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Multilateral Cooperation in Asia's Nuclear Sector: Prospects for Growth and Safety

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EXECUTIVE SUMMARY

This working paper explores prospects for growth and multilateral cooperation in Asia's nuclear sector and argues the need for effective regulation and continued multilateral cooperation.

Main Findings

Nuclear power has a long and vibrant history in Asia. China, India, Japan, South Korea, and Taiwan have built robust nuclear industries, while the region as a whole is the primary growth market for the global nuclear industry. Yet despite a generally positive growth outlook, Asia's nuclear sector faces significant challenges. Incidents in both Japan and South Korea have highlighted the importance of safety culture and regulatory practice for maintaining sector vitality, while new nuclear countries such as Bangladesh and Vietnam will need to build up their regulatory framework and capacity to ensure the safe, reliable use of nuclear energy. Individually and collectively, the countries of the Asia-Pacific must work to improve safety and operational practices in order to maintain current reactors and ensure continued growth.

Policy Implications

- Asia's nuclear industries have always involved close bilateral or multilateral cooperation between regional or extraregional actors**.** Maintaining bilateral or multilateral cooperation can provide resiliency, support, and innovation, but it also means having to delicately balance political sensitivities between partners, particularly on issues related to nonproliferation and nuclear security.
- Dealing with spent nuclear fuel has been a vexing issue for nuclear industries around the world, yet the longer-term viability of any nuclear sector depends on being able to properly manage such material. Interim storage in above-ground dry casks for several decades could provide temporary relief and allow more time for developing long-term management options.
- Actually realizing Asia's nuclear growth plans will require strong, stable financing for nuclear construction and operation firms, but to create public acceptance, safety must not be compromised for the sake of lower construction costs. Various public and private actors involved must work to balance safety and affordability. Governments must optimize the regulatory process—while maintaining strict safety standards—to reduce licensing costs and time, and reactor vendors and operators must continue to develop safer designs and practices.

Nuclear power has a long and vibrant history in Asia, as the region was an early adopter of civilian nuclear technologies. By the mid-1950s, several Asian countries had launched nuclear energy programs, and the region eagerly welcomed former U.S. president Dwight Eisenhower's Atoms for Peace program. India's Aspara Research Reactor was the first research reactor to go online in Asia in 1956, and Japan was the first Asian country to connect a nuclear reactor to the power grid with the Japan Power Demonstration Reactor (JPDR) in 1963. Since that time, China, India, Japan, South Korea, and Taiwan have built robust nuclear industries, and the region is the primary growth market for the global nuclear industry, currently accounting for roughly 63% of all reactors under construction globally.

Yet despite a generally positive growth outlook, Asia's nuclear sector does face significant challenges. The Fukushima Daiichi nuclear accident has left Japan's domestic nuclear industry in an uncertain condition, with all of the country's reactors currently shut off and nuclear reactor operators in a poor financial state. In South Korea, a scandal involving bribery and faked safety tests for equipment used throughout that country's nuclear reactor fleet was revealed in 2013.[1] Both Japan and South Korea recently established independent nuclear regulatory agencies in order to avoid conflicts of interest and improper regulator-industry relationships, and these new regulators face difficult challenges overcoming scandal and controversy. Both of these incidents highlighted the importance of safety culture and regulatory practice for maintaining sector vitality. Individually and collectively, the countries of the region must work to improve safety and operational practices in order to maintain current reactors and ensure continued growth.

To address these issues, this paper explores prospects for growth and multilateral cooperation in Asia's nuclear sector. The first section provides an overview of the current status and history of nuclear power in Asia. Next, the paper examines key issues for government and industry actors, including financing, spent fuel management, multilateral cooperation, and safety. The paper concludes by arguing for the need for effective regulation and multilateral cooperation.

[1] Choe Sang-hun, "Scandal in South Korea over Nuclear Revelations," *New York Times*, August 3, 2013, http://www.nytimes.com/2013/08/04/world/asia/scandal-in-south-korea-over-nuclear-revelations.html.

Status of Nuclear Power in Asia

Regional Nuclear Generation and Reactor Construction

For the purposes of this paper, Asia will refer to the regions conventionally defined as Northeast Asia, Southeast Asia, and South Asia (roughly from Pakistan west to Japan). The countries that operate commercial nuclear power plants in this region are China, India, Japan, Pakistan, South Korea, and Taiwan. Nuclear power in the Middle East and Russia will not be explicitly covered, although those countries do have important commercial and government connections to the nuclear sectors in the rest of Asia. For example, South Korea is building four nuclear reactors in the United Arab Emirates, and Russia has nuclear projects in Bangladesh, China, and India.

