency, physical protection, safety, and reliability, Generation IV designs are still largely on the drawing board and will not be operational before 2020 at the earliest, though probably later. The DOE's Gen IV Program recognizes six designs as those most likely to revolutionize the nuclear power field, discussed below.

The DOE produces reactor ratings in four categories: sustainability, safety, economics, and proliferation. Sustainability is focused on waste management and resource utilization. Economics broadly considers the competitive costs and financial risks of nuclear energy systems. Safety is judged on safe and reliable operations, improved accident management, minimization of accident consequences, investment protection, and reduced need for off-site emergency response. Finally, proliferation resistance and physical protection consider means for controlling and securing nuclear material and nuclear facilities.

Very High Temperature Reactors

The very high temperature reactor (VHTR) system uses a graphite moderated once-through uranium cycle operable at temperatures of up to 1,000 degrees Celsius or more.[446] The primary cooling circuit is connected to a steam generator to deliver heat. The VHTR is primarily aimed at process heat applications, such as coal gasification and thermochemical hydrogen production, with superior efficiency; however, the system can

[446] "A Technology Roadmap for Generation IV Nuclear Energy Systems," *U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum,* (2002), http://www.gen-4.org/PDFs/GenIVRoadmap.pdf, (accessed Jan. 28, 2011).

generate electricity as well. With the ability to adopt an uranium/plutonium mix fuel cycle the VHTR offers enhanced waste minimization.[447]

The VHTR system is highly ranked in economics because of its high hydrogen production efficiency, and in safety and reliability because of the inherent safety features of the fuel and reactor. It is rated good in proliferation resistance and physical protection, and neutral in sustainability because of its open fuel cycle. The DOE envisions the VHTR as the nearest-term hydrogen production reactor, and is estimated to be deployable by 2020.[448]

Supercritical Water-Cooled Reactor

The supercritical water-cooled reactor (SCWR) system features two fuel cycle options: the first is an open thermal cycle; the second is a closed cycle with full actinide recycle.[449] Both options use a high-temperature, high-pressure, water-cooled reactor. The fuel cycle for the thermal option is a once-through uranium cycle. The second, fast spectrum option uses central fuel cycle facilities based on advanced aqueous processing for actinide recycle.[450] In either option, the plant is expected to have a 1,700 MWe power level.[451] Passive safety features similar to those of the simplified boiling water reactor are incorporated.

The SCWR system is highly ranked in economics because of the high thermal efficiency and plant simplification. If the fast-spectrum option can be developed, the SCWR system will also be highly ranked in sustainability. The reactor is rated good in

[447] "A Technology Roadmap for Generation IV Nuclear Energy Systems," *U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum,* (2002), http://www.gen-4.org/PDFs/GenIVRoadmap.pdf, (accessed Jan. 28, 2011).
[448] Ibid.
[449] Ibid.
[450] Ibid.
[451] Ibid.

safety, and in proliferation resistance and physical protection. The SCWR is estimated to be deployable by 2025.[452]

Gas-Cooled Fast Reactor

The gas-cooled fast reactor (GFR) system features a fast-neutron spectrum and closed fuel cycle. The fast-neutron aspect offers management of produced actinides. The reactor is envisioned to be a 288 MWe, helium-cooled system operating with high thermal efficiency. As such, the GFR system is top-ranked in sustainability because of its closed fuel cycle and excellent performance in actinide management. It is rated good in safety, economics, proliferation resistance and physical protection. Given the research and development needs for recycling technology development, the GFR is not estimated to be deployable until 2025.[453]

Lead-Cooled Fast Reactor

The lead-cooled fast reactor (LFR) system also features a fast-neutron spectrum and a closed fuel cycle for management of actinides. The system uses a lead or lead/bismuth liquid-metal cooled reactor. Options include a range of plant ratings, including a battery of 50 to 150 MWe that features a very long refueling interval, a modular system rated at 300 to 400 MWe, and a large monolithic plant option at 1,200 MWe.[454] The term battery refers to the long-life, factory-fabricated core. Inside the core would be metal or nitride-based fuel containing fertile uranium. The most advanced of these is the lead/bismuth battery, which employs a small size core with a very long (10 to 30 year) core life, a potential advantage of the LFR.

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[452] "A Technology Roadmap for Generation IV Nuclear Energy Systems," *U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum,* (2002), http://www.gen-4.org/PDFs/GenIVRoadmap.pdf, (accessed Jan. 28, 2011).
[453] Ibid.
[454] Ibid.

The LFR system is top-ranked in sustainability because a closed fuel cycle is used, and in proliferation resistance and physical protection because it employs a long-life core. It also offers flexibility in its three size options and can be factory-fabricated. The reactor is rated good in safety and economics; the safety is enhanced by the choice of a relatively inert coolant. It is envisioned for electricity and hydrogen production and actinide management with good proliferation resistance. Again, given the necessity for greater research and development for the fuel, materials, and corrosion control, the LFR system is estimated to be deployable by 2025.[455]

Sodium-Cooled Fast Reactor

The sodium-cooled fast reactor (SFR) features a fast-neutron spectrum and a closed fuel cycle. This unusual reactor uses a liquid sodium coolant. The SFR system is top-ranked in sustainability because of its closed fuel cycle and excellent potential for actinide management. It is rated good in safety, economics, proliferation resistance, and physical protection. Based on the testing available for this reactor, the DOE estimates this reactor will be deployable in 2015.

Molten Salt Reactor

The molten salt reactor (MSR) features molten salt and a closed fuel cycle tailored to the efficient utilization of plutonium and other minor actinides. A full actinide recycle fuel cycle is envisioned for the MSR. Unlike the above salt reactor, in the MSR the molten salt plays the role of fuel: as a liquid mixture of sodium, zirconium, and uranium fluorides, the molten salt fuel flows through graphite core channels, producing heat. The heat generated in the molten salt is transferred to a secondary coolant system

[455] "A Technology Roadmap for Generation IV Nuclear Energy Systems," *U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum,* (2002), http://www.gen-4.org/PDFs/GenIVRoadmap.pdf, (accessed Jan. 28, 2011).

and then to the power conversion system. Interestingly, there is no need for fuel fabrication.

The MSR will have a power level of 1,000 MWe.[456] The reactor operates at low pressure and has a coolant outlet temperature above 700°C, which allows for improved thermal efficiency. The MSR system is top-ranked in sustainability because of its closed fuel cycle and excellent performance in waste burndown. It is rated good in safety, and in proliferation resistance and physical protection, and it is unfortunately rated neutral in economics because of its large number of subsystems. The MSR is estimated to be deployable by 2025.[457]

Figure 7.9 maps out the ratings of the six Generation IV reactors in terms of sustainability, safety, proliferation risk, and economics. To clarify, those that can support actinide recycling and management (the GRF, LFR, SFR, and MSR) are rated excellent in terms of sustainability because the closed, actinide recycling fuel cycle holds the promise to reduce repository volumes, reduce the radioactivity and longevity of nuclear waste, and increase available fuel when natural uranium deposit volumes decrease, thus affording a great sustainability record. The VHTR on the other hand receives only a good rating in sustainability because it cannot support a closed fuel cycle (the SCWR has the flexibility to use either cycle and receives a good rating).

[456] "A Technology Roadmap for Generation IV Nuclear Energy Systems," *U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum,* (2002), http://www.gen-4.org/PDFs/GenIVRoadmap.pdf, (accessed Jan. 28, 2011).
[457] Ibid.

Figure 7.9. DOE Gen IV Reactor Comparison

Reactor	Sustainability	Safety	Proliferation	Economics	Deployment Est.
VHTR	□+	+	□+	+	2020
SCWR	□+	□+	□+	+	2025
GFR	+	□+	□+	□+	2025
LFR	+	□+	+	□+	2025
SFR	+	□+	□+	□+	2015
MSR	+	□+	□+	□	2025

Source: Compiled from "A Technology Roadmap for Generation IV Nuclear Energy Systems," *U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum,* (2002), http://www.gen-4.org/PDFs/GenIVRoadmap.pdf, (accessed Jan. 28, 2011).

Note: + excellent, ✓+□good, ✓neutral

SMALL MODULAR REACTORS

Technology

Small modular reactors (SMRs) are, as implied, small nuclear reactors (often 300 MWe or less).[458] The term 'modular' in the context of SMRs refers to a single reactor that can be grouped with other modules to form a larger nuclear power plant. Even though current large nuclear power plants incorporate factory-fabricated components into their designs, SMRs are largely fabricated in factories and are envisioned to require limited on-site preparation. The DOE has advertised SMRs as ready to "plug and play" when they arrive from the factory.[459] Plus, SMRs are based on proven reactor designs from nuclear submarines and warships. There is both a domestic and international market for SMRs. The IAEA estimates that by 2030 there will be at least 40 SMRs in

[458] "Small Modular Reactors," *The U.S. Department of Energy's Office of Nuclear Energy,* http://nuclear.energy.gov/pdfFiles/factSheets/2011_SMR_Factsheet.pdf, (accessed Feb. 4 2011).
[459] Ibid.

operation.[460] The DOE stated in a February 2010 report that the United States industry is "well positioned to compete for these markets."[461]

Numerous countries, mainly in Asia but also the United States, are designing SMRs. In Russia, the Russian atomic energy organization, Rosatom, is building a floating nuclear power plant using modular designs.[462] In the United States, two companies, NuScale and Hyperion, are designing SMRs. Both companies' designs reduce capital costs, while the kilowatt cost is estimated to be about the same of that of a large nuclear power plant. Also, both are operable after a few years of construction and begin to generate revenue as soon as the first reactor is fired up, a big reactor traditionally takes a decade to erect.[463] Also, with mostly factory rather than field construction, fewer workers and families must be moved, at a large expense, to distant building sites. Companies in the Britain, Canada, China, India, and the U.S. have shown interest in the NuScale and Hyperion reactors.

Advantages/Disadvantages

SMRs are expected to provide to number of advantages concerning economics, site locations, and proliferation risks. Concerning economics, SMRs provide simplicity in design, economies, and quality of factory production, and offer more flexibility (financing, siting, sizing, and end-use applications) compared to larger nuclear power plants.[464] SMRs will reduce the nuclear plant owner's capital investment due to the lower plant capital cost. Also, modular components and factory fabrication can reduce

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[460] "Thinking Small," *The Economist*, (Dec. 9, 2010), http://www.economist.com/node/17647651.
[461] "Small Modular Reactors," *The U.S. Department of Energy's Office of Nuclear Energy,* http://nuclear.energy.gov/pdfFiles/factSheets/2011_SMR_Factsheet.pdf, (accessed Feb. 4 2011).
[462] "Thinking Small," *The Economist*, (Dec. 9, 2010), http://www.economist.com/node/17647651.
[463] Ibid.
[464] "Small Modular Reactors," *The U.S. Department of Energy's Office of Nuclear Energy,* http://nuclear.energy.gov/pdfFiles/factSheets/2011_SMR_Factsheet.pdf, (accessed Feb. 4 2011).

construction cost and time. With economies of scale, factory production may lower the economic burden of nuclear reactors.

Because of their size, SMRs are excellent for applications where large power plants are either not needed or infeasible given the space or infrastructure. A large support infrastructure is necessary for large nuclear power plants, thus SMRs are ideal for smaller electrical markets, isolated areas, smaller grids, or limited water and acreage sites. Plus, additional modules can be added as demand for energy increases.

SMRs also provide potential non-proliferation benefits to the United States and the wider international community. Some SMRs are being designed to operate for decades without refueling. These SMRs would be fabricated and fueled in a factory, sealed, and then transported to sites for power generation, and then returned to the factory for refueling or decommissioning at the end of the life cycle.[465] This approach could help to minimize the transportation and handling of nuclear material.

On the other hand, skeptics fear that these small, cheaper reactors may not be profitable after long licensing procedures and the cost of building many smaller rather than large power plants.[466] Another concern is that the small plants may be more prone to terrorist attacks; yet the small reactors can be shielded by layers of concrete and buried, possibly affording greater protection from terrorists.[467]

<u>THORIUM REACTORS</u>

So far, the technology covered has concerned the uranium fuel cycle. However, research of a thorium-based fuel cycle has been occurring since the 1940s. Today, India is particularly interested in a thorium fuel cycle given its large thorium reserves. Even

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[465] "Thinking Small," *The Economist*, (Dec. 9, 2010), http://www.economist.com/node/17647651.
[466] Ibid.
[467] Ibid.

abroad, thorium has become an exciting resource. Nobel Laureate Carlo Rubbia at CERN (the European Organization for Nuclear Research) claimed that thorium "may be the magic bullet we have all been hoping for."[468]

Technology

Thorium is a naturally occurring actinide, available abundantly. The element cannot undergo nuclear fission itself and it cannot sustain a nuclear chain reaction once its starts, thus thorium cannot be used, or would be very difficult to use, as weapons material. Thorium is, however, fertile, meaning it can absorb a neutron and decay into uranium-233, a fissile chain-reaction supporting material.[469] Since thorium cannot sustain a chain reaction on its own, mixed fuel must be used for thorium reactors (including uranium, plutonium, and thorium).

Advantages/Disadvantages

Thorium is lighter than uranium, and thus does not produce as many heavy or radioactive by products. Also, with uranium-233 not uranium-238, no plutonium is bred with a thorium fuel cycle. Thorium produces less waste, the byproducts have shorter half-lives, and the waste is less radioactive, though there is increased gamma radiation with thorium. Most exciting, is that thorium can incinerate elements such as plutonium and other actinides found in radioactive waste and spent fuel.[470] Plus, a thorium fuel cycle is possible for some uranium-designed reactors. For example, thorium fuel can be used in a CANDU 6 reactor.

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[468] Ambrose Evans, "Obama Could Kill Fossil Fuels Overnight with a Nuclear Dash for Thorium," *The Telegraph*, (Aug. 29, 2010).
[469] Tim Dean, "New Age Nuclear," *Cosmos: The Science of Everything*, issue 8, (Apr. 2006).
[470] Ambrose Evans, "Obama Could Kill Fossil Fuels Overnight with a Nuclear Dash for Thorium," *The Telegraph*, (Aug. 29, 2010).

Yet, the current thorium industry has disadvantages. Mainly, thorium provides competition for uranium. There is a lot of investment in uranium technology today. While some claim the lack of thorium technologies is a triumph of vested interests over scientific progress, switching to thorium still would be very costly. In order for thorium to be economical and possible, thorium technologies will have to be developed for the future and wait for the current wave of uranium-based technologies to pass. Unfortunately, this may take another 60 to 120 years.

FAST BREEDER REACTORS/FAST NEUTRON REACTORS

Technology

Fast-neutron reactors (FNRs) and fast breeder reactors (FBRs) offer prospects to use uranium resources much more efficiently. Plus they offer the ability to burn up actinides, which otherwise are long-lived components of nuclear waste. FBRs/FNRs do not use a moderator, instead they utilize the fast traveling neutrons.[471] This generates power from plutonium while making more of it from the uranium-238 isotope in or around the fuel. While they get more than 60 times as much energy from the original uranium compared with normal reactors, they are expensive to build. Further development of them is likely in the next decade, especially in India; new models in the include the SFR, GFR, and SCWR discussed above.

NEW REPROCESSING TECHNOLOGY

Pyroprocessing

Pyroprocessing is a reprocessing technique pioneered in the Argonne National Laboratory in the U.S. and now being further developed by the South Korean Atomic

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[471] "Fast Neutron Reactors," *World Nuclear Association,* http://www.world-nuclear.org /info/inf98.html, (accessed Feb. 2, 2011).

Energy Research Institute (KAERI). Compared to the more common PUREX (plutonium-uranium extraction) approach, pyroprocessing does not produce a pure stream of plutonium. Instead, the spent nuclear fuel is cut into pieces, heated to an elevated temperature, burning off volatile fission products and producing a powder containing uranium, plutonium, and several other irradiated elements.[472] This material is then placed in a molten bath of salts.[473] An electrical current is run through the bath to dissolve the radioactive metal and to separate its elements in several stages, beginning with the recovery of uranium. This operation continues until the actinides in the molten salt can also be separated.[474] These can then be directly refabricated into metallic fuel that can be used in fast reactors but cannot be directly applied toward the making of weapons.[475]

Pyroprocessing has the potential to greatly limit the amount of nuclear waste in South Korea and provide the nation with greater energy security (by having a source of domestic fuel for fast reactors). Also, advocates of pyroprocessing say that the lack of direct plutonium extraction makes pyroprocessing less proliferation-prone than other reprocessing techniques.[476] As such, they propose that pyroprocessing not be considered reprocessing at all; this appears to be more of a political than scientific argument. Many non-proliferation advocates, however, say that the differences in processes are not significant enough and that the technique still poses a proliferation risk.

Despite its advantages, pyroprocessing has not been used outside of KAERI laboratories or at a commercial scale. This is partly because a 1974 U.S.-South Korean

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[472] Seong Won Park, "Why South Korea Needs Pyroprocessing," *Bulletin of the Atomic Scientists*, http://www.thebulletin.org/web-edition/op-eds/why-south-korea-needs-pyroprocessing, (Oct. 26, 2009).
[473] Ibid.
[474] Ibid.
[475] Ibid.
[476] Ibid.

agreement that bars South Korea from reprocessing or enriching uranium domestically. In short, South Korea cannot adopt pyroprocessing without either declassifying pyroprocessing as reprocessing or renegotiating the agreement when it expires in 2014.[477] This situation is not relevant to other nations, who may be interested in the technology, also known as "electrometallurgical pyroprocessing." Russia, in particular, has an established facility for such reprocessing, while both China and Japan have expressed interest in it for the future.[478]

CONCLUSION

The nuclear industry has advanced technologically in a number of crucial areas, from specific materials to reactor designs. While popular discussion has focused on the progress and innovation of renewable technologies, the nuclear industry deserves much credit for its efforts to respond to social needs and demands. For nuclear power to become a significant factor in reducing carbon emissions and meeting the growing energy demand in Asia, it must continue to expand as a global industry, which means it must continue to advance technologically. There is every indication that this will happen.

As this report has shown, the industry has developed a diverse array of reactor possibilities, as well as new reprocessing ideas that reduce the chances of proliferation. These possibilities suggest that nuclear power could soon be as flexible in scale as natural gas generation, ranging from small modular reactors appropriate for distributed use to giant multi-reactor installations able to power entire cities. Such possibilities are striking

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[477] Seong Won Park, "Why South Korea Needs Pyroprocessing," *Bulletin of the Atomic Scientists,* http://www.thebulletin.org/web-edition/op-eds/why-south-korea-needs-pyroprocessing, (Oct. 26, 2009).
[478] "Processing of Used Nuclear Fuel," *World Nuclear Association*, http://www.world-nuclear.org/info/inf69.html, (accessed Feb. 22, 2011).

when compared to a generation ago. Yet, to be fully realized, they must continue their progress toward meeting certain, specific demands. These demands include:

(1) *Managing nuclear waste, effective fuel utilization, and increased environmental benefits.* Effectively managing nuclear waste has become a large issue in the West; the lack of a viable solution may constrain the scale of future development. However, the issue must be solved for the world as a whole. The nuclear industry must work toward extending the nuclear fuel supply into future centuries by recycling used fuel to recover its energy content, creating less waste generating technologies, and reducing the lifetime and toxicity of the residual radioactive wastes sent to repositories.

(2) *Competitive economics*. Here, goals for the industry include achieving an economic life cycle and economic energy production costs for nuclear power plants, including innovative advances in plant and fuel efficiency, design simplifications, and plant sizes. Also, the industry must strive to reduce the economic risk to nuclear projects through the development of plants built using cheaper, safer construction techniques (such as factory made plants or modular designs).

(3) *Safety performance*. Safety improvements will prove to be the most vital for the nuclear energy industry and any hope of having a "nuclear renaissance." The industry should continue to improve reliability, improve accident management, increase the use of inherent safety features (such as inert coolants), use transparent safety features that can be understood by non-nuclear experts, and enhance public confidence in the safety of nuclear energy. While the nuclear industry has had an excellent safety record, a major accident could wreak havoc on the entire industry, as Chernobyl did more than two decades ago.

(4) *Proliferation risk through secure nuclear energy systems and nuclear materials*. Aside from improvements made in the non-proliferation regime and political realm, the nuclear industry too can set goals for reducing the proliferation risk of nuclear power plants. These goals should include continuing the improved design features and other measures at plants, such as using non-fissile fuel like thorium, as well as increasing physical protection against terrorism by increasing the robustness of new facilities. As with a major safety accident, a proliferation or terrorist situation stemming from a nuclear power plant could endanger the global nuclear industry and erode public perception.

Future innovations appear very likely to bring safer, cheaper, more efficient, more proliferation-resistant, and less waste-generating reactors to the market over the next two to three decades, the period when the industry will undergo its next major phase of growth, centered in Asia. It is therefore crucial that nations like China, with large forecasted nuclear growth, take advantage of these new technologies and not rush their programs so that they are forced to rely on older Generation II technology. Provided this happens, and nuclear continues its track record of superior safety, its reception in the West will turn more favorable, even as it continues to grow in the East.

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Chapter Eight

NUCLEAR SAFETY AND WASTE DISPOSAL: THE ROLE OF PUBLIC PERCEPTION

Michelle Tong

Abstract:

Public concerns about the safety of nuclear power, especially with regard to accidents and waste, have greatly slowed the growth of the industry in most advanced nations, as well as the establishment of final underground repositories for high-level waste. To evaluate these concerns, this section analyzes safety regulations of the fossil fuel and nuclear industries, past nuclear accidents, and approaches to hazardous waste management. The emerging data shows that improvements in reactor design, operator training, and strong safety regulations have minimized nuclear accidents and proven nuclear energy a safer alternative to fossil fuels. For waste management, the situation is more critical. As demonstrated by the terrible effects at the Mayak site, nuclear waste must be properly managed. Experts agree that underground storage in geologic repositories is the best long term solution. However, public fear, opposition from local communities and political wrangling have held up the creation of such repositories. There are now signs in Scandinavia that such repositories will be built and tested. This is important, since the alternative, interim storage at power plant sites is only a temporary measure that ironically increases the vulnerability of waste to disturbance and theft.

INTRODUCTION:

According to energy yield, technological knowledge, and carbon dioxide emissions, nuclear energy outperforms fossil fuels and renewable energy, such as solar, wind, and biofuels. As an energy source, nuclear generation provides the advantages of low-carbon and especially high power density over fossil fuel sources. Measured against renewable energy, nuclear energy boasts a reliable baseload power on a mass scale that renewable sources cannot presently come close to achieving. Furthermore, continued research and development of new nuclear technologies promises to increase safety and efficiency while reducing cost. Yet while these facts may indicate that nuclear power is an ideal solution to reconcile increasing global energy demands with the threat of climate change, in practice, the civilian nuclear industry has been repeatedly stymied by public pressure and apprehension over nuclear technology.

Due to the link to nuclear weapons, an absence of widespread dissemination of how nuclear energy is produced, sensationalized media coverage of accidents across the world, and fear of radioactivity, nuclear energy has gained a mixed reputation in the public discourse.[479] In Japan, a 2010 government poll reported that 54 percent of citizens are still anxious about nuclear power, despite the fact that over 30 percent of the country's electricity is derived from nuclear energy, with plans for more in the future.[480,481] Many of the respondents of the poll claimed fears of accidents, though Japan has only recorded one major nuclear accident (which will be discussed below). Another common worry was earthquake damage; though the passive safety system at Japan's largest nuclear plant has already safely averted a major earthquake in 2007.[482] This gap between reality and public perception is significant because public fears are among the most persistent obstacles to nuclear energy.

This section will investigate common safety fears by analyzing nuclear energy along the criteria of harmful byproducts, industry accidents, environmental damage, and effect on human health. Going beyond a comparison to fossil fuels, this section will also address the issue of long-lasting radioactive waste, an ongoing concern unique to nuclear energy with significant environmental and political implications. Ultimately, this section seeks to determine whether nuclear energy presents a reasonable threat to continued

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[479] Gwyneth Cravens, *Power to Save the World: the Truth About Nuclear Energy* (New York: Alfred A. Knopf, 2007).
[480] Jonathan Adams, "Earthquake Prone Japan Sees Green in New Nuclear Power Plants," *Christian Science Monitor,* March 1, 2010.
[481] "Nuclear power in Japan," *World Nuclear Association,* http://world-nuclear.org/info/default.aspx?id=344&terms=japan (accessed Feb. 20, 2011).
[482] "IAEA Issues Report on Kashiwazaki-Kariwa Nuclear Plant**,"** *IAEA,* http://www.iaea.org/newscenter/news/2007/kashiwazaki-kariwa_report.html (accessed Feb. 20, 2011).

human and environmental safety, as anti-nuclear fears claim, and finds that with proper safeguards and regulations, nuclear energy is a safe and efficient alternative to fossil fuels.

Byproducts and Radiation: General Concerns

Over the life cycle of extraction, processing, transmitting energy, and disposal, every energy source incurs some amount of waste and negative externalities, whether in the form of physical byproducts, gaseous emissions, or leftover heat. Historically, nuclear energy has gained an infamous reputation for its toxic waste, which has millennia-long lifetimes. However, nuclear waste (which will be discussed in more detail) is not the only hazardous, long-term derivative of energy generation. Traditional fossil fuels produce an incredibly damaging and long-lasting substance: carbon dioxide, which survives for thousands of years in the atmosphere. Beyond the well-publicized emissions of CO_2, the coal, natural gas, and oil industries also produce millions of tons of ash, mercury, lead, cadmium, arsenic, sulfur dioxide, nitrogen oxides, and traces of other particulates yearly.[483] This litany of compounds causes acid rain (sulfur dioxide), ozone-depleting smog (nitrogen oxides), human death and ecological damage (mercury, arsenic, lead, and other particulates).[484] Conventional fuel plants are also radioactive. Though fossil fuel waste is similarly harmful, and in certain cases just as long lasting, these negative externalities are much less recognized and therefore result in relatively little public or political resistance to the industries generating this waste. Consequently, there is negligible regulation and monitoring of fossil fuel plants.

[483] Scott Montgomery, *The Powers That Be: Global Energy for the Twenty-First Century and Beyond*. (Chicago: University of Chicago Press, 2010), 93.
[484] "Environment, Health and Safety in Electricity Generation," *World Nuclear Association*, http://www.world-nuclear.org/education/ehs.html (accessed Jan. 16, 2011).

There is a difference in the potency of the types of waste produced by varying energy sources. High-level nuclear waste continues to produce 20 times the fatal human dose of radiation per hour even 10 years after removal from a reactor.[485] Radiation sickness caused by large amounts of direct exposure can lead to human death in a matter of days, whereas the negative health effects from exposure to lead, mercury, and other waste products of fossil fuels generally manifest over long periods of time, after prolonged exposure.[486] However, one of the most pertinent differences between nuclear waste and fossil fuel waste does not concern the relative toxicity of each substance, but rather how the waste is regulated and stored. While the nuclear industry is inundated by regulations and restrictions, coal, oil, and natural gas are left largely unmonitored. There is a long record of death and disease in fossil fuels' history; in the Great London Smog of 1952, 4,000 people died from coal pollution in one week.[487] Even when accounting for fossil fuels' longer period of usage, data indicates that pollution from coal, natural gas, and oil have caused significantly more disease and deaths compared to nuclear waste. Yet these incidents have not resulted in a comparable level of regulation. Despite various clean air initiatives enacted internationally, harmful pollution from fossil fuels continues, largely unmonitored.[488]

In comparison, almost every aspect of the nuclear industry is strictly regulated and monitored, from uranium extraction through waste disposal. From the front-end of nuclear energy (namely, concerning exploration, mining, and refining process) uranium

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[485] "Backgrounder on Radioactive Waste," *United States Nuclear Regulatory Commission*, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/radwaste.html (accessed Jan. 18, 2011).
[486] "What is Radiation," *World Nuclear Association*, http://www.world-nuclear.org/how/default.aspx?id=1072&terms=radiation%20sickness (accessed Jan. 18, 2011).
[487] Scott Montgomery, *The Powers That Be: Global Energy for the Twenty-First Century and Beyond*. (Chicago: University of Chicago Press, 2010), 96.
[488] Ibid, 128.

mining and enrichment results in harmful radon gas, residual ground rocks, and depleted uranium, all of which are radioactive and dangerous to workers and the surrounding area if ignored. However, regulations ensure that radon gas is carefully ventilated and diluted, residual ground rocks are collected into tailings to contain radioactivity, and depleted uranium recycled to manufacture other products (such as anti-tank ammunition and shielding) or stored in reinforced containers. The high-level of waste created by the back-end of nuclear energy is even more heavily regulated, sent to be reprocessed or sealed away carefully for interim storage and final disposal.

Furthermore, the safety precautions of the nuclear industry extend beyond government regulation. The fear of nuclear proliferation and energy has prompted the creation of several international and non-governmental agencies such as the International Atomic Energy Agency (IAEA), the World Nuclear Association (WNA), the Nuclear Energy Agency (NEA), and watchdog groups like the Nuclear Threat Initiative (NTI), all of which share the goal of recording uranium usage, spreading best practices to improve safety throughout the industry, and monitoring countries and companies to ensure compliance. No other energy industry can boast this level of alertness or maintenance; in fact, the opposite is true. Despite the availability of established technology to capture carbon emissions and desulphurization equipment to minimize sulfur dioxide emissions, few coal plants employ these technologies in order to conserve cost. In contrast with fossil fuels' relative negligence, public perception and necessity have fostered a more cooperative and safety-oriented culture within the nuclear power industry.

Accidents and Occupational Risks

Outside of general health hazards to public, it is also important to consider how these energy industries have affected their workers, as occupational health and the rate of fatal accidents are strong indicators of the safety within a particular industry. In spite of public fear and proximity to highly radioactive material, the number of immediate fatalities for coal, natural gas, and hydropower all outstrip nuclear fatalities by thousands between 1970 and 1992.[489] Coal alone accounts for more than half of the combined fatalities in the mentioned industries, with over 6,000 deaths, mostly from mining accidents. In the same time period, nuclear energy has been responsible for 31 immediate deaths, from the single accident at the Chernobyl plant in 1986.[490]

Of course, the number of immediate deaths alone fails to include the extent of total death and disease suffered at Chernobyl. In the days after the initial accident, the immediate response, evacuation, and containment of the reactor exposed emergency workers to high doses of radiation and led to approximately 100 additional documented cases of death attributable to radiation exposure.[491] Nearby communities experienced a marked increase in illness due to contact with the escaped radiation, although with the exception of thyroid cancer, the human health impact has been short-lived.[492] Exact data for the total number of people affected by this accident are impossible to determine, though more recent studies done by the World Health Organization and the United

[489] "Environment, Health and Safety in Electricity Generation," *World Nuclear Association*, http://www.world-nuclear.org/education/ehs.html (accessed Jan.16, 2011).
[490] Ibid.
[491] "Chernobyl Accident," *World Nuclear Association* http://www.world-nuclear.org/info/chernobyl/inf07.html (accessed Jan. 20, 2011).
[492] Ibid.

Nations have concluded that the much higher initial figures were subject to "unprecedented speculation and exaggeration by parts of the media."[493]

The cause of the Chernobyl accident is also significant. Contrary to popular belief that the accident at Chernobyl was a nuclear explosion, the accident was actually caused by steam. More importantly, the root causes of the accident lie in a combination of a flawed reactor design with inadequate containment safeguards operated by poorly trained personnel. Both the maintenance and the design of the plant failed to meet international safety guidelines, making Chernobyl an isolated incident. Studies of the incident have proven that public perception and the media were incorrect in terms of total damage, lingering health effects, and the cause of accident. Ultimately, the Chernobyl incident functions more as testament of how little understood the nuclear field is, rather than as an example of the dangers of nuclear power generation.

More recent nuclear incidents include the Tokaimura accident in Japan and the Wolsung incident in South Korea. Regarded as the worst civilian nuclear accident in Japan, the Tokaimura accident occurred on September 30, 1999.[494] Workers at the plant caused the reactor to reach criticality—an uncontrolled chain reaction—when they improperly mixed fuel past normal enrichment levels. The uncontrolled reaction led to the release of noble gas, iodine, and increased gamma radiation to the surrounding neighborhoods. Later analysis showed that the doses of radiation proved too small to cause considerable threat to the public health, although two of the workers were exposed to fatal doses of radiation—marking the first deaths attributable to Japan's civilian

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[493] "Chernobyl Accident," *World Nuclear Association* http://www.world-nuclear.org/info/chernobyl/inf07.html (accessed Jan. 20, 2011).
[494] Tsunoda Katsuya, "Public Response to the Tokai Nuclear Accident," *Risk Analysis,* 21 (6): 1039-104. 2001.

nuclear program.[495] Only a week later in South Korea, the heavy water reactor at the Wolsung plant was reported to be leaking, exposing 22 workers and emergency responders to radiation.[496] In the Wolsung incident, the radioactive water was successfully contained, so that the surrounding population and environment remained unaffected; likewise, the exposed workers and responders suffered no significant effects.

At Wolsung, as with the Japanese case and Chernobyl, the underlying cause of the accident can be attributed to insufficient training and poor design rather than any inherent danger of nuclear reactors. These accidents demonstrate a noticeable trend of human error in nuclear accidents. Consequently, future generations of nuclear reactors have increased safeguards by reducing the human margin for error by relying on passive safety. The passive safety design of newer reactors relies on automatic monitoring and response. In the case of loss of pressure or excess heat, the reactor is programmed to adjust cooling controls or automatically shut down.[497] Additionally, these passive safety systems have also significantly improved the safety of nuclear plants in natural disasters. In 2007, the Niigata earthquake threatened the Kashiwazaki-kariwa plant in Japan with seismic activity exceeding the estimated level that the plant could withstand. However, the plant's passive safety mechanisms automatically deployed, shutting down the four active reactors on the plant.[498] As a result, the plant only sustained light superficial damage and no nuclear-related accidents or fatalities occurred.

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[495] Tsunoda Katsuya, "Public Response to the Tokai Nuclear Accident," *Risk Analysis,* 21 (6): 1039-104. 2001.

[496] "Radiation Exposure in South Korea Plant," *New York Times,* October 06, 1999.

[497] Michael Valenti, "A New Generation of Nuclear Reactors," *Mechanical Engineering*, no. 117.4 (1995): 70-75.

[498] "IAEA Issues Report on Kashiwazaki-Kariwa Nuclear Plant," *IAEA,* http://www.iaea.org/newscenter/news/2007/kashiwazaki-kariwa_report.html (accessed Feb. 20, 2011).

Again, it is essential to view these facts and concerns in the context of energy safety generally. While the nuclear industry has been continuously researching to improve safety, between 1,600 and 5,000 people have died in Chinese coal mines every year during the 2000s, with an additional 700,000 deaths in the country annually attributed to pollution-enhanced respiratory illness.[499] Elsewhere in the world, hundreds of coal miners perish every year. Accidents also claim limbs and lives in the petroleum industry, with an average of 12 or more deaths per annum in offshore platform accidents.[500] In light of these statistics, renewable and nuclear technologies constitute the safest forms of energy production at present and in the foreseeable future.

Environmental Impact

Another dimension of energy safety concerns the environment. The health of the environment and the health of populations are inseparable, as pollution inflicted on the environment will inevitably impact humans through groundwater, agriculture, and atmosphere. While nuclear waste is much more highly regulated and carefully monitored than the hazardous byproducts of coal, natural gas, and oil, regulation is not perfect and monitoring cannot be completely consistent across nations.

An example of this lies with the Russian Mayak complex near the Southern Ural Mountains. Beginning operation in mid 1948, the Mayak complex was a core component of the Soviet nuclear program and one of its earliest nuclear reactors.[501] However, this

[499] "Thousands of Deaths Caused by China's Coal Energy," *Public Radio International,* http://www.pri.org/business/global-development/thousands-of-deaths-because-of-china-s-coal-energy2500.html (accessed Feb. 25, 2011).
[500] "TIMELINE-Major Offshore Accidents in the Global Oil Industry," *Reuters,* http://www.reuters.com/article/2010/05/13/venezuela-platform-idUSN1327238620100513 (accessed Feb. 25, 2011.
[501] Boris Segerstahl, and Alexander Akleyev, "The Long Shadow of Soviet Plutonium Production," *Environment (St. Louis), no.* 39 (1): 12-20. 1997.

also meant that nuclear technology was new to the Soviet Union at the time of construction. As a result, many design and operational flaws beset the complex. In the early years of operation, the Mayak complex had 20 noted accidents, seven of them critical. The workers were frequently exposed to dangerous levels of radioactivity; they were forced to clean uranium and plutonium filters manually and personally cleaned radioactive spills, which were common occurrences due to regular corrosion of equipment.[502]

Outside of the complex, the people living nearby also felt the effects. Since the year the complex was completed, low-level radioactive waste from the plants and reactors was routinely dumped into the surrounding environment. According to Greenpeace International, until 1956, radioactive waste was directly poured into the Techa River, a major source of drinking water for villages in the region.[503] As storage space ran out in the frantic rush to enrich more weapons grade uranium and plutonium, this practice expanded to include intermediate and high-level waste as well. In 1957, a storage tank exploded, which released approximately half the amount of radiation discharged the Chernobyl accident. The initial mismanagement that led to the explosion was followed by more negligence, as the Soviet government failed to take significant action to evacuate nearby towns, leaving over 200,500 people exposed to dangerous doses of radioactivity.[504] Additionally, during this period, the complex also made use of

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[502] Boris Segerstahl, and Alexander Akleyev, "The Long Shadow of Soviet Plutonium Production," *Environment (St. Louis)*, no. 39 (1), (1997): 15.
[503] "The Second Biggest Nuclear Disaster in History," *Greenpeace International* http://www.greenpeace.org/international/en/news/features/mayak-nuclear-disaster280907/ (accessed Jan. 29, 2011).
[504] Ibid.

Lake Karachay as a storage site, and continued to set up defective waste reservoirs along the Techa River, which leaked into the water.[505]

The net result of the Mayak practice of regular dumping can still be seen decades later. Even now, Mayak is one of the most radioactive places on earth. Studies of the health effects on people exposed to radiation via the Techa River have confirmed chronic radiation sickness in at least 66 cases and recorded a marked increase in cancer.[506] The full long-term effects of radiation exposure are still unknown, and vary from region to region.

Mayak's legacy is significant for several reasons. The ongoing nuclear waste dumping remained unknown to many and was later overshadowed by the Chernobyl accident. Such a demonstrated lack of transparency within national borders poses a considerable threat to nuclear security and human safety. Most of these actions took place before widespread knowledge of the consequences of radiation exposure and preceded the signing of the Nuclear Non-Proliferation Treaty (NPT) and establishment of the IAEA for international monitoring. Yet even with the NPT in place, Mayak is still relevant as the authoritarian nature of states seeking to expand or establish nuclear power programs, notably China and North Korea, promises relatively low transparency on national nuclear activities.

Examples of nuclear dumping also serve to highlight how crucial expertise and regulation are in the nuclear field, both on a regional and international basis. The operators at Mayak, like those at Tokaimura and Chernobyl, were unaware of the long-lasting damage they were inflicting on themselves, the environment, and nearby

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[505] Boris Segerstahl, and Alexander Akleyev, "The long shadow of Soviet plutonium production," *Environment (St. Louis), no.* 39 (1): 12-20. 1997.
[506] Ibid, 17.

populations. Finally, Mayak provides an example of continued mismanagement, as the Russian government continues to utilize the plant for reprocessing both domestic and foreign imported fuel without significant equipment upgrades or clean up of past pollution.[507]

The implications of the Mayak example emphasize the fact that nuclear pollution and toxic exposure are preventable. With increased transparency and more stringent international measures, nuclear pollution can be influenced across boundaries. In regards to Russian spent fuel imports for reprocessing at Mayak, some bilateral action has already been taken to decrease improper storage and environmental degradation. In the 1990s, upon discovery of the disposal methods at Mayak, Finland, Hungary, Slovakia, and the Czech Republic have all halted exports of spent fuel to Russia.[508]

FINAL WASTE DISPOSAL

While this chapter has touched upon several comparisons of safety concerns in both nuclear and conventional fuel generation and processing, it is important to acknowledge that nuclear disposal is unique. As established, the externalities from fossil fuel burning are no less dangerous than nuclear waste; however, because the waste generated from nuclear power is highly concentrated, nuclear waste disposal must be specially designed and engineered. This unique characteristic of nuclear waste requires a deeper examination of nuclear waste disposal policy and practices around the world.

Radioactive nuclear waste is separated into three categories: low-level waste, intermediate-level waste, and high-level waste. Low-level waste accounts for the bulk of

[507] "Import of Spent Nuclear Fuel to Russia," *Bellona,* http://www.bellona.org/english_import_area/international/russia/nuke_industry/waste_imports/22414 (accessed February 7, 2011).
[508] Ibid.

radioactive waste volume and comes mainly from the medical field and research laboratories; this type of waste is only slightly more hazardous than conventional garbage and can be burned or buried in separate landfills. At the intermediate level, radioactivity is higher and requires shielding and special treatment before final disposal, also through burial. Intermediate-level waste usually consists of equipment that has been exposed to radioactivity, such as reactor components, and chemical leftovers. High-level waste often refers to the small amounts spent fuel or the highly toxic reprocessing waste, which are responsible for the majority of radioactivity.[509] Due to its high radioactivity, high-level waste must be separately contained and delayed for 40 to 50 years to allow radioactive decay; after this period, it becomes much safer to handle and transport to a permanent storage site.

General procedure for permanent high-level waste disposal calls for solidifying (or vitrifying) the waste with glass and sealing the mass in stainless steel containers to keep the waste from traveling and potentially seeping into the surrounding environment. A more advanced form of vitrification can also be achieved with Synroc, a synthetic rock comprised of ceramic materials best suited for absorbing radioactive waste.[510] The canisters are kept in specially designed pools or contained in reinforced storage facilities for several decades before it is safe to move the vitrified waste to a final waste repository.[511] Ideally, final storage sites will be located deep underground at stable geological points, far from natural resources and population centers. Additionally the

[509] "Waste Management," *World Nuclear Association,* http://www.world-nuclear.org/education/wast.htm (accessed Jan. 25, 2011).
[510] "Synroc Wasteform," *World Nuclear Association,* http://www.world-nuclear.org/info/inf58.html (accessed Feb. 10, 2011).
[511] Ibid.

locations would also have flat terrain and minimal rainfall to decrease the probability of leakage, water damage to the containers, and waste travel.[512]

At present, no final centralized civilian repositories have been fully completed, although Sweden and Finland lead the world in nuclear waste disposal, with the only two active long-term projects.[513] Sweden's underground fuel storage facility near Oskarshamn is estimated to be completed by 2015, and Finland is moving forward with plans for its Onkalo site.[514] Both countries are planning deep, bedrock granite repository designs. These two countries stand out as premier examples of waste disposal because of their public involvement in site selection and long-range forecast.

Approaches

While many of the world's nuclear capable nations have suffered delays and cancellations of final repository site selection due to local objection, Sweden's interactive approach to site selection has helped the country avoid last minute political maneuvering and cancellations. Swedish feasibility studies for possible geological sites not only examined bedrock and geology but also took account of local approval.[515] Significantly, both candidates for the final site selection had volunteered to host the repository. The final repository was approached as a long-term investment rather than an external burden placed on local communities.

