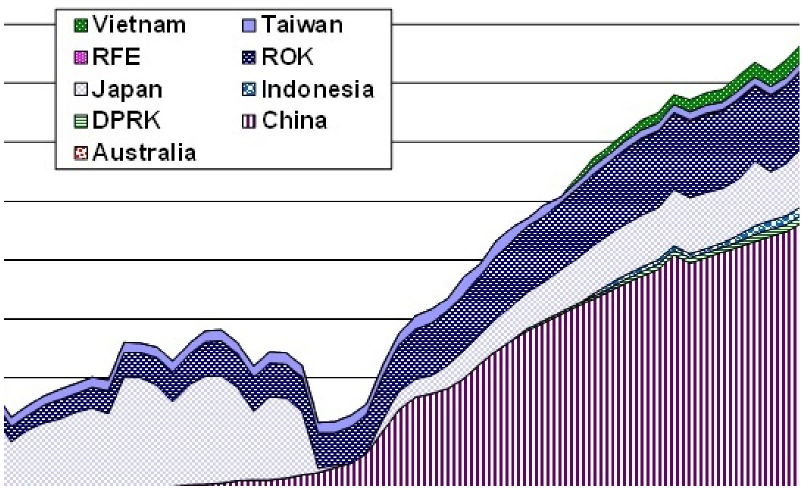
NAPSNet Special Report

CONCERTED STRATEGIES FOR MANAGEMENT OF SPENT NUCLEAR FUEL IN NORTHEAST ASIA



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Summary

Within the Nautilus Institute's "Reducing Risk of Nuclear Terrorism and Spent Fuel Vulnerability in East Asia" and "After Fukushima: Radiological Risk from Non-State Diversion of or Attack on Spent Fuel" projects, funded by the MacArthur Foundation, as well as in earlier collaborative research efforts, Nautilus Institute and colleagues from Northeast Asia have been exploring the connections between nuclear fuel cycle management and nuclear safety/security by analyzing the risk of radiological releases resulting from an attack on or accident at nuclear facilities, identifying the factors that increase or decrease this risk, and making realistic recommendations for changes in the storage, management, and disposal of spent fuel to reduce this threat. This report provides an update of Nautilus' analysis of scenarios for nuclear fuel cycle cooperation in East Asia within the context of three different nuclear energy paths for the nations of the region.

- In each of our three nuclear capacity paths (Business as Usual, Minimum, and Maximum), China is responsible for most of the growth in nuclear capacity in the region. From 2015 capacity of about 80 GWe (gigawatts of electric power) regionwide, regional capacity rises to about 230 GWe in the BAU case, 390 GWe in the MAX case, and 125 GWe in the MIN case, with most net growth capacity in the BAU and MIN cases taking place before 2035.
- Our preliminary calculations have indicated that the costs of spent fuel management in general are very modest when compared to the full cost of nuclear generation, and particularly when compared with the cost of electricity in Japan, the ROK, and China (Japan especially). Costs of nuclear cooperation (or non-cooperation) scenarios that include reprocessing are higher than those without reprocessing, and costs for increased dry-cask storage (reducing the amount of fuel stored in high-density spent fuel pools) are likely to be a tiny part of overall nuclear fuel cycle costs. This means that there is little reason for cost to play a significant role in decisions to modify spent fuel management planning, rather, that radiological risk and attendant political, social, and legal concerns should drive decisions regarding spent fuel management. Further, the additional costs associated with dry cask storage are very small when compared with the likely damage to economic assets and human health of a worst-case accident at or terrorist attack on a spent fuel pool at a reactor near a major population center, making accelerated conversion to dry cask storage a relatively inexpensive "insurance policy" against radiological risk.

Key follow-on activities related to the work described in this Report include:

- Building on previous work on the topic and Nautilus' existing quantitative analysis, further investigate the potential for nuclear fuel cycle cooperation in the region using a combination of expert analysis and input, development of possible organizational structures and activities for nuclear fuel cycle cooperation institutions in the region, and one or more workshops to discuss the political, organizational, institutional, and economic challenges that might be faced in developing nuclear cooperation.

- The underpinnings of Nautilus' work on nuclear fuel cycle cooperation in general, and spent fuel management in particular, has been our work since 2000 with Country Teams on energy sector status, policy, and futures in the countries of the region. Continuing and deepening this work, including advanced full energy-sector and national/regional energy futures modeling, will continue to provide the full economic, environmental, political and social context for nuclear energy, and thus, nuclear spent fuel management and nuclear cooperation scenarios. Broadening the group of participating nations to include those in the East Asia and Pacific region with nascent or proposed nuclear energy programs offers significant opportunities for sharing of knowledge and perspectives, and for uncovering both challenges to and opportunities for cooperation in nuclear fuel cycle management.

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List of Acronyms and Abbreviations

AFR:	Away from Reactor (spent fuel storage)
BAU:	Business as Usual
BWR:	Boiling Water Reactor
CANDU:	CANada Deuterium Uranium reactor
CO_2:	Carbon Dioxide
DBD:	Deep Borehole Disposal
DPRK:	Democratic People's Republic of Korea
GHG:	Greenhouse gases
GW:	Gigawatts
GWe:	Gigawatts of electric power
GWh:	Gigawatt-hour
HLW:	High Level Wastes
IAEA:	International Atomic Energy Agency
LILW:	Low and Intermediate Level Radioactive Waste
LWR:	Light Water Reactor
MOx:	Mixed Oxide Fuel
MW:	Megawatts
MWe:	Megawatts of electric power
MWth:	Megawatts of thermal power
NPP:	Nuclear Power Plants
NRA:	Japan's Nuclear Regulation Authority
Pu:	Plutonium
PWR:	Pressurized Water Reactor
R&D:	Research and Development
RFE:	Russian Far East
ROK:	Republic of Korea
SNF:	Spent Nuclear Fuel
SWU:	Separative Work Units
tHM:	Tonnes of Heavy Metal (Uranium/Plutonium)
TWh:	Terawatt-hour
U:	Uranium