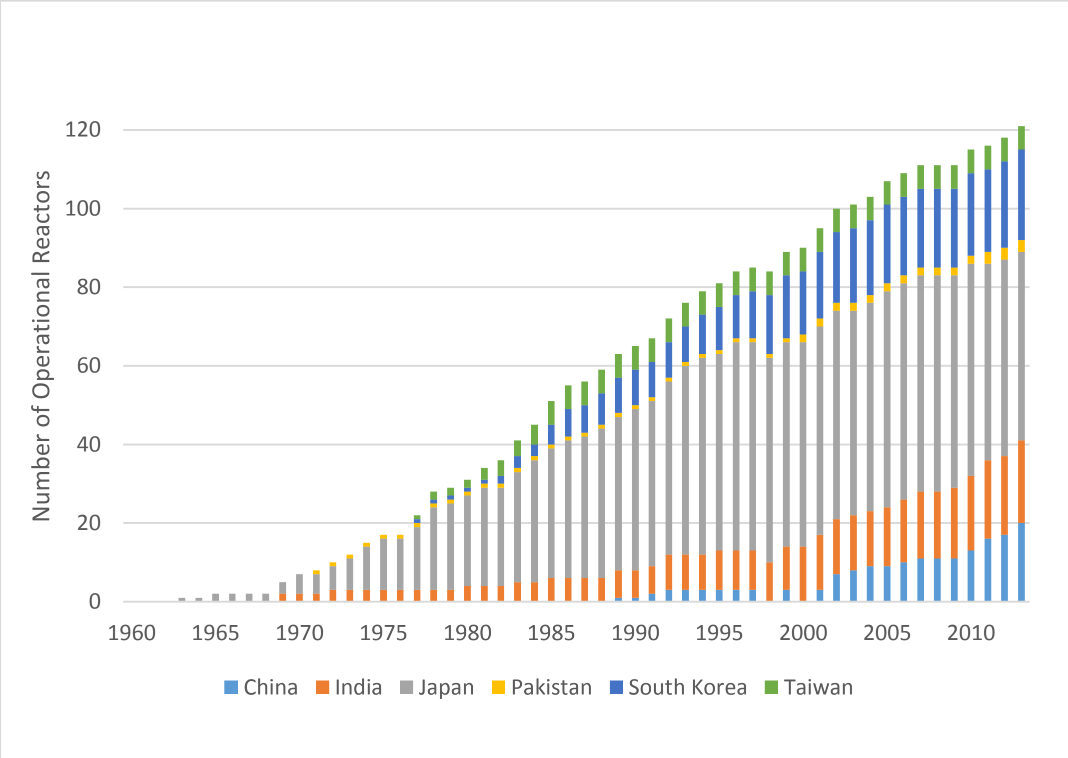
As **Figure 1** highlights, Japan drove much of the early growth in nuclear power in Asia during the 1960s, 1970s, and 1980s. Prior to 1990, Japan accounted for 60% of the nuclear reactor construction starts in Asia. Since 1990, China, India, and South Korea each have begun more new reactor construction projects than has Japan, and over half of the new reactor construction starts in Asia since 2000 have occurred in China. **Figure 2** charts the growth in nuclear generation and the drop since 2011 resulting from Japan's reactors going offline following the Fukushima accident.

Prior to Fukushima, Japan's 2010 energy plan called for building nine new nuclear reactors by 2020 and fourteen new reactors by 2030, which would have raised nuclear power's share of total electricity generation in Japan to 50%.[2] Meeting this goal would have required a construction boom that had not yet started in 2011. Two reactor construction projects that began before 2011 were allowed to restart after the Fukushima accident. Taiwan's two current reactor construction projects have also been a point of political contention and protest since Fukushima, and those projects remain uncompleted fifteen years after construction on both began in 1999.[3]

[2] "The Strategic Energy Plan of Japan," Ministry of Economy, Trade and Industry (Japan), June 2010, http://www.meti.go.jp/english/press/data/pdf/20100618_08a.pdf.

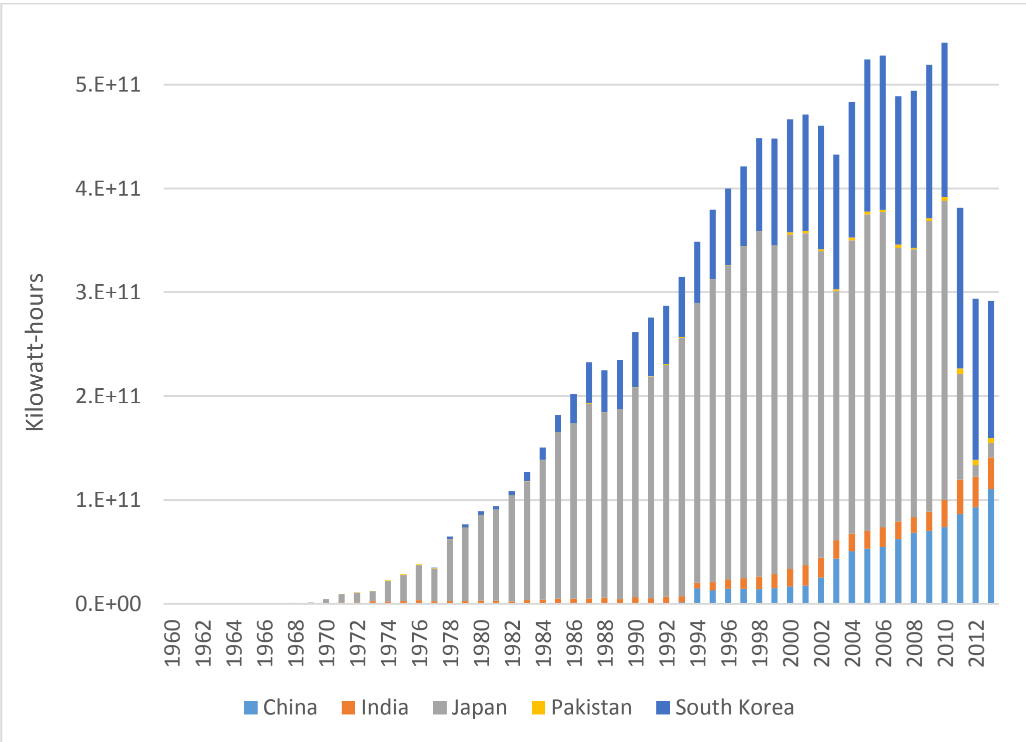
[3] J. Michael Cole, "Taiwan Rocked by Anti-Nuclear Protests," *Diplomat*, April 28, 2014, http://thediplomat.com/2014/04/taiwan-rocked-by-anti-nuclear-protests.

Figure 1 *Operational Nuclear Power Plants in Asia*



Source: Author's analysis of data compiled from the International Atomic Energy Agency's Power Reactor Information System, http://www.iaea.org/PRIS.

