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TASK FORCE REPORT

A New Nuclear Era: The U.S. Role in the Shifting Global Energy Landscape

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Contents

Executive Summary

The U.S. has been the world's leader in nuclear power since the first civilian reactors began to generate power. Its work in this role for a half-century has been extremely important to the safety and security of nuclear plants everywhere and to non-proliferation efforts as well. This role, however, appears to be declining. Nuclear energy in the United States has been dormant in many aspects for over two decades, even as a new nuclear era begins, based on the programs of China, Russia, India, South Korea, and other countries, which have grown ever more sophisticated. Indeed, even as several of these nations, notably Russia and China, have begun exporting their technology around the world while advancing their domestic reactor fleets, the U.S. has been closing more reactors than building new ones. Nuclear globalization has shifted to include more developing countries, which view nuclear power as able to provide large amounts of reliable power while reducing carbon emissions and pollution levels. It has been the work of this Task Force to examine the new nuclear era in the light of America's fading leadership, what this might mean for the U.S. and the world, and what might be done so that such leadership can be regained.

Future expansion in the U.S. nuclear program seems uncertain for a number of reasons. Deregulated electricity markets and an oversupply of natural gas, plus direct federal and state support of renewable sources, have together weakened the economic situation of nuclear power, with its high upfront costs. In addition, growing public acceptance was dealt a blow by the Fukushima accident, despite the lack of any casualties. All of these factors, finally, have aided the perception among investors that nuclear plants have high risk in the U.S. While there is much hope that this perception can be overcome by the advent of small modular reactors and other new designs, it remains too early to say.

The U.S. currently has 99 operating reactors that make up 19.5% of the electricity generated in the country, and accounts for over 30% of the nuclear electricity generated worldwide. Nuclear energy runs at a capacity factor averaging 80-90% whereas fossil fuels run at 45-55%, and renewables much lower. Because nuclear energy is a non-carbon emitting and high capacity energy source, this makes it appealing to the increasing energy demands and efforts to reduce carbon emissions. The sustainability and reliance of nuclear power demonstrates its effectiveness compared to renewable sources of energy. Unfortunately, the current reactors in the U.S. are set to expire without enough replacements. This would mean that 64% of the U.S.' carbon-free energy would be gone, leaving the demand to carbon-emitting sources to fulfill.

In order for the U.S. to have sustainable clean energy and to demonstrate global leadership, it's necessary to expand the U.S.'s nuclear energy program. There needs to first be revived government support to demonstrate the commitment and investment. Nuclear power has a lot of participation from the private sector, which indicates the need for an enhanced public-private partnership to promote nuclear energy. Following Fukushima, there has been a decline in support for nuclear power but there has also been an increase in safety regulations and emergency response procedures to prevent a similar accident. Public perception plays a large role in the U.S. agenda and the knowledge gap often correlates to the level of public acceptance. With the U.S.' closed fuel cycle, there has yet to be a permanent repository for nuclear waste, although there are current projects underway.

Expanding the U.S. nuclear program is no simple task, and needs comprehensive support and commitment to move forward. There are numerous challenges that need to be addressed. However, nuclear energy growth in the U.S. would resolve energy security. It would enhance international cooperation for research and development, while promoting nuclear energy and nonproliferation goals. If the U.S. expands its nuclear program, its leadership on the nuclear global landscape would have

more influence and stand as a model for other countries. Because climate change and energy demands aren't exclusive to one country, promoting nuclear energy is extremely promising with the U.S.' lead.

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PART I:
Domestic Nuclear Energy Context

The Status of Nuclear Power in the U.S. Today:
Benefits and Hurdles to Growth in U.S. Nuclear Program

Natalie Riel

Energy and Climate Change

Energy and the environment are inextricably linked. In fact, energy production processes are the largest source of anthropogenic emissions, and are thus a leading cause of climate change. In 2015, energy-related activities "account[ed] for 84.3% of total greenhouse gas emissions" and 5,549.4 million metric tons of CO_2 equivalent[1]. Not all energy sources are equal in their impact on the environment. Causing 91.8% of greenhouse gas (GHG) emissions in 2015, fossil fuels are undoubtedly the most harmful. While there has been some debate about the legitimacy of climate change from the current first administration, scientists almost unanimously agree that the Earth is exhibiting serious signs of maltreatment. Precipitation has increased over many parts of the Earth; the salinity and acidity of the ocean is changing, affecting marine life; and glaciers are melting at a rapid pace, causing the sea level to rise and threatening the geography of coastal areas. In addition, the Intergovernmental Panel on Climate Change reports with high confidence that "globally average combined land and ocean surface temperature data…show a warming of 0.85 degrees Celsius over the period 1880-2012.[2]" These statistics point to a startling conclusion: energy production from fossil fuel combustion is a leading cause of climate change In order to combat climate change, the U.S. must transition to low-carbon energy production—and fast.

Indirectly contributing to the deaths of 6.5 million people each year, coal's energy impact is widely considered the worst. The U.S. Energy Information Administration reports that between 2.07 and 2.17 pounds of CO_2 are released per kilowatt-hour of energy produced by coal, which is higher than that of both natural gas (1.22 pounds of CO_2/kWh) and oil (about 1.7 pounds of CO_2/kWh)[3]. Though dependence on coal as a source of energy has somewhat declined in recent years, the share of electricity generated by coal in the U.S. was 33% in 2015[4]. Combustion of coal releases a number of harmful substances to the atmosphere: chemicals such as carbon dioxide and sulfur dioxide disrupt natural ecological systems, and fine particles pollute the air and are often inhaled by humans. The environmental and health consequences of this are devastating. For example, pollution from coal use has gotten so bad in some regions of China that the air is toxic. The average number of fine particles of per cubic meter ($PM_{2.5}$) in China is nearly 3 times the global average[5]. The outlook is even worse for big cities, where the $PM_{2.5}$ has reached over 1,000 $\mu g/m^3$, more than 10 times the number recommended by the World Health Organization (10 $\mu g/m^3$)[6]. Exposure to $PM_{2.5}$ particles, which are released during coal combustion, has been correlated to a number of serious health risks, including lung cancer and cardiovascular diseases[7]. In fact, the number of deaths attributed to air pollution is nearly 18,000 per day—more than the total number of deaths caused by HIV/AIDS, tuberculosis, and traffic accidents combined[8]. Given the world's heavy dependence on coal as a source of energy, this trend is predicted to continue at an even sharper rate unless countries commit to alternative energy sources.

Another contributor to climate change is natural gas, which provided a similar amount of U.S. energy as coal plants in 2015 (33%). Natural gas is cheap due to oversupply created by the fracking revolution, which has made the U.S. one of the largest gas producers in the world. Natural gas doesn't emit as much carbon as coal combustion, but it contributes something much worse to the environment: methane gas. From extraction through distribution methane is prone to leaking, causing more environmental harm on a pound by pound basis than CO_2. The EPA estimates that "the comparative impact of CH_4 on climate change is more than 25 times greater than CO_2 over a 100-year period.[9]" As the U.S. has come to realize the environmental consequences of coal use, it has transitioned to natural gas as an alternative source of energy. Unfortunately the continued use of fossil fuels, no matter the type, continues to harm the environment in catastrophic ways.

The majority of world leaders are in agreement regarding the critical importance of mitigating climate change. At the Paris Conference in November 2015, a delegation from the United States met with scientists and leaders of 194 other countries to develop a comprehensive strategy to alleviate the negative effects of climate change worldwide. The outcome of the two-week conference was the Paris Agreement, which lays out a formal policy for combating climate change. A key component of the framework is a commitment to "holding the increase in the global average temperature to well below 2° Celsius" with a goal of eventually reducing this number to 1.5° C. Clearly, changing the way the world produces energy is a crucial step in achieving this goal. Transitioning away from fossil fuels towards low-carbon alternatives will reduce the harmful affects of greenhouse gas emissions on the earth and pave the way towards a greener energy future.

Nuclear Energy in the United States

Nuclear is the highest capacity, lowest carbon-emitting, most reliable energy source available. Transitioning to nuclear power will reduce dependence on high carbon-emitting sources of energy such as coal and natural gas. In fact, using nuclear power over fossil fuel alternatives has already avoided nearly 60 billions tons of greenhouse gas emissions since 1970, and continues to save almost 2 billion tons of emissions each year[10]. Nuclear power plants are also the most efficient source of energy. The amount of power produced as a percentage of total installed capacity, known as the capacity factor (CF), is much higher for nuclear than that of any other energy source. In 2016, the average CF for nuclear power was 80-90%, with many plants operating at 93-95% capacity. Compared to solar thermal (10-20%), wind (25-30%) and fossil fuels (45-55%), nuclear generates a *significantly* higher output over a given period of time[11]. The high reliability of nuclear power means that electricity is consistent. This can't be said for renewables, which depend on the whims of nature to produce energy. Nuclear is not just a short-term option; it is a necessity that can be relied upon to produce energy for the foreseeable future. While the world's coal supply is rapidly being depleted due to overuse, uranium (the main element needed for creating nuclear power) is a relatively common metal. What's more, a significantly smaller quantity of uranium is needed in order to produce a given amount of energy than fossil fuel alternatives. Only 8-kilowatt hours (kWh) of heat can be generated from 1 kg of coal. The same quantity of uranium-235, on the other hand, generates approximately 24 million kWh[12]. The abundance of uranium combined with the small amounts needed in order to produce vast amounts of energy makes nuclear the most sustainable long-term energy source available.

Since the beginning of the nuclear age, the U.S. has been a world leader in promoting nuclear power as a non-carbon source of energy. In fact, electricity generated by nuclear power in the U.S. accounts for more than 30% of nuclear-generated electricity worldwide[13]. Domestic investment in nuclear research, especially during the mid 20th century vastly expanded the U.S. nuclear program. One hundred and eight reactors became operational in the country over the span of just twenty years, from 1970 to 1990. Today, nuclear power provides about 19.5% of total electricity generation and 64% of all non-carbon power generation in the U.S.[14]. These numbers, as well as the total amount of low-carbon electricity in the country, could significantly decline if existing nuclear plants were allowed to close without viable replacements. As of February 2017, no less than 87 reactors (88% of the total fleet) had been relicensed, with applications for eight more under consideration. With continued upgrades, some reactors might continue operation for an additional 30 years or more. However, at some point before mid-century, the vast majority of U.S. reactors will need to be replaced. At the moment, plans for such replacement using nuclear technology are lacking. There are four reactors under construction that are expected to go online in the early 2020s, but this will not be enough to replace the 99 plants that will be over 60 years old by 2050. If the U.S. allows all of its nuclear power plants to expire without replacements in place, nearly 20% of the country's energy and 64% of its carbon-free energy will be lost[15] and likely replaced by natural gas, the cheapest alternative.

Given the enormous consequences of fossil fuels, the time has never been more crucial for the U.S. to invest in the nuclear industry.

Although the benefits of nuclear power are obvious, the U.S. must overcome various factors that impede its ability to transition to nuclear. Accidents at nuclear power plants in the U.S. and abroad have dominated media and swayed the public's opinion of the industry as a whole, which today remains quite negative. These accidents are extraordinarily rare and the deaths associated with nuclear power are significantly less than those attributed to fossil fuels, but the perception of nuclear inhibits the government's ability to construct new plants. The radioactive waste produced by nuclear energy is another source of public concern. Informing the public about the immense safety measures enacted in contemporary power plants is the first step to overcoming these hurdles.

Domestic politics and changing administrations also make long-term projects like nuclear power plants especially difficult. The average length of construction of a nuclear power plant (not including citing and licensing) can take around 5-7 years[16], potentially longer than a president is in office. The Clinton administration is the utmost example of the difference a fluctuation in domestic politics can make in shaping energy policy. In an address to a joint session of Congress in 1993, President Clinton announced, "We are eliminating programs that are no longer needed, such as nuclear power research and development.[17]" Under this guidance, Congress shut down multiple nuclear power projects that were in process including the EBR-2 and the Integral Fast Reactor, which were a few years away from completion. The administration also had an impact on human capital. The nuclear industry requires an extensive network of scientists, engineers, and mechanics with extensive training and knowledge of the intricacies of nuclear power production. In 1970s, when nuclear was just emerging as an energy source, over 75 universities had nuclear engineering programs. Today that number is down to 25, as the extreme cuts to the nuclear industry resulted in a decreased demand for workers versed in nuclear science. The U.S. must devote more resources to training a new generation of scientists in order to advance nuclear research and technology. The Clinton administration is considered to be the worst blow to the U.S. nuclear program, but the industry has been recovering ever since.

Despite the challenges posed by administrations in the past, recent events have demonstrated a renewed interest by the federal government as well as private companies and organizations in reshaping the nuclear landscape in the U.S. In November 2015 the Obama administration held the White House Summit on Nuclear Energy, a historic conference dedicated to exploring the role of nuclear power in addressing the impacts of climate change. Here, the Department of Energy announced the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative, which is dedicated to advancing nuclear power by removing barriers associated with research and development of nuclear projects in the U.S[18]. In addition to making nuclear information more accessible, GAIN promotes innovation in the field by providing vouchers to small businesses. Eight companies have received vouchers so far, which allow them to have access to nuclear laboratories, as well as information databases[19]. Investing in businesses dedicated to designing safe and sustainable nuclear technology and encouraging private-public sector partnerships are the keys to revitalizing this industry in the U.S.

Nuclear Power and Renewable Sources of Energy

Climate change is an impending threat. The world no longer has the option of sitting complacently while coastlines and ecological systems are destroyed, and millions of people killed, due to energy-related pollution. An integrated energy system that makes use of both nuclear and renewable energy sources offers the best strategy for complying with the Paris Agreement and fully transitioning to carbon-free power. The intermittency and relatively low capacity factor of renewables can by offset by the reliability of nuclear power. The high up-front costs as well as the longer timeframe of nuclear plant construction can be balanced by renewables, which can be online in 2-3 years at a lower capital cost. Replacing coal and natural gas means replacing a baseload source of electricity, which can't feasibly be done by renewables alone. Renewable energy sources can provide carbon-free energy in the short term, as nuclear projects are in the process of development through licensing, construction, and ultimately to operation. A hybrid system comprised of multiple sources of carbon-free energy is necessary in order to effectively transition to U.S. to a carbon-free future.

Conclusion

Nuclear energy offers enormous benefits in the form of reliability and efficiency without the negative environmental consequences that plague other energy sources. Many are opposed to nuclear because of the radioactive waste produced during the energy production process, but this pales in comparison to the hazards that both coal and natural gas generate. The U.S. needs to invest in nuclear power in order to transition to a carbon-free energy landscape—the future of the country and the world depends on it.

Economic and Market Realities:

U.S. Nuclear Energy Industry

Zain Abid

The economic and market potential of nuclear power will play a crucial role in determining the industry's expansion in the United States. Typically, a new U.S. nuclear plant represents a $6 billion to $8 billion initial investment.[20] Furthermore, these facilities produce major contributions to local, state, and national economic growth. Each year, nuclear power plants employ thousands of U.S. workers and contribute millions of dollars to domestic consumption. High capital cost is the industry's primary economic disadvantage. In developed states, nuclear power capital costs demonstrate consistent increases. U.S. nuclear power historical cost increases are among the highest in the world. Alongside this, the nuclear energy industry possesses secondary impediments. These include excessive regulations and a counter-productive licensing regime. Fearing delays, cost increases, and regulatory uncertainty, U.S. private sector actors are reluctant to invest in nuclear power. Due to pure economic factors like cost of raw materials, significant reductions to nuclear power's basic upfront costs will not be seen in the immediate future. Secondary impediments however, can and must be mitigated in order to raise nuclear power consumption in the U.S. For this, a robust public-private partnership, combining government support and the business elements of productivity, innovation, and competition appears to be best path forward. In this partnership, government may support industry with mechanisms such as subsidies, a carbon pricing scheme, and regulatory and licensing reform.

The Cost of Nuclear

Nuclear power contains three main cost categories: capital costs, plant operating costs, and system costs. A capital-intensive energy source, nuclear energy's upfront costs are significantly higher than its competitors' capital expenses. This makes it comparatively difficult to make initial investments and finance new nuclear power plants.

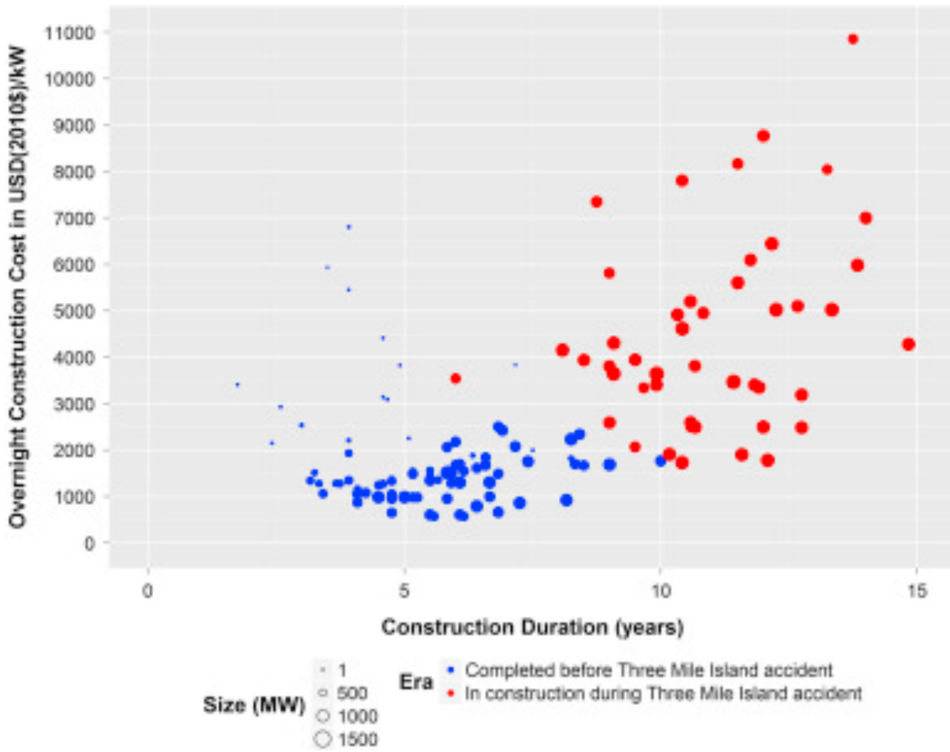
Capital Costs

There are two main tools to measure the total capital cost of nuclear power plants, which comprises the bare plant cost, owner's cost, cost escalation, and inflation. The more common method is to calculate the Overnight Capital Cost (OCC), a term typically used in the power generation industry to describe the cost of building a facility overnight, including the direct engineering, procurement, and construction.[21]

The drawback is that it excludes the financing costs and inflation. In recent U.S. figures, the basic OCC ranged from $2,444 per kW to $3,582 per kW for new nuclear power plants.[22] When the cost of cooling towers, site works, land and transmissions costs, and risk management were included the cost rose to $3,108 per kW to $4,540 per kW.[23]

The more comprehensive cost indicator is the 'all-in-cost' or the construction cost, which combines the overnight expenses and the financing costs up to the start of construction. Clearly, it is extremely useful for identifying the effects of construction delays. When interest charges are added to the OCC figures, the average total capital cost rises to $5,780 per kW to $8,701 per kW.[24] Compared to other sources in the energy market, nuclear power is the chief capital-intensive industry. While there are means to produce slight OCC reductions, nuclear power is unlikely to overcome this initial disadvantage.

In the current literature, the historical costs of U.S. nuclear power plants experience the most frequent economic inspection. While precise conclusions vary, general results among analysts are consistent. In recent years, nuclear power plant capital costs have increased, especially in industrial and post-industrial countries. From the late 1990s to 2009, the average nuclear power plant OCC in OECD countries doubled.[25] The U.S. historical cost increase is the highest in the world, rising over 266 percent between the early 1960s and 1970s. Koomey and Hultman (2007) and Escobar-Rangel and Leveque (2015) assert that U.S. nuclear power displays consistently sharp cost increases in contrast to slowly rising costs of other developed states.[26] Despite this analysis, Lovering, Yip, and Nordhaus (2016) illustrate a more complex picture of cost trends. Based on historical OCC studies, this conclusion creates several cost stages. Between 1958 and 1968, 18 U.S. commercial nuclear power reactors were ordered and built. Throughout the initial stage, OCC decreased from $6,800 per kW to $1,300 per kW. The development of these early U.S. nuclear reactors demonstrated an annual 14 percent OCC decrease.[27] The second cost analysis stage represents the period between 1964 to 1967. Among this stage's 14 nuclear reactors, OCC decreased by a figure of 33 percent.[28] Lastly, 51 nuclear reactors began the construction process between 1968 and 1978. During the 1979 Three Mile Island accident, each reactor was under construction. At this point, analysts observe very sharp OCC increases. The majority of these nuclear reactors contained OCC levels between $3,000 per kW and $6,000 per kW.[29] In addition to OCC, average construction duration increased after the Three Mile Island accident. The cause of this price hikes was largely due to the added costs associated with increased oversight such as regulation and licensing.



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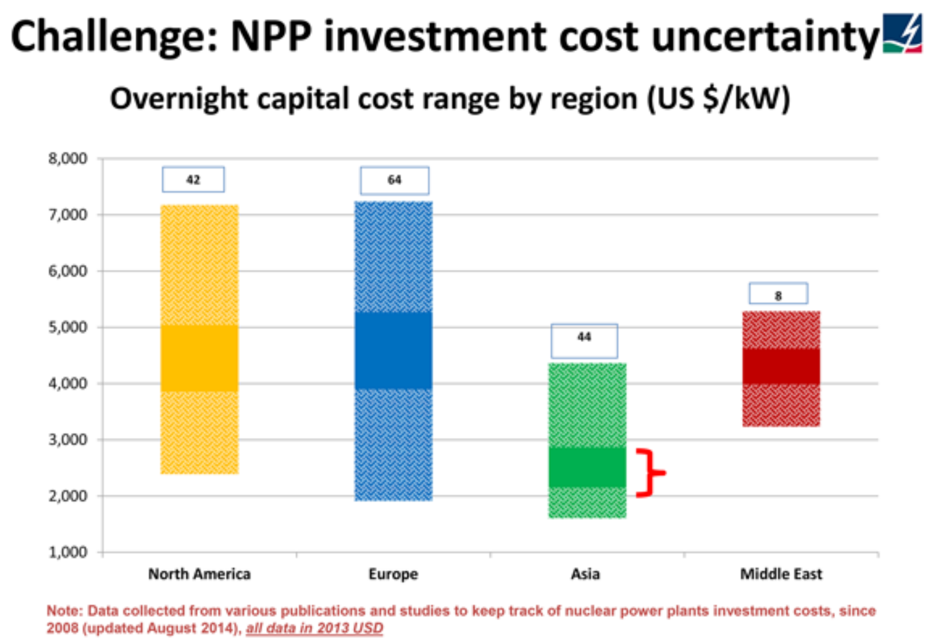
Historical cost analysis also puts light on U.S. nuclear power's secondary impediments. Alongside upfront costs, U.S. nuclear power facilities are plagued by excessive regulation and a counter-productive licensing regime. According to Khatib and Difiglio, "With increasing privatization and liberalization…, private investors are generally not interested in investing in nuclear without one or another type of government assistance to reduce their financial risk, due to… long and uncertain time to construct and license the plant and possible safety delays."[31] Nuclear power's initial OCC setbacks cannot be restrained. However, issues such as immoderate regulation and stringent licensing requirements can be reformed. One path forward would be to forge a stronger partnership between government and industry, in which government can reduce investment risk through several financing mechanisms while the private sector can sustain projects through different political administrations and drive efficiency.

Unlike other technologies, U.S. nuclear power has a disadvantaged commercial history. Public safety concerns and the government oversight that follows help to explain this phenomenon. For commercial nuclear power, U.S. government institutions such as the Nuclear Regulatory Commission (NRC) are a source of excessive and uncertain regulations as well as counter-productive licensing standards. In addition to this, the government has not pursued standardization and modularization in regards to the types of reactors that have been built. Instead, many U.S. reactors have been first-of-a-kind, significantly driving up costs and production inefficiency. One potential strategy for the U.S. to reduce costs would be to encourage a standardized advanced reactor. In the figure below, there is comparatively small cost uncertainty in Asia, some of which is due to centrally-planned economies who have focused on design standardization to reduce costs.



[32]

Alongside regulatory and licensing reform, there are other opportunities for government to actively support U.S. nuclear power. Many government programs that intend to support non-carbon energy sources with direct or indirect production subsidies exclude nuclear energy. Yet, if a uniform U.S. carbon pricing scheme existed, it would likely increase nuclear power's cost competitiveness with natural gas, its major competitor for baseload power. Overall, high early capital costs make nuclear power plants extremely difficult to finance. This is especially true in liberalized markets and requires government support and the mitigation of secondary impediments.

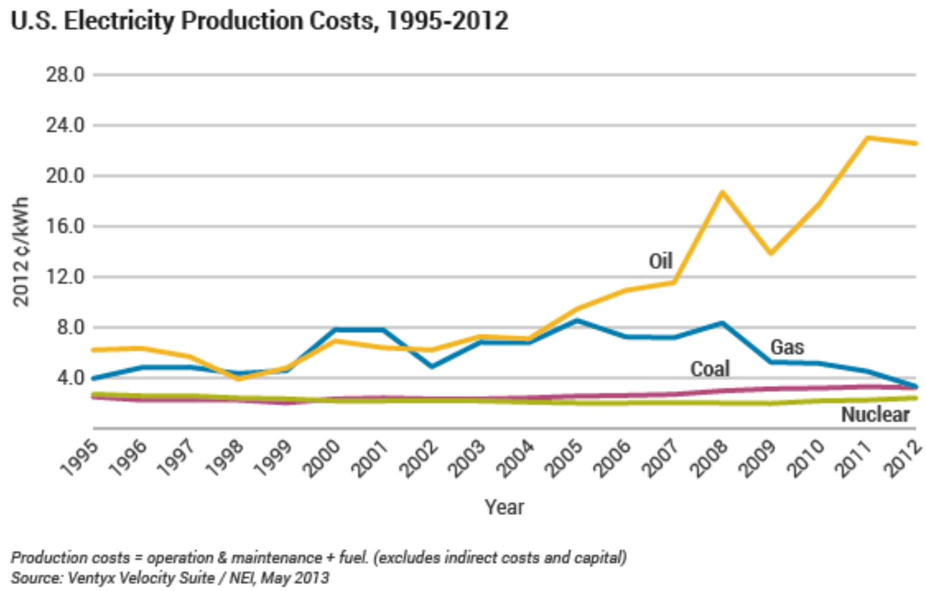
Post-Capital Costs

While nuclear power is not cost-competitive in terms of upfront costs, it has significant advantages in operating and system costs (post-capital). The components of operating costs include operating and maintenance plus fuel (management and final waste disposal). Since Uranium is widely available from stable U.S. allies, the overall fuel cost is relatively small at around 10 percent of overall costs per kW. The fuel cost structure in July 2015 for 1 kilogram of uranium which produced around 360,000 kilowatt hours of electricity was $862 for Uranium (46 percent), $599 for enrichment (32 percent), $300 for fuel fabrication (16 percent), and $120 for conversion (6 percent), totaling $1,180.[33] While additional operational cost savings can be accrued through fuel reprocessing, this is against the U.S. NRC regulations because it increases the possibility of weapons proliferation.