UOx	Uranium Oxide (fuel)

CONCERTED STRATEGIES FOR MANAGEMENT OF SPENT NUCLEAR FUEL IN NORTHEAST ASIA

1 Introduction

The energy and, by extension, nuclear energy and nuclear spent fuel management situation in Northeast Asia is a mix of both shared and unique problems and approaches among a group of very different countries. Energy demand in the mature Japanese economy is not growing, and perhaps decreasing, as Japan's population continues aging and begins to decline. The Fukushima accident has led Japan, more than any other nation, to rethink its national energy priorities. How that re-think will affect nuclear power and spent fuel management in the medium- and long-term is not yet clear. However, the reconsideration of Japan's energy future has already had a remarkable impact on deployment of renewable energy, and, to perhaps a lesser extent, energy efficiency. These developments, coupled with ongoing and long-planned electricity market liberalization, may shake up Japan's energy sector in unexpected ways, in large part through their effect (together with that of the nuclear shut-down) on the finances of the large utility companies that dominate the energy sector, and their relationship with government. In Japan, significant growth in the nuclear energy sector, apart from restarting existing reactors— in which is still, as of this writing, in its early phases and still uncertain as to how many reactors will be restarted—seems unlikely.

Both energy demand and nuclear generation capacity in the Republic of Korea (ROK) continues to grow, but at a decreasing rate. Very large-scale additional deployment of new reactors in the ROK now seems unlikely, due to a combination of limited remaining available reactor sites and the social and political difficulties associated with siting new plants.

Japan and the ROK share several conundrums. First, both are highly dependent on energy imports, which was a key driver of the development of nuclear energy in the first place. Second, both are running out of at-reactor spent fuel pool space to store spent nuclear fuel. Third, both are hamstrung by a combination of laws and regulations, and by local opposition, with regard to siting of alternative at-reactor dry cask spent fuel storage. In addition, a lingering commitment among nuclear industry actors inside and outside of government to reprocessing in Japan, and to a not-yet-allowed (by the United States) variant of reprocessing, called pyroprocessing, in the ROK, also acts to slow movement toward a sustainable spent fuel management solution.

China faces different issues. With significant resources of its own, though not enough to fuel its massive economic growth, its energy imports are increasing, but are not yet at the 90-plus percent level in the ROK and Japan. China's nuclear sector is young by comparison to Japan and the ROK, but growing fast, as most of the reactors built worldwide are being built in China. With a large land area and a not-yet-powerful civil society sector, siting of nuclear plants and spent fuel facilities is not yet a major problem for China, though it may grow to be so in the future. China's use of many different kinds of reactors, ordered and funded by different provinces, and only loosely coordinated with power grid development, may prove to be problematic soon, and may complicate nationally coordinated management of spent fuel.

Added to this mix are:

- Taiwan (Chinese Taipei), also suffering from a lack of storage space for spent fuel, embroiled in a contentious domestic argument over whether to revive work on a long-stalled (but nearly complete) fourth reactor complex (Lungmen), and facing difficulties in developing alternatives for spent fuel storage similar to those in Japan and the ROK;[1]
- Mongolia, rapidly becoming a large exporter of coal and metals to (mostly) China, and with a large, open land area and a nuclear weapons-free zone status that, some have argued, may make it a potential host for a regional nuclear facility (though many Mongolians say otherwise);
- Russia, which would like to export oil, gas, and electricity to the major markets of the region, and has started to do so, albeit not to the extent that has been projected for many years; and
- The DPRK, which physically stands in the way of overland gas and electricity exports from Russia to the ROK, and whose relationship with its neighbors and the international community in general, specifically regarding its nuclear weapons program, but in many other ways as well, adds considerations to nuclear plans in the ROK and Japan. At the same time, however, the desperate situation of the DPRK's energy sector, and the DPRK's desire to address its energy issues, may offer opportunities to catalyze energy cooperation in the region.

One goal shared by all nuclear nations—if not with equal levels of concern among governments, groups, and individuals—is the securing of radioactive materials from release during accidents or attacks, including terrorist attacks, on nuclear facilities. Here a key distinction is between spent fuel stored in spent fuel pools and in dry casks, the two major ways that spent fuel is stored pending the development of long-term storage or disposal facilities. Spent fuel pools are deep pools of circulating water, typically adjacent to and/or contiguous with nuclear reactor containment buildings, in which irradiated fuel removed from the reactor core is cooled, usually for at least five years but often longer, before being moved to other storage facilities or being reprocessed to separate plutonium and uranium from other components of the fuel. Dry-cask storage typically encases fuel elements in a sealed metal canister from which water has been removed, and which has been filled with an inert gas. The metal canister is then placed in a concrete and/or steel overpack, creating a massive (tens of tons), robust package. Dry-cask storage of spent fuel appears much less vulnerable to release of radiation through accident or attack than storage of fuel in in spent fuel pools. Release of radiation from fuel stored in dry casks essentially requires a concerted effort targeted specifically at the dry cask to not only break it open—requiring high explosives detonate essentially on the cask or physically drilling into the cask, requiring proximity of attackers—but to ignite the spent fuel assemblies stored in the cask. Zircaloy-clad fuel assemblies in dense-racked spent fuel pools, on the other hand, can ignite if water from the pool is lost, as dense-racked pools lack the ability to passively release sufficient heat through the air when coolant is lost, leading to rising temperatures and, eventually, ignition of fuel cladding, resulting in releases of radioactivity. Most of the spent fuel pools in use in Northeast Asia (and in many other places, including the United States) today use dense-racking

[1] See, for example, World Nuclear Association (2016), "Nuclear Power in Taiwan", last updated September 26 September 2016), and available as http://www.world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx.

systems to conserve space in spent fuel pools, due to a lack of alternatives for spent fuel storage/processing/disposal.