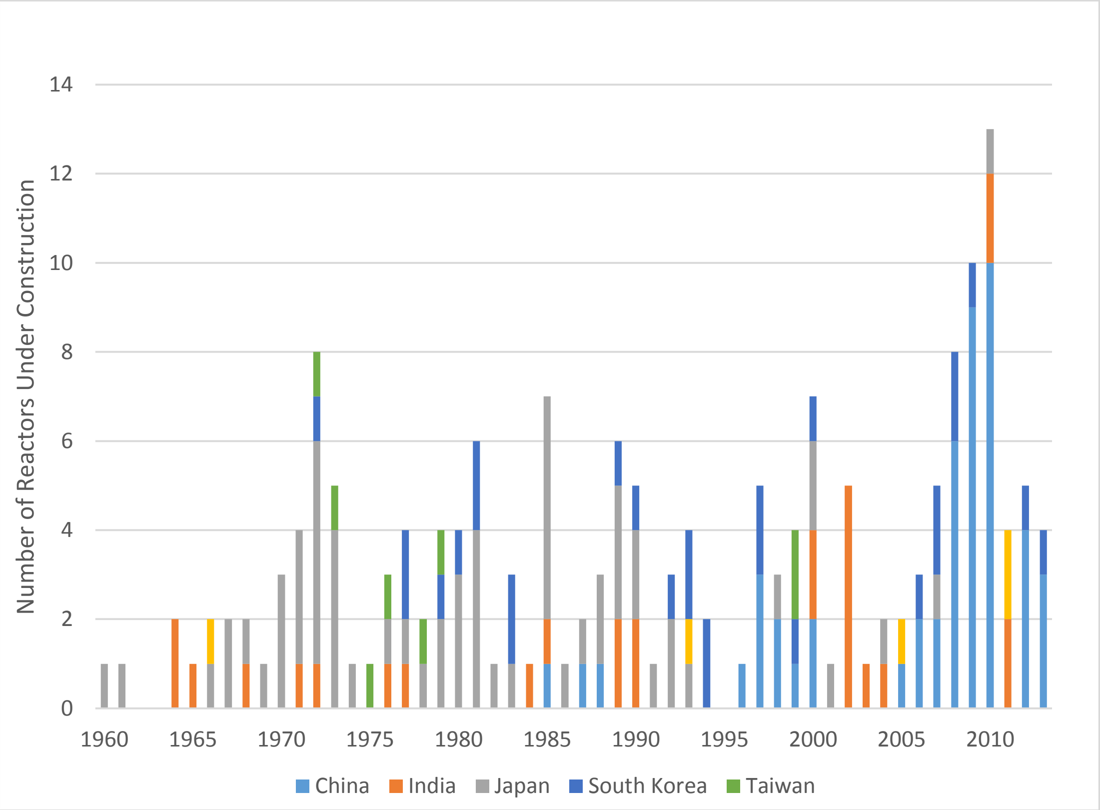
Figure 2 *Nuclear Generation in Asia*



Source: Author's analysis of data compiled from the World Bank's World Development Indicators, http://data.worldbank.org/data-catalog/world-development-indicators.

New reactor construction has continued in the rest of Asia after Fukushima, as shown in **Figure 3**. India and Pakistan each initiated construction on two new reactors in 2011 after the events in March. There was a pause in reactor construction starts in China immediately after Fukushima, but China began construction on seven reactors in 2012 and 2013. South Korea also launched construction on one new reactor in 2012 and another in 2013. China, South Korea, and India are now firmly the growth markets among Asian countries with existing nuclear power industries. Rapid growth in China's and South Korea's nuclear sectors is reflected by the rise in operational reactors and nuclear generation. India's current fleet of reactors is similar in number to that of China and South Korea, but Indian reactors are generally lower in generating capacity, which results in less output.

Figure 3 *Nuclear Reactor Construction Starts in Asia*



Source: Author's analysis of data compiled from the International Atomic Energy Agency's Power Reactor Information System, http://www.iaea.org/PRIS.

The following two tables summarize the current status of nuclear power in Asia. **Table 1** lists the operational reactors and reactors under construction in the region, with those reactors' corresponding installed capacity in megawatts-electric (MWe). **Table 2** lists the overall electric generation in gigawatt-hours (GWh), generation from nuclear sources in GWh, and nuclear power's share of total electric generation in Asia in 2013.

Table 1 *Operational Reactors and Reactors under Construction in Asia*[4]

	Reactors		Capacity (MWe)	
	Operational	Under Construction	Operational	Under Construction
China	21	28	18,047	30,505
India	21	6	5,780	4,300
Japan	48	2	44,198	2,756
Pakistan	3	2	750	680
South Korea	23	5	21,678	6,600
Taiwan	6	2	5,214	2,700
Total Asia	122	45	95,667	47,541
World	435	72	372,812	68,374

Source: Author's analysis of data compiled from the International Atomic Energy Agency's Power Reactor Information System, http://www.iaea.org/PRIS.

Table 2 *Overall Power Generation and Nuclear Generation in 2013*

	Nuclear (GWh)	Overall (GWh)	Nuclear Share of Overall
China	110,710	5,245,110	2.1%
India	30,293	859,202	3.5%
Japan	13,947	812,821	1.7%
Pakistan	4,397	100,707	4.4%
South Korea	132,465	479,541	27.6%
Taiwan	40,079	209,851	19.1%
Total Asia	331,890	7,707,231	4.3%

Source: Author's analysis of data compiled from the International Atomic Energy Agency's Power Reactor Information System, http://www.iaea.org/PRIS.

Table 1 shows China's importance to nuclear growth in the region, accounting for over half of the total reactors under construction, and Table 2 shows the strong relative dependence on nuclear power in South Korea and Taiwan. Japan was similarly dependent on nuclear power prior to the Fukushima accident, with nuclear energy providing 26% of Japan's electricity in

[4] Operational means that a reactor is able to operate and has not been put in a permanent shutdown or decommissioning status, but it does not necessarily mean that a reactor is currently in operation. For example, Japan has 48 operational reactors, but none of these reactors are currently in operation while awaiting safety inspections by Japan's Nuclear Regulation Authority.