System costs include costs associated with grid connection, extension and reinforcement, short-term balancing costs, and long-term costs of maintaining adequate back-up. These costs are typically passed on to the customer and seldom compared in determining grid supply options. However, nuclear power's modest system costs of $1-3 per MWh supplement its cost competitiveness. In comparison, system costs for intermittent renewable energy sources range from $15 per MW to $80 per MW.[34]

Economic Comparisons of Different Energy Sources

The levelized cost of electricity (LCOE) is the primary tool used to measure annual production costs for dispatchable generating facilities. LCOE demonstrates the per-kilowatt hour cost of constructing and operating a power generating facility. Some of the methodology's key factors include capital costs, fuel costs, operating costs, and utilization rates. For 2015, U.S. nuclear power's average LCOE was $99.70 per MW.[35] Upfront costs make the highest contribution to nuclear energy's LCOE. In comparison, the 2015 Conventional Combined Cycle (CCC) natural gas LCOE was $56.40 per MW.[36] Unfortunately, intermittent energy technologies such as wind and solar power are not directly comparable to baseload sources using LCOE. However, single LCOE components, such as tax credit and capacity factor, can be used to compare these sources. Annually, solar power and wind power tax credits dwarf nuclear energy's tax credit amounts. Despite this, nuclear electric power maintains the highest capacity factor among energy sources. Specifically, 2015 U.S. government data show that, at a LCOE of $99.70 per MW, nuclear power sustained an average capacity factor of 90 percent. Comparatively, solar energy's (PV) average LCOE of $74.20 per MW produced an average capacity factor of 26 percent.[37] Based on cost of production and output, nuclear power is significantly more efficient than its competitors.



[38]

Additionally, small discount rates in the form of tax incentives and subsidies increase nuclear energy's overall cost competitiveness. For example, if a 3 percent discount rate were applied for nuclear power, it would be significantly cheaper than renewable energy sources. Furthermore, a 7 percent to 10 percent discount rate would establish cost competitiveness between nuclear electric power and coal and natural gas.[39]

Lastly, nuclear power's operation and maintenance expenses are highly competitive in comparison to other energy sources. In 2012, historical U.S. figures demonstrated that post-construction nuclear electric power was far cheaper to generate than fossil fuel based power. Precisely, nuclear energy produced electricity at 2.40 cents per kW, compared with coal at 3.27 cents per kW and natural gas at 3.40 cents per kW.[40]

Nuclear Power Economic Benefits

Despite some cost setbacks, nuclear electric power contains numerous economic benefits. Mainly, these returns are observed in terms of job creation, increased consumption, and overall economic growth. Locally, every U.S. dollar invested in a nuclear power plant returns $1.04. At the state level, the average investment return is $1.18. Nationally, the return figure is $1.87. In the U.S., nuclear power plants produce $40 billion to $50 billion of electricity sales revenue each year. In result, these facilities employ more than 100,000 workers and each facility creates roughly $40 million in average annual labor income. Nuclear energy's domestic economic benefits are observed in primary and secondary gains. First, a nuclear power plant generates $453 million in expenditures for goods, services, labor, and profit. Secondly, nuclear electric power facilities contribute roughly $393 million in indirect and induced spending in the national economy.[41] As an industry that produces comprehensive domestic economic growth, advancement of the U.S. commercial nuclear power will result in further gains.

Another major economic motivation by government and public actors to pursue nuclear energy lies in external cost savings, such as environmental and health benefits that result from reduced emissions and pollution. Since the 1990s, the European Commission and the U.S. Department of Energy have analyzed these cost savings. Major external cost savings research studies include factors such as emissions, dispersion, and ultimate impact. Regarding nuclear power, methodologies consider the risk of accidents as well as estimates of unsafe radiation exposure. Still, some external cost methodologies demonstrate external cost savings and do not consider emission costs. A non-carbon source, this feature further supplements nuclear energy's external cost savings. According to a 1991 European Commission and U.S. Department of Energy study, nuclear power demonstrated impressive external cost savings compared to competitors. For example, nuclear power saved between 0.9 Euro cents per kW to 1.9 Euro cents per kW in comparison to natural gas. Alongside this, the same research study concluded that nuclear power saved 3.6 euro cents/kWe in comparison to coal.[42] Similarly, a 2001 calculation of the ExternE-Methodology concluded that nuclear energy incurs about one-tenth of the costs of coal.[43] Furthermore, this study excluded global warming's external costs.

In addition to the external cost benefits and economic gains, government also receives significant tax revenues from commercial nuclear electric power consumption. Each U.S. nuclear plant generates an average state and local tax revenue of $16 million. Furthermore, each U.S. nuclear plant's average federal tax payment is nearly $67 million.[44] In result, U.S. nuclear energy plays a key role in public goods.

Government & Private-Sector Collaboration

Like most advanced states, the U.S. possesses a liberalized power generating market. Therefore, private sector actors play the chief part in the American energy sector. Among these industry players, there is a large reluctance to invest in nuclear power.

A major function of the U.S. NRC is to regulate and license new and existing nuclear power plants. The licensing process for U.S. nuclear energy facilities requires large amounts of time and funds. Commonly, applicants experience significant delays due to stringent oversight issues. As profit seeking actors, this reality severely affects the private sector. For example, Entergy Corporation's Pilgrim Nuclear Power Station will shut its doors in 2019. Due to NRC safety upgrade requirements, it will soon lose profitability for its parent company. Despite this, the facility is qualified to operate for an additional two decades.[45] Ultimately, the Entergy Corporation facility's situation is highly representative of nuclear power plants across the U.S. Furthermore, the NRC is required to recover 90 percent of its budget from licensees and applicants. Often, large fee requirements push investor projects years behind schedule and billions of dollars over budget.

In addition to regulatory and licensing reform, government can take an active role to support U.S. nuclear power through numerous financial mechanisms such as a carbon pricing scheme and subsidies. Today, most U.S. states do not enforce carbon pricing schemes such as carbon taxes or cap-and-trade programs. Compared to fossil fuels, this significantly weakens nuclear power's capital cost competitiveness. Based on fossil fuel commodity price fluctuation, strict enforcement of a carbon pricing scheme will likely expand nuclear power in the U.S. In the absence of coordinated U.S. carbon pricing, some experts recommend direct nuclear energy subsidies. Precisely, the 2016 U.S. Secretary of Energy Advisory Board Task Force on the Future of Nuclear Power (SEAB) recommends $0.0027 per kW production payment for nuclear reactors that operate at above a 90 percent capacity factor.[46]

Private sector disinterest in U.S. nuclear power is due to excessive regulations, a counter-productive licensing regime, and the lack of government support. Ultimately, it is opportune for the U.S. to address these issues in a public-private partnership to expand American nuclear energy. In addition to regulatory moderation and licensing reform, government can encourage investment with economic incentives for nuclear power.

Public Attitudes:
History, Status, and Outlook

Su Rim Han

As nuclear power becomes a more prominent source of energy, public opinion regarding nuclear power has been controversial and fickle, oftentimes shifting in light of new economic conditions, safety perceptions, political influences, and media portrayals. Public attitudes, especially the opposition, play an important and often disregarded role in the development of nuclear power. For example, a negative public perception can lead to anti-nuclear protests that might make a suitable location for a power plant or waste repository site off-limits or more work than its worth. It also limits further research and development of nuclear power. The leading reason for opposition is radiation concerns, which are oftentimes exaggerated or distorted by the media, especially after events like Fukushima in 2011. Despite its history of controversy, nuclear power is gaining favor as a solution for energy security and a source of non-carbon power to combat climate change.

History

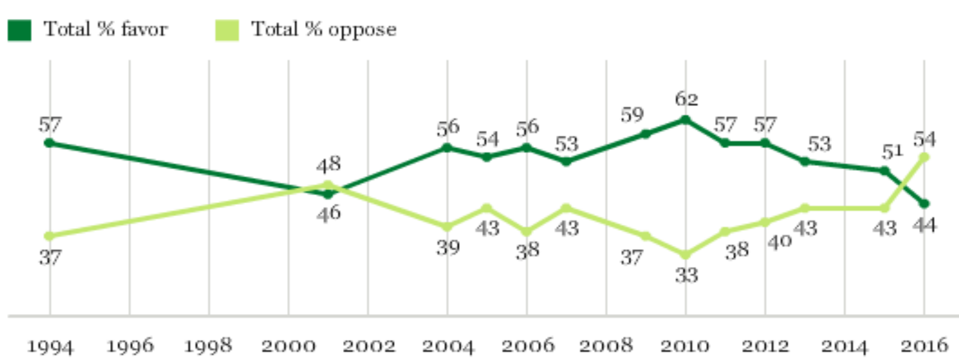


Figure 1. Gallup poll data on U.S. public attitudes towards nuclear power (favor, oppose) for years 1994-2016. Source: Gallup, 2016

Public attitudes toward nuclear power in the United States fluctuate. Gallop polls conducted over the period of 1994 to 2016 reflected the change in public opinion. The question asked was "overall, do you strongly favor, somewhat favor, somewhat oppose, or strongly oppose the use of nuclear energy as one of the ways to provide electricity for the U.S.?"[47] In 1994, those who favored nuclear was 57%, and those who opposed made up 37% of those surveyed. In 2001, the percentage of respondents in favor of nuclear power dropped to 46% but then gradually increased[48]. The post-2001 gain in nuclear favor was caused by many factors. One major influence was the terrorist attacks of September 11, 2001. Striking up a fear of foreign aggression, the incident made people desire strong domestic protection measures, giving rise to more popular nuclear sentiments. After 2001, there were up and downs in the percentages of those who favored and opposed nuclear with support reaching its peak in 2010 at 62%[49]. However, the Fukushima explosion in 2011created a lasting negative perception that has resulted in a noticeable decline in nuclear public favor ever since. This has occurred despite the fact that there were no deaths or injuries directly related to Fukushima. According to the Gallop poll, about 54% of the U.S. population opposes nuclear power, while 44% support it today.[50]

Current Public Attitudes

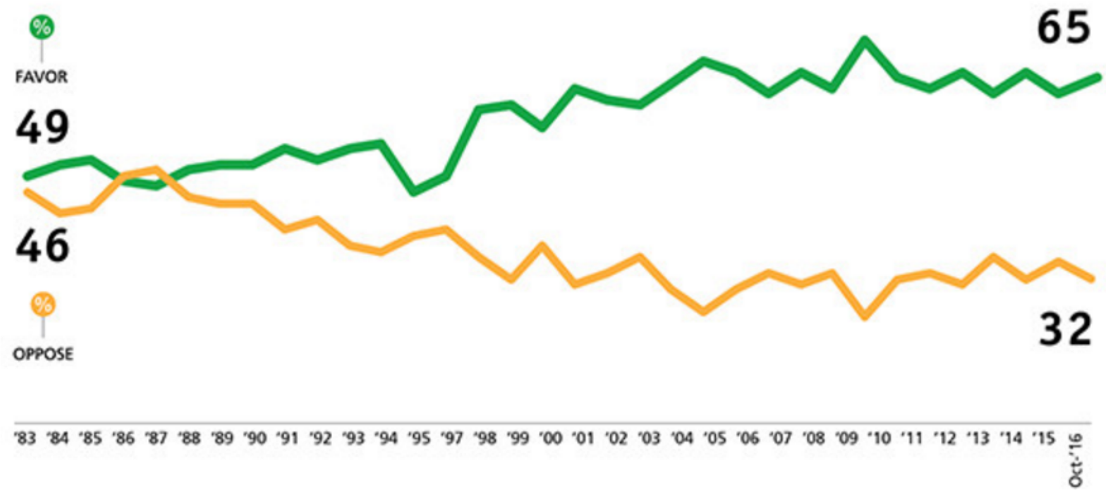


Figure 2. NEI poll data on U.S. public attitudes towards nuclear power (favor, oppose) for years 1983-2016. Source: NEI, 2016

The Gallop and NEI polls used to determine public opinion show different results. In Figure 2, the NEI poll shows that opposition to nuclear power is much lower than the Gallop poll would indicate. What, then, explains the differing survey results? The reasons for this variance could be attributed to survey method, survey population, and the wording of the questions. The polls both used the same survey method, contacting a random sample of households by telephone and asking questions with the same wording. Thus, the survey population is the differentiating factor. A study by the Pew Research Center showed how different populations will result in varied results.

Their survey asked science-related questions to both the general public and the members of the American Association for the Advancement of Science (AAAS). One of the questions was if they "favor building more nuclear power plants to generate electricity" or not; 45% of general public supported more nuclear power plants in comparison to 65% of AAAS members[51]. This result indicates that scientists are more likely to favor nuclear power than non-scientists. While survey results vary to some extent, especially in the large and diverse U.S. population, the underlying trend is that there are mixed opinions regarding nuclear power – not only is there no consensus yet, but opinions are likely to change in the future as well.

Q154a. [ASK IF Q154aa = OPPOSE] What is your **top concern** regarding nuclear power generation?

Ranked by % in Wave 10

W3	W5	W6	W7	W8	W9	W10	%
373	*556*	*514*	*532*	*577*	*549*	*526*	*Base*
28	27	35	33	33	34	34	The effects of nuclear radiation on my community
27	30	26	30	28	27	24	Nuclear waste storage
21	24	19	21	20	21	19	Power plant meltdown
18	15	14	13	15	16	18	A possible terrorism target
6	4	6	3	4	3	5	Other

Figure 3. Energy poll data on U.S. top concern regarding nuclear power generation. Source: University of Texas at Austin, 2016

It's then important to examine why people are in favor or opposed to nuclear energy. As figure 3 shows, there are four main reasons why people oppose nuclear power generation: "the effects of nuclear radiation on my community", "nuclear waste storage", "power plant meltdown", and "a possible terrorism target"[52]. The issues that most concern people are the potential consequences of radiation and waste storage, such as those that would arise if a terrorist group were to target a nuclear plant.

Q154b. [ASK IF Q154aa = SUPPORT] What is the **top reason you support** nuclear power generation?

Ranked by % in Wave 10

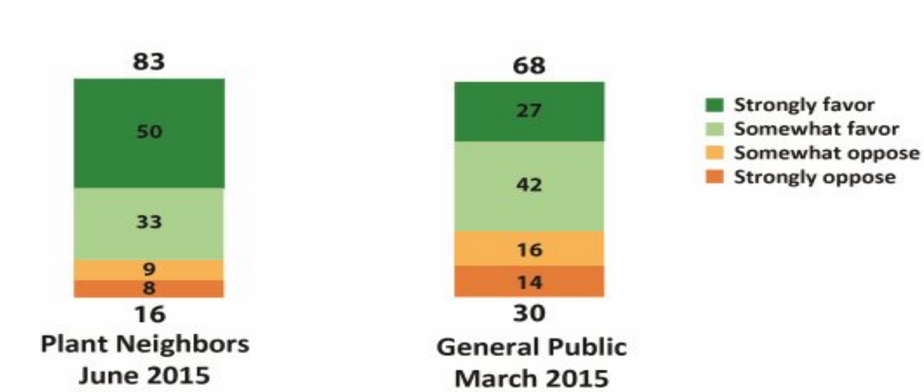
W3	W5	W6	W7	W8	W9	W10	%
810	*785*	*785*	*803*	*717*	*703*	*792*	*Base*
87	84	84	84	83	84	81	Nuclear power provides a steady, reliable source of energy
11	14	14	14	16	15	19	There are no emissions
2	3	2	2	2	1	1	Other

Figure 4. Energy poll data on U.S. top reason for supporting nuclear power generation. Source: University of Texas at Austin, 2016

Figure 4 shows the results of a survey investigating the reasons for public support of nuclear power. The significant increase in climate and environmental concerns has played a major role in turning many away from fossil fuel sources and towards nuclear power generation as a viable baseload power source[53]. Today, cost-competitive, pollution-heavy fossil fuels are the most common sources of energy, but their future may be limited.

Figure 5. World Nuclear Association map on U.S. nuclear power plant in 2017. Source: World Nuclear Association, 2017

There are ten states that use nuclear power as a major energy source: Mississippi, New Jersey, Virginia, Florida, Michigan, Connecticut, Ohio, South Carolina, Illinois, and Pennsylvania[54]. In Mississippi, 100% of emission-free power comes from nuclear power. There is only one nuclear power plant in the state, but it makes up about 18% of total electricity produced[55]. Another noticeable state is South Carolina. The four nuclear power plants in the state make up 97% of non-carbon energy sources but generate 50% of the state's electricity[56]. Figure 6 shows that the people who live in states or areas where nuclear energy is generated tend to favor nuclear power more than the general public. The higher levels of fear from the general public comes from uncertainty and misperceptions about the



dangers of nuclear power. For example, Nevada, which has zero nuclear plants, has historically had many anti-nuclear protests. Since the 1950's, hundreds of protesters have showed their disapproval for testing nuclear power plants in the area[57]. The protests were revived in the last few years after the after attempts to plan a nuclear waste repository at Yucca Mountain. Nevada governors were opposed to having a nuclear waste repository at due to the geology of Yucca Mountain, possible leakage of radioactive substances or possible accidents, and uncertainty of funding from the Department of Energy (DOE)[58] .

Attitudes in Other Countries & U.S. Implications

While most countries face public opposition to nuclear power, some countries have strong public acceptance, such as Finland. Recently, Finland has been working on building nuclear repositories at Olkiluoto and already has a repository for low-level waste (LLW) and intermediate-level waste (ILW)[59]. Two factors are thought to influence public support in this area: knowledge about nuclear waste and public trust in the government. People in Olkiluoto "believe the waste will be safer a thousand feet underground" (Montgomery & Graham 2017), which is true and represents how informed the Finland populace is. Another example of a country with strong public acceptance is South Korea, though for different reasons. Unlike Olkiluoto, South Korea faced strong opposition in the beginning. To reverse this, South Korea decided to "invite towns that wanted repository facility and sweetened them with a subsidy of about $230 million and the promise of locating a major corporate headquarters locally"[60]. The South Korean government did not necessarily have the trust of the people, but they could persuade their citizens with subsidies.

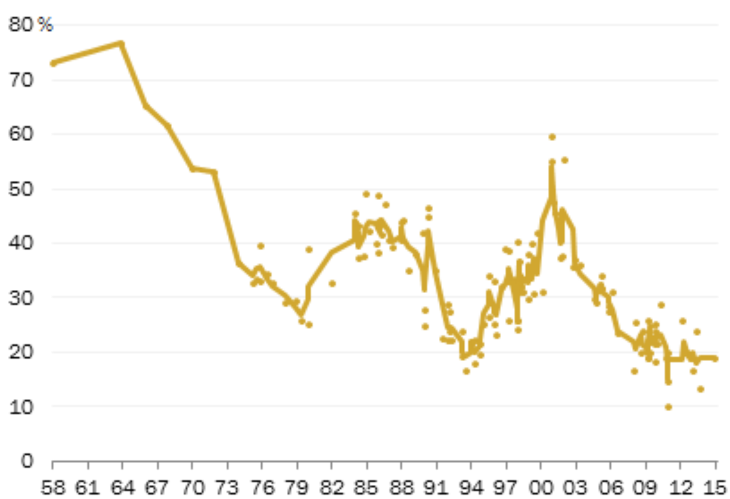


Figure 7. PEW poll data on U.S. public trust in government for years 1958-2015. Source: Pew Research Center, 2015

Finland and South Korea set good examples of the successful development of nuclear power plant and repository systems. Building off of these examples, the U.S. needs to find its own way of increasing public acceptance. As shown in figure 7, recent trends regarding U.S. public trust in the federal government has been around 19%. With this low trust in government, it is hard to develop nuclear power in the same way that Finland did. Trust in state government, rather than federal, however, can change local attitudes toward building nuclear power plants. One action the Federal government can take is in regards to funding.

What is Needed to Change Public Attitudes?

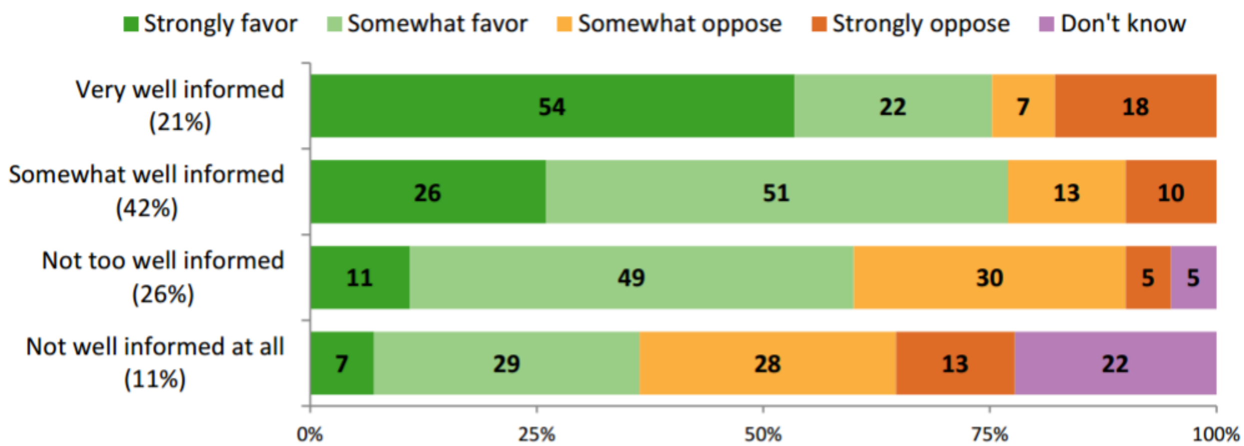


Figure 8. Bisconti Research, Inc. poll data on U.S. favorability to nuclear energy by level of feeling informed about nuclear energy. Source: NEI, 2016

The best way to change public attitude towards nuclear power generation is to inform the public. The graph above shows the trend that people who are more informed about nuclear energy tend to favor its use. Misconceptions about nuclear power, often stemming from accidents like Three Mile Island in 1974 and Fukushima in 2011, serve to obscure the realities surrounding the safety and reliability of nuclear power generation. To some extent, the government can influence public attitudes through the policy and economic decisions it makes regarding nuclear power. The government needs to "establish a stable market and regulatory structure" and also "address the management of nuclear waste"[61]. Establishing a stable market lowers the price of the energy source. The cheaper the price gets, the more people will favor the use of nuclear power. The government should also find a place that is geologically stable for nuclear waste storage and inform the public of the radiation it may produce. It is also important for the government to "manage international linkage of nuclear power"[62]. People's concern about proliferation and terrorist attacks can be reduced by well-secured nuclear facilities, which are in fact already required

Conclusion

Public attitudes toward nuclear power cannot be ignored since they play an influential role in the development of nuclear power plants and waste repository systems throughout the U.S. The main reason for nuclear opposition comes from fear of radioactive effects on the community. In order to change public attitude positively, government should consider funding and providing more information on nuclear power instead of letting the media's coverage be the main source of information. Public opinion will not be settled until people believe in the safety and security of nuclear power plants.

Nuclear Waste Disposal

Hung Nguyen

Since the emergence of the nuclear power industry in the 1950s, management of radioactive waste has been intensely scrutinized in Congress, specifically the safe disposal of waste to prevent nuclear weapons proliferation. The U.S. prohibited used fuel reprocessing in 1977 due to the continued waste accumulation and questions of health safety and environment protection from the public. Due to increasing public concern of nuclear disposal in the wake of the Three Mile Island accident, Congress passed the

Nuclear Waste Policy Acts (NWPA) in 1982, calling for permanent disposal of spent nuclear fuel and other types of nuclear waste in a deep geologic repository. Congress directed the Department of Energy (DOE) and two other federal agencies: the Environment Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC) to investigate potential sites and develop a plan. In 1987, Congress added another amendment to NWPA that restricted the DOE's repository site studies to Yucca Mountain in Nevada, prompting backlash from the state government and local communities. In 2008, under political pressure, the Obama administration stopped the project, stating that "developing the Yucca Mountain repository is not a workable option and the Nation needs a different solution for nuclear waste disposal"[63]. As a result, it remains the responsibility of the nuclear power plant owners to store radioactive waste in under water pools at reactor sites.

Nuclear Waste Policy Act of 1982

Faced with 77 million gallons of radioactive waste that came from the production of nuclear weapons and energy in 1982, the Nuclear Waste Policy Act laid the foundation for the safe disposal of high-level radioactive waste.[64] However, this act had a rough start and has been amended several times since its inception; a reoccurring problem was settling on a location.

Despite the general consensus on the need for legislation to establish a comprehensive national policy for the disposal of highly radioactive nuclear waste, no such legislation had been enacted since the 1950s. Public concern and opposition grew in the wake of the 1974 Three Mile Island accident, which involved the partial meltdown of a reactor station in Pennsylvania. The House and the Senate then passed the Nuclear Waste Policy Act in 1982. Congress established the Office Civilian Radioactive Waste Management (OCRWM) in the Department of Energy (DOE) to conduct site inspection, construction, operation, and closure of a repository for both civilian and military high-level radioactive waste. In addition, Congress requested the EPA and NRC, in cooperation with OCRWM, to enforce safety standards and regulations of the repository. Within the 1982 law, Congress:

- Required the DOE to study five potential sites for the location of a permanent, underground repository and to recommend three of those sites to the president by Jan. 1, 1985, for further site characterization studies.
- Required that five more potential sites, including at least three not included in the first five, be studied and three of them recommended to the president by July 1, 1989, as possible sites for a second repository. These site selections will be divided into those east and west of the Mississippi River.
- Required an environmental assessment of each potential repository site, including a description of the decision process by which the site was recommended and an assessment of the regional and local impacts of locating a repository at the site.
- Required the DOE to hold public hearings in the vicinity of each site considered.
- Required an established date (1998) by which the federal government had to have a final repository open.[65]

Before the construction of a permanent nuclear waste storage facility commenced, Congress ordered the DOE to develop plans for building monitored, retrievable storage (MRS) facilities, where waste could be kept for 50 to 100 years and then be removed for permanent disposal. However, this bill gave more power to state governments, allowing them to veto the federal decision if their state is chosen for a repository, unless there is a unanimous vote from both chambers of Congress to override the state decision. After Congress passed the 1982 bill, DOE studied six sites in the West and three sites in the South for the repository, which set off a considerable amount of local and tribal opposition. By 1986, the DOE recommended three candidate sites: Yucca Mountain in Nye County, Nevada; Deaf Smith County, Texas; and Hanford, Washington. The DOE also listed two possible substitutes (Richton Dome in Perry

County, Miss. and Davis Canyon in San Juan County, Utah), should one of the other three be rejected in the public hearing. In 1967, Congress continued discussing options for nuclear waste; ultimately, both the states of Washington and Texas were excluded from the reviews, leaving Nevada as the only option.[66]

Later that year, Congress requested that the DOE perform studies to determine Yucca Mountain's suitability for a repository and set up a mechanism that requires nuclear power companies to pay for it. The DOE was also authorized to make contracts with commercial nuclear plants to collect fees over the custody of spent fuel in 1998, making the nuclear power the only energy industry that pays for its waste disposal. However, due to strong opposition to the construction of the Yucca Mountain repository and technological issues, the DOE was not able to start the construction on time, thus resulting in the repository program being postponed.