Overall, the complex and varied East Asia/Pacific region shares many energy sector problems, though not all, and although cooperation on energy sector and nuclear sector (and other) issues has not generally been the hallmark of international relations in the region, cooperation may, in fact, bring mutual benefits, as discussed later in this Report.

The remainder of this Report is organized as follows:

- **Section 2** provides an overview of the electricity and nuclear energy situation in Northeast Asia, and in East Asia more broadly.
- **Section 3** presents three scenarios of future nuclear capacity for the countries of East Asia.
- Summaries of four regional fuel cycle cooperation scenarios explored in this Report are provided in **Section 4**, along with some of the nuclear fuel cycle cooperation options explored to date—including “front end” (uranium supply, enrichment, and fuel fabrication), and “back end” (spent fuel management and disposal) options.
- **Section 5** presents the analytical results, both quantitative and qualitative, of our analysis of four regional fuel cycle cooperation scenarios..
- **Section 6** provides a results summary and the overall conclusions of the research into fuel cycle cooperation scenarios, and identifies possible next steps building on the research results.

2 Summary of Overall Northeast Asia Energy/Energy Policy Situation

Over the past two decades, economic growth in East Asia—and particularly in China, the Republic of Korea (ROK), Vietnam, Taiwan, and Indonesia—has rapidly increased regional energy requirements, especially electricity needs. Although economic growth slowed in much of the region during the global recession of 2008-2010, and electricity demand in Japan declined in the aftermath of the accident at the Fukushima reactor following the March, 2011 Sendai earthquake and Tsunami, overall growth in demand for electricity in the region continues. As a recent, eye-opening example of these increased needs, China added nearly 100 GW of generating capacity—more than the total generation capacity in the ROK as of 2010—between 2009 and 2010 alone. Despite increasing efforts to boost hydroelectric and other renewable generation, the vast bulk of the capacity China has added annually in recent years is coal-fired, underlining concerns regarding the global climate impacts of steadily increasing coal consumption.

With the difficult lessons of the “energy crises” of the 1970s in mind, several of the countries of East Asia—starting with Japan in the mid-1970s, and continuing with the ROK, Taiwan, and, in the early 1990s, China—have sought to diversify their energy sources and bolster their energy supply security, as well as achieving other policy and social objectives, by developing nuclear power. Several other East Asian nations are currently discussing adopting nuclear power as well, if not, like Vietnam, taking concrete steps toward developing their own nuclear facilities. At the same time, global security concerns related to terrorism and to the nuclear weapons activities of the Democratic People’s Republic of Korea (DPRK), Pakistan, and India, as well as the (nominally peaceful) uranium enrichment programs pursued by Iran and, as revealed publically in 2010, the DPRK, have focused international concern on the potential for proliferation of nuclear weapons capabilities associated with nuclear power. In addition, old concerns regarding the management of nuclear spent fuel and other wastes, including the safety and long-term implications of various means of spent fuel management and/or disposal, as well as the siting of spent fuel facilities, remain, at best, only partially addressed.

One means of addressing proliferation concerns, reducing environmental and safety risks of nuclear power, and possibly modestly reducing the costs of nuclear energy to the countries of the region, is regional cooperation on nuclear fuel activities. A number of proposals for regional cooperation on safety, enrichment, spent-fuel and waste management, and other issues have been offered over the years, some from within the region, and some from outside the region. The net impact, however, of regional nuclear cooperation on the energy security—expressed broadly to include supply security, economic impacts, environmental security, and security related to social and military risks—requires a more detailed look at how cooperation on nuclear power might be organized and operated. Working with a network of collaborating teams in nine countries of the region, Nautilus Institute has defined several different scenarios for nuclear fuel cycle cooperation in East Asia, evaluated those scenarios under different sets of assumptions regarding the development of nuclear power in the region. These evaluations of the physical flows of nuclear fuel cycle materials and services, and of the costs of different elements of the fuel cycle, help to shed light on the relative readily quantifiable costs and benefits of different regional fuel cycle cooperation options. At least as important, however, are the relative impacts of different fuel cycle options on other aspect of (broadly defined) energy security, which can be evaluated qualitatively.

East Asia and the Pacific includes three nuclear weapons states—including the United States based on its physical proximity and jurisdiction over several Pacific territories, as well as its geopolitical and cultural importance in the region—plus one (the DPRK) that has been nuclear-armed since 2006. The region also includes three major economies that are nearly completely dependent on energy imports and for which nuclear energy plays a key role, a nuclear materials supplier nation currently without commercial reactors of its own, and at least two populous and fast-developing nations with stated plans to pursue nuclear energy. Table 2-1 provides a summary of the status of major nuclear fuel-cycle activities in each country covered by the analysis summarized here. To this listing can be added Mongolia, which has significant uranium resources and a history of uranium production and exploration during Soviet times. Though Mongolia has no other active commercial nuclear facilities, its involvement in regional nuclear fuel cycle activities related to uranium supply has been proposed.[2] Mongolia's status as a nuclear weapons-free state, a process begun in 1992 and recently (2012) formalized through recognition by the five permanent members of the United Nations Security Council,[3] also potentially makes it an interesting "player" in nuclear weapons and nuclear energy policy in the region, though when one of the authors of this Report visited Mongolia, the officials he talked

[2] Agvaanluvsan, U. (2009), "The Global Context of Nuclear Industry in Mongolia". Mongolia Today, the Mongolian National News Agency, December 2009, available as http://iis-db.stanford.edu/pubs/22822/AgvaanluvsanMongolia_nuclear_industry.pdf. See also, for example, J. Berkshire Miller (2012), "Mongolia Eyes Nuclear Ties", *The Diplomat*, March 6, 2012, available as http://thediplomat.com/flashpoints-blog/2012/03/06/mongolia-eyes-nuclear-ties/.