Although Finland's Onkalo site has not been officially confirmed, the Onkalo proposal is one of the most advanced plans currently under consideration. The company

[512] "International Proposals for Nuclear Waste Sites," *Living Earth,* www.loe.org/series/three/international.htm (accessed Feb. 7, 2011).
[513] Sandra, Upson, "Finland's Nuclear Waste Solution," *Ieee Spectrum*, no. 46.12 (2009): 24.
[514] "Waste Management," *World Nuclear Association,* http://www.world-nuclear.org/education/wast.htm (accessed Jan. 25, 2011).
[515] "Nuclear Power in Sweden," *World Nuclear Association,* http://www.world-nuclear.org/info/default.aspx?id=376&terms=sweden (accessed Jan. 30, 2011).

responsible for this undertaking, Posiva, is operating on the longest timescale in the nuclear disposal history: 100,000 years.[516] Posiva has already excavated 5,000 meters of tunnels and is in the midst of extensive testing to prove that its multilayered design and copper technology can successfully contain radioactive material through earthquakes, ice ages, and other natural disasters expected in the next one hundred millennia.[517] If approved, Onkalo will be the world's first permanent nuclear waste repository and prove that a technological, economical, and social solution to nuclear waste is possible.

However, Sweden and Finland's progress in nuclear disposal is hardly the norm. In other nations, permanent waste repositories continue to present a controversial political issue. Though several countries are in the process of exploration and evaluating sites, no active projects are on the table. Another alternative to the aforementioned approaches would be regional or international waste repositories. Bilateral nuclear waste importation has been undertaken or proposed in several countries, most notably in Russia. However, larger multinational proposals have remained in the realm of theory. In 2005, the IAEA researched the possibility of an international repository and released a report that concluded such a site could "enhance global safety and security by making timely disposal options available to a wider range of countries," especially those without suitable domestic sites available.[518] The agency considered an international site a viable option for safe, permanent disposal. At the same time, the report admitted an international site would be heavily dependent on strong cooperation and equal burden sharing between states. The IAEA also noted that confidence was an integral issue in

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[516] Sandra, Upson, "Finland's Nuclear Waste Solution," *Ieee Spectrum*, no. 46.12 (2009), 24.
[517] Ibid, 26.
[518] "Developing Multinational Radioactive Waste Repositories: Infrastructural Framework and Scenarios of Cooperation)," *IAEA*, http://www-pub.iaea.org/MTCD/publications/PDF/te_1413_web.pdf. (accessed Feb. 7, 2011).

pursuing a multilateral repository; states would only be willing to fund and contribute to a shared repository if transportation, security, and safety were guaranteed. The current absence of national final disposal sites thus presents another significant obstacle to building confidence in technological ability to permanently store nuclear waste.

Given this level of uncertainty, any progress in final disposal is likely to occur first on the national level. However, even on this smaller scale, public perception and ensuing politics have stalled many projects. In the United States, interim onsite containment is currently the only option for civilian spent fuel waste. A national final repository has been pursued since 1987, when Yucca Mountain in Nevada was designated as the most promising potential site.[519] On a technological level, the Yucca Mountain site was selected for its distance from population centers, lack of mineral resources, and distance from water sources, although other sites also shared these common characteristics. More importantly, the site was located on federal land, which allowed Congress to dismiss objections from the state of Nevada.[520] As the sole designated site, Yucca Mountain was extensively studied and evaluated for safety, while the state of Nevada continued to delay the project with litigation. Regulatory procedure also contributed to multiple delays, since applications to license Yucca Mountain took years to be reviewed by the Nuclear Regulatory Commission (NRC).[521] Additionally, if the licensing application were accepted, another construction license would be needed before work could begin on the site.

[519]Richard B. Stewart, "U.S. Nuclear Waste Law and Policy: Fixing a Bankrupt System," *NYU Environmental Law Journal*, no. 1 (2008): 783-825.
[520] Ibid, 797.
[521] Ibid, 804.

Though the site remained the focus of a final U.S. repository for decades, in 2010 the Yucca Mountain project was essentially abandoned. In the past year, the Obama administration applied to withdraw the licensing application for Yucca Mountain, citing that the project was no longer a viable option.[522] The withdrawal is still currently under consideration in court, although without active support and funding from the federal government, Yucca Mountain is effectively stalled. Consequently, years of study and billions of dollars have been wasted. The approximately 64,000 metric tons of spent fuel ready for final disposal remains scattered across 120 temporary sites in 36 states.[523] The decision to withdraw from Yucca Mountain was not related to scientific reasoning for the suitability of the site, as proven by the vague motive given. Instead, politics and especially local opposition were the driving factors. Yucca Mountain demonstrates how site selection is an intensely political process, both for the initial selection and ultimate abandonment. Additionally, it serves as an example of how geological characteristics and investment can be overruled for political reasons.

With the cancellation of the Yucca Mountain site, the U.S. is now considering another decentralized approach to nuclear waste, via oil deep drilling technology. This "borehole" strategy consists of drilling narrow holes five kilometers deep into rock beds and filling the bottom two kilometers with canisters of nuclear waste. The remaining three "surface" kilometers would be filled in with clay, concrete, and asphalt.[524] Advocates of borehole drilling argue that this method capitalizes on domestic abundance of basement rock sites and uses more reliable natural conditions to contain waste (as

[522] Luther J. Carter, Barrett Lake H., and Kenneth C. Rogers, "Nuclear Waste Disposal: Showdown at Yucca Mountain," *Issues in Science and Technology*, 27.1 (2010), 80-4.
[523] Ibid, 81.
[524] Phil McKenna, "Insight: Drilling Deep to Dispose of Nuclear Waste," *New Scientist*, no. 205.2754 (2010).

opposed to Finland's predominantly engineered approach). However, this alternative is only at the theoretical stage.

In contrast with the United States, Germany has faced many technological problems with, as well as political opposition to, its nuclear waste repositories. Since 1963, the German government has recommended using salt formations, rather than granite or other deep bedrock, for final storage.[525] In the 1970s, the Gorleben salt dome and Asse salt mines were approved for final disposal. However, these soon encountered problems with leakage and the Asse site has since been shut down. Similarly, another salt site in Morsleben has been closed for repairs and reinforcement. Other sites for interim and final disposal throughout Germany have been contested for poor design, and insufficient protection.[526] Germany's ongoing difficulties with securing its nuclear waste have been attributed to poor regulation.

CONCLUSION

Around the world, many countries are still in the initial stages of final waste disposal. China, Japan, Russia, and France are still in the process of studying potential sites. Concrete information about these programs will be unavailable for years until site selections and examinations can occur. As nuclear programs increase, it is important to acknowledge the role of public perception and politics in all aspects of the civilian nuclear industry, from plant operations to final waste disposal.

In comparison to fossil fuels and renewable energy, nuclear power not only provides a viable, baseload, and carbon-free alternative, it also possesses a comprehensive regulatory standard that fossil fuel industries lack. Although public

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[525] "Nuclear Power in Germany, " *World Nuclear Association*, http://www.world-nuclear.org/info/default.aspx?id=332&terms=Germany (accessed Feb. 11, 2011).
[526] Ibid.

opinion often emphasizes nuclear accidents such as the Chernobyl incident, data shows that the mining and refining process of the coal, gas, and oil industries has resulted in significantly higher worker fatalities. Furthermore, notable nuclear accidents have occurred as a result of human error, rather than any inherent danger of reactors; increased training and new designs have already greatly reduced this risk. When properly regulated, nuclear power is safer than fossil fuels.

As shown by examples in the Soviet Union and Germany, high-level waste disposal is a vital component of nuclear safety. The nuclear dumping at the Mayak site and the leakage in the German salt repositories have caused much more damage to human and environmental safety than any nuclear accident to date. Yet while disposal sites and methods are imperative to maintaining human and environmental safety, public perception and policy have proven to be huge obstacles to this process. Local opposition has even halted the large-scale and heavily invested project at Yucca Mountain in the United States.

The fear of final nuclear repositories can only stall construction for so long, at the detriment of health and safety, as the trends of rising energy demand and increased awareness of climate change have already prompted many countries to increase nuclear energy production. Rather than forcing countries to rely on interim storage methods for high-level nuclear waste, which are highly unsustainable and inefficient, the Swedish and Finnish examples show how public involvement can be utilized. By recognizing the social dimension of locating waste sites and actively seeking the support of the local community, Sweden and Finland have shown incredible progress in researching and developing their respective sites.

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Chapter Nine

THE REALITY OF REPROCESSING: OPEN VERSUS CLOSED NUCLEAR FUEL CYCLES

Sylvia Gozdek

Abstract:

Rising world demand for energy, particularly for electricity in Asia, is being met by an expansion in nuclear power, which has led to growth in fuel cycle technology. This has implications for global security because of inherent risks associated with rising volumes of fissile material, radioactive waste, and related concerns over proliferation. Open and closed fuel cycles are integral to both of these topics of concern. This section presents an overview of the mechanics involved in open and closed fuel cycles. Crucial issues to be considered when developing a policy plan for either open or closed systems are discussed, with particular focus on Asia. Topics addressing the issue of waste management include costs of direct waste disposal versus reprocessing. Regulatory protocols define another essential issue for both open and closed systems in terms of waste, by-products diversion, and the establishment of an international fuel center. It is argued that although the closed-cycle approach is more efficient and possibly more sustainable, current political and economic factors are not conducive to the widespread use of reprocessing technology.

INTRODUCTION

There are currently 438 nuclear power reactors operating in 30 nations and within the past four years, over 50 nations without any facilities have approached the International Atomic Energy Agency to ask for assistance in design and construction.[527,528] The impending decommissioning dates for existing plants, combined with the pressure to construct new ones, will soon increase demand on the industries of mining, fuel fabrication, enrichment, and reprocessing. Open and closed fuel cycles manage the methods of each of these industries in different ways. Open cycles allow for the direct disposal of waste products into storage, while closed cycles permit the

527 Charles Ebinger and Kevin Massy, "Security Implications of the Expansion of Nuclear Energy," *South Asian Survey,* 17.1 (2010): 77.

528 Robert H. Socolow and Alexander Glaser, "Balancing Risks: Nuclear Energy & Climate Change," *Daedalus,* 138.4 (2009): 34.

reprocessing of this waste. The choice of nations to follow one or the other of these approaches holds heavy influence over the future of global security.

Nuclear power has widespread appeal in Asia, for reasons of energy security, lowering carbon emissions, and in some nations, for providing electricity for economic development. Asian states are rapidly becoming the nexus of a major new era in nuclear reactor construction. Most plant designs follow the structure of conventional pressurized water reactor (PRW) models, yet with safety, efficiency, and other improvements over the previous generation of PWRs. These are compatible with forms of fuel created for both open and closed fuel cycle systems, but there is a push towards the installation of fast breeder reactors as well, which require highly enriched fuels. This could increase demand on the industries of mining, enrichment and reprocessing.[529] The moves taken by India, China, Japan, South Korea, and Russia, in terms of domestic and foreign support of these industries, will set the precedent for Asia. Increasing demand for electricity in Thailand, Myanmar, Indonesia, and Vietnam is pushing these states to adopt nuclear technology according to the methods exemplified by the regional leaders. The support of either closed- or open-cycle technology implementation thus has many implications for political, energy, national, environmental, and human security.

Most nuclear fuel today relies on uranium mining and enrichment. Bilateral and multilateral trade agreements delegate the nature of the distribution of raw uranium, plutonium, and enriched fuel. Modern interest in reprocessing technology, as a means to decrease the volume of spent fuel and acquire fuel domestically, is growing. A closed fuel cycle however, commonly generates new plutonium, a potential proliferation risk,

[529] Gong Yidong and Dennis Normile, "Asia's Demand for Electricity Fuels a Regional Nuclear Boom," *Science*, 309 (2005): 1177.

while adding to the burden of regulatory commissions installed to oversee the securing of nuclear materials and defense against proliferation. Although closed fuel cycles present opportunities for decreasing waste volume and increasing individual state autonomy, widespread implementation would not be appropriate and is not warranted by economic realities. Uranium is currently abundant and available at low prices, with plentiful remaining reserves. However, it is not clear how long this situation will persist given forecasted levels of new reactor construction. As the technological capabilities of fuel cycle systems continue to change according to advances in science, it is imperative to have a political regulatory dialogue that follows along.

In order to comprehensively assess the status of the debate over which path states should choose, this chapter will briefly describe the mechanics involved in these types of fuel cycles and then highlight a series of the most pressing political arguments. Current research indicated that the economic costs of reprocessing outweigh the benefits it could provide for long-term storage. As well, the political climate is not conducive to render a shift toward greater diffusion and support for this technology. While reprocessing holds promise for the future in terms of tapping into the resources of spent fuel, current market prices and risks to proliferation make it an inadvisable choice. In light of these realities, this paper concludes that it would be productive to invest in an international fuel center, as this would prevent countries from seeking reprocessing technology autonomously in the present, and preemptively facilitate a transition toward the adoption of these types of systems in the future.

MECHANICS OF OPEN AND CLOSED FUEL CYCLES

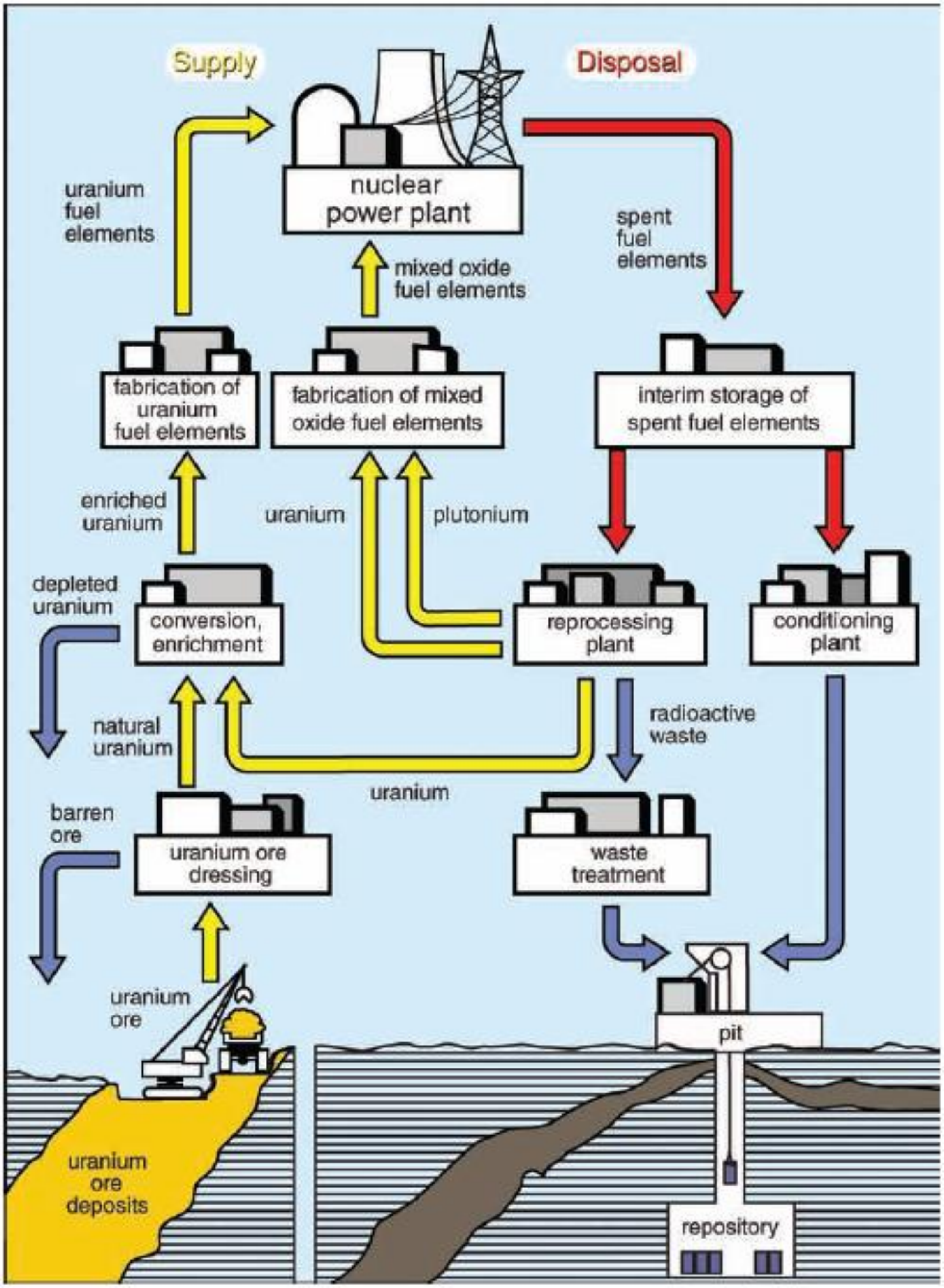
The nuclear fuel cycle is partitioned into three components, each dealing with different stages of fissile material supply, use, or disposal. The first stage, termed the "front end," is the part of the cycle in which uranium ore is mined and processed into enriched fuel. The second stage, the "service period," is when the fuel is sent through the reactors during operation. The final stage is the "back end" and deals with the safe management, containment, and reprocessing or disposal of spent fuel.[530] A visual overview of all these components to the system is given in Figure 10.1. Open and closed fuel cycles differ from one another in their treatment of spent fuel. In an open fuel cycle approach to the "back end," spent fuel waste is disposed of and moved to a repository or to interim storage, whereas in a closed fuel cycle, the waste is reprocessed and cycled through the reactor up to two times more before it is disposed.

Open Fuel Cycles

In an open fuel cycle nuclear fuel is run through a reactor only once and the spent fuel is never reprocessed. The resulting spent fuel is extremely hazardous waste and must be stored in spent fuel pools for a period of interim holding for up to six years.[531] After cooling, this waste is stored in casks on-site or is transferred to more permanent holding areas, such as deep geological repositories. Open fuel cycles maximize waste volume, which has resulted in many civilian nuclear facilities reaching or approaching their maximum capacity for storage. In western, democratic nations, public opposition to geological waste repositories based on "nimby-ism" (Not in My Back Yard), has stymied underground storage, resulting in the growing accumulation of spent fuel waste in power

[530] Frank A. Settle, "Uranium to Electricity: the Chemistry of the Nuclear Fuel Cycle," *Journal of Chemical Education*, 86.3 (2009): 317.
[531] IAEA, "Country Nuclear Fuel Cycle Profiles," *International Atomic Energy Agency*, (2005): 18.

Figure 9.1. Mechanics of the Nuclear Fuel Cycle



Source: Frank A. Settle, "Uranium to Electricity: the Chemistry of the Nuclear Fuel Cycle," *Journal of Chemical Education*, 86.3 (2009): 326.

plant surface locations. Such on-site storage is intended to be temporary. However, the long-term fate of such waste remains undetermined in most countries.

Closed Fuel Cycles

A closed fuel cycle involves reprocessing of spent fuel to recover additional fuel. This method employs the chemical reactions of redox, precipitation, and extraction to either isolate the fissile materials for fuel reproduction or directly "burn" them for energy generation and to reduce their toxicity and volume. Fissionable plutonium and uranium can be separated from the other components within the spent fuel.[532] The radionuclides that are produced as waste from light water reactors can also be destroyed or converted into shorter-lived hazardous materials.[533] This is currently achieved using one of three methods: plutonium and uranium extraction (PUREX), the use of integral fast reactors (IFRs) and pyro-processing, or partitioning and transmutation.

The method used by the majority of commercial reprocessing centers is the PUREX process. In this method, waste undergoes an aqueous separation process during which fissionable materials, such as uranium and plutonium are separated out.[534] The process begins by removing the outer cladding of the spent fuel either mechanically or chemically after which the remaining fuel is boiled in nitric acid. This resulting solution has its pH raised and then equilibrated with a solution of tri-*n*-butyl phosphate (TBP) while immersed in kerosene.[535] What results are extracts of uranium and plutonium which are put toward two uses: either they are added to the front end of the fuel cycle and

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[532] Frank A. Settle, "Uranium to Electricity: the Chemistry of the Nuclear Fuel Cycle," *Journal of Chemical Education,* 86.3 (2009): 320.
[533] Behnam Taebi and Jan Kloosterman, "To Recycle or Not to Recycle? An Intergenerational Approach to Nuclear Fuel Cycles," *Science and Engineering Ethics,* 14.2 (2008): 181.
[534] Charles Ebinger and Kevin Massy, "Security Implications of the Expansion of Nuclear Energy," *South Asian Survey,* 17.1 (2010): 83.
[535] Frank A. Settle, "Uranium to Electricity: the Chemistry of the Nuclear Fuel Cycle," *Journal of Chemical Education,* 86.3 (2009): 320.

put through the reactor core, or they are added to another solution already containing plutonium dioxide (also derived from reprocessing) to produce mixed oxide fuel (MOx) which is also cycled through the reactor.[536] MOx fuel can be reprocessed once more after its second run through the reactor. Because of its plutonium content, MOx fuel can only be used in reactors set up to handle higher neutron flux levels than common light water reactors.

A less common method of reprocessing uses IFRs and pyroprocessing. IFRs are designed to generate energy from the spent fuel by using all fissionable isotopes as fuel. Such a reactor utilizes liquid sodium as a coolant. Two reactors consume the plutonium, uranium, and 90 percent of the actinides so efficiently that the waste stream is basically free of fissile material.[537] At the same site as the nuclear power generator, a fast breeder is integrated into the system to create a facility that has a greatly reduced volume of waste. The basic fast reactor design has been proven to be efficient, recovering almost all of the energy remaining in the spent fuel.[538]

Pyroprocessing is a method used in the IFR design. It is a multi-step process that breaks down spent fuel without isolating plutonium.[539] Spent fuel is cooled in a dry cask, moved to an adjacent remote-handling facility, and is subjected to a sequence of chemical and electrical processes. It is dissolved in molten salt and when an electrical current is run through it, a mixture of fissile materials is collected at a cathode. These materials include plutonium, uranium, rare-earth fission products, and transuranic elements like

[536] Charles Ebinger and Kevin Massy, "Security Implications of the Expansion of Nuclear Energy," *South Asian Survey*, 17.1 (2010): 82.
[537] George S. Stanford, and Arjun Makhijani, "The Integral Fast Reactor Could Do It," *The Bulletin of the Atomic Scientists*, 57.3 (2001): 4.
[538] Ibid, 5.
[539] Charles Ebinger and Kevin Massy, "Security Implications of the Expansion of Nuclear Energy," *South Asian Survey*, 17.1 (2010): 83.

americium, curicium and neptunium.[540] Many people are concerned about the proliferation risks associated with reprocessing but the pyroprocessing method removes these risks. This system creates a resulting mixture of plutonium and other elements, which is very difficult to divert for weapons creation. This work is accomplished through the use of mechanical manipulators; technicians must use robotic arms to do delicate work thus it necessitates the construction and practice of sophisticated forms of technology.[541]

Partitioning and transmutation (P&T) is a new technology that still requires serious investment but aims to reduce the level of toxicity of nuclear waste.[542] It separates (partitions) the different categories of elements within waste and eliminates (transmutes) the long-term radioactive hazard by replacing it with a short-term hazard.[543] P&T extends the separation process for plutonium from waste to also isolate neptunium, americium, and curicium. Materials are then transmuted, or burned, in a neutron field to transform them into shorter-lived fissionable products.[544] P&T can reduce the radiotoxicity of waste as well as the time it takes to do this, which can further reduce the residual heat in geological repositories and impact their design, size, and characteristics. In short, this process can reduce the burden placed upon geological disposal of waste.

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[540] Edwin Lyman and Frank N. Hippel, "Reprocessing Revisited: the International Dimensions of the Global Nuclear Energy Partnership," *Arms Control Today*, 38.3 (2008): 8.
[541] Gwyneth Cravens, *Power to Save the World: The Truth About Nuclear Energy* (New York: Alfred A. Knopf, 2007), 266.
[542] Behnam Taebi and Jan Kloosterman, "To Recycle or Not to Recycle? an Intergenerational Approach to Nuclear Fuel Cycles," *Science and Engineering Ethics,* 14.2 (2008): 179.
[543] "Partitioning and Transmutation: Making Wastes Nonradioactive," *Oak Ridge National Library*. http://www.ornl.gov/info/ornlreview/rev26-2/text/radmain.html#radanch1 (accessed Feb. 7, 2011).
[544] Salvatores, M, and G Palmiotti, "Radioactive Waste Partitioning and Transmutation Within Advanced Fuel Cycles: Achievements and Challenges," Progress in Particle and Nuclear Physics, 66.1 (2011): 147.

After the recycling of reprocessed fuel, vitrified waste, a mixture of fission products and minor actinides, remains.[545] Vitrified waste must also be stored either on-site or in deep geological repositories. The radioactive decay of the plutonium-free, uranium-free final residue is more rapid than that of conventional spent fuel.[546] However, the immediate decay heat of waste from the resulting materials is much higher than that from the open cycle spent fuel. This means it must be stored above ground longer before it can be moved for more permanent storage.[547]

FISSILE MATERIALS COST

In the European Union alone, there resides approximately 2,500 tons of spent fuel containing over 25 tons of plutonium, 3.5 tons of minor actinides and 3 tons of fissionable products.[548] Although present in relatively small concentrations, these radioactive elements are harmful to the environment and human health when released. In order to mitigate the damaging effects of spent fuel, the materials must be isolated and deposited into a secure environment until their toxicity reaches acceptable levels. Current analysis estimates that it would cost a total of $350 billion to treat the waste from decades of nuclear activities in order to ensure that the public would receive no more than a very low dose of radiation. During the first 100 years of storage, radiotoxicity is dominated by the presence of fissionable products, while in the long term it is dominated

[545] Behnam Taebi, and Jan Kloosterman, "To Recycle or Not to Recycle? an Intergenerational Approach to Nuclear Fuel Cycles," *Science and Engineering Ethics*, 14.2 (2008): 182.
[546] Gwyneth Cravens. *Power to Save the World: The Truth About Nuclear Energy* (New York: Alfred A. Knopf, 2007), 266.
[547] Charles Ebinger and Kevin Massy, "Security Implications of the Expansion of Nuclear Energy," *South Asian Survey*, 17.1 (2010): 83.
[548] Massimo Salvatores and Giuseppe Palmiotti, "Radioactive Waste Partitioning and Transmutation Within Advanced Fuel Cycles: Achievements and Challenges," Progress in Particle and Nuclear Physics, 66.1 (2011): 145.

by the actinides plutonium and americium isotopes.[549] The difference in time scales brings the technologies discussed previously into the debate on how to approach nuclear waste.

Some analysts have proposed reprocessing as a way to limit the amount of nuclear waste produced since currently there is no widely accepted route for long-term storage. As temporary storage units near capacity, the pressure is building to find a more permanent solution for this waste. Nuclear waste is stored in one of two ways; either on-site at the regional nuclear facility, or in a national repository. To combat the limited capacity of storage facilities, the volume or nature of waste could be altered through the use of new reprocessing technology. However, a cost comparison between direct disposal and reprocessing treatment of waste reveals that reprocessing is not yet an economically viable option.

Another argument in favor of reprocessing technology is that of its ability to conserve resources at the front-end of the fuel cycle. By extending the value of unmined uranium and plutonium resources, the concentrations already in rotation can be used extensively. However, the costs associated with reprocessing spent fuel and the market realities of mining and enrichment place reprocessing at an economic disadvantage.

Cost of Direct Disposal versus Reprocessing

Open fuel cycles direct the spent fuel immediately to a storage unit whereas closed fuel cycles allow for the treatment of waste prior to being stored. Risk is transferred from future generations to the present in a closed fuel cycle because reprocessing reduces the ultimate volume of waste by rendering it more intense for a

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[549] Massimo Salvatores and Giuseppe Palmiotti, "Radioactive Waste Partitioning and Transmutation Within Advanced Fuel Cycles: Achievements and Challenges," Progress in Particle and Nuclear Physics, 66.1 (2011): 145.

shorter period of time.[550] Costs associated with nuclear waste are twofold: there is the cost of investment in storage units and the expenditures required for processing the waste. Maintenance of on-site storage facilities is intricate and expensive: they must have the requisite structures to house cranes to lift and transport the hot, multi-ton, storage casks.[551] Storage pool water must be constantly deionized and filtered. In addition, these immediate storage facilities are viewed as temporary solutions and wait for the discovery of more permanent options.[552] Locating appropriate sites for a long-term storage project, as well as the actual construction of one, has proven to be a complex and slow process, as seen through the $9 billion dollar failure of Yucca Mountain.[553] However, costs of reprocessing fuel are higher than those associated with directly depositing the waste into storage sites. These findings are based on the use of PUREX technology and thermal reactors and vary in magnitude across studies. The lowest estimates put the cost of reprocessing at six percent more than to dispose directly but other estimates are as high as 200 percent.[554] Much of the variance can be attributed to the inclusion of different input variables for different studies. Both open and closed fuel cycles require long-term storage solutions but the character of these structures is contingent upon the attributes of the waste.

Overall capacity of long-term storage units is determined by the heat of the waste being stored, not its volume. On a long-term time scale, the radioactive decay of waste

[550] Behnam Taebi and Jan Kloosterman, "To Recycle or Not to Recycle? an Intergenerational Approach to Nuclear Fuel Cycles," *Science and Engineering Ethics,* 14.2 (2008): 178.
[551] Gwyneth Cravens, *Power to Save the World: The Truth About Nuclear Energy* (New York: Alfred A. Knopf, 2007), 267.
[552] Jane I. Dawson and Robert G. Darst, "Russia's Proposal for a Global Nuclear Waste Repository: Safe, Secure, and Environmentally Just?," *Environment*, 47.4 (2005): 12.
[553] Giles Whittell, "Yucca Mountain Nuclear Waste Site Dropped Despite Plans for New Plants," *The Times*, Feb. 3, 2010.
[554] Peter Orszag, "Costs of Reprocessing Versus Directly Disposing of Spent Nuclear Fuel," *Committee on Energy and Natural Resources,* Nov. 14, 2007.

and the heat it emits is dependent upon the concentration of minor actinides present. These decay less rapidly than fission products.[555] Cost comparisons between reprocessing and direct disposal revolve around this evaluation of efficiency; whether it is cost effective to use reprocessing to treat spent fuel so that it may be stored at higher densities and decrease the overall volume of waste. Reprocessing spent fuel offers the benefits of lowering the heat and volume of the waste long term as well as extending the usage of mined fissile resources, thereby increasing their value.

There are different levels of heat linked to each type of waste fuel created through open or closed fuel cycles. Spent fuel that has been reprocessed and gone through a period of cooling has a lower heat than that of spent fuel itself. The heat of the waste resulting from the recycling of reprocessed spent fuel is higher than that of the original spent fuel waste. This means that the benefits garnered from the first round of reprocessing and potential for densification for storage are eliminated. In order to lower the need for and cost of long-term repositories, the long-term repository would have to be equipped with an outside storage area to store the heated waste for an interim period.[556]

The benefits brought by reprocessing technology also have economic disadvantages. There are costs attached to the construction of specialized facilities to recover usable materials from the spent fuel as well as those for the long-term storage of super-hot recycled spent fuel.[557] Two recent cost analysis surveys took place to quantify the relative prices of direct disposal and reprocessing, one led by the Boston Consulting Group (BCG) in 2006 and the other by Harvard University's Kennedy School of

[555] Peter Orszag, "Costs of Reprocessing Versus Directly Disposing of Spent Nuclear Fuel," *Committee on Energy and Natural Resources*, Nov. 14, 2007.
[556] Ibid.
[557] Ibid.

Government in 2003. These studies included the costs of handling the waste after being discharged from the reactor including reprocessing services, transportation, long-term disposal, interim storage and positive offsets through "fuel credits."[558] For the volume of waste expected from surveyed generators, BCG concluded that reprocessing would cost $2 billion more than direct disposal while the Kennedy survey estimated $26 billion more.[559] The discrepancy in these numbers can be explained by different assumptions of interest rates on future costs, a reprocessing plant's yearly operating cost versus total capacity cost, the time horizon of plant operation, the long-term repository costs, and the degree of densification for storage. The Congressional Budget Office reviewed both of these studies and controlled for the differences to conclude with an estimate of between $5 and $11 billion.[560] The remaining gap can be explained by differing estimates of the cost of building and operating a reprocessing plant.

These calculated estimates would shift in the instance of two possibilities: the construction of an immense reprocessing facility or a chance in the market value of reprocessed fuel. Currently, there does not exist a reprocessing facility in the world large enough to handle the 2,200 metric tons of waste produced in the U.S. annually. The construction of such a facility might alter the estimation of reprocessing costs, but these calculations would still operate under the assumption that the facility would run at full capacity through its entire service period. In addition, the cost of uranium dictates the market value of reprocessed fuel because if the costs of mining increase, recycled fuel

[558] Peter Orszag, "Costs of Reprocessing Versus Directly Disposing of Spent Nuclear Fuel," *Committee on Energy and Natural Resources*, Nov. 14, 2007. This term is used to reflect the value of reprocessed fuel in terms of savings on the costs of newly purchased fuel.
[559] Ibid.
[560] Ibid.

would become a more viable option.[561] It should be noted, that some reactors would need to be modified to use recycled fuel, which would entail further costs.

The CBO tested the sensitivity of their input variables to shifts like present-value cost, operating costs, operating lifetimes, cost of long-term repositories and increasing capabilities for densification. Under all these shifting conditions, it still concluded that the cost of reprocessing is at an economic disadvantage to direct disposal.[562]

Cost Effectiveness of Reprocessed Fuel

Outside of allowing waste to be stored at a greater density, thereby lowering the long term cost of storage facilities, proposed benefits for the front end of the nuclear fuel cycle support reprocessing technology by extending the usage of already mined products. Reprocessing lowers the cost of mined fissile materials and their subsequent enrichment. The value is extended because the products are integrated into a longer production cycle. Sequestered uranium can be used as fuel once more after being enriched, while plutonium may be mixed with uranium to create MOx fuel.[563] The plutonium recovered is an additional front end cost saver because it is not subject to as many fuel preparation costs as uranium.[564] As nuclear facilities continue to be erected to meet Asia's rising energy demand, the demand for uranium resources will continue to climb. However stocks of these elements are so abundant that thrift is not economically justified. If China were to utilize nuclear energy for 20 percent of its demand by the year 2050, it would have to

[561] Peter Orszag, "Costs of Reprocessing Versus Directly Disposing of Spent Nuclear Fuel," *Committee on Energy and Natural Resources*, Nov. 14, 2007.
[562] Ibid.
[563] Charles McCombie and Thomas Isaacs, "The Key Role of the Back-End in the Nuclear Fuel Cycle," *Daedalus*, 139.1 (2011): 33.
[564] Ibid.

acquire 75 percent of its known reserves.[565] The immense demand of China as a nation reveals that reserves are in fact enormous and that currently, there is no incentive to shift toward expensive reprocessing technology for material conservation. While this attribute is valuable in its prudent approach toward resources, current markets for fissile products make the investment in reprocessing economically inadvisable.

WASTE REGULATORY PROTOCOL

Diversion of fissile materials into the creation of nuclear weapons is a pressing concern for global security. The ability to enrich and reprocess fuel decreases the time it takes to convert peaceful nuclear programs into an arsenal.[566] This reduces the effect of both internal and external constraints meant to prevent proliferation. Several characteristics determine a fuel cycle's resistance to proliferation: how easily a non-weapon Nuclear Non-Proliferation Treaty (NPT) signatory could acquire weapons material from a facility subject to IAEA supervision, how quickly a nation could acquire a significant amount of nuclear materials, and how easily a group could divert nuclear materials.[567] Use of reprocessing technology increases the possibility of the diversion of materials toward the construction of an arsenal because it lowers the radioactivity of the materials decreasing the "self-protection standard."[568] Stockpiling of resources could take place with the use of reprocessing technology, which is very threatening to non-proliferation efforts. In addition, the relative ease with which spent fuel assemblies can be tracked makes other alternatives less viable and decreases the chance of foreign

[565] Gong Yidong and Dennis Normile, "Asia's Demand for Electricity Fuels a Regional Nuclear Boom," *Science*, 309 (2005): 1178.
[566] Edwin Lyman and Frank N. Hippel, "Reprocessing Revisited: the International Dimensions of the Global Nuclear Energy Partnership," *Arms Control Today*. 38.3 (2008): 6.
[567] Ibid, 9.
[568] Ibid: The level of radioactivity needed to render the material unable to transport without the use of specialized tools because of the damage that would be inflicted upon the human transporting it.

support in the construction of facilities for non-signatory NPT nations. The spread of reprocessing technology has inherent conflicts of interest with non-proliferation initiatives. The establishment of an international fuel center (IFC) may work as a tool with which to address issues created during a transition to the use of reprocessing technology. Creating a forum for international discussion and negotiation, an IFC could provide a structure that would facilitate the implementation of effective and efficient systems of nuclear power.

Diversion of fissionable material

During reprocessing, uranium and plutonium are sequestered, which makes them easier to divert for clandestine purposes. Additionally, it lowers the radiation of the materials, further increasing its chances of being intercepted and taken by interested parties. Spent fuel has relatively low proliferation risk because of its mixed nature, which would need to undergo a delicate process of separation to isolate weapons materials. At the same time, perpetual contributions to spent fuel volumes by open cycle processes are creating a storage problem, which some have argued is reason enough to start reprocessing on a mass scale. Reprocessing can mitigate the current practice of most nuclear facilities storing waste on-site, but this method is counterproductive to international efforts toward the regulation and security of these materials. It increases the chance for targeting by attack initiatives as well as elevating consequent damage levels. While centralizing and securing waste materials is key to preventing proliferation, reprocessing, with all its proliferation risk, may not be the best option for resolving the issue.

Reprocessing technology requires a cautious approach because of its production of plutonium and uranium products. Although the isotopes commonly derived at civilian plants require more enrichment to become weapons grade, the levels of radiation are lowered making it less risky to divert the materials. As it becomes more abundant, it will become more available to groups attempting to acquire it.[569] Alternative reprocessing technologies are being developed to prevent the isolation of plutonium through the extraction process in anticipation of the increased prevalence of MOx compatible reactors. The diffusion of Generation IV technology will place demand on greater concentrations of uranium fuel. The combination of this highly enriched fuel type with low enriched types used for light water reactors can be a concern for proliferation. Dual usage makes for complex issues for these forms of technology because fast reactors may be used to breed plutonium using sources of depleted uranium.[570] The newest enrichment plants use lasers; these plants are harder to detect from satellite scanning, making the verification work of oversight regimes more difficult. Increasing likelihood of domestic installment of enrichment or mining activities is also of concern for proliferation because of the inherent linkages of these processes to weapons creation.[571]

Reprocessing technology requires a proficient level of economic affluence as well as infrastructure to support such cutting edge science. This means that nations requesting implementation of such technology are of a certain status.[572] Intent to utilize reprocessed materials for energy production may be combined with that of producing a nuclear

[569] Charles Ebinger and Kevin Massy, "Security Implications of the Expansion of Nuclear Energy," *South Asian Survey,* 17.1 (2010): 82.
[570] Miles Pomper, "IAEA, Leading Nations Push for Fuel Assurances," Arms Control Today. 36.6 (2006): 44.
[571] Charles Ebinger and Kevin Massy, "Security Implications of the Expansion of Nuclear Energy," *South Asian Survey,* 17.1 (2010): 81.
[572] Anonymous, "Fast Breeding in the East," *The Economist*, 334.7902 (1995): 69.

arsenal for increasing political clout.[573,574] As exemplified by the conflict resulting from the disagreement between the U.S. and South Korea over the categorization of pryo-processing as a means of reprocessing, wide scale implementation of these new technologies must be mirrored with the development of international regimes and institutions that will adapt to the dynamic components of nuclear systems.[575]

Establishing an International Fuel Center

As nuclear energy systems rise to meet the increasing energy demands of Asian states, assurance of nuclear fuel supply becomes imperative. While the cost varies between Asian states, generally the cost of nuclear power is higher than that produced by coal or hydropower.[576] These expenses must be justified in terms of achieving the prestige associated with the adoption of nuclear technology, as well as assurances of access to fuel materials. An international fuel center has the ability to resolve both of these issues. An IFC could meet the rising demand for fuel and oversee the full operations of nuclear energy systems to ensure they are only being used for peaceful energy production.

Partnerships amongst nuclear and non-nuclear states have a history of forming over common issues such as non-proliferation or the diffusion of nuclear technology. The U.S. proposal for a Global Nuclear Energy Partnership (GNEP) was an attempt to place limits on which states had access to forms of reprocessing technology. This proposal reversed many of the previous stances against the spread of reprocessing

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[573] George S. Stanford and Arjun Makhijani, "The Integral Fast Reactor Could Do It," *The Bulletin of the Atomic Scientists,* 57.3 (2001): 4.

[574] Miles Pomper, "IAEA, Leading Nations Push for Fuel Assurances," *Arms Control Today,* 36.6 (2006): 44.

[575] Charles Ebinger and Kevin Massy, "Security Implications of the Expansion of Nuclear Energy," *South Asian Survey,* 17.1 (2010): 82.

[576] Anonymous, "Fast Breeding in the East," *The Economist*, 334.7902 (1995): 69.

technology and instead stated that those that had already acquired it and Japan could continue to do so, as long as plutonium was not sequestered. The plan instructed nations who had not yet acquired this technology to ship spent fuel to nations that had. As the proposal was implemented, it became more flexible in order to appease and gain support from major reprocessing nations like France, Japan, and Russia. Currently, 21 nations have signed onto the GNEP Statement of Principles that embraces the use of reprocessing technology. By signing, they are not committed to impede the spread of this technology.[577]

Proposals for an international fuel center, by contrast, are lead largely by the International Atomic Energy Agency (IAEA), which is a global organization. The intent is to establish a controlled international fuel bank that is structured as follows:

> The voluntary IAEA mechanism would include three basic elements. The IAEA would facilitate new commercial arrangements if a country should find its supply interrupted for reasons other than failure to comply with non-proliferation obligations. Reserves of enriched uranium, held nationally or perhaps by the IAEA, would serve as a fuel reserve of "last resort." The agency would determine eligibility based on a country's compliance with IAEA safeguards, and acceptance of nuclear safety standards, as well as the renunciation of "sensitive fuel cycle activities," such as uranium enrichment or spent fuel reprocessing.[578]

A significant step toward realizing this goal was made in March 2010 with the creation of a fuel reserve in Angarsk, Russia. This International Uranium Enrichment Center was designed to supply low enriched uranium for peaceful power purposes to countries that meet commitments to the international community but are denied fuel for political

[577] Edwin Lyman and Frank N. Hippel, "Reprocessing Revisited: the International Dimensions of the Global Nuclear Energy Partnership," *Arms Control Today*. 38.3 (2008): 7.
[578] Miles A. Pomper, "IAEA, Leading Nations Push for Fuel Assurances," *Arms Control Today*, 36.6 (2006): 44.

reasons.[579] Debate on this form of institution centers on requirements for participants to forgo domestic enrichment and reprocessing activities. These stipulations run counter to declarations made in the NPT, which states that nations have the right to develop and produce nuclear energy. Costs of discontinuing or abandoning the prestige associated with the technology render these issues unable to be negotiated. This implies that the establishment of such a multi-national regime may result in exacerbating the division between nuclear 'haves' and 'have nots.'[580] The establishment of an effective IFC would critique any nations incentive for implementing nuclear energy systems because enrichment or mining activities would be required to either be eliminated or subject to heavy inspection. Such assurances of transparency are powerful tools by which to fight against the proliferation of weapons or diversion of fissile materials for such usage.