In 2002, the DOE conducted a reassessment of the repository plan in Yucca Mountain and reaffirmed the vitality of the plan. President Bush recommended the site to Congress, who subsequently approved the Yucca Mountain site as the location for the national geologic repository. In 2008, the DOE submitted a license application to the NRC seeking authorization to begin the construction of the nuclear waste repository, which was approved. The disposal repository was set to open in 2020. However, in 2009 the Secretary of Energy submitted a notice to Congress stating that Yucca Mountain was no longer an option. The decision to abandon the plan was political, not science-based. It is widely believed that the Democratic Majority Senator Harry Reid requested the President to terminate the repository program in his home state, in return for his support on the President's other agendas. President Obama dismantled OCRWM and transferred the responsibility for waste management to the Office of Nuclear Energy (NE).

In 2010, the DOE officially filed a motion to withdraw the application for the Yucca Mountain site "with prejudice". However, the NRC's Atomic Safety and Licensing Board reaffirmed that the DOE must follow the guidelines legislated by Congress and that the DOE's motion to withdraw the licensing application based on unsubstantial evidence is illegal.[67] The Board released a statement requesting the DOE to restart the application process and to continue activities in Yucca Mountain. However, due to "budgetary limitations", the Obama Administration did not continue any activities with regards to the Yucca Mountain repository project, raising serious doubts of whether the repository will be able to commerce in 2020. Nuclear power plant owners continue to pay custody fees for spent fuel despite no progress on the Yucca Mountain project.

Since Congress passed the act, nuclear power plants have paid over $17 billion into the Nuclear Waste Fund for the DOE to take custody of spent fuel, with 0.1 cent per Kwh of electricity sold, to be paid by nuclear companies. According to a report by World Nuclear Association, the funding in 2010 accumulated over $31 billion. Of this, about $8 billion has been used to fund the Yucca Mountain Project for preliminary works including site inspection and application process. Each year, more than $750 million from utility inputs and $1 billion per year from interest are collected into this fund. Meanwhile, the spent fuel that is stored at reactor sites has reached 72,100 tons as of 2012. Since there is no certainty over the possibility of the Yucca Mountain repository program, there are concerns of public health and environment protection, casting doubts on government's commitments towards safe waste disposal.[68]

Standards for Yucca Mt. Repository and Considerations Regarding its Closure

Public Health and Environmental Radiation Protection Standards

Following the 1987 amendment that required the DOE to focus resources on the Yucca Mountain site, Congress requested the EPA set standards to protect public health by limiting the radiation exposure to individuals living closest to the facility and those most likely to be exposed to released radioactive materials. The EPA's guidelines address all environmental pathways, including air, groundwater and soil. The standards are as follows:

- Set a dose limit to reasonably maximally exposed individual of 15 millirem per year (150 microsieverts per year) for the first 10,000 years after disposal.
- Set a dose limit of 100 millirem per year (1 millisievert per year) between 10,000 years and 1 million years.
- Take into account for dose limits exposure through all potential pathways, and account for releases caused by a borehole going through a waste container and into the underlying groundwater (the "human intrusion" standard).
- Require the DOE to assess the effects of climate change, earthquakes, volcanoes, and corrosion of the waste packages on the performance of the repository system during the 1 million-year period.[69]

Termination of the Yucca Mountain Repository Program: Advantages and Disadvantages

Although the decision to abandon the Yucca Mountain site in favor of other alternatives is imbued with politics, the termination of the repository program has both advantages and disadvantages, as argued by Government Accountability Office (GAO).

Advantages

Opposition to the proposal is strong in Nevada. The GAO points out that by dismantling the repository plan, the federal government could identify other locations that might have more support. If an alternative is identified, it would have the potential to avoid costly delays. According to the National Research Council of the National Academies, "the only alternatives capable of ensuring the safety and security of spent nuclear fuel are continued storage and geologic disposal".[70] The Council evidenced that alternatives that include reprocessing spent fuel and disposal in narrow shafts bored deep into the ground may be feasible but face significant cost and technological issues. These solutions do not permanently dispose of nuclear waste. Therefore, even with advanced methods, the Council argued that the federal government could not eliminate the need for a geologic disposal facility.

Disadvantages

Terminating the Yucca Mountain repository program in 2010 has several drawbacks; specifically, the time-consuming and costly search for an alternative, the continuation of on-site storage, and the damage to DOE's credibility. In the aftermath of a termination, the federal government would need to restart expensive process of searching for an alternative site that has local and state support. If the federal government officially terminated the Yucca Mountain project, the $15 billion invested would be a sunk cost. The search for alternatives would certainly take a toll on financial capitals. Even if the DoE goes ahead with the construction of temporary centralized interim storage before a more permanent solution is found, it would likely to take 17 to 33 years to complete the facility.[71] Such a facility will be open somewhere from 2029 to 2045, much later than the date that the Yucca Mountain repository was originally set to operate. In addition, almost 60% of the cost of developing the Yucca Mountain repository has thus far been paid for by the nuclear waste fund (about $8 billion out of $15 billion), and power plant owners only pay into the fund for as long as their reactors are operating. Since the rate of newly built nuclear power plants is slowing down and some of reactors are expected to be decommissioned or pending re-licensing in the coming decades, it is unlikely that the Nuclear Waste Fund will have built up a sufficient surplus to license, construct, and operate a new repository. Nuclear power plant owners also requested the DOE suspend collection of utility fees into the Nuclear Waste Fund. They reasoned that it was unfair to be charged disposal fee for a repository program that has been shut down with no work done for an alternative.

Moreover, the halt of the Yucca Mountain repository program led to discussions of on-site storage of spent fuel by private companies. Some nuclear power plants argued that with the extension of on-site storage due to the delays in opening the Yucca Mountain repository, reactor plants are running out of space for spent fuel. Therefore, companies are resorting to the use of dry-cast storage systems. According to a 2009 GOA report, reactor operators pay about $30 million to $60 million per reactor annually as more spent nuclear fuel is added to dry storage. If a repository is not open in 2020 as planned, nuclear plant owners can file a lawsuit against the government for violation of the 1982 law. Together with the increased cost of spent fuel storage and potential lawsuits, the termination of the Yucca Mountain repository could increase opposition to the nuclear industry and restrain the economic development of local communities. Without progress on a permanent solution on high-level radioactive waste disposal, many people are concerned with the long-term on-site storage of spent nuclear fuel. For this reason, tribal and environmental organizations voiced concerns objecting to the relicensing of nuclear reactors in Minnesota and New Jersey. As for local communities, some representatives said that it is difficult to develop and sell property because prospective buyers may feel uneasy about living next to a site storing spent nuclear fuel. Even with decommissioned nuclear plants, local communities must provide additional security and emergency response mechanisms to secure on-site storage.

The termination of the repository also severely damaged the DOE's credibility. Due to several delays in the Yucca Mountain project, several experts expressed concern that the DOE did not seriously honor its commitment to permanently dispose of spent fuel and high-level radioactive waste. Many believe that partisan issues have compromised the DOE's ability to impartially carry out the plan.

Waste Isolation Pilot Plants

Before the Nuclear Waste Policy Act was passed, Congress approved the DOE's request to build a deep geologic repository, also known as the Waste Isolation Pilot Plant (WIPP) for military transuranic and low-level radioactive waste in the state of New Mexico. After the Administration terminated the Yucca Mountain repository project in 2010, the DOE suggested that WIPP could be the alternative for permanent disposal of high-level nuclear waste from both civilian and military sources, citing that the facility passed regulation and safety standards, with no on-site accidents.[72] However, due to a 2014 incident involving a waste explosion and airborne release of radioactive materials into the environment, policymakers have questioned whether or not WIPP would be a safe replacement for the Yucca Mountain repository. In addition, the state government of New Mexico has prohibited disposal of high-level waste at WIPP, resulting in the alternative being disregarded. After 3 years of cleaning up the contamination (which cost approximately $500 million) and applying new safety equipment to the WIPP, the DOE reopened the facility on January 9, 2017.[73]

The WIPP and the Yucca Mountain Repository Program: A Comparison

Despite the fact both are mined repositories, the WIPP received more support than Yucca Mountain. This is largely due to the transparent communication with local communities by the WIPP management team in New Mexico. In 1978, the DOE created the New Mexico Environmental Evaluation Group to address public concern regarding to the construction of the facility. This group, tasked with overseeing the WIPP, verified statements, facts, and studies conducted and released regarding the facility to help advance the facility with little public opposition. However, this is not the case for the Yucca Mountain site. Despite effort to engage residents and state officials with the project, the Yucca Mountain management team found little success in gaining acceptance. This is due to Congress's decision to choose the Yucca Mountain in the first place, as residents of Nevada believed that Congress was dumping nuclear waste into their state because no other states wanted it. Despite their state government's strong opposition to the decision and their attempt to veto it, Congress was willing to block it and designated Yucca Mountain as the national geological repository for nuclear waste.

Recent Developments (2010-2016)
Despite the challenges, since the termination of the Yucca Mountain repository program in 2010, there have been several developments regarding high-level nuclear waste disposal policy. Specifically, the establishment of the Blue Ribbon Commission in 2010 (BRC) and the release of New Wastes Strategy in 2013.

In the aftermath of the DOE's decision to withdraw the licensing application for the repository, President Obama dismantled the OCRWM and transferred the responsibility of high-level radioactive waste management to the DOE's Office of Nuclear Energy. Meanwhile, he established the Blue Ribbon Commission to develop an alternative nuclear waste policy. The President appointed 15 members to lead the Commission, consisting of scientists and policymakers, to suggest how the country should proceed with management of used fuel. In January 2012, the Commission submitted a report to Congress after two years of policy review.

In their report to Congress, the BRC outlined three major changes to the existing nuclear waste policy. It recommended that the administration develop a process to site facilities collaboratively with the public, communities, stakeholders, and with governments at the state, tribal, and local levels. This "consent-based" approach, as the Commission argued, is the core element to develop long-term, sustainable management of spent nuclear and high-level radioactive waste. Secondly, the Commission recommended that both the legislative and executive branches transfer the responsibility for the radioactive waste management program to a new organization, independent of the DOE. Thirdly, the management of the Nuclear Waste Fund, which is estimated to be worth $31 billion as of 2010, should be changed to ensure that the fund is used for the intended purpose. In addition, the Commission also called for "immediate efforts to commence development of at least one geologic disposal facility, as well as efforts to prepare for the eventual large-scale transport of spent nuclear fuel and high-level waste from current storage sites to those facilities."[74]

Based on the recommendations from the BRC in 2012, the Secretary of Defense submitted a new waste strategy guideline in 2013, laying out steps to set up a new organization that manages the siting, development and operation of the future waste stores. As the Secretary of Defense emphasized in his memo, this new organization will be given more independence to exercise its authority and develop the plan for a repository. According to the timeline of the strategy, a "pilot interim store" would start operation in 2021, taking used nuclear fuel from decommissioned power plant sites. Furthermore, by 2025, the federal government would open a larger "full-scale interim store" and finally, by 2048, a deep geologic disposal facility would be completed to permanently store spent fuel and other high-level radioactive materials.

At the end of 2013, President Obama introduced the bipartisan bill to Congress to establish a new Nuclear Waste Administration, which Congress subsequently approved. The president appointed a single administrator to lead the organization and a five-member board to oversee the operations. This administration would take over responsibility from NE for waste management. In addition, Congress authorized the President to create a new Working Capital Fund in the Department of Treasury that takes over the utility fee paid by nuclear plants owners, approximately $765 million per year.[75]

Deep Borehole Disposal: A Viable Alternative?
After work on the Yucca Mountain site ceased in 2010, some scientists and policymakers recommended that the DOE should consider an old-but-new alternative, Deep Borehole Disposal (DBD), for spent fuel and high-level radioactive waste. Some believe DBD makes for better storage than Yucca

Mountain due to its technological advantages and better safety protection. Borehole injection method of hazardous industrial wastes, including lethal material from the chemical and petroleum industries, has been routine for more than four decades. Every year, millions of gallons of waste are injected into deep and confined rock formations (Class 1 well). Despite the promising demonstration of this method, there are no known radioactive waste disposal wells operating in the U.S.

The idea of building a deep borehole disposal is not new. The U.S. National Academy of Sciences (UNAS) included it as one of the options for high-level radioactive waste in 1957. However, because the U.S. and the international community in the last century primarily focused on mined repositories, DBD was not given much policy consideration until recently. DBD is the process of disposing of high-level radioactive waste from nuclear reactors in extremely deep boreholes as much as 5 kilometers beneath the surface of the Earth, relying on the thickness of geological barriers to isolate waste. The safety of DBD relies on the depth of burial, the isolation provided by the deep natural geological environment, and the integrity of borehole seals both down hole and at the surface. This is a big difference from traditional mined geological repositories, which rely on engineered system, such as waste canisters and/or buffer materials, to shield radioactive waste.

In 2011, Sandia National Laboratories (SNL) began to work on a generalized concept, consisting of drilling a borehole (or array of boreholes) into crystalline basement rock to a depth of about 5,000 m, emplacing waste canisters containing used nuclear fuel in the lower 2,000 m of the borehole, and sealing the upper 3,000 m. of the borehole. The disposal zone in a single borehole can contain about 400 waste canisters of approximately 5 m. in length. Alternating layers of compacted betonies clay and concrete are used to seal off the disposal zone. According to scientists, there are several factors that prove this method's viability and safety. Crystalline basement rocks are relatively common at depths of 2,000 to 5,000 meters in stable continental regions, which suggests that numerous sites in the U.S. could be used for the disposal. Existing drilling technology permits the reliable construction of sufficiently large diameter boreholes to a depth of 5,000 m., although this remains to be demonstrated. Total costs for such a deep borehole disposal system, including drilling, casing, borehole completion, waste canister fabrication and loading, emplacement, and borehole sealing have been estimated at about $40 million per borehole. SNL estimates that with the current fleet of nuclear reactors in the U.S, if operated through 2055, the projected waste inventory could be disposed in about 580 boreholes. The construction the boreholes would cost approximately $25.5 billion, which is significantly cheaper than the planned cost of the Yucca Mountain repository. A non-technical advantage that DBD offers over a mined repository is the facilitation of incremental construction and loading at multiple locations. Furthermore, low permeability and high salinity in the deep continental crystalline basement suggest extremely limited interaction with shallow fresh groundwater resources, which is the most likely pathway for human exposure to radionuclides released from the waste. Geochemically reducing conditions in such a deep subsurface limit the solubility and enhance the sorption of many radionuclides in the waste, leading to reduced mobility in groundwater. Thus, scientists believed DBD is more effective in protecting the environment and public health than the mined repositories.[76]

In 2016, the DoE entered into a contract with DOSECC and Enercon Federal Services to evaluate the technical aspects of drilling deep, large diameter boreholes in the crystalline rock for the safe and effective disposal of waste. The purpose of this is to investigate the geological and geochemical properties of deep granite and evaluate techniques for drilling large diameter (8-3/4') holes to a depth of 5,000 meters in this environment, demonstrating whether DBD is feasible. No nuclear waste will be used in the project, which will take place near the town of Nara Visa, New Mexico. According to the DOSECC's timeline, the project will spend a considerable amount of time in 2017 working with local communities and government to communicate the purposes and methods the testing and will begin collecting scientific data in the spring of 2018.

Before the DOE gave the contract to DOSECC, Battelle Memorial Institute was chosen to conduct a similar experiment in North Dakota. The institute planned to drill two holes up to 5 kilometers deep into the grate bedrock beneath the rolling prairie. However, its proposal met strong resistance from residents of rural Pierce County, who feared that drilling would open the door to nuclear waste.[77] Due to this strong opposition, Battle Memorial Institute withdrew the plan and the DOE assigned this project to DOSECC, which has a stronger history of building trust with local communities through previous works it had done.

Despite that outcome of this testing is not yet known, scientists believe if the data gathered at the disposal site in New Mexico proves its safety and efficacy, deep borehole disposal would open a new chapter of nuclear waste treatment in the future, potentially with more public support than the Yucca Mountain site.

Efforts in Other Nations

While the United States struggled to complete a permanent repository for spent fuel and other high-level radioactive materials, Finland and Sweden took the initiative and succeeded in carrying out their repository plans. According to a report by the World Nuclear Association, Finland has four nuclear reactors providing nearly 30% of its electricity, with a fifth reactor under construction. In the early 1970s, the government planned to export spent fuel if possible, and if not, to reprocess it. But after intense debates following geopolitical change within Europe in the 1980s, Finland's spent fuel policy oriented towards building deep geological sites to avoid the dependence on Russia for waste disposal.

In 1983, the Finnish government initiated the nuclear waste management program and set up a fund to oversee the management process. The fund is paid for by the public through additional charges on generated electricity. After debating between four domestic locations, Olkiluoto was chosen for the nuclear waste repository. This small island located off the country's southeast coast already had a nuclear power plant and a repository for low- and intermediate-level radioactive waste (LLW and ILW). In 1994, Congress tasked Posiva Oy with the responsibility to develop a plan for the geologic repository in Olkiluoto. In 2004, the construction of a deep geologic repository began on the existing pool storage facility, after the local residents voted in favor of the project. It was set to start commercial operation in 2020, making Finland the only country by far to select a geological repository for high-level nuclear waste, to complete and approve a design for it, and set aside the funding and start the construction.[78]

Another Scandinavian country, Sweden, has nine operating nuclear power reactors providing about 40% of its electricity. In the 1980s, Sweden planned to phase out nuclear power in the aftermath of the U.S. Three Miles Island incident, but soon realized the importance of nuclear power for energy security. As public opinion became more in favor of nuclear energy, Parliament voted to repeal the 1980 policy in 2010, effectively putting nuclear power back as the most important strategic source of energy.

Since the nuclear plants started commercial operation in the 1970s, Sweden passed the Waste Legislation (Stipulation Act) in 1977. This law required that nuclear power plants come together to establish the Swedish Nuclear Fuel and Waste Management Company (SKB). Their mission is to develop a comprehensive concept for the management and disposal of spent fuel and other radioactive wastes. After reviewing all options, a deep geological repository was chosen to permanently store spent fuel and nuclear wastes. Later, the government decided to build a permanent repository for high-level radioactive waste in Forsmark, which has one of the country's nuclear plants as well as a repository for LLW and ILW. Even though the license application has yet to be completed, it is reported that local residents are in strong favor of the repository.[79]

Finland and Sweden demonstrate success in carrying out their repository plans due to public trust and support. These countries focused on public communication and involving affected residents from the early stages of the repository conversation.[80] Unfortunately, this appears not to be the case in the U.S. In the future, the U.S. should aim to head off public opposition of disposal methods by addressing residents' concerns and releasing information to the public in a timely manner. In addition, there is a lack of public trust between affected residents and the federal government within the U.S, which is not the case in Finland and Sweden. Since the DOE overemphasized the technological fitness of the site without mentioning local issues, residents and state officials have argued that the federal government did not consider their interests or treat them with respect. Low social acceptability and weak public trust, as scholars and policymakers argued, are among the most decisive factors contributing to the failure of the Yucca Mountain project.

Conclusion

It has been almost four decades since Congress passed the Nuclear Waste Policy Act of 1982. However, despite efforts to construct a repository for high-level radioactive waste, Congress was unable to complete this plan. Since the termination of the Yucca Mountain waste disposal site in 2010, there have been several developments to nuclear waste policies, such as the establishment of Blue Ribbon Commission in 2010 that recommended changes to the existing policies and the New Waste Strategy that outlined the timeline of a temporary interim storage facility. The termination of the Yucca Mountain also prompted the DOE to search for more accepted alternatives. Among all options, scientists and policymakers believe that deep borehole disposal will be a strong candidate to rival the Yucca Mountain site due to several advantages. If the testing facility in New Mexico proves that the method is feasible, this will open a new chapter in handling nuclear waste.

Domestic Energy Security:

U.S. Grids, Aging Infrastructure, and Cybersecurity

Julian Augustus

The United States is the world's largest supplier of commercial nuclear power, generating more than 30 percent of the world's nuclear electricity.[81] The benefits of pursuing nuclear power include its lack of carbon emissions and its position as a reliable and consistently priced source of energy. However, the expansion of the nuclear industry has been slow in the United States, due to competing energy sources and wavering public opinion. The "nuclear renaissance" began in the 2000s with the proposal of the U.S. Nuclear Program of 2010. The program involved companies from the states of Mississippi, Illinois and Virginia to consult with the Nuclear Regulatory Commission (NRC) on the construction of light water reactors. However, the 2011 Fukushima incident created a negative public perception nuclear power. After a peak of 112 operating nuclear reactors in 1991, there are just 99 currently in operation. The number of plants now undergoing construction stands at 4 and are facing obstacles from new regulations issued by the U.S. government.

Nuclear power plants run at a relatively high capacity overall; however, after a period of declining investments and technological advancements, the U.S. is in a vulnerable position with its aging infrastructure. Other security concerns that threaten the U.S. nuclear energy industry are its base load capabilities and cyber security.

U.S. Electrical Grid System

An electrical grid system partly determines nuclear security; the electrical grid must be stable and have the capacity to provide the necessary power to assure safe start-up, operation and necessary shut-down of a nuclear power plant. Any high-performance system within a nuclear power plant must have adequate grid interconnectedness, adequate reserve margins, modern load dispatching centers, and reliable high-speed protective system continually in operation. With these characteristics, fluctuations and outages in energy is well managed. Alternatively, according to the IAEA a grid that operates at a low performance:

- May experience voltage and frequency fluctuations of high magnitude
- has long periods at off-nominal frequency and voltage conditions
- Has frequent or extended unscheduled generation or transmission outages

Reliability, quality, and protection determine if a grid performs well. Reliability as defined by the IAEA is the degree to which the grid can maintain an uninterruptible power supply is the measure of grid reliability. Grid quality refers to the voltage and frequency stability of the grid supply. Although it is difficult to establish the criteria and how to convey an order of magnitude to be used for qualitative appreciation, the grid protection system has the capability of clearing the fault in a short time so that the rest of the grid remains healthy.

The electrical grid system in nuclear power plants was the standard for decades; however, the system is based on a centralized network where large generation plants produce electricity that is used at an industrial or domestic level. This results in power losses in transmission due to the physical distance between generation and consumption sites.[82]

U.S. Smart Grid System

The smart grid was developed in order to increase energy efficiency. The smart grid system was created as an alternative to the traditional electrical grid system used in the nuclear power industry. The smart grid accounts for energy demand, resulting in customers being able to pay low cost during peak hours when energy prices are more expensive.

Smart grid technology was widely implemented in the early 21st century to meet a growing demand for electricity. During 1970s and 1990s, this demand led to an increasing number of power stations. However, peak times of electrical demand resulted in poor power quality, leading to black outs, power cuts, and brownouts. The smart grid was earned legislative support under the Energy Independence and Security Act of 2007. As part of the modernization effort of the national electrical and distribution system of the United States, characterizations of the smart grid include:

- Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electrical grid
- Dynamic optimization of grid operations and resources with full cyber security
- Deployment and integration of distributed resources and generation, including renewable resources
- Development and incorporation of demand, response demand side resources, and energy-efficiency resources
- Deployment of smart technologies
- Integration of smart appliances and consumer devices
- Deployment and integration of advance electricity storage and peak shaving technologies
- Provision to consumers of timely information and control options
- Development of standards for communication and inoperability of appliances and equipment connected to the electrical grid
- Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices and services

The use of the smart grid system is also seen as positive from environmental experts as using this type of technology to help solve harmful climate changes, and avoid excessive carbon emissions. The smart grid provides a means of peak shaving and accurate information on the status of the network.

Aging Infrastructure

The growing age of nuclear power plants is starting to become a concern as inspections are helping to pick up defects in aging nuclear power plants before they cause trouble. In 2016, there were multiple ultrasonic tests to identify signs of wear and tear on stainless-steel bolts in the reactor core. After an analysis identifying why some reactors failed inspection, the NRC is considering whether to expand the life of 40-year old reactors for more than 20 years.

The issue of damaged bolts in nuclear reactors are just one example of the problems nuclear plants can face with age. Though these problems are not exclusive to the U.S., both the International Atomic Energy Agency (IAEA) and the NRC assert that the problem maybe the most acute for the U.S., whose fleet of 99 reactors are the largest and oldest. The nuclear power industry has been struggling economically in competition with cheaper fossil fuels, and companies prefer to invest in maintenance and upgrades of existing plants rather than investing in the construction of new nuclear power plants. However, there is growing debate among those in the nuclear industry on the reliability of the maintenance and replacement of critical parts. While some agree that there is no reason why longevity would not continue with the replacement of parts, others are less optimistic. The counter argument against maintenance and replacement is the lack of information on the durability of underground power cables, as well as about how materials age.[83] Of greater concern are the concrete containment structure and steel pressure vessels at the heart of reactors, as well as the kilometers of wires that snake through the plants.