[3] See, for example, Daryl G. Kimball (2012), "Mongolia Recognized as Nuclear-Free Zone", Arms Control Today, October 2012, available as http://www.armscontrol.org/act/2012_10/Mongolia-Recognized-as-Nuclear-Free-Zone.

with seemed less than enthusiastic about Mongolia's participation in nuclear activities, and indicated that recent stated Mongolian energy policies omit nuclear power and related endeavors.[4]

Table 2-1: Summary of Nuclear Energy Activities in East Asia/Pacific Countries

Country	Nuclear Generation	Front-end Fuel Cycle Activities	Back-end Fuel Cycle Activities
Japan	Mature nuclear industry (~47 GWe as of 2010) with continuing slow growth until Fukushima accident. Post-Fukushima 4 units closed, all other power reactors in Japan shut down for inspection as of late May, 2012[5]; some since at least briefly restarted, including Sendai units in late 2015/early 2016.	No significant mining, milling. Some domestic enrichment, but most enrichment services imported.	Significant experience with reprocessing, including commercial-scale domestic facility now in testing (though much delayed), plus significant reprocessing carried out in Europe; interim spent-fuel storage facility (Mutsu) complete but not yet in use.
ROK	Mature nuclear industry, 25 units totaling 23.0 GWe at 4 sites as of late 2016[6].	No significant uranium (U) resources, enrichment services imported, but all fuel fabrication done domestically.	No reprocessing, but "pyroprocessing" under consideration; at-reactor spent fuel storage thus far.
DPRK	Has small (5 MWe equivalent) reactor for heat and plutonium (Pu) production, partly decommissioned, now at least intermittently back in operation; policy to acquire LWRs, and currently building LWR with domestic technology estimated at 100 MWth[7].	At least modest uranium resources and history of U mining; some production exported; operating 2000-centrifuge enrichment plant recently revealed.[8]	Reprocessing of spent fuel from 5 MWe reactor to separate Pu for weapons use. Arrangements/plans for spent fuel management for new reactor unknown.
China	Relatively new but rapidly-growing nuclear power industry; 31.6 GWe in 35 units as of late 2016.[9]	Domestic enrichment and U mining/milling, but not sufficient for large reactor fleet.	Nuclear weapons state. Small reprocessing facility; plans underway for spent fuel storage facilities.

[4] David von Hippel's personal communication with Mongolian officials, 2013 and early 2014.

[5] Akira Nagano (2012), "Current Status and Efforts in Japan after Fukushima Accident", JAIF International Cooperation Center (JICC), June, 2012, available as http://www.iaea.org/NuclearPower/Downloads/Infrastructure/meetings/2012-06-18-20-TM-Vienna/10.Status_and_Efforts_after_Fukushima.pdf.

[6] See, for example, World Nuclear Association (2016), "Nuclear Power in South Korea", dated 20 September 2016, and available as http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx.

[7] This thermal output is the equivalent of approximately 25-30 MWe.

[8] Hecker, S.S. (2010), A Return Trip to North Korea's Yongbyon Nuclear Complex. NAPSNet Special Report, dated November 22, 2010, and available as http://www.nautilus.org/publications/essays/napsnet/reports/a-return-trip-to-north-korea2019s-yongbyon-nuclear-complex.

[9] World Nuclear Organization (2016), "Nuclear Power in China", dated October, 2016, available as http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx.

Country	Nuclear Generation	Front-end Fuel Cycle Activities	Back-end Fuel Cycle Activities
Russian Far East (RFE)	One small plant (48 MWe) in far North of RFE, with others planned. (Russia itself has a large reactor fleet); plans for larger (1 GWe scale) units for power export.	Domestic enrichment and U mining/milling (but not in the RFE).	Nuclear weapons state. Russia has reprocessing facilities, spent fuel storage facilities (but not in RFE).
Australia	No existing reactors above research scale; has had plans to build power reactors, but currently very uncertain.	Significant U mining/milling capacity, major U exporter (over 6000 t U in 2011, just under 6000 tU in 2015[10]); no enrichment.	No back-end facilities.
Taiwan	~5 GWe in 6 reactors at 3 sites, 2 additional units at 4th site under construction since late 1990s, but their completion is under review post-Fukushima, with conversion to gas investigated.[11]	No U resources, no enrichment—imports enrichment services.	Current spent-fuel storage at reactor, no reprocessing. Siting of low-level waste and intermediate spent fuel storage under discussion.
Indonesia	No current commercial reactors, but full-scale reactors planned.	Some U resources, but no production; no enrichment.	Consideration of back-end facilities in early stages.
Vietnam	No current commercial reactors, but a number of full-scale reactors planned, with agreements signed recently with Russia, Japan, ROK for reactor construction and finance.[12] Enthusiasm for nuclear power in Vietnam seems to have waned in recent years.[13]	Some U resources, but no production; no enrichment.	Consideration of back-end facilities in early stages.

[10] World Nuclear Association (2016), "Australia's Uranium", updated August 2016, and available as http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/australia.aspx. Note that 2010 and 2011 production were substantially lower than the average of over 8000 t U per year in the previous decade (2000-2009), a trend that has continued, with average output and exports post-2011 close to 6000 tU per year.