CONCLUSION

Open and closed fuel cycles each have their own merits and provide nuclear fuel systems with different advantages. A shift away from the current practice of open, one time through fuel cycles would be turbulent in today's economic and political climate. There does not yet exist an imperative to transition toward fuel reprocessing based on the cost of basic uranium or plutonium resource acquisition, as these materials are abundant in the environment and the processes of mining and enrichment are already well established. In addition, the activities of reprocessing as a means of rendering long-term storage facilities more valuable are still more expensive than the practice of direct storage of spent fuel. Many concerns arise over issues of proliferation with the installment of reprocessing facilities because access to pure fissile materials increases and the time

[579] Charles Ebinger and Kevin Massy, "Security Implications of the Expansion of Nuclear Energy," *South Asian Survey,* 17.1 (2010): 86.
[580] Ibid.

necessary to convert energy facilities into weapons facilities decreases. Because of the nature of these issues, the diffusion of reprocessing technology makes the U.S. and international regulatory agencies very anxious. An IFC would increase the transparency requirements for all nations requesting the implementation of nuclear energy systems and could prevent nations from giving into the temptation to divert materials for the creation of arsenals. Besides combating the desire for prestige and power associated with nuclear weapons, the center would assure more nations interested in a nuclear alternative of access to fuel materials. Currently, given the high cost and high risk associated with a closed-cycle, the use of reprocessing technology is not yet justifiable under the current atmosphere to legitimize a shift in policy support.

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Part IV

Dual-Use Technology and the Threat of Proliferation

Chapter Ten

THE STATUS AND FUTURE OF THE NON-PROLIFERATION TREATY

Mbasireh Saidybah

Abstract:
Global expansion of nuclear power is underway, bringing with it major concerns over proliferation. Since 1970, the Nuclear Non-Proliferation Treaty (NPT) has been a platform for the international community to work together on the basis of defined norms to promote peaceful nuclear use. After 40 years of success, the NPT is now in crisis. New "breakout" states like North Korea and Iran assault the treaty's authority from one side, while the refusal of the U.S. and Russia to disarm weakens the NPT from another angle. The treaty is also threatened by the rise in international terrorism, which the treaty was not designed to fight, and by the states of India, Pakistan, and Israel, which have nuclear weapons but refuse to join the NPT. This paper analyzes the various threats to the future viability of the NPT and finds that coordinated international efforts are needed to prevent the complete collapse of the treaty and the non-proliferation regime.

INTRODUCTION

The end of the Cold War marked the end of the bipolar balance of power struggle but not the end of nuclear threats. Although the fall of the Cold War order eased security relations between the two former superpowers, it also gave way to a variety of new military risks and today's world is more fragmented and less predictable than it was before the fall of the Soviet Union. Concern about the spread of nuclear weapons has undoubtedly increased in significance on the international agenda, and many of the factors that have made it so important have been underway for several decades. Knowledge of the destructive effects of nuclear energy dates back to the bombings of the Japanese cities of Hiroshima and Nagasaki. Equally important is the fact that in 1945 the U.S. was the only country that had the ability to manufacture nuclear weapons, whereas today a total of eight other states have the infrastructure to construct at least crude nuclear devices. The growing global demand for nuclear power, stimulated by concerns over energy security and climate change, puts the issue of weapons proliferation in the spotlight once again. Some 30 states presently have operating nuclear power plants, but the International Atomic Energy Agency (IAEA) notes that no less than 50 states have recently expressed interest in beginning nuclear programs. These facts, along with the nuclear ambitions of North Korea and Iran, have further highlighted the non-proliferation issue.

The Nuclear Non-Proliferation Treaty (NPT) is the world's primary means to stop the spread of nuclear weapons and has therefore become a central focus of attention as well. The treaty, which was formed as a platform for the international community to join forces and closely work together on the basis of defined norms, was crafted to create a balance between nuclear weapon states (NWS) and non-nuclear weapon states (NNWS). The commitment, referred to as the "balance obligation concept," commits NNWS not to acquire nuclear weapons and to submit to international safeguards and inspections of any nuclear facilities.[581] In exchange for this for this commitment by the NNWS, NWS have agreed to reduce their nuclear arsenals with the long-term goal of complete disarmament and a weapons free world. These commitments, as stipulated in Articles I, II, III and IV of the NPT, have been the cornerstone of the non-proliferation regime and the measure of its successes and challenges. There is currently a wide range of viewpoints concerning the effectiveness of the treaty.

The NPT faces several obstacles. A major problem has concerned the disarmament commitment of NWS. Policy here been highly impacted by both supporters of nuclear deterrence and critics of weapons of mass destruction (WMDs). Those in

[581] Thomas Graham Jr., *Nuclear Power and Nuclear Non-Proliferation*, Committee of Foreign Affairs, U.S House of Representatives, Sep. 24, 2010 (accessed Jan. 24, 2011).

favor of nuclear deterrence, who argue that the NWSs need to maintain a certain number of their weapons in order to deter rogue states and adversaries, have likely influenced the slow pace and lack of will for complete disarmament amongst NWS. Another notable challenge involves the original compliance structure, as states like North Korea and Iran have used Article IV, which allows the transfer of nuclear technology for peaceful purposes including enrichment and reprocessing, to develop clandestine weapons programs. A third critical problem rests with the three nuclear weapon states of India, Pakistan, and Israel, all of which are outside of the treaty and thus frustrate the goal of universality. Despite these problems and challenges, much success has-been achieved ensuring compliance with International Atomic Energy Agency (IAEA) safeguards in developing civilian nuclear technology and in signatory states controlling fissile materials.

These challenges have for the past 40 years slowed progress and have come to undermine the future long-term viability of the NPT.[582] It is in this regard that this paper will review the current status of the treaty, focusing on the successes, problems, and challenges that it now faces as it enters its fifth decade. The research will also discuss and present different views on the future of the NPT in relation to the identified successes and challenges. This paper will conclude by analyzing proposed amendments to the treaty and their potential for strengthening the non-proliferation regime and the future viability of the treaty.

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[582] Thomas Graham Jr., *Nuclear Power and Nuclear Non-Proliferation,* Committee of Foreign Affairs, U.S House of Representatives Sep. 24 2010, (accessed Jan. 24, 2011).

BACKGROUND AND EVOLUTION OF THE TREATY

History of the NPT

The Nuclear Non-Proliferation Treaty was negotiated in the 1960s. The treaty opened for signatories in 1968 and entered into force in 1970. According to the United Nations Office of Disarmament Affairs (UNODA), the NPT is an international treaty "whose objectives are to prevent the spread of nuclear weapons and weapons technology, promote cooperation in the peaceful uses of nuclear energy and to further the goal of achieving nuclear disarmament and general and complete disarmament."[583] The NPT is the only binding multilateral commitment to both disarmament and weapons proliferations and, in view of what could have come to pass over the last 40 years, it is understood to be an example of successful global cooperation on a critical issue. As of 2011, there are no fewer than 190 signatories, including the five recognized nuclear-weapon states of France, the United Kingdom, Russia, China and the United States. The specific goals written into the treaty are to prevent the spread of nuclear weapons, safeguard nuclear materials and facilities, make information on peaceful nuclear energy accessible to non-nuclear weapon states, and to equally promote disarmament among nuclear weapon states.[584]

Text of the Treaty

The NPT is the key to the global non-proliferation regime and is a legally binding framework developed on three principles; the treaty stipulates that states without nuclear weapons prior to 1967 will not acquire any; the five NWS as of 1967 will not assist non-

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[583] *Report of the United Nations Office of Disarmament Affairs*.. http://unhq-appspub-01.un.org/UNODA/TreatyStatus.nsf/ (accessed Jan. 25, 2011).
[584] Kathleen C. Bailey, *Strengthening Nuclear Non Proliferation*, (Boulder: West Press, 1993). http://www.reachingcriticalwill.org/resources/bib/books.html (accessed Jan. 25, 2011).

nuclear states in acquiring nuclear weapons or related technology and will eventually eliminate their own stockpiles; and, lastly, NNWS will have guaranteed access to civilian nuclear technology.[585] Signatory states, referred to as 'parties to the treaty,' have agreed to 11 legally binding articles.

According to Articles I, II, and III, of the treaty, the five NWS agree to forgo any transfer of nuclear weapons, other nuclear explosive devices, or related technology to other countries, as well as not to help, encourage or push them toward production of such weaponry or facilities. These articles also commit NNWS to not seek, receive, create or acquire nuclear weapons or other nuclear explosive devices from other states and to accept safeguards, set forth in agreements to be negotiated with the IAEA, covering the source and control of all fissionable materials in the peaceful pursuit of nuclear energy. Article V guarantees, under appropriate international observation and procedures, the potential benefits of peaceful nuclear explosions available to NNWS on a non-discriminatory basis.

Article IV, a focus of much concern in recent years, states that "no provision of the treaty shall be interpreted as limiting the inalienable rights of all the parties to the treaty to research, develop, produce and use nuclear energy for peaceful purposes without discrimination."[586] Paragraph II of Article IV further commits the parties to cooperate with one another in the "fullest possible exchange of equipments, materials and scientific and technological information for the peaceful uses of nuclear energy." NNWS have the

[585] Council on Foreign Relations, *Global Nuclear Nonproliferation Regime Report,* September, 2010. http://www.cfr.org/world/global-nuclear-nonproliferation-regime/p18984 (accessed Jan 20, 2011).
[586] *Preamble of the Treaty, Article VIII,* Women's International League for Peace and Freedom. Reaching a Critical Mass of Political Will for Nuclear Disarmament. http://www.reachingcriticalwill.org/legal/npt/npttext.html (accessed Feb 12, 2001).

right under the NPT to acquire enrichment and reprocessing technology and know-how. North Korea and Iran have proven this to be a dangerous pathway to the creation of nuclear weapons; enrichment and reprocessing in order words, are dual-use technologies and have been used as such. Article IV clearly speaks to the rights of states to access the benefits of nuclear technology, but this is conditioned on states remaining fully open to monitoring and supervision by the IAEA. This stipulation proved ineffective in the cases of North Korea and Iran.

Article VI, on the other hand, concerns disarmament. It requires NWS to negotiate in good faith toward "effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament." It further requires negotiations toward a treaty "on general and complete disarmament." In combination with Article IV then, the NWS are essentially required to stand ready both to provide enrichment and reprocessing capabilities to NNW if so asked, while simultaneously seeking to eliminate their own arsenals.

The remaining articles of the treaty (VII-XI) are concerned primarily with procedural matters. Articles VIII states that any signatory may propose amendments to the treaty and proposes that a five yearly review conference be held with a view to assure that the preamble and provisions are being met. Articles X and XI state that each party to the treaty shall in exercising its national sovereignty have the right to withdraw if it deems that extraordinary events related to the subject matter of the treaty jeopardize its national interest. The NPT therefore contains provisions that have proved to be problematic over time. Yet it also offers the means, through continued negotiation and amendment, to address the difficulties that have arisen. Whether these means will prove sufficient to keeping the treaty vital and effective is not yet clear. A review of the NPT's status today may help shed light on this question.

STATUS OF THE NUCLEAR NON-PROLIFERATION TREATY

More than 40 years into the nuclear age, the world still grapples with the challenges of developing peaceful nuclear energy without the dangerous shadow of weapons proliferation. The prevention of states from using nuclear materials, technology, and knowledge to build weapons has been the preoccupation of the NPT since its inception. Regarded as the most widely adhered to weapons control treaty in history, the NPT now faces new challenges. These challenges are wide-ranging and relate to the changing global order of security and conflict. They do not diminish the past successes of the treaty, however.

Successes of the Nuclear Non-Proliferation Treaty

Although many argue that it is currently in crisis, the Nuclear Non-Proliferation Treaty has been very successful in a number of respects. Progress has been made in developing an international standard against the acquisition and spread of nuclear weapons through the establishment of an inspection regime led by the IAEA, which has repeatedly helped prevent the diversion of nuclear materials to weapons production. The treaty also provided a bilateral framework that allowed former Soviet countries like Belarus, Ukraine and Kazakhstan, to give up their nuclear stockpiles inherited from the Soviet Union and eventually join the non-nuclear weapon states. Furthermore, the treaty successfully encouraged countries like South Africa, Libya, Brazil, Sweden, Australia, and Argentina, which had weapons programs prior to joining the NPT, to abandon their nuclear weapons programs. These countries have since become signatories to both the treaty and their regional non-proliferation pacts. Since the signing of the NPT, nuclear stockpiles have decreased globally by 22,400, inarguably, one of the major successes of the treaty.[587] The non-proliferation norms, fostered by the NPT, have also led to the creation of many supplementary organizations, which work to end nuclear proliferation. One such organization is the Proliferation Security Initiative (PSI), which was established in 2003 by a coalition of likeminded states to obstruct the illicit trade in nuclear and other weapons of mass destruction. The PSI has over 90 member states and has been successful in developing best practices and as an information-sharing forum to thwart terrorist efforts.[588]

The control of fissile nuclear materials is another notable success of the treaty. There are 135 nuclear facilities worldwide using highly enriched uranium (HEU) as fuel, which house enough nuclear material to create 400 nuclear weapons.[589] According to Council on Foreign Relation's Global Nuclear Non-Proliferation Regime (GNNPR) report, as of 2008, 75 percent of weapons-usable nuclear material sites in the former Soviet Union had been secured.[590] Securing fissile material is important to the non-proliferation agenda, as it helps reduce the potential risk of fissile materials becoming available to terrorists or rogue states. The proposed Fissile Material Cut-off Treaty (FMCT), which bans the production of HEU and plutonium except for peaceful purposes, also has the potential to strength nuclear non-proliferation norms by adding a binding

587 *The World Nuclear Stockpile Report*, Ploughshares Fund. http://www.ploughshares.org/news-analysis/world-nuclear-stockpile-report (accessed Feb. 17, 2011).
588 Lawrence Scheinman and William Potter, *The Nuclear Conundrum, Reconciling Nuclear Energy and Non-Proliferation*. http://uwashington.worldcat.org.offcampus.lib.washington.edu/wcpa/oclc/374298013 (accessed Feb 14, 2011).
589 Ibid.
590 Council on Foreign Relations, *Global Nuclear Non-proliferation Regime Report.* http://www.cfr.org/publication/18984/global_nuclear_nonproliferation_regime.html (accessed Jan 20, 2011).

international commitment to existing constraints on nuclear weapons-usable fissile materials.[591]

1995 and 2010 Review Conferences

The review conferences of 1995 and 2010 greatly strengthened the treaty and were regarded as major successes by non-proliferation advocates. At the 1995 review conference signatory states unanimously approved to extend the treaty indefinitely, which was also a key U.S goal.[592] The extension of the treaty lent further legitimacy to the NPT and confirmed the legally binding power of the IAEA. Another success of the 1995 review was securing the support of NNWS in outlining specific disarmament steps, calling on those states who are not yet members of the treaty to accede to requests to join in order to ensure the universality of the treaty and supporting the creation of a nuclear-weapons-free zone (NWFZ) in the Middle East. These issues are all critical to nuclear disarmament, non-proliferation and the future viability of the NPT.

The 2010 review conference was declared a success by most analysts and scholars in the nuclear discourse, largely due to the unanimous reaffirmation and recommitment to the articles of the treaty.[593] The conference also unanimously adopted agreements on nuclear disarmament and the establishment of a NWFZ in the Middle East.[594] These are both important for the NPT, because the NWSs' failure to disarm has been and continues

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[591] Emily Ewell Daughtry and Fred L. Wehling, *Cooperative Efforts to Secure Fissile Materials in Newly Independent States The Non-proliferation Review,* Special Report, (2000). http://cns.miis.edu/npr/pdfs/ewell71.pdf (accessed Feb. 16, 2011).
[592] Paul K. Kerr, Mary Beth Nikitin, Amy F. Woolf, and Jonathan Medalia, *2010 Non-Proliferation Treaty (NPT) Review Conference: Key Issues and Implications,* Congressional Research Service, (2010). http://www.fas.org/sgp/crs/nuke/R41216.pd (accessed Feb. 13, 2011).
[593] *2010 Outcome Document and Action Plan*, Women's International League for Peace and Freedom. Reaching a Critical Mass of Political Will for Nuclear disarmament. http://www.reachingcriticalwill.org/legal/npt/npttext.html (accessed Feb. 12, 2001).
[594] William Potter, Patricia. Lewis, Gaukhar. Mukhatzhanova, Miles. Pomper. *The 2010 NPT Review Conference: Deconstructing Consensus.* http://cns.miis.edu/stories/pdfs/100617_npt_2010_summary.pdf (accessed Feb. 17, 2011).

to be a contentious issue between the NWS and NNWS. The recommitment of the NWS through the newly renegotiated Strategic Arms Reduction Treaty (START II) and President Obama's reassurance of a nuclear free world both in Prague and at the conference, made many disarmament advocates optimistic for the future. Equally, the establishment of a NWFZ in the Middle East will hopefully prevent an arms race in the region and ease the geopolitical tension between the haves and the have-nots. It will also lower the threat of Israel and Iran among other Arab nation states. Although the conference was noted as a success, the treaty continues to be faced by serious challenges today.

CHALLENGES TO THE NUCLEAR NON-PROLIFERATION TREATY

The NPT is hailed by many as the most successful treaty in the history of international relations. However, the treaty is experiencing a persistent and serious erosion of confidence in its effectiveness and in the willingness of states to fulfill their treaty obligations.[595] Although there are measured successes, serious challenges do exist in the implementation of treaty articles and in cooperation between parties to the treaty. There are also broad challenges concerning states withdrawing from the treaty, difficulties of enforcement, threats of nuclear terrorism, loopholes in the articles of the treaty which make ensuring security and safeguards more difficult, constraints on and opposition to arms reduction, lack of universality, and the implications of the United States-India nuclear deal. These issues are crucial for the legitimacy and future viability of the treaty.

[595] Bill Robinson, *Bridging the Divide: Addressing Key Challenges to the NPT*, The Canadian Pugwash Group, Physicians for Global Survival, (2005). http://www.ncrb.unac.org/bridgingDivideNPT.pd (accessed Feb. 17, 2011).

Withdrawal of States from the Nuclear Non-Proliferation Treaty

The withdrawal of North Korea from the NPT in 2003 is a major challenge to the strength of the treaty, though it was allowed by Article X, which some now consider to be a dangerous loophole in the treaty. Article X states that each party, in exercising its national sovereignty, has the right to withdraw from the treaty given three months advance notice, if it deems that the supreme interest of its country is jeopardized.[596] North Korea took advantage of this article and withdrew on the grounds that the United States had not fulfilled its obligations under the 1994 agreed framework, claiming that the U.S. has not supplied light water reactors for energy production and had therefore jeopardized its national interest. The 1994 agreed framework was meant to supply light water reactors to replace graphite-moderated nuclear power plants and to supply oil while the reactors were shut down.[597] Furthermore, the North Korean leadership claimed that their sovereignty and the likelihood of a pre-emptive strike were eminent after having been listed as part of the "Axis of Evil" by the U.S. government. North Korea used the agreed framework, the "Axis of Evil" pronouncement, and the right to withdraw, as a pretext to resume its clandestine nuclear program. North Korea tested a nuclear device in 2006 and is currently suspected of violating all articles of the treaty.[598]

North Korea's withdrawal without sanctions could lead other states to consider using their sovereign right to withdraw and engage in dangerous nuclear weapons activities. Other Asian states, such as South Korea and Japan, could also be pressured to

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[596] *Preamble of the Treaty, Article X,* Women's International League for Peace and Freedom. Reaching a Critical Mass of Political Will for Nuclear Disarmament. http://www.reachingcriticalwill.org/legal/npt/npttext.html (accessed Feb. 12, 2011).
[597] *The U.S.-North Korean Agreed Framework at a Glance.* http://www.armscontrol.org/factsheets/agreedframework (accessed Feb. 18,2011).
[598] Ibid.

acquire nuclear weapons in response. The challenge of North Korea's withdrawal from the treaty poses a danger to proliferation because the IAEA no longer has the ability to verify its non-nuclear status or the security of its nuclear facilities. The lack of repercussions for North Korea's non-compliance and withdrawal from the NPT could serve as an incentive for other nations to do the same, leading to the erosion of future compliance. Given all these geopolitical possibilities, North Korea's nuclear weapons acquisition poses a major threat to the NPT and to global peace.

Problems With Enforcement and Compliance: The Case of Iran

Under Article III of the treaty, the NNWS agree not to receive, create, or acquire nuclear weapons or other nuclear explosive devices from other states, and to accept safeguards set forth in agreements with the IAEA, which include the source and control of all fissionable materials in states' peaceful nuclear activities.[599] Iran was among the first signatories of the safeguard agreements but it was later found to be engaged in clandestine nuclear activities that contravened the articles of the treaty. Since 2002, Iran has repeatedly been found in breach of its NPT Safeguards Agreement and Subsidiary Arrangements, for conducting nuclear activities, which it had not declared to the IAEA, and for failing to declare the construction of its nuclear facilities. Despite negotiations and repeated talks, Iran has failed to comply with the enforcement measures ordered by the UN Security Council.

Iran, like North Korea represents a major challenge, both to the non-proliferation regime and to regional and international politics. Although Iran has not withdrawn from the NPT, it has continually ignored the demands of the IAEA. Iran's lack of cooperation

[599] *Preamble of the Treaty*, Women's International League for Peace and Freedom. Reaching a Critical Mass of Political Will for Nuclear disarmament. http://www.reachingcriticalwill.org/legal/npt/npttext.html (accessed Feb. 12, 2011).

raises fears its relation with the international community could further deteriorate and lead to its withdrawal from the NPT. These fears have been exacerbated by Iran's recent declaration to the IAEA that it was building a new enrichment facility. President Obama said in response:

> The existence of this facility underscores Iran's continuing unwillingness to meet its obligations under UN Security Council resolutions and IAEA requirements. We expect the IAEA to immediately investigate this disturbing information, and to report to the IAEA Board of Governors. Now, Iran's decision to build yet another nuclear facility without notifying the IAEA represents a direct challenge to the basic compact at the center of the non-proliferation regime.[600]

Iran's non-compliance and attempts to develop nuclear weapons have escalated geopolitical tensions in the Arab world. Iran's nuclear ambitions coupled with Israel's nuclear abilities could trigger an arms race in the region and encourage Syria, Saudi Arabia, or other Arab nations to obtain nuclear weapons and kill the prospect of a NWFZ in the Middle East. The threat of proliferation in the hand terrorists and other non-state actors is an increasing danger in a region known as a hot spot for terrorism.

The Threats of Terrorists and Non-State Actors

The increasing rise of global terrorism and regional instability, coupled with rogue states, has heightened the worry over non-state actors. The greatest danger to proliferation and global security is the possibility of nuclear materials, technology, and know-how falling into the hands of terrorist groups and other non-state actors. Some experts hold the view that, given current security measures, it is only a matter of time before terrorists lay their hands on crude versions of these weapons. An IAEA database on illicit trafficking has recorded approximately 630 confirmed incidents of trafficking of

[600] Statement by Obama, Sarkozy, Brown *on Iran Nuclear Facility*. THE WHITE HOUSE, Office of the Press Secretary September 25, 2009. http://www.whitehouse.gov/video/Obama-Sarkozy-and-Brown-on-Iranian-Nuclear-Facility (accessed Feb 16, 2011).

nuclear and other radioactive materials since 1993.[601] This threat is enhanced by the availability of small quantities of both fissile materials and radioactive materials on the black market, traded by the likes of A.Q. Khan, a nuclear scientist and the pioneer of Pakistan's nuclear program. Khan ran a vast, clandestine, and hugely profitable business for over a decade, which sold nuclear technology and equipment to rogue states like North Korea, Iran and Libya.[602] A.Q. Khan and his network of illicit traders underscore the problem of clandestine sources of supply of nuclear materials and technology. The number of incidents as reported by the IAEA shows that there are fundamental control and security lapses, which non-state actors can easily exploit.

Furthermore the threat of terrorism is a unique challenge to the non-proliferation regime, because the negotiated and adopted treaties at the time were primarily aimed at the activities of states and are not specifically designed to address the problem of the use of nuclear weapons by non-state actors. Though there is effective routine verification by the IAEA under the treaties, these are targeted toward government facilities. However, in 2004 the UN Security Council passed Resolution 1540, which requires all states to criminalize proliferation to non-state actors and to establish, review, and maintain appropriate and effective export controls systems.[603]

Security and Safeguards

The security and safeguard clause of the treaty, which is stated in Article III, requires "all non-nuclear weapons states to ensure that fissile nuclear materials and

[601] Mohamed El Baradei, *Nuclear Proliferation and the Potential Threat of Nuclear Terrorism,* NuclearFiles.org Project of the Nuclear Age Peace Foundation, (2004). http://www.nuclearfiles.org/
[602] David. Albright and Corey Hinderstein, *Unraveling the A.Q. Khan and Future Proliferation Networks*, The Center for Strategic and International Studies and the Massachusetts Institute of Technology, The Washington Quarterly, (2005). http://www.twq.com/05spring/docs/05spring_albright.pdf, (accessed Jan. 22, 2011).
[603] Ibid.

technology from civilian activities are not diverted to weapons programs and shall conclude agreements with the IAEA to meet the requirements of the article individually or together with other states."[604] These agreements are meant to ensure states do not violate their right under Article X to use peaceful nuclear technologies and to prevent states from providing fissile materials to other states or non-state actors who do not use nuclear technology for peaceful purposes. This is particularly difficult as the technologies used for nuclear power can be quickly converted to use for weapons purposes without detection. These safeguards, which are based on assessment of the correctness and completeness of states' declared nuclear material and nuclear activities, are seriously hindered by non-compliance.

There are numerous reported cases of states not implementing their safeguard agreements.[605] In 2008, Syria refused to grant access to the IAEA to inspect its three nuclear sites and the relevant documents mandated by the protocols.[606] Many NNWS also refused to sign the Additional Protocol of the IAEA. Emergence of new sources of supply of nuclear technologies and their components for indigenous development of weapons-relevant equipment and facilities, like in the case of Iran, pose major challenges to the IAEA's regulatory infrastructure.

The mandate and scope of the IAEA are broad and the agency is challenged with critical gaps. The IAEA does not have sufficient resources for effective coverage in implementing the existing safeguard systems, particularly since state contributions to its

[604] *Preamble of the Treaty*, Women's International League for Peace and Freedom. Reaching a Critical Mass of Political Will for Nuclear disarmament. http://www.reachingcriticalwill.org/legal/npt/npttext.html (accessed Feb. 12, 2001).
[605] IAEA Safeguards Overview: Comprehensive *Safeguards Agreements and Additional Protocols.* http://www.iaea.org/Publications/Factsheets/English/sg_overview.html (accessed Jan. 24, 2011).
[606] Pierre Goldschmidt. *Concrete Steps to Improve the Nonproliferation Regime,* Carnegie PAPERS, Non-proliferation Program Number 100, (2009). http://carnegieendowment.org/files/improve_nonpro_regime.pdf (accessed Feb. 18, 2011).

programs are voluntary. Under funding incapacitates the IAEA to inspect, verify, and monitor the activities of states, especially those who are likely to engage in weapons development programs. The IAEA's resources will be stretched further as more nations obtain nuclear power and build new nuclear plants. Furthermore, the IAEA has no power to investigate non-signatory states, which arguably excludes half of the world's nuclear states from the provisions of the treaty. With such free-range, the possibility of fissile materials falling into the wrong hands, such as those of A.Q. Khan and his associates, are greatly increased.

The securities and safeguards of the NPT are further weakened by states' refusal to ratify subsequent non-proliferation treaties. The Comprehensive Test Ban Treaty (CTBT) has been signed by 182 countries and ratified by 153 countries, but has not been ratified by key nuclear weapon states.[607] Failure to ratify the Fissile Material Cut-off Treaty (FMCT) has also slowed progress in banning the production of weapons grade material.[608] These challenges have greatly hindered the implementation of the NPT and will create further ramifications for cooperation between NWS and NNWS.

Lack of Commitment to Nuclear Disarmament

The disarmament debate has become the single most divisive and challenging problem threatening the NPT. Nuclear disarmament critics, who support nuclear deterrence policies, believe that nuclear arsenals remain essential for international peace and security and to deter rogue states and adversaries. Some progress has been made in reducing stockpiles, but thousands of weapons remain. There are currently an estimated

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[607] *Status of Signature and Ratification of Comprehensive Test Ban Treaty*. http://www.ctbto.org/the-treaty/status-of-signature-and-ratification (accessed Feb. 23, 2011).
[608] *Ending Further Production*, Fissile Material Cut off Treaty National Threat Initiative Working for a Safer World. http://www.nti.org/b_aboutnti/b1_board.html (accessed Jan. 31, 2011).

22,400 nuclear weapons worldwide, which while still very many, is much fewer than at the height of the Cold War.[609]

The difficulty in disarmament is that nuclear powers have different interpretations of their treaty obligations and performance of those obligations. They are not being pressured to change their nuclear policies or incentivized to disarm. Many NWSs have failed in their implementation of the 13 practical steps to disarmament as defined in the final document of the 2000 NPT review conference, which NNWSs have used to call into question their commitment to complete disarmament. These steps include: signing the CTBT, stopping testing, ratifying the FMCT, negotiating nuclear disarmament, establishing principles of irreversibility, abolishing nuclear weapons, upholding and implementing treaties, working step by step to disarmament, putting excess fissile material under IAEA control, and obtaining general and complete disarmament.[610]

The issue of nuclear disarmament by nuclear weapon states remains a dividing dichotomy in the NPT and has left some feeling that disarmament has fallen off the agenda. Some see the actions of the NWSs as deliberate and meant to undermine the legitimacy of the NPT. Many nuclear analysts have argued that the perceived failure to make progress toward disarmament has been a major factor in the unwillingness of many UN member states to support sanctions against Iran for NPT violations. However, not all agree with the negative view of the NWSs. In his assessment of the NPT at "Age Forty," Kepron notes that the past two decades have witnessed impressive treaty gains on disarmament through "declining nuclear weapons utility: actual battlefield use, threats of

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[609] *The World Nuclear Stockpile Report*, Ploughshares Fund. http://www.ploughshares.org/news-analysis/world-nuclear-stockpile-report (accessed Feb.14, 2011).
[610] *The Promises of the 2000 NPT Review Conference,* Women's International League for Peace and Freedom. Reaching a Critical Mass of Political Will for Nuclear Disarmament. http://www.reachingcriticalwill.org/legal/npt/npttext.html (accessed Feb. 10, 2011).

battle use, overall stockpile size, warheads deployed, nuclear-weapons tests, and fissile material production for weapons."[611] He relates these gains to the diminishing value placed on nuclear weapons since the Cold War ended. However, the majority of analysts argue that many nuclear weapon states do not take the commitment to disarm seriously and that this recognition seems to contribute to the hesitation of some states to strengthen the enforcement of the treaty. The contradictory objective of the NWS in trying to stop nuclear proliferation, while continuing to hold on to their nuclear arsenal, weakens the future of the NPT and may lead to more proliferation.

U.S.-India Deal

The U.S.-India civil nuclear cooperation agreement, which lifted a three-decade U.S. moratorium on nuclear trade with India, was signed in 2008 to provide assistance to India's civilian nuclear energy industry. The deal, seen by the United States as an effort to bring India into the fold of accepting non-proliferation efforts, was viewed by many critics as counterproductive to the efforts of the NPT.[612] The exemption of India from the non-proliferation rules clears the way to provide assistance to a country that has refused to sign an international agreement designed to prevent the spread of nuclear weapons. Furthermore, critics of the deal argue that the arrangement will effectively give India access to sensitive nuclear technology, accorded only to nuclear weapon states in full compliance with global non-proliferation standards, and exempt it from the comprehensive international nuclear safeguards of its military nuclear facilities.[613]

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[611] Michael Kepron. *The NPT at Age Forty*, Stimson Center, (2010). http://www.stimson.org/essays/the-npt-at-age-forty/ (accessed Feb. 14, 2011).
[612] George. Perkovich. *Global Implication of the U.S.-India deal*, Daedalus, Vol. 139, No. 1 (2010). http://carnegieendowment.org/publications/index.cfm?fa=view&id=24674 (accessed Jan. 22, 2011).
[613] Daryl.G Kimball, *A Non- Proliferation Reality Check*, Economic and Political Weekly, Vol. 40, No. 35, (2005) http://www.jstor.org/stable/4417072 (accessed Feb. 2, 2011).

India's ability to decide which of its facilities are to be classified as civilian, and the inaccessibility of its military facilities to international inspections, increases the risk of production of fissile material for nuclear weapons. This further creates a huge potential for India to provide nuclear assistance to other countries given the loose export and safeguard controls enjoyed as a result of this deal.

Another criticism of the deal is that the exemption status accorded to India as a "responsible state with advanced nuclear technology" clearly sends a message to other states that the U.S gets to decide "who is good and who is part of the axis of evil."[614] David Kimball, a critic of the deal, argues that the U.S. relaxes the rules when it is convenient for its business dealings and for its allies.[615] Kimball argues that bending the rules will make other states "regard the NPT as an anachronism," and this may tempt them "to reconsider their self-restraint by the precedent that India has successfully established with American blessing."[616]

While there are thoughtful criticisms of the deal, proponents argue that the deal stands to strengthen proliferation efforts in a variety of ways. The deal encourages India to accept safeguards on its facilities to which the IAEA were not previously allowed access. It has made India abide by the strict export controls on nuclear technology set by the Nuclear Suppliers Group (NSG). The deal also revealed that India had set strict controls and credible safeguard standards for its nuclear programs during the past 30 years as a non-NPT member.[617]

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[614] Daryl.G Kimball, *A Non- Proliferation Reality Check*, Economic and Political Weekly, Vol. 40, No. 35, (2005) http://www.jstor.org/stable/4417072 (accessed Feb. 2, 2011).
[615] Ibid.
[616] Ibid.
[617] Bajoria Jayshree, *The U.S.-India Nuclear Deal,* Council on Foreign Relations (2010) http://www.cfr.org/publication/9663/usindia_nuclear_deal.html (accessed Feb. 15, 2011).

Given both sides of the argument, it is apparent that the deal falls short of addressing the bigger problem of India's non-NPT status and its impact on regional politics in South Asia. The deal has clearly created a precedent for other states to ask for similar favors. This is evidenced by Pakistan's swift reaction to the deal. According to a leading Pakistani newspaper, *The Dawn*, what is "bothering" Pakistan about the deal is that although India, like Pakistan and Israel, has refused to join the NPT, the deal amounts to de facto acceptance of India as a legitimate nuclear weapon state. Pakistan's Foreign Minister Khurshid Kasuri declared the administration's refusal to offer Pakistan similar terms "discriminatory" and "unacceptable." He indicated that Pakistan wants equal treatment and will go elsewhere for nuclear support.[618]

Pakistan approached China for a similar deal to purchase nuclear reactors, since the U.S was not willing to make a deal. The deal has greatly altered the balance of power within the region. A recent report by *The New York Times* reveals Pakistan's reaction to the deal. According to the report, "Pakistan has steadily expanded its nuclear arsenal since President Obama came into office, and it is building the capability to surge ahead in the production of nuclear-weapons material, putting it on a path to overtake Britain as the world's fifth largest nuclear weapons power."[619] This nuclear buildup is a chilling testimony to the rivalry that exists between India and Pakistan. The deal may also push China to strengthen its nuclear arsenal, sparking a potential nuclear arms race in the region, which may only be further exacerbated by North Korea's nuclear program.

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[618] Shehzad Nadeem, *The Regional Implication of the U.S.-India Nuclear Agreement*, Foreign Policy In Focus Asia & Pacific Region, (2006), http://www.fpif.org/articles/the_regional_implications_of_the_us-india_nuclear_agreement (accessed Feb. 11, 2011).

[619] David E. Sanger and Eric Schmitt, "Pakistan Nuclear Arm Pose Challenge to U.S. Policy," *The New York Times*, (2011), http://www.nytimes.com/2011/02/01/world/asia/01policy.html (accessed Jan. 31, 2011).

Undeniably, the U.S-India deal has had huge implications for the treaty and poses a major challenge to cooperation between NPT signatories.

Lack of Universality

Universality, defined as the inclusion and equal treatment of all states to the standards of the NPT, is an important factor in the consolidation of the normative strength of the treaty and in ensuring cooperation between NWS and NNWS.[620] The lack of uniform standards for all states remains a contentious issue at the heart of the debate. India, which has its own nuclear program and is a beneficiary of a deal with U.S, has even noted the discriminatory nature of the treaty. It has accused the five permanent members of the UN Security Council of creating imparity between states by deciding who can and who cannot possess nuclear weapons. The refusal of India, Pakistan, and Israel to join the NPT, without any sanctions or force, undermines the treaty's universality and sets precedence for other states to follow. Equally detrimental to the treaty's universality is the U.S.-India, which, as detailed above, rewarded India a civilian technology deal as a non-NPT member.

The lack of universality and the double standard to which many states are held weakens the support for the treaty by non-weapon states. Iran evoked these sentiments at the 2010 review conference. The Iranian response asserted, "the NWS states have to live up to their commitment for the NNWS to follow, Iran is willing to cooperate with the International world, but it has to see that we all play by the same rules."[621] Properly

[620] Marvin Miller and Lawrence Scheinman, "Israel, India and Pakistan: Engaging the Non-Proliferation States in the Non-Proliferation Regime," *Arms Control Today,* (2005), http://www.armscontrol.org/print/1431 (accessed Feb. 2, 2011).
[621] *Working paper, submitted by the Islamic Republic of Iran*, 2010 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, (2010), http://www.reachingcriticalwill.org/legal/npt/revcon2010/MCIII-Report.pdf (accessed Feb. 17, 2011).

enforced universality could further raise the cost of noncompliance by increasing the prospects of collective response to non-adherence and enforcement of the treaty and the regime's norms, rules, and principles.[622] To achieve the goal of universality, states must be convinced that the rules of the treaty apply equally to all parties. This would enhance the legitimacy to the NPT and could lead to other states joining the treaty.

FUTURE OF THE NUCLEAR NON-PROLIFERATION TREATY

The debate over the NPT has increased in intensity and there is growing concern over the future of the treaty. The stated problems and challenges have led many to conclude that the treaty is in a crisis state and on the verge of collapse. The risk of erosion of the treaty hinges on identified challenges that the regime is currently facing. North Korea's withdrawal, non-compliance of Iran, and the slow pace of disarmament by the nuclear weapon states, stand crucial to its future. The commitment given to the Strategic Arms Reduction Treaty (START II) will likely serve as an indicator of NWSs' willingness to pursue true disarmament. As well, Pakistan, India, and Israel continue to pose a challenge both to the NPT and to the international community. The future of the NPT therefore depends on how states deal with these challenges and these critical nations.

Current Proposals for Strengthening the Nuclear Non-Proliferation Treaty

Given the current challenges and severe strains testing the NPT, there is growing need for the international community to come up with consensual and practical amendments to fix the treaty and instill a belief of its legitimacy in the international

[622] *Working paper, submitted by the Islamic Republic of Iran*, 2010 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, (2010), http://www.reachingcriticalwill.org/legal/npt/revcon2010/MCIII-Report.pdf (accessed Feb. 17, 2011).

community. Several scholars, and recently the 2010 Review Conference, have come up with amendments and recommendations for strengthening the NPT.

Goldshmidt, the former head of the IAEA and prominent nuclear analyst, has proposed amendments to increase the future effectiveness of the treaty. To address problems of enforcement and compliance, particularly with Iran, he recommends that the Board of Governors "adopt a resolution declaring that Iran's multiple and continuous breaches of Article 48 of its safeguards agreement and of Code 3.1 of its Subsidiary Arrangements General Part constitute a case of noncompliance under Article XII.C of the IAEA Statute."[623] The purpose of such a resolution, Goldschmidt asserts, is not to increase penalties on Iran but to avoid establishing the wrong precedent for other states. Furthermore, he recommends that the IAEA take concrete steps to reassert its verification and that the UN Security Council improves its enforcement mechanisms to assist the agency in dealing with future proliferation issues. Goldschmidt also recommends that the IAEA Additional Protocol become mandatory. The Additional Protocol would add to the existing Safeguard Agreed Framework of the treaty by asking states to allow IAEA inspectors short notice or no-notice inspections, environmental sampling of nuclear sites to ensure compliance, and to provide the agency with early design information on new and modified facilities.[624] These measures could ensure increase universality, tighten export controls, and eventually address the issues of noncompliance.[625]

[623] Pierre Goldschmidt. *Concrete Steps to Improve the Nonproliferation Regime,* Carnegie PAPERS, Non-Proliferation Program, No. 100, (2009). http://carnegieendowment.org/files/improve_nonpro_regime.pdf (accessed Feb 18, 2011).
[624] Theodore Hirsch, "The IAEA Additional Protocol, What Is It and Why It Matters Report," *The Nonproliferation Review*, (2004). http://cns.miis.edu/npr/pdfs/113hirsch.pdf (accessed Feb. 24, 2011).
[625] Pierre Goldschmidt. *Concrete Steps to Improve the Nonproliferation Regime,* Carnegie PAPERS, Non-Proliferation Program, No. 100, (2009). http://carnegieendowment.org/files/improve_nonpro_regime.pdf (accessed Feb. 18, 2011).

To address the problem of state's withdrawal from the treaty, illustrated by North Korea, Goldschmidt recommends that the UN Security Council adopt a generic resolution under Chapter VII of the UN Charter, stating that if a "state withdraws from the NPT after being found by the IAEA to be in noncompliance with its safeguards undertakings, then such withdrawal constitutes a threat to international peace and security under Article 39 of the UN Charter."[626] Such a resolution would strip the sanctioned country of all bilateral and multilateral assistance and force it to surrender all material given to it for its nuclear activities. This measure is hoped to dissuade states from withdrawing to pursue clandestine nuclear activities.

Furthermore, recommendations from the 2010 Review Conference Preparatory Committee called on nuclear weapon states to take advantage of the success of the conference to reaffirm their commitment to nuclear disarmament. Given President Obama's April 2009 speech in Prague on U.S leadership in a nuclear weapons-free world, there is growing optimism over the newly negotiated START II treaty, which expresses urgency on the importance of a moratorium on nuclear testing. The committee recommended that the nuclear weapons states consider the adoption of an action plan setting practical achievable steps to disarmament. Specifically, it recommended that the U.S. congress and the Russian parliament should ratify the CTBT and pending this achievement, maintain a moratorium on nuclear testing. The committee also recommended that the U.S. and Russia commence negotiations at the Conference on

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[626] Pierre Goldschmidt. *Concrete Steps to Improve the Nonproliferation Regime,* Carnegie PAPERS, Non-Proliferation Program, No. 100, (2009). http://carnegieendowment.org/files/improve_nonpro_regime.pdf (accessed Feb. 18, 2011).

Disarmament (COD) on a verifiable fissile material treaty.[627] It further recommended that nuclear weapons states should expand transparency in implementing disarmament commitments by ensuring irreversibility of disarmament activities; reducing the operational status of nuclear forces; diminishing the role of nuclear weapons in security policies; and placing fissile materials from dismantled nuclear weapons under IAEA monitoring and verification. The committee also recommended that the nuclear weapons states should also commit to support the CTBT financially to enable it to establish an effective international monitoring system.