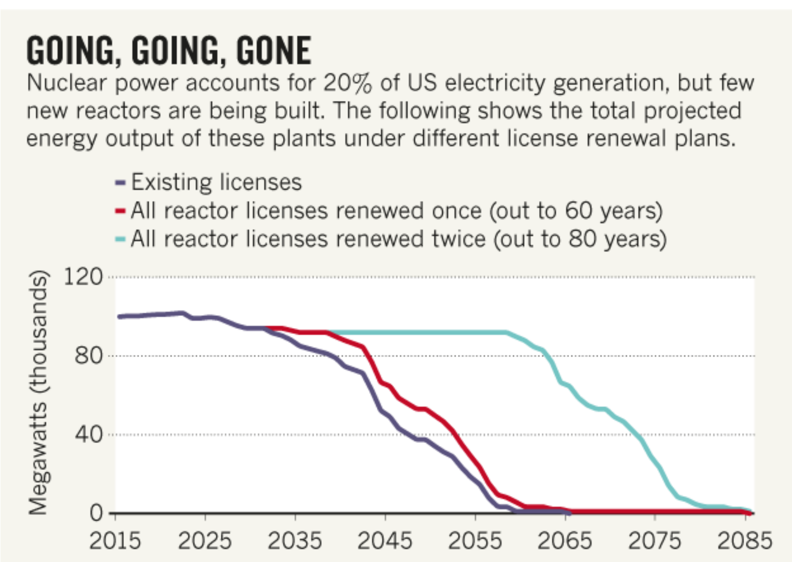


Figure 1: Total projected energy output of plants. Source: nature.com.

Base Load Capacity

The base load on a grid is the minimum level of demand on an electrical grid over 24 hours. Base load power sources are power stations which can consistently generate the electrical power needed to satisfy this minimum demand. Nuclear power is a reliable source of energy for the base load to receive its power. Development of nuclear power has been historically challenging due to opposition from the public. Due to fears including proliferation and waste storage, obstacles remain for the civilian use of nuclear energy for generation of electricity. However, the World Induced Technical Change Hybrid (WITCH) model speculated that if commonly imposed restrictions were relaxed, the simulated growth paths for nuclear energy, along with other non-carbon energy resources, generate benefits in terms of air pollution reduction and energy security enhancement. Such an improvement would provide incentives to develop deploy new reactors of generation III and generation IV.[84]

Cyber Security

The possibility of a cyber security attack on nuclear facilities could have devastating consequences for the national security of the United States. Worries about proliferation, involving the use of uranium for a nuclear weapon, or a non-state actor causing the plant to meltdown are potential concerns. Cyber security attacks of nuclear facilities can be effective in two different ways: they can be used to undermine the security of nuclear materials and facility operations, and they can compromise nuclear command and control systems.[85] For the production of reliable, safe, and efficient nuclear power, the issue of cyber security has become more relevant. After the attacks of 9/11, proposals of the security enhancement of nuclear facilities were imposed as initial requirements. In March 2009, the NRC's security rule for the operation of nuclear facilities was finalized, covering power reactor licenses and applicants for new reactor licenses.[86] The orders issued by the NRC made the licenses a requirement for each nuclear plant's cyber security program to protect its digital computer and communication systems and networks against potential cyber-attacks. The requirements include safety- related functions, such as emergency preparedness functions, including offsite communications, and support systems and equipment important to safety and security.[87]

In 2010, the NRC issued a regulatory guide that would provide licensees an acceptable way to meet cyber security standards and requirements. Recently, the NRC considered the need for cyber security measures for fuel cycle and spent storage facilities, non-power reactors, decommissioned nuclear facilities, and materials licenses. As a result, the Cyber Security Directorate (CSD) was established by the NRC to centralize the agency's oversight of the security measures established. The responsibility of the directorate is to plan, coordinate, and manage all agency activities in relation to cyber security for NRC licenses. This includes making rules, providing guidance, licensing, policy advice, and oversight related to cyber security requirements. Part of the CSD is the Cyber Assessment Team who responds to cyber events that occur at licensed facilities and reviews the actions of licensees.[88]

The rise in popularity of smart grids has necessitated cyber security measures to be taken, as the smart grid system is vulnerable to online attacks through:

- Customer security; this includes private consumer information that may track a consumer's activities and devices being used.
- Greater number of intelligent devices; these can act as attack entry points into the network.
- Physical security; plants are vulnerable to physical access.
- The lifetime of power systems and implicit trust between traditional power devices; this may act as weak security points with the current power system devices within nuclear power.
- Implicit trust between traditional power devices; device-to-device communication in control systems is vulnerable to data spoofing.
- Workforce; unorganized communication between teams might lead to bad decisions.
- Using internet protocol (IP); devices using IP are vulnerable to IP-based network attacks.
- More stakeholders; this leaves the system vulnerable to insider attacks.[89]

Cybersecurity attacks pose a potential threat to national defense as well; the Stuxnet virus that damaged Iran's power grid in 2010 was aimed to disrupt its suspected nuclear weapons program. The virus was a landmark in the cybersecurity field, as before, it was only hypothesized that it was possible to infiltrate an electrical grid system. This forced the energy industry around the world to reexamine their energy structures, concluding that the only way to best avoid attack was to strengthen defense of critical cyber infrastructure. The event also represents the power that cyber warfare now possesses: the internet is a place that terrorists can recruit and communicate on a global level, and can often operate with anonymity. No event similar to Stuxnet has occurred since; it seems that terrorist organizations still prefer physical attacks.[90]

Conclusion

Nuclear power is a valuable part of the energy infrastructure; its benefits demand increased reliance on nuclear as a source. Nuclear power is a promising source for the future as it is cheaper to operate in comparison to other renewable sources, however, the high initial cost of building a nuclear plant is an impediment to investment. Security of nuclear plants and the grid system are important to national security as they are vulnerable to both physical attack and cyberattacks. Physical infrastructure must be upgraded and maintained to ensure a consistent and reliable supply of energy.

PART II:
U.S. Foreign Policy

International Nuclear Cooperation: A Necessity for A Safe World

Selma Sadzak

Since President Eisenhower's "Atoms for Peace" speech in 1953, the United States has been a hegemonic force in promoting the peaceful use of nuclear energy. The U.S. has established bilateral and multilateral treaties with many countries and provides vast funding and assistance to states attempting to launch or expand their nuclear energy and research programs. In a world where development is dependent on energy, especially electricity, and millions die annually because of pollution and other anthropogenic forces, international cooperation on nuclear energy is more crucial than ever. Multilateral and bilateral nuclear energy organizations are the main mechanisms for the advancement of nuclear technologies. Organizations such as the International Framework on Nuclear Energy Cooperation (IFNEC), the International Atomic Energy Agency (IAEA), the Nuclear Energy Agency (NEA), the Generation IV Forum (GEN IV), the International Nuclear Energy Research Initiative (I-NERI), the International Nuclear Cooperation (INC) and others play a major role in the success of a safe and sustainable global nuclear landscape. The United States has a leadership part in all of these cooperation efforts, and the importance of this role is growing considerably as nuclear power expands to new nations.

Nuclear as an Imperative Alternative

International cooperation is necessary for stable and reliable energy production. Humanity relies on electricity for some of the most important functions performed, from healthcare to food production. In the future, this dependency is predicted to increase. This is especially relevant for developing nations, where more than one billion people remain without this fundament of modern life, and two billion more have only intermittent access to it. The U.S. Energy Information Administration (EIA) reports that world energy consumption will increase by the equivalent of about 4,000 power plants by 2035, clarifying: "While 4,000 new power plants worth of energy consumption sounds like a lot, after taking projected population growth into account, by 2035 global per capita energy use increases only by about 23%. In other words, from 2010 to 2035 global per capita energy consumption is projected to grow from about the average per capita consumption of Chile today to that of Croatia today, which is not a big change."[91]

Countries where this is the case will require great quantities of energy to grow and advance their economy. For instance, sub-Saharan Africa (with the exception of South Africa) has about 30 gigawatts of electricity generating capacity. To raise the region to the average per capita electricity access available in a developed country, such as South Africa, would require 1,000 gigawatts. The scope of the energy access challenge is best described when comparing levels of energy usage by developed versus developing countries. "… sub-Saharan Africa would need to increase its installed capacity by 33 times to reach the level of energy use enjoyed by South Africans — and 100 times to reach that of Americans. The scale of the challenge is enormous." [92]

Another challenge regarding future growth in energy use is the clear need for a global transition to renewable energy resources. Fossil fuels, because of their cheap costs and relatively simple plant designs, are by far the most used energy source but have negative side effects on the environment and global population.[93] Energy is essential, but clean non-carbon sources of energy are the only methods by which sustainable living can be attained. Nuclear energy provides an answer to this problem, and through international cooperation it's possible to maximize the utility of this source. Agreements to reduce carbon emissions, such as the Paris Agreement of 2015, are not possible without the expansion of a reliable alternative. Advanced countries can encourage and assist developing ones in finding alternative sources of energy.

International cooperation is also important in that it provides a great opportunity for innovation and development of new technologies. By sharing knowledge and experience, scientists worldwide can collaborate to improve nuclear technology; especially waste disposal and high costs. These two issues are ones that provide the most challenge and are often used by critics and advocates against nuclear energy to stir public disapproval. Past nuclear cooperation efforts have been successful in efficiently regulating waste, such as the Global Nuclear Energy Partnership. Now known as the International Framework for Nuclear Energy Cooperation (IFNEC) and signed by 33 countries, it aimed to make the usage of nuclear fuel more efficient and decrease the production of waste. Under this program, the nations of the group that utilize the fuel cycle would provide enriched nuclear fuel to partner countries, which would generate electricity before returning the used fuel. This fuel would then undergo "advanced reprocessing so that the uranium and plutonium it contained, plus long-lived minor actinides, could be recycled in advanced nuclear power reactors. Waste volumes and radiological longevity would be greatly reduced by this process, and the wastes would end up either in the fuel cycle or user countries."[94] The IAEA would oversee the entire process in order to ensure the fuel wasn't being inappropriately used. This program is still in the process of being developed, but could be very useful to countries that employ an open fuel cycle such as the United States or Canada.

IFNEC also aims to address cost issues associated with the development and expansion of nuclear power in developing countries. Nuclear programs require a high degree of technical and industrial expertise, and this is a serious obstacle for developing countries hoping to utilize nuclear power. A cooperation effort that can solve this is to increase the number of indigenously-trained nuclear experts through a variety of education and training initiatives, performed by professionals from developed countries.[95] Although international nuclear cooperation heavily depends on financing from developed countries, advances in the designing, planning, and manufacturing of nuclear power plants increase efficiency and make investment more cost-effective.

A global consensus on non-proliferation of weapons requires a worldwide commitment. Since nuclear technologies are of dual nature, nuclear energy sharing is a still a somewhat controversial business. The same process (fission) and supplies (fuel, methods for uranium enriching) are needed to produce both energy and a bomb. Cases such as India's "Smiling Buddha" have shown that it is possible to make a weapon from a reactor intended for civilian and peaceful use. This is perhaps the strongest argument against nuclear energy - as Professor Scott L. Montgomery indicates, "reactors and weapons are too closely linked".[96] Therefore, international programs are crucial to containing proliferation; with proper surveillance mechanisms and timely monitoring, sharing knowledge and equipment for nuclear energy can be successful.

Bringing energy to developing countries, innovating, finding solutions to waste and finance problems, and preventing the use of nuclear technologies for non-peaceful uses are not easy tasks. However, when nations pool their expertise, findings and resources, these tasks have a greater chance of being achieved. The organizations described below are some of the most effective establishments for nuclear cooperation and will surely shape the future of carbon-free electricity production.

The Generation IV Forum

The Generation IV International Forum (GIF) was established in 2001 and has fourteen members that collaborate to develop the next generation of nuclear energy systems to meet future global energy needs. The core document of this organization is the GIF Framework Agreement, which was the first agreement aimed at the international development of advanced nuclear energy systems.[97] The members of this group are the United States, China, Canada, Russia, France, Japan, Argentina, Australia, Brazil, Euratom, the United Kingdom, Republic of Korea, South Africa, and Switzerland. The GIF aims to identify and research six nuclear energy systems that will be further developed for wide scale use in the future. The selected systems vary from one another, and include "thermal and fast neutron spectra cores, closed and open fuel cycles, small size and large size".[98] These systems are expected to be deployed commercially somewhere between 2030 and 2040.

The Generation IV International Forum is a prime example of how international cooperation creates innovation that will make nuclear energy more accessible to an increased number of countries in the future. New generation reactors "represent advances in sustainability, economics, safety, reliability and proliferation-resistance, and were selected on the basis of being clean, safe and cost-effective means of meeting increased energy demands on a sustainable basis, while being resistant to diversion of materials for weapons proliferation and secure from terrorist attacks."[99] Four of the six systems use conventional operating methods, and therefore have working experience in most respects of their design, which means they require less time and resources for planning. This allows plants to be created at a faster pace and at less cost, which opens the market to developing countries that have less resources to spare.

The GIF addresses non-proliferation concerns with its Proliferation Resistance and Physical Protection (PR&PP) evaluation approach, as well as creating energy systems that increase the assurance that they are "unattractive and the least desirable route" for diversion or theft. Most of these routes focus on making plutonium non-extractable. For example, one of the six systems, the fast neutron reactors, are not "conventional fast breeders", because they do not have a blanket assembly where plutonium-239 is produced. Instead, "plutonium production takes place in the core, where burn-up is high and the proportion of plutonium isotopes other than Pu-239 remains high. In addition, new electrometallurgical reprocessing technologies will enable the fuel to be recycled without separating the plutonium."[100] The PR&PP approach ensures hypothetical proliferation or terrorism scenarios (including diversion, misuse, clandestine operation, sabotage, and theft) are not possible through systematic and comprehensive assessments and optimizations of reactor designs, at all stages. [101]

The United States was central to the creation of the organization. The Generation IV project started when the U.S. Department of Energy's (DOE) Office of Nuclear Energy, Science and Technology convened a group of senior governmental representatives from Argentina, Brazil, Canada, France, Japan, the Republic of Korea, the Republic of South Africa, and the United Kingdom in 2000 to begin discussions on international collaboration in the development of new nuclear energy systems. Every two years, a different member country assumes the role of Chairman, and from 2013-2015, the United States had this position. In this period, under Chair John E. Kelly, significant progress was made in developing safety approaches for the systems and interacting with regulators. He also extended the Framework Agreement, which is considered the "most powerful legal vehicle for multilateral cooperation on advanced nuclear technology development" by the U.S.'s Department of Energy. [102]

International Framework for Nuclear Energy Cooperation

INFEC is a partnership of countries aiming to "ensure that new nuclear energy initiatives meet the highest standards of safety, security and non-proliferation."[103] Thirty-four member countries and thirty-one observer countries collaborate on political, technological, financial and infrastructure aspects of nuclear energy development. The issues that INFEC specifically addresses are global expansion of nuclear energy, efficiency of the current nuclear fuel cycle, cost issues and non-proliferation. Two working groups are responsible for carrying out these tasks. The first group, the Reliable Nuclear Fuel Services Working Group (RNSWG), specializes in dealing with the challenges associated with nuclear fuel, such as international leasing and shipping of nuclear fuel, as well as attempting to extract the most value possible through the recycling of spent fuel. This group is led by France and Japan, which both have a closed fuel cycle, meaning all fuel is reprocessed. The second group, the Infrastructure Development Working Group (IDWG), is responsible for addressing the wide range of infrastructure challenges associated with nuclear power, from financing options and managing waste, to staffing the plant. It is led by the U.K. and U.S. [104]

The first group researches methods to improve the efficiency of the current nuclear fuel cycle. The U.S., the largest producer of nuclear power, uses a 'once through' fuel cycle. The fuel is used once and then sent to be stored. This method wastes large amounts of useable energy that could be created through recycling. Other countries, such as the RNSWG leaders, recover the residual uranium and plutonium from the used fuel to recycle the plutonium in light water reactors. The United States could greatly benefit from new fuel recycling technologies, since waste storage is a pressing issue. Significant amounts of used nuclear fuel are stored in different locations around the country, while planned waste repositories, such as Yucca Mountain, keep getting delayed due to vocal public disapproval. Recycling used fuel would greatly reduce the amount of waste destined for disposal, and increase the amount of energy for the same amount of fuel.

The Yucca Mountain Repository has been under inspection since 1987, and in this time it has been the subject of intensive site research, as well as controversy. Over two decades it has been delayed multiple times, but in 2015 the NRC published a final safety evaluation report, stating that the repository would be safe and environmentally sound for "the one-million-year period of waste isolation specified in the regulations". [105] Construction of the repository is scheduled to start this year, but its opening will not be for at least another 15-30 years. It is estimated that every year of delay will cost taxpayers an additional $500 million, so it is very important to be on schedule.

International cooperation plays into this because advances in the treating of nuclear waste made by groups such as the IFNEC can be employed within the Yucca Repository and help speed up the waste management process.[106]

The IFNEC also aims to address cost issues associated with the development and expansion of nuclear power in developing countries. A major obstacle in the pursuit of nuclear energy is infrastructure requirements. The IAEA, in partnership with the IFNEC, assists developing countries with infrastructure assessment and guides them in meeting the needs for nuclear power plants. This enables the countries receiving feedback to make informed policy decisions on whether and how to pursue nuclear power. The IFNEC also provides training for nuclear engineers in developing countries, which is cost-saving in the long run because they don't have to hire experts from foreign countries.

Participation by the United States in this organization has varied throughout the years. In 2007, Congress allocated $167 million for the organization, in 2008 that amount was cut to $120 million, and in 2009 the IFNEC, then known as the Global Nuclear Energy Partnership, didn't receive any funding from the U.S. This severely constrained the fuel cycle developments. After the renaming and restructuring of the organization in 2010, the United States returned to the IFNEC, and funding was reinstated. Currently, the organization's Chairman is Edwards McGinnis, from the United States, who has made financing nuclear energy systems a top priority. U.S. membership in the organization may result in a solution for the national problem of nuclear waste disposal while allowing the U.S. to take a leadership role in the safe and sustainable global expansion of nuclear energy. [107]

International Atomic Energy Agency

The International Atomic Energy Agency (IAEA) is well known for its non-proliferation efforts, but it addresses many issues. Its creation has a direct relation to the foreign policy of the United States, as the inspiration for its establishment was drawn from Eisenhower's "Atoms for Peace" address to the General Assembly of the UN. Although the IAEA reflected the fears and uncertain future of nuclear technology discoveries and diverse uses, President Eisenhower presented nuclear energy as a hope, not a fear. The President's words at the UN General Assembly in December of 1953 sent a message of unification: "In fact, we did no more than crystallize a hope that was developing in many minds in many places … the splitting of the atom may lead to the unifying of the entire divided world."[108] At 168 member countries, the IAEA has the most out of any international nuclear organization. It is also the only international organization set to host an international uranium fuel bank. The IAEA Low Enriched Uranium Bank is set to be built in Kazakhstan by September of this year, and will serve as a "supplier of last resort" for member states, meaning it will be a backup source of fuel in the case of exceptional circumstances that disable member countries from obtaining the fuel themselves. The bank is planned to be a physical reserve of up to 90 metric tons of low enriched uranium, enough to power a large city for three years.[109] The fuel bank system protects member countries from potential disruptions in existing supply arrangements by creating an assured supply of nuclear fuel.

Another major project the IAEA is working on is improving and accelerating the decommissioning process in member countries. The last phase in the life cycle of a nuclear plant, decommissioning happens at a very slow pace. It encompasses removing all nuclear aspects from a site and making it available for other uses. This takes a lot of time due to the lack of finances, national policy, regulations and qualified staff.[110] In February of 2017, 25 member countries came together to discuss a possible framework, as well as technologies, that could speed up and improve decommissioning practices. This initiative, once actualized, will allow member states to assist one another with decommissioning nuclear facilities using the IAEA's technologies and regulatory framework.[111]

The IAEA also works alongside various international organizations and corporations in order to help the international community achieve seventeen sustainable goals. Among these goals are achieving food security and sustainable agriculture, ensuring clean water and sanitation for all, ensuring access to affordable, reliable and sustainable energy for all, and taking urgent action to combat climate change and its impacts.[112]A recent example of this was using nuclear technology in Burkina Faso to suppress the tsetse fly, a bloodsucking insect that has brought much damage to the economy of the country, as well as the people and animals. In cooperation with the Food and Agriculture Organization of the United Nations, the IAEA created a plant where radiation is used to sterilize male insects in an attempt to drastically reduce the populations. The tsetse fly is responsible for the death of over three million livestock in the sub-Saharan continent every year, generating US $4.5 billion in losses annually to the country's agricultural industry.[113] The flies also transmit diseases among both humans and animals. The example of Burkina Faso demonstrates the nuclear energy can be a solution to a wide array of issues.

Nuclear Energy Agency

The Nuclear Energy Agency was established in 1958 to explore nuclear energy as a possible solution to the rapidly increasing energy needs for the recovery of Europe's economy post World War II. In 1972, the organization's name changed from European Nuclear Energy Agency to Nuclear Energy Agency to reflect the membership growing beyond European countries. Today, the NEA is a multinational organization that facilitates cooperation among countries with advanced nuclear infrastructure.[114] The NEA publishes consensus positions on key issues, such as radioactive materials management and operational safety issues. By doing this, the organization provides member countries with credible references that they can refer to for their own energy systems. Thirty-one nations, representing about 83% of the world's installed nuclear capacity, pool their expertise, which provides each member with access to substantial experiences and knowledge of others.

The NEA stands out from similar organizations in that it is the only intergovernmental agency which brings together a selection of countries from North America, Europe and the Asia-Pacific region in a forum dedicated to sharing expertise in the field of nuclear energy.[115]Each member country is responsible for funding and carrying out its technical work, and because of this, the NEA is very cost-effective. Besides exchanging information between member countries, the NEA also provides technical secretariat services for the IFNEC and Generation IV forum.

Due to mutual interests, the United States has been a very active member of the NEA, especially in projects related to nuclear technology regulation, safety, and radiation protection. U.S. delegates from the DOE and the Nuclear Regulatory Commission (NRC) maintain roles in different NEA committees and working groups. The NEA has been led by former Director of Nuclear Energy at the U.S. DOE, William D. Magwood, who assumed the position of Director-General. [116] Among many shared interests between the NEA and the U.S., the country has a specific interest in:

1. A NEA global task force created to address a looming crisis regarding the supply of medical radioisotopes which account for approximately two-thirds of all diagnostic medical isotope procedures. Americans rely on the crucial treatments for approximately 16 million life-saving medical procedures annually.
2. The NEA continues to evaluate the lessons learned from Fukushima, including safety research and study of accident progression.
3. The United States is working closely with the NEA to prepare for nuclear emergency response and management of radiological emergencies (INEX-5).
4. The NEA is enhancing nuclear science/data bank products and services, particularly the creation of high quality benchmark experimental data to support the validation of computer models.[117]

These shared interests show the true scope of nuclear energy, and its applicability to a wide range of subjects. U.S. participation in the NEA is especially important because it directly affects the lives of a large number of Americans. This organization is also significant because it has strong ties to other nuclear energy organizations, and representatives from the NRC and DOE have the opportunity to network and create new relations with experts around the world.

Bilateral Cooperation

The United States has nuclear energy bilateral agreements with China, India, France, Russia and Japan and is a partner in the International Nuclear Energy Research Initiative and the International Nuclear Cooperation Framework. These programs focus on research and development and consist of collaborations between scientists, laboratories, research institutes and universities from both countries. The most significant collaboration with the Chinese is the U.S.-China Bilateral Civil Nuclear Energy Cooperative Action Plan, which employs six technical working groups to advance the technical aspects of nuclear energy production. The history of collaboration between the United States and India is a controversial one, due to India's history of proliferation, but relations have improved after the U.S.-India 123 Agreement was signed. The U.S.–India Civil Nuclear Energy Working Group was set up to ensure technical cooperation exists in the future. Relevant to today's political climate is the agreement between U.S. and Russia, and the Civil Nuclear Energy Cooperation Action Plan Working Sub-Group (which is co-chaired by both the Department of Energy Assistant Secretary for Nuclear Energy and the Rosatom Deputy Director General). The long-term objectives are to advance the growth of clean, safe, secure, and affordable nuclear energy through innovative nuclear technologies.[118]

International Nuclear Energy Research Initiative

The International Nuclear Energy Research Initiative (I-NERI) was established in 2001 by the U.S. Office of Nuclear Energy to encourage collaboration by the United States, the Republic of Korea, the European Union and Canada for research and development of nuclear energy systems. It is a research oriented initiative that alleviates costs for each member through resource sharing and data exchange, that each country would otherwise have to pay for.[119] The Republic of Korea is a unique country in this collaboration due to its proximity and political tensions with North Korea, as well as its status as an easily transitional nuclear power. Currently, South Korea does not have any nuclear weapons, but does have the infrastructure, expertise and resources to change that in a short amount of time.

International Nuclear Cooperation

The International Nuclear Cooperation (INC) Framework was created to assist former Soviet Union countries and Eastern European countries with the proper handling of Soviet-designed nuclear technologies. Countries such as Ukraine and Kazakhstan were "born" nuclear weapon states, but decided to turn the weapons in, sign the Nuclear Proliferation Treaty, and use nuclear energy for peaceful purposes only. However, these Eastern European countries lacked the professional expertise and resources to operate nuclear power plants. The INC successfully introduced modern safety practices and technology into Ukraine's reactors, and recommended shut downs and upgrades in Kazakhstan and Armenia. This decreased the chance of an accident occurring in this region. [120]

Although this program is no longer in use, it is a success story for bilateral cooperation and an effective example of how countries assisting one another promotes a safer global nuclear landscape. Under this program, no nuclear materials were stolen or lost, and no nuclear accidents occurred. The misplacement of nuclear materials is a huge proliferation concern today, especially with large numbers of sophisticated terrorist networks present all around the world. Nuclear materials require proper handling, but as the INC has showed us, through extensive education and training, the chances for accidents are very slim.

Conclusion

As nuclear technologies evolve, so will the challenges associated with them. Continued U.S. participation in nuclear cooperation efforts is crucial to respond to these challenges. In the future, it would be beneficial if the United States maintained or increased its participation levels. Although the U.S.' future of international cooperation on nuclear energy is uncertain in this time of shifting political leadership, the past contributions of the nation to nuclear energy innovation have surely brought much benefit to ourselves and the entire world.

Before the United States can lead the world towards more sustainable development using nuclear energy, it must assess its own nuclear state. The U.S. has room to improve in regards to its nuclear infrastructure and technology. In order to promote nuclear energy internationally, the United States can increase funding to international research institutes, foreign universities and international organizations. With every cooperation effort made, the world gets closer to bringing energy to developing countries, finding solutions to existing problems, and preventing the use of nuclear technologies for non-peaceful uses.

Nuclear Weapons Proliferation in the Era of Globalizing Nuclear Energy

Kayley Knopf

In the new nuclear era of globalizing nuclear power, the threat of nuclear weapons proliferation is a major concern for the United States. In order for the United States to utilize nuclear energy as a primary power source, proliferation concerns need to be addressed to respond to civilian fears. In the past, nuclear energy technology has been diverted to nuclear weapons programs, specifically in India, Pakistan, Iran, Israel and North Korea. The possibility of proliferation from nuclear power programs to nuclear weapons programs negatively impacts public perception, which hinders the success of U.S. nuclear energy expansion. Already, American foreign policy has played a leading role in reducing proliferation attempts and mitigating proliferation concerns. In order for the U.S. to prevent the proliferation of nuclear weapons while promoting clean energy, they must aid the strengthening and expansion of nuclear regulating bodies and agreements.