[11] See, for example, Platts (2012), "Taiwan mulls conversion of under-construction nuclear power plant to gas-fired", dated November 1, 2012, and available as http://www.platts.com/RSSFeedDetailedNews/RSSFeed/ElectricPower/7213676.

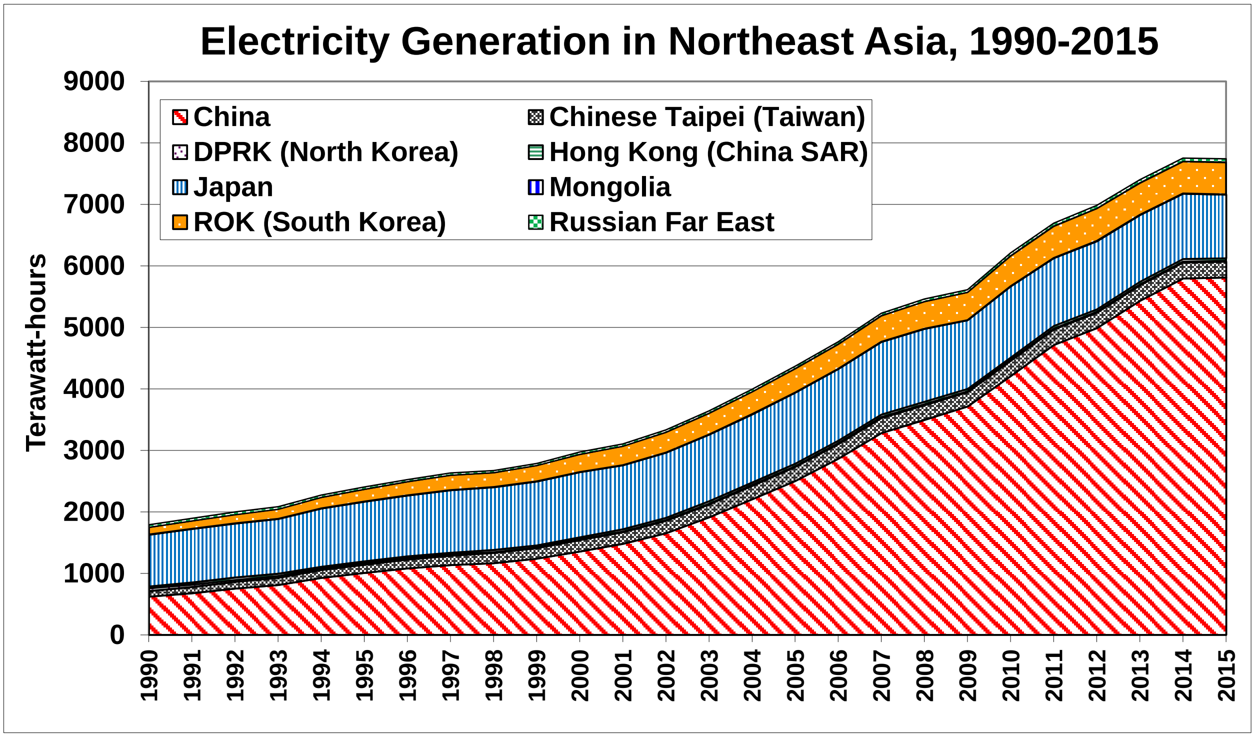
[12] See, for example, World Nuclear Association (2012), "Nuclear Power in Vietnam" updated November 2012, and available as http://www.world-nuclear.org/info/vietnam_inf131.html.

[13] David von Hippel, personal communication with Vietnamese officials. The Vietnamese economy has not performed as well as hoped, and although nuclear plants remain of interest in Vietnam, it appears that the cost of the plants may become more of a barrier to large-scale adoption of the technology. See also: Associated Press, "Vietnam scraps plans for its first nuclear power plants," November 10, 2016, at: http://bigstory.ap.org/article/544e8f5088b347f0bf71138bf3f1bdb3/vietnam-scraps-plans-its-first-nuclear-power-plants?mkt_tok=eyJpIjoiT0daak56UmtZakZtTXpneCIsInQiOiJkNWxVblNxbXRvVVRCdnd4aldSY3RUa1wva3BLb1wvZTBtTlZFS3UxQll0T0lMZWd0QytxVkdITEFWenVMWTVtWjVtSGpYem8zUmxkekxZZERVcFlTQTUzeExZejArcjhseUVOdG5hODdsRTlzPSJ9

2.1 Current Status of Electricity Consumption and Nuclear Generation

Recent growth in electricity generation and use in East Asia has been remarkable. As an example, Figure 2-1: Electricity Generation in Northeast Asia, 1990-201 shows total electricity generation in the Northeast Asia region more than tripled between 1990 and 2015, with generation in China increasing by more than a factor of nine, generation in Taiwan increasing by a factor of nearly three, and generation in the ROK increasing by a factor of 4.4. Even though electricity production in Japan—which in 1990 had the highest generation in the region—grew by only 23 percent (an average of 0.8 percent annually), the fraction of global generation accounted for by the Northeast Asia region grew from just over 15 percent in 1990 to over 32 percent in 2015, even as electricity generation in the rest of the world grew at an average rate of 2.1 percent annually. As notable as this increase in overall consumption and of the fraction of the world's electricity has been in Northeast Asia, the last few years have seen a decline in electricity generation in Japan, a leveling-off of generation in the ROK, and even, between 2014 and 2015, near-zero growth in reported generation in China, though previous years (2009-2014) saw annual increases in generation in China in the 6 to 13 percent range.