Other recommendations by the committee concerned the universality of the treaty. The universality of the treaty remains elusive, given the three non-NPT states and North Korea, but it is the cornerstone of the global disarmament and non-proliferation regime. Its full implementation is vital to international peace and security. The conference called upon signatory states to reaffirm their commitment to achieving universal membership and called upon all states that are not parties to adhere to the treaty promptly without preconditions.[628]

The committee also addressed regional non-proliferation and disarmament initiatives. With regard to the 1995 resolution to secure a NWFZ in the Middle East, the committee recommended that the international community seriously address regional politics in the Middle East by reaffirming that NWFZs have made and continue to make important contribution to strengthening regional stability. The committee proposed that

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[627] *Draft Recommendation to the Review Conference*, Third Session, New York, (2009). http://www.reachingcriticalwill.org/legal/npt/prepcom09/papers/CRP4.pdf (accessed Feb, 23,2011).
[628] Ibid.

the nuclear weapon states convene a meeting of all states in the Middle East region to address ways to ways and means to implement the 1995 resolution.[629]

On the issue of global leadership in strengthening the NPT, the U.S was called upon to engage states in dialogues to secure cooperation on non-proliferation issues. Many others, in and outside the U.S, have echoed this sentiment. In his article, "Strengthening the Non-Proliferation Regime," Lettow called upon President Obama to put nuclear issues near the top of his foreign policy agenda given the challenges faced by the treaty.[630]

CONCLUSION

The NPT has been incredibly successful in preventing the spread of nuclear weapons and in creating international norms against proliferation. However, these past successes are not enough and most experts agree that the NPT is currently in crisis. To prevent further proliferation, the IAEA and the international community must strengthen the NPT by addressing the efficiency and effectiveness of safeguards and securities; achieving consensus on enforcement of noncompliance; addressing the growing danger of non-state actors and rogue states' access to sensitive nuclear materials and technologies; and reconciling the views of NWS and NNWS regarding disarmament. The suggested recommendations for strengthening the NPT must be given collective effort if their implementation is to be successful. The NWS must treat and engage NNWS as partners in the fight against proliferation, and move away from exceptionalism. In a world of growing political divide, consensus building is difficult to achieve but

[629] *Draft Recommendation to the Review Conference*, Third Session, New York, (2009). http://www.reachingcriticalwill.org/legal/npt/prepcom09/papers/CRP4.pdf (accessed Feb. 23,2011).
[630] Paul Lettow, "Strengthening the Nuclear Nonproliferation Regime," *Council on Foreign Relations*, International Institutions and Global Governance Program, Council Special Report No. 54, (2010). http://www.cfr.org/proliferation/strengthening-nuclear-nonproliferation-regime/p21807 (accessed Feb. 22, 2011).

absolutely necessary. The member states of the NPT must not relent in accommodating the divergent views of all states. Instead, they must work toward a compromise for international peace and security through a weapons-free world. With stronger reforms and consensus, the NPT can provide an effective base for future non-proliferation efforts, which can simultaneously safely harness the benefits of nuclear energy for all.

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Chapter Eleven

NUCLEAR "HOT SPOTS" & PREVENTING NEW NUCLEAR WARS

Kristina Backstrom

Abstract:
The end of the Cold War did not eliminate conflict among nuclear weapons states, nor dissuade all nations from pursuing such weapons. The newest nuclear powers, and states seeking to begin nuclear power programs, are sources of international concern, as many of them are located in "hot spot" areas of political unrest, violence, and terrorist activity. North Korea, India, Pakistan, Israel and Iran are the five most recent states that fit this description. North Korea and Iran are considered (and have acted as) nuclear pariahs vis à vis the international community, while the ongoing tension, violence, and weapons build-up involving India and Pakistan are sources of huge concern. The histories of nuclear politics in each of these states provide important clues about their current positions and intentions. As a major nuclear state and the world's only superpower with national interests in all these areas, the U.S. is the only nation that can potentially intervene in a successful way to defuse conflict in each of these areas.

INTRODUCTION

The end of the Cold War and collapse of the Soviet Union, while greatly reducing any likelihood of global nuclear conflict, did not eliminate hostilities or the potential for confrontation between nuclear weapons states. Nor did it dissuade all other nations from pursuing such weapons. Increased proliferation, represented by North Korea and, in all probability, Iran, is alarming precisely because it upsets the delicate balance struck between powers at the end of the Cold War. This imbalance means an end to the policy of Mutually Assured Destruction (MAD), and it carries the potential for future arms races and even nuclear war on a local or regional basis. Since the 1970s, the number of states known to have nuclear weapons has increased from five (in order of acquisition: the United States, Russia, United Kingdom, France and China), to nine with the addition of Israel, India, Pakistan, and North Korea. These newest nuclear powers, none of which are full adherents to the Nuclear Non-Proliferation Treaty (NPT), along with a sizeable number of other states seeking to begin nuclear power programs, are the cause of much international concern. A major reason for such concern is that these nations tend to be located in "hot spots" or areas of conflict, which are particularly volatile political regions, as well as parts of the globe where terrorism is a potential or growing activity.

If nuclear power is to expand in the coming decades, as a global means to mitigate climate change, it becomes essential to examine such "hot spots," since a nuclear conflict of any scale in any of these areas would likely have a dramatic impact on any future growth of civilian nuclear power. At present, the regions of greatest concern are Northeast Asia, due in large part to North Korea's nuclear ambitions, South Asia, particularly India and Pakistan, and the Middle East, where Israel and Iran threaten peace in the whole region. In this chapter, I will examine the history of nuclear politics in each of these regions, focusing particularly on U.S. interactions, to determine their current nuclear weapons status and intentions with regard to future non-proliferation treaties. Overall, each of these states' high perceived threat to their national security, as well as their exceptional behavior, suggest a need for a more multilateral directly diplomatic approach to non-proliferation negotiations and treaties.

NUCLEAR WEAPONS IN NORTHEAST ASIA

Motivations behind North Korea's Nuclear Threat

Within Northeast Asia, the state of greatest concern with regard to nuclear proliferation is the Democratic People's Republic of Korea (DPRK). This is due to North Korea's two nuclear tests, its long-term refusal to denuclearize, and its state of continued aggression with South Korea as a residual of the Korean War (1950-1953). While an armistice ended the fighting, the two countries technically remain in a state of war, with the border between them the most heavily armed in the world. This historical tension along with the foreseeable collapse of the Soviet Empire, were key motivators in the DPRK's initial investment in nuclear energy. Since the 1960s, the two nations have engaged in multiple exchanges of fire, the latest involving the actual sinking of a South Korean warship by a North Korean torpedo, followed by the shelling of Yeonpyeong Island. Both events occurred in 2010 and resulted in a combined 46 deaths.

Statements by DPRK officials claim the expansion of their nuclear arsenal has always been in response to perceived threats from the United States and others against the North Korean regime.[631] Their security paranoia is reinforced by the DPRK's economically "peripheral" status in the international system. Like Iran, and formerly Libya and Iraq, the DPRK is not economically integrated into the "pluralistic security community."[632] At the same time, economic considerations alone cannot explain a state's pursuit of nuclear weapons if the state believes they are imperative to its national security.[633] As non-proliferation scholar Cirincione notes, "despite being one of the world's poorest countries, Pyongyang continues to pursue nuclear weapons and spends 25 percent of its GDP on defense each year."[634] This suggests that whether or not they are being created in response to U.S. threats, the DPRK believes nuclear weapons to be essential to their security.

U.S. threat assessments describe the DPRK's nuclear capabilities as being "more

[631] Mary Beth Nikitin, "North Korea's Nuclear Weapons: Technical Issues," *Congressional Research Service* (2011), www.fas.org/sgp/crs/nuke/RL34256.pdf (accessed Jan. 18, 2011) 16.
[632] Joseph Cirincione, *Bomb Scare: the History and Future of Nuclear Weapons*, (New York: Columbia University Press, 2007), 53.
[633] Ibid.
[634] Ibid, 77.

for deterrence and coercive diplomacy than for war fighting."[635] These same reports assume the DPRK most likely would "not attempt to use nuclear weapons against U.S. forces or territory unless it perceived the regime to be on the verge of military defeat and risked an irretrievable loss of control."[636] The DPRK does not have the necessary missile capabilities to effectively launch an attack on the U.S. However this does not prevent its neighbors and U.S. allies in Northeast Asia, notably South Korea and Japan, from feeling a very real threat to their own national security, which has made some believe that an arms race is the safest and best way to proceed. Assuming that the DPRK only intends to use their nuclear weapons as a final resort, the main purpose of these weapons is to provide leverage in diplomatic negotiations. It should be noted that DPRK's announcements of new nuclear technology and generally threatening rhetoric often coincide with times of internal domestic crisis or transitions in negotiations.

DPRK's Nuclear History and Points of International Contention

An analysis of the history of the DPRK's nuclear program reveals how closely the development of the program was linked to perceived international threats and that, from a strategic diplomacy perspective, nuclear capability is one of the few cards the DPRK has to play. In 1985 U.S. officials announced for the first time that they had intelligence data proving a secret nuclear reactor was being built near the small town of Yongbyon. The U.S. had known of the construction at Yongbyon for eight years from official reports from the International Atomic Energy Agency (IAEA). That same year, under international pressure, including that from the Soviet Union, Pyongyang acceded to the Nuclear Non-Proliferation Treaty (NPT). However, they refused to sign a safeguards

[635] Mary Beth Nikitin, "North Korea's Nuclear Weapons: Technical Issues," *Congressional Research Service* (2011), www.fas.org/sgp/crs/nuke/RL34256.pdf (accessed Jan. 18, 2011), 16.

agreement with the regulatory IAEA, an obligation it had as a party to the NPT. This led to the widely held belief that although the DPRK had joined the NPT, the plutonium it reprocessed was intended for use in nuclear weapons. In 1992 the DPRK finally submitted its nuclear material declarations to the IAEA, officially declaring seven sites and some 90 grams of plutonium that could be subject to IAEA inspection. The DPRK claimed the nuclear material was the result of reprocessing 89 defective fuel rods in 1989. While conducting inspections to verify the completeness of the declaration North Korea finally submitted in 1992, IAEA inspectors discovered several discrepancies for which they requested clarification, including the amount of reprocessed plutonium.[637] In 1993 the IAEA demanded special inspections of two sites believed to store nuclear waste. Outraged by this treatment, the DPRK refused the IAEA and announced it would withdraw from the NPT.[638]

The many sanctions placed on the DPRK in response to their presumed weapons program were not enough to change their policy. However, when the U.S. tried a kinder, more diplomatic approach, by having former President Jimmy Carter and Kim Il Sung meet in 1994, Kim Il Sung agreed to freeze the nuclear program if the U.S. resumed high-level talks. The U.S. did, and together they created the "Agreed Framework," which specified that North Korea would stop all plutonium separation and hand over its spent fuel in return for two light water reactors and 500,000 tons of heavy oil for heating and electricity. While the DPRK continued research on missile technology, it appeared to have held to this nuclear agreement, although many suspect the DPRK continued to produce weapons material in secret.

[637] "Chronology of U.S.-North Korean Nuclear and Missile Diplomacy," *Arms Control Association*, http://www.armscontrol.org/factsheets/dprkchron (accessed Jan. 20, 2011).
[638] Ibid.

Escalating American Threat

The DPRK's continued research in missile technology, despite U.S. sanctions, led to President George W. Bush's famous declaration in his 2002 State of the Union Address that Iraq, Iran, and North Korea are the three members of the "axis of evil." In 2003 the U.S. went to war against Iraq, citing Iraq's possible development of weapons of mass destruction (WMDs) as the main reason for invasion. Talks in Washington enthusiastically discussed the possibility of the "War on Terror" continuing on from Iraq to Tehran, Damascus and Pyongyang.[639] In addition to labeling North Korea the enemy, the Bush administration's 2002 Nuclear Posture Review gave the DPRK even more reason to fear an American attack. While the review validated the reductions in nuclear warheads agreed upon by the U.S. and Russia in 1997, in general it advocated for an increase in the U.S.'s nuclear weapons program (NWP), calling for increased funding and development of a new generation of strategic nuclear weapons for the next fifty years, new designs, and new uses for nuclear weapons against non-nuclear threats. Even more menacing, the review *explicitly* discussed plans for using these weapons on China, North Korea, Syria, Iraq, Iran, Libya and other countries.[640]

In October 2002 the Bush Administration accused North Korea of having a clandestine uranium enrichment program. North Korea denied the program, but claimed they would be "entitled" to have such a program or "an even more powerful one" to deter a preemptive U.S. attack.[641] This comment is particularly revealing as it suggests a continuing secrecy in the DPRK's nuclear development and its deep-seeded distrust of

[639] Joseph Cirincione, *Bomb Scare: the History and Future of Nuclear Weapons,* (New York: Columbia University Press, 2007), 135.
[640] Ibid.
[641] Mary Beth Nikitin, "North Korea's Nuclear Weapons: Technical Issues," *Congressional Research Service* (2011), www.fas.org/sgp/crs/nuke/RL34256.pdf (accessed Jan. 18, 2011), 16.

the U.S. The conflicting information led the IAEA to adopt another resolution, calling upon North Korea to "clarify" its "reported uranium-enrichment program," which North Korea rejected, saying the IAEA's position was biased in favor of the U.S.[642] In response, the DPRK withdrew from the NPT on January 10, 2003, ending the freeze on its plutonium program, and over the next several years potentially increasing its holdings of fissile material fivefold.[643] In 2007, U.S. intelligence officials publicly admitted to doubts about how much progress the uranium enrichment program had actually made in 2002, underscoring questions about the ability of intelligence agencies to discern the precise status of foreign weapons programs, and how the interaction might have been better handled.[644]

This withdrawal from the NPT prompted the creation of the six-party talks, an international convention on the denuclearization of the Korean Peninsula that included the U.S., Russia, China, the DPRK, South Korea, and Japan. The first several of these were largely inconclusive, at least until 2005 when Condoleezza Rice returned to the more diplomatic strategy proven effective while outlining the "Agreed Framework." By mid-2005 U.S. rhetoric had softened; the U.S. initiated several bilateral talks, and engaged in actual negotiations that proved to be effective. In the "joint statement," the DPRK formally committed to giving up all nuclear weapons and existing nuclear programs and to returning to the NPT in exchange for a nonaggression pledge from the

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[642] "Chronology of U.S.-North Korean Nuclear and Missile Diplomacy," *Arms Control Association*, http://www.armscontrol.org/factsheets/dprkchron (accessed Jan. 20, 2011).
[7] Joseph Cirincione, *Bomb Scare: the History and Future of Nuclear Weapons,* (New York: Columbia University Press, 2007), 119.
[644] David Sanger and William J. Broad, "U.S. Had Doubts on North Korean Uranium Drive," *New York Times*, March 1, 2007, http://www.nytimes.com/2007/03/01/washington/01korea.html (accessed Jan. 13, 2011).

U.S. as well as economic and energy aid.[645] The deal seemed to collapse in February 2006 when new demands from Washington regarding North Korean counterfeiting operations were added to a full negotiating list. This was the straw that broke the camel's back and in demonstrating its frustrations, the DPRK tested a nuclear device on October 9, 2006, allegedly to prove its possession of nuclear weapons to protect its sovereignty.

Nevertheless, the DPRK remained committed to disabling its nuclear weapons facilities and from November 2007 to April 2009 three reactors at Yongbyon were disabled under the supervision of the IAEA.[646] In 2009, the DPRK abandoned the Six-Party Talks indefinitely in response to U.S. and UN condemnation of a "satellite" launch widely believed to be an unsuccessful test for the Taepodong-2 DPRK Inter-Continental Ballistic Missile (ICBM).[647] Later that same year, North Korea set off its second nuclear device, which experts recognized as far more successful than its first device.

Continuing Political Tensions

In late 2010, North Korea revealed construction had begun on a new light water reactor at Yongbyon. It also revealed a previously unknown gas centrifuge uranium enrichment plant at Yongbyon and reportedly offered to invite international inspectors to verify the enrichment facility would produce only low enriched uranium for nuclear reactor fuel. An inspection by Siegfried Hecker of Stanford University confirmed the North Korean claims that the facility was oriented toward production of electricity, not weapons, but Hecker also emphasized that an enrichment set-up always remains a

[645] Joseph Cirincione, *Bomb Scare: the History and Future of Nuclear Weapons,* (New York: Columbia University Press, 2007), 138.
[646] Mary Beth Nikitin, "North Korea's Nuclear Weapons: Technical Issues," Congressional Research Service (2011), www.fas.org/sgp/crs/nuke/RL34256.pdf (accessed Jan. 18, 2011), 27.
[647] Richard Lloyd Parry, "Barrack Obama leads condemnation as North Korea launches Rocket" *The Sunday Times*, April 5, 2009.

potential dual-use facility.[648]

There is nonetheless a serious split between the former members of the Six-Party Talks as to whether or not further negotiations with the DPRK should continue. China, the DPRK's main ally and aid provider, and Russia along with the DPRK believe the talks should continue. The U.S., Japan, and South Korea are more reluctant; particularly after the DPRK's seemingly belligerent recent attacks against South Korea.[649] The other six-party talk members must demonstrate a united front against these deplorable actions while maintaining diplomatic relations. It is possible these aggressive actions are a desperate plea for attention as the DPRK economy has almost collapsed. Under the Trading with the Enemy Act, started during the Korean War, U.S. trade with the DPRK is not allowed. However, to forestall disaster in the famine-stricken country and maintain good will, the U.S. has given over $33 million in aid. While the U.S. does not want to be extorted by what are essentially DPRK terrorist acts, strengthening the economy of the DPRK could help ease international tension. South Korea is growing rapidly, but with the effects of the global recession and its new leader, it may not be as open to helping the DPRK. Furthermore, there remains the looming question of whether or not the increased proliferation of the DPRK will cause South Korea or Japan to pursue their own nuclear weapons.

Conclusion

The full extent of the DPRK's nuclear program is shrouded in mystery. However,

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[648] Siegfried Hecker, "North Korea's Yongbyon Nuclear Complex" *CISAC* November 20, 2010, http://cisac.stanford.edu/people/siegfriedshecker/ (accessed Feb. 25, 2011).
[649] David Gollust, "US Promises 'Measured, Unified' Response to North Korean Attack" November 23, 2010 (VOANews.com) http://www.voanews.com/english/news/US-Promises-Measured-Unified-Response-to-North-Korean-Attack--110216324.html (accessed Jan. 18, 2011).

there are certain hard facts that can be drawn from its history. The DPRK currently believes nuclear weapons are essential to their state security, likely as a deterrent against the involvement of more powerful states, particularly the U.S., as well as a method of attaining international attention to combat their extreme poverty with weapons negotiations. When the U.S. responded with suspicion and threatening rhetoric, the DPRK retreated from multilateral regulations and negotiations, relying on aid from China to survive in times of sanctions. This is particularly frustrating when the sanctions are well founded, and points to the importance of international cooperation in pressuring new nuclear states to follow non-proliferation regulations. On the other hand, there is reason to believe the U.S. has sometimes unfairly singled out the DPRK as rule-breaker. The U.S. has been more successful when it has engaged in direct diplomacy via talks that recognized the DPRK as a negotiation participant.

NUCLEAR ARMAMENTS IN SOUTH ASIA:

India's Motivations for Nuclear Armament

The case of India is demonstrative of a different form of American exceptionalism. Unlike the DPRK, which was singled out as untrustworthy and was subject to additional regulations, U.S. favoritism in the case of India has enabled it to succeed as a nuclear state without following the rules set by multilateral organizations for other states.

India's initial motives for nuclear proliferation included deterrence of China and Pakistan. In the case of China, India feared future military action due to remaining tension from the 1962 Sino-Indian War, which ended abruptly leaving Sino-Indian borderlines unresolved.[650] With regard to Pakistan, India had at least a 500-year religio-cultural based rivalry, which also involved unresolved national borderlines and eventually led to the Kashmiri Conflict. Attainment of nuclear weapons technology would give India political clout due to increased military might, as well as serve as an international indicator of a highly developed scientific nation, garnering global attention.

Current Indian policy under Prime Minister Manmohan Singh claims its nuclear weapons are defensive. India has a "no-first-use" policy, indicating the WMDs would only be used in the event of a nuclear attack on India.[651] Its number of nuclear warheads is said to be at a "credible minimum deterrence" level.[652] India supports non-proliferation and disarmament, but only on a global scale. At the same time, it rejects regional disarmament measures. Currently India is still developing its NWP to maintain its deterrence policy. However, India has expressed that it is willing to disarm provided that others do too.

India's Nuclear Weapons History and U.S. Favoritism

To an extent, U.S. favoritism should not come as a surprise given that the U.S. and Canada helped create the first nuclear energy facilities in India via their "Atoms for Peace" program. By 1958 India had already begun acquiring parts for a plutonium processing facility at Trombay.[653] Despite its international ties to nuclear power, India was vocally opposed to the NPT even before it was finalized based on the principles of non-discrimination and the need for nuclear powers with massive arsenals to get serious about disarmament. India complained the NPT discriminated against countries that did

[650] Joseph Cirincione, Jon B. Wolfsthal, and Miriam Rajkumar. *Deadly Arsenals: Nuclear, Biological, and Chemical Threats.* (Washington: Carnegie Endowment for International Peace, 2005), 222.
[651]Ibid, 227.
[652] Ibid.
[653] Ibid, 225.

not yet have nuclear weapons while at the same time increasing the difficulties for countries trying to develop their own nuclear energy capabilities and failing to force existing nuclear weapons states to engage in serious disarmament.[654] India's hostility also reflected its security interests in developing nuclear weapons to deter threats from Chinese conventional and nuclear weapon capabilities. Upon its finalization in 1968, India refused to join the NPT, enabling India to pursue nuclear weapons technology without having to break the treaty.

On May 18, 1974, India detonated a "peaceful" nuclear device. Despite this being in clear defiance of the spirit of the Atoms for Peace program, and potentially distancing India from nuclear supplier states, most Indians seemed to take enormous pride in the accomplishment.[655] In another case of surprising exceptionalism, the nuclear supplier states seemed not to care. Neither China nor the USSR criticized the test, and even the U.S. seemed to give their unofficial approval.[656] After the test, the Nuclear Suppliers Group (NSG) was formed in 1974, in an attempt to regulate the trade of nuclear materials to non-nuclear states who did not follow IAEA safeguards. By joining this multilateral organization, the 44 member nations agreed not to export any items unique to the production of nuclear weapons and materials, nor the 65 "dual-use" designated items that have legitimate use outside of weapons proliferation, to nuclear facilities that are not

[654] David Fidler and Sumit Ganguly, "Take a Fresh Look" *The Times of India*, December 10, 2009., http://timesofindia.indiatimes.com/home/opinion/edit-page/Take-A-Fresh-Look/articleshow/5319392.cms (accessed Feb. 16, 2011).
[655] Joseph Cirincione, *Bomb Scare: the History and Future of Nuclear Weapons*, (New York: Columbia University Press, 2007), 37.
[656] Ibid.

subject to inspections by the IAEA.[657] It was this safeguard organization the U.S. and India had to maneuver around for their nuclear deal in 2006.

During the mid-late 1990s, India continued its expansion of nuclear weapons technology and disregard for international non-proliferation agreements. The pro-nuclear, Hindu-nationalist Bharatiya Janata Party strongly pushed for nuclear development and testing.[658] When the NPT was indefinitely extended in 1995, India still refused to join. Similarly, when the UN adopted the Comprehensive Test Ban Treaty (CTBT) in September 1996, stating that signatories refuse to test any new nuclear devices, India did not sign. In response to Pakistan's test of a 1,300 km-ranged Ghauri missile in April 1998, India detonated five nuclear devices, and declared itself a nuclear state. Afterward both countries pledged to refrain from tests.[659]

The seemingly unperturbed reaction from the U.S. in response to these tests is further proof of international policy bias. In the 1990s, after realizing that India would not sign the NPT, the U.S. refocused its aims from persuading India and Pakistan to sign treaties to a more general goal of stabilizing relations and capping nuclear weapons. To accomplish this goal and improve Indo-U.S. relations, Presidents Clinton and Bush frequently visited India between 2000 and 2006.[660] This cooperation culminated in the 2006 U.S.-India Peaceful Atomic Energy Cooperation Act, also known as The U.S.-India Deal.

The U.S.-India Deal was a boon for India. In conjunction with a waiver from the NSG, it allowed India to buy technologies for fuel reprocessing and waste management

[657] Joseph Cirincione, *Bomb Scare: the History and Future of Nuclear Weapons,* (New York: Columbia University Press, 2007), 37.
[658] Ibid, 68.
[659] Ibid, 128.
[660] Ibid.

and to import uranium for existing reactors without becoming a member of the NPT. Furthermore, the negotiation enabled India to avoid military facility inspection by international third parties (and is therefore protected from the prying eyes of Pakistani intelligence) while still expanding its nuclear energy capabilities. This agreement put India in a strong position both regionally and globally but it also gave India a unique status, which has attracted resentment from other nations who must abide by the NPT. The deal also benefited the U.S. who found in India a strong Asian ally, capable of balancing any perceived threat from China.[661] Similarly, the Bush administration saw India as an ally against Pakistani terrorist organizations in the "War on Terror." It also increased trade between two huge markets as well as India's nuclear transparency as it created legitimate means whereby the state could acquire nuclear technology.

Nevertheless, it is difficult to determine whether the good in this scenario truly outweighs the bad. By allowing India to operate separately from the rest of the world, the U.S. and the NSG are potentially weakening their position to create and enforce other treaties in the future or hold current signatories to the policies as they stand today. There are concerns that inconsistencies in the enforcement of such a major treaty will weaken the NPT to the point where it will be ineffective.[662] The perception of a double standard operating in this case could be harmful to future political environments where cooperation and goodwill are key.

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[661]George Pervokich, "Global Implications of the U.S.-India Deal," *Daedalus*, v. 139 no. 1 (Winter 2010) 22.
[662] Ibid, 24.

Future Concerns

India's stability seems to be improving. Increasing economic dependence between India and China draws them closer together. Meanwhile, efforts are being made to bring peace between Pakistan and India and several agreements, talks, and confidence building measures have taken place. India's incredible economic growth has also led to an improvement in their global status, suggesting that perhaps soon India might consider itself high enough to be one of the nuclear "haves" and might be willing to join the NPT.[663] Still the situation is not ideal. Major points of international contention, such as the land disputes from the Sino-Indian War (Kashmiri territory dispute), remain unresolved. The Kashmir conflict also continues. India is already capable of hitting China and Pakistan with nuclear weapons, and is developing Intercontinental Ballistic Missiles (ICBMs) and submarine technology, increasing the probability of a nuclear arms race in the region. Furthermore, the U.S.-India Deal, and the resulting "special" relationship that has enabled India to participate in nuclear trading without being a member of the NPT, not only gives a weak impression to would-be proliferators that the consequences of proliferation are not dire, it also incites jealousy in Pakistan, and other would-be proliferators, further fueling the regional conflict that, at its heart, is responsible for continued nuclear proliferation.

Conclusion

India's nuclear weapons motivations include regional security in the aftermath of historic conflict, as well as national status elevation. Like North Korea, India early on recognized an inherent bias in the NPT that favors pre-existing nuclear states, like the

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[663] David Fidler and Sumit Ganguly, "Take a Fresh Look" *The Times of India.* December 10, 2009. http://timesofindia.indiatimes.com/home/opinion/edit-page/Take-A-Fresh-Look/articleshow/5319392.cms (accessed Feb. 16, 2011).

U.S., which remains the alleged cause of India's refusal to join. This points to a need to redress the NPT with the intention that all states should be equally regulated by its contract. Despite their refusal, the U.S. has done little to encourage India to join the NPT, and instead has created an exceptional regulatory process specifically for India to the countries mutual exclusive benefit. This bilateral "favoritism" weakens the non-proliferation regime as it implies breaking the rules is acceptable as new rules can be drawn up. This suggests a need for the U.S. to be more universal in their treatment of new nuclear weapons states, and encourage bilateral talks to ultimately lead to multilateral agreements.

Pakistan's Nuclear Proliferation Motivations

Pakistan's nuclear proliferation is emblematic of a small country's fear of domination by a much larger, stronger country, such as India, leading to an arms race. Evidence to support this claim is seen throughout the shared history of these two countries. For example, Pakistan has reported that it will not sign the NPT until India does. Pakistan was also ambiguous about its nuclear status, until India detonated its bomb in 1974. As U.S. officials attempted to maintain NPT standards while maintaining regional stability, Pakistan endured dramatic U.S. policy fluctuations. However, during times of sanction, Pakistan did not find it overly difficult to receive nuclear exports from other parts of the world, which again illustrates the importance of international cooperation for non-proliferation measures to be successful.

Pakistan's Nuclear History

India and Pakistan's nuclear energy programs have common beginnings in the "Atoms for Peace" program. But in 1972, after the Indo-Pakistani War, Pakistan decided to launch a nuclear weapons program to match India's developing capabilities. It was set back in 1974 when the newly founded NSG created an embargo on nuclear exports to Pakistan after India's first test of a nuclear device. In 1976, the Glenn-Symington Amendment halted U.S. military and economic aid to Pakistan to dissuade it from continuing its NWP. This aid refusal was reversed in 1983, while Soviet troops were in Afghanistan, as it was in U.S. interest to defend against Soviet expansion and support Pakistan as an anti-Soviet force.[664] In 1990, when Pakistan was no longer needed in the war effort in Afghanistan, the U.S. Pressler Amendment withheld Pakistani military equipment even though Pakistan had paid for it.[665] The Brown Amendment of 1995 allowed all non-military materials to be exported and was a step toward repairing U.S.–Pakistan relations. Yet Pakistan continued to research uranium and plutonium enrichment. U.S. desire for stability in South Asia and U.S. non-proliferation obligations have been frequently pitted against one another. The most recent war in Afghanistan has led once again to an increase in U.S. aid to the strategically important region of Pakistan. Although Pakistan has been fairly transparent about its nuclear activities, it still refuses full IAEA inspections, and it is believed it now has enough highly enriched uranium for up to 100 warheads.[666]

What gave Pakistan the ability to continue their nuclear program despite U.S. sometimes-opposition was technology exported from other states. In 1983, China reportedly supplied Pakistan with bomb designs. It acquired a tritium purification and production facility from West Germany in 1987. In 1989 a 27-kilowatt research reactor

[664] U.S. Senate, "The Pressler Amendment and Pakistan's Nuclear Weapons Program," July 31, 1992, http://www.fas.org/news/pakistan/1992/920731.htm (accessed Jan. 22, 2011).
[665] Ibid.
[666] "Pakistan's Nuclear Folly" *The New York Times* February 20, 2011. http://www.nytimes.com/2011/02/21/opinion/21mon1.html (accessed Feb. 21, 2011).

was built with Chinese help, and Pakistan was able to purchase 5,000 ring magnets from China to be used in gas centrifuges for uranium enrichment, despite the embargo from the NSG.[667]

All of this occurred in the midst of a small-scale arms race with India. In 1990, fearing a new war with India, Pakistan made cores for several nuclear weapons.[668] After India successfully tested the Privthi II missile in 1994, Pakistan responded by revealing its first ballistic missile, the Hatf-3, capable of reaching New Delhi in India's interior. Finally, in 1998, in reaction to hearing that India intended to conduct a nuclear test, Pakistan exploded six nuclear devices in two locations. Both countries have since pledged to conduct no more nuclear tests, despite the penalties for these actions being "modest and short-lived."[669]

Many analysts are rightly wary of Pakistan's nuclear capabilities. There remains the possibility that tension over Kashmir could escalate into a war, which could be particularly disastrous if both states employ their nuclear weapons. India and Pakistan were able to conclude the Kargil Crisis of 1999 with negotiations instead of war, but whether negotiations would currently prevail after the recent increase in bombings widely alleged to be the work of Pakistani terrorists is questionable. There is also a question of how long Pakistan can economically support nuclear proliferation, as larger arsenals necessitate a greater investment in protecting and maintaining the arsenal.[670] Pakistan's

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[667] "Timeline: Pakistan's Nuclear Program" *CNN.com* February 4, 2004. http://www.cnn.com/2004/WORLD/asiapcf/02/04/pakistan.nuclear.timeline.reut/ (accessed Jan. 20, 2011).
[668] Robert Windrem, "Pakistan's Nuclear History Worries Insiders," *NBC News* November 6, 2007, http://www.msnbc.msn.com/id/21660667/ns/nightly_news/ (accessed Feb. 13, 2011).
[669]Kurt M. Campbell, Robert J. Einhorn, and Mitchell Reiss. *The Nuclear Tipping Point: Why States Reconsider their Nuclear Choices.* (Washington, D.C.: Brookings Institution Press, 2004), 318.
[670] Volha Charnysh,"Pakistan's Nuclear Program," *Nuclear Age Peace Foundation.* http://www.nuclearfiles.org/menu/key-issues/nuclear-weapons/issues/proliferation/pakistan/charnysh_pakistan_analysis.pdf (accessed Feb. 08, 2011).

President Bhutto said in 1964 that if India had nuclear weapons, Pakistan would too, "even if they had to eat grass."[671] Today this is dangerously close to the truth as a country that cannot feed its people, or defeat insurgents without billions of dollars in foreign aid, with China's help is now building a fourth nuclear reactor to produce more weapons fuel.[672] Furthermore, there is the issue of increased proliferation within the region, both to other states and to non-state actors. One of the biggest fears is that Pakistan will enable nuclear weapons and technology to fall into the hands of terrorists.[673] This fear increased after Pakistan's 2009 release of A.Q. Khan from house arrest and the subsequent lifting of all travel restrictions on the nuclear scientist. Many have taken Khan's release as a signal that Pakistan does not take the risk of nuclear proliferation seriously.[674]

Conclusion

Pakistan's proliferation is a direct response to their perceived nuclear weapons threat from India. The U.S.'s inconsistent policy in Pakistan along with clear favoritism in India is unlikely to gain Pakistani cooperation with multilateral negotiations. In times of sanctions, Pakistan was still able to trade nuclear technology with China. Both of these situations suggest a need for multilateral regulations that are universally employed, particularly as the situation in Pakistan grows more dire, with increased poverty and terrorist activity.

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[671] Jyotindra Nath Dixit, *India-Pakistan in War and Peace*, (London: Rutledge, 2002), 226.
[672] "Pakistan's Nuclear Folly," *The New York Times*, February 20, 2011. http://www.nytimes.com/2011/02/21/opinion/21mon1.html (accessed Feb. 21, 2011).
[673] Cirincione, Joseph. *Bomb Scare: the History and Future of Nuclear Weapons.* New York: Columbia University Press, 2007. Print. p. 92
[674] Volha Charnysh,"Pakistan's Nuclear Program," *Nuclear Age Peace Foundation.* http://www.nuclearfiles.org/menu/key-issues/nuclear-weapons/issues/proliferation/pakistan/charnysh_pakistan_analysis.pdf (accessed Feb. 08, 2011).

NUCLEAR ARMS IN THE MIDDLE EAST

Israel's Motivations for Nuclear Proliferation

Israel is a particularly interesting case study because, although it has known nuclear reactors, it has chosen to remain officially ambiguous about its weapons status. Despite C.I.A. assurances and a preponderance of evidence that Israel has WMDs, the Israeli state has never forthrightly announced this status. Still, Israel's motivation for having nuclear weapons capability is clearly security. It remains the only Jewish nation surrounded by Arab countries, many of which continually refuse to even acknowledge its existence as a state. These neighboring enemies, including Bahrain, Iran, Iraq, Lebanon, Kuwait, Omar, Saudi Arabia, Syria, Yemen, and United Arab Emirates (UAE), have both substantial populations and large conventional arsenals. With the memory of the Holocaust still fresh in the collective memory of its people, it is easy to understand why Israel might turn to nuclear armament, with the intent that such an atrocity should never happen again. It is also unsurprising that the U.S. should take exception to Israel's NWP given that they have had a special relationship since Israel's Declaration in 1948. The majority of U.S. foreign aid still goes to Israel.

Israel's Nuclear Weapons History

It is believed the Israeli NWP began in the fall of 1956, when France secretly agreed to help Israel build a plutonium-producing device at Dimona and develop nuclear weapons to curb Arab nationalism.[675] It is estimated that by 1966 Israel may have completed research and development of a nuclear program and by 1967 Israel had already improvised the assembly of two nuclear devices and placed them on operational

[675] "Nuclear Weapons—Israel," *Federation of American Scientists*. January 8, 2007, http://www.fas.org/nuke/guide/israel/nuke/ (accessed Feb. 3, 2011).

alert.[676] The first presumed test of an Israeli bomb occurred September 22, 1979, in what was called the VELA incident. Two bright, consecutive flashes resembling an atomic explosion were detected off the coast of South Africa. David Albright stated in the *Bulletin of Atomic Scientists*, "If the 1979 flash was caused by a test, most experts agree it was probably an Israeli test."[677]

Israel's nuclear policy has long been exceptionalist in that it aims to prevent its neighboring states from acquiring nuclear technology. In 1981 Prime Minister Begin introduced the "Begin Doctrine," in which he declared Israel would *prevent* other Middle Eastern nations from developing nuclear programs. The doctrine was utilized to justify the subsequent "pre-emptive" attack on the Iraqi Osiraq plutonium plant. The U.S. condemned these unilateral actions and suspended the delivery of four F-16 fighter jets, however the suspension was lifted only two months later.[678] The audacity of Israel's unilateral action and the weak international repercussions incensed the region and throughout the 1980s, Iran, Iraq, Syria, and Libya all accelerated their development of biological and/or chemical weapons as well as their delivery systems. In April 1990, Saddam Hussein threatened to destroy "half of Israel" with chemical weapons if Iraqi nuclear installations were attacked and by April 1991, the Iraqi government had set a date to create a nuclear weapon through a "crash program."[679]

Despite their antagonistic behavior, Israel has participated in a number of international non-proliferation conferences. One such conference was the Middle East

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[676] "Nuclear Weapons—Israel," *Federation of American Scientists*. January 8, 2007, http://www.fas.org/nuke/guide/israel/nuke/ (accessed Feb. 3, 2011).
[677] David Albright, "South Africa and the Affordable Bomb" *The Bulletin of the Atomic Scientists*, (July/August 1994), 42.
[678] David Kreiger, *The challenge of abolishing nuclear weapons*, (N.J. Transaction Publishers, 2009), 161.
[679] Mitchell Bard, "The Gulf War," *Jewish Virtual Library*, http://www.jewishvirtuallibrary.org/jsource/History/Gulf_War.html (accessed Feb. 10, 2011).

Peace Conference in Madrid, 1991, which concluded with the very positive general consensus that a roadmap had been created for future summits. Still the success is debatable, as some major Middle Eastern antagonists, notably Iran and Iraq, did not participate. In 1995 the NPT was reviewed and extended indefinitely. Israel participated in the conference, yet resisted international pressure to sign. With regard to the NPT, Israeli Prime Minister Netanyahu famously announced that Israel "will not sign because we will not commit suicide."[680] This statement is revealing as it implies acknowledgement that Israel *does* have nuclear capabilities, and is also expressive of the Israeli government's perceived threat to its state, that it considers the proliferation of WMDs necessary to its survival. It should be noted that in September 1996 Israel did become a signatory of the CTBT, demonstrating a willingness to limit nuclear power, but like India, it prefers disarmament on a regional rather than individual level.[681]

Part of the perceived double standard in the U.S.'s approach to Iran's NWP and Israel's is the fact that Israel already has so much fissile material, as well as the delivery system technology to cause serious damage, and yet it receives special treatment. Israel's exact number of WMDs is unknown, but last estimated in 2005 to be between 100 and 175. Israeli delivery systems include short, medium and inter-continental ballistic missiles, a variety of aircraft and submarines with second-strike capabilities.[682] Nevertheless, as a U.S. ally, they are treated as if they are far less likely to start a nuclear war than Iran, who does not have nearly as many weapons delivery vehicles.

[680] Eli Lake, "Secret U.S.-Israel Nuclear Accord in Jeopardy," *The Washington Post,* May 6, 2009.
[681] "Israel Signs Facility Agreement," *Comprehensive Nuclear Test Ban Treaty Organization*, September 23, 2004, http://www.ctbto.org/press-centre/press-releases/2004/israel-signs-facility-agreement/ (accessed Feb. 20,2011).
[682] "Missiles of the World" *Missile Threat.com*, http://www.missilethreat.com/missilesoftheworld/ (accessed Jan. 18, 2011).

Conclusion

In the case of Israel, one can see how pre-emptive attacks and negligible international repercussions weaken the non-proliferation regime by creating enmity within the Middle Eastern region. There is a general consensus that without peace in the Middle East, Israel will not give up its nuclear weapons. However, while Israel was originally motivated by the prospect of nuclear security, their exceptional status has encouraged others to further develop their own military capabilities. Despite signing the CTBT, Israel does not seem willing to give up nuclear weapons as its enemies are still developing unconventional weapons and ballistic missiles. This suggests a strong need for the U.S. to encourage peace in the region while holding Israel to the NPT standard, and strengthening sanctions against them when this standard is broken.

Iran's Nuclear Proliferation Motivations

Iran is a country that does not yet have WMDs but is believed to have actively pursued nuclear weapons since the mid-1980s, despite being a party to the NPT since 1970. Its motivations include its rivalry with Iraq, a desire for pre-eminence in the Persian Gulf, and the belief that WMDs may serve as a deterrent toward intervention by major world powers like the U.S., whose exceptionalist behavior towards Iran is particularly hostile.

Iran's Nuclear Weapons History and U.S. Suspicions

U.S.-Iran relations today are incredibly different than in the in the 1950s when the U.S. helped launch Iran's nuclear power as part of the Atoms for Peace program. Under the rule of Shah Mohammad Pahlavi, a leader the U.S. helped install via a CIA coup in 1953, plans were made to construct up to 20 nuclear power stations, and numerous contracts were signed with various firms.[683] This relationship changed dramatically with the Islamic Revolution of 1979, which called for an overthrow of capitalism and American influence in the Middle East[684]. At the end of the revolution, Iran informed the IAEA of its plans to restart its nuclear program. Iran had paid the U.S. to deliver new fuel and upgrade its power. However, the U.S. never delivered the fuel nor returned the billions of dollars it had been paid, exacerbating Iranian mistrust of America and the West.