2010.[5] Nuclear reactors still account for about 15% of Japan's total installed generating capacity, but only two reactors in Japan operated for a thirteen-month period between 2012 and 2013, which resulted in the low nuclear generation numbers.[6]

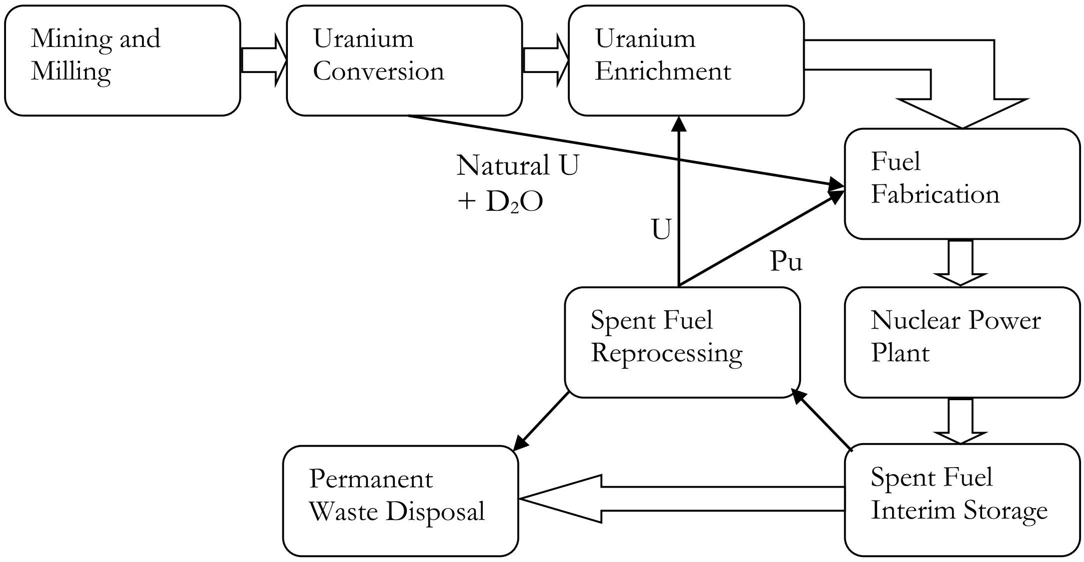
Varying Regional Fuel Cycle Capabilities and Policies

Asian countries also have a range of nuclear fuel cycle capabilities. The nuclear fuel cycle is the total life cycle employed to generate electricity with nuclear energy. Most operational nuclear reactors are light water reactors (LWR), which use similar fuel cycles. The other major reactor type in use is the pressurized heavy water reactor (PHWR). The fuel cycles for both types starts with uranium mining and milling. LWRs require that the uranium be converted to a gaseous form and then enriched, but PHWRs can use natural (unenriched) uranium. The next step is nuclear fuel fabrication, and the fuel is put into a reactor. After being used in a reactor, the fuel is put into interim storage, and after at least a few years there, the fuel can either be reprocessed or permanently disposed of. Closed fuel cycles employ reprocessing, and open fuel cycles do not. The front end of the cycle consists of mining and milling, conversion, and enrichment, and the back end of the cycle includes spent fuel interim storage, permanent waste disposal, and reprocessing. Reprocessing and permanent disposal are two methods of spent nuclear fuel (SNF) management. SNF can be either reprocessed into fresh fuel or disposed of directly in geologic repositories, but some radioactive waste that also must be permanently disposed of is produced in reprocessing. **Figure 4** is a basic schematic of this nuclear fuel cycle.

[5] "World Development Indicators," World Bank, http://data.worldbank.org/data-catalog/world-development-indicators.

[6] "Japan – Analysis," U.S. Energy Information Administration, October 29, 2013, http://www.eia.gov/countries/cab.cfm?fips=ja.

Figure 4 *Flow Chart of the Nuclear Fuel Cycle*



Legend
D_2O = Deuterium Oxide, also written as ^2H_2O and commonly called heavy water
U = Uranium
Pu = Plutonium

Note how using natural uranium and heavy water in PHWRs bypasses the uranium enrichment step. The two most sensitive steps from a security and nonproliferation perspective are uranium enrichment and spent fuel reprocessing. These are the two steps that create fissile materials—primarily uranium-235 or plutonium-239—which are the isotopes necessary to make commercial nuclear fuel or nuclear weapons.

China, India, and Japan have plans to develop closed fuel cycles and have varying levels of domestic uranium enrichment and SNF reprocessing capabilities.[7] Pakistan, South Korea, and Taiwan employ open fuel cycles with no domestic enrichment or reprocessing capabilities.[8] No Asian country is self-sufficient in its nuclear fuel cycle, and **Table 3** displays the sources of fuel cycle services for each country. Among extraregional actors, Australia, Canada, Kazakhstan, Namibia, Niger, and Uzbekistan are some of the major sources of uranium ore, and France, Russia, and the United States are the major sources of nuclear technology and services, particularly in enrichment, fuel fabrication, and reactor design and construction services. This demonstrates the inherently international nature of Asia's nuclear power sector,

[7] India's nuclear fuel cycle is distinctly different from the fuel cycle displayed in Figure 1 but is still a closed fuel cycle. All other countries considered in this paper generally follow the cycle displayed in Figure 1.

[8] Pakistan has enrichment and reprocessing capabilities for military use.

which requires bilateral and multilateral cooperation among national governments, international organizations, state-owned companies, and private companies.

In Table 3, “downstream” means that the service is performed by the downstream provider of the next step in the fuel cycle. For example, Japan does not have domestic uranium conversion capability. Japanese companies contract various countries for uranium ore, and Japan’s foreign providers of enrichment services also perform conversion. The “NA” under “Reprocessing” for Pakistan, South Korea, and Taiwan means that those countries employ an open fuel cycle that does not include reprocessing.

Table 3 *Sources of Nuclear Fuel Cycle Services for Asian Nuclear Industries*

	Uranium Ore	Conversion	Enrichment	Fuel Fabrication	Reactor Design and Construction	Reprocessing
China	Domestic, Kazakhstan, Namibia, Niger, and Uzbekistan	Domestic	Domestic, Russia, and URENCO[9]	Domestic	Domestic, France, Russia, and United States	Domestic (with French cooperation)
India	Domestic, France, Kazakhstan, Namibia, Mongolia, Russia, and South Africa	Domestic	Domestic and Russia	Domestic	Domestic and Russia	Domestic
Japan	Australia, Canada, Kazakhstan, Namibia, and Uzbekistan	Downstream	Domestic, France, Russia, and United States	Domestic	Domestic	Domestic, France, and United Kingdom
Pakistan	Downstream	Downstream	Downstream	China	China	NA
South Korea	Australia, Canada, Kazakhstan, and Niger	Downstream	France, Russia, United States, and URENCO	Domestic	Domestic	NA
Taiwan	Downstream	Downstream	Downstream	France and United States	United States	NA

Source: Author’s analysis of data compiled from the World Nuclear Association’s country profiles at http://www.world-nuclear.org/info/Country-Profiles.