Figure 2-1: Electricity Generation in Northeast Asia, 1990-2015



Sources: Data from British Petroleum "Statistical Review of World Energy 2016" workbook[14] for all countries except the DPRK (based on updated Nautilus Institute results not yet published[15]), Mongolia (based on data from USDOE/EIA and other sources[16]), and RFE (estimated from paper by Gulidov and Ognev[17]). Generation figures shown are for gross generation (that is, including in-plant electricity use), except for Mongolia and the RFE.

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[14] File downloaded 10/28/16 from http://www.bp.com/content/dam/bp/excel/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-workbook.xlsx.

[15] See D. von Hippel and P. Hayes (2012), Foundations of Energy Security for the DPRK: 1990-2009 Energy Balances, Engagement Options, and Future Paths for Energy and Economic Redevelopment, Nautilus Institute Special Report, dated September 13, 2012, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/12/1990-2009-DPRK-ENERGY-BALANCES-ENGAGEMENT-OPTIONS-UPDATED-2012_changes_accepted_dvh_typos_fixed.pdf, for an earlier version of the updated DPRK electricity generation results used for this figure.

[16] United States Department of Energy, Energy Information Administration (2016), "International Energy Statistics, Mongolia", with data on net electricity generation available as http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=2&pid=2&aid=12&cid=MG,&syid=1980&eyid=2012&unit=BKWH (through 2009), Kh.Erdenechuluun, August 2014, "Mongolian power sector: Background and current policy", https://eneken.ieej.or.jp/data/5590.pdf (2010 through 2013), and Namjil ENEBISH, May, 2016, "Overview of Energy/Electricity demand and Renewable energy potential in Mongolia", https://www.renewable-ei.org/images/pdf/20160525/Enebish_Namjil.pdf (estimates for 2014 and 2015).

[17] Gulidov R. and A. Ognev (2007), "The Power Sector in the Russian Far East: Recent Status and Plans", prepared for the 2007 Asian Energy Security Project Meeting "Energy Futures and Energy Cooperation in the Northeast Asia Region", Tsinghua University, Beijing, China, October 31 – November 2, 2007. Presentation available at http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Russia-Energy-Changes.ppt.

Against this backdrop of growth in electricity needs—existing "business as usual" projections call for continuing strong increases in electricity use in the countries of East Asia (with the possible exception of Japan)—many of the countries of the region face significant energy resource constraints. The industrialized economies of Taiwan, the ROK, and Japan import over 90 percent of their energy needs. Vietnam and Indonesia, though they have been net energy exporters for several decades, are at or near the point where they will become net importers. China, though endowed with large reserves of coal and significant oil and gas reserves, is obliged to meet the energy needs of an increasingly affluent 1.3 billion people, and the economy that sustains them. As a result, China is increasingly an energy importer as well. The sparsely settled Russian Far East has a vast resource endowment—including hydraulic energy, coal, oil, and natural gas—that could potentially be harnessed for export to its neighbors. A combination of severe climatic conditions, politics, and huge financial requirements for the infrastructure needed to accomplish oil, gas, and power exports have slowed development of these resource sharing schemes. Even massive international pipelines and powerlines, however, will only make a modest contribution to the energy needs of Russia's energy-hungry neighbors.[18]

The resource constraints faced by most of the nations of the region, together with the technical allure of nuclear power, have made East Asia a world center for nuclear energy development, and—news reports of a global nuclear renaissance notwithstanding—one of the few areas of the world where significant numbers of nuclear power plants are being added. Nations have chosen nuclear power because they wish to diversify their energy portfolios away from fossil fuels (especially oil) and thus improve their energy supply security, because nuclear power provides a stable sources of baseload power with low air pollutant emissions (particularly compared with coal), and for the less practical but still significant reason that being a member of the nuclear energy "club" is seen as offering a certain level of status in the international community.

3 Future Nuclear Capacity and Generation Paths

Table 3-1 and Table 3-2 summarize the nuclear capacity included for each the three nuclear capacity expansion paths (Business as Usual, Maximum Nuclear, and Minimum Nuclear) for each country for the years 2010, 2030, and 2050. Figure 3-1, Figure 3-2, and Figure 3-3 shows the capacity trends by year and country if all nations follow each of the three paths, though in practice it is likely that the nations of East Asia and the Pacific will not all choose the same one of the three paths described, thus the capacities in these three figures shown could be thought of as an approximate bounding of a wide range of potential combinations. In fact, the internal and external conditions that would cause each country to adopt a "MAX" or "MIN" (or BAU) path vary by country, although some trends toward the extremes could be driven by international events (for example, another Fukushima-like event) or agreements (for example, nuclear fuel cycle cooperation that reduces tensions and increases citizen confidence in nuclear power) with impacts in many nations of the region. Descriptions of the assumptions driving Business as Usual (BAU), Maximum (MAX) and Minimum (MIN) nuclear capacity

[18] See, for example, von Hippel, D.F., and P. Hayes (2008), Growth in Energy Needs in Northeast Asia: Projections, Consequences, and Opportunities. Paper prepared for the 2008 Northeast Asia Energy Outlook Seminar, Korea Economic Institute Policy Forum, Washington, DC, May 6, 2008, and available as http://s3.amazonaws.com/zanran_storage/www.keia.org/ContentPages/44539229.pdf.

paths in each nation are summarized below. In many cases, these assumptions update work done by project colleagues from each of the different countries as prepared for previous Nautilus collaborative projects.