A similarly negative U.S.-Iran interaction occurred in 1983, when the IAEA planned to provide assistance to Iran to produce enriched uranium. However, the U.S. persuaded the IAEA to terminate its project in Iran. As a result, Iran was encouraged to look elsewhere, training nuclear technicians and engineers in China, who also supplied Iran with two research reactors. After much negotiation, in 1997, the U.S. managed to pressure China into agreeing to cease all nuclear assistance to Iran.[685] Russia also signed an USD 800 million agreement with Iran in 1995 under which Russia was to complete one of the partially built German reactors and provide low enriched uranium fuel for ten years, but soon dropped the agreement in response to U.S. sanctions.[686]

The U.S. justified these obstructions to Iranian nuclear development by claiming they had intelligence reports suggesting Iran had been conducting covert research on fissile material production, supported by smuggling.[687] This led the U.S. to compel the IAEA to have "special" visits, during which Iran allowed them to visit any location and

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[683] Sharon Squassoni, "Iran's Nuclear Program: Recent Developments," *CRS Report for Congress*, September 6, 2006, http://www.fas.org/sgp/crs/nuke/RS21592.pdf (accessed Feb. 3, 2011), 1.
[684] U.S. Department of State, "Iran," http://www.state.gov/p/nea/ci/ir/index.htm (accessed Jan. 19, 2011).
[685] Joseph Cirincione, Jon B. Wolfsthal, and Miriam Rajkumar, Deadly Arsenals: Nuclear, Biological, and Chemical Threats. (Washington: Carnegie Endowment for International Peace, 2005), 260.
[686] Ibid, 258.
[687] Ibid, 263.

no violations of the pact were discovered.[688] In 2002 Iran publicly revealed the existence of two nuclear sites under construction: a uranium enrichment facility in Natanz and a heavy water facility in Arak. The IAEA immediately sought access to these facilities. According to the guidelines of the IAEA, Iran did not have to allow inspections until six months before nuclear material was introduced. The IAEA decided to change this so that facilities had to be reported in the planning phase.[689]

The U.S. also led an NSG-coordinated embargo against Iran, outlawing the export of nuclear power plants, major components for them, uranium enrichment equipment, and equipment for reprocessing. Notably, Russia defied the embargo, arguing that there was not enough persuasive evidence that Iran was pursuing nuclear weapons.[690] Not surprisingly, Iran regularly objects to these U.S. efforts to hinder assistance to its nuclear program. It claims that the Western embargo and U.S. pressure to not sell to Iran is in violation of Article IV of the NPT, which guarantees the inalienable right of all parties to the treaty to develop, research, produce, and use nuclear energy for peaceful purposes.[691]

France, Germany, and the UK (the EU-3) tried a more diplomatic approach to resolving questions regarding Iran's nuclear program. Under the resulting collaborative Tehran Declaration, the EU-3 agreed to recognize Iran's nuclear rights and discuss ways Iran could provide satisfactory assurances regarding its nuclear power program. In return, Iran agreed to cooperate with the IAEA, implement an additional protocol, and

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[688] Joseph Cirincione, Jon B. Wolfsthal, and Miriam Rajkumar, Deadly Arsenals: Nuclear, Biological, and Chemical Threats. (Washington: Carnegie Endowment for International Peace, 2005), 258.
[689] IAEA Director General, "Implementation of the NPT safeguards agreement in the Islamic Republic of Iran," June 6, 2003, IAEA, http://www.iaea.org/Publications/Documents/Board/2003/gov2003-40.pdf (accessed Feb. 3, 2011), 4.
[690] "Iran: U.S. Spied to Get Nuke Info," *Associated Press*, December 9, 2007, http://www.foxnews.com/story/0,2933,316221,00.html (accessed Feb. 3, 2011).
[691] Joseph Cirincione, Jon B. Wolfsthal, and Miriam Rajkumar, Deadly Arsenals: Nuclear, Biological, and Chemical Threats. (Washington: Carnegie Endowment for International Peace, 2005), 257.

suspend its enrichment and reprocessing activities. On November 14, 2004 under the terms of the agreement, Iran suspended its uranium enrichment program after pressure from the EU-3.[692]

Mahmoud Ahmadinejad disapproved of Iran giving up its right to nuclear research and development. After his election in 2005, Iran removed the seals on its uranium enrichment equipment. Several days later, the EU-3 offered Iran a package in return for permanent cessation of enrichment, which Iran refused.[693] The Bush administration did not approve of this behavior from a member of "the Axis of evil." In March 2006, the U.S. declared it would not accept any uranium enrichment in Iran and would accept no compromises. Ahmadinejad publicly offered to debate George W. Bush regarding Iran's right to nuclear energy but was rebuffed. On April 11, 2006 Ahmadinejad announced that Iran had successfully enriched uranium. He vowed that Iran would not back away from enrichment and scoffed at the UN sanctions that were threatened.[694]

Continuing Political Tensions

The main controversy with Iran's nuclear program in the international community is that they hid their uranium enrichment program for 25 years causing suspicion of further illicit activities. Iran has claimed that it hid its enrichment program from the IAEA because of unfair U.S. bias. It maintains it has a right to enrich uranium and repeatedly insist its use of nuclear power is peaceful. The new Obama administration supports a diplomatic approach to Iran, with Obama himself claiming the U.S. needs to

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[692] "Chronology of Iran's Nuclear Programme: 1957-2007," *Oxford Research Group*, http://www.oxfordresearchgroup.org.uk/oxford_research_group_chronology_irans_nuclear_programme_1957_2007 (accessed Feb. 5,2011)

[693] Ibid.

[694] Ibid.

"ratchet up tough but direct diplomacy with Iran" in what is being referred to as the "carrot and stick" policy. [695] Iran responded by urging Obama to adopt an "interactive" policy, indicating they do not believe Obama's directness will amount to more than the same type of U.S. demands made by the Bush administration before walking away.[696]

Very recently it seems there are others who prefer to take direct non-diplomatic action against Iran's NWP as Iran was attacked by a cyber worm known as the Stuxnet malware. The virus appears to have been designed to destroy some first generation P-1 centrifuges at the Natanz plant by altering the frequency that controls the speed at which the centrifuges spin.[697] Initial estimates by Secretary of State Clinton and outgoing director of the Mossad Meir Dagan claimed, due to this setback, Iran would not be able to make a nuclear weapon before 2015. However, recent reports claim Iran has been able to quickly replace broken machines, and continues a steady production of low enriched uranium.[698] If Israel or the U.S. is found to be involved in this attack, the consequences could be dire. Not only is the malware in clear violation of the NPT, but also employing its unknown destructive capabilities could potentially be considered an act of war.

Conclusion

Previous U.S.-Iran relations offer little reason for Iran to trust or be willing to negotiate with the U.S. Iran has been frequently and ineffectively treated with suspicion, as well as hostile rhetoric, and, in the case of the Stuxnet virus, outright aggression. In contrast, the EU-3 talks were much more successful, once more underlining the need for

[695] "Iran Shuns US Carrot and Stick Policy" *BBC News*. December 08, 2008. http://news.bbc.co.uk/2/hi/7771821.stm (accessed Feb. 03, 2011).
[696] Ibid.
[697] Warrick, Joby. "Iran's Natanz nuclear facility recovered quickly from Stuxnet cyberattack" *The Washington Post.* February 16, 2011. http://www.washingtonpost.com/wp-dyn/content/article/2011/02/15/AR2011021505395.html (accessed Feb. 17, 2011)
[698] Ibid.

a multilateral, diplomatic approach in non-proliferation negotiations.

Conclusions: Lessons Learned

Each new nuclear state presents an immediate threat as their current actions might induce other states to develop nuclear weapons, to bolster their own security. For others, the exceptional status of these states with regards to international regulations inspires courage to create their own nuclear weapons state outside the scope of the IAEA. To prevent further proliferation it is necessary to create an international policy that can curtail these rogue states, and make a positive example of them through improved international regulations. The new strategic aim of non-proliferation policy should be to achieve universal compliance with the rules of a toughened non-proliferation regime.

Significant patterns exist among these new nuclear states. Each country perceives its national security to be extremely threatened due to isolation or regional conflict, and all respond more positively to direct multilateral diplomacy that acknowledges their countries' concerns than trade sanctions and threatening rhetoric. This indicates non-proliferation policy requires a high level of international cooperation and compromise, perhaps even with states with which the U.S. has been previously un-willing to negotiate (i.e. Iran, North Korea).[699] Still the U.S. should remember that indirect "tough talk" in the past (i.e. the "axis of evil") has caused legitimate fear and increased proliferation.

Another pattern revealed is the problem of international exceptionalism to existing rules. The U.S. must end non-proliferation policy favoritism, seen in the cases of India and Israel, and discrimination, as evidenced by demanding and indirect diplomacy with North Korea and Iran. Both scenarios weaken the non-proliferation regime as they

[699] Joseph Cirincione, *Bomb Scare: the History and Future of Nuclear Weapons,* (New York: Columbia University Press, 2007), 136.

call into question rule enforcement. Instead, the U.S. should universally increase penalties for withdrawing from the NPT, and enforce compliance with strengthened treaties. Cooperation between governments is imperative if economic and political pressures are to be effective. The U.S. cannot hope to change Iran's mind via toughened sanctions if Russia is still willing to trade.

The giant elephant in the room when discussing international exceptionalism to non-proliferation is the United States. While worrying about others having 2 to 100 WMDs, the U.S. has in the neighborhood of 1,500 deployed weapons and several thousand un-deployed. This incredibly large amount is arguably in opposition to the NPT, which calls for reduction to zero. Although the U.S. has made some major steps toward reduction, they have been unable to persuade states like India and Pakistan, who have noticed the NPT is biased in favor of those already possessing nuclear weapons. To address NPT-bias it is necessary to universally reduce current global stockpiles and take existing weapons off hair-trigger status. If the U.S. hopes to convince other countries to give up nuclear weapons it needs to lead by example. This means signing measures like the CTBT, promising an end to future nuclear weapons tests, and discouraging more nuclear weapons research. Along with other pre-NPT nuclear weapons holders, notably Russia, the U.S. needs to reduce its armaments to a level that can be accepted by the international community. The U.S. and Russia could halve their nuclear stockpiles and still be far ahead of other new-weapons states, but this reduction would be seen as an incredible show of faith for a proliferation-free future.

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Chapter Twelve

THE PREVENTABLE THREAT OF NUCLEAR TERRORISM

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Abstract:
Terrorism is violence that seeks a political end, to make a point, or to instill fear. The consequences of nuclear terrorism would be far reaching, as its effects would immediately include widespread physical as well as psychological damage. Terrorist groups with a history of brutal violence and with access to nuclear knowledge include several types: socio-political organizations, nationalist or separatist groups, non-state actors, and possibly even state actors. This paper examines past incidents of theft of fissile material and attempts to sabotage nuclear facilities in Russia and Pakistan, plus similar attempts by Al Qaeda and the Aum Shinrikyo cult in Japan. This paper also analyzes the security measures implemented in response and finds that many have been effective in preventing nuclear terrorism. The research suggests that United States, as the world's sole superpower and past target of terrorist attacks, can directly help to prevent such an attack by working with the international community to better secure fissile material and place safeguards on all nuclear weapons and materials.

INTRODUCTION

Terrorism is public violence that may seek to achieve political objectives, prove a point, or simply to instill fear in a community. Terrorism is becoming better organized, with many terrorist networks throughout the world, with better financing, clearer objectives, and more sophisticated weapons technology. Terrorist groups today employ tactics that increasingly cause massive and violent destruction, of which the attacks on 9/11 are only one tragic example.[700] In the United States, particularly in the post-9/11 world, terrorism is a key threat to the security of the American people. If terrorists were to acquire plutonium or highly enriched uranium (HEU) to build a nuclear weapon, it would take terrorism to a whole new level in terms of the magnitude of damage.

[700] Bonnie Jenkins, "Combating Nuclear Terrorism: Addressing Nonstate Actor Motivations," *The Annals of the American Academy*, no. 607 (2006): 36.

Casualties would be concentrated in the immediate blast area, but the psychological effects would be widespread and long lasting.

The safety and security of nuclear materials is an important concern. Around the world, countries have not lived up to the ideals of complete non-proliferation. Today, there are hundreds of tons of nuclear material that remain dangerously vulnerable to theft in countries all over the world. Of particular concern are countries that are home to terrorist groups, have had past incidents of nuclear terrorism, or show the propensity to engage in nuclear terrorism for any number of reasons. These countries include, but are not limited to: Russia, Pakistan, and North Korea, either due to incomplete accounting of weapons or political instability.[701] Russia is often emphasized due to its vast inventory of nuclear weapons, its political instability following the fall of the Soviet Union, which may have allowed the diversion of some material, and also the ongoing acts of terrorism by Islamic separatists from the north Caucasus region. Other countries with potentially vulnerable stockpiles include India and Pakistan, the former due to attacks by Hindu nationalists.

Since there is not one singular motivation for terrorists' desires for nuclear weapons capabilities, it is imperative to first explore the background and motives of a few different terrorist groups that have demonstrated nuclear ambitions. These groups include the Al Qaeda network, the Aum Shinrikyo cult from Japan, and the Chechen separatist group in Russia. These groups provide insight into the motivations that groups have for violence and the consequences that may arise from their actions. Further, discussion of Russia and Pakistan is included in this research since the Chechen

[701] David Krieger, "What Happens If…? Terrorists, Revolutionaries, and Nuclear Weapons," *Annals of the American Academy of Political and Social Science* no. 470 (1977), 47.

separatists and Al Qaeda are based in these two countries respectively and both have sought to steal government supplies or obtain information and technology from state actors. Second, by examining these groups' past attempts to obtain nuclear materials and what they may be capable of, this paper will make a clear case for the actions that need to be taken to safeguard fissile material, nuclear weapons, and technology. Many lessons were learned from the U.S.'s dealings with Russia and the improvements made by the Russian government. In conclusion, this paper illustrates the availability of nuclear weapons to terrorists today, but highlights the fact that with more careful safeguards put in place and agreed upon by the international community, nuclear terrorism can be prevented. By drawing from past lessons from Russia, the U.S. and its allies should be able to structure a campaign against Al Qaeda's nuclear ambitions and put the prospect of nuclear terrorism to rest.

THE NUCLEAR DIMENSION OF TERRORISM

There are a number of avenues through which nuclear terrorism could occur. Terrorists could acquire a usable bomb either by building it, stealing it, buying it from other thieves, or acquiring it from a state that may support terrorism. The simplest approach would be for terrorists to use a small weapon stolen from an arsenal from one of the nuclear states or one constructed from stolen materials.[702] Many of these are small enough to fit into a compact suitcase and can be easily concealed from public view. It may be easiest for terrorists to build a nuclear weapon from fissile material since it is smaller, lighter, plentiful, and typically has fewer security measures in place for its protection. With access to weapons-grade material, notably highly enriched uranium

[702] Allison Graham, *Nuclear Terrorism, The Ultimate Preventable Catastrophe* (New York: Times Books/Henry Holt, 2004), 22.

(HEU), terrorists could likely build a gun-type bomb, which is the most basic type of nuclear weapon.[703] Nations with spent fuel reprocessing plants have the plutonium necessary to construct nuclear weapons, which without proper safeguarding, terrorists could steal for clandestine purposes. Since a certain amount of material is unaccounted for in reprocessing, it is impossible to know with certainty if some of it is diverted. Terrorists could also use this fissile material to construct a dirty bomb, a radiological weapon that combines radioactive material with conventional explosives. Another concern is the acquisition of an intact nuclear weapon either from a state voluntarily sharing one, or from a senior official who for different motives might provide one. The most direct way for a terrorist group to acquire an intact nuclear weapon would be to receive one directly from a government, which would greatly simplify the means and security systems they would have to overcome to obtain one. This worst-case scenario of rogue states teaming with ruthless terrorists has structured foreign policy toward certain states. For example, Iraq, under the leadership of Saddam Hussein, was feared and seen as a major threat to providing weapons of mass destruction to terrorists, and this belief was used as grounds for invasion.

The threat of nuclear terrorism does not only include the construction or theft of nuclear weapons; terrorists may also threaten the security of nuclear facilities and power plants. A terrorist group could attempt to harm vital plant systems in order to maximize damage to a nuclear power plant facility and threaten the production of energy. The attack could target numerous plant components and release radiation into the nearby community, harming or causing panic in the local populace. However, since hitting more

[703] Matthew Bunn and Anthony Weir, "Terrorist Nuclear Weapon Construction: How Difficult?," *The Annals of the American Academy*, no. 607 (2006): 139.

than one target at one plant simultaneously would be very difficult, most nuclear power plants would likely be resilient to a serious terrorist attack.[704] By learning from international terrorist incidents and the events of 9/11, safeguards have been strengthened in the security of nuclear plant facilities, including in the U.S. and Russia.

RUSSIA

Russia's multitude of nuclear weapons is considered at risk due to the impoverishment of Russia's military security arrangements and the destruction of the accountability records responsible for securing them. Russia has an estimated 400 tons of weapons-grade plutonium considered by western experts to be "at risk" from theft because of poor security. U.S. government experts are negotiating with Russian officials to speed through urgently needed safety upgrades.[705] For example, the U.S. is encouraging Russia to adopt a more sophisticated coding system for its arsenal. Every weapon in the American arsenal is identified and accounted for by a unique serial number. In contrast, Russia's arsenal was produced by type, and lacks identification numbers for each individual weapon, making them easier to disappear unnoticed.[706]

Russia is an area of concern for theft by terrorists, not because the Russian government would intentionally sell or lose weapons or materials, but because it may not be able to account for its entire inventory. There were grave concerns at one time that political instability and economic impoverishment following the collapse of the Soviet Union increased incidents of theft, as the government was ill equipped to completely

[704] Charles D. Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism* (New York: Routledge, 2005), 259.
[705] Nick Paton Walsh, "Russian Nuclear Theft Alarms US," *The Guardian*, Jul. 19, 2002.
[706] Graham Allison, *Nuclear Terrorism, The Ultimate Preventable Catastrophe* (New York: Times Books/Henry Holt, 2004), 49.

account for its arsenal.[707] Although these threats pose a great risk to Russia, they are also concerning for the international community, considering the possibility of Russian nuclear arms being stolen and transported to distant locations. From outright nuclear theft and smuggling, to more general problems of inadequate resources for nuclear security systems, Russia's lapses could prove fatal to other nations.

The collapse of the Soviet Union also presented an enormous threat to nuclear security because the Soviet's ominous arsenal was spread across four newly created countries. Efforts to transport weapons from Kazakhstan, Belarus, and Ukraine to Russia required significant speed and diplomatic muscle during a period of extreme political and economic chaos. The Soviet Ministry of Defense had to move 22,000 tactical nuclear weapons to Russia. Corruption and criminality also increased during this time, as inflation jumped over 2,000 percent, perhaps fueling the motives of terrorists to steal nuclear materials. In light of these historical realities, it is conceivable that most nuclear weapons were recovered, however, the Russian government did not make nuclear security spending a priority amid other political instabilities and it is possible that some were lost. In contrast to immediately after the fall of the Soviet Union, currently the Russian government has the financial resources to pay for more effective nuclear security, and has dutifully increased the security measures at Russian nuclear facilities, especially at those closest to the Chechen border.[708]

Considering Russia's extensive arsenal, it is incredibly important for Russia to work closely with the international community to commit to safeguarding nuclear

[707] Graham Allison, "Nuclear Terrorism: How Serious a Threat to Russia?" *Russia in Global Affairs* (2005): 3.
[708] Matthew Bunn and Anthony Weir, "Terrorist Nuclear Weapon Construction: How Difficult?," *The Annals of the American Academy*, no. 607 (2006): 36.

facilities and fissile material. Russia will need to help lead the world's effort to prevent any incidents of nuclear terrorism. It is known that "not a single former Soviet nuclear weapon has been found in another country or in an international arms bazaar. This incredible result is testament to the determined efforts of the Russian government, including in particular the nuclear guardians in its Ministry of Defense and Ministry of Atomic Energy."[709] Already they have developed and improved technologies for locking up at-risk materials, and shown evidence of improved security. These measures will have positive effects for public perception in Russia, as well as in the international community.

Russia still possesses one of the world's largest arsenals and consequently has one of the largest jobs of all the nuclear powers in securing and reducing its arsenal. The total number of nuclear weapons in the world has been declining for over a decade due to dismantlement by the U.S. and Russia. Both countries have dismantled thousands of nuclear weapons since the 1980s, but they still exist which raises the concern for theft. Russian nuclear materials have been stolen at least a dozen times.[710] The security of these nuclear materials is a grave concern to both Russia and the U.S., and these incidents have motivated both governments to take more serious, concerted efforts toward increasing security for these nuclear possessions.

Many of the implemented measures in Russia have been successful and can be learned from by the international community. The Russian government fit its weapons with locks to prevent unauthorized deployment. This would make the deployment of a bomb virtually impossible. The U.S. has also funded the Nunn-Lugar Cooperative Threat

[709] Graham Allison, "Nuclear Terrorism: How Serious a Threat to Russia?" *Russia in Global Affairs* (2005): 5.
[710] Graham Allison, *Nuclear Terrorism, The Ultimate Preventable Catastrophe* (New York: Times Books/Henry Holt, 2004), 33.

Reduction Program, which works to secure nuclear weapons and materials in Russia and to find work for underemployed ex-Soviet nuclear scientists, reducing their incentive to sell nuclear materials or technology for extra cash.[711] The Russian government has also implemented a new system of regulations for its nuclear material transport trains, enhanced its high-level security forces, and improved security strategies against attacks at all of Russia's nuclear power plant facilities.[712] With more funding, Russia has exhibited much better control of its stockpiles. Russia provides a very important area of learning for the U.S., especially as it must work with other countries to make securing nuclear facilities and materials an urgent priority. There have been many improvements that Russia has taken that are in the power of other countries to mimic in order to increase worldwide security against the threat of nuclear terrorism.

CHECHEN SEPARATISTS AND THE CAPACITY FOR TERROR

The only confirmed case of attempted nuclear terrorism in Russia occurred in 1995, when a crude bomb was placed in Moscow's Ismailovsky Park by Chechen separatists. The group alerted a national television station of the crude bomb's location, and though the bomb was not ultimately detonated, the group succeeded in threatening the public with what it could do to inflict harm. Even today, some people living near Moscow's Izmailovsky Park are convinced they were somehow contaminated by the cesium from the undetonated bomb.[713]

While traditional political groups are motivated by political goals, separatist groups likely see possession of a nuclear device as having strategic value in their quest to gain recognition by the international community and the target country. In fear of

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711 Robin M. Frost, *Nuclear Terrorism after 9/11* (New York: Abingdon, 2004), 23-27.
712 Ibid.
713 Ibid, 9-12.

international backlash, it is unlikely that they would actually detonate a nuclear device, using it instead to instill fear. The rebels in Chechnya have engaged in conflict with Russia to gain independence for over ten years. Over 100,000 civilians have died from this war and it is the deadliest conflict in the former Soviet Union. More recently, Islamists from neighboring Ingushetia and Dagestan have also engaged in similar pursuits against the Russian government. To advance their agenda against the Russian government, Chechen separatists have showed interest in acquiring nuclear weapons technology and material, and believe in the use of biological and chemical warfare.[714] They have also showed a strong capacity for violence and terror, including torture and beheadings, and have links to Islamic extremist organizations, including Al Qaeda. Although their main target would likely be Moscow, their motivations could also extend to other countries, due to their financial backing by Al Qaeda and other Islamic extremist groups. Further, Chechens have proved a ready audience for Islamic extremism due to their impoverishment, disenfranchisement, increasingly large sources of financial backing from Al Qaeda, and close ties to senior officials.[715]

Chechen separatists have a long history of nuclear interest and involvement. In 2000, Chechen militants successfully stole low enriched uranium (LEU) from a nuclear waste plant in Grozny, the capital city of the Chechen republic. They also stole radioactive materials, including plutonium, from the Volgodonskaya nuclear power station in 2001. In this incidence of theft, they took over the use of the railway system and special trains, which are used to ship all nuclear weapons and materials across

[714] Paul Murphy, *The Wolves of Islam: Russia and the Faces of Chechen Terror* (New York: Potomac Books, 2004): 189.
[715] Graham Allison, *Nuclear Terrorism, The Ultimate Preventable Catastrophe* (New York: Times Books/Henry Holt, 2004), 33.

Russia.[716] No one doubts that in the Chechen fighters, the Russian government faces capable, determined adversaries. Chechen fighters have demonstrated imagination, organization, ruthlessness, determination, and willingness to sacrifice lives in a series of terrorist attacks.

Due to past Chechen terrorist attempts, Russia has overhauled security measures and paid more careful attention to Chechen activities, including the group's finances. The Chechen separatist group is officially recognized as a terrorist organization and in the U.S. they have been added to the U.S. Treasury Department's Office of Foreign Control Assets List in the "Specifically Designated Global Terrorists" category. Their U.S. assets were frozen, and U.S. citizens and organizations are prohibited from making contributions or receiving any funds, goods, or services for the benefit of groups on the Treasury Department's list.[717] In freezing their assets, the U.S. has shown that it will not allow this terrorist group to flourish in its country and is helping to take a stand against the group's expansion. The Chechen separatists have been severely weakened by Russian and U.S. government efforts and it is unlikely that they will be able to obtain nuclear weapons in the future. However, the Chechen's capacity for terror makes clear the importance of implementing the necessary security measures to take a stance against the threat of nuclear terrorism.

PAKISTAN

Pakistan is especially an area of concern because it serves as the headquarters for Al Qaeda, and its stockpile is more likely than any in the world to come into the hands of

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[716] Graham Allison, *Nuclear Terrorism, The Ultimate Preventable Catastrophe* (New York: Times Books/Henry Holt, 2004), 33.
[717] Paul Murphy, *The Wolves of Islam: Russia and the Faces of Chechen Terror* (New York: Potomac Books, 2004), 204.

Islamist extremists.[718] Pakistan is believed to possess a minimum of 70-90 nuclear weapons and possibly as many as 110. It suffers from a volatile domestic political situation and some of its population harbor support for radical Islamists. These include a number of different groups who wish to install a fundamentalist regime, as well as the Taliban, which strikes at government targets in revenge for Pakistani military attacks on its possessions within the country. The Pakistani government faces threats from Al Qaeda and nuclear insiders, some of whom might be willing to sell nuclear weapons technology to terrorists, including Dr. A.Q. Khan, a leading Pakistani nuclear weapons program official. Khan admitted to providing highly sensitive material to several nations in black-market dealings, including Iran, Libya, and North Korea.[719]

Actors like Khan pose potentially the greatest threat to nuclear security. Khan acquired the technological components and fissile material needed to begin a nuclear program in Pakistan under the Pakistan Atomic Energy Commission (PAEC). He was educated in Germany and worked in the Netherlands, and used that training to bring nuclear weapons to Pakistan. Khan founded the uranium enrichment project in the 1970s, and during the 1990s, there were intermittent clues that Khan was discussing the sale of nuclear technology to countries of concern. By early 2000, it became clear that Khan was at the center of an international proliferation network, involved in clandestine black market dealings. Khan was the central figure in the proliferation network, but he was assisted over the years by a number of money-seeking freelancers from other countries. They sold materials and components related to centrifuge technology to what is believed to be at least

[718] Matthew Bunn and Anthony Weir, "Terrorist Nuclear Weapon Construction: How Difficult?," *The Annals of the American Academy*, no. 607 (2006): 28.
[719] Charles D. Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism* (New York: Routledge, 2005), 56.

Libya and Iran though the Pakistani government denied any involvement in these black market dealings.[720] Khan's actions show a willingness to sell nuclear weapons technology to outside parties interested in attaining it, an important consideration that Pakistan's government will have to curb in order to secure their arsenal.

Pakistan continues to increase the size of its nuclear arsenal and it will soon be the fifth largest nuclear weapons holder. The real concern behind its increased nuclear program is the production of fissile material, especially plutonium. Pakistan is in the final stages of work on a large new plutonium-producing reactor, which will increase its ability to produce a powerful new generation of weapons, defying the prospect of halting the production of weapon-grade material.[721] Interestingly, at the same time, the government pledges that it has taken critical steps to increase the safety and security of its fleet. In 2004, the U.S. began helping Pakistan to develop security measures, including authorization codes to safeguard its weapons, which would prevent terrorists from using them if they gained possession of them. This agreement was based on the promise that Pakistan would fight militants. Although the U.S. opposes nuclear buildup in Pakistan, the two countries consider themselves allies on nuclear issues. However, the U.S. has also accused Pakistan's military intelligence agency, the Inter-Services Intelligence (ISI), of supporting terrorist organizations. Although Pakistani officials have denied involvement, some are believe to have connections to the 2008 bombing of the Indian embassy. ISI has also been accused of supporting militant groups on the U.S. State Department's Foreign Terrorist Organizations list, operating in the

[720] Paul Murphy, *The Wolves of Islam: Russia and the Faces of Chechen Terror* (New York: Potomac Books, 2004): 204.
[721] David E. Sanger and Eric Schmitt, "Pakistani Nuclear Arms Pose Challenge to U.S. Policy," *The New York Times,* Jan. 31, 2011.

disputed Kashmir region along the Pakistan-India border, though the ISI has denied any wrongdoing or connections with such groups.[722]

Pakistan's desire to increase the size of its nuclear arsenal makes it a point of interest. The U.S. and international community must pay special attention and carefully analyze its inventory and implemented security measures. So far, it has implemented efforts to improve its existing security measures. Among these, its largest success has been the use of security code technology for its weapons, which would prevent any unauthorized person from using them. Authorization code technology can play a large role in securing existing arsenals and should be implemented in arsenals that do not yet have such technology. Also, during peacetime, nuclear and non-nuclear components of Pakistan's nuclear weapons are kept separate, which greatly deters terrorists' efforts to seize an intact nuclear device.[723]

THE AL QAEDA NETWORK AND ISLAMIC EXTREMISM

The Al Qaeda network is known for its extremist beliefs and violence. Its disdain of the western world and the U.S. make this group of particular concern and it is given special attention in the effort to prevent a terrorist attack. Were it to attack the U.S. again, New York and Washington, D. C. would be likely target cities, though other possibilities include Los Angeles, San Francisco, and Chicago. Any of these targets would likely cause profound destruction, much akin to the events of 9/11. In a 1998 interview, Osama bin Laden, Al Qaeda's headman, stated that,

> Acquiring weapons for the defense of Muslims is a religious duty. If I have indeed acquired these weapons, then I thank God for enabling me to do so. And if I seek to acquire these weapons, I am carrying out a duty. It would be a sin for Muslims not to

[722] Robin M. Frost, *Nuclear Terrorism after 9/11* (New York: Abingdon, 2004), 26.
[723] Charles D. Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism* (New York: Routledge, 2005), 79.

> try to possess the weapons that would prevent the infidels from inflicting harm on Muslims.[724]

This quote highlights the well-justified concern that the U.S. has for Al Qaeda. Abu Gheith, spokesman for Al Qaeda, said in much the same terrorizing fashion: "We have the right, to kill 4 million Americans – 2 million of them children – and to exile twice as many and wound and cripple hundreds of thousands."[725] So long as nuclear materials are readily available for taking, some terrorist groups will likely continue to attempt to gain access to them and further their nuclear scientific knowledge. The ideology of Al Qaeda clearly points to the capacity for terror that this group possesses, and the clandestine nature of their dealings and leadership makes this group a continuing threat that deserves special attention.

Osama bin Laden's goal is to overtake the U.S. as a global superpower and to free the Muslim world of American influence by way of holy war. The use of nuclear weapons would have an extraordinary psychological impact on the target country, as well as the catastrophic physical damage.[726] Al Qaeda targeted the U.S. on 9/11 and also in the bombing of two U.S. embassies in East Africa in 1998, and in 2000, when they attacked the U.S.S. Cole. Other groups affiliated or inspired by Al Qaeda, have engaged in other mass-casualty terrorist attacks. These include the train bombings in Madrid, Spain in 2004 in which hundreds died and thousands more were injured. The Moroccan Islamist Combat Group and Salafiya Jihadiya are both groups investigated for the Madrid train bombings and are believed to be associated with Al Qaeda.[727] These worldwide events show the scope of their

[724] "Osama bin Laden v. the U.S.: Edicts and Statements," PBS Frontline, http://www.pbs.org/wgbh/pages/frontline/shows/binladen/who/edicts.html (accessed Feb 1, 2011).
[725] Allison Graham, *Nuclear Terrorism, The Ultimate Preventable Catastrophe* (New York: Times Books/Henry Holt, 2004), 12.
[726] Charles D. Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism* (New York: Routledge, 2005), 22.
[727] Robin M. Frost, *Nuclear Terrorism after 9/11* (New York: Abingdon, 2004), 56.

accomplishments and the need for urgency in preventing them from obtaining nuclear weapons.

Al Qaeda has plentiful resources for funding and corresponds with scientists knowledgeable about nuclear engineering. Al Qaeda leaders have met on several different occasions with Sultan Bashiruddin Mahmood, one of Pakistan's leading specialists in uranium enrichment who is also an Islamic extremist. Mahmood spent thirty years at the Pakistani Atomic Energy Commission and at the Kahuta plant that produced the enriched uranium for Pakistan's first bomb test. In the early 1990s, Al Qaeda officials took repeated trips to Central Asia and corresponded with Soviet officials. According to the National Intelligence Council, there were four separate occasions in which weapons-usable nuclear materials were stolen from Russian institutes and possibly sold to the Al Qaeda network. The U.S. Central Intelligence Agency believes that they have experimented with chemical weapons, including nerve gas, biological weapons such as anthrax, and dirty bombs.[728] Al Qaeda has a clear hatred for the Western world and the U.S. is a likely target for future terrorist attacks. It is unknown exactly what its next step will be and a nuclear attack is a frightening possibility. The U.S. government needs to make combating nuclear terrorism its utmost priority in order to prevent an attack that would cause severe physical and psychological damage.

THE AUM SHINRIKYO CULT

Aum Shinrikyo is a cult, which was formed in Japan in the 1980s. It was started by Shoko Asahara, who preached the end of the world was drawing near, predicting its end in 1996, or between 1999 and 2003. He predicted a violent end to humanity, sparked

[728] "Osama bin Laden v. the U.S.: Edicts and Statements," PBS Frontline, http://www.pbs.org/wgbh/pages/frontline/shows/binladen/who/edicts.html (accessed Feb. 1, 2011).

by a nuclear cataclysm caused by a U.S. attack on Japan with weapons of mass destruction in a World War III-type exchange. He preached that only followers of Aum, meaning "supreme truth", would survive such an apocalypse.[729] The group accumulated wealth from operating businesses and recruited top-notch university students, often from elite Japanese families, those who could "have been among society's most fulfilled," as well as scientists and engineers.[730] After several Aum members unsuccessfully ran for Japanese parliament, the cult spent time building a factory near Mount Fuji to produce weapons and build an arsenal.[731]

In 1995, cult perpetrators put a liquid form of sarin, a highly toxic nerve gas and chemical weapon, into tightly contained packages, onto five cars on three subway lines that converged at the Kasumigaseki station in Japan, around which many government ministries are concentrated. Witnesses said that subway entrances resembled battlefields as injured commuters lay gasping on the ground with blood gushing from their noses or mouths. Asahara wanted to destroy the capital of Tokyo, create an Aum state, and rule as its king. Twelve members of Aum, including Aum founder Shoko Asahara, were sentenced to death for the deadly subway attack. The incident killed twelve and caused thousands to seek medical attention.[732]

This attack stands as the most deadly terrorist attack in Japan's modern history. It caused massive disruption and instilled widespread fear throughout Japanese society. The subway attack is significant, because it showed the world the ease with which a small

[729] Graham Allison, *Nuclear Terrorism, The Ultimate Preventable Catastrophe* (New York: Times Books/Henry Holt, 2004), 40.
[730] Onishi, Norimitsu, "After 8-Year Trial in Japan, Cultist is Sentenced to Death," *The New York Times*, Feb. 28, 2004.
[731] Graham Allison, *Nuclear Terrorism, The Ultimate Preventable Catastrophe* (New York: Times Books/Henry Holt, 2004), 43.
[732] "Country Reports on Terrorism – Terrorist Organizations." U.S. Department of State, http://www.state.gov/s/ct/rls/crt/2007/103714.htm (accessed Feb. 4, 2011).

cult or group of terrorists with limited means to engage in chemical warfare could cause much disruption. It illustrated that groups not affiliated with rogue states posed a great national security risk.[733] During the 1990s, Aum attempted to purchase nuclear technology and data from Soviet officials and when they were not successful they attempted to steal sensitive nuclear power plant information. Aum's "construction minister," Kiyohide Hayakawa, made several trips to Russia to recruit physicists and engineers. Documents from the investigation of the 1995 sarin subway attack included price quotes for several nuclear warheads and evidence that Aum had purchased equipment to be used in the construction of a nuclear bomb in the U.S.[734]

At the time of the sarin attack, the Aum Shinrikyo cult claimed 40,000 members worldwide, mostly in Japan and in Russia. Today, their numbers are much fewer, approximately 1,500. The group split into two factions in 2007 due to internal friction over attempts to moderate the cult's religious beliefs and improve its public image. Both groups remain under surveillance by Japanese authorities for its previous attempts to carry out chemical and biological attacks. Most of Aum's current 1,500 members live in Japan while about 300 reside in Russia. This group had at one time amassed an expansive number of members throughout the world but it has not been able to continue its popularity at the same level and is no longer a major concern. Although all terrorists groups should be watched closely for their activities and dealings, Aum Shinrikyo is no longer a very large threat and it is unlikely it will obtain nuclear weapons in the future.

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[733] "Aum Shinrikyo." Council on Foreign Relations, http://www.cfr.org/japan/aum-shinrikyo/p9238 (accessed Feb. 1, 2011).

[734] Graham Allison, *Nuclear Terrorism, The Ultimate Preventable Catastrophe* (New York: Times Books/Henry Holt, 2004), 41.

EFFORTS TO PREVENT TERRORISM BY THE U.S. AND INTERNATIONAL ORGANIZATIONS

So long as nuclear weapons are in existence, they will likely be viewed as important instruments of power and prestige in the international community and terrorist groups will aim to seize them.[735] The security and safety of existing nuclear weapons and fissile material is a continuing threat. Countries that have signed the Nuclear Non-Proliferation Treaty have not committed to complete reduction and elimination of their arsenals. Existing arsenals are in the U.S., Pakistan, India, United Kingdom, France, China, Russia, North Korea, Israel, and possibly Iran. The International Atomic Energy Agency (IAEA)'s Illicit Trafficking Database (ITDB) indicates that the majority of past trafficking incidents involved natural uranium, depleted uranium or LEU reactor fuel, which is not weapon-usable. There have been twenty incidents involving HEU or plutonium-239, but in small fractions of the 25 kilograms of HEU required for a basic bomb.[736]

Since 9/11, the U.S. has heightened its dedication to curbing terrorism and has taken steps to work with the international community on this effort. The goals of these collaborative measures are to prevent and deter the acquisition of nuclear weapons and materials by terrorist groups, to reduce and cease production of new nuclear weapons, monitor nuclear stockpiles, and prepare to react to a terrorist nuclear event, should one occur.[737] There is enthusiasm for world leaders to commit to further non-proliferation efforts and to increase worldwide security of nuclear stockpiles. In preventing the risk of

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[735] Jenkins, Bonnie. "Combating Nuclear Terrorism: Addressing Nonstate Actor Motivations," *The Annals of the American Academy*, no. 607 (2006): 36.
[736] Robin M. Frost, *Nuclear Terrorism after 9/11* (New York: Abingdon, 2004), 13.
[737] Matthew Bunn and Anthony Weir, "Terrorist Nuclear Weapon Construction: How Difficult?," The Annals of the American Academy, no. 607 (2006): 108.

terrorism by Al Qaeda, the U.S. may need to work on its foreign relations policies in the Middle East to curb the spread of further anti-Western sentiment and to secure nuclear stockpiles there.

The Nuclear Regulatory Commission (NRC) has also increased its response to the threat of a terrorist attack. It has initiated a thorough review of its security program; inspected nuclear facilities to ensure they are equipped with upgraded security measures; formed the Office of Nuclear Security and Incident Response, which works closely with the Department of Energy and the Department of Homeland Security; and has established a five-level threat alert system. Other countries have also stepped up security measures of their nuclear facilities, including France, which has implemented a strict no-fly zone above its nuclear facilities. In Russia, power plant security personnel have conducted training exercises to prevent attacks.[738]

The IAEA has been an important regulating organization for providing resources to the nuclear security effort and its leadership will likely be critical to creating a worldwide security plan to fight nuclear terrorism. IAEA programs that assist its members include training programs intended to help raise security standards and contingency planning for use in the case of a terrorist attack. To aid in this effort, the agency has urged its member states to design a plan to assess the most critical security enhancements that are needed. The IAEA Emergency Preparedness Review (EPREV) also assists in designing emergency preparedness plans.[739] Furthermore, the IAEA has coordinated conferences between many countries to increase international cooperation in fighting nuclear terrorism. At the 47th IAEA General Conference in Vienna in 2003, a

[738] Charles D. Ferguson and William C. Potter, *The Four Faces of Nuclear Terrorism* (New York: Routledge, 2005), 239.
[739] Ibid, 247.

resolution was adopted to emphasize the importance of the agency's safeguards for the international community.[740]

CONCLUSION

Public perception and exaggeration have espoused a sense of fear and widespread concern, suggesting that nuclear terrorism is the single biggest threat to security throughout the world. The ramifications of a nuclear explosion in a major city would have political, economic, and security impacts for a country that would reverberate throughout the world. Drawing from the past history of many terrorist groups and actors, it is clear that these groups share in common a propensity for violence and a willingness to inflict mass casualties to achieve their objectives. More realistically, however, there is considerable evidence that shows that the speculation surrounding nuclear terrorism is exaggerated. There are many technical considerations that must be considered, including that assembling enough fissile material for a nuclear device would be very difficult and costly.[741] To date, the ITDB has shown that not enough HEU has been stolen collectively to make a nuclear bomb. LEU has been stolen in larger amounts, but LEU is not weapons-usable without further enrichment.

The incidents to date suggest that there are many types of threats and many different forms of perpetrators. Terrorist groups that have a history of purposeful infliction of violence and that possess access to nuclear knowledge include socio-political organizations, nationalist or separatist groups, non-state actors, individual actors, and possibly even state actors. Al Qaeda, perhaps the gravest terrorist group of concern, is independent, while others, such as Hezbollah is sponsored by Iran, a state actor. Aum

[740] "The IAEA General Conference," IAEA, http://www.iaea.org/About/Policy/GC/GC47/index.html (accessed Feb. 1, 2011).
[741] Robin M. Frost, *Nuclear Terrorism after 9/11* (New York: Abingdon, 2004), 69.

Shinrikyo portrayed clear apocalyptic motivations and suggests a potential future threat from religious cults with similar visions. Although different terrorist groups have different ideologies, their objectives are often similarly destructive.

Though the threat is grave, a lot of helpful information can be drawn from past incidences of nuclear theft, group activities, and successful measures taken to prevent nuclear terrorism in the future. Russia has improved its nuclear security through the use of code technology, training, and increased financing for this task. Pakistan has followed suit and with the U.S.'s help is increasing its use of code authorization technology. This is progress but it is not enough and the need for further measures to prevent theft of the essential components of nuclear weapons is truly a global problem. Every country where nuclear weapons, plutonium, or HEU exist needs to take further steps to ensure that these deadly stockpiles are secure. More should be done to exchange nuclear security practices and to strengthen the culture of security initiatives, in addition to creating a strong multilayered defense mechanism.

Nuclear terrorism is a preventable catastrophe and one that deserves more attention and cooperative effort from the international community. Although nuclear weapons and nuclear materials throughout the world remain vulnerable to theft, higher international security standards and safeguards can prevent a terrorist nuclear attack. The U.S. and its allies must treat this worldwide security threat as an urgent issue and work diligently to prevent it.