Prospects for Nuclear Growth in Asia

As previously stated, Asia is the largest growth market for nuclear power in the world. Table 1 showed that there are 45 reactors under construction in the region, with 28 in China

[9] URENCO operates four enrichment plants in Germany, the Netherlands, the United Kingdom, and the United States. See “About URENCO,” URENCO, http://www.URENCO.com/news/2/about-URENCO.aspx.

alone. Moreover, most of the reactors under construction will have installed capacity of at least 1,000 MWe, which can power around 700,000 homes; by comparison, many new solar and wind power plants have capacities in the tens or hundreds of megawatts. These are very large power stations that can provide electricity for urban areas or industrial facilities.

Many reactors under construction in Asia are of more advanced Generation III or Generation III+ designs, such as the ACPR1000, AP1000, and VVER-1000 in China; the Advanced Boiling Water Reactor (ABWR) in Japan and Taiwan; and the APR-1400 in South Korea. Most operational reactors in the world today are Generation II designs. Whereas Generation II designs use active safety systems, Generation III designs use passive safety systems that "require no active controls or operational intervention to avoid accidents in the event of malfunction, and may rely on gravity, natural convection or resistance to high temperatures."[10] In addition, Generation III designs are standardized to expedite licensing and reduce capital cost and construction time, and they have other design features intended to more efficiently use the fuel and extend the operational life of the reactor. Some Generation III designs also are capable of load-following. Overall, they are intended to improve the safety and economic viability of nuclear energy.

Asia's nuclear growth can be divided into three broad categories: modest growth in existing nuclear countries, expansion into new nuclear countries, and incredible growth particular to China.

Modest Growth in Existing Nuclear Countries: India, South Korea, and Japan

India's 6 current reactor construction projects would add 4.3 GWe of installed capacity, and the country has plans for 22 more reactors with a capacity of over 21 GWe. Interestingly, 10 of the 22 planned reactors are LWR designs.[11] LWRs are not part of India's current three-stage nuclear program, which uses heavy water reactors and fast breeder reactors. This departure from the three-stage program perhaps suggests India's need to meet growing electricity demand by importing larger-capacity LWR designs. These planned LWRs also would diversify and integrate India's nuclear industry further into the global nuclear market by increasing nuclear cooperation with Europe, Russia, and the United States.

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[10] "Advanced Nuclear Power Reactors," World Nuclear Association, April 2014, http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Power-Reactors/Advanced-Nuclear-Power-Reactors.

[11] "Nuclear Power in India," World Nuclear Association, April 2014, http://world-nuclear.org/info/Country-Profiles/Countries-G-N/India.

South Korea has five reactors under construction with a capacity of 6.6 GWe and has plans for an additional six reactors with a capacity of 8.7 GWe. In December 2013, the South Korean government announced intentions to have nuclear power account for 29% of installed capacity by 2035.[12] South Korea also is pushing to change the terms of its nuclear cooperation agreement with the United States (a so-called 123 Agreement), which is due for renegotiation in 2016. The current 123 Agreement, signed in 1973, prevents South Korea from developing enrichment and reprocessing capabilities (ENR). For managing spent nuclear fuel, however, South Korea is interested in developing pyroprocessing.

Since India's first nuclear explosive test in 1974, the U.S. government has opposed the spread of ENR technologies for weapons nonproliferation reasons, and it remains opposed to South Korea developing or acquiring them. Washington also is concerned about the effect that South Korean acquisition of ENR technologies would have on North Korea's nuclear weapons program and argues that these technologies are too expensive and unnecessary for South Korea. Seoul claims that it needs pyroprocessing, a type of reprocessing, to reduce the volume and radioactivity of its reactors' spent nuclear fuel. Long-term management of spent nuclear fuel in South Korea is difficult due to the small size and dense population of the country, which makes siting a spent nuclear fuel disposal facility particularly problematic. Seoul also desires enrichment capability to support the country's nuclear export industry and argues that Washington created a double standard by permitting Japan to continue ENR development after 1974. The two sides will have to compromise by 2016 in order to continue bilateral nuclear cooperation, with Washington ceding some on its current nonproliferation stance and Seoul some on its desire for ENR technology.

Meanwhile, prospects for new nuclear building in Japan appear uncertain beyond the two ongoing construction projects. The Japanese public overall remains skeptical of nuclear power, and the country's nuclear operators are focusing on restarting existing reactors and returning to profitability. To compensate for the loss of nuclear capacity, Japanese utilities have increased imports of fossil fuels, particularly liquefied natural gas (LNG). According to the U.S. Energy Information Administration, "Japan is the world's largest liquefied natural gas importer, second largest coal importer, and third largest net oil importer…Japan consumed about 37% of global LNG in 2012."[13] Energy imports as a percentage of overall energy use, including energy for

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[12] "Nuclear Power in South Korea," World Nuclear Association, January 30, 2014, http://world-nuclear.org/info/Country-Profiles/Countries-O-S/South-Korea.

[13] "Japan—Analysis," U.S. Energy Information Administration, October 29, 2013, http://www.eia.gov/countries/cab.cfm?fips=ja.

electricity generation, transportation, and heating, increased from around 80% before 2011 to 94% in 2012.[14] These imports have put a financial strain on Japanese nuclear operators, with many operators recording large losses since 2011. Restarting existing reactors and regaining public trust are a higher priority than building new reactors for the time being in Japan.