Table 3-1: Regional Nuclear Generation Capacity, Summary of BAU, MAX, and MIN Paths

	Total Nuclear Capacity Net of Decommissioned Units (GWe)								
	BAU (Reference) Case			Maximum Nuclear Case			Minimum Nuclear Case		
Nation	2010	2030	2050	2010	2030	2050	2010	2030	2050
Japan	49.16	46.39	26.23	49.16	56.36	33.29	49.16	26.14	2.27
ROK	17.72	36.71	32.70	17.72	38.14	41.25	17.72	24.15	20.42
China	10.26	97.28	141.82	10.26	114.35	240.81	10.26	75.55	99.29
RFE	0.05	0.47	0.77	0.05	1.77	8.77	0.05	0.17	0.17
Taiwan	5.14	3.90	3.90	5.14	7.77	11.70	5.14	-	-
DPRK	-	1.35	3.95	-	5.30	11.40	-	0.13	0.33
Indonesia	-	2.10	6.30	-	2.10	10.50	-	-	-
Vietnam	-	3.50	10.40	-	5.80	19.26	-	-	2.40
Australia	-	-	-	-	2.00	12.00	-	-	-
TOTAL	82.33	191.70	226.06	82.33	233.59	388.97	82.33	126.13	124.87

Table 3-2: Regional Nuclear Electricity Output, Summary of BAU, MAX, and MIN Paths

	Total Nuclear Electricity Output (TWhe)								
	BAU (Reference) Case			Maximum Nuclear Case			Minimum Nuclear Case		
Nation	2010	2030	2050	2010	2030	2050	2010	2030	2050
Japan	288	206	162	288	304	219	288	69	6
ROK	141	284	258	141	295	325	141	185	161
China	71	752	1,109	71	876	1,873	71	585	777
RFE	0	2	5	0	9	61	0	1	1
Taiwan	40	29	29	40	58	87	40	-	-
DPRK	-	9	28	-	35	90	-	1	2
Indonesia	-	16	47	-	16	78	-	-	-
Vietnam	-	26	77	-	43	143	-	-	19
Australia	-	-	-	-	16	95	-	-	-
TOTAL	541	1,323	1,715	541	1,651	2,971	541	841	966

Figure 3-1: Trends in Regional Nuclear Generation Capacity, BAU Path

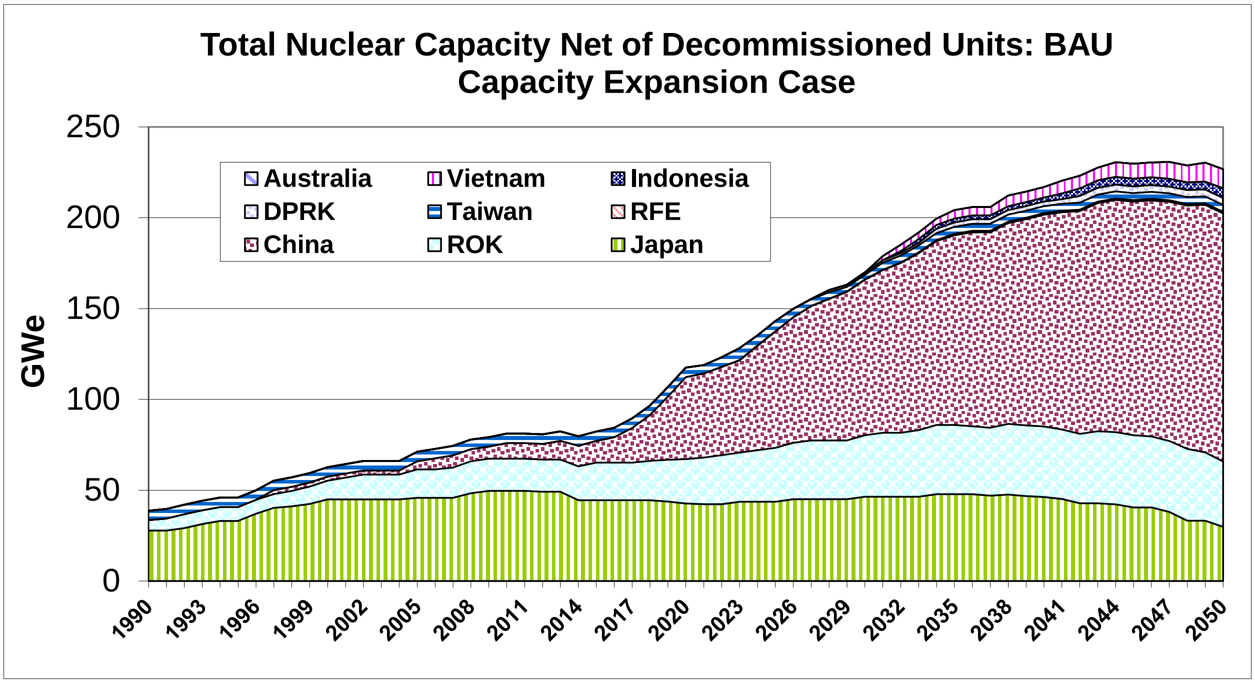


Figure 3-2: Trends in Regional Nuclear Generation Capacity, Sum of National MAX Paths