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Chapter Thirteen

IMPLICATIONS OF THE U.S.-INDIA DEAL

Chantal Anderson

Abstract:

India, the world's largest democracy and a nuclear weapons state, is a crucial U.S. ally in Asia but has never signed the Nuclear Non-Proliferation Treaty (NPT). India developed its military and civilian nuclear technology as a stepping-stone to prestige, national security, and energy security, but did so in isolation. India is very important to the United States, both for positive and negative reasons; as a counter to China and as a nemesis to neighboring Pakistan. Partly for these reasons, the U.S. struck a deal outside of the NPT with India, providing them access to U.S. technology and resource sharing. The U.S. claims the deal benefits the global community, since the deal includes IAEA regulation of India's civilian reactors. The deal specifically benefits the U.S. through increased trade with India. For India itself, the deal offers a chance for it to expand its civilian power sector significantly and thus bring electricity and related development to many of its people. However non-proliferation advocates have raised concerns that the deal represents a damaging precedent and a step backward by discrediting the NPT. While certainly legitimate, such concerns are seen by most U.S. officials as outweighed by the present and future need to bring India into the international nuclear community. Based on research and analysis, this report argues bilateral agreements addressing nuclear power like the U.S.-India deal are necessary to ensure the safety of civilian and military reactors.

INTRODUCTION

Since the creation of the Nuclear Non-proliferation Treaty (NPT), Indian diplomats have faced a difficult decision; join the NPT and relinquish all rights to test weapons and create a defense shield strong enough to compete with fellow NPT states; or refuse to sign the treaty. The world's largest democracy decided to turn its back on the NPT and continued to pursue a secret nuclear weapons program already well underway. In 1974, four years after the NPT entered into force, India successfully tested a nuclear device, announcing its decision to the world and posing a major challenge to the new treaty. The path chosen by India was perhaps partly determined by regional political conflicts, including those with Pakistan and also China, which set off its own nuclear device in 1964, only two years after humiliating the Indian military in a border war. India was well-positioned to develop a hidden weapons program due to its having secured facilities for the complete fuel cycle, including a heavy-water research reactor from Canada and a reprocessing plant. India's ability to produce, as it said, a "peaceful nuclear explosion," had existed for some time.

But then, in 1998, India surprised the world once again with their decision to test nuclear weapons. In response to these tests Pakistan set off several nuclear devices of its own, heightening tensions in the region. This move worried U.S. officials and a few months later President Bill Clinton made his first trip to India. While no concrete legislation came out of this meeting, it was an important step in clarifying U.S. policy on the matter. In 2005, President George W. Bush took his first trip to India. After 9/11, the stakes for U.S. security had increased and the U.S. government feared Islamic extremists groups throughout the Middle East and Asia. U.S. diplomats decided it had become imperative to separate India's civilian reactors from its military programs, and to regulate the agency. In exchange for this, the U.S. would ensure through the Nuclear Suppliers Group (NSG) that India could trade nuclear materials with America and other countries, though these materials were supposed to be used for energy advancement alone. On July 18, 2005, President Bush and Indian Prime Minister Manmohan Singh signed a joint statement creating the framework for such an agreement.

The agreement between India and the U.S. outside of the NPT was an unprecedented movement of cooperation between the NSG and the U.S. Congress. Some feared the deal was a step back for a world in pursuit of non-proliferation, while policymakers and others swore the deal would bring India into the fold of nuclear power states, as well as ignite economic relations between the two countries and advance development in India by improving access to electricity. The U.S. undoubtedly saw (and continues to see) India as its greatest ally in Asia, particularly with regard to a rising and nuclear-armed China. In that spirit, the Bush administration's decision to approve the deal chauffeured India into its role of upcoming superpower. The deal was extremely controversial for non-proliferation advocates who felt the special agreement would weaken the NPT and incite an arms race in Asia. However, as argued in this paper, the bilateral deal (and perhaps certain future deals) was a type of "necessary evil," given the unlikelihood of India joining the NPT, and the need to bring the country more into the community of nuclear power states. Such a move was necessary to ensure the safety and monitoring of India's civilian nuclear program and to address global warming concerns, as India is a major consumer of coal. Additionally, imperfect deals like the NPT are not equipped to address the advancement of non-NPT country nuclear reserves, which will be necessary for the growth of nuclear power. This paper first explores the history and controversy surrounding the deal, and then addresses the effects of signing the treaty on U.S. foreign relations in regards to non-proliferation and energy growth in India today.

INDIA'S ENERY SITUATION

One of the Indian government's fundamental development goals is to bring electricity to its entire population. The government has also committed itself to finding ways to lower carbon emissions, yet its largest natural resource in the energy domain is coal, with lesser endowments of oil and gas. Nuclear power thus has the capability to serve three primary government policy objectives: economic development, energy security, and, by replacing fossil fuels, reduced carbon emissions. During the 2000s, however, India's nuclear program was running low on uranium fuel (its reactors were running at 50 to 60 percent capacity), which had to be produced domestically from small reserves, as the country remained under international trade restrictions in nuclear materials. The U.S.-India deal opened up the country to international fuel supply; since a 2008 spin-off agreement with the Nuclear Suppliers Group (NSG), India has signed cooperation agreements with a number of fuel supplying countries, including Russia, Kazakhstan, Mongolia, and Namibia. This has significantly aided India's ability to pursue nuclear power advancement.

Electricity usage in India is escalating along with population expansion. It is estimated that per capita electricity use will double by 2020.[742] India relies on coal for 68 percent of electricity demands, but reserves are not sufficient to support a significant expansion at present extraction levels and would also greatly increase the nation's pollution levels and carbon emissions. India is reliant on other countries for the majority of its petroleum and natural gas and may need to import as much at 90 percent of these fuels by 2025.[743] A potential reliance on Middle Eastern oil could increase supply concerns for India, the U.S. and the world.[744] Until India develops other reliable and more sustainable power sources, over 580 million people will remain without consistent electricity.[745] Approximately 20 percent of the Indian population remains in the dark.[746] For the 80 percent who have access to electricity, blackouts and brownouts are common

[742] "Nuclear Power in India | Indian Nuclear Energy," *World Nuclear Association* | Nuclear Power - a Sustainable Energy Resource, http://www.world-nuclear.org/info/inf53.html (accessed Feb. 1, 2011).
[743] "MORE THAN 1.6 BILLION PEOPLE LIVE WITHOUT ELECTRICITY," *Europe Energy High Beam Research*. http://www.highbeam.com/doc/1G1-95531792.html (accessed Feb. 9, 2011).
[744] Ibid.
[745] Ibid.
[746] "World Nuclear Power Reactors | Uranium Requirements | Future Nuclear Power," *World Nuclear Association*. http://www.world-nuclear.org/info/reactors.html (accessed Feb. 16, 2011).

occurrences. Without a reliable and expandable alternative to coal, India will continue to suffer from high levels of poverty, pollution, and potential civil unrest. Since India is the world's largest democratic state and a strong ally of the U.S., bolstering India's economy and civilian nuclear commerce through the U.S.-India deal was viewed as a win-win agreement, beneficial for U.S. interests as well as India's. The agreement opened up physical and knowledge resource trading for India by aiding technological development of safe nuclear energy systems and supplying enriched uranium for civilian nuclear purposes.

India has made large advances in the past half century toward using clean energy, and despite its lack of substantial fossil fuel reserves, the country is working toward a higher level of energy independence, largely through investments in nuclear technology. Currently India has 20 operational reactors generating 4,385 net GWe of nuclear energy. This represents a mere four percent of its total electricity, but the country has big plans for the next several decades, with as many as 58 total reactors planned or proposed as of February 2011. At this level, nuclear plants could generate over 49,000 GWe or 25 percent of the country's electricity.[747,748] India is in agreements with the U.S. and Russia in building several of these reactors.

India's government is also interested in next-generation reactor types, specifically those that employ thorium as a principal fuel, since India is not naturally rich in uranium, the traditional fuel used in the nuclear power cycle. India currently supports the leading

[747] "World Nuclear Power Reactors | Uranium Requirements | Future Nuclear Power," *World Nuclear Association.* http://www.world-nuclear.org/info/reactors.html (accessed Feb. 16, 2011).
[748] "Nuclear Power in India | Indian Nuclear Energy," *World Nuclear Association*. http://www.world-nuclear.org/info/inf53.html (accessed Feb. 1, 2011).

R&D program in thorium.[749] In 2005, India released what it dubbed the "safest nuclear reactor in the world."[750] This thorium breeder reactor can produce 600 MW for two years with almost all automatic controls (limiting chances of human error) and no necessary refueling. The reactor uses a plutonium seed (neutron source) to transform thorium-232 into uranium-233 which then fissions, so that no enriched uranium is required. Operational since 2005, the advanced thorium breeder reactor is considered an important step forward.

The U.S.-India deal enables India to import uranium and build reactors with fewer restrictions and has ignited the nuclear solution to solve India's fossil fuel shortage. India has increased its production of nuclear energy significantly since signing the deal.[751] Improved international cooperation has placed India on a path toward reaching its 2010 goal of producing 60 GWe of nuclear energy by 2032. The deal also helps relieve India's growing reliance on Middle Eastern countries for natural gas, particularly states with which the U.S. has poor relations, such as Syria, Sudan, and Iran. This bilateral deal was necessary to aid India in its pursuit of energy security solutions. Without the agreement, India's nuclear energy program would not have been able to expand and grow at the rate it has since 1998.

INDIA'S NUCLEAR HISTORY

India's long history of technological advancements in nuclear power is necessary to understand why the U.S. chose to make a nuclear deal with India outside of the NPT.

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[749] "Next100 - A Dialogue on the Next Century of Energy," *Next100 - A Dialogue on the Next Century of Energy*, http://next100.com/nuclear, N.p., n.d. (accessed Feb. 16, 2011).
[750] "World's safest N-reactor by India," *Rediff.com*. http://www.rediff.com/news/2005/aug/25nuke.htm (accessed Feb. 8, 2011).
[751] "Nuclear Power in India | Indian Nuclear Energy," *World Nuclear Association*. http://www.world-nuclear.org/info/inf53.html (accessed Feb. 1, 2011).

At the time of the NPT's creation in 1970, the UN recognized five countries as nuclear-weapon states. Four years later India became the world's sixth nuclear weapon state, and faced the options of disarming and joining the treaty, or staying outside of the agreement. India chose the latter, and to this day argues the treaty is an unfair arrangement that favors certain countries over others. This section addresses India's unique situation, from important moments in India's nuclear history, like the state's nuclear beginnings as a secret nuclear program, to the 1998 tests that accelerated tensions in Asia and led to the eventual signing of the U.S.-India Agreement.

In 1948, a few months prior to independence, India created its first nuclear program backed by Prime Minister Jawaharlal Nehru and physicist Homi Bhabha. [752] Nehru encouraged the birth of the Indian Atomic Energy Commission (IAEC), while simultaneously writing legislation that ensured the secrecy of this organization. In the wake of the first war with Pakistan over Kashmir, India felt pressure to build up the state's military arsenal. This build up was comparable to that seen in the U.S. during the Cold War. Nehru postulated that this privacy would protect the commission from technology theft. This veil of secrecy over the program remains controversial today. India's naturally rich thorium reserves inspired Nehru to develop cheap electricity, while also creating the groundwork for the full nuclear cycle to be realized. Nehru imagined an India that was home to ore mining, infrastructure for processing and fuel fabrication, research and power reactors, fuel reprocessing facilities, heavy water production, and waste disposal facilities.[753]

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[752] "The Nonproliferation Policy Education Center," *The Nonproliferation Policy Education Center-NPEC.* http://www.npolicy.org/files/Ramana-NuclearPowerInIndia.pdf (accessed Feb. 9, 2011).
[753] "NTI: Research Library: Country Profiles: India," *Nuclear Threat Initiative*. http://www.nti.org/e_research/profiles/India/index.html (accessed Jan. 25, 2011).

In 1970, the Nuclear Non-Proliferation Treaty was ratified. This treaty was signed before India gained nuclear capabilities and India chose to avoid signing on as a non-nuclear weapon state.[754] In 1974, India tested a fissile device under the Subterranean Nuclear Explosion for Peaceful Purposes project. This secretive bomb, known as "Smiling Buddha," surprised many countries and invoked concern over dual-use technology and the potential for reprocessing of nuclear fuel for weaponry.[755] India used plutonium separated from fuel used in a research reactor that had been built by Canada with the intent that it be used for peaceful purposes only.[756] After these tests the U.S. refused nuclear cooperation with India for 25 years and encouraged other countries to follow suit.[757] This project and other nuclear programs were paused during the Janata party ruling government from 1977-1979. In the late 1980's pressure from Pakistan's interest in acquiring nuclear weapons induced then Prime Minister Rajiv Gandhi to approve the weaponization of India's nuclear program.[758]

In the 1990s India worked on growing their nuclear capabilities before future regulations or NPT rules could shut down testing programs. However, U.S. intelligence learned of these planned tests, and convinced Prime Minister Narashimha Rao to postpone them.[759] When the Hindu Nationalist Party, the Bharatiya Janata Party (BJP), came into power again in 1996 the tests were reconsidered, but political fears and tension

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[754] "Asia's Nuclear Energy Growth," *World-Nuclear*, http://www.world-nuclear.org/info/inf47.html (accessed Jan. 21, 2011).

[755] India's Nuclear Weapons Program - Smiling Buddha: 1974," *The Nuclear Weapon Archive - A Guide to Nuclear Weapons*. http://nuclearweaponarchive.org/India/IndiaSmiling.html, (accessed Feb. 9, 2011).

[756] "US, India reach nuclear reprocessing deal - The Times of India," *The Times of India.* http://timesofindia.indiatimes.com/india/US-India-reach-nuclear-reprocessing-deal/articleshow/5739263.cms (accessed Feb. 5, 2011).

[757] "The U.S.-India Nuclear Deal - Council on Foreign Relations," *Council on Foreign Relations*. http://www.cfr.org/publication/9663/usindia_nuclear_deal.html, (accessed Jan. 21, 2011).

[758] "NTI: Research Library: Country Profiles: India," *Nuclear Threat Initiative*. http://www.nti.org/e_research/profiles/India/index.html (accessed Jan. 25, 2011).

[759] Ibid.

quelled plans until 1998. The BJP considered signing the NPT but decided the power and prestige associated with cementing their nuclear capabilities were more important than adhering to the NPT's demands. Author George Perkovich's book, *India's Nuclear Bomb* explains, "The government said that 'the nuclear environment in India's neighborhood' had necessitated the tests to 'provide reassurance to the people of India that their national security interests are paramount.'"[760] Concern over Pakistan's nuclear missile capabilities propelled India into a face off of military tests and tension, not unlike the Cold War.[761] The Janata Party approved and deployed two rounds of nuclear tests, surprising the world, and specifically President Clinton and the U.S. security administration, which was working on peacetime negotiations between India and Pakistan.[762] Before these tests, Indian leaders insisted their state was not interested in building and testing nuclear weapons.[763]

These tests announced India's defensive nuclear policies to the world while also inciting Pakistan to set off five of its own underground devices only two weeks afterward. India's nuclear policies included a "no-first-use" policy and a minimum deterrent doctrine. The "no-first-use" policy states that India will only use nuclear weapons in response to a nuclear attack. The minimum deterrent doctrine states, "The fundamental purpose of Indian nuclear weapons is to deter the use and threat of use of nuclear weapons by any state or entity against India and its forces anywhere."[764,765] After

[760] George Perkovich, *India's Nuclear Bomb: The Impact on Global Proliferation*, (Berkeley: University of California Press, 1999), 417.
[761] Ibid.
[762] "NTI: Research Library: Country Profiles: India," *Nuclear Threat Initiative*. http://www.nti.org/e_research/profiles/India/index.html (accessed January 25, 2011).
[763] George Perkovich, *India's Nuclear Bomb: The Impact on Global Proliferation*, (Berkeley: University of California Press, 1999), 446.
[764] "Asia Times Online :: South Asia news, business and economy from India and Pakistan," Asia Times Online. http://www.atimes.com/atimes/South_Asia/KF04Df03.html (accessed Feb. 17, 2011).

the tests, Indian scientists announced at a press conference that they had tested several different types of nuclear weapons including a thermonuclear device, though this claim was later disputed by American scientists who believed India was incapable of that type of production.[766]

More importantly, the tests put India in a position of power in its negotiations with the U.S. While holding on to some power with economic sanctions put in place after the 1998 tests, President Clinton took a trip to India in March 2000. During this time, rumors of a special treaty for India were abuzz. India's nuclear capabilities placed the U.S. in a complicated position. The options were in India's favor. The U.S. could leave India alone, continue sanctions, and risk the unregulated growth of India's weapons program, or strike a side deal and upset NPT signatories like Japan, Germany, South Africa, Sweden, Argentina, and Brazil, but be able to keep an eye on India's nuclear programs.[767]

Diplomats from India had always been against the NPT saying the treaty separated "nuclear haves with nuclear have-nots."[768] Indian diplomats also argued that without nuclear weapons India would never be seen as a leading world power. Without nuclear weapons, India feared it would not be seen as a major player on the world stage for partnerships in technology for civilian rectors and dual-use high technology like supercomputers.[769]

Despite concerns, in 2005, U.S. President George W. Bush and Indian Prime

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[765] "NTI: Research Library: Country Profiles: India," *Nuclear Threat Initiative*. http://www.nti.org/e_research/profiles/India/index.html (accessed Jan. 25, 2011).
[766] "Nuclear Power in India | Indian Nuclear Energy," *World Nuclear Association*. http://www.world-nuclear.org/info/inf53.html (accessed February 18, 2011).
[767] George Perkovich, *India's Nuclear Bomb: The Impact on Global Proliferation*, (Berkeley: University of California Press, 1999), 491.
[768] Ibid.
[769] Bharat Karnad, *India's Nuclear Policy, (*Westport: Praeger Security International, 2008), 150.

Minister Manmohan Singh signed a bilateral agreement known as a 123 agreement (referring to section 123 of the United States Atomic Energy Act of 1954 which addresses the terms for civilian U.S nuclear cooperation with groups or states in response to non-proliferation concerns). In this deal, India agreed to separate its nuclear civilian programs from its military nuclear work and to subject its civilian program to inspections by the International Atomic Energy Agency (IAEA). The deal was formally known as United States-India Nuclear Cooperation Approval and Non-proliferation Enhancement Act and was approved by the U.S. Congress and President Bush in October 2008.[770] India's long history of nuclear advancements and continued economic and political growth as a superpower in Asia required a deal with the U.S. and India be signed. Without such an agreement, India would have undoubtedly continued its nuclear pursuits, unregulated, while weakening its partnership with the U.S.

EFFECTS OF THE DEAL

The U.S.-India deal expanded India's nuclear energy research capabilities by lifting a three-decade hold on nuclear trade with India.[771] The U.S. had three main reasons for striking this unique deal with India: India's longstanding tradition of nuclear research and a need for regulation (due to its refusal of the NPT); India's unique position as a democratic ally against a rising China and potential terrorist threats in the Middle East; and simply to improve economic relations between the U.S. and India. Skeptics of the deal warned this would jump-start the nuclear arms race in Asia, while also increasing nuclear weapons risks of terrorism and war. However, India was continuing to grow its nuclear weapons program unregulated and would not sign the NPT. After two successful

[770] "The U.S.-India Nuclear Deal," *Council on Foreign Relations*. http://www.cfr.org/publication/9663/usindia_nuclear_deal.html, (accessed Jan. 21, 2011).
[771] Ibid.

rounds of tests and increasing tensions with Pakistan, the U.S. had to address India's nuclear capabilities. India's unique position as a key U.S. ally, surrounded by a sea of undemocratic countries, also heightened the importance of boosting Indian-U.S. relations for the sake of strengthening and important defense partner.

What the Deal Does

In a nutshell the deal creates checks and balances for India's nuclear energy program, ensuring outside inspections of its civilian nuclear program by the IAEA.[772] India also committed to several "non-proliferation" moves, such as: bolstering security of nuclear arsenals, refraining from nuclear weapons testing, and allowing U.S. companies to build nuclear reactors in India. Mimicking the NPT, India also agreed to sign a Fissile Material Cutoff Treaty, which committed India to a future ban on atomic weapons making. This deal ensured that India would begin safeguarding domestic nuclear plants and placed future civilian thermal reactors under IAEA regulations.[773] The U.S. received a waiver from the NSG to allow trade in nuclear materials between NSG countries and India before the deal was enacted. This approval was crucial in supporting the U.S.'s decision to bypass the NPT.

One aspect of the deal recently approved was regulation of reprocessing nuclear-origin fuel in the civilian reactors under IAEA safeguards fully separated from military reserves. This deal ensures India cannot use reprocessed fuel from the U.S. for weapons making and quells worries from countries like Canada, who supplied India with nuclear materials for peaceful purposes in the 1970s, only to discover later that these were used

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[772] "The U.S.-India Nuclear Deal," *Council on Foreign Relations*. http://www.cfr.org/publication/9663/usindia_nuclear_deal.html, (accessed Jan. 21, 2011).
[773] Ibid.

for weapons purposes.[774] Without a 123 agreement, no formal memorandum held India accountable to U.S. and world interests of safety and non-proliferation.

Effects on the Non-Proliferation Regime

For arms control and disarmament advocates, the deal was seen as counterproductive to the non-proliferation regime. While India already had nuclear capabilities, some feared that without a clear distinction between military and civilian facilities written into the agreement, India's private companies could spread banned nuclear technology around the world. A loophole in the deal gave India full control over deciding which reactors were considered civilian, and not military. Nuclear warfare analysts worried allowing India freer reign in its nuclear production would incite a nuclear arms race between India and Pakistan.

The deal allowed India to produce "vast quantities of fissile material."[775] Previously China, Russia, France, Britain, and the NPT had slowed this kind of production in India. Gareth Evans of the International Commission for Nuclear Non-proliferation and Disarmament spoke openly against the deal. He explains,

> It was a very bad deal from the point of view of non-proliferation and the kinds of principles that most of us are committed to simply because it did not demand enough of the Indian government in terms of issues such as non-production of fissile material or even non resumption of testing.[776]

The deal also opened up India's potential to increase uranium reserves for weapons purposes. Non-proliferation advocates worried this meant India would use imported

[774] "US, India reach nuclear reprocessing deal," *The Times of India.* http://timesofindia.indiatimes.com/india/US-India-reach-nuclear-reprocessing deal/articleshow/5739263.cms (accessed Feb. 5, 2011).
[775] Jim VandeHei and Linzer Dafna, "U.S., India Reach Deal On Nuclear Cooperation," *The Washington Post.* http://www.washingtonpost.com/wp-dyn/content/article/2006/03/02/AR2006030200183.html (accessed Jan. 21, 2011).
[776] "India-U.S. deal a major hurdle," *The Hindu,* Jan. 22, 2011. http://www.hindu.com/2010/01/27/stories/2010012759191000.htm (accessed Jan. 21, 2011).

uranium for civilian reactors while saving domestic uranium sources for weapons making.[777]

After the Deal for India

Upon signing the deal, President Bush and Prime Minister Manmohan Singh declared the contract between the world's two largest democracies a success. President Bush signed the deal in the name of increasing bilateral relations and strengthening trade between the two countries, which it succeeded in doing.[778] By bolstering India's defense mechanisms, economic system, and offering a higher level of prestige, the U.S. was simultaneously seeking an important check against the rising regional power of China.[779]

The economic benefits of the deal for American and Indian companies were felt almost instantly. One year after the agreement was signed, the Indian government pursued the purchase of more than $150 million worth of U.S. nuclear reactors.[780] India's interest in nuclear programs also promised to create over 27,000 high-paying jobs in the next decade in the American nuclear industry.[781] However, the deal did not just offer the U.S. economic prospects in India's nuclear scene. Russian-based company Atomstroyexport and French firm Areva (as well as companies from other NSG states) heightened competition for U.S. nuclear plant construction and management

[777] Charles D. Ferguson, "The U.S.-India nuclear deal--one year later," *Bulletin of the Atomic Scientists*. http://www.thebulletin.org/web-edition/features/the-us-india-nuclear-deal-one-year-later (accessed Jan. 21, 2011).
[778] Jim Vande Hei and Dafna Linzer, "U.S., India Reach Deal On Nuclear Cooperation," *The Washington Post.* http://www.washingtonpost.com/wp-dyn/content/article/2006/03/02/AR2006030200183.html (accessed Jan. 21, 2011).
[779] Ibid.
[780] Charles D. Ferguson, "The U.S.-India nuclear deal--one year later," *Bulletin of the Atomic Scientists*. http://www.thebulletin.org/web-edition/features/the-us-india-nuclear-deal-one-year-later (accessed Jan. 21, 2011).
[781] Ibid.

companies.[782] From India's perspective, the deal opened up the door to the global business of nuclear power. Before news of U.S. plans to sign the deal in 2008, both Russia and Australia turned away agreements with India citing NSG restrictions, but upon hearing of the upcoming contract between the U.S. and India, both countries reversed their policies to sell enriched uranium to India.

IMPLICATIONS FOR OTHER BILATERAL DEALS

The U.S.-India deal is not entirely unique. The U.S. has entered into similar 123 agreements with 25 states (including China) and two organizations. These agreements set the groundwork for U.S. nuclear deals with other countries and must be approved by the president. Section 123 of the U,S. Energy Act of 1954 titled, "Cooperation with other Nations" states that before the U.S. cooperates with any nation, group of nations, or defense organization in pursuit of nuclear defense, certain conditions must be agreed on. These include maintaining safeguards for nuclear materials transferred in effect of these agreements, following IAEA safeguards for non-nuclear states, and a stipulation that if a cooperating party detonates a bomb or abrogates an IAEA safeguard, the U.S. has the right to require the return of U.S. nuclear materials or equipment.[783] These bilateral deals are necessary to ensure states with nuclear materials are regulated by IAEA safeguards while providing the U.S. with the ability to trade materials and technologies with non-NPT nuclear states.

[782]Charles D. Ferguson, "The U.S.-India nuclear deal--one year later," *Bulletin of the Atomic Scientists*. http://www.thebulletin.org/web-edition/features/the-us-india-nuclear-deal-one-year-later (accessed Jan. 21, 2011).
[783] "United States Nuclear Regulatory Commission," *Atomic Energy Act of 1954*. www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0980/ml022200075-vol1.pdf#pagemode=bookmarks&page=14 (accessed Feb. 26, 2011).

U.S.-Pakistan Talks

Pakistan is asking for an exemption similar to the U.S.-India deal. The threat of global warming and the need for energy security has encouraged the country to push the U.S. for a nuclear technology deal that would open Pakistan to resource and technology sharing in exchange for IAEA regulation of its civilian facilities. Until recently, the Obama administration has been against an agreement with Pakistan. The U.S. government was concerned about Pakistan's unstable history of supporting extremist groups and its backdoor nuclear technology deals in 2004.[784]

The U.S. must proceed with extreme caution when deciding the path to take with Pakistan. Indeed Pakistan, like India, has a history of safe nuclear weapons use. However, a U.S. exemption from the NPT for Pakistan could further incite tensions between India and Pakistan while giving Pakistan a backdoor route to importing uranium and reprocessing it into fuel for its own nuclear weapons use or for other non-U.S. ally states.[785] On the other side of the argument, some foreign policy experts assert energy security could help buffer Pakistan from jihad groups. Like India, Pakistan is not interested in what the NPT has to offer. Until the NPT undergoes heavy amendments it will remain irrelevant to weapons countries. A bilateral deal with Pakistan will become inevitable unless the NPT is amended to allow present non-member nuclear weapon states the right to retain weapons upon signing the treaty. Pakistan's nuclear weapons

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[784]James C., Bennett, "US may offer India-like nuclear deal to Pakistan," *The Times of India*, March 22, 2009. http://www.freerepublic.com/focus/f-news/2476225/posts (accessed Feb. 14, 2011).
[784] Saeed Shah, "Pakistan pushes US for nuclear technology deal," *The Guardian*. http://www.guardian.co.uk/world/2010/mar/22/pakistan-us-nuclear-technology-deal (accessed Feb. 22, 2011).

need to be regulated and a deal with Pakistan may be the only way for the U.S. to prevent Pakistan's nuclear materials from getting into the hands of terrorists.

CONCLUSION

As India faces an energy crisis and does not have a secure energy supply for the future, its economic and political development is uncertain. The approval of the U.S.-India deal enabled the state to further pursue serious research and development regarding nuclear power possibilities, like innovative thorium breeders that are necessary for India's energy security. India's reliance on foreign oil will increase oil prices in India and the U.S. as the country's energy consumption increases without the creation of new energy technologies. The more the U.S. assists India in lowering its carbon emissions through nuclear power technology, the less the U.S. will have to restrict its own consumption of fossil fuels. Today, India uses nuclear power for just three percent of its total energy demand. India is among the top ten nations in coal reserves but continues to increase its use of energy sources, which creates a strong desire for energy security.[786] The country is rapidly developing, but electricity blackouts and water shortages are slowing business.[787] It is not yet clear whether the country will follow through on its plans to build many new civilian plants over the next two decades. Such an expansion could lend more legitimacy to the 123 deal.

While India's energy demands are paramount, regulation of its nuclear technologies was an obvious necessity for the Bush administration. India has consistently refused to sign the NPT, while continuing to grow and strengthen its nuclear capabilities often behind the scenes. The U.S. had no choice but to strike a bilateral

[786] "The U.S.-India Nuclear Deal - Council on Foreign Relations," *Council on Foreign Relations*, http://www.cfr.org/publication/9663/usindia_nuclear_deal.html, (accessed Jan. 21, 2011).
[787] Ibid.

agreement with India to create some form of regulation in India's fuel creation cycles and improve relations between the two countries. Bilateral agreements will remain a necessary evil as long as the NPT remains unwilling to adjust for the three non-NPT countries with weapons. In the meantime, the U.S. must facilitate nuclear power technology waivers with allies that require energy security assistance. The U.S. must make an agreement with Pakistan, unless it decides to sign the NPT. This side agreement should provide lawful terminology for separating civilian and private reactors, and for providing IAEA regulations for the civilian reactors, because Pakistan will undoubtedly reject the regulation of its private military facilities. These agreements have the ability to ignite tremendous nuclear power growth as seen in India.

The NSG waiver in India had a large impact by opening the country to nuclear energy investment. With 18 reactors planned and 40 proposed, investment in nuclear has become increasingly popular.[788] As India's energy needs continue to grow, the country's leadership is aware that the resource poor country needs new technology, such as thorium reactors, if it ever wishes to be energy independent. Without energy independence, India will continue to rely on other countries for its energy needs. Additionally, India has the prospect of being one of the U.S.'s strongest allies in the Asia. Politically, a nuclear partner in the war on terrorism will strengthen U.S. defense mechanisms in Asia against power hungry countries like China.

Bilateral agreements are important in encouraging energy security through nuclear power technology. As energy consumption increases and current resources diminish, the world must rely on the creation of power through other means. With

[788] "Nuclear Power in India | Indian Nuclear Energy," World Nuclear Association | Nuclear Power - a Sustainable Energy Resource, http://www.world-nuclear.org/info/inf53.html (accessed February 1, 2011).

careful regulations and inspections through organizations like the IAEA, safe nuclear reactors have and will continue to be successful.

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VandeHei, Jim, and Dafna Linzer. "U.S., India Reach Deal On Nuclear Cooperation." *The Washington Post.* http://www.washingtonpost.com/wp-dyn/content/article/2006/03/02/AR2006030200183.html (accessed Jan. 21, 2011).

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Chapter Fourteen

REDUCING EXISTING ARSENALS: THE PATH TO NUCLEAR SECURITY

Heather Early

Abstract:

Since the beginning of the nuclear age, leaders have sought to control and limit the destructive power of nuclear weapons. There have historically been many examples of this that can inform the course of future reduction efforts. Looking at the case of South African complete disarmament provides a tool to help consider possible paths to further complete disarmament programs. Understanding nuclear reduction treaties between the United States and Russia helps to illustrate how far these two nuclear superpowers have come from the arms race of the Cold War and gives a window into future reduction policies. Despite these successful reductions, there are roadblocks to further reductions, many of which revolve around security issues. There are also differing thoughts on the possibility of complete disarmament, inhibiting further reductions. By considering many of the facets of arms reduction, this paper concludes that while a nuclear free world may appear ideal, it is unlikely, and that through cooperation and trust nuclear security can be reached through further arms reductions.

INTRODUCTION

Since the beginning of the nuclear age, the international community has recognized the truly destructive power of nuclear weapons and has sought to control the spread and use of them. Yet, as is wont to happen in an international collaborative effort, agreeing on a common strategy has been difficult. In its first resolution adopted in London in January 1946, the United Nations General Assembly embraced the goal of eliminating all nuclear weapons that could be adapted to mass destruction. Later that year, the U.S. government produced the Acheson-Lilienthal report and Baruch Plan and the Soviet Union offered its own Gromyko plan, all of which were aimed at eliminating nuclear weapons. None of these proposals were able to gain traction with the majority of the international community. Despite this, a body of mutually reinforcing, internationally recognized standards, norms, and legal obligations for nuclear disarmament, non-proliferation, and nuclear material security have gradually emerged.

At the heart of these standards and norms is the Nuclear Non-Proliferation Treaty (NPT) of 1968, which is now embraced by the vast majority of the world's leaders. This removed considerable uncertainty about the future and created a framework for future efforts in nuclear non-proliferation and disarmament. By permanently establishing a barrier to the spread of nuclear weapons, the NPT helps to limit the emergence of additional nuclear weapon states, and also fosters an environment in which Russia and the United States, who have the largest nuclear weapons stores, can decrease their reliance on nuclear weapons. International safeguards, such as those implemented by the International Atomic Energy Agency (IAEA), are recognized for making essential contributions to effective non-proliferation.

The United States has been at the forefront of arms reductions since before the creation of the NPT. One of the core objectives of the United States is to ensure U.S. security, and protecting the lives and safety of Americans. Arms control and non-proliferation efforts are two of the tools that the U.S. has utilized to attain this goal. Effectively pursuing non-proliferation and disarmament efforts helps to enhance U.S. national security in a number of ways. For example, arms control measures that promote transparency can build confidence among wary adversaries. Another reason reducing existing nuclear arsenals is essential to U.S. as well as global security, is that proliferation can exacerbate regional tensions that might escalate to conflict and involve or threaten U.S. forces or those of its friends and allies.

This report looks at reducing existing nuclear arsenals around the world in terms of U.S. and global security and outlines some of the many paths to nuclear disarmament and concludes that although attaining a nuclear weapon free world is ultimately unlikely, nuclear arms reduction is feasible and desirable. It is divided into four main sections. The first section reviews arms reductions both past and present beginning with the successful complete disarmament and disposal of nuclear weapons in South Africa, continuing with arms control agreements between the United States and Russia, and ending with reductions by France and Great Britain. The second section considers multilateral nuclear non-proliferation efforts, including the North Atlantic Treaty Organization's Arms Policy and Nuclear-Weapon-Free Zones (NWFZ). The third section discusses roadblocks to further arsenal reductions such as issues of transparency and longstanding and rigid military planning and targeting strategies. The final section considers the different perspectives of complete nuclear disarmament and assesses the realistic possibility of a nuclear free world.

NUCLEAR REDUCTION: PAST AND PREST

South Africa

In the 1970s and 1980s, South Africa built six nuclear weapons and then scrapped them in 1990-91.[789] As one of the few states to produce nuclear weapons, it is also the only to dismantle its entire arsenal. South Africa began its nuclear enrichment and explosives research as civilian programs primarily for commercial use. Although it is difficult to pinpoint a specific date and cause of the state's shift to a weapons program, it is accepted that South Africa chose to make this decision between 1977 and 1979 because

[789] Peter Liberman, "Rise and Fall of the South African Bomb." *International Security,* Vol. 26, No.2 (2001):45.

of a feeling of military insecurity.[790] During this time, South Africa faced material and reputational incentives for nuclear restraint. Western pressure against nuclear testing was intense following the August 1977 discovery of the South African test site in the Kalahari Desert. The 1978 U.S. Nuclear Nonproliferation Act threatened to starve South Africa's nuclear power industry of fuel.[791] At the same time, the international community ostracized South Africa because if its apartheid policies, thus the South African government felt that joining the NPT would provide no relief from nuclear sanctions.

South Africa continued to develop its nuclear weapons program despite intense international sanctions and a complete military embargo. The security concerns that many believe drove South Africa to develop nuclear weapons continued to increase due to years of constant military conflict. South Africa justified its small, secret nuclear deterrent because the region had turned into a proxy Cold War battlefield, with conflicts from Angola to Mozambique and "front-line states" that challenged the white ruled government.[792]

By the late 1980s the Cold War was coming to an end and the security risk that South Africa used to justify its nuclear weapons program was becoming less valid. With the end of apartheid in 1989, the South African government made the choice to dismantle its nuclear weapons program. In 1989, the government ordered that the country's six nuclear weapons and the seventh that was under construction be dismantled. In 1991 South Africa joined the NPT. After the dismantlement of the country's nuclear weapons

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[790] Peter Liberman, "Rise and Fall of the South African Bomb." *International Security,* Vol. 26, No.2 (2001): 49.
[791] Ibid, 50.
[792] Scott Peterson, "What does it Take For a Country to Give up its Nuclear Weapons?" *Christian Science Monitor,* 5 May 2011.

the international community lifted its economic sanctions, allowing the country the opportunity and ability to grow economically.

The case of the South African nuclear weapons program may be used as a tool to understand and perhaps unwind the nuclear concern with Iran. Iran is clinging to its nuclear energy program similar to the way South Africa clung to its program. When ordered by the UN Security Council to suspend uranium enrichment until questions were resolved about weapons work, Iran instead boosted enrichment plans.[793] Although Iran's security needs differ from those of South Africa and it does not have a full-fledged nuclear weapons program as did South Africa, the lessons learned are beneficial. When South African security became more certain and local threats had diminished, there was little excuse to maintain the nuclear weapons program. In fact, it was hurting the country because of the harsh economic sanctions. Iran's security environment is far from certain, between nuclear rival Israel, and tens of thousands of U.S troops on its borders. Using the past example of a successful disarmament situation can help inform current policies. A sense of security cannot grow overnight, but by being aware of the situation and what worked before, the United States may have the tools to form a more successful policy.

ARMS CONTROL BETWEEN THE U.S. AND THE SOVIET UNION

The Early Years of the Cold War

The Cold War resulted in an arms race between the United States and the Soviet Union that produced nuclear arsenals capable of bringing civilization to an end. Yet even before this time of unprecedented weapons build up, states saw the need to limit the continual build up of nuclear arsenals. The roots of U.S.-Soviet nuclear arms control

[793] Scott Peterson, "What does it Take For a Country to Give up its Nuclear Weapons?" *Christian Science Monitor*, 5 May 2011.

negotiations are in the sweeping proposals on "General and Complete Disarmament" written during the late 1940s and 1950s. The proposals, discussed primarily under the auspices of the United Nations, were based on an attempt to apply post-WWI thinking on disarmament in the new nuclear era.[794] They were unsuccessful in achieving a comprehensive disarmament agreement or even serious negotiations, and unsurprisingly, the U.S. and Soviet arsenals continued to grow unabated. In the late 1950s and early 1960s, in an attempt to move out of stalemate, the focus shifted from comprehensive disarmament to limited agreements in the hope that partial measures would prove more achievable and could possibly lead to more comprehensive agreements. The most important achievement of these early negotiations and agreements was the opening of dialogue between the superpowers that created an environment in which the United States and the Soviet Union could ultimately agree upon arms reductions.

Arms Reductions in the 1970s: Era of Detente

The United States and Soviet Union signed their first formal agreements limiting nuclear weapons in May 1972. This agreement initiated a process, which helped moderate and eventually end the dangerous superpower arms race. The Strategic Arms Limitation Talks (SALT) produced two agreements: the *Interim Agreement on Certain Measures with Respect to the Limitation of Strategic Offensive Arms* (the Interim Agreement on Offensive Arms) and the *Treaty on the Limitation of Anti-Ballistic Missile Systems.* The Interim Agreement on Offensive Arms imposed a freeze on the number of launchers for intercontinental ballistic missiles (ICBMs) and submarine-launched ballistic missiles (SLBMs) that the United States and the Soviet Union could deploy. The parties

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[794] Ralph Earle II, "Arms Control and Disarmament: An Historical Perspective." *New Horizons and new Strategies in Arms Control* (1999): 3.

agreed that they would not begin construction of new ICBM launchers after July 1, 1972; at the time the United States had 1,054 ICBM launchers and the Soviet Union had 1,618 ICBM launchers. Additionally, they agreed to freeze their number of SLBM launchers and modern ballistic missile submarines, although they could add SLBM launchers if they retired old ICBM launchers. A protocol to the treaty indicated that the United States could deploy up to 710 SLBM launchers on 44 submarines, and the Soviet Union could deploy up to 950 SLBM launchers on 62 submarines.[795] Because there was such great inequality between these two numbers the U.S. Congress adopted a provision, known as the Jackson Amendment, which mandated that all future arms control agreements contain equal limits for the United States and the Soviet Union. To allow for changes in the future to be taken into consideration, the Interim Agreement on Offensive Arms was to remain in force for five years unless the parties replaced it with a more comprehensive agreement limiting strategic offensive weapons. In 1977, both nations agreed to observe the agreement until they could reach an agreement on the SALT II Treaty.

The United States and the Soviet Union completed the SALT II Treaty in June 1979. During these negotiations, the United States sought quantitative and qualitative limits on Soviet forces. In adherence to the Jackson Amendment, the treaty limited each nation to a total of 2,400 ICBM launchers, SLBM launchers, and heavy bombers with this number declining to 2,250 by January 1, 1981. Within the total, the treaty contained sublimits for the number of launchers that could be deployed for ICBMs with multiple independent reentry vehicles (MIRVed ICBMs) and MIRVed SLBMs, MIRVed surface-

[795] Department of State, *Strategic Arms Limitation Talks (SALT I)*, 1972. http://www.state.gov/www/global/arms/treaties/salt1.html (accessed Feb. 4, 2011).

to-air ballistic missiles (ASBMs) and heavy bombers.[796] The treaty did not limit the total number of warheads that could be carried on these delivery vehicles, which was a growing concern with the deployment of a large number of multiple warhead missiles, but the nations did agree that they would not increase the number of warheads on existing missiles and would not test new types of ICBMs with more than 10 warheads and new types of SLBMs with more than 14 warheads.[797] Surprisingly, they also agreed to provisions that were designed to limit missile modernization programs in an effort to restrain qualitative improvements in their strategic forces.

The SALT II Treaty was highly controversial, despite proposing equal limits on U.S. and Soviet forces. Some analysts argued that the treaty would fail to rein in the arms race because it did not call for actual reductions, that the limits on forces were equal to the numbers already deployed by the United States and Soviet Union; this camp argued for lower limits and actual reductions. Other analysts argued that because the Soviet force of large, land-based ballistic missiles would be able to carry a far greater number of warheads; even within the equal limits on delivery vehicles, it would allow the Soviet Union to maintain strategic superiority over the United States. Some argued that, with this advantage, "the Soviet Union would be able to target all U.S. land-based ICBMs in a first strike, which created a 'window of vulnerability' for the United States."[798] The treaty's supporters argued that the Soviet advantage in large MIRVed and ICBMs was more than offset by the U.S. advantage in SLBM warheads, which could not be destroyed in a first strike and could retaliate against Soviet targets, and the U.S. advantage in heavy

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[796] Department of State, *Strategic Arms Limitation Talks (SALT II),* 1979. http://www.state.gov/www /global/arms/treaties/salt2-2.html (accessed Feb. 2 2011).
[797] Amy F. Woolf, Mary Beth Nikitin, and Paul K. Kerr, "Arms Control and Nonproliferation: A Catalog of Treaties and Agreements," (Congressional Research Service, 2010): 5.
[798] Ibid.

bombers. This dissent and fear over the continuing Soviet build-up of strategic nuclear forces, along with the taking of U.S. hostages in Iran and other challenges to the strong U.S. international position in the late 1970s raised questions as to whether the Senate could muster the votes needed to ratify the treaty. Unsurprisingly, as soon as the Soviet Union invaded Afghanistan in December 1979, President Carter withdrew the treaty from the Senate's consideration.