Expansion into New Nuclear Countries

Several other countries in Asia have expressed interest in developing nuclear power programs, including Bangladesh, Indonesia, the Philippines, Vietnam, Thailand, Malaysia, and Singapore. Among these states, Bangladesh and Vietnam have made the most progress in planning and preparing to start nuclear programs. In 2011, Bangladesh contracted with Russia for the provision of two LWRs. Construction is expected to start within the next two years, and both reactors are projected to be operational by 2022. Russia will provide fresh fuel for the reactors and take back spent fuel.[15]

In 2010, Vietnam signed reactor construction agreements with Japan and Russia. Each country agreed to provide two reactors with a total capacity of around 4,000 MWe. Construction was originally planned to begin in 2014 on the Russian reactors and in 2015 on the Japanese reactors, but both construction projects have been delayed a few years due to continuing negotiations on technology and financing. Vietnam also signed nuclear cooperation agreements with Canada, China, France, South Korea, and the United States.[16] After signing a 123 Agreement between Vietnam and the United States in October 2013, U.S. secretary of state John Kerry said, "Vietnam has the second-largest market, after China, for nuclear power in East Asia, and our companies can now compete. What is a $10 billion market today is expected to grow into a $50 billion market by the year 2030."[17] This statement demonstrates the potential of Vietnam's nuclear plans despite the delays.

[14] "World Development Indicators."

[15] "Nuclear Power in Bangladesh," World Nuclear Association, November 2013, http://world-nuclear.org/info/Country-Profiles/Countries-A-F/Bangladesh/.

[16] "Nuclear Power in Vietnam," World Nuclear Association, May 2014, http://world-nuclear.org/info/Country-Profiles/Countries-T-Z/Vietnam/.

[17] "Agreement Opens U.S.-Vietnam Nuclear Trade," World Nuclear News, October 10, 2013, http://www.world-nuclear-news.org/NP-Agreement_opens_US_Vietnam_nuclear_trade-1010134.html.

Incredible Growth in China

In addition to the 28 reactors under construction, China has plans to start construction on 58 reactors by the end of the decade, with a total installed capacity of over 61 GWe.[18] China also has plans to expand domestic uranium mining and build new uranium enrichment, fuel fabrication, and reprocessing facilities to increase self-sufficiency in its closed fuel cycle.[19] With increased domestic capacity and experience, China likely will become a major exporter of nuclear technologies and provider of fuel cycle services, which makes regional engagement with China on nuclear safety and security practices more vital.

Key Questions for Policymakers

In both countries with existing nuclear industries and countries developing a nuclear industry, Asian states have ambitious and potentially lucrative nuclear growth plans. Yet, as the Fukushima accident demonstrated, unexpected events and shocks can disrupt industries and have national and international ripple effects. To help prevent such unexpected disruptions to reactor construction and operation, policymakers and nuclear sector planners will need to address several core issues with the development of the nuclear sector. This includes paying particular attention to construction financing, spent nuclear fuel management, multilateral cooperation, and nuclear safety guarantees.

Construction Financing

Building a new nuclear power plant is a long, capital-intensive project. The Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD) estimates that a typical Generation III reactor costs about $5–$6 billion and takes five to seven years to build. Construction cost and time can be lower in non-OECD countries due to lower labor costs and faster licensing but are still relatively high for nuclear reactors compared with fossil fuel power plants. The financing of construction can constitute up to 75% of a reactor's total life time costs, which means that securing stable financing upfront is

[18] "Nuclear Power in China," World Nuclear Association, May 15, 2014, http://world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Power.

[19] "China's Nuclear Fuel Cycle," World Nuclear Association, May 12, 2014, http://world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Fuel-Cycle.

critical.[20] Helping this situation in Asia is that the reactor operators in the primary growth markets discussed in this paper (Bangladesh, China, India, South Korea, and Vietnam) are all fully or partly state-owned firms. State backing can provide financial stability that is more difficult to secure for private nuclear operators in North America and elsewhere.

Actually realizing Asia's nuclear growth plans will require strong, stable financing for nuclear construction and operation firms, but to gain public acceptance, safety must not be compromised for the sake of lower construction costs. The various public and private actors involved must work to balance safety and affordability. Governments must optimize the regulatory process—while maintaining strict safety standards—to reduce licensing costs and time, and reactor vendors and operators must continue to develop safer designs and practices. In addition, governments should provide channels for reactor operators to secure financing, either domestically or through multilateral venues. Even in countries with private nuclear operators, it may be that only governments or multilateral organizations can provide the security necessary to guarantee financing for reactor construction projects.

Spent Nuclear Fuel Management

The management of spent nuclear fuel has been a vexing issues for nuclear industries around the world. Spent nuclear fuel must initially be stored for a few years in on-site cooling pools, and after that management options include reprocessing or disposal in geologic repositories. Direct disposal of this fuel after one use in a reactor also is challenging due to the difficulties in siting a facility. Even after finding a site with the proper geology, many local communities are wary of hosting a nuclear waste storage facility. In addition, disposing of fuel after one use leaves a significant amount of fissile uranium and plutonium unused.

On the other hand, the development of reprocessing technology is costly, and current reprocessing methods have not proved to be very economical. The current standard method of reprocessing is called Plutonium and Uranium Recovery by EXtraction (PUREX). France's La Hague industrial reprocessing facility uses PUREX, and Japan's reprocessing facility under development at Rokkasho is based on the La Hague facility. France has been able to generate extra revenue at La Hague by reprocessing other countries' spent nuclear fuel, including Japan's. It is unclear if PUREX would be economically viable outside France, and other reprocessing methods, such as pyroprocessing, have yet to be commercially proven. Even so, many Asian countries, including China, Japan, and South Korea, are conducting R&D on various

[20] "Economics of Nuclear Power FAQs," Organisation for Economic Co-operation and Development–Nuclear Energy Agency, July 6, 2012, https://www.oecd-nea.org/press/press-kits/economics-FAQ.html.

reprocessing methods. Especially for space-constrained countries like Japan and South Korea, the siting of geologic repositories is politically and technically challenging, and those energy resource–poor countries also find a closed fuel cycle appealing for energy security reasons.