India

After independence in 1947, India began a nuclear program to ensure a self-reliant energy source; in this process, interest in a nuclear weapons program ensued. When The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) opened for signature in 1968 India did not sign, as they wanted to first see a comprehensive plan for current weapons states towards disarmament.[1] While much of India's nuclear program served to display the scientific might of the nation, it was also used as a deterrent against China.[1] Under Eisenhower's Atoms for Peace program, India received nuclear technology for the purpose of peaceful energy production from the United States and Canada. Once India tested its first nuclear weapon in 1974, outrage ensued, as the U.S. claimed their support had been used for non-peaceful purposes. Today India has both a functioning nuclear weapons and power program. India has a plutonium production reactor, as well as uranium enrichment facility.[1]

Pakistan

Pakistan began its nuclear weapons program in 1972 as a deterrent to India. Out of the Atoms for Peace program, the United States began opening nuclear programs at American universities to international students; this included a handful of Pakistani physicists. Dr. Ishrat Hussain Usmani, Chair of the Pakistan Atomic Energy Commission, was able to secure a deal for a small 137 MW CANDU heavy water reactor.[2] As Pakistan's nuclear weapons program progressed, the United States became cautious and placed an arms embargo on Pakistan. Sill in need of supplies, Pakistan looked to China, who provided them with military equipment and aid.[2] To obtain the necessary funding, the Pakistani Prime Minister visited with Libyan Colonel Muammar Gaddafi, and a cooperation agreement between the two nations began. This provided an estimated \$100 to \$500 million to Pakistan's nuclear program. In exchange for financial backing and uranium, Pakistan agreed to train Libyan scientists.[2] In 1973, Pakistan had an indigenous production program from uranium oxide fuel at the Karachi Nuclear Power Plant, KANUPP.[2] However, after India's nuclear test in 1974, Canada required all 'customer' states to sign the NPT and open all of their facilities to safeguards. Therefore, without a signature, nuclear supplies and fuel were cut off to the KANUPP facility in 1976. After India's nuclear test, efforts to accelerate Pakistan's program intensified, starting with the induction of Abdul Qadeer (A.Q.) Khan into the program. With his help, the Khan Research Laboratories (KRL) were created, where enrichment of necessary nuclear materials and work on centrifuges was conducted. Concerned with India's possession of nuclear weapons in the region, China supplied Pakistan and the KRL with highly enriched uranium, heavy water, and 5,000 ring magnets.[2] China's materials paired with Khan's design and leadership allowed Pakistan to acquire enough enriched uranium in the 1980's to help fuel its first nuclear test in 1998.[2]

Iran

Iran's journey towards nuclear weapons began and ended with the United States. After signing a nuclear agreement with Iran in 1957 under the Atoms for Peace program, the U.S. helped build and supply The Tehran Nuclear Research Center that included a single nuclear reactor.[3] In the mid 1970's Iran began developing a nuclear power program. After the Islamic revolution in 1979, U.S. assistance into the program ended; Russia then forged an agreement with Iran in 1992 to build a two-unit nuclear power plant.[4] As a member of the IAEA all work and operations were under IAEA safeguards.[4] However, in 2003 the IAEA found that Iran had hidden nuclear development technologies capable of producing nuclear weapons. The specific technology of concern was the uranium and plutonium separation from used fuel, a signal of a weapons program.[4] This example is important in evaluating which countries should develop enrichment and reprocessing facilities. In efforts to stop the nuclear weaponization of Iran, the November 2013 Geneva Agreement: Interim Joint Plan of Action limited Iran's enrichment to 5% U-235 with further inspections in exchange for sanction relief.[4] Reasons for Iran's nuclear aspirations include securing their sovereignty and emerging as a nuclear force in the Middle East, to deter invasion.

North Korea

After five nuclear tests within the last ten years, North Korea's nuclear program remains of large international concern. Initially sponsored by the Soviet Union through an agreement in 1959, North Korea's nuclear program started out as a nuclear research complex in Yongbyon.[121] North Korean engineers were able to divert the research facility into a weapons program from the training they received in Moscow. Additionally, North Korea received gas-centrifuge technology from the A.Q. Khan network in exchange for ballistic missiles technology.[121] Today, North Korea has rich reserves of uranium ore as well as weapons-grade-plutonium.[121] It is believed that their first test was of a plutonium bomb. While a plutonium and a uranium bomb just as deadly, if North Korea was in possession of a uranium bomb, it would indicate a larger technological achievement. They currently posses uranium enrichment capabilities but the functionality of its centrifuges is unclear.[121]

Israel

Israel's alleged desire for nuclear weapons rose from a security imperative. President Eisenhower's Atoms for Peace program helped Israel initially acquire a research reactor. In 1956 an opportunity to work with France gathering intelligence on independence movements in North Africa provided Israel with a reactor.[122] After Israel seized the Sinai, they asked France for an updated research reactor, one that could produce large amounts of plutonium.[122] France also provided Israel with a reprocessing plant as well as information on how to manufacture nuclear weapons, thus giving Israel the ability to separate plutonium and create a bomb.[122] After a suspicious heavy water sale from Norway to Israel, the U.S. became suspicious of an Israeli weapons program.[122] This led to American inspections of an Israeli nuclear facility. The intended purpose of the facility was hidden from American inspectors, leading them to believe it was not solely for research purposes. Today Israel still maintains a nuclear ambiguity; however, it is firmly believed that they are in possession of multiple weapons. They have not admitted to their possession nor signed the Nuclear Non-Proliferation Treaty.

South Africa

South Africa acquired its nuclear weapons program through the Atoms for Peace program, given a nuclear reactor as well as highly enriched uranium (HEU) fuel in 1965 through the collaboration.[123] In efforts to begin producing plutonium, South Africa designed the SAFARI-2 reactor using heavy water from the United States.[123] They deserted the project when it began consuming resources from the uranium enrichment program that began in 1967. However, with the technological experience this second reactor supplied, South Africa capitalized on the Ploughshares Peaceful Nuclear Explosion (PNE) program.[123] The PNE program allowed for non-military nuclear explosions for purposes such as building canals and harbors. In 1977, their first nuclear explosive device was completed.[123] By 1989 they possessed six nuclear weapons. Their weapons program was triggered by a desire to secure their borders and feeling of international isolation due to apartheid.[123] Improved security on South Africa's borders and the end of apartheid led to the full dismantling of their weapons program and their signature on the Nuclear Non-Proliferation Treaty in 1991.

Methods of Proliferation

The management of nuclear waste and spent fuel reprocessing technology is critical in assuring peaceful nuclear programs are not diverted to military use. The IAEA cites safeguarding nuclear reprocessing plants as a priority in reducing the risk of nuclear proliferation.[124] Nations can develop nuclear weapons programs from the separated plutonium and fissile material found in spent fuel. In a closed nuclear fuel cycle, which utilizes spent fuel reprocessing, the full energy potential of the uranium can be used and creates less waste than a once through cycle.[125] To mitigate the concern of reprocessing while still utilizing its capacities, Japan has mixed uranium with the plutonium in spent fuel so pure plutonium does not leave the final reprocessing point.[124] In this management structure energy potential can be maximized while waste and proliferation concerns can be minimized.

While relatively small in scale and requiring less fuel than a power reactor, some research reactors contain highly enriched uranium (HEU) that can be used for the creation of a nuclear weapon. Research reactors allow for nuclear energy and medical innovations in addition to training and testing. The concern is not of the uranium, but of plutonium production that can occur when using HEU. Most research reactors using HEU today use 20% enriched U-235, however, many of the research reactors used until the late 1970's used HEU enriched to 93%, above weapons grade.[126] Unlike other reactors, research reactors are often located in civilian areas such as universities where security is not as tight.

It is not necessary for research reactors to use HEU. Instead, high-density low-enriched uranium (LEU) is sufficient for the working capacity of research reactors. Moves to replace HEU with LEU support non-proliferation efforts. As the U.S. was a major world supplier of HEU research reactors under the Atoms for Peace program, they launched the Reduced Enrichment for Research and Test Reactors (RERTR) program.[126] This program allied with the mission of the Global Threat Reduction Initiative (GTRI) in 2004 to work towards removing HEU fuel from research reactors. In 2014, 24 research reactors in 14 countries replaced and down-blended the HEU in their reactors to LEU.[126] Russia's fleet of research reactors has not been converted to LEU as of September 2016, posing a potential threat to non-proliferation objectives.[126]

In today's nuclear age, a security breach of civilian nuclear facilities by non-state actors is a major proliferation concern. Proper security, accountability enhancement and the minimization of access to sensitive materials are important components of proliferation resistance in the design of new nuclear facilities and plant upgrades.[124] An example of the wrong person gaining access to nuclear facilities is A.Q. Khan, who, from his time working at the Dutch Ultra Centrifuge Nederland, Khan "…gained crucial knowledge of centrifuge-based enrichment operations" and stole blueprints of centrifuge and infrastructure designs in addition to over 100 contacts of companies who supplied centrifuge material.[121] He brought these back to Pakistan where he not only helped build a Pakistani nuclear weapons program, but established a grey market for nuclear materials. As the Khan network represents proliferation from a non-state actor, it is important to understand A.Q. Khan's motives for his grey market. While some feel it was for ideological reasons in spreading nuclear power to Muslim countries, it appears Khan's reasons were financial. He personally pocketed from each transaction and made deals with North Korea, a non-Muslim country, as well as Iran, a Shi'a majority country. A.Q. Khan's network was vast, trading nuclear materials and intelligence for decades. Thorough security is thus essential in quelling heightened fears of nuclear weapons proliferation by non-state actors.

Allied nations trading nuclear intelligence and materials are a potential threat to proliferation; specifically, it becomes an issue when these nuclear transfers are undocumented by the IAEA. Reliable intelligence plays a large role for the United States and other nations in catching these deals prior to the transfer of materials. A.Q. Khan and North Korea are an example of such deals. North Korea successfully traded ballistic missiles technology in exchange for gas centrifuges without international knowledge.[121] A.Q. Khan also managed to transfer these materials to Libya and Iran.[121] As the transfer of materials in this context were not IAEA regulated and could lead to the production of nuclear weapons, early discovery is crucial to resisting proliferation. Today, proliferation to terrorist organizations remains a great international concern. For terrorist organizations to make a nuclear weapon they must acquire readily usable fissile material. Of the countries possessing nuclear weapons, Pakistan and North Korea show the weakest stability and thus pose the largest threat to the trade of nuclear materials for peaceful purposes.[127]

U.S. Role in Nuclear Non-Proliferation

American foreign policy has the power to quell the concerns of nuclear weapons proliferation that arise with globalizing nuclear energy. Under the NPT Article IV, all nations have the right to pursue nuclear energy.[128] This includes states located in conflict zones, states run by corrupt and authoritarian regimes as well as states who the U.S. does not have strong relations. In addition, Article IV gives the freedom of reprocessing to all nations.[128] As this technology can be diverted for nuclear weapons programs, American foreign policy can confront the extent of these technologies, as seen in the Iran agreement. Using the Iran agreement as a precedent, the U.S. can further its international engagement in establishing measures to lower the risk of proliferation in nations it sees as a risk.

In the building of nuclear energy programs in conflict zones and weak states, the United States' foreign policy can work to influence these nations to avoid enrichment and reprocessing technologies. This can be seen by its membership in the Nuclear Suppliers Group (NSG) that places export restraints on nuclear transfers to these regions of instability.[129] In authoritarian or corrupt nations, there is concern that governments could exploit nuclear energy technology for military purposes.[125] Before programs are established in these nations, conditions on their implementation, such as requiring IAEA membership and the use of certain technologies can be negotiated. If a nation already in possession of a nuclear power program shows signs of corruption or a change to an authoritarian regime, the international community can respond with sanctions and amplified inspections.

In efforts to limit the spread of reprocessing technology, the U.S. set a precedent in 1976 when President Ford announced:

"…the reprocessing and recycling of plutonium should not proceed unless there is sound reason to conclude that the world community can effectively overcome the associated risks of proliferation ... that the United States should no longer regard reprocessing of used nuclear fuel to produce plutonium as a necessary and inevitable step in the nuclear fuel cycle, and that we should pursue reprocessing and recycling in the future only if they are found to be consistent with our international objectives."[130]

While the United States has continued to withhold from domestic reprocessing, it has maintained commitments to Western Europe and Japan in their use of plutonium for civil nuclear programs.[130] By addressing the proliferation concerns of enrichment and reprocessing technologies in new nuclear nations with agreements between the U.S. and other states, the country can advance the confidence of secure nuclear power expansion.

After years of sanctions and negotiations, the Iran nuclear deal strengthened international non-proliferation. In 2015, an agreement for the Joint Comprehensive Plan of Action (JCPOA) between Iran, the P5 states, Germany and the European Union was reached. This agreement blocks all methods Iran could use through uranium enrichment or plutonium to construct a nuclear weapons program.[131] Along with increased IAEA inspections and monitoring, Iran also agreed to dilute its uranium stock, holding enrichment at 3.67%, to be used solely for power and research purposes.[131] In January of 2016, the IAEA confirmed that Iran had completed the compulsory steps; as a result the United States agreed to lift all nuclear-related sanctions on Iran.[131] Some nations in the Middle East, namely Saudi Arabia, are worried about the economic consequences a revived Iranian economy could have on the region. There is also concern that American interests have shifted from previous alliances in the Middle East as a result of this deal.[132] However, as seen by the strides already taken by Iran under the JCPOA, the robust IAEA initiatives and the international commitment to sanctions if Iran were to violate the terms, it is clear that the Iran deal is a success for non-proliferation efforts. It is a continuation of U.S. and international goals in preventing the proliferation of weapons while promoting the peaceful uses of nuclear energy.

The U.S. has been the dominant leader in non-proliferation for over 50 years. It is imperative that the U.S. maintains a leading role in nuclear non-proliferation efforts in the changing state of the global energy landscape. As new nations gain access to nuclear technology, as well as nations such as China, Russia and India continue to rise in nuclear advancements; the legitimacy of America's role in the new nuclear age relies on their ability to continue to innovate nuclear policy and technology. In addition, the emergence of regional hegemons such as Iran, Turkey and Brazil and growing international conflict has the potential to create uncertainties for the non-proliferation regime. In order to decrease the risk of proliferation the U.S. must bolster their nuclear reach. Additionally, U.S. policymakers must take steps to eliminate proliferation threats by strengthening international cooperation and nuclear regulating bodies.[133] To supervise a changing world, U.S. leadership in global nuclear power will be crucial to non-proliferation efforts.

Limiting the Threat of Proliferation

Enlargement of the IAEA's regulating capacities can limit the threat of weapons proliferation. Their mission is to foster the peaceful use of nuclear energy while implementing the safeguards system established by the NPT. To be effective in their mission, their reach must encompass the quickly growing quantity of nuclear facilities. Limits in the IAEA's regulating abilities came to light in 2002 when an undeclared nuclear facility in Natanz, Iran was discovered by their media.[134] Ultimately, it was discovered that the hidden nuclear facility at Natanz contained advanced enrichment capabilities that had the potential, if left unmonitored, to become used for military purposes.[135] The time period between discovery of suspicious nuclear activity in Iran and resolute action is an indicator of the limits of the IAEA to coerce behavior.[136] In a statement given at the Brookings Institute in 2014, IAEA Director General Yukiya Amano, admitted, "IAEA resources are limited, demand from Member States for our services continues to grow and our budget is being squeezed."[134] Enlargement of the IAEA would enable its capacity to accurately track and inspect nuclear activity. With the emergence of new nuclear programs, IAEA expansion can aid in the early detection of nuclear materials. Specifically, extending IAEA authority over weaponization as well as expanding its budget and personnel to match the rate of nuclear energy development will help in securing a peaceful nuclear future.

Similarly, expanding the supervision capacities of nuclear materials trade can prevent the proliferation of materials for weapons. The Nuclear Suppliers Group (NSG) and the Zangger Committee have governed almost all nuclear trade since World War II. A vital component of the NSG are its dual-use guidelines as outlined in Part 2 of INFCIRC/254 that clarify the rules of nuclear trade for materials that have both nuclear and non-nuclear uses.[129] Additionally the guidelines "…ensured that only those signatory to the NPT and other States with comprehensive safeguards agreements could benefit from nuclear transfers."[129] The NSG maintains a comprehensive list of protocols and membership procedures to avoid proliferation from nuclear transfers. Unlike the Zangger Committee, the NSG does not require its suppliers to be signatories of the NPT. While the same binding commitments of the Zangger Committee exist in the membership of the NSG framework, questions of motive or integrity for nations who desire to be suppliers but not to be subject to NPT conditionality's may be concerning. Despite the tight trade guidelines of nuclear transfers that the NSG requires, the group does not possess the capability to enforce compliance.[129] In recent years the NSG has lost some of its credibility to maintain transparent nuclear commerce. Member states have diverted from NSG guidelines in nuclear transfers for their own economic or defense agendas.[136] One way in which this can occur is through transshipment, where one country exports goods to another using an intermediary nation. To expand the supervision capacities of nuclear materials the NSG wants to implement controls on illicit brokering and transshipment to eliminate loopholes in trade and authorize personnel to intervene in suspicious transactions.[137] However, like much of the NSG's guidelines, these controls would be implemented on a voluntary basis by participating governments and would therefore not be legally binding.[137]

International efforts to further technological advancements for safer and more secure reactor designs can be shared to limit the ability of weapons proliferation from nuclear energy. While offering tightened safety measures, Generation IV nuclear energy systems also offer the potential for countries to reduce their plutonium stock.[137] Additionally they offer the function of converting plutonium and high-enriched uranium to less sensitive materials.[137] However, the implementation of Generation IV nuclear technology would require large reprocessing capabilities, raising proliferation concerns.[137] International acceptance of stringent safeguards on these facilities could help to both mitigate proliferation concerns, while also bringing higher safety and efficiency standards.

A major component of global nuclear cohesion is the past and future role of the NPT. While this treaty remains an important facilitator of nuclear regulations, especially the right of all countries to possess nuclear energy capabilities, it may be less effective in its non-proliferation role. This can be seen through the example of Iran who, despite being an NPT signatory, resisted compliance with IAEA safeguards and a hid nuclear facility. Additionally, the existence of nuclear weapons states not signatory to the NPT (India, Pakistan, North Korea and Israel) threaten its practicality. The Additional Protocol INFCIRC/540 of the IAEA fills the gaps of the NPT.[138] Although it is voluntary for states to undertake, once they have signed, it becomes legally binding.[138] This gives the IAEA full authority to intelligence and nuclear sites of signatories.[138] In this age of nuclear energy globalization, The Additional Protocol is a key tool in the assurance of the absence of clandestine nuclear materials and activities.[138] The strengthening measures The Additional Protocol brings to the non-proliferation efforts set forth by the NPT, has a powerful place in the nuclear era as more states decide to sign.

Conclusion

The expansion of nuclear energy is of important interest to the United States' foreign policy and non-proliferation efforts. In order for the U.S. to be a benchmark of safety and security standards they must take a leading role in nuclear technology advancement. The Iran Deal is an important example of how the U.S. can effectively promote the peaceful uses of nuclear energy while reducing the threats of weapons proliferation. Global cohesion will continue to play an important role in implementing safeguards regulation. Expansion of nuclear governing bodies such as the IAEA and its Additional Protocol have the ability to ease public tensions surrounding the divergence of nuclear energy materials for weapons purposes. These actors are crucial in ensuring not only a peaceful nuclear future, but also one with extensive positive environmental impacts. For the world to benefit from the positive impacts of nuclear energy, concerns surrounding proliferation need to be addressed. As the above sections outline these concerns include the authority of nuclear regulating bodies, nuclear waste, reprocessing technology, the use of HEU fuel in research reactors and the role of non-state actors to capitalize on these opportunities. By addressing each of these concerns with transparent and comprehensive solutions, U.S. civilian fears of nuclear weapons proliferation, through the globalization of nuclear power, can be mitigated to allow significant environmental benefit.

U.S. 123 Agreements: How Far They Can They Grow?

Woojoong Shin

Commonly known as U.S. 123 Agreements, Section 123 of the U.S. Atomic Energy Act of 1954 provides for transfers of nuclear technology and assistance programs from the United States to other nations. They have proved to be a valuable tool in U.S. foreign policy with regards to advancing nonproliferation. While it is important for U.S. nonproliferation principles, it has also proven to be contentious in some cases. The Republic of Korea (ROK), interested in full control of the total fuel cycle, including reprocessing of spent fuel, has been seeking to negotiate with the U.S. for the revision of the agreement. On the other hand, the United Arab Emirates (UAE) has been closely working together with the U.S. under 123 Agreements to develop nuclear energy in order to lessen its reliance on natural gas and oil. It is important to acknowledge the significance of these agreements as a way for nations to cooperate as nuclear energy technology evolves. The U.S. has 123 Agreements with 23 nations, as of 2017. These agreements offer the U.S. a way to maintain its leadership in the development of nuclear energy. Understanding the contents of the agreements and examining each will provide information on how U.S. 123 Agreements benefit and possibly harm both U.S. and overall development of nuclear energy in the present and future.

History and Content of Section 123 of the U.S. Atomic Energy Act

The Atomic Energy Act of 1954 was enacted by congress during Dwight D. Eisenhower's presidency on August 30, 1954. The law dictates development, usage, and control of nuclear materials on both the civilian and the military level. The act reaffirmed the authority of the Atomic Energy Commission, which later became the Nuclear Regulatory Commission (NRC), over civilian nuclear power development. The act not only regulates use of nuclear powers but also requires civilian facilities to be licensed by the NRC. According to the NRC, the goal of the act is to advocate world peace and social welfare, and encourage the involvement of private sectors in the industry.[139] Section 123 of the act establishes conditions between the U.S. and other participating states to cooperate in the nuclear industry. It is related to the transfer of elements, science, and technology exchanges and safety. Because of proliferation concerns, there are nine criteria that each participating state needs to meet:

1. Nuclear material and equipment transferred to the country must remain under safeguards in perpetuity.
2. Non-nuclear-weapon states partners must have full-scope IAEA safeguards, essentially covering all major nuclear facilities.
3. A guarantee that transferred nuclear material, equipment, and technology will not have any role in nuclear weapons development or any other military purpose, except in the case of cooperation with nuclear-weapon states.
4. In the event that a non-nuclear-weapon state partner detonates a nuclear device using nuclear material produced or violates an IAEA safeguards agreement, the U.S. has the right to demand the return of any transfers.
5. U.S. consent is required for any re-transfer of material or classified data.
6. Nuclear material transferred or produced as a result of the agreement is subject to adequate physical security.
7. U.S. prior consent rights to the enrichment or reprocessing of nuclear material obtained or produced as a result of the agreement.
8. Prior U.S. approval is required for highly-enriched uranium (HEU) and plutonium obtained or produced as a result of the agreement. An agreement permitting enrichment and reprocessing (ENR) using U.S. provided material requires separate negotiation.
9. The above nonproliferation criteria apply to all nuclear material or nuclear facilities produced or constructed as a result of the agreement.[140]

Through the Nuclear Proliferation Assessment Statement, the participating states prove how they meet the above nine criteria. Congress will consider their acceptance within 90 days. As of early 2017, nations that have signed 123 Agreements with the U.S. including the following[141]: Argentina, Australia, Brazil, Canada, China, Colombia, Egypt, European Atomic Energy Community (Euratom), International Atomic Energy Agency (IAEA), India, Indonesia, Japan, Kazakhstan, Korea Republic of, Morocco, Norway, Russia, South Africa, Switzerland, Taiwan, Thailand, Turkey, Ukraine, and the United Arab Emirates.

Case Study 1: Republic of Korea

The Republic of Korea (ROK) is a prominent country in nuclear power generation. Currently its 25 operating reactors provide 29% of nation's total energy consumption at 23 Gigawatt-Electric (Gwe) per plant.[142] Three reactors are under construction and eight more are in the planning stage. Nuclear energy is a priority to the South Korean government in developing their future energy industry. The government plans to increase the number of operating reactors to 38 by 2030 in order to increase the power generation capacity by 70%.[143] The major part of South Korea's current and future plans for nuclear power involve exporting nuclear technology and training to other nations. Ideally, this would include fuel as well as reactor and power plant technologies.

Former President Lee Myung-bak expressed commitment towards nuclear as part of the nation's green growth strategy, stating in 2010 that "nuclear is one of the most efficient power generation methods that will lead us to a low carbon society, and I intend to make sure that Korea keeps up with its role as one of the major suppliers of these zero carbon power plants."[144] With government support, South Korea's nuclear energy technology has grown vastly. In 2009, the ROK agreed to build four new generation nuclear reactors in the United Arab Emirates. ROK consortium achieved this bidding over competitors from Japan and France. Rising as an international exporter of nuclear plant, this $20 billion contract with the UAE became a fundamental footstep for the ROK's announcement to export 80 nuclear reactors by 2030.[145]

Energy security is essential for economic development, and the ROK has seen rapid economic growth in the past five decades. Due to the rapid growth in GDP, the ROK's electricity consumption grew from 33 Terawatt-hours (TWh) in 1980 to 545 TWh in 2014.[143] The electricity demand in the ROK has increased over 9% per year in 1990s, and projected to increase 2.5% per year until 2020. The International Energy Agency reported that the ROK has ranked as the world's 11th highest energy consumer.[142] Being a highly energy-intensive economy, the ROK can reduce emissions and save money by maintaining and developing nuclear energy technology. In 2011, the ROK spent $170 billion on importing energy. According to the Korea Electric Power Corporation, nuclear energy was able to save $20 billion that year.

123 Agreements between the U.S. and the ROK were signed in 1974 under U.S. President Richard Nixon and ROK President Park Chung-hee. The agreement was originally set to expire in March 2014; however, the U.S. and ROK governments decided to extend it for two years in order to reach a middle ground between their conflicting stances; the contentious issues being uranium enrichment and spent-fuel reprocessing.[146] While the U.S. prohibits the development of technologies on reprocessing spent-fuel, ROK government has insisted that it is crucial to the nation's nuclear future. In 2008, ROK reached 10,083 tons of spent fuel, which has increased by 700 additional tons each year. It is estimated that by the end of the century, the ROK will need 80 square kilometers' underground repository to store its waste.[147] In 2013, the government spent $247 million and granted other benefits in an attempt to keep down the public opposition in Gyeongju, a major location for nuclear waste storage in Korea.[148] Gyeongju is a rural town in the southern part of Korea with 260,000 people. Strong public opposition against the nuclear waste storage has been problematic for the ROK government, as it delays the development of nuclear power and increases costs.