Reagan and the 1980s

Despite campaign pledges to restore U.S. nuclear capabilities, upon taking office in January 1981, President Ronald Reagan and his administration outlined negotiating positions to address intermediate-range missiles, long-range strategic weapons, and ballistic missile defenses. In December 1979 NATO decided upon a "two track" approach to intermediate-range nuclear forces (INF) in Europe; it would seek negotiations with the Soviets to eliminate such systems, and at the same time schedule deployments to spur these negotiations.[799] Negotiating sessions began in the fall of 1980 and continued until November 1983, when the Soviets left the talks upon deployment of the first U.S. INF systems in Europe. The negotiations resumed two years later in January 1985. At the negotiations, the Reagan Administration called for a "double zero" option, which would eliminate all short- as well as long-range INF systems. Though many felt the Soviets would never agree to such a plan, significant progress occurred during the Gorbachev regime.

At the Reykjavik summit in October 1986, Gorbachev agreed to include reductions of Soviet INF systems in Asia. In June 1987, the Soviets proposed a global

[799] Amy F. Woolf, Mary Beth Nikitin, and Paul K. Kerr, "Arms Control and Nonproliferation: A Catalog of Treaties and Agreements," (Congressional Research Service, 2010): 6.

ban on short- and long-range INF systems, which was surprisingly similar to the U.S. proposal for a double zero. Gorbachev also accepted the U.S. proposal for an intrusive verification regime.[800] The United States and the Soviet Union signed the treaty on Intermediate-Range Nuclear Forces on December 8, 1987. This treaty was seen as an incredible milestone in arms control and reduction because it established an intrusive verification program and because it eliminated entire classes of weapons that both sides regarded as modern and effective. The verification program that was put into place with this treaty helped to set the stage for future verification regimes and increased transparency.

The incorporation of intrusive verification programs helped to encourage a level of trust and cooperation useful for further disarmament. The United States and the Soviet Union agreed to destroy all intermediate-range and shorter-range nuclear-armed ballistic missiles and ground-launched cruise missiles and their launchers.[801] The Soviets agreed to destroy approximately 1,750 missiles and the United States agreed to destroy 846 missiles, establishing a principle that asymmetrical reductions were acceptable in order to achieve the goal of greater stability. For the U.S. the principle systems destroyed were the Perishing II ballistic missile and the ground launched cruise missile (GLCM), both single warhead systems.[802] On the Soviet side, the principle system destroyed was the SS-20 ballistic missile, which carried three warheads.[803] Both of these countries' systems were highly mobile and able to strike such high-value targets as command-control

[800] Seiitsu Tachibana, "Much Ado About Something: The Factors that Induced Reagan and Gorbachev to Conclude the INF Treaty." *Hiroshima Peace Science*, Vol. 11 (1988): 173.
[801] Amy F. Woolf, Mary Beth Nikitin, and Paul K. Kerr, "Arms Control and Nonproliferation: A Catalog of Treaties and Agreements," (Congressional Research Service, 2010): 6.
[802] Department of State, *INF Treaty*,1987. Art. 3(1.a). http://www.state.gov/www/global/arms/treaties/inf2.html (accesed Feb. 4, 2011)
[803] Ibid, Art. 3(1.b).

centers, staging areas, airfields, depots, and ports. The Soviets also agreed to destroy a range of older nuclear missiles, as well as the mobile short range SS-23, a system developed and deployed in the early 1980s.[804] Both countries had eliminated all their required weapons by May 1991.

One of the most important aspects of the INF Treaty was the verification regime that permitted on-site inspections of selected missile assembly facilities and all storage centers, deployment zones, and repair, test, and elimination facilities.[805] Although it did not permit "anywhere, anytime" inspections, it did allow up to 20 short-notice inspections of sites designated in the treaty. In order to account for all systems covered by the agreement, both sides agreed to an extensive data exchange. The treaty also established a continuous portal monitoring procedure at one assembly facility in each country meaning that the physical barriers, buildings, and equipment along the perimeter, at the portal, and at the other exits of a facility can be continuously monitored.[806] The data exchange and monitoring that were implemented under the treaty were further strong steps toward increased transparency. Building aspects of transparency into treaties has proven to be extremely useful to increasing trust between the countries involved. Under the INF Treaty, inspections continued until May 2001.

The 1990s: Aftermath of the Soviet Collapse

The United States and the Soviet Union signed the first Strategic Arms Reduction Treaty (START) on July 31, 1991. Of course the collapse of the Soviet Union in December 1991 immediately brought into question the future of the treaty. There were a

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[804] Department of State, *INF Treaty,*1987. Art. 3(2.b). http://www.state.gov/www/global/arms/treaties/inf2.html (accessed Feb. 5, 2011).
[805] Ibid. Art. 9(5).
[806] "Definitions Annex," *Federation of American Scientists,* http://www.fas.org/nuke/control/start1/text/defini.htm#77 (accessed Feb. 5, 2011).

large number of nuclear weapons covered by START that were deployed at bases in Russia, but the rest were deployed in Ukraine, Kazakhstan, and Belarus. Russia initially sought to be the sole successor to the Soviet Union for the treaty but unsurprisingly, the three other republics did not want to cede all responsibility for the Soviet Union's nuclear status and treaty obligations to Russia. In May 1992, the four republics and the United States signed a protocol that made all four republics parties to the treaty.[807] During the lead up talks, the leaders of Belarus, Ukraine, and Kazakhstan agreed to eliminate all their nuclear weapons during the seven-year reduction period outlined in START. They also agreed to sign the NPT as non-nuclear weapon states.[808]

On October 1, 1992 the United States Senate agreed to the ratification of START and the Russian Parliament gave its consent on November 4, 1992.[809] However, the Russian Parliament stipulated that Russia would not officially ratify the treaty until all three of the republics adhered to the NPT as non-nuclear states. Kazakhstan and Belarus completed this process by early 1994. Ukraine's parliament approved START in November 1993, but its approval was conditioned on Ukraine's retention of some of the weapons based on its territory and the provision of security guarantees by other nuclear weapon states.[810] Because Ukraine insisted upon extra compensation and security assurances in exchange for the weapons based on its soil, the Ukrainian parliament did not approve the NPT until November 16, 1994. START officially entered into force on December 5, 1994 with the exchange of the instruments of ratification.

[807] "START I Chronology," *Federation of American Scientists*, http://www.fas.org/nuke/control/start1/chron.htm (accessed Feb. 5, 2011).
[808] Ibid.
[809] Ibid.
[810] Ibid.

The provisions of START were a positive step towards reducing nuclear arsenals. The treaty limited long-range nuclear forces (ICBMs, SLBMs, and heavy bombers) in the United States and the newly independent states of the former Soviet Union. Each side could deploy up to 6,000 warheads on 1,600 ballistic missiles and bombers and deploy up to 4,900 warheads on ICBMs and SLBMs. It also limited each side to 1,540 warheads on "heavy" ICBMs which was a 50 percent reduction in the number of warheads deployed on the SS-18 ICBMs in the former Soviet republics.[811] Interestingly, START did not require the elimination of most of the missiles removed from service, instead the signatories had to eliminate *launchers* for missiles that exceeded the permitted totals, but often could be placed in storage and warheads could either be stored or reused on missiles remaining in the force and still remain in compliance with the treaty.

One of the most progressive aspects of the START Treaty, and the most important for future nuclear arms reductions, was the complex verification stipulations. Both sides were able to use their own satellites and remote sensing equipment to collect most of the information needed to verify compliance. However, the parties also used data exchanges, notifications, and on-site inspections to gather information about forces and activities limited by the treaty. The inclusion of this transparency and verification in the treaty was to provide each nation with the ability to deter and detect militarily significant violations. The verification regime is an essential aspect of the START treaty because the cooperation needed to implement the mandated measures builds confidence and encourages openness among the signatories. The trust and confidence that is built between signatories can lead to increased trade that is beneficial to both countries, which

[811] Amy F. Woolf, Mary Beth Nikitin, and Paul K. Kerr, "Arms Control and Nonproliferation: A Catalog of Treaties and Agreements," (Congressional Research Service, 2010): 9.

in turn creates another level of cooperation between them. This is an important benefit of nuclear disarmament and can be used to encourage other nuclear countries to sign treaties for disarmament. All parties were in full compliance with the treaty by the designated date of December 5, 2001.

Bush and Putin: The Early-Mid 2000s

The next step for disarmament and arms reduction between the United States and Russia came during a summit meeting between President Putin and President Bush in November 2001. President Bush announced that the United States would reduce its operationally deployed strategic nuclear warheads to between 1,700 and 2,200 warheads during the decade and that this reduction would be conducted unilaterally, without signing a formal agreement. Russia sought a legally binding agreement that would ensure irreversibility of the document and provide the predictability and transparency that such an agreement requires.[812] The United States wished to maintain flexibility in the size and structure of its nuclear forces in response to its own needs and thus preferred a less formal process. The Bush Administration eventually was convinced to agree to a legally binding treaty. The U.S. and Russia signed the Strategic Offensive Reductions Treaty on May 24, 2002 and it entered into force on June 1, 2003.[813] The treaty was designed to remain in force until December 30, 2012, after which time it could be extended or replaced by another agreement.

Article I of the treaty contains the only limit present, stating that the U.S. and Russia will reduce their "strategic nuclear warheads" to between 1,700 and 2,200 warheads by December 31, 2012. The treaty does not limit delivery vehicles or impose

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[812] "Strategic Offensive Reductions Treaty: At a Glance," *Arms Control Association*, http://www.armscontrol.org/factsheets/sort-glance (accessed Feb 4. 2011).
[813] Ibid.

sublimits on specific types of weapons systems. Each party shall "determine for itself the composition and structure of its strategic offensive arms."[814] The two parties opted to not include any monitoring or verification provisions in the treaty because they both already collected information about strategic nuclear forces under START I.

Beginning in mid-2006 the United States and Russia began to discuss their options for arms control and further disarmament after START. Neither side wanted to extend START in its original form and both sides were having difficulty coming to possible solutions because, yet again, the Bush Administration wanted to rely on informal agreements rather than a formal treaty. In December 2008 both sides agreed that they would need to replace START but acknowledged that negotiations would have to be left to Russia and the incoming Obama Administration.

The Obama Administration

The United States and Russia began to hold talks on a new treaty during the first few months of the Obama Administration and in March 2009 Secretary of State Hillary Clinton met with Russia's Foreign Minister Sergey Lavrov. Presidents Obama and Medvedev met in Moscow on July 6-7, 2009 where they signed a Joint Understanding for the START follow-up treaty.

The Joint Understanding helped to move negotiations forward and, on April 8, 2010, the United States and Russia signed New START. This latest agreement limits each country's deployed strategic nuclear warheads to 1,550 and strategic delivery systems (ICBMs, SLBMs, and heavy bombers) to 800 deployed and non-deployed with a

[814] Amy F. Woolf, "Nuclear Arms Control: The Strategic Offensive Reductions Treaty," (Congressional Research Service. 2010): 9.

sublimit of 700 deployed.[815] The treaty accountable warhead limit is 30 percent lower than the 2,200 upper limit of SORT, and the delivery vehicle limit is 50 percent lower than the 1,600 allowed in START I.[816] The verification regime included in the treaty combines elements of START I with new elements. These include on-site inspections and exhibitions, data exchanges and notifications related to strategic offensive arms and facilities covered by the treaty and provisions to facilitate the use of national technical means of treaty monitoring.[817] The treaty has a duration of ten years unless a new agreement is drafted and ratified in that time. The United States and Russia may agree to extend the treaty for no more than five years. The United States Senate voted to ratify the treaty on December 22, 2010 and the Russian Parliament followed suit on January 26, 2011. The New START Treaty officially entered into force with the exchange of instruments of ratification on February 5, 2011.

Of the ratification of the newest treaty between the United States and Russia, Secretary of State Hilary Clinton said, "with the exchange of these instruments, we commit ourselves to a course of action that builds trust, lessens risks, and improves predictability, stability and security."[818] This treaty shows the continuing effort of the world's two largest nuclear powers, holding over 90 percent of the world's nuclear weapons, to maintain their commitments to the NPT and furthering the goal of non-proliferation globally. It is important to note that many signatories of the NPT feel that the United States has not done its part to pursue the goals of non-proliferation and is in

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[815] Department of State, *New Start,* 2010. Art. 2(1). http://www.state.gov/t/avc/newstart/c39903.htm (accessed Feb. 3, 2011)

[816] "U.S.-Russian Nuclear Arms Control Agreements: At a Glance," *Arms Control Association,* http://www.armscontrol.org/factsheets/USRussiaNuclearAgreementsMarch2010 (accessed Feb. 4, 2011).

[817] Department of State, *New Start,* 2010. Art. 10. http://www.state.gov/t/avc/newstart/c39903.htm

[818] Secretary of State Hilary R. Clinton, "Exchange of New START Instruments of Ratification," http://www.state.gov/secretary/rm/2011/02/156047.htm (accessed Feb. 7, 2011).

fact not entirely in compliance with the treaty which stipulates gradual reduction and eventual complete elimination of nuclear weapons. This point of contention between non-nuclear signatories and nuclear signatories of the NPT is discussed in more depth in Chapter 12 of this report. This step forward by the United States and Russia provides encouragement to NPT signatories that the nuclear powers are moving toward ever greater nuclear arms reductions. The United States has had a long commitment to nuclear arms control beginning before the Cold War and this commitment is still strong today, with well-laid plans for the future.

Implications

The history of disarmament negotiations between the U.S. and Russian governments is long, and it appears that it will continue into the future. These disarmament negotiations suggest a few conclusions. The first is that arms reductions through negotiations and treaties are possible. The United States and Russia were at odds yet the leaders of both countries saw the danger of further proliferation. Despite the animosity and distrust between them, the U.S. and Russia have managed to create treaties that have reduced their nuclear weapon stockpiles by the thousands. Their efforts show that it is possible for countries today to successfully participate in disarmament negotiations. Despite differing ideological, political, or religious views, it is possible for countries to implement treaties that further nonproliferation and reduction efforts for the world's overall safety.

The disarmament negotiations between the United States and Russia also show that one of leaders' main goals is to ensure the security of their country and to protect the lives of their citizens. The arms race initially began as a way to ensure these two goals.

As the two countries built more and more weapons and their destructive potential increased, U.S. and Russian leaders began to understand that proliferation was not the answer to security. Instead, through negotiations they came to use reductions and non-proliferation efforts as tools to maintain their security. This lesson can be extended to negotiations with countries such as India and Pakistan who argue that nuclear weapons are needed to maintain their security. The United States and Russia's actions show that proliferation can in fact exacerbate both regional and global tensions and that disarmament can lead to increased prosperity and cooperation.

The history of disarmament negotiations between the United States and Russia proves that treaties do work to reduce nuclear weapons stores and proliferation. Existing treaties help to set an example for future disarmament negotiations and can be used as a framework for future treaties. The increased cooperation and prosperity between the United States and Russia can serve as an example for leaders that are hesitant to reduce their nuclear arsenal or sign the NPT.

MULTILATERAL NUCLEAR NON-PROLIFERATION EFFORTS

The NPT, which entered into force in 1970 and was extended indefinitely in 1995, is at the heart of the nuclear non-proliferation regime. The NPT recognizes five nations (the United States, Russia, France, Britain, and China) as nuclear weapon states. The NPT is unique because it is a nearly universal treaty; only India, Pakistan, Israel, and North Korea are outside of the treaty. By signing the NPT, non-nuclear weapon states (NNWS) pledge not to acquire nuclear weapons in exchange for a pledge by the nuclear weapon states (NWS) not to assist the development of nuclear weapons by any NNWS and to facilitate "the fullest possible exchange of equipment, materials, and scientific and technological information for the peaceful uses of nuclear energy."[819] The NPT is essential to the pursuit of nuclear disarmament because in signing, NWS, defined as any state that has tested a nuclear explosive before 1967, agree to "pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament."[820] There are many repercussions of the NPT and it has differing implications for the various signatories as well as the states who have opted out which are discussed in depth in Chapter 12. Concerning the issue of nuclear arms reduction, the NPT provides the framework for all arms control treaties and programs. It holds NWS accountable for the nuclear weapons in their possession and requires them to work toward reducing those numbers, while also ensuring that NNWS will maintain their pledge to not obtain nuclear weapons and pursue only peaceful uses for nuclear energy.

Several regions have gone a step beyond the NPT and implemented treaties that ban the development, use, and possession of nuclear weapons. These regions include Latin America (Treaty of Tlatelolco), Central Asia (Treaty on a Nuclear-Weapon-Free Zone in Central Asia), the South Pacific (Treaty of Rarotonga), Africa (Treaty of Pelindaba), and Southeast Asia (Treaty of Bangkok). Mongolia has declared itself a single-state nuclear weapons-free zone.[821] The Treaty of Antarctica also established that Antarctica will be used for peaceful purposes only. International treaties also ban nuclear weapons on the seabed, in outer space, and on the moon.[822] Article VII of the NPT affirms the right of countries to establish specified zones free of nuclear weapons. The

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[819] NPT, Art 4(2). http://www.un.org/en/conf/npt/2005/npttreaty.html (accessed Feb. 2 2011).
[820] NPT, Art 6. http://www.un.org/en/conf/npt/2005/npttreaty.html (accessed Feb. 2 2011).
[821] "Nuclear Weapons Free Zones: At a Glance," *Arms Control Association*, http://www.armscontrol.org/factsheets/nwfz (accessed Jan. 28, 2010).
[822] Amy F. Woolf, Mary Beth Nikitin, and Paul K. Kerr, "Arms Control and Nonproliferation: A Catalog of Treaties and Agreements," (Congressional Research Service, 2010): 29.

UN General Assembly reaffirmed that right in 1975 and outlined the criteria for such zones. Although nuclear weapons cannot be held inside these zones, countries within them are permitted to use nuclear energy for peaceful purposes.

Each treaty establishing a nuclear-weapons free zone includes a protocol for the five nuclear weapon states that are recognized under the NPT. These legally recognized and binding protocols call upon the NWS to respect the status of the zones and to not use or threaten the use of nuclear weapons against treaty states. These treaties are unique in that they are designed to remain in force indefinitely, although each does include a withdrawal option with 12 months' advance notice.[823] The verification of these treaties is also extremely impressive. Each state adopts comprehensive safeguards that are administered by the International Atomic Energy Agency (IAEA), which verifies that states are not pursuing nuclear weapons illicitly.

Nuclear weapon-free zones are a solid step forward for nuclear arms reductions. They have proven that it is possible for states to exist and flourish without the possession of nuclear weapons. It is important to consider however, the idea of the United States' nuclear umbrella. Although states in nuclear weapon free-zones do not possess nuclear weapons, some have a guarantee of U.S. nuclear protection in the event of an attack. Thus, although nuclear weapons-free zones promote the idea of non-proliferation, they do not entirely promote the goal of complete nuclear disarmament. The provision allowing for the peaceful use of nuclear technology for energy allows these countries to participate in the opportunities that are available through nuclear energy. The nuclear-weapon-free zones reinforce the undertakings of the NPT non-nuclear weapon state members as well

[823] "Nuclear Weapons Free Zones: At a Glance," *Arms Control Association,* http://www.armscontrol .org/factsheets/nwfz (accessed Jan. 28, 2010).

as the nuclear weapon state members because it gives them the assurance that any help they give for nuclear energy will only be used for peaceful purposes.

NATO has also played a large role in attempts to reduce the number of nuclear arms around the world. In November 2010, NATO adopted a new Strategic Concept and a Summit Declaration that outlined the alliance's future nuclear policy and established two new processes to discuss deterrence and arms control. In the new Strategic Concept, NATO commits itself for the first time to, "create the conditions for a world without nuclear weapons," but cautions that this goal must be pursued "in accordance with the goals of the Nuclear Non-Proliferation Treaty, in a way that promotes international stability, and is based on the principles of undiminished security for all."[824] Prior to this summit, NATO relied heavily on a deterrence policy and it recent years it has been heavily criticized for this. The new Strategic Concept states that NATO has reduced reliance on nuclear weapons but affirms that the alliance will continue to have at its disposal, "the full range of capabilities necessary to deter and defend against any threat to the safety and security of our populations."[825] NATO representatives stated that it would maintain a mix of nuclear and conventional forces.[826] In addition to discussing a shift away from a deterrence policy, the summit included a talk on the role of NATO in arms control. A decision was reached that its role was to provide advice on weapons of mass destruction, arms control, and disarmament.

The 2010 NATO summit and the new Strategic Concept provide the structure for discussing nuclear issues. The summit gave NATO members a clear understanding of the

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[824] "Official Text: Active Engagement, Modern Defence," *NATO,* http://www.nato.int/cps/en/natolive /official_texts_ 68580.htm. (accessed Feb. 4, 2010).
[825] Ibid.
[826] "NATO Revises Nuclear Policy," *Arms Control* Associationhttp://www.armscontrol.org/act/2010_12/ NATO_Nuclear (accessed Feb. 4, 2010).

nuclear issues that are on the agenda of the arms control committee. It also provides an environment in which member countries can discuss the effects of disarmament. National decisions regarding arms control and disarmament may have an impact upon the security of some or all alliance members. In the new Strategic Concept, NATO commits to maintain and develop appropriate consultations among allies on these issues.[827] By committing to create the conditions for a nuclear free world, NATO has provided allies with the opportunity to further reduce nuclear arms. NATO provides a space in which member countries can discuss security concerns between member states and non-member states, in doing so it is paving the way for further nuclear reductions.

ROADBLOCKS TO REDUCING EXISTING ARSENALS

Although there has been incredible progress since the nuclear build up during the Cold War there are still many issues that stand in the way of further nuclear arms reductions. One of the key concerns of the nuclear countries is their longstanding military doctrine that has included and often revolved around nuclear weapons.

On February 5, 2010 Russian President Medvedev approved a new military doctrine for Russia reserving the right to use nuclear weapons only in response to the use of nuclear arms and other types of weapons of mass destruction against it or its allies. While this new Russian military doctrine limits the scope of nuclear weapons, the prevailing view in Russia's political-military leadership is that nuclear weapons play a key role in ensuring Russia's security. This is because Russia's general-purpose forces continue to become outdated as a result of the economic crisis of the 1990s.[828] The

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[827] "Official Text: Active Engagement, Modern Defence," *NATO*, http://www.nato.int/cps/en/natolive /official_texts_ 68580.htm. (accessed Feb. 4, 2010).
[828] International Panel on Fissile Materials, "Reducing and Eliminating Nuclear Weapons," (Report for Princeton University, 2010): 75.

degradation of Russia's military position has led some to believe that the possession of nuclear weapons will allow Russia to delay the costly process of updating and re-equipping its military until its economic situation improves. The overall weakness of the Russian military forces plays another role in Russia's decision to maintain a large number of nuclear weapons. As China continues to grow and become stronger, Russian leaders fear the possibility of conflict. They believe that in the event of a large-scale military conflict between the Russian Federation and China, Russia would not be able to guarantee the security of its far eastern land holdings without nuclear weapons. This situation will only get worse as China rapidly increases its economic and military capabilities. In relation to the United States, Russia is worried that U.S. efforts to develop ballistic-missile defenses and to deploy intercontinental missiles with conventional warheads could in the future neutralize Russia's shrinking deterrent.[829]

Further nuclear arms reductions are also of concern for the West. For the United States, France, and the United Kingdom, hesitation surrounding the elimination of nuclear weapons is closely tied to concerns about maintaining the current international order. This order emerged with the collapse of the European empires and the rise of the United States, and nuclear weapons have long helped to maintain this order.[830] Yet this puts these states in a difficult position as they push for further nuclear disarmament and seek to prevent proliferation.

For the United States, the issue of its nuclear weapons in several European states is also of contention. These weapons were initially placed in countries in the name of protecting U.S. allies and fulfilling its commitments. Many of these weapons were

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[829] International Panel on Fissile Materials, "Reducing and Eliminating Nuclear Weapons," (Report for Princeton University, 2010): 78.
[830] Ibid, 6.

removed at the end of the Cold War, but several hundred still remain. Recently, Belgium, Germany, Luxembourg, the Netherlands, and Norway have called for the remaining few hundred U.S. nuclear weapons to be withdrawn from Europe, but the United States is hesitant and insists that these weapons remain in Europe to serve as a "bargaining chip in future nuclear-reduction negotiations with Russia."[831]

Two of the largest issues standing in the way of further disarmament are those of transparency and verification. Currently nuclear states have very differing views on the role of transparency. The United States, France, and the United Kingdom are among the most transparent weapon states. The U.S. has published information on the history of its fissile material production and disposition while the UK has made public declarations on the size of its total stockpile. On the other end of the spectrum, Russia is believed to have fissile material stockpiles that are larger than those of the United States, but refuses to declare their size. China believes that maintaining secrecy about its weapon and fissile material stockpiles is a "way to create additional uncertainty that the deterrence posed by China's modest number of nuclear weapons could successfully be neutralized."[832] Similarly Israel sees increased transparency as something that would undercut what little opacity it thinks it has regarding its nuclear weapons capabilities. Ultimately, it is likely that unless it wants to eliminate its nuclear weapons, Israel will resist disarmament initiatives that include transparency or verification obligations.

Treaties can overcome many of these roadblocks. The United States and Russia have set a strong example of the power of negotiations and treaties with their many arms

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[831] "U.S. Signals Its Nuclear Arms Stay In Europe For Now," *Reuters,* http://www.reuters.com/article /2010/04/22/us-nato-nuclear-idUSTRE63L54Q20100422 (accessed Feb. 5).
[832] International Panel on Fissile Materials, "Reducing and Eliminating Nuclear Weapons," (Report for Princeton University, 2010): 6.

reductions treaties. Instead of just creating treaties that encourage reductions, future treaties can be negotiated that include a section about non-aggression. If a treaty with such a clause was signed between Russia and China, the Russian fear of future Chinese aggression would help to mitigate its fear of arsenal reduction. Despite that most nuclear weapon states will not completely disarm all of their nuclear weapons, a non-aggression clause may help to instill a higher level of trust between nuclear and non-nuclear weapon states.

The United States has a history of taking the first step to reach a global goal and this history can be used to help encourage reductions. By taking the first step to remove its nuclear from the European states that have called for their removal. Removing these "bargaining chips" would show to NWS and NNWS that the U.S. takes arms reductions seriously. It would encourage Russia to further its reductions or at the least to come to the table to discuss further reductions. Also it would prove that the United States is attempting to remain in compliance with the NPT. Setting an example on the global stage is something that the United States has long prided itself in and a tool it has used to overcome roadblocks. Taking such a positive step toward arms reduction could act as a catalyst for further global reductions.

ISSUE OF COMPLETE DISARMAMENT

Complete nuclear disarmament and even extensive arms reductions pose a difficult issue for many states, and some question if either is a realistic possibility. There are persuasive arguments for both sides of the issue. In a recent article in the Wall Street Journal, for example Harold Brown and John Deutch argue against complete disarmament. Brown and Deutch contended that eliminating all nuclear weapons would be counterproductive because it would not advance "substantive progress on nonproliferation" and it risks "compromising the value that nuclear weapons continue to contribute, through deterrence, to U.S. security and international stability."[833] It is widely held that countries without nuclear weapons programs seek them out for security reasons. Like some other experts, Brown and Deutch insist that if the United States decides it will eliminate a certain number of weapons in the future, this will have no bearing upon the security of a states elsewhere in the world looking to develop nuclear weapons. It certainly will have little impact upon a terrorist organization that is planning a nuclear attack.

The issue of compliance with the NPT for weapon states to pursue disarmament is a constant point of contention, yet acting now in full compliance of the treaty may not be the best idea. While continuing to work towards further arms reductions is a worthy goal, some insist that it may not be the best time for complete disarmament or anything close to this. Many experts see little realistic chance that a path will soon be paved to a world free of nuclear weapons. One influential writer on the topic, Thomas Schelling, emphasizes that any nation which eliminates its arsenal would remain a "latent nuclear state" and would be able, and likely willing, to use its technical knowledge in a time of major war.[834] States that currently have nuclear weapons would also be able to secretly retain a few of their weapons. Because states would be working under the guise and trust that all nuclear weapons were dismantled, there would be no formal way to know whether countries had weapons or not. This contrasts with the current situation, where

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[833] Harold Brown and John Deutch, "The Nuclear Disarmament Fantasy," *The Wall Street Journal*, 19 November 2007.
[834] Thomas C. Schelling, "A world without nuclear weapons?" *Daedalus* Fall 2009, 124-129.

there are enough treaties and regulatory bodies in lace, such as the NPT and the IAEA that the world can rest relatively assured it knows who has nuclear weapons.

Another key concern of those who oppose complete disarmament is the idea that it will inadvertently lead to proliferation by encouraging allies currently under the U.S. nuclear umbrella to then pursue their own weapons programs. In September 2008, Secretary of Energy Samuel Bodman and Secretary of Defense Robert Gates said:

> The role nuclear forces play in the deterrence of attack against allies remains an essential instrument of U.S. nonproliferation policy by significantly reducing the incentives for a number of allied countries to acquire nuclear weapons for their own. . . In the absence of this "nuclear umbrella," some non-nuclear allies might perceive a need to develop and deploy their own nuclear capability.[835]

If the United States begins complete disarmament or even steep arms reductions, they may create a nuclear arms vacuum that will be filled by those NNWS currently protected under the U.S. nuclear umbrella, but if they retain an adequate number of weapons, this need may never be felt.

There are also many arguments for complete nuclear disarmament that are very convincing and refute some of the fears noted above. Scott Sagan maintains that the fear that U.S. allies will seek to build their own weapons if the United States disarms would be unfounded if the term "nuclear umbrella" was removed from the strategic lexicon.[836] This strategy fails to differentiate between the U.S. commitment to use nuclear weapons if an ally is attacked by an enemy who uses any kind of force and a U.S. commitment to use nuclear weapons only in retaliation against a nuclear attack. Adopting this strategy would allow for eventual complete disarmament because limiting the role of U.S. nuclear weapons to deterrence of other states' use of nuclear weapons would show strong support

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[835] Scott D. Sagan, "Shared Responsibilities for Nuclear Disarmament," (Cambridge: American Academy of Arts and Sciences, 2010): 8.
[836] Ibid.

for eventual complete disarmament. If a "no-first-use" nuclear doctrine became universally accepted, the existing NWS would be able to more readily coordinate an across-the board and eventual complete elimination of nuclear weapons.[837] A coordinated global effort would help to alleviate some of the trust issues that surround complete disarmament. Grounding the global effort for disarmament in an already proven U.S. military policy would give the effort a concrete example to follow.

The argument that nuclear weapons must be maintained as a deterrent can also be viewed from a different angle. If NWS and NNWS both work towards disarmament, they will hold violations against the NPT much more seriously than they do currently because small-scale cheating would pose a greater risk to international security. Scott Sagan argues that the existence of large arsenals in the United States and Russia encourages some leaders to be complacent about the spread of nuclear weapons to new nations.[838] Faith in the strength of nuclear deterrence leads some policy-makers to believe deterrence will keep NWS from using their arsenals if nuclear negotiations fail, as in the case of North Korea or Iran. In a nuclear-free world, such belief in nuclear deterrence would be far less present in policy and all of the major powers would harbor deeper fears of the emergence of new nuclear states. Although on the surface nuclear deterrence seems like a valid reason to maintain nuclear weapons, it in fact runs the risk of increasing proliferation. Relying on having the largest and most destructive weapon as a way to maintain security, may in fact, lead to a less secure world.

Possibly one of the most widespread motivations for disarmament is the belief that progress by the NWS to reduce and eventually disarm will strongly influence the

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[837] Scott D. Sagan, "Shared Responsibilities for Nuclear Disarmament," (Cambridge: American Academy of Arts and Sciences, 2010): 9.
[838] Ibid, 12.

future willingness of the NNWS to stay within the NPT. Sagan states that if this is true, "the choice for the future is not between the current nuclear order of eight or nine NWS and a nuclear-weapons free world" but instead the choice between moving toward a nuclear-weapon-free world or a world in which most states have nuclear weapons.[839] This point of view leaves no room for a middle ground, either states will completely disarm or more and more will begin the proliferation process. The world of nuclear weapons is not as black and white as this, but it allows for a way understand and frame future policy.

There are many arguments for and against complete reductions, yet common ground can be found between them. Although it is not possible to "unlearn" the basis of nuclear technology and how to make weapons, it is possible to implement further regulations on that knowledge prohibiting the weapons from falling into the wrong hands. With this understanding of safety, nuclear states can begin reductions without the fear that they need to maintain large numbers of weapons as a deterrent. The knowledge to make nuclear weapons will always exist thus a nuclear free world is impossible, yet further reductions are possible through mutual trust and treaties and remain as the best alternative.

CONCLUSION

In the past 50 years, the world has gone from feverishly manufacturing tens of thousands of the most destructive weapons imaginable to dismantling the greater part of them. This is not to say that the world is safe from the looming threat of nuclear weapons, for they still exist in vast numbers and are still integral parts of many military

[839] Scott D. Sagan, "Shared Responsibilities for Nuclear Disarmament," (Cambridge: American Academy of Arts and Sciences, 2010), 2.

arsenals and deployments. Yet progress is being made. With the signing of the NPT the framework was created for the non-proliferation and disarmament regime and since then many treaties have followed.

As the two countries that have 90 percent of the world's nuclear weapons, the United States and Russia have been the states most involved in creating and implementing arms reduction treaties. Beginning on May 26, 1972 with SALT I, the United States and Russia started a long history of arms control treaties. This continues today with the New START signed on April 8, 2010 by Barack Obama and Dmitry Medvedev. Although these two countries have the largest stockpiles of nuclear weapons, their history of successful treaties serves as a testament to the possibility of further nuclear arms reductions. One of the key reasons for the arms build up between the two countries was security; leaders of both countries feared each other's actions. A similar situation is occurring between India and Pakistan. Both countries have sought nuclear weapons as a way to maintain their security and the safety of their people. By using the lessons learned from the United States and Russia during the Cold War and the success of their reductions negotiations and treaties, India and Pakistan could work toward a solution. Looking to the history of the U.S. and Russia, India and Pakistan may come to see that nuclear weapons can decrease security and may be counter to their goals. Using the negotiations and treaties between the United States and Russia as a framework, the two countries have the tools to take the early steps toward cooperation and eventual disarmament.

Unfortunately, it is not quite as easy as signing a treaty to enter a world free of nuclear weapons. There are many issues that stand in the way of a nuclear weapons free world. Leaders and their people fear uncertainty and at the same time, fear divulging too much information and transparency plays a huge factor in nuclear disarmament. Unless world leaders can manage to find a way to move past the issue of transparency in warhead dismantlement the possibility of a nuclear free world is very unlikely.

Balance between countries is also a key issue that can prevent leaders from achieving a nuclear free world. The West came out on top when the global balance shifted, and nuclear weapons are seen as a way to maintain that balance and stability. There is a very present fear among the leaders and the public of these countries that if all of the world's nuclear weapons are dismantled, the balance could be upset and the West may not come out on top. Politicians prefer to deal in absolutes rather than possibilities and the possibility that the power that the West currently holds may be upset is not a risk many are willing to take.

Ultimately, although a nuclear free world seems like a wonderful idea, it may be just that, an idea. States, even the closest of allies have always been suspicious of one another. The fear will remain no matter the alleged transparency, that one state (or two, or three) will hide away a weapon or retain the capability to build one on short (perhaps very short) notice. Once a technology of such power and influence has been created, the chances of "un-creating" it are highly unlikely. The best option for world leaders appears to be adopting the goal of working with each other to reduce the number of nuclear weapons to the lowest possible level. In addition, safeguards need to be put in place to prohibit non-nuclear states from becoming nuclear states, and to keep terrorists from obtaining nuclear materials or weapons. As there are fewer and fewer nuclear weapons in the world, the chance of them falling into the wrong hands lessens and global security increases. In the long run, cooperation between states will be fostered through treaties and agreements, and although nuclear weapons will likely exist for many decades ahead, if not forever, leaders around the world will finally be on the same page viewing them as something to be guarded and never used.

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U.S. Department of State. *Strategic Arms Limitation Talks (SALT I).* http://www.state.gov/www/global/arms/treaties/salt1.html (accessed Feb. 4 2011).

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Chapter Fifteen

SECURING CIVILIAN NUCLEAR MATERIALS

Nikki Thompson

Abstract:

Civilian use of nuclear power has entered a new era of growth, especially in Asia, bringing concerns about security and safety. No major accidents have occurred in more than 30 years, since Chernobyl, yet this impressive safety record cannot be assumed for the future. Risk of accidental damage caused by human or mechanical failure has led to the formation of dozens of government and private sector monitoring organizations around the world. Intentional damage to nuclear power plants or damage caused with materials obtained from civilian nuclear facilities is also a serious threat. This paper examines the safeguards currently in place to prevent and minimize human error, malfunctions or attacks involving civilian nuclear power plants, and presents a realistic prediction of the worst-case-scenarios resulting from inadequate security. Analysis of the current security system suggests that civilian use of nuclear power will continue to face risks but can be effectively secured. International cooperation and funding for training nuclear operators, upgraded safety protocols, creating a universal standard for nuclear power plant security, and further monitoring of the transportation of radioactive materials will go a long way in preventing any future incidents.

INTRODUCTION

As the use of nuclear power expands rapidly in foreign countries, particularly in Asia, it is important to consider the safety and security implications of this increased presence of civilian nuclear materials. The potential for an attack on nuclear facilities and the damage caused by such an attack, the possibility of theft of radioactive or fissile materials for use in weapons, and the chance of human error leading to a catastrophic health or environmental damage, all need to be considered carefully. Evaluations of the risks of nuclear energy need to remain realistic and in context of the comparable threats posed by other industries. Nonetheless, the fact that nuclear materials command a unique place in the mind of the public and that weapons-grade uranium can be used to make a simple weapon fairly easily, both indicate that special attention should be given to the securing of civilian nuclear facilities. Detonation of a "dirty" bomb or an actual nuclear device in an urban center would have huge global impacts, not least on the nuclear industry itself.

This paper will first outline the significant role of the International Atomic Energy Agency in the overall global management of nuclear materials and then discuss specific subtopics of civilian nuclear security. Safe operation of nuclear power plants, security of nuclear plants against attack, security of civilian materials against theft for use in weapons, safety and security of civilian nuclear materials in transport, and smuggling issues will all be considered as manageable elements that must be addressed as part of the formation of global nuclear security strategies which maintain the safety and security of civilian nuclear materials. The U.S. has a significant role to play in managing these issues and can benefit from involvement in setting security standards and even serving as a role model for maintaining human and environmental safety. With appropriate investment and self-regulation, the U.S. can not only avoid danger from safety and security breaches in other parts of the world but can position itself as a center for education and excellence in the nuclear power industry.

THE INTERNATIONAL ATOMIC ENERGY AGENCY

The International Atomic Energy Agency (IAEA) is the most established and far reaching organization for securing and regulating civilian nuclear materials globally. Established in 1957 as part of the United Nations group of agencies, the IAEA was a response to President Eisenhower's Atoms for Peace address to the UN General Assembly delivered on December 8, 1953, which proposed the creation of an "atomic energy agency" for the world that would, "devise methods whereby...fissionable material would be allocated to serve the peaceful pursuits of mankind."[840] While the agency has remained true to its original mission, its full span of activities has evolved over time. Its main areas of work can be divided into three domains: safeguards and verification; safety and security; and science and technology.

IAEA Safeguards' Capabilities

The aim of the safeguards and verification branch of the IAEA is to provide credible assurance to the world that nuclear materials are being used for peaceful purposes.[841] The IAEA controls three types of safeguard agreements: comprehensive safeguard agreements, item specific safeguard agreements, and voluntary offer safeguard agreements. Comprehensive agreements give the IAEA the right and responsibility to inspect all nuclear materials in a country, including inspections for undeclared materials, and ensure that no nuclear material is diverted to nuclear weapons or other explosive devices. Comprehensive agreements with the IAEA are signed by Non-Nuclear Weapon States (NNWS) as per their obligation under the Nuclear Non-Proliferation Treaty (NPT). Other comprehensive agreements are signed as part of larger regional treaties such as the African Nuclear-Weapon-Free Zone Treaty.[842] India, Israel and Pakistan are the three official non-NPT signatory states and therefore do not allow comprehensive inspection by the IAEA. In these countries, item-specific safeguard agreements are used to ensure the safety and security of nuclear materials. The IAEA will implement an item-specific safeguard agreement when one of these three countries is working with the IAEA, when importing equipment to be used in nuclear reactors, for example. Other item-specific

[840] "Atoms for Peace," *International Atomic Energy Association*, http://www.iaea.org/About/history_speech.html (accessed Feb. 22, 2011).
[841] International Atomic Energy Agency, *Annual Report: Safeguards*, 2009, http://www.iaea.org/Publications/Reports/Anrep2009/safeguards.pdf (accessed Feb. 26, 2011), 80.
[842] Ibid.

agreements can be implemented as part of bilateral agreements between one of these countries and a third party country with the help of the IAEA. An example of this scenario is the U.S.–India deal, which opened India to more trade in nuclear materials in exchange for extended item-specific cooperation with the IAEA. Finally, voluntary offer agreements are concluded between the IAEA and the five nuclear weapon states (NWS), which are otherwise not required to submit to safeguard inspections.[843,844] The nature of the voluntary offer agreements varies from state to state and specifically excludes materials related to national security. These three levels of agreements give the IAEA a minimum level of authority to inspect all nuclear facilities around the world and ensure their peaceful use. The availability of information obtained through safeguards agreements is subject to the continuing cooperation of each state but the IAEA also uses external information sources to monitor the use of nuclear materials around the world. Other sources available for the IAEA include government and scientific publications, news reports, illicit trafficking databases and commercial satellite imagery.[845]

To ensure IAEA inspection capabilities keep pace with the changing nuclear landscape, the IAEA is constantly investing in new equipment and training for inspectors. The United States plays a critical role in making sure the IAEA has the funding it needs to fulfill its duties and ensure the safe and peaceful use of nuclear technology. The Program of Technical Assistance to IAEA Safeguards (POTAS) is a U.S. sponsored program that has been in place since 1977 and receives funding from the State Department's Non-Proliferation and Disarmament Fund, the Nuclear Regulatory

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[843] China, France, the Russian Federation, the United Kingdom and the United States of America
[844] International Atomic Energy Agency, *The Safeguards System of the International Atomic Energy Agency*, 2010, (accessed Feb. 23, 2011), 2.
[845] Ibid, 10.