Regardless of the method used to manage spent nuclear fuel, the longer term viability of any nuclear sector depends on being able to properly manage it. South Korea's spent fuel pools, for example, are projected to reach their maximum capacity within the next five to ten years, and no viable interim or long-term management option would constrain the South Korean nuclear industry's ability to continue operations beyond that.[21] Interim storage of spent fuel in above-ground dry casks for several decades could provide temporary relief by getting some of it out of the storage pools and giving more time for developing long-term management options.

Multilateral Cooperation

Asia's nuclear industries have always involved close bilateral or multilateral cooperation between regional or extraregional actors, as displayed earlier in Table 3. Early on, regional nuclear actors adopted technology and received financial and technical support from Western and Russian sources. China, India, Japan, and South Korea all developed indigenous reactor designs, and China, Japan, and South Korea became exporters of nuclear technology, both within and outside the region. Yet all four of these countries still rely on cooperation with extraregional actors for fuel and other nuclear services, and new nuclear countries will require assistance from regional and extraregional actors.

Maintaining bilateral or multilateral cooperation can provide resiliency and support, as well as help foster innovation, but it also means having to delicately balance political sensitivities between partners, particularly ones related to nonproliferation and nuclear security. Such sensitivities can be seen in the difficult discussions between South Korea and the United States over renegotiating their 123 Agreement. On the other hand, as with other energy technologies and fuels, diversity in sources of nuclear technology and fuel can bolster supply security. For example, Ukraine recently signed a new nuclear fuel supply agreement with Westinghouse partly to reduce dependence on Russia for nuclear fuel.[22]

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[21] Jungmin Kang, "The ROK's Nuclear Energy Development and Spent Fuel Management Plans and Options," NAPSNet Special Reports, January 22, 2013, 10, http://nautilus.org/napsnet/napsnet-special-reports/the-roks-nuclear-energy-development-and-spent-fuel-management-plans-and-options.

[22] "Westinghouse and Ukraine's Energoatom Extend Long-Term Nuclear Fuel Contract," Westinghouse Electric Company, April 11, 2014, http://www.westinghousenuclear.com/News_Room/PressReleases/pr20140411.shtm.

Guaranteeing Nuclear Safety

The Fukushima accident vividly demonstrated the potential effects of a major nuclear accident and the need to formulate and enforce proper safety regulations. For the general public, the two most important issues related to nuclear power are the cost to consumers and safety. Governments and reactor operators have the most control over the latter issue. One of the first steps that any government takes when setting up a nuclear energy program is to establish safety regulations and a regulatory agency. **Table 4** lists the nuclear safety regulatory agencies of the Asian countries covered in this paper.

Table 4 *Nuclear Safety Regulators in Asia*

Country	Nuclear Safety Regulator	Parent Agency
Bangladesh	Bangladesh Atomic Energy Commission	Independent
China	National Nuclear Safety Administration	Ministry of Environmental Protection
India	Atomic Energy Regulatory Board	Atomic Energy Commission
Japan	Nuclear Regulation Authority	Independent (under Ministry of Environment)[23]
Pakistan	Pakistan Nuclear Regulatory Authority	Independent
South Korea	Nuclear Safety and Security Commission	Independent
Taiwan	Atomic Energy Council	Independent
Vietnam	Vietnam Agency for Radiation and Nuclear Safety and Control	Ministry of Science and Technology

Source: Author's analysis of data compiled from the World Nuclear Association's country profiles at http://www.world-nuclear.org/info/Country-Profiles.

As seen in Table 4, not all of the regulators are independent agencies. As a general rule, the International Atomic Energy Agency (IAEA) recommends that a nuclear safety regulator be independent of industry and government. As an independent agency, the regulator can then "make autonomous decisions based purely on ensuring the proper level of care for public safety in a legal policy framework—but absent from either political or commercial interference."[24]

Especially in the case of state-owned operators, it is imperative that regulators are kept independent on paper and in practice. Yet independence should not mean isolation from operators, government planners, or the public. Regulators must remain engaged with operators and government planners in order to create a stringent yet efficient regulatory system. Isolation

[23] Japan's Nuclear Regulation Authority is an "external organization of the Ministry of the Environment with a high degree of independence and is classed as an 'Article 3 Authority.'" An Article 3 Authority is a "a council-system organization based on Article 3, Clause 2 of the National Government Organization Act, ensuring its independence without any control or supervision by other organizations (i.e., Ministers of other governmental organizations)." See "Nuclear Regulation Authority, Japan," Nuclear Regulation Authority, 3, http://www.nsr.go.jp/english/e_nra/leaflet/data/nsr_leaflet_English.pdf.

[24] "India's Nuclear Regulation Must Improve," World Nuclear News, August 24, 2012, http://www.world-nuclear-news.org/RS_Indias_nuclear_regulation_must_improve_2408121.html.

can lead to ineffective regulations or adversarial relationships between regulators and operators. Trust and healthy relationships between regulators, operators, and the public can be built through open, transparent, and regular engagement among all parties involved.

Each regulator above faces differing circumstances but still must be able to independently create and enforce proper safety standards. Japan's Nuclear Regulation Authority and South Korea's Nuclear Safety and Security Commission were created in 2012 and 2011, respectively, and are charged with independently enforcing safety regulations and restoring public trust in their respective nuclear industries. Previously, the regulators in Japan and South Korea were not independent from the energy planning ministries, which created a conflict of interest, so these new regulators were created to ensure independence. The capacity of the National Nuclear Safety Administration in China must be able to keep up with the pace of nuclear construction.

New nuclear countries, such as Bangladesh and Vietnam, must build up their regulatory framework and capacity. As domestic nuclear capability is developed, it may seem natural or efficient for one government agency to oversee all nuclear activities, but independent regulatory agencies should be created as soon as possible and certainly before reactor siting and construction projects begin in earnest. Bangladesh and Vietnam can learn how to build a regulatory framework and receive training from regional and global partners, as described in the next section.