South Korea hopes to develop a reprocessing capability called pyroprocessing by revising its 123 Agreement with the U.S. Pyroprocessing divides spent fuel into smaller sizes and turns it into a powder form by adding excessive amounts of heat. This process burns off fission products including krypton, xenon, iodine, and cesium, forming a metal that dissolves into separate pieces by electric current in a bath. When transuranic materials are separated with other fission products, it can be refabricated into metallic fuel for fast reactors.[147] Pyroprocessing reduces the amount of spent fuel that needs to be reprocessed. Under both the Bush and Obama Administration, negotiation for 123 Agreements determined that pyroprocessing is still reprocessing.[149] Korean nuclear scientists argue that it is proliferation resistant and not a part of processing spent fuel.

Nonproliferation remains a priority for the U.S. in its 123 Agreements. Most reactors in South Korea are either exported from the U.S. or use U.S. designs. This includes the four U.S. designed reactors that ROK will export to the UAE. Many U.S. nuclear industries are involved in this project. Without 123 Agreements that insure the transfer of technology related to nuclear energy, ROK's development in the industry will be hindered. On the other hand, it also means that U.S. nuclear exporting industries are directly impacted by the relationship with participating nations. Nuclear energy industries are significant to U.S. economy and its export of technologies. Export Import Bank of the U.S. financially supports the ROK and UAE contract; this will create 5000 American jobs across 17 states.[150] With the economies of both countries involved, the two states are interdependent.

On June 2015, the U.S. and the ROK updated and extended their 123 Agreements for another 20 years. Every five years the agreements will be automatically renewed. It made changes in the favor of the ROK in terms of reprocessing and enrichment of uranium. The updated agreements allow the ROK to transfer used fuel abroad for disposal. While reprocessing and enrichment are still prohibited, the uranium enrichment technology can be developed with further U.S. inspection and management.[151] This revised nuclear pact could set precedent for renegotiation of other 123 Agreements.

Case Study 2: United Arab Emirates

The United Arab Emirates (UAE) is one of the most significant nations in the field of nuclear energy development in the Middle East region. UAE's involvement in developing nuclear energy began with joining the Gulf Cooperation Council (GCC) which was founded in 1981. GCC is a regional political and economic union of six Middle Eastern states: Saudi Arabia, Kuwait, the UAE, Qatar, Bahrain, and Oman.[152] In December 2006, GCC commissioned the joint study on the peaceful civilian nuclear energy program and became the signatories of the Non-Proliferation Treaty (NPT) and made agreements with the International Atomic Energy Agency (IAEA). GCC members together generate 520 billion kWh electricity per year from only natural gas and oil. In addition, the total demand for electricity in these countries has increased 10% by 2015. Prompting the GCC to install 60 Gwe more in addition to its currently owned 90 Gwe capacity.[153]

In 2013, the UAE alone produced 19 Gwe capacity; 99% of which came from natural gas. Even importing 1000 Megawatt electric (Mwe) from Iran, the demand for electricity in the UAE is very high. The nation completely relies on electricity for desalination, which is crucial for producing potable water. According to the Embassy of the United Arab Emirates, with the annual growth rate of 9% from 2007, the annual demand for electricity will reach 40000 Mwe by 2020.[154] After studying its energy security, the government determined that coal and natural gas based energy is insufficient for sustained growth and hazardous for the environment, and other desirable renewable energy would only be able to supply 6 to 7 percent of its necessity.

While the UAE has the fourth largest natural gas reserves and the fifth largest oil reserves in the Middle East, the high sulfur content in natural gas increases the cost of electricity generation. In 2007, the UAE produced 1659 Billion cubic metres of natural gas (Bcm) and consumed 1457 Bcm which accounted for much of its government spending on energy.[155] In addition to its cost, the negative environmental effects concern the UAE. With increasing demand for electricity, energy security is a serious problem in the UAE, despite its large reserves of fossil fuels, and its government is looking to nuclear power as the answer.

The UAE, working together with the IAEA, founded the Nuclear Energy Program Implementation Organization, and the Emirates Nuclear Energy Corporation (ENEC) with $100 million in funding.[153] In 2009, the ENEC received offers from nine corporations for its first nuclear plant construction. Competition for the construction was fierce, but the government finally accepted a bid from the Korean Consortium in December 2009. They provided an Advanced Pressurized Water Reactor, valued at $20.4 billion. The UAE's goal by 2020 is to run four 1400 Mwe nuclear units and to produce 25% of its national electricity with nuclear energy.[153] The government aims to be a primary exporter of electricity in the Gulf region.

The Peaceful Civilian Nuclear Energy Corporation 123 Agreement between the U.S. and the UAE was signed in 2009. It was first proposed under the Bush administration and negotiated by the Obama administration; the agreement came into force in December that year. It enabled the UAE to acquire nuclear technologies, materials, and equipment from the U.S.; however, there are certain limitations. The UAE is required to have support from its neighbors in order to fully benefit from the 123 Agreement. Despite legislation controlling nonproliferation exports in 2007, it is still known as a major illegal proliferation transit place.[156] The major issue for the U.S. is the UAE's loosely controlled port that has been known to export illegal goods to Iran.[157] Also, the nuclear energy program will require long term commitment for the government, including training domestic experts and building proper infrastructures. As the nation starts to build its first reactor, it heavily relies on foreign industries and technologies for the security and safety of the program.

By making the nonproliferation agreement with the UAE, the U.S. has more opportunity to spread responsible nuclear energy practices in the Middle East. This relationship sets an important precedent for future nonproliferation agreements that the U.S. will have, called the "gold standard." The nonproliferation "gold standard" is for the UAE to forgo enrichment of uranium and reprocessing of spent fuel.[156] By holding the UAE to a high standard, the U.S. has sent an important message on prevention of proliferation in the Middle East. While Iran has demonstrated its development with nuclear fuel cycling capability, it has created controversy in the NPT and in the U.S. 123 Agreements with other nations, especially on uranium enrichment and spent fuel reprocessing that can threaten the nonproliferation principles that the U.S. upholds.[158]

The Future of U.S. 123 Agreements

Recently Vietnam (2014), Kazakhstan (2016), and Norway (2016) signed 123 Agreements. With this strong foundation, the U.S. can continue to influence the development of nuclear energy. In order to expand its leadership and propose nonproliferation principles, there are several prospective states that the U.S. government can consider; such as Belarus and Saudi Arabia. Any of these countries can be a new "gold standard" for the U.S. nonproliferation.

Belarus, located in Eastern Europe, can cooperate with the U.S. to compete with Russia's development of the nuclear energy. As of 2017, Belarus has two nuclear reactors under construction and two more proposed. Belarus only produces 31 TWh per year, almost entirely relying on natural gas. While 90 percent of its gas is imported from Russia, the government is looking for a way to reduce its dependence on Russia.[159] The newly planned pressurized water reactor is expected to provide 30 percent of the national electricity by 2020, reducing the cost of electricity to 50 percent of what it was when electricity was imported from Russia.

Saudi Arabia, a member of the GCC, currently does not own any nuclear reactors; however, 16 reactors have been proposed. The population growth of Saudi Arabia is massive, from 4 million in 1960 to over 32 million in 2017. With its rapid population growth, the production and consumption of electricity also increased 32 percent over the past two years. The electricity used for desalination and heat production is a major part of the growth, and currently relies on oil for 57 percent of its needs.[160] Similar to other Middle East nations, the development of nuclear energy is significant for its future energy usage. In this situation, as was the case for Iran and the UAE, the U.S. 123 Agreements can provide mutual benefits.

Conclusion

The case studies of the ROK and the UAE demonstrate both the importance and limitations of U.S. 123 Agreements. The ROK, a promising market for the nuclear industry, is rapidly building and exporting reactors and related technology. With 123 Agreements with the ROK, the U.S. can secure the exporting related technologies and experts due to the ROK's evident reliance on U.S. nuclear reactor designs and materials. Also, it will bring U.S. nuclear industry workers larger job markets via reactor building contracts. However, allowing the ROK's pyroprocessing capabilities, thereby revising the original 123 Agreements, weakens the U.S. position in future nonproliferation principles. The UAE, located in the Middle East, is the second nation in the region that made agreements with the U.S. As a swing state with significant influence in the Gulf Cooperation Council, the UAE's decision on following U.S. lead on nuclear energy and nonproliferation is significant to U.S. policy in the Middle East. Even with expected uncertainty with its neighboring nations, setting the "gold standard" of forgoing reprocessing of spent fuel and uranium enrichment gives the U.S. stronger voice in nonproliferation principles. Thus, 123 Agreements still stand as a significant tool for U.S. nuclear policy. U.S. success with the 123 Agreement, an essential part of the nonproliferation regime, has been highly dependent on American leadership in civilian nuclear power. Should this leadership erode significantly, the potential for expanding such agreements to new nuclear power states will erode as well. Such must be a major concern for the future of nonproliferation. It is unlikely, after all, that China or Russia, two states that remain strongly committed to nuclear energy, will fill the gap left by the U.S., should it back away from this source of non-carbon energy. With constantly negotiating and expanding the states participating in these agreements, the U.S. firmly set the foundation as a leader of nuclear energy industry and nonproliferation.

PART III:
The New Nuclear Energy Landscape

Global Nuclear Power

The New Global Landscape of Nuclear Power: Programs of Major States Where Nuclear Power is Growing

Brian Park

The 21st century ushered in the beginning of a new nuclear era, in which major states are engaged in expanding domestic nuclear fleets and advancing reactor technology. With China at the forefront, other major states, such as India, Russia, and South Korea move to dominate large nuclear technology export markets, worth hundreds of billions of dollars. This expansion in nuclear technology will increase energy security and scientific labor forces, provide new commercial export opportunities, and elevate international status among participating major states. This globalization *vis-à-vis* nuclear technological development will work to create a unique network of influence with the rest of the world.

While the U.S. has decelerated its progress on nuclear technology, other major states have moved ahead by launching various nuclear programs. These programs are focus on planning and developing newer nuclear technologies, particularly Gen III/IV reactor designs, to shift away from unreliable and pollutant energy sources. Over the next few decades, the world may observe a shift in the nuclear power dynamic away from the U.S. to Eurasia. This shift represents a global energy landscape that will be imperative to a non-carbon future and a continued key element in nuclear non-proliferation.

Current Nuclear Projects of Major States

China

Since 2012, China has led the world with the largest installed power capacity reaching 1,245 GWe in 2014, or 21% of the global capacity. China's mainland electricity is predominantly produced from fossil fuels, with 73% coming from coal since 2015; only ~3% of electricity comes from nuclear[161]. The rapid growth in demand and reliance on burning coal for energy has led to economic and environmental issues, such as power shortages and air pollution resulting in nearly 6% loss of GDP[162]. Chronic and widespread smog, attributed to coal burning, has risen fine air particles to lethal levels[1], which poses serious health risks. This enormous dependence on coal for electricity generation has not only made it one of the leading factors of China's air pollution, but has also made it very challenging for China to transition to alternative sources of non-carbon energy, namely nuclear.

To reduce China's dependence on coal, the State council published the *Energy Development Strategy Action Plan (2014-2020)*[163]. The project's aim was to cut China's reliance on coal and promote the use of clean energy. This was to be done by launching new nuclear power projects along the East coast for feasibility studies regarding constructions of plants inland, as well as research to improve upon the nuclear fuel cycle system, namely the reprocessing of fuel. The strategy focused on promoting the utilization of large pressurized water reactors (PWRs), high temperature gas-cooled reactors

[1] Rose to record 993 mcg/m^3 in 2013; World health Organization Guideline is 25 mcg/m^3

(HTRs), and fast reactors[164]. These projects have already begun to take place upon State Nuclear Power Technology Corp's (SNPTC) confirmation of Westinghouse's AP1000 reactor design in 2006; two are to be constructed each at Sanmen and Yangjiang[165]. In 2007, China Guangdong Nuclear Power Group (CGN) signed an $8.7 billion contract with Areva to use their design in the 'Taishan Project'. The Taishan 1 and 2 are the first reactors based on Areva's European Pressurized Reactor (EPR) design to be constructed in China; Taishan 1 is projected to begin operating during the first half of 2017[166]. The commencement of these reactors marked the beginning of new generation nuclear reactor technology in China.

In 2008, China began one of its key projects: The development of the Large Advanced Passive PWR Nuclear Power Plant (LPP or AWPR). Westinghouse announced its cooperation with the SNPTC and Shanghai Nuclear Engineering Research & Design Institute (SNERDI) in order to develop a passively safe design for large-scale deployment, known as the CAP1400[167]. In doing so, this opened doors to the possibility of China working alongside Westinghouse to becoming a major exporter of these new larger units. In 2012, CGN and China National Nuclear Corporation (CNNC) rationalized their respective reactor designs to create the 'Hualong One', a Gen III PWR design, and in 2015, the HPR-1000, which has become one of China's main export reactor designs[168]. According to the World Nuclear Association, China currently has 35 operable reactors, 22 under construction, and 40 more planned[169].

In 2016, China formalized its thirteenth Five-Year Plan, which focuses on the following nuclear projects and goals:

- Complete four AP1000 units at Sanmen and Haiyang.
- Build demonstration Hualong One reactors at Fuqing and Fangchenggang.
- Start building the demonstration CAP1400 reactor at Rongcheng (Shidaowan).
- Accelerate building Tianwan Phase III (units 5&6).
- Start building a new coastal power plant.
- Active preparatory work for inland nuclear power plants.
- Reach target of 58 GWe nuclear operational by end of 2020, plus 30 GWe under construction then.
- Accelerate and push for building demonstration and large commercial reprocessing plants.
- Strengthen the fuel security system[170]

In light of this plan, China has begun various projects focusing on developing advanced reactor technology. In 2011, the China Academy of Science launched a R&D program on thorium-breeding molten-salt reactors (Th-MSR or TMSR), a Gen IV reactor design[171]. Currently under construction at the Shanghai Institute of Applied Physics, the first MSR prototype is set for operation in 2020. Since then, China has become the global leader of research on molten salt reactors and plan to export these advanced nuclear reactors by 2030[172].

In 2016, CGN and CNNC, capitalizing on U.S. and Russia's idea of floating nuclear reactors, began the development small modular reactor (SMR) designs[173]. The goal is to successfully create a marine platform for nuclear technology and to solve the issue of providing power to all radar systems, lighthouses, barracks, ports and airfields set up on China's newly built island chain in the South China Sea[174]. The project will be expensive in terms of transmission costs, maintenance, as well as its unique design costs, but the floating nuclear plant has nevertheless opened a new window of economic opportunities. Through these new nuclear technological advancements, as well as the 136 proposed reactors along the way, China has cemented itself at the forefront of this new nuclear era.

South Korea

South Korea has enjoyed a boom in its economy, averaging an annual growth of 8.6% in GDP over the past 40 years; this has caused an analogous growth in electricity consumption as well[175]. Energy consumption per capita has skyrocketed from 860 kWh/yr in 1980, to 9700 kWh/yr in 2013[176]. Although South Korea has become a major player in the global landscape of nuclear power, according to Korea Electric Power Company (KEPCO), around 96% of its energy is imported, with the import bill reaching $170 billion in 2011[177]. This dependence on energy imports and the increase in energy demand have pushed South Korea to launch new nuclear projects. Their aim is to become a global leader in nuclear reactor exports; also to have nuclear power as the main element of domestic electricity production.

In 2014, the Ministry of Education, Science & Technology's (MOTIE) announced their second Energy Master Plan, the first being in 2008[178]. The goals of this plan were simple: reach 29% of electricity from nuclear power by 2035, improve demand management, and improve public acceptance. The following year, MOTIE released the government's "7th basic long-term power development plan of electricity supply and demand"[179]. To meet the electricity demands, which are expected to increase 2.2% annually until 2029, the plan focuses on the construction of 12 new reactors, which are to be in operation by 2029; in doing so, nuclear capacity would increase to 38.3 GWe, 23.4% of total electricity. This strategy aims not only to double the country's nuclear capacity, but also to cut greenhouse gas emissions and promote the efficacy of nuclear energy[180].

Over the course of the late 20th century, South Korea's nuclear industry partnered with Combustion Engineering (now part of Westinghouse) to embark on a program to standardize a design of nuclear plants, using the CE System 80 (2-loop) steam supply system as the basis of standardization[181]. Starting with the standardization of the Korean Standard Nuclear Plant (KSNP), which was later improved upon to produce the Gen II design, KSNP+ (i.e. Optimized Power Reactor), Korea has since commenced the development of Gen III reactors, namely Advanced Pressurized Reactors (APR)[182]. In 2016, Korea succeeded in commercially operating their first Korean-designed APR-1400, the Shin Kori 3[183]. The OPR-1000 and APR-1400 are South Korea's most actively marketed designs in the Middle East and Northern African countries. Most significantly, in 2009, the APR-1400 was selected as the basis of the United Arab Emirates(UAE) nuclear power program with four reactors currently under construction at Barakah to be operating by 2020[184].

In light of this deal, MOTIE launched a plan in 2010, known as Nu-Tech 2030. This plan aims to reach exports of 80 nuclear reactors worth $400 billion by 2030[185]. In January 2015, the SMART Power Company Ltd (SPC), was established with support from six companies as the sole entity responsible for the export and construction of small reactor technology[186]. From then onward, the Korean Atomic Energy Research Institute (KAERI) has been working on developing SMART (System-integrated Modular Advanced Reactor), a 330 MWt pressurized water reactor[187]. Although Nu-Tec 2030 does seem a bit unrealistic, it is clear that Korea, having done marketing and contracting with smaller states, such as Egypt, Jordan, Turkey, as well as Vietnam and the Philippines during the past decade, is attempting to globalize its nuclear industry. With 25 operable reactors, 3 under construction, and 8 planned, Korea is on its way to not just becoming a nuclear powerhouse, but also one of the world's largest suppliers of nuclear technology.

Russia

Since the 1960s, Russia has been operating commercial nuclear power plants, but its nuclear industry has been plagued with numerous problems[188]. After the 1986 Chernobyl accident and various economic reforms following the fall of the Soviet Union, the industry saw a shortage of funds for nuclear developments, and a number of projects were halted. During the late 1990s, negotiations to export reactors to China, Iran, and India revived Russia's stalled domestic constructions with the gain in capital. By the mid 2000s, Russia's resolve to develop nuclear power once more had solidified, and in February 2010, the government approved the Proryv (Breakthrough) Project[189]. Rosatom's (Russia's national nuclear corporation) long-term strategy up to 2050 moved focus to inherently safe fast reactors with a closed fuel cycle and envisages nuclear providing 45-50% of electricity at that time, expected to rise to 70-80% by the end of the century[190]. The question will come to be whether or not Russia, under a sanctioned regime, will be able to sustain such a long-term project given their fiscal and material limitations.

Russia's nuclear technological future focuses on a number of aspects revolving around the development of their VVER (pressurized water reactor) design, fast reactors, small modular reactors, and high temperature reactors. Russia currently has 35 operable reactors, 7 under construction, 25 planned, and 23 proposed[191]. Rosatom has been working with Gidropress, a Russian state-led construction office, in order to design various Gen III and IV reactor technologies[192] The BN- series fast reactors are the main aspect of the Proryv project; Rosatom envisions that by 2020-25, fast neutron power reactors will play an increasing role in Russia, especially with regard to fuel development[193].

What has set Russia apart from other major states is its efforts to create a global network in developing parts of the world, such as Bangladesh, Egypt, Indonesia, Jordan, Myanmar, Saudi Arabia, and Vietnam[194]. Since 2010, Rosatom has signed contracts and cooperative agreements with over two dozen nations, particularly lesser states that already have nuclear programs, in order to build first time nuclear power plants, supply fuel, and operate them as well[195]. A majority of Rosatom's export projects for nuclear power plants focus on 1000 and 1200 MWe-class VVER reactors, but floating nuclear power plants have shown to have export potential as well[196]. According to the World Nuclear Association, as of 2016, there are 65 reactors under construction, 173 ordered or planned, and a staggering 337 more new reactors proposed, which are divided among 50 states. Russia has contracts and agreements with a majority of these states, 31 currently having nuclear programs[197]. Russia not only has the ability to compete in the expanding global nuclear market, but more importantly can secure its sphere of influence in the new global nuclear landscape as a leading exporting force.

India

India's total installed electricity capacity is 300 GWe, making it the fifth largest electricity generating state in the world. Of this, 210 GWe is fueled by carbon-emission energy sources.[198] Despite being a major energy consumer, India remains relatively energy-poor in comparison to developed countries; 19% of the total population did not have access to electricity in 2013.[2] Like China, India also faces a pollution crisis, which has caused lethal environmental and health risks throughout the country. Yet

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[2] The estimated total electricity consumption during the year to the estimated mid-year population of that year was around 1,000 kilowatt hours (kWh) in 2014-15. Developed countries average around 15,000 kWh. China has a per capita consumption of around 4,000 kWh.

it remains difficult for India to transition to alternative sources of energy due to its heavy reliance on fossil-fuels to meet energy demands. In committing to reduce carbon-emission levels, and increasing total installed electrical capacity, nuclear power will play a key role in India's technological development in the next few decades.

Due to India's exclusion from the 1970 Non-Proliferation Treaty (NPT), India's nuclear programs have been largely self-sufficient, proceeding predominantly without fuel or technological assistance from outside nations. As a result, India nuclear development focused on taking advantage of its abundant thorium resources and development of pressurized heavy-water reactor (PHWR) designs, which require less natural uranium[199]. Throughout the mid 2000s, the Nuclear Power Corporation of India Limited (NPCIL) collaborated with several foreign reactor vendors, including Russia's nuclear engineering international export company, Atomstroyexport, Westinghouse, and Atomic Energy of Canada Ltd (AECL)[200]. India's long term nuclear program goal aims to make its fast reactor program 30 to 40 times bigger than its current PHWR program. The Indian Atomic Energy Commission's (AEC) target is to reach 500 to 600 GWe nuclear over the next 50 years or so, including export opportunities[201]. This project has already kicked- off upon Bharatiya Nabhikiya Vidyut Nigam Ltd's (BHAVINI) approval to begin constructing two 500 MWe prototype fast breeder reactor (PFBR) at Kalpakkam and a 1000 MWe fast reactor using metallic fuel, which is to begin construction around 2020[202]. In 2010, AEC and Rosatom made a scientific and technical agreement, which focuses on joint development of new generation fast reactors[203].

India's most significant long term goal will be the development of an advanced heavy-water thorium cycle. In 2014, the design of the 300 MWe Advanced Heavy-Water Reactor (AHWR) was completed in Bhabha Atomic Research Centre (BARC)[204]. In addition to the AHWR, an export model aimed towards developing countries and a Gen IV Indian Molten Salt Breeder Reactor (IMSBR) have since been developed.[205] India still has a ways to go before reaching its nuclear energy goal of 14.5 GWe by 2024. As infrastructure, power grids, and fast breeder reactors continue to develop, India's nuclear sector will hopefully grow to supply a fourth of its domestic electricity by 2050[]. Through these technological developments, India will rise as a global leader in advanced thorium based nuclear technology.

Conclusion

A new nuclear era has begun. This is apparent in the comprehensive programs and expanding plans for new generation reactors in major states, particularly China, Russia, and India; also in less powerful but technologically advanced states, such as South Korea. China's aim is to surpass the U.S. both in the scale and technological level of reactor development within the next few decades. By mid-century, China could have well over 200 operating reactors, which more than twice the current number in the U.S. These reactors would consist of several advanced LWR and non-LWR designs. Russia and India, though pursuing different specific trajectories, have programs aimed at more than doubling their output of nuclear-generated electricity, as well as using advanced reactor designs. These domestic developments only encompass a part of the spectrum of this new era. More than three dozen other governments have expressed strong interest in nuclear power, and many have begun nuclear programs by working with the IAEA. Russia's state-owned nuclear company, Rosatom, had signed agreements with over 30 nations by the end of 2016. Chinese and South Korean companies are also involved in agreements and deals to build reactors in states currently without nuclear plants.

This new nuclear era has provided the U.S. with some key challenges. If the U.S. continues to focus its energy industry on fossil fuels instead of transitioning to renewables and nuclear power, it will eventually result in a loss of global standing and authority for the U.S. Nuclear is becoming the modern energy trend, and the U.S. has long possessed power that controls its framework; however, the country needs to maintain and increase its participation in the global nuclear industry to compete with states like China and Russia. How the global landscape of nuclear power will change over the next few decades will depend on which nations will be able to sustain their respective programs, global outreach, and success with utilizing nuclear energy as a predominant source of electricity; this will prove to be one of the greatest challenges of the 21st century.

Nuclear Power and Developing Countries

Stacey Hurwitz

Globalization spurred rapid development across the world, however many nations now face serious constraints to expanding their economic growth and development due to insufficient power generation. Constructing new metropolitan areas, increasing industrialization, and exploring new technologies requires large amounts of electricity, which is critical to attaining modernization. Therefore, an overwhelming majority of the growing demand for consistent and stable energy sources across the world rests in developing nations. This is where the most rapid potential energy growth takes place, as more than 1 billion people, 17% of humanity, continue to live without electricity, and another 2 billion or more only have limited or sporadic access.[206] Although nuclear energy is a strong candidate for meeting energy demands in developing nations, it is often put aside for renewable and fossil fuel energy sources due to concerns over economic feasibility, politicization, nuclear weapons proliferation, and public acceptance. Developing nations oftentimes prioritize using cheaper, more harmful, sources of energy (especially coal) to develop more rapidly, rather than investing in sustainable, long term energy projects that are more beneficial to both their nation and the environment. Every energy source has certain limitations:

- Coal produces the largest volume of harmful pollution and carbon greenhouse gas emissions
- Hydropower depends on the weather and oftentimes has large seasonal fluctuations, which frequently disrupts ecosystems
- Solar is intermittent, inefficient, and has a very low capacity factor

Nuclear power provides a non-carbon alternative that avoids many conventional energy limitations. A close examination of pre-existing energy grid infrastructures of developing countries, economic and political complications, along with developmental priorities will help illuminate the barriers developing nations face, resulting in a lack of investment in nuclear energy as their primary power source. With new advanced reactor designs and the global need for more carbon-free energy, how does nuclear power fit into the energy landscape and domestic policies of developing nations? What is the feasibility of expanding nuclear reactor programs across the developing world to meet increasing energy demands?

The Feasibility of Nuclear Energy Programs in Developing Nations:

In the context of energy poverty, developing nations are starting to look for different methods of producing stable, efficient, and clean energy. While sources such as coal, hydropower, solar, and petroleum have served as prominent forms of energy in the past, they are not always abundant and cannot always provide a consistent energy flow.