Commission, the Department of Defense, and the Department of Energy. The POTAS responds to requests from the IAEA for specific projects and projected expense estimates published annually.[846] U.S. involvement in the funding of the IAEA is critical to the agency's continued success. As the privileges and responsibilities of the IAEA in different countries expand, it will be important for the IAEA to maintain secure sources of funding and ensure that the quality of available IAEA services and IAEA investigations does not suffer.[847]

Areas of Concern for Safeguards

The IAEA's annual report details the significant events for safeguards and monitoring systems every year. The most recent publicly available report covers IAEA findings from the year 2009 and mentions three potentially concerning developments for safeguards in Iran, Syria, and the Democratic People's Republic of Korea (DPRK). Iran has been uncooperative with the required IAEA safeguards inspections since 2007 and has recently refused to resolve IAEA concerns about potential military use of its nuclear facilities.[848] Iran has a confirmed enrichment program, which it has refused to shut down despite United Nations direction to do so, claiming its right under the NPT to have full access to peaceful nuclear technology, including fuel enrichment for use in power plants.[849] Israel destroyed a nuclear facility in Syria in 2007 and in 2009 the IAEA confirmed the presence of chemically processed nuclear particles around the site of the incident. These particles have led to suspicion about the nature of Syria's nuclear

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[846] "The U.S. Support Program to IAEA Safeguards, International" *Safeguards Project Office,* http://www.bnl.gov/ispo/ussp.asp (accessed Feb. 23, 2011).
[847] Ibid.
[848] International Atomic Energy Agency, *Annual Report: Safeguards*, 2009, http://www.iaea.org/Publications/Reports/Anrep2009/safeguards.pdf (accessed Feb. 26, 2011), 80.
[849] Ibid, 81.

activities which have not yet been fully accounted for.[850] The DPRK has not participated in IAEA inspections fully since 2002 and on April 14, 2009 the DPRK requested the IAEA remove all inspection equipment from their nuclear facilities.[851] On May 25, 2009 the DPRK announced that it had conducted an underground nuclear test and the UN adopted a resolution requiring the DPRK to cease testing and re-enter six party talks.[852] To date, these talks have not proceeded due to political tensions and between the involved nations, such as the American sanctions against DPRK.[853] IAEA monitoring of these high-risk areas will continue and IAEA reports may be used to formulate appropriate policies toward these countries.

IAEA Safety and Security Programs

The IAEA established the International Nuclear Safety Center (INSaC) in 2009 in order to, "provide a platform for promoting harmonization, sustainability and knowledge management" for member states beginning new nuclear power programs. Six different studies were done to appraise the safety and security of different reactor models as part of the IAEA's Generic Reactor Safety Review. Among the models evaluated during the IAEA's 2009 Probabilistic Safety Assessments (PSAs) were the DPRK's new advanced reactor and Pakistan's Chashma Unit-1 nuclear power plant.[854] Operational safety evaluations are also conducted by the IAEA in a variety of states every year. Recently six major missions on this front were conducted including in China and Ukraine with

[850] International Atomic Energy Agency, *Annual Report: Safeguards*, 2009, http://www.iaea.org/Publications/Reports/Anrep2009/safeguards.pdf (accessed Feb. 26, 2011), 82.
[851] Ibid, 81.
[852] Ibid.
[853] "New Six-Party Talks," *U.S. Department of State*, http://www.state.gov/p/eap/rls/rm/2010/09/147020.htm (accessed Feb. 23, 2011).
[854] International Atomic Energy Agency, *Annual Report: Safety of Nuclear Installations*, 2009, http://www.iaea.org/Publications/Reports/Anrep2009/safetynuclinst.pdf (accessed Feb. 26, 2011) 62.

positive results.[855] The IAEA also considers state and private sector involvement in safety and security to be very important and partners with national level nuclear security programs frequently.[856]

IAEA Safety Concerns

The IAEA has developed several different programs in an attempt to improve international security. One area of concern for the IAEA is transport security. Nuclear materials become vulnerable to theft or attack when they need to be moved; generally the highest risk materials are those which are no longer useful for power generation. These materials are called orphaned materials and the lack of security surrounding orphaned materials is exacerbated by the general lack of appropriate permanent disposal facilities.[857] The IAEA has recently tried to combat this trouble-area in the international security system by conducting IAEA missions in 24 member states to investigate the type and frequency of nuclear shipments and what improvements are needed in each region to enhance security. The programs developed in these missions are called Radiation Safety Information Management Systems (RASIMS) and are important to communicate nuclear transportation needs and expectations between member states and the IAEA.[858]

Emergency incident response is another major area of nuclear security that the IAEA monitors. The IAEA strives to ensure that any incident involving nuclear or radiological materials, whether real or perceived is treated seriously and professionally. By establishing international emergency response procedures to address potential

[855] International Atomic Energy Agency, *Annual Report: Safety of Nuclear Installations*, 2009, http://www.iaea.org/Publications/Reports/Anrep2009/safetynuclinst.pdf (accessed Feb. 26, 2011) 62.
[856] Ibid, 64.
[857] International Atomic Energy Agency, *Annual Report: Radiation and Transport Safety*, 2009, http://www.iaea.org/Publications/Reports/Anrep2009/safetyradtr.pdf (accessed Feb. 26, 2011), 66.
[858] Ibid, 65-67.

accident or attack scenarios, the IAEA helps nations respond quickly to any nuclear emergency. The majority of IAEA resources in this area recently have gone to emergency investigation of suspected threats and emergency preparedness training. In 2009 the IAEA conducted 25 national and regional safety response training sessions and now considers all member nations capable of adequately identifying, reporting and responding to any dangerous scenario in their country.[859] 211 incident reports were sent to the IAEA in 2009 regarding suspected human or environmental exposure to radiation. Most all reports were investigated and controlled quickly resulting in no human or environmental damage. One incident in Ecuador involved improper handling of an industrial radiography source containing iridium and the man involved was moved to France for medical treatment where he later recovered.[860] The IAEA has published emergency preparedness materials including the First Responder's Toolkit so that now materials for response are available to all levels of nuclear power plant operations.[861]

IAEA Science and Technology Program

The IAEA recognizes the need for nuclear power in a variety of different settings including affordable non-carbon electricity generation, desalinization, and as a way to fight poverty, sickness and pollution around the world.[862] To help the international community achieve these goals, the IAEA further supports safety and security by promoting new scientific research and technological development through its Department of Technical Cooperation, Department of Nuclear Sciences and Applications, and

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[859] International Atomic Energy Agency, *Annual Report: Radiation and Transport Safety*, 2009, http://www.iaea.org/Publications/Reports/Anrep2009/safetyradtr.pdf (accessed Feb. 26, 2011), 59.
[860] Ibid, 60-61.
[861] Ibid, 61.
[862] "Pillars of Nuclear Cooperation," *International Atomic Energy Agency*, http://www.iaea.org/OurWork/ST/index.html (accessed Feb. 23, 2011).

Department of Nuclear Energy.[863] New developments in the nuclear industry can help reduce human and environmental risks present in older versions of nuclear technologies. Construction of new nuclear power plants and other new facilities for the processing or storage of nuclear materials around the world provides a unique opportunity to implement lessons learned from old facilities and improve the overall safety and performance of the nuclear industry.[864]

THE THREAT OF HUMAN ERROR TO CIVILIAN NUCLEAR SECURITY

The risk of human error accidentally causing a catastrophic event at a nuclear power plant is very low considering the construction regulations and intensive training standards required by international monitoring organizations like the IAEA. More specific than the IAEA, the World Association of Nuclear Operators (WANO) is just one of several associations created specifically to ensure safe operation of civilian nuclear facilities. WANO operates in 34 different countries and has several regional training and security facilities around the world. WANO was established by nuclear operators, in the wake of the tragic accident at the Chernobyl nuclear generating station, who wanted to work together to ensure another tragic incident like Chernobyl never happens again. WANO is a voluntary organization in which member power stations assess and improve their performance, especially in the realm of safety, through, "mutual support, exchange of information and sharing of best practices."[865] WANO has an excellent record of improving safety conditions in nuclear power plants and is given partial credit by policy makers interested in international nuclear safety for the last 25 years of uninterrupted safe

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[863] "Pillars of Nuclear Cooperation," *International Atomic Energy Agency*, http://www.iaea.org/OurWork/ST/index.html (accessed Feb. 23, 2011).
[864] Ibid.
[865] "Our Mission," *World Association of Nuclear Operators*, http://www.wano.info/about-us/our-mission/ (accessed Feb. 23, 2011).

operation of nuclear power plants around the world.[866] Nearly all nuclear plants in operation today are WANO members and are held to even more rigorous safety standards than those imposed by the IAEA. WANO member power plants provide their nuclear operators with additional intensive training sessions, participate in nuclear operator exchanges for training purposes, and share the technological and logistical developments in their plants that could improve safety with other WANO members.[867] The one possible exception to WANO's exceptional global safety coverage is the proposed civilian nuclear site in DPRK which currently lacks wide-spread international recognition and does not participate in WANO training or information sharing.[868] Figure 15.1 is a map of the operating civilian nuclear reactors in Asia as of 2010.

Measures taken by WANO and the IAEA ensure that all nuclear operators have the best possible training. Operator exchanges and extensive time spent in emergency simulations help operators prepare to handle all known possible emergencies so that if an incident like the Chernobyl meltdown or some other catastrophic technical failure should ever occur in the future, operators will not make the same errors in judgment that allowed significant damage to occur. These training standards are desirable both for operators concerned for their own safety and the safety of their communities and also for nuclear power companies interested in maintaining working facilities and favorable public perception which allows them to continue operation. Information about safety hazards and breeches in security can be terribly damaging for the nuclear power industry when

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[866] *"WANO adapts to changing nuclear landscape,"* World Association of Nuclear Operators,*http://www.wano.info/press-release/moving-forward-safely-in-a-changing-world/ (*accessed Feb. 23, 2011).

[867] "Programs," *World Association of Nuclear Operators*, http://www.wano.info/programmes/ (accessed Feb. 23, 2011).

[868] "Tokoyo Center," *World Association of Nuclear Operators*, http://www.wano.info/regionaloffices/tokyo-centre/ (accessed Feb. 23, 2011).

this information reaches the general public. This fragility in the nuclear power industry provides further incentive for nuclear power plants to invest in safety and training that meets or exceeds the strict international standards set by WANO and the IAEA.[869]

Figure 15.1. Civilian Nuclear Reactors in Asia

Source: "International Nuclear Safety Center at Argonne National Laboratory," *International Nuclear Safety Center*, http://www.insc.anl.gov/pwrmaps/map/asia.php (accessed Feb. 25, 2011).

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[869]"Remarks by Sig Berg: Inaugural Ceremony of the World Nuclear University," *World Nuclear University*, http://www.world-nuclear-university.org/about.aspx?id=15916(accessed Feb. 23, 2011).

Development of new nuclear technologies is another way safety and security of nuclear power plants can be enhanced. Organizations like the World Nuclear Association's World Nuclear University have been able to build on the strong connection between good security and sound business practices to create and promote their own organization on the grounds of nuclear education and security.[870] Nuclear power is a quickly growing industry and the rapid change in the global energy market along with the security risks associated with nuclear power have created a situation where strong leadership in implementing safe new technologies and providing top-rate security training is very important. Whatever private-sector or government agency invests in taking on this leadership role by developing and sharing their expertise in nuclear power is likely to benefit greatly from this new era of emerging nuclear energy dominance.

NUCLEAR POWER PLANTS AS POTENTIAL TARGETS

Nuclear plants themselves may be attractive targets for terrorist attacks. The power generated from a nuclear power plant is valuable to the surrounding community and disrupting the flow of electricity to an area could be economically and psychologically stressful for the affected population. Public fear and misunderstanding of nuclear science could also lead to fearful reactions disproportionate to the likely physical damage caused by any attack on a nuclear plant. Two common misconceptions about the vulnerability of nuclear power plants must be addressed so that logical safety precautions can be taken without placing an undue burden on the nuclear power industry. The first misconception is that an attack, like a bombing, on a nuclear power plant would cause the plant itself to explode as a large atomic bomb. The second misconception is

[870] "What is WNU?," *World Nuclear University*, http://www.world-nuclear-university.org/about.aspx?id=15036 (accessed Feb. 23, 2011).

that an attack could easily cause a meltdown in the nuclear reactor and release deadly radiation into the surrounding environment.

A nuclear reactor cannot produce an atomic explosion for several reasons. Primarily, the fissile material used to fuel a nuclear reaction for the generation of electricity is not the same as the fissile material used to create a nuclear bomb. The enrichment level in weapons materials is much higher than it is in fuel for nuclear power plants and without a high level of enrichment a nuclear reactor could not possibly explode like a nuclear bomb would.[871] Second, access to a nuclear reactor, even in the most loosely guarded civilian power plant, is not easy to obtain and the difficulty would only increase if a person were carrying a weapon or explosive device. Nuclear power plants are regulated by the IAEA and state level inspections. Even in regions such as Pakistan, which is considered among the least secure states for nuclear power plants, armed guards and redundant security screenings are done on site. Operation of a civilian nuclear power plant requires many people and even to even to travel between different sections of a nuclear facility without appropriate clearance, would arouse suspicion of plant operators, security forces, and other personnel making an attack or heist of nuclear material nearly impossible. An attempt to coordinate the entire staff of a nuclear power plant to execute an attack from within the containment facility of a nuclear reactor carries such a low chance of success and such a high probability of detection by monitoring agencies that it will likely never be attempted.[872]

If a civilian nuclear reactor were ever attacked, the likelihood of radioactive material being released into the surrounding environment is very low. Because of strong

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[871] "Radiological Attack: Dirty Bombs and Other Devices," *National Academy of Sciences*, 2004.http://www.dhs.gov/xlibrary/assets/prep_radiological_fact_sheet.pdf (accessed Feb. 23, 2011).
[872] Ibid.

security in all regions of the world, including Pakistan, Ukraine, and other countries considered comparatively less secure, the only probable form of attack on a nuclear power plant would come from outside of the grounds of the facility. In contrast to the circumstances surrounding famous civilian nuclear disasters of the past, such as Chernobyl, reactors today are built inside of incredibly durable containment structures designed to protect the reactor and shield any radioactive material from being released into the surrounding environment.[873] These structures are generally five-foot thick, rebar-enforced concrete structures with steel lining. They are built to withstand both large earthquakes and hurricane force winds, without any damage to the reactor or the environment.[874] Since the September 11th attacks, the possibility of a plane crashing into a nuclear reactor has also been highlighted as a potential cause for concern but this too is a highly unlikely scenario. Realistically, even if a pilot could maneuver a plane close enough to the ground and with enough control to directly strike the containment facility of a nuclear reactor it would not break through the wall or cause any damage to the reactor inside. This has been demonstrated by crash tests of fighter jets into mock containment walls. These crash tests consistently destroy the planes and leave the walls standing.[875] The most famous of these tests used a small jet as a test, which is logical because the high speed and compact impact area for a plane like the F4 Phantom used in the experiment would actually have the greatest chance of seriously damaging a containment building wall. Even though commercial jets are much heavier than the

[873] "Safe," *Vermont Yankee Nuclear Generating Station*, http://www.safecleanreliable.com/safe.htm (accessed Feb. 23, 2011).
[874] "Targets for Terrorism: Nuclear Facilities," *Council on Foreign Relations*, http://www.cfr.org/homeland-security/targets-terrorism-nuclear-facilities/p10213#p5 (accessed Feb. 23, 2011).
[875] "F4 Phantom Crash Test," *World News*, http://wn.com/Crash_test_of_a_F-4_Phantom (accessed Feb. 23, 2011).

smaller jets, the impact area is also much larger. The force exerted on any one point in the wall, even if the wall was hit squarely with the engine of the commercial jet which is the heaviest and most dense component of the plane, would likely cause less damage than seen in the test of the F4 Phantom.[876] Furthermore, navigating a large plane very near to the ground makes steering quite difficult and for this reason a commercial jet is unlikely to ever directly strike a nuclear power plant.[877]

Trucks and small weapons are similarly unrealistic methods for attack of a nuclear plant because it is too difficult to get close to the hazardous material without being intercepted by security even in the most relaxed civilian power stations. The most practical way to attack a civilian nuclear power plant would be to damage the external systems the plant needs to produce electricity like the cooling system or the electrical wires running away from the power plant so that electricity would be temporarily shut down in the area. Power outages could spread panic among people who do not have information about the technology and/or realistic long-term outcomes of an attack. This panic could also have a substantial negative economic impact on an area, which could make nuclear plants an attractive target for terrorists.[878] However, nuclear power plants in this sense are no more attractive as targets than any power generating station including hydroelectric dams or coal plants, both of which have tend to employ less security and, if damaged in an attack, would have environmental and economic impacts likely to exceed those of a damaged nuclear power plant.[879]

[876] "F4 Phantom Crash Test," *World News*, http://wn.com/Crash_test_of_a_F-4_Phantom (accessed Feb. 23, 2011).
[877] Gwyneth Cravens, *The Power to Save the World: The Truth About Nuclear Energy* (New York: Vintage Books, 2007), 228-232.
[878] Ibid, 161.
[879] Ibid, 142.

POTENTIAL FOR BUILDING NUCLEAR WEAPONS FROM CIVILIAN MATERIALS

Acquisition of radioactive and fissile materials for either a nuclear bomb or a radiological dispersal device (RDD), or "dirty bomb," by a terrorist group is a significant concern for civilian nuclear security. To adequately prevent dangerous terrorist-related scenarios, security for civilian materials must be strong both at all sites with radioactive materials and at likely targets for attack around the world.

The most difficult obstacle for a terrorist to overcome when making a nuclear weapon is the acquisition of bomb-grade fissile materials.[880] The IAEA is responsible for monitoring both materials, which can be made into nuclear weapons, such as highly enriched uranium (HEU) and weapons grade plutonium, as well as civilian radioactive materials, such as spent fuel waste from nuclear power plants and research reactors. All of these materials are highly radioactive and toxic and therefore difficult to handle; this is especially true of bomb-grade uranium and plutonium.[881] The United States Department of Homeland Security considers terrorist acquisition of weapons grade fissile material a major potential security threat, but the likelihood of a terrorist attack with a fully functional nuclear weapon depends on several factors at different stages in weapon construction and detonation.[882] A terrorist group would need to acquire suitable fissile materials, build the weapon, transport the weapon without being detected, and detonate the weapon. Furthermore, for this process to even begin, a hostile party like a terrorist

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[880] Sandia National Laboratories, *Global Nuclear Materials Management: Building the Framework*, 2011, http://www.nti.org/e_research/official_docs/labs/glob_nuc_mat_man.pdf (accessed Feb. 23, 2011), 3.
[881] "NNSA Conducts Radiological Training in Malaysia," *National Nuclear Security Administration*, http://nnsa.energy.gov/mediaroom/pressreleases/irapter22511 (accessed Feb. 23,2011).
[882] "Radiological Attack: Dirty Bombs and Other Devices," *National Academy of Sciences*, .http://www.dhs.gov/xlibrary/assets/prep_radiological_fact_sheet.pdf (accessed Feb. 23, 2011).

group would need to decide that a nuclear weapon is their best available method for attacking a target. Considering the level of preparation and technical skill required to bypass security systems, construct a functioning weapon, and organize a successful attack while avoiding all opportunities for external discovery, it is likely that a terror group would choose a different method of attack such as a dirty bomb.[883]

The security measures in place to stop a hostile party from creating an actual nuclear weapon and using it in the United States or elsewhere are extensive but not flawless. At each stage of the process necessary to make and use a nuclear weapon, there are safeguards, monitoring agencies, and technical obstacles that are likely to prevent a successful attack. Security measures to prevent terrorists from acquiring materials are strong and internationally coordinated through organizations such as the Nuclear Suppliers Group (NSG) and the IAEA. These multinational security organizations try to control when fissile materials are moved and for what purpose. Under the NPT, countries with civilian nuclear power are responsible for securing dangerous materials and can be inspected by the IAEA to insure compliance with strict safety standards.[884]

In this regard, the U.S. has itself taken on the responsibility to help secure and even collect HEU from other nations. This applies specifically, though not exclusively, to the more than 55 research reactors worldwide, many of which still operate on HEU fuel. As of 2010, the U.S. has helped 67 reactors shutdown or convert to low enriched uranium (LEU) fuel, a recent example being Chile, which turned over all of its HEU to

[883] Sandia National Laboratories, *Global Nuclear Materials Management: Building the Framework*, 2011, http://www.nti.org/e_research/official_docs/labs/glob_nuc_mat_man.pdf (accessed Feb. 23, 2011), 2.
[884] International Atomic Energy Agency, *Annual Report: Safeguards*, 2009, http://www.iaea.org/Publications/Reports/Anrep2009/safeguards.pdf (accessed Feb. 26, 2011), 80.

have it down-blended into LEU for sale.[885] In some countries where there is civilian nuclear power but the country in not an NPT member the United States has set up bilateral agreements which try to set security standards. One example of this type of agreement is the U.S.–India Deal.[886]

Nuclear plant security standards are, in most countries, very high. Armed guards and multiple levels of screening for visitors make it very difficult for anyone to casually remove fissile material from a nuclear power plant at the majority of civilian sites. There are however some countries, particularly Pakistan and some former Soviet states, which have potentially inadequate security measures to prevent theft of fissile material from a nuclear power plant or during transport. Another method of acquiring materials would be to buy them from an employee of a nuclear power plant. However, monitoring of fissile materials is so strict in most states that any opportunity for any individual to illegally sell dangerous radioactive substances and actually move them to a desired target area is unlikely.[887]

Creating HEU or weapons-grade plutonium from most forms of radioactive material is a difficult and expensive process that a terrorist group would most likely be unable to do because it involves expensive equipment and time-consuming procedures that would likely become obvious to international observers before any material was ready for use in a bomb. Stealing materials while in transit is one other option for acquiring fissile materials and this prospect will be addressed in the next section.

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[885] "Chile Gives U.S. Weapons-Grade Uranium," *CBS News*, http://www.cbsnews.com/stories/2010/04/08/world/main6375246.shtml (accessed Feb. 26, 2011).

[886] George Perkovich, "Global Implications of the U.S. – India Nuclear Deal" *Academy of Arts and Sciences* (2010): 20.

[887] "Radiological Attack: Dirty Bombs and Other Devices," *National Academy of Sciences*, .http://www.dhs.gov/xlibrary/assets/prep_radiological_fact_sheet.pdf (accessed Feb. 23, 2011).

RISKS FOR MATERIALS IN TRANSPORT

Transportation security for civilian nuclear materials is a concern for the international community because it is arguably the most vulnerable point in the civilian nuclear energy process. Nuclear materials in transport lack the established security structures built into nuclear power plants and are therefore potentially more likely to suffer theft or attack.[888] Not surprisingly, responsibility for safe transport falls under a broad range of domestic and international policies. An estimated 10 million shipments of nuclear materials are moved around the world for civilian use annually, and very few of these shipments ever present a safety or security threat. Of the 10 million annual shipments only about 500,000 (five percent) are actually related to nuclear energy production.[889] Other radioactive materials include medical supplies, special alloys for testing, agricultural equipment, and so forth. All shipments of nuclear materials are monitored by the IAEA and a variety of other local and international regulators, such as the World Nuclear Transport Institute. Private sector regulations from individual corporate decisions all the way to industry-wide safety and security standards are also in place to provide security.[890] Figure 15.2 provides an overview of several different international transportation regulators and the types of shipments they monitor.

[888] "Radiological Attack: Dirty Bombs and Other Devices," *National Academy of Sciences*, .http://www.dhs.gov/xlibrary/assets/prep_radiological_fact_sheet.pdf (accessed Feb. 23, 2011).
[889] "Nuclear Fuel Cycle Transport." *World Nuclear Transport Institute*, http://www.wnti.co.uk/UserFiles/File/public/publications/factsheets/wnti_fs.pdf (accessed Feb. 26, 2011).
[890] Ibid.

Figure 15.2. Safety Regulations for the Transport of Radioactive Material

Mode of Transport	International/ Regional Organization	Name of Regulation / Agreement / Codes	Current Version	Scope
All	IAEA	Regulations for the Safe Transport of Radioactive Material, TS-R-1	TS-R-1; 2005 Edition	Worldwide
All	UN	Recommendations on the Transport of Dangerous Goods	2007 Edition (15th Revised Edition)	Worldwide
Sea	IMO	International Maritime Dangerous Goods Code (IMDG Code)	2007 Edition (with amendment 33-06)	Worldwide
Sea	IMO	International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes on Board Ships (INF Code)	2000 Edition	Worldwide
Air	ICAO	Technical Instructions for the Safe Transport of Dangerous Goods by Air (TI)	2007 - 2008 Edition	Worldwide
Air	IATA	Dangerous Goods Regulations (DGR)	2008 Edition	Worldwide
Road	UN/ECE	European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR)	2007 Edition	Regional
Rail	OTIF	Regulations concerning the International Carriage of Dangerous Goods by Rail (RID)	2007 Edition	Regional

Post	UPU	Universal Postal Convention and its detailed regulations	2005 Edition	Worldwide

Source: "Nuclear Transport Facts: Regulations." *World Nuclear Transport Institute*. 2010 http://www.wnti.co.uk/nuclear-transport-facts/regulations.

There are several concerns for transport safety, which the IAEA addresses in the 2005 Regulations for Safe Transport of Radioactive Material, also known as TS-R-1.[891] The first, and most likely, source of danger from transport, according to the IAEA, is improper packaging and human-error leading to a release of radioactivity. To prevent dangerous mistakes in moving and handling radioactive materials, strict rules about temperature, pressure, and packaging are all in place. Even in the event of a catastrophic accident, the packaging required by the IAEA standards would be sufficient to prevent radioactive contamination from leaking out into the environment.[892] Moreover, the people working as transporters of nuclear materials have been trained to handle many different types of radioactive material in a variety of situations.[893] As with all security standards, some companies and some countries are more vigilant than others. Still, international standards have been established at reasonable levels to ensure security and safety and all transport services have strong records of safe and efficient shipment of radioactive materials. Only one transportation-related incident of radioactive exposure has been reported in the last 20 years where an industrial radiography source, not related to energy production, was inappropriately moved on a passenger in Cochambama,

[891] International Atomic Energy Agency, *Regulations for the Safe Transport of Radioactive Material Safety Requirements, No. TS-R* (2005), http://www-pub.iaea.org/mtcd/publications/pdf/pub1225_web.pdf. (accessed February 9, 2011),1.
[892] Ibid.
[893]" World Nuclear Transport Institute," *Nuclear Fuel Cycle Transport*.(2006) http://www.wnti.co.uk/UserFiles/File/public/publications/factsheets/wnti_fs.pdf (accessed Feb. 26, 2011),2-4.

Bolivia and later the same year a soil moisture probe containing americium was stolen from transport in the same region.[894] The IAEA and local authorities responded to this incident and have since increased security and training in the region to prevent any further mistakes. No lasting health affects, environmental damages or terrorist activities have been reported as a result of the Cochambamba incidents.[895]

The second major concern for transport of radioactive material is terrorism. This includes both the threat of terrorist attack on materials in transit as well as terrorist theft of nuclear supplies or nuclear waste out of the transit system. Because of the packaging and handling rules mentioned above, an attack on transport carrying nuclear materials should theoretically be no more dangerous than an attack on the average truck, train or ship as far as human and environmental health impacts. Clean up in the case of an attack on a shipment of radioactive materials could potentially be slightly more costly than clean up of other situations but the overall impact and cost of this scenario is low enough that nuclear transport is not likely to be an attractive target to any person interested in doing significant damage. The psychological impact of an attack involving fissile material or radioactive material is potentially high and could be seen as a terror strategy for this reason. However, compared to other options, transportation systems are unlikely to be attacked simply because they are carrying civilian nuclear material.

Terrorists might take interest in transportation of radioactive material because of the opportunity movement of materials provides for theft. Outside of the security compounds surrounding nuclear power plants, radioactive materials are more vulnerable

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[894] International Atomic Energy Agency, *The Radiological Accident in Cochabamba* (2009) http://www-pub.iaea.org/MTCD/publications/PDF/Pub1199_web.pdf (accessed Feb 26, 2011), 1.
[895] Ibid.

to theft.[896] However, packaging designed for safety also becomes a security device because all of the highly radioactive materials in transport are packaged in a way that makes it excessively cumbersome for any person or small group to move them without equipment and expertise.[897] Finally, long-distance transportation of stolen radioactive materials, particularly if stolen in a dramatic event such as an attack on transportation services, would be difficult considering the many levels of monitoring and control on movement of radioactive materials.

SMUGGLING AND BORDER CONTROLS

Smuggling radioactive or fissile material, either by itself or in weapon, is quite challenging and new measures are developing to increase border security and check points that would make unnoticed movement of radioactive material across national borders even more difficult. Because quite often the source country for accessible radioactive or fissile materials is not the same as the potential target country for terrorism, careful monitoring of radioactive materials crossing between countries is one viable way to prevent civilian nuclear materials from ever being used in a weapon. The Nuclear Smuggling Outreach Initiative (NSOI) creates partnerships between the United States and countries which are considered at risk of smuggling with the aim of preventing and responding to smuggling of nuclear materials.[898] NSOI activity is limited, however, to working with a small selection of mostly former Soviet states and could be improved by expanding relations to countries like Pakistan where security and smuggling are a

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[896] " World Nuclear Transport Institute, "*Nuclear Fuel Cycle Transport*.(2006) http://www.wnti.co.uk/UserFiles/File/public/publications/factsheets/wnti_fs.pdf (accessed Feb. 26, 2011),2-4.
[897] Ibid, 4.
[898] "About Our Program: Prevent, Detect and Respond," *Nuclear Smuggling Outreach Initiative*, http://www.nsoi-state.net/ (accessed Feb. 19, 2011).

great concern for the United States.[899] The National Nuclear Security Administration (NNSA) is in the process of implementing three initiatives under its Second Line of Defense (SLD) program which aims improve global civilian nuclear security. The first is the SLD Core Program, which will equip 650 sites, mostly border crossings in Russia and Eastern Europe, with detection equipment to monitor any movement of radioactive materials. Mobile, van-mounted, radiation detection systems will also be incorporated into the SLD Core Program to help with this effort.[900] The Megaports initiative will install radiation detection and scanning equipment in over 100 ports by 2018 and scan approximately 50 percent of global shipping at this time. The SLD Sustainability Program will work to ensure the Core and Megaport programs continue to function by training host countries in operating the systems and setting up long term monitoring with all of the partner countries. Current estimates in the SLD program are all based on what is considered reasonable progress for the year 2018 but further negotiations are underway and if construction and implementation goes smoothly in the currently proposed sites, detection and scanning equipment for other sites is likely to be added to the SLD Program's long-term goals.[901] Despite the far-reaching goals of the NNSA and the NSOI in preventing smuggling of radioactive materials, global shipping is a very difficult industry to monitor fully and more progress is required to fully prevent smuggling within and across international borders.[902] Thorough inspections often are slow to conduct and every moment of delay in the world of shipping is equated to money lost. This financial

[899] "About Our Program: Prevent, Detect and Respond," *Nuclear Smuggling Outreach Initiative*, http://www.nsoi-state.net/ (accessed Feb. 19, 2011).
[900] "Fact Sheet: Second Line of Defense Core Program," *National Nuclear Security Agency*, http://nnsa.energy.gov/mediaroom/factsheets/nnsassecondlineofdefenseprogram (accessed Feb 26, 2011).
[901] Ibid.
[902] Carolyn Nordstrom, *Global Outlaws: Crime, Money, and Power in the Contemporary World*. (Berkeley: University of California Press, 2007), 165.

conflict makes tackling the problem of smuggling nuclear materials very difficult. Radiation detection systems, good international communication and standardized procedures between different ports and border crossings can help reduce the economic impacts of monitoring on the shipping industry and speed the improvement of security to prevent illegal transport of nuclear goods but in the end this is an area where perfect security is likely to remain elusive. For this reason it is important to remember that no one type of security is sufficient to prevent nuclear attack and that the overall safety and security system surrounding civilian nuclear materials is important to global and national security.

CONCLUSION

The information presented in this chapter has outlined the responsibilities of the International Atomic Energy Agency to ensure the safety and security of civilian nuclear materials and examined the effectiveness of the IAEA and other agencies in preventing a variety of potential safety and security threats. While there are many real risks facing the nuclear energy industry the internationally-coordinated measures in place to ensure safety and security of civilian nuclear materials have led to a nearly perfect safety record in the last quarter-century. As civilian use of nuclear power continues to grow, international evaluation of the risks posed by nuclear power must also adapt. Based on the recent history of the IAEA working with civilian nuclear power plants, technology sharing and cooperative training will reduce the risk of dangerous mechanical failures or human error. Increased monitoring of transportation systems will help reduce the risk that radioactive materials might be stolen and moved for use in nuclear weapons or dirty bombs. Responsible operation of civilian nuclear facilities is important to global and national security, and also important to the future success of the nuclear industry. Today, cooperation between government and industry has a great opportunity to establish truly impressive levels of monitoring and innovation which will benefit all parties involved and ensure that the new era of expanding civilian nuclear power remains prosperous, safe and secure.

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Conclusion and Policy Recommendations

Christan Leonard and Darren Levin

All available information points to nuclear power as a key element in tackling the world's climate change problem. Because it addresses three urgent global issues--the need to reduce carbon emissions, the rising demand for electricity, and the concern over energy security--nuclear power is rapidly expanding in the world today, especially in Asia, where these issues are particularly relevant. The United States would undoubtedly benefit from reduced dependence on fossil fuels, a phase out of coal-fired plants, and a global leadership role in ensuring the future safety of nuclear power, and international cooperation over non-proliferation.

This task force asserts that nuclear power is the only existing low-carbon technology able to provide efficient baseload power on a scale commensurate with actual energy demands. These demands are growing most rapidly in developing nations. As illustrated in this report, a nuclear plant producing 1,000 megawatts takes up only a third of a square mile, an important factor for densely populated states. A wind farm would have to cover over 200 square miles to obtain the same result, and a solar panel over 50 square miles. Further, nuclear waste is minor in volume compared to the waste from coal power plants and, though dangerous, diminishes in radioactivity over time, whereas the many toxins in coal ash remain forever.

Regarding economics, the problem is not that nuclear is expensive; the problem is that coal, in particular, is cheap. Yet new reactor programs in East Asia are showing that nuclear power plants can indeed be built far more cheaply and safely than in the past. Given the unique cost structure of nuclear power, the U.S. government should play a participatory role as infrastructure requires legislation, regulation, subsidies, and research. With the help of government, coal's negative effects and their costs can be added back in through carbon taxes and cap-and-trade agreements. As the cost of coal goes up, nuclear will take the lead as the most cost-effective alternative. Nuclear technologies' research and development have been under-funded, while solar and wind technologies have received generous financial support. This task force asserts that this needs to change.

The French were able to build 56 reactors that had the capability to provide nearly all of France's electricity in just 20 years due to an efficient licensing process. As a result, France has the cleanest air in Europe, the lowest electrical bills, and a valuable export business that sells energy to its neighbors. France shut down its last coal-fired power plant in 2004 and emits 70 percent less carbon dioxide per capita than the U.S. Asian nations, such as China and South Korea, have learned directly from the French example. The U.S. cannot afford to ignore these developments and fall behind in nuclear development and energy security. Fortunately, the U.S. Nuclear Regulatory Commission has learned from the French approach and now integrates standardized designs and licensing processes.

Weapons and security are valid concerns for any significant expansion of nuclear power. This Task Force recognizes the critical role of the Nuclear Non-Proliferation Treaty in the past and the need to strengthen its relevance, through amendment if necessary, for the future. Continued disarmament, the banning of further nuclear testing, and aggressive diplomatic and legal actions to discourage all new weapons programs, are essential elements if the world is to remain safe from the horrors of nuclear conflict. This is no less true for the issue of nuclear terrorism, which has been rightly called the ultimate preventable catastrophe.

According to renowned scientist, Jim Lovelock, nuclear power as our main source of energy would pose an insignificant threat compared with the dangers of intolerable temperatures and rising sea levels. Never one to mince words, Lovelock states, “we have no time to experiment with visionary energy sources; civilization is in imminent danger and has to use nuclear-the one safe, available, energy source" or endure the worst impacts of climate change to come. Not everyone agrees with these sentiments but this may not matter. Nuclear power has entered its next era of major expansion, which will continue with or without the participation of the West. It is unlikely, however, that climate change can be realistically solved without such expansion. It would be far better, for America and the world, if the U.S. were a leading player in this unfolding "nuclear renaissance."

Recommendations

Several recommendations for U.S. policy should be made regarding climate change, Asia’s emerging energy demand, and nuclear power’s low-carbon advantage over other energy sources. Climate change must be communicated to the public as a non-partisan, non-ideological issue of scientific importance and potential threat. This might be achieved in several ways:

- Use of social networking websites, government sponsored commercials, and advertising focused on the public health dimension and economic costs of climate change.
- Through public education. Schools should incorporate the science and challenges of global warming into their curricula.

The U.S. needs to play an official role in combating climate change at the international level. This should include:

- Serving as a leader in all future climate negotiations, to help frame and to sign and ratify the next global climate agreement in 2012, after the expiration of the Kyoto Protocol.
- Adopting economic and regulatory measures to aid the construction of new nuclear power plants within the United States, while simultaneously applying current Environmental Protection Agency clean air standards to all existing coal plants.
- Encouraging nations that are major carbon emitters, like China and India, to pursue their safe expansion of nuclear power in place of future coal- and oil-burning power plants, and to offer technical or other assistance in this regard.
- Encouraging nations that are major coal and oil users to end or significantly reduce any subsidies for these fuels, in order to bring their price to market levels and thereby improve the economic competitiveness of nuclear power.
- Urging large emitter nations to consider a carbon pricing system, whether as a tax or trading scheme, which could be implemented gradually, in step-wise fashion, in order to improve the health and thus economic capacity of their populations.

There are several recommendations that consider the economics of nuclear power. Nuclear development in East Asia should serve as an example for the U.S. to follow. This task force suggests three primary areas that the U.S. can improve upon:

- Nuclear power plants should use higher-capacity reactors to achieve economies of scale, they should be standardized to achieve substantial cost savings, and a simplified regulatory framework should be devised to reduce unnecessary costs.

- There needs to be increased funding for the Department Of Energy's Loan Guarantee Program as outlined by President Obama's budget proposal to retain the U.S. as a vital center for nuclear technology.
- As part of this funding increase, current Nuclear Regulatory Commission standards should be continually re-evaluated and, if needed, reformed to implement a still more efficient nuclear plant approval process even beyond the current combined license (COL) system.
- Considering supply, the global abundance and low cost of uranium preclude the need to reprocess uranium in a closed fuel cycle. For this reason, and for non-proliferation reasons, the U.S. should not alter its current open fuel cycle approach. However, this policy should remain open to discussion and change, should the economic situation change significantly.
- The U.S. should establish a model for more stringent mining industry regulations in order to minimize the health and environmental impacts that arise from uranium extraction.

This report has recommendations that take into account the human and environmental safety concerns surrounding nuclear power. The task force suggests that:

- The U.S. develops a long term, safe, high-level waste repository, modeled after Sweden or Finland. Geologic options should include storage in appropriate settings along the continental shelf (subsea), in thick and vertically continuous granites, and in a location adjacent to the Waste Isolation Pilot Plant in southeastern New Mexico.

- Any such effort must seek the involvement of local communities, modeled on Finland's comprehensive plan, plus full disclosure of all plans and facts related to the burial of radioactive waste. Financial incentives should also be considered.
- Because interim storage is unsustainable and unsafe in any country, the U.S. should also pursue the option of one or more international repositories. These are recommended for long-term policy, but may not feasible until several national repositories have been successfully built and proven safe.
- Current licensing procedures in the U.S. for a repository are lengthy and complicated, and need to be streamlined.
- State-level bans on new nuclear plants in the U.S. should be removed, if at all possible .
- Instead of encouraging foreign or domestic reprocessing, the U.S. should work to establish an international fuel center.

The U.S. as a global leader should put nuclear issues at or near the top of its foreign policy agenda. The new strategic aim of non-proliferation policy should be to achieve universal compliance with the rules of a toughened non-proliferation regime. The U.S. must be a levelheaded leader in direct, diplomatic non-proliferation negotiations, avoiding both favoritism and discrimination. Non-proliferation requires a high level of international cooperation and compromise, perhaps even with states with which the U.S. has been previously un-willing to negotiate. To encourage universality among NPT treaty signatories, the U.S. should start leading by example. As a sign of good faith, the U.S. should:

- Ratify the Comprehensive Test Ban Treaty and promise an end to all future nuclear weapons tests.
- Discourage more nuclear weapons research and eliminate plans to modernize its nuclear fleet; specifically, the U.S. must end the Reliable Replacement Warhead Program.
- Demonstrate its commitment to disarmament. The U.S. currently has 1,500 nuclear weapons on hair-trigger alert. The U.S. should unilaterally take one-third (500) of these off hair-trigger alert, and commit to taking another third off hair-trigger alert as soon as Russia commits to do the same and encourage IAEA inspectors to confirm this reduction.
- Permanently open its facilities to IAEA inspections, given that the IAEA promises to not disclose proprietary information.
- Pull its nuclear weapons out of Europe, respecting the countries that have called for their removal (Belgium, Germany, Luxembourg, the Netherlands, and Norway).
- Implement all measures needed to bring into force the Additional Protocol of the Nuclear Non-Proliferation Treaty and encourage other states to do the same through high level negotiations and by requiring such acceptance as a condition for receiving nuclear exports.

These unilateral actions will help the U.S. gain credibility and increase U.S. negotiating power in working toward the following multilateral efforts:

- To strengthen compliance with the Nuclear Non-Proliferation Treaty (NPT), the U.S in collaboration with the UN Security Council and General Assembly should adopt a resolution that will require that states lose all bilateral and multilateral assistance, including materials given for nuclear activities, when they withdraw or are found in noncompliance of their treaty obligations, especially Articles I, II, III and X. This should apply retroactively to North Korea and should be used to deter further Iranian research into weapons development.
- The U.S. should lead an effort to encourage all nuclear weapon states to expand transparency in implementing disarmament commitments by ensuring irreversibility of disarmament activities; reducing the operational status of nuclear forces; diminishing the role of weapons in security policies and placing fissile materials from dismantled nuclear weapons under IAEA monitoring and verification.
- The U.S.-India Deal should not set a precedent for other 123 agreements with non-NPT countries but the U.S. should be open to agreements as a "necessary evil" or "strategic concession" if countries prove wholly recalcitrant to signing the NPT or abiding by its obligations.
- 123 agreements should be amended to include IAEA regulation of military power plants.

- The U.S. should encourage the use of nuclear power in countries using 123 agreements and Nuclear Suppliers Group signings while also heavily regulating nuclear activities through the IAEA.
- The U.S. should continue discussions with India and other non-NPT states about joining the NPT. If India refuses to sign, the U.S. should pursue IAEA regulation of India's military reserves.
- To address proliferation and to help prevent nuclear terrorism, the U.S. must work to secure nuclear materials and facilities around the world.
- The U.S. should continue to support the IAEA in its safety and security programs and increase IAEA funding for inspections and safety education around the world, and particularly in high-risk areas like Pakistan.
- The U.S. should work with the Nuclear Smuggling Outreach Initiative and transportation regulation agencies to stop radioactive materials from being smuggled across borders. In particular, the U.S. should work with seaports and shipping companies to emphasize the importance of security over short term profit.
- To increase nuclear security and to assure the international community of its commitment under the NPT to help other nations obtain the benefits of peaceful nuclear power, the U.S. should become a global center for education and training. This will also benefit the U.S. economically in the long run.
- The U.S. should increase funding to universities for nuclear projects, promote technology sharing, and work to adopt best practices to encourage safe and efficient nuclear power in the U.S. and abroad.

These recommendations provide the necessary framework for the United States to respond to nuclear energy expansion in Asia. By following these recommendations, the U.S. can prosper in a new nuclear era while maintaining its interests of climate security, energy security and national security.