Multilateral Nuclear Safety Cooperation

As with nuclear technology and fuel supply, bilateral and multilateral cooperation should be used to improve safety practices and regulation. Cooperation on nuclear safety must occur at both the industry and government levels. At the industry level, the World Association of Nuclear Operators (WANO) was established in 1989 and has five major programs for international cooperation on nuclear safety: peer reviews, the sharing of operating experience, the sharing of technical support and exchange, professional and technical development, and internal and external communication.[25] WANO peer reviews have been conducted at every commercial nuclear reactor in the world, and the frequency of these reviews was increased to every four years after the Fukushima accident. The peer reviews "help members compare themselves against standards of excellence through an in-depth, objective review of their

[25] "Programmes," World Association of Nuclear Operators, http://www.wano.info/en-gb/programmes/Pages/default.aspx.

operations by an independent team from outside their organization."[26] Peer reviews are conducted both before a reactor enters operation and during a reactor's operational life, and also assess the safety culture in member organizations. WANO's other programs are all aimed at sharing information, providing technical support and training, and creating channels of communication between interested parties. Bangladesh, Vietnam, and other countries developing nuclear energy programs in Asia should be included in WANO programs in order to help ensure safe operations from the beginning.[27] It is in the interest of all nuclear operators that reactors in all countries are operated safely and efficiently. New nuclear countries must be aided from the early planning stages to ensure safe, economic operations from the beginning.

Nuclear vendors also can play an important role in promoting safety in the countries where they sell and build reactors. In 2011, all the major global nuclear vendors, except in China, agreed to the Nuclear Power Plant Exports' Principles of Conduct.[28] The China National Nuclear Corporation participated in the drafting of the Principles of Conduct but has not adopted them yet.[29] Regarding safety, the Principles of Conduct state that a vendor must ensure that a customer state has the "legislative, regulatory, and organizational infrastructure needed for implementing a safe nuclear power program."[30] While both WANO and the Principles of Conduct are voluntary measures, they are critical venues for sharing safety information and practices and promoting corporate responsibility. The Principles of Conduct also are an acknowledgement of the fact that a nuclear safety incident in one country can adversely affect the nuclear industry in other parts of the world.

At the government level, Asian nuclear regulators can receive multilateral support and share information through the IAEA's Asian Nuclear Safety Network (ANSN) and the European Union's Instrument for Nuclear Safety Cooperation (INSC). The ANSN was created in 2002 "to

[26] "Peer Review," World Association of Nuclear Operators, http://www.wano.info/en-gb/programmes/peerreviews.

[27] Currently, only operators of existing nuclear facilities are WANO members. For a list of WANO members in Asia, see "WANO Members," World Association of Nuclear Operators, http://www.wano.info/en-gb/members/members.

[28] The Carnegie Endowment for International Peace convenes meetings regarding the Principles of Conduct. The current participants are AREVA, ATMEA, Babcock & Wilcox Company, Candu Energy, Hitachi-GE Nuclear Energy, JSC Rosatom Overseas, Korea Electric Power Corporation, Mitsubishi Nuclear Energy Systems, Mitsubishi Heavy Industries, Westinghouse Electric Company, and Toshiba.

[29] "History: Nuclear Power Plant Exporters' Principles of Conduct," Carnegie Endowment for International Peace, http://nuclearprinciples.org/about/history.

[30] "Safety, Health, and Radiological Protection," Carnegie Endowment for International, http://nuclearprinciples.org/principle/safety-health-and-radiological-protection.

pool, analyse and share nuclear safety information, existing and new knowledge and practical experience among the countries" and is expanding to become "a forum for broader safety strategy among countries in the region."[31] Countries participating in ANSN are Australia, Bangladesh, China, France, Germany, Indonesia, Japan, Kazakhstan, Malaysia, Pakistan, the Philippines, Singapore, South Korea, Thailand, the United States, and Vietnam. For non-EU countries, the INSC promotes and develops "effective regulatory frameworks, technical support to regulatory bodies, nuclear operators and national technical safety organisations, including in the field of nuclear safeguards, radioactive waste management and emergency preparedness."[32] The U.S. Nuclear Regulatory Commission also provides bilateral support to foreign nuclear regulators through advice, training, and other assistance.[33] As at the industrial level, nuclear safety regulators both in countries with existing nuclear energy programs and in countries developing nuclear energy programs must be included in these bilateral and multilateral efforts.

Conclusion

Building on the region's deep history with nuclear technology, Asia's nuclear industry has ambitious growth plans for the future. As nuclear sectors in some North American and European countries struggle economically, Asia's importance to the vitality of the global nuclear industry will only increase. Nuclear power could continue to be an essential component of Asia's energy mix to meet growing electricity demand and be an important source of electricity that is free of greenhouse gas emissions.

Yet Asia's nuclear industries and their extraregional partners must work to ensure that the region's nuclear growth does not come at the expense of safety. The Fukushima accident in Japan and the parts supply scandal in South Korea have not yet had much impact in other Asian countries, but other accidents or scandals in the future could have significant spillover effects throughout the region. Public trust in the safety of nuclear power must be preserved in order for Asia's nuclear industry to continue to grow. Domestic nuclear regulators must be able to independently create and enforce safety regulations, and safety information and support needs to be provided through bilateral and multilateral cooperation efforts. It is not enough for

[31] "What Is ANSN?" Asian Nuclear Safety Network, http://ansn.iaea.org/Common/WhatIsANSN/WhatIsANSN.aspx.

[32] "Instrument for Nuclear Safety Co-operation," European Union, http://eeas.europa.eu/nuclear_safety/index_en.htm.

[33] "Bilateral Relations," U.S. Nuclear Regulatory Commission, June 20, 2013, http://www.nrc.gov/about-nrc/ip/bilateral-relations.html.

regulators and organizations to exist on paper; these bodies must be given the necessary authority and be allowed to work effectively.

While China, India, Japan, and South Korea all have issues to address in their domestic nuclear sectors, they also must lead by example and provide assistance to the new nuclear countries in Asia. There are existing forums for sharing information and building capacity. These forums must be taken seriously and reformed if necessary to function properly. Given Asia's position as the main growth market in the global nuclear industry, it is critical that the countries of the region are able to safely and economically develop and operate their nuclear facilities.