Perhaps one of the greatest impediments to implementing nuclear energy, besides the expensive start-up costs, is social acceptance by the public, as past "reactor disaster" events gave nuclear energy a negative reputation. Lack of public education continues to be a barrier—as misconceptions stemming from the politicization of the dangers of waste, water pollution, proliferation, and general public safety have deterred the implementation of a nuclear energy program. As a result of politicized media discourse, the public is misinformed about the reality of nuclear energy dangers and is unaware of other issues surrounding alternative and renewable energy sources. As people become more educated in understanding the important role that nuclear energy can play for both developed and developing nations energy needs, the advantages heavily outweigh the disadvantages. Nuclear energy is non-carbon emitting, and responsible for a lower cause of death (less injury on the job) versus other energy sources, such as the many tragedies caused by coal mines collapses, oil spills and explosions, and gas leakages. So why are we not embracing the potential of nuclear energy? In many developing nations, histories of colonialism shape the existing energy infrastructure, which has left developing countries with dated and ageing energy grids that make changing their energy sources more difficult and costly.

Constructing new nuclear reactors initially comes with a steep price as nuclear energy production is "expensive to build, and relatively cheap to run".[207]In an energy cost comparison, nuclear energy averages 0.4 euro cents per kWh, versus coal at 4 euro cents, and gas averaging 1.2-2.3 euro cents per kWh.[208] Wind energy is the only cheaper energy source, yet it is highly unreliable in many regions for stable and sufficient energy flow. Building nuclear reactors can be very beneficial economically, and provide more reliable and sustainable energy over time so that developing nations have the power they need in order to innovate. Developing countries can overcome this financial barrier by financing these projects with the help of more developed nations, and strategic prioritization of their budget as nuclear energy has been successfully implemented in once-developing nations. For example, Japan, whom 30% of their energy production is currently being run by their 50 nuclear reactors, is closely followed by Ukraine, China, and South Korea.[209] Nuclear energy is the future for cleaner, more sustainable and reliable energy, which will be imperative to providing consistent energy flow so that these developing nations can address public health, economic, and technology concerns.

Current Nuclear Energy State of Developing Nations

India

With India's economic growth soaring at a rate faster than that of China's, its pollution has also increased, causing India to become the world's second largest CO2 emissions producer. Due to a decrease in the agricultural sector and increased investment in the industrial sector, energy is vital to India's continuous growth. Currently 300 million people in India live without electricity, with an additional portion of their population having access to electricity sporadically. In particular, the rise of megacities across India has produced enormous demand for more electricity.[210] In response, India has turned to coal to meet this need, which is currently providing 54.5% of India's electricity (4th largest coal user) along with the increase of solar electricity.[211] India currently has 10 megacities containing over 3 million people each. The country is projected to produce 7 additional megacities by 2030, with Delhi being the second most populous city (9.6 million people).

Nuclear energy is a solution that can meet the imminent demand of these rising megacities throughout India.

The current Indian government plans to advance and expand its nuclear power programs to decrease its reliance on coal and other fossil fuels in order to provide consistent energy supply to all of its citizens. India's 22 operable nuclear reactors account for only 3.5% of India's power. There are currently five nuclear reactors under construction, with 20 nuclear reactors being planned in January 2017 and 44 more being proposed.[212] It is predicted that by 2050, 25% of India's energy will come from nuclear power.[213] India demonstrates global leadership in expanding its nuclear energy potential, as Prime Minister Modi has strongly emphasized the importance of putting nuclear energy programs at the forefront of India's domestic policy in order to meet the nation's energy demands and to decrease carbon pollutions. With energy demand likely to double by 2020 due to India's growing middle class, Prime Minister Modi's "Make in India" campaign works to further attract foreign investment and participation from companies and governments abroad to take part in moving their business to India. These businesses that India would attract can only thrive if they are receiving reliable energy, which nuclear energy provides and would continue to help India be an attractive place for foreign companies to offshore to. In July 2016, Modi consulted with the Department of Atomic Energy to triple its nuclear capacity to 17 GWe by 2024, and invest more than $100 billion in nuclear power over a 25 year period, illustrating the importance of nuclear energy for India's future.[214]

Nigeria

In Nigeria, energy poverty is a prominent concern that hinders Nigeria's ability to develop and therefore, the nation must prioritize expanding effective and reliable energy sources. The entire country has the same amount of energy as the city of San Francisco, even though it has the highest GDP of any African nation. Nigeria is currently experiencing an "Energy Supply Crisis" and relies on natural gas and hydropower to produce energy, but unfortunately, these energy sources can be incredibly inconsistent and unreliable. The Nigerian grid system that was initially installed by colonials is also now old and fragile. As the pre-existing energy grid continues to degrade and cannot be revitalized, Nigeria has taken steps towards developing nuclear reactors to power its nation and attract foreign investment to improve its economy, similar to India. With a booming population, Nigeria needs to expand its energy supply to keep up with its increasing energy demands, so what has prevented Nigeria from significantly expanding nuclear energy?

Currently, Nigeria is privatizing its nuclear energy potential to create a nuclear energy program to power its nation. The Government is working with Niger Delta Power Holding Company (NDPHC) to privatize 10 newly built generation plants, along with working with Russia's ROSATOM to construct new power plants and transmission facilities that meet the political interests of Russia. ROSATOM signed a three-year agreement with Dassault Systèmes, who is the world leader in 3D design software, in order to deploy multi-dimensional systems across the African continent, where emerging countries like Ghana, Kenya and Nigeria are developing complex projects such as implementing nuclear energy as their main power source. This agreement was signed at the third International Conference on Nuclear Knowledge Management held at the IAEA in Vienna. It is designed to deliver "greater support for customers' innovation processes in nuclear power, as well as other segments of the energy process and utility industry".[215]

It is in Nigeria's best interests to build nuclear reactors to fuel it growing industry and create innovations to attract foreign investment to fund energy and development projects. Nigeria has sought out the support of the International Atomic Energy Agency (IAEA) to develop plans to have 4000 MWe of nuclear capacity by 2025.[216] With Nigeria being Africa's most populous country, power shortages for its citizens and industries have caused foreign investment opportunities to relocate from Nigeria to Ghana. This has been a large detriment to Nigeria's ability to grow economically. The Nigerian government continues to take steps to increase nuclear energy potential throughout its country and within its legislation, while also establishing controlling and governing agencies, such as the Nigerian Nuclear Regulatory Authority (NNRA), to provide regulatory oversight for nuclear production. While Nigeria cannot afford to finance its own nuclear energy facilities, it has relied heavily on Russia for financing its nuclear endeavors, and hopes to launch its first facility by 2025.[217] As a developing nation, Nigeria recognizes the role of nuclear energy in improving national health, safety, economic growth, and energy potential through pursuing these safer, more sustainable energy options.

Malaysia

Southeast Asia has become a "hot spot" for attracting foreign investment due to its growing middle class with a demand for commodities. Malaysia's current heavy reliance on gas (51.6%) has caused a significant amount of pollution, which led the government to consider nuclear power alternatives in 2009.[218] As Malaysia is an exporter of oil and liquefied natural gas, the nation primarily relies on fossil fuel as a domestic energy source. During the month of October 2016, the Malaysian government welcomed a team of experts led by the IAEA to take part in an Integrated Nuclear Infrastructure Review (INIR) mission to further the progress of Malaysia's nuclear potential.[219] Malaysia has a history of nuclear research, as the TRIGA PUSPATI research reactor at the Malaysian Nuclear Agency was used for science and education since it became operational in 1982. It was not until Malaysia's rise in economic growth and energy consumption, along with the depletion of its own resources, that it had started prioritizing nuclear energy potential.

Public sentiments post-2011 Fukushima disaster also initially affected the general social acceptability of nuclear power in Malaysia. Former Prime Minister of Malaysia, Tun Dr Mahathir Mohamad, expressed his objection of nuclear energy, and brought up the issue of dumping radioactive waste in Perak. Additionally, he spoke about how nuclear power is disaster prone, as Malaysia is at higher risk for tsunamis similar to Japan. However, within a few years, nuclear energy regained public favor in Malaysia[220] as the population continued to demand industrialization and modern lifestyles. By July 2014, plans to build a nuclear power plant to operate in 2024 had a significant positive response from the public. By 2030, the nation plans to have 3-4 reactors providing 10-15% of electricity.[221] It is probable that Malaysia will follow through with its nuclear energy program, working towards one day becoming fully reliant on nuclear energy and removing its current classification as a developing nation.

Conclusion

As developing nations prioritize industry growth, health, and investment in innovative technologies in pursuit of modernity, the availability of energy plays a large factor to initiate and sustain growth. Although many nations have expressed concerns over the use of highly polluting energy sources, and despite the Paris Agreement of 2015, carbon emissions and air pollution levels in most of these developing nations have continued to rise. The choices that these nations make in the next 10-15 years to power their economies will be locked in for many decades. If these choices are mostly for high-carbon energy sources, there will be little chance for the world to mitigate future climate change to any major degree. As we have seen through international agreements to reduce carbon emissions, the United States plays a role in determining nuclear feasibility for developing nations, and often provides funds in exchange for non-proliferation. This power dynamic causes a complex mosaic of international relations, in regards to who gets the "right" to obtain nuclear power, with the United States oftentimes being a dominant actor.

Currently, as the Iran Nuclear Deal is in effect, we have seen the United States influence how much nuclear potential is "too much" for nations, which can further complicate the feasibility for developing nations to utilize nuclear energy due to their political ties. Given the concerns over proliferation and climate change, coupled with immense energy demand, how should the international community influence nations seeking nuclear energy? Nuclear energy programs in developing nations have proven to be successful, and will be necessary in order to meet the economic and social demands of developing nations.

The State of Current and New Reactor and Fuel Technologies:
The New Technologies that can Change the Nuclear Landscape

John Salber

Quick Facts:

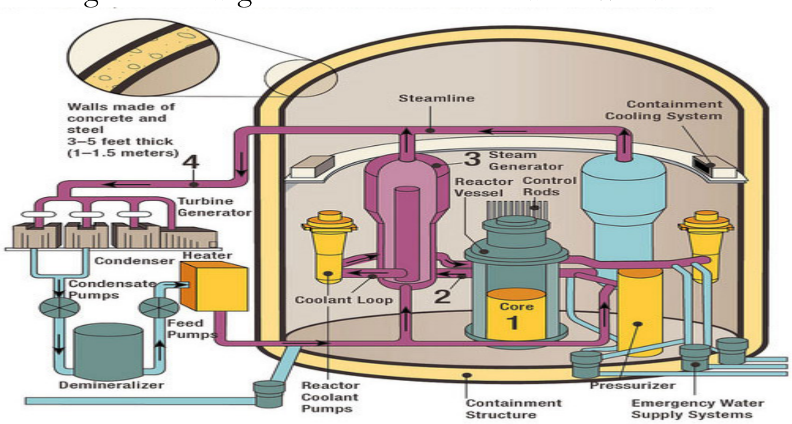
- According to the Nuclear Energy Institute, in 2015 nuclear energy had the highest capacity factor (capacity factor is the average amount of power generated divided by the peak theoretical power of a power plant) of any power generation method with an average capacity factor of 92.2%[222].
- In 2015 nuclear power provided 19.5% of the total energy used in the United States and generated 797,177,533 Megawatt hours (MWh)[223]. Nuclear power was responsible for 20.6% of the total energy produced in the United States in 2001[224].
- Out of 99 total reactors in the U.S. 34 are boiling water reactors (BWRs), while the remaining 65 are pressurized water reactors (PWRs)[225].
- In the world as a whole, nuclear power accounts for over 11% of total power generation[226].

New technology development will eventually make nuclear power cheaper and safer than ever. However, some new technologies, such as SMRs, are going to have a more immediate impact in the world, while others such as thorium reactors will take longer to research, develop, and implement.

Current Technology
Nuclear reactors produce energy through using fuel, in most cases uranium, in order to create nuclear fission[227]. Fission happens when a neutron is fired into the nucleus of an atom causing the atom to split apart and produce heat as well as releasing other neutrons[228]. This process releases large amounts of energy in the form of heat[229]. This heat is used to heat up water and produce steam which turns large turbines to generate electricity[230]. This basic process is shared by nuclear reactors of many types. Despite there being many types of reactors, two produce the large majority of energy

generated by nuclear power plants: pressurized water reactors (PWRs) and boiling water reactors (BWR).

In the world as a whole, pressurized water reactors (PWRs) comprise over half of the 247 nuclear reactors currently operating[231]. As of 2014 there are 277 PWRs in use around the world, including the U.S fleet. These types of reactors use water, which is kept liquid at high pressures (about 150 bar) to heat up and make steam out of a separate source of water to power the turbine[232]. All radiation is contained by the primary circuit, keeping the secondary, turbine powering circuit separate[233]. This means that the second circuit can draw water from any source and recycle it back with no ill effects to the environment. This is why PWRs are used to power nuclear submarines and large ships[234]. The diagram below gives a basic idea of how a PWR works[235].



The second most prevalent type of reactor in use today is the boiling water reactor (BWR). These reactors are similar to PWRs but are under less pressure (about 75 bar) and BWRs only have one circuit of water for cooling and generating steam to move the turbine[236]. The condenser cools down the steam to turn it back into liquid again, slightly irradiating the turbine and requiring more containment and safety measures[237].

PWRs and BWRs account for most of the nuclear reactors in the world today. They are also the only two types currently being used in the United States[238]. PWRs are based on designs used in submarines and large ships which helps explain their popularity in the U.S.[239]. There are currently four other types of reactors that are in use today around the world. But they account for just 18% of the total reactors used in power generation[240].

Boiling water reactors and pressurized water reactors are both older technology that has been continuously improved over the decades. Like PWRs and BWRs, other rector designs currently in use make plutonium as a byproduct of uranium fission[241]. This is a concern for non-proliferation because plutonium is much easier than the uranium that is used in reactor fuel to convert into nuclear weapons material as well as plutonium being better suited for weapons use due to its small critical mass (the smallest amount needed to sustain fission). Reprocessing reactor spent fuel separates out the plutonium making it easier to obtain and use for weapons programs. This is one of the reasons that the United States stopped reprocessing used nuclear fuel[242]. Once fuel is burned for about 18-36 months it is no longer practical to continue to use it as fuel as there is less fissionable left in the fuel[243]. In the U.S., the open fuel cycle policy results in about 96% of the original uranium left unburned. This produces a lot of waste that has to be stored and takes up lots of space in underground and aboveground nuclear waste disposal sites. However, if the U.S. switches to a closed fuel cycle policy, the stored waste can be recycled and reprocessed.

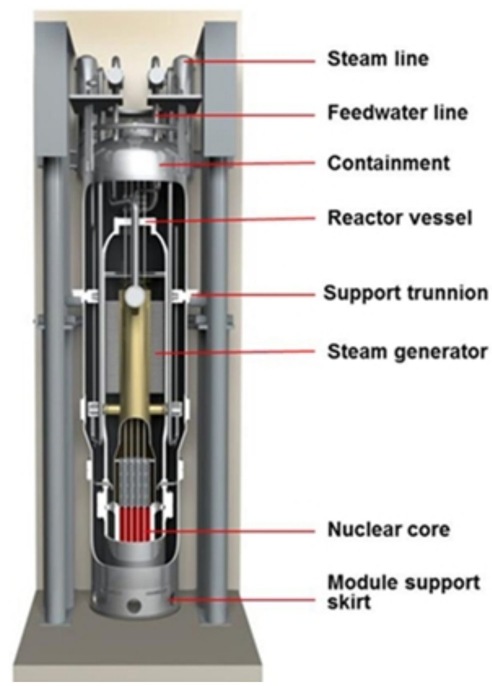
The extensive amount of space that is required to build reactor sites and house radioactive waste poses geographical and political challenges. However, emerging SMR, Thorium, and Generation IV reactor technologies have great potential in addressing these concerns through reducing the land needed, the waste produced, and the concerns raised surrounding nuclear weapons proliferation.

New Technologies

As many existing nuclear energy programs are operating with technology that is over half a century old, current research aims to find new replacements for aging reactor models both in the U.S. and abroad. These new technologies attempt to solve some of the problems that have come from conventional nuclear power plants such as size, safety, cost, and proliferation. Due to insufficient U.S. government initiative, private companies are spearheading most of the new research on new and advanced technologies. In the U.S. and Canada alone, over 50 private companies are researching the future of nuclear technology[244]. New technologies include small modular reactors, thorium reactors, and generation IV reactors. Many, but not all, of these reactor types have been proven effective by previous small scale pilot projects in the United States.

Small Modular Reactors

Like the name suggests, small modular reactors (SMRs) are nuclear reactors that are scaled down and simplified, allowing them to be manufactured quickly and cheaply. The International Atomic Energy Agency's defines SMR's as reactors of any type that are smaller than 300 MW[245]. SMRs have many potential advantages including being cheaper, faster, and easier to make than a conventional nuclear power plant. They can be built in a factory with an assembly line, which aids in greatly reducing the time it takes to build a reactor because they all have the same basic design[246]. This will speed up production and allow many to be made in a shorter amount of time. Sharing the same streamlined design will also shorten the application process, the cost of production, and decrease potential issues with production. Due to their affordability and small size, SMR technology is promising not only for countries wishing to expand existing nuclear power programs, but also for developing nations who are experiencing increasing energy demands.[247]



Small modular reactors are essentially scaled-down versions of larger reactors and because of this, they are the most viable new technology for immediate implementation. The private company NuScale is currently looking into the possibilities of SMRs and are the closest of any organization to creating an operational SMR in the near future. They have designed a small modular reactor for civilian power generation and sent it for approval with the United States Nuclear Regulatory Commission (NRC). The NRC is "currently engaged in pre-application activities on the NuScale small modular reactor (SMR) design"[248]. They are the closest of anyone to producing a SMR and will likely be the first to ever operate a SMR.. Their goal is to have a working demonstration of their SMR technology by 2024[249]. Pictured to the right is a NRC diagram of a NuScale reactor[250]. The reactor is a conventional light water reactor which produces steam to power turbines.

Thorium

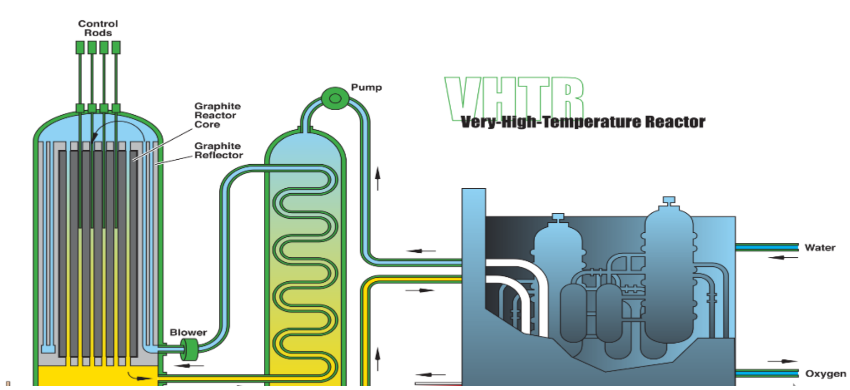
In addition to SMRs, researchers are also looking into the possibility of creating reactors that run on an alternative fuel source: thorium. Thorium is a radioactive element that is much more abundant than uranium[251]. However it is not a fissionable material like uranium[252]. To be used as a fuel, thorium must first absorb a neutron to become protactinium-233, which can then be made into uranium-233 (U-233)[253]. To be made into U-233, thorium needs a fuel to "drive" the reaction and turn it into fissile material[254]. This driver has to be U-233, U-235, or plutonium-239 (Pu-239). One of the goal of thorium based fuel is to have a net gain in the fuel bred by the reactor compared with the fuel used by the reactor. This means that more useable fuel is made by the reactor than is burned. That way thorium reactors could be used to produce fuel for other types of reactors. This is something that has been worked on but has proven hard to do.

Another advantage of thorium is that it is proliferation resistant. The U-233 made by thorium "contains U-232 which decays to produce very radioactive daughter nuclides and these create a strong gamma radiation field"[255]. This makes it very hard to transport and easy to detect with radiation detection devises. It is also hard to make into a functional nuclear weapon. Thorium can also be "driven" by recycled fuel to make or breed new fissile material[256], which could help reduce waste while providing energy.

In the past, a few thorium-based reactors effectively produced electricity. However, one major problem is the type of material that has driven all of the reactors so far have been high-enriched uranium (HEU) and thorium combined fuel. HEU is not likely to be used again in a thorium reactor due to the higher proliferation risk it poses compared to low-enriched uranium. If thorium reactors that use low enriched uranium (LEU) can be developed, then the HEU will not be necessary. Although the thorium reactor plants effectively produced electricity, they are no longer in operation because of the difficulty in obtaining HEU. However, this technology is proven to work, and has potential for large scale nuclear power plants.

Thorium reactor testing was initially done in the United States[257], however India is now leading innovative thorium research. As a nation with abundant thorium stockpiles, India sees the strong potential for thorium reactor designs in their domestic nuclear energy programs.[258] As a rapidly industrializing country, nuclear power and new thorium technology has the potential to meet India's growing energy demands without increased proliferation risk.

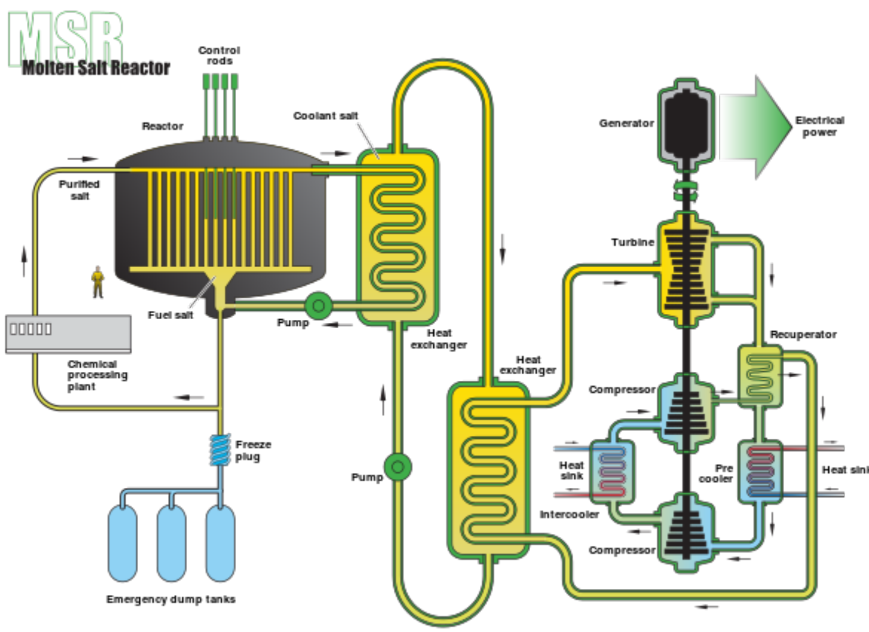
Generation IV Reactors



The Generation IV (Gen IV) reactors consists of six different designs for future nuclear reactors that are currently being developed across the world. The Generation IV Forum (GIF) "is an international collective representing governments of 14 countries[3] where nuclear energy is significant now and also seen as vital for the future"[259]. This includes the U.S. as well as Russia, China and South Korea. The six types of reactors are:

- Very-high-temperature reactors as seen here (VHTR)[260]
- Sodium-cooled fast reactors (SFR)
- Supercritical-water-cooled reactors (SCWR)
- Gas-cooled fast reactors (GFR)
- Lead-cooled fast reactors (LFR)

Molten salt reactors as show below(MSR)[261]



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These reactors are all at varying degrees of commercial readiness. One Gen IV reactor is almost ready to start commercial use. It is a high temperature gas cooled reactor pebble-bed module (HTR-PM) located in China[263]. A test HTR-PM reactor was completed in 2015 and the full power plant will come online and connect to the grid by the end of 2017[264]. China is also researching other types of Gen IV reactors as part of Generation IV Forum. Some like the VHTR and the SFR are similar to other current reactors, therefore have already been demonstrated, and are expected to be in use by

[3] The member Countries are: Argentina, Australia, Brazil, Canada, France, Euratom, Japan, Peoples Republic of China, the Republic of Korea, Russian Federation, the Republic of South Africa, Switzerland, the United Kingdom and the United States

2020[265]. Russia and India has operated sodium cooled fast reactors that have produced electricity[266], while South Korea has a planned research reactor set for 2028[267] Others, such as lead cooled fast reactors, still need to be tested and refined before technological demonstration reactors can be built. Some new reactor designs also come with the added bonus of being able to produce hydrogen for industrial as well as potential fuel use, as well as power[268]. The Gen IV fleet will be the best and most efficient reactors ever built, and like most new technology, they will also be very expensive. Gen IV's are not suitable for developing states with emerging nuclear power industries, but rather wealthy countries that have a back ground in nuclear power. Because the United States is one of the members of GIF, they are on the leading edge of nuclear power research. This is crucial to staying on as a leader in the nuclear world as not researching would lead to falling behind and having less sway.

International Financing for Plant Construction

Brandon Kavalok

For a number of reasons, nuclear power has attracted interest from dozens of nations outside the 30 countries now with operating reactors. Growing demand for electricity, need for energy security, and, not least, the drive to lower carbon emissions all count high among such reasons. These are long-term concerns for nations today, particularly those in the developing world, where lack of sufficient power generation is widespread and places an unwanted brake on development.

Building a nuclear plant is expensive. Costs are concentrated in the upfront stages of a plant, including design, engineering, land, and, above all, construction. The total investment needed to bring a full-size plant online can vary from roughly $4 billion to $9 billion, not including any cost overruns. This would normally place such plants beyond the financial resources of many developing nations. However, recognizing the potential for a new global market in civilian nuclear technology, several countries with advanced nuclear programs have come up with new kinds of financial arrangements to accommodate many levels of national wealth. Working through state-owned companies for the most part, Russia, China, South Korea, Japan, and France are the countries pursuing this new market.

The new financial arrangements involve various levels of equity investment by vendor companies, either individually or as part of a consortium. A consortium of this kind could involve investors of various kinds, including other national vendor companies, host state companies, and other entities. In some cases, the entire cost of the nuclear plant, as well as fuel and operational expenses, would be covered by a vendor company or consortium, which might then operate the facility and derive income from the sale of the electricity. After a specified period of time, the plant would be turned over to the host nation for the rest of its operational life. Such is only one type of new arrangement that has been offered. Moreover, though developing nations are the primary target for such financing, the mentioned nations have also moved to invest in new plants in emerging and even developed nations, as with Russia in Belarus and Hungary and China in the UK.

Liberalized electricity markets in much of the OECD may make such investments less attractive than in countries where markets are regulated, as in much of the developing world. Yet the matter much depends on perceptions of risk. Investors and lenders in advanced nations, with encouragement from the 2008 financial crisis and the 2011 Fukushima nuclear accident, have viewed new nuclear plants as high risk projects. However, this may well prove less relevant for Chinese and Korean companies looking to gain equity in nuclear projects worldwide.

Still, a major concern is that this new era of nuclear exports and financing does not involve U.S. companies. Though a number of reactors being built, planned, and proposed in other nations are based on designs originally created by American entities like Westinghouse, U.S. firms find themselves burdened with economic challenges at home. With comparatively minor government support, they are in no position to move assertively into a leadership role in the new era of exports. As a result, two of America's global rivals, Russia and China, have been moving assertively to fill the role the U.S. once had in expanding the global market for nuclear power. The situation therefore raises many questions, and not a few concerns, about the next several decades in civilian nuclear development[269].

Conventional Financing of Nuclear Plants

From the dawn of the nuclear age, starting with the Manhattan Project, government has played the largest role in funding nuclear energy projects. Through the U.S., too, began in this fashion, the Eisenhower Administration established a different approach by involving private utilities and newly created nuclear companies in building a national program for power reactors. By the 1970s, when rapid development took place, private industry was responsible for most construction. This differed significantly from other nations, including those in Europe, Here, the financing of nuclear plants has significant or even complete government support. The situation in the U.S. has left nuclear companies particularly vulnerable to perceptions of risk when it comes to securing financing, which has resulted in the lack of any new plants being built for two decades after 1996[270].

Today, innovation in nuclear technology, though partly based on early government-sponsored research efforts, is coming from the private industry. Several private firms across the globe are developing new ways to make nuclear technology more powerful, more efficient, and more economical. Yet the private sector does not have the resources to pursue the construction of new reactor designs at full scale. It seems clear, in other words, that actual demonstration of Gen IV technologies will largely, perhaps even entirely, take place in nations where state-owned or state-funded companies exist and are willing to take the lead. China, Russia, and South Korea are prime examples. Molten salt reactors have been already built and tested in China, while Russia has continued to operate and test fast breeder reactors at its Beloyarsk facility.

The key exception to this situation may prove to be small modular reactors (SMR), as discussed elsewhere in this report. A number of small, entrepreneurial nuclear firms in the U.S. and Canada now seek both private and government financing to build test versions of their individual reactor designs. At the same time, it is fair to say that the public-private partnership model currently being used, whereby the U.S. Department of Energy provides matching funds up to about $226 million, is not intended to finance actual construction of an SMR facility and would not be sufficient to do so. It seems more than likely that these companies will be forced to have their concepts tested in other countries through partnerships with state-owned firms. Alternatively, they could be financed by such companies to build a demonstration reactor in the U.S. Either way, government funding would play a major role.

New International Financial Arrangements:

Russia, China, and South Korea

Russia and China have redefined how the international system is financing nuclear power plant construction to make nuclear power a reality for many who thought it was out of reach only a decade ago. This innovation in construction from both countries of nuclear power plants has shaken up the nuclear political system and has put Russia and China and the East on the forefront of where nuclear power could be going in the near future.

Russia has traditionally been at the nuclear forefront in the East. From its first nuclear weapons test on August 29, 1949, Russia has always sought to be seen as legitimate a nuclear power as the western nuclear states. As a result of the Cold War and the Chernobyl disaster, Russia's relationship with its nuclear power programs have undoubtedly defined much of how nuclear technology is perceived today by the East and West. Despite the setbacks, the Russian nuclear program is still a very large part of the Russian economy. Russia has significantly increased the efficiency and focus of their nuclear program since moving out of the Cold War era. The electrical power demands for Russia are increasing and the Russian government has put forth a policy calling for the control of the nuclear program by the government with independent firms working in conjuncture to aid in the construction process. Expanding the Russian domestic nuclear capability will not be enough to put Russia ahead in the race to spread nuclear influence in the near future. The Russian government knows this, and has heavily invested in bringing nuclear power to outside states, such as Turkey, Belarus, Iran, and India[271], to further along the nuclear age in Russian allies and put Russia in the lead. Russia exported $133 billion in nuclear power related goods and services by the end of 2016[272] and is looking to expand their global reach even further in the near future.

Russia has revolutionized where the money is coming from by scaling their financing. In the short-term, this means heavily investing in the construction of these plants with Russian government money in the initial investment and staffing of nuclear plants abroad. Then as Russia turns over the staff and technology to the country where the plant has been built to Russian-trained, local engineers and workers, Russia simultaneously turns over the maintenance costs to the other nation as well. The operational costs in the mid-term life of the plant go to the state that owns the plant and is combined with private investment and as the plant ages the maintenance costs in the long-term come from increasing investment from private funding. By combining the two, this scale reduces the hardship of initial investment from private firms and the headache of long-term investment made by the government. This concept has come to be known as a Build-Own-Operate (BOO) model.

While Rosatom, the Russian state-owned nuclear company, has several signed deals (e.g. Turkey, Jordan) and agreements for building and financing reactors with many other nations, its ability to actually carry out such arrangements seems limited. This is because the Russian economy has been hard hit by the combination of low oil/gas prices and sanctions placed on the country's petroleum industry as a result of its Crimea annexation. Russian dependence on revenues from this industry is high and directly impacts Rosatom's ability to finance deals abroad. The situation has improved somewhat in 2017, with an increase in oil prices of about 25%. Nonetheless, Rosatom will almost certainly need to bring in other investor partners to advance its nuclear export plans.

Here enters China, which is an up and coming "new player" in the nuclear power landscape. This late entrance has not hurt the Chinese however due to the fact that they were able to learn from the mistakes in many other countries overcoming difficulties with their own nuclear agendas. As the Chinese economy is heavily based on exports of manufactured goods and technology combined with the large population, China has an astronomical need for energy to produce electricity in the modern world. China is famous for its use of coal and other sources of power to support the Chinese manufacturing industry. As China has been developing rapidly, increasing wealth, China has a very strong interest in pursuing nuclear technology for its immense power capabilities and ability to reduce the deadly pollution. For China, the pursuit for nuclear technology makes sense for them economically and for the sake of quality of life. China has been the first country to label nuclear power as a renewable energy source and has treated it as such.

China currently has 36 nuclear reactors in operation, 21 under construction, and many more plants planned and proposed[273]. China's nuclear program is almost entirely government planned and funded. The Chinese model moving forward is to build significantly more reactors than other nations, to demonstrate and scale-up advanced reactor designs, and to export its technology around the world. Its plan includes long-term R&D support for work on all stages of the fuel cycle. At the same time, as illustrated by its participation in the Hinkley C reactor project, China will continue to explore equity investments in nuclear power projects both in developing and developed nations. The potential for such investments in several or more European countries presents an intriguing new prospect. With regard to nuclear exports, Chinese state-owned companies have been in talks with a number of countries, including Turkey, Saudi Arabia, Argentina, Sudan, and Pakistan[274]. Some of these projects, should they be realized, will require large-scale financing by Chinese companies. One of these will be the China National Nuclear Corporation (CNNC). This firm has also pursued cooperative research with the University of Manchester in the UK and has recently signed agreements to collaborate with France's Areva on technologies related to the entire fuel cycle.[275] It is clear, in other words, that China is interested in pursuing export opportunities both on its own and in combination with other vendors, including those in western nations.

China is using this expansion of nuclear technology abroad to further strengthen its share in a global market that may come to represent $700 - $1,000 billion. Like South Korea, France, England, and possibly some companies in the U.S., the Chinese are also interested in developing SMRs for export. Financing of these reactors remains undefined at present, as SMRs have yet to be built and demonstrated. It is evident, however, that China's plans for the next several decades include building the world's largest nuclear fleet at home and developing a considerable export industry for nuclear technology abroad. Success in both domains would make China's leadership likely in global nuclear power, perhaps for many decades[276].

The Russian model is their tool for spreading their influence in global policy and is going to affect how other international political decisions will be made. China and Russia are leading the way in state run financial planning and will continue to do so if the West does not force the increased involvement of the government in financial arrangements for constructing new reactors.

In the past 40 years, South Korea has come a long way in developing its own nuclear program both domestically and abroad in Finland and the UAE[277]. South Korea began with only a handful of borrowed reactors from the U.S., Canada, and Europe, and now it is building its own Generation III reactors in the seventh richest nation[278] (by GDP per capita), the UAE. Winning the contract for four new reactors was South Korea's breakthrough into the export market for nuclear power technology.

This has been a result of South Korea's heavy investment in research and development, resulting in design of the Advanced Pressurized Reactor-1400 (APR-1400). Financing of the four APR-1400s at the UAE Barakah nuclear facility involves several parts: the total cost of $24.4 billion will be handled by direct loans of $19.6 billion from the Abu Dhabi government and the Export-Import Bank of Korea, with an additional $4.7 billion coming from equity investment by Korean Electric Power Company (KEPCO) and Emirates Nuclear Energy Corporation. The deal also includes provision by KEPCO for the training of UAE nuclear engineers by Korean instructors and plant operators. South Korea exemplifies the concept of reactor vendors taking equity stakes in power plant projects.

France & England

France is still one of the leading nations in the world in developing nuclear technology. France has also been able to export a great deal of its electricity to other nations in the European Union because of the low-cost France takes to produce their nuclear electricity[279].

France is using this edge in technology it has been developing over decades of research and engineering to team up with England and move nuclear energy forward in Europe[280]. The French and English both have the private sector to thank for this innovation. Although this could not be done without one or the other, as the government needs outside focus on nuclear technology from private firms and private firms need the support of the government to fund their designs and produce them to move forward. The French have revolutionized the way the production of a nuclear power plant can take place. This would not have happened without the heavy involvement of the private sector.

France and England have looked to make the production of nuclear plants cheaper for sake of long term costs being lower both domestically and abroad. Although, their programs have yet to travel abroad, both nations are seeing successful work within their own borders. France and England have designed reactors that can be built via an assembly line version on a nuclear plant scale that can be mass produced for faster and more efficient construction. This strategy is a short-term loss but a long-term gain by creating experts in the field of construction of this type of plant. France is able to mass produce and lower costs and help the private sector be competitive in innovation and manufacturing. Moving forward with this design has the potential to spark new innovation that can keep nuclear technology new and improved creating more power while lowering pollution and cost of electricity for governments and firms alike.

To further the expansion of opportunities in the West, heavy investment is coming from Chinese investment firms, financial institutions, and even the Chinese government in the expansion of European nuclear power. However, this does not rule out the idea that the U.S. could further expand its own nuclear influence in the global market by investing in international programs not limited to developing countries.

Conclusion:

It is now evident that an essential part of the new nuclear era consists of new ways to finance nuclear power plants. New approaches are being pioneered especially by Russia, China, and South Korea. Expanded access to financing capital is now coming from state-owned companies in these nations that take a significant or even 100% equity share in projects. Other options are provided by China through its Asian Infrastructure and Investment Bank, launched in late 2014. Such options suggest that nations with large sovereign wealth funds might also act as providers of capital for full-size or SMR nuclear projects, including those in Europe. Currently, the 1956 Atomic Energy Act in the U.S. prohibits any foreign entity from having a majority share of a nuclear power plant. In Europe, EU rules significantly restrict the ability of governments to make financial deals with other governments, a factor that opens the door for non-EU states like Russia and China to fill the gap and pursue agreements not available to European companies.

Perhaps the largest change of the past decade, proved by South Korea's success in the UAE, is that OECD and non-OECD nuclear vendors now compete head-to-head for export contracts. OECD vendors like Areva or GE-Hitachi are no longer seen as inevitably superior in what they can offer, especially not when China and South Korea are building domestic plants for $3 billion - $5 billion, nearly half of what similar plants cost in Europe and Japan. Non-OECD nations are leading the way in crafting new financial arrangements for funding the construction of a plant, They face the task, at some point, of convincing both foreign governments and their peoples that nuclear plants can be built by ex-communist nations safely and in a manner that provides affordable power long-term. These same nations are also showing the world that innovation in developing nuclear technology requires heavy commitment from the government in order to make progress due to the sensitivity and cost of nuclear projects.

Implications for U.S. Policy

Domestic

New nuclear technology has the potential to greatly increase the use and the positive public perception of nuclear power in the United States. While nuclear energy only powered 19.5% of the U.S.'s total energy in 2015, that energy was carbon free[281]. Moreover, unlike other fuel sources, nuclear energy does not release toxins and other waste products into the atmosphere or water sources. Expanding nuclear power will vastly reduce the carbon emissions produced by the United States. Furthermore, new small modular reactor technologies will make it cheaper and easier to build new power plants. SMRs have many different potential uses in the U.S. and abroad and have unique flexibility that is not available with traditional nuclear power plants. SMRs can be used in places that are not connected to a power grid or in areas with local power grids, and for industries that require a lot of electricity such as mining. Because they are modular, these reactors can be added or removed based on the dynamic power needs of the place they are operating. Other new technologies like the Generation IV reactors can help nuclear power become even more efficient and useful by producing hydrogen for industrial uses, as well as electricity. Nuclear power plants will be critical for the U.S. as its energy consumption grows larger and fossil fuels become more rare and expensive. Moreover, as other forms of clean energy technology expand, like electric cars, more power will also be needed to run and charge them. These new technologies must be a central focus in U.S. domestic policy so that it is possible to stay ahead of the curve and to help usher in a carbon free era.

International

The new nuclear technologies will not only help the United States, but will also greatly benefit countries across the international community. As the world continues to develop, access to electricity is expanding to new populations. Stable and plentiful energy is needed for modern lifestyles and is a basic necessity for full development. Nuclear power can provide clean power to such places with the help of new technologies. Small Modular Reactors are inexpensive, easy to build, and transportable, which is a promising energy poverty solution for developing countries. Additionally, thorium technology addresses concerns over weapons proliferation, which could play a key role in furthering the potential for nuclear programs across the world. Instead of turning to dirty fossil fuels for power, countries can turn to nuclear power, which will help mitigate global greenhouse has emissions. By researching and developing, as well as making exportation of new technology a key foreign policy, the U.S. can help provide clean and safe energy to the developing world.

Outlook

The United States must invest in nuclear technologies to stay relevant in the nuclear world. This means keeping promises to reduce greenhouse gas output and leading by example when it comes to clean energy. Being part of the Generation IV Forum is a good start but by itself is not enough. A lot of the research being done in the U.S. on nuclear technology is done by private companies. If the U.S. desires to maintain its place as a leading voice on nuclear issues, the nation must provide more government backing and research for nuclear energy projects. Nuclear power plants are extremely expensive, so increasing government grants and subsidies will aid with startup and research costs, therefore incentivizing research and production of new nuclear technology. Only four new nuclear reactors are currently under construction in the U.S., two each at two different sites; more will have to be constructed to keep up with rising demand and ensure energy security[282].

Policy Outlook: Key Points for the Future of Nuclear Power in the U.S.

Celia Louie

According to BP's 2017 Energy Outlook report, fossil fuels will continue to be the primary source of global energy for many decades, even as renewables grow by a factor of four to 2035.[283] Such growth would be far from sufficient to curtail the global rise in carbon emissions and in lethal air pollution. Without an expansion in nuclear power, currently the world's major non-carbon electricity source, there is little chance for emissions to be brought under control.

Nuclear energy runs at a capacity factor of 80-90%, making it the most reliable source of electricity among all forms of energy generation. The U.S.' international role in nuclear energy is declining, as countries such as Russia and China increase their influence. Therefore, contrary to BP's projection of slow growth for nuclear energy, there needs to be a large-scale expansion of nuclear power within the U.S. Currently, however, such expansion for the U.S. appears uncertain. There are hurdles that must be overcome in order for nuclear power in the U.S. to seriously move forward. These involve a number of areas, mainly related to government support, economic challenges, public concern, and waste disposal. Despite hurdles, the benefits of nuclear beyond reduced emissions fall into three main categories: security, international cooperation, and future U.S. leadership goals.

Hurdles to Future Growth

Government Support

- The U.S. government has reduced its support to nuclear programs in recent years as renewables are prioritized over nuclear energy.

The government has an enormous role in nuclear energy, and nuclear energy cannot grow without government commitment and investment. While there are currently 99 operating reactors, the U.S.' ageing fleet is set to retire without concrete plans to be replaced. Following events at Chernobyl and Fukushima, university programs have been decreasing, which raises concern for the future labor market and research and development. Without academic support, there will be a shortage in human capital that will not be able to compete with foreign labor forces. Today, much of the current research on nuclear technology in the U.S. is from private companies rather than the government.

The changing administrations and domestic politics make long-term plans for nuclear energy difficult. Appealing to both major parties in the U.S. is a challenge to having a cohesive governmental agenda and funding. Having government backing and research is fundamental if an expanded nuclear program is to be promoted. Governmental support and transparency in research and development can help alleviate current public fears about radiation, waste, and proliferation, as well as reducing costs in the long run.

Policy Recommendation: The Government must increase federal support of nuclear energy across the board as a non-carbon, high-reliability energy source, from increasing funding for research institutes to launching nuclear education campaigns, to providing tax breaks and subsidies to private sector actors.

Economic Challenges

- Nuclear energy presents much potential for the U.S. energy industry but the unique cost structure remains a market challenge.

The main economic disadvantage is the high capital costs, which often deter prospects and investments. Yet this is offset by comparatively lower maintenance and systems costs. Secondary impediments include regulation and licensing and these delays can be mitigated with greater government support. Without an adequate public-private partnership for funding and creation of a low-risk market, there remains private sector investment reluctance and an absence of government intervention.

The U.S. energy market's deregulation has disadvantaged a major source of non-carbon power. Since a nuclear power plant can cost between $6 billion to $8 billion, it is important that there is proper funding planned throughout the development and lifetime components. Nuclear energy has numerous economic benefits such as job creation, higher consumption, economic growth, and external cost savings. Commercial nuclear power growth is an important issue with many economic benefits but there are barriers that need viable solutions.

Policy Recommendations: The government must not only reform current regulations and licensing, but also pursue innovative financial mechanisms to support the growth of the nuclear industry, such as tax breaks, subsidies, and carbon-pricing schemes. To help with financing plants, the government can also encourage foreign equity investments in U.S. nuclear plants. In regards to current reforms, the government should streamline the nuclear licensing process while reducing associated fees, as well as decrease the excessive regulations. In order to bring nuclear jobs to the U.S. and lower domestic costs, the government should encourage nuclear component manufacturing and work to create a skilled nuclear labor force.

Public Concerns

- Following the accident at Fukushima, there has been an apparent decrease in acceptance of nuclear power.

The public's fear of nuclear energy largely stems from hyped incidents and a lack of knowledge about the realities of radiation and nuclear energy. There remains much misperception about radiation, waste, and proliferation, which indicates a gap between the general public, scientists, policy makers, and the government. This lack of collective support further alienates the public rather than mobilizing the public to help advocate for more nuclear power on the agenda. Negative attitudes towards nuclear energy challenge the further research and development. The public needs to be made aware of the strict and comprehensive safety regulations imposed on nuclear facilities and assured that safety is the number one priority. Following Fukushima, public concern heightened despite the fact that there has been a significant increase in precautionary safety measures and emergency response procedures for nuclear facilities.

There remains a need to address the lack of knowledge and to educate the general public to increase public trust and social acceptance over time. Since there is more public acceptance for nuclear power plants in communities neighboring a plant, this correlation could be useful in resolving waste deposit concerns. Public confidence needs to be increased and trends indicate that the more informed people are about nuclear energy, the higher the favorability is. In areas of concern regarding proliferation risks, the government's role is crucial in developing greater civilian trust.

Policy Recommendations: The government should work to inform citizens about the significant benefits of nuclear. One aspect of this could be providing funding for nuclear energy education programs within Universities and encouraging states to include nuclear energy as part of their elementary, middle, and high school science curriculums. Another aspect is to provide incentives for states to hold town-hall meetings in order to raise public awareness about the advantages of nuclear power, specially targeting areas that have potential for waste repositories or nuclear facilities.

Waste Disposal

- The U.S. has struggled to locate a permanent repository for nuclear waste disposal.

Nuclear energy generates little waste compared to its energy generation. In fact, the U.S. could even reduce our relatively small amount of waste if we switched to a close fuel cycle rather than our current once-through-cycle model, which was chosen because it reduces proliferation risks. There also remains much public fear about waste management and the perceived dangers of radiation. The Nuclear Waste Policy Acts (NWPA) and government plans with the Department of Energy (DOE), Environment Protection Agency (EPA), and the Nuclear Regulatory Commission (NRC) have worked to find a permanent disposal for nuclear waste in a geologic repository. Yucca Mountain was considered as a site but the repository program was eventually terminated due to public backlash. The later establishment of the Blue Ribbon Commission and New Wastes Strategy changed the existing nuclear waste policy and created the Nuclear Waste Fund. However, the fund remains at a standstill, waiting for Congressional appropriation.

Alternative methods for disposing of waste exist. For instance, the Deep Borehole Disposal (DBD) that has the safety and technology to diminish public concern. There is a current project in New Mexico to conduct geologic tests but this will take time to complete, especially as they work to be transparent with local communities. Meanwhile, countries such as Finland and Sweden have taken the initiative for their repositories. The high social favorability and government-civilian trust indicates some lessons and goals the U.S. should keep in mind.

Policy Recommendation: In regards to nuclear waste management, the government has two potential options: 1) continue pursuing the extremely controversial Yucca Mountain repository site, or 2) focus on and devote more resources to determining a new repository site. Given the highly-stigmatized nature of the Yucca Mountain site, this Task Force recommends option 2, despite the significant sunk costs. In the next attempt, the government should work closely with local communities to encourage public cooperation.

Major Factors for Growth

Security Factors

- Nuclear energy demonstrates a reliable addition to U.S. domestic energy security, although security concerns need to be addressed.

Expanding the U.S. nuclear program would decrease dependence on fossil fuels, domestic and imported and secure a consistent source of energy, one that would have increased immunity from volatile oil and gas markets. Nuclear is the most sustainable and reliable energy source since a low amount of uranium is needed to produce a high quantity of energy.

Proliferation presents another security concern and a hurdle in promoting nuclear energy. By strengthening security measures abroad, U.S. foreign policy can mitigate these concerns. The Iran nuclear deal demonstrates strengthened international nonproliferation and indicates a course of action to promote nonproliferation and the IAEA safeguards. The research and development of plutonium as a byproduct of uranium fission remains a concern for potential proliferation and needs to be addressed. Further safeguards and mechanisms are crucial in monitoring the development and safety of nuclear programs abroad.

Policy Recommendation: While nuclear power offers significant benefits, the government must be prepared to deal with cyber security challenges and should develop a cyber security agreement with other countries, as well as share resources to enhance cyber protection within a participating country's domestic infrastructure. The government should require the installation of training systems that would bolster their capabilities to prevent cyberattacks.

Expansion of nuclear monitoring bodies such as in the IAEA and their Additional Protocol, as well as the NSG, are necessary to avoid nuclear diversion and proliferation as the number of nuclear power plants continues to grow. The U.S. needs to continue to take a leading role in nuclear proliferation reduction efforts, including the promotion of down blending spent fuel and use of LEU instead of HEU in research reactors. Additionally, U.S. involvement in international agreements regarding new nuclear construction should be representative of their non-proliferation interests to limit the possibilities of nuclear materials diversion.

International Cooperation

- The U.S.' current role in international organizations to fund and take part in additional research and development is a priority

International cooperation is crucial in providing shared innovation and development of new technologies, as well as enhancing overall knowledge and expertise. Multilateral cooperation programs such as the Generation IV Forum, the International Framework for Nuclear Energy Cooperation (INFEC), the International Atomic Energy Agency (IAEA), and the Nuclear Energy Agency (NEA) serve as international efforts for mutual interests to research and development and nonproliferation. This global cooperation plays an imperative role in implementing safeguards regulations and promoting nuclear energy.

Present day technology consists largely of pressurized water reactors and boiling water reactors. Current reactor research has explored resolving concerns over size, safety, cost, and proliferation. Small modular reactors, thorium reactors, and generation IV reactors are some of the newer technologies. These newer technologies could help to eliminate some of the financial and security concerns for developing nuclear programs abroad and enhancing their energy capacity. The 123 Agreements work as a mechanism for bilateral cooperation but there remains uncertainty in how much control and regulations are needed for developing countries to fulfill nuclear energy efforts but ensure non-proliferation.

Policy Recommendation: In the future, the U.S. should seek to regain its leadership role in international cooperation efforts regarding nuclear energy. The primary way to do this is to increase funding to organizations such as the Generation IV Forum, INFEC, IAEA, and the NEA. In addition, the government should encourage U.S. nuclear experts, from the government, private sector, and academia, to pursue leadership roles within the previously mentioned international organizations.

U.S. Leadership Goals

- The U.S.' influence, status, and prestige in the global nuclear energy is declining with the rise of China and other nuclear power programs in the rest of the world.

In the U.S. and most of Europe, nuclear power has plateaued. China and Russia have shifted to become primary exporters of nuclear technology, thus having an increased influence on other nations. China's extensive plans for clean energy has led to multiple nuclear projects and a steady increase for approved nuclear reactors. With Russia and China expanding the global market for nuclear power, the U.S.' leadership role has decreased. For the U.S. to remain a key player - if not the leader in global nuclear energy - addressing domestic challenges is important. New financial agreements for building nuclear plants would change the feasibility of construction. Having a balance of government and private sector financing options are needed to establish international relationships for funding.

In order for the U.S. to remain relevant and a leader in the nuclear world, more investments in research and development are needed. The U.S.' 123 Agreements are a valuable tool in U.S. foreign policy to advance nonproliferation and expand nuclear energy participant states. Agreements with the Republic of Korea and United Arab Emirates indicate a limitation on the U.S.' principles and a need for further negotiations.

Policy Recommendations: The U.S. should promote nuclear power as a way to reduce emissions and mitigate climate change in accordance with the Paris Agreement. Additionally, the U.S. should continue to cooperate with prospective nuclear states to expand the number of nations participating in 123 Agreements, such as developing nations that can truly benefit from the significant advantages that nuclear provides. In line with that, the U.S. should encourage and support nuclear programs in developing nations along with the transfer of technological expertise. The government must also encourage domestic institutions to collaborate with other countries that have up-and-coming nuclear programs, which requires evolving our own nuclear industry to stay competitive.

Conclusion

For the U.S. to expand its nuclear energy program, a fair number of hurdles need to be recognized and addressed. The chief barriers to growth in nuclear include a lack of sufficient government support, market complexities, little public confidence, and uncertainty regarding nuclear waste. Despite these challenges, the factors favoring nuclear energy hold great promise and overcoming these hurdles is feasible with proper support and planning. Expanding the U.S.' nuclear energy would generate more non-carbon energy, encourage international cooperation, and revive the U.S. of its leadership in the nuclear era.

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