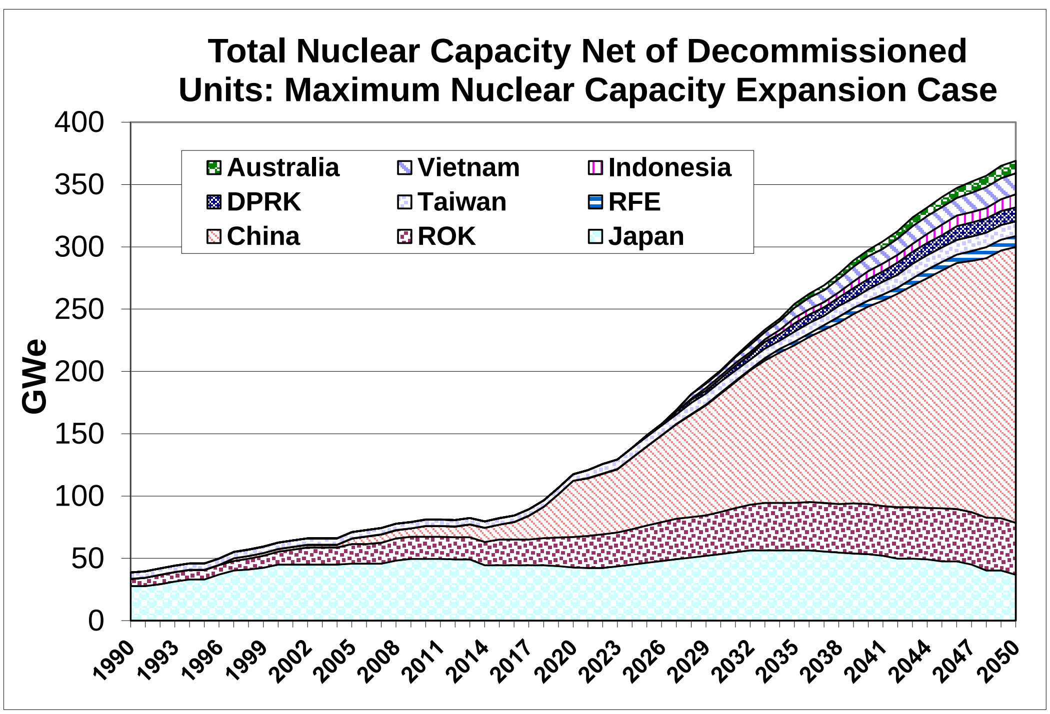
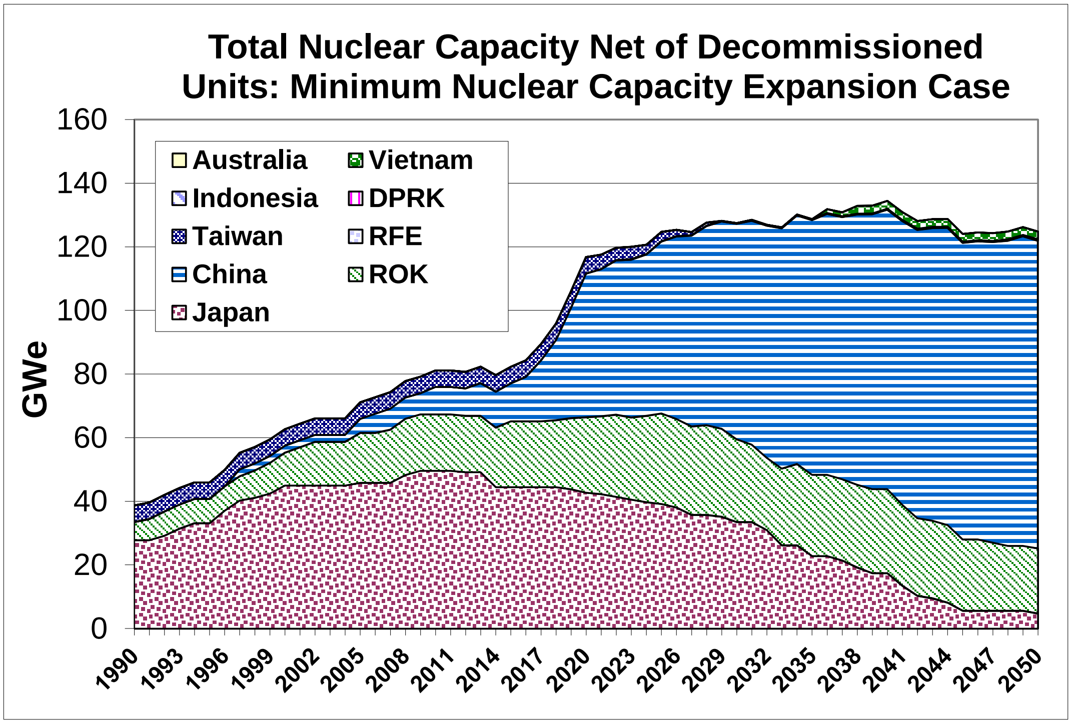


Figure 3-3: Trends in Regional Nuclear Generation Capacity, Sum of National MIN Paths



Key assumptions by country used to determine nuclear capacity and output for the other nations of East Asia and the Pacific are presented below, along with summary capacity results. Graphs showing capacity and output by year and by nation are available in Annex 1.

3.1 Nuclear Capacity Paths for Japan

Assumptions for **Japan** are based on recent work by Nautilus, but informed by work prepared by Dr. Kae Takase and other colleagues in the course of previous MacArthur-funded work.[19] In the **MAX** path, the nuclear industry starts most of its existing fleet of light water reactors in the next five years, extends reactor lifetimes to sixty years, and constructs new reactors that have been planned, mostly on existing sites. Overall, 30 of Japan's existing reactors (beyond the two Sendai units restarted in 2015) are assumed to restart within 10 years, excluding those at Fukushima Daiichi, where all units remain offline and decommissioning of the damaged reactors and undamaged reactors (in all, units 1 through 6) continues. Other older reactors for which decommissioning is underway are also decommissioned. In the MAX path for Japan, nuclear generation capacity increases to a maximum of about 56 GWe in 2029-2033, declining slowly thereafter to about 33 GWe in 2050 as older plants are decommissioned.

The **BAU** path for Japan follows the MAX path, but returns reactors to operation at a slower pace under the assumption that it will take more time to get the necessary permissions for reactor

[19] The three nuclear generation paths for Japan are based on three "Nuclear Restart" paths, the development and evaluation of which are described in the forthcoming Nautilus Institute Special Report David F. von Hippel and Peter Hayes (2016), *Japan's Post-Fukushima Choice: Future Nuclear Fuel Cycle Paths and Their Implications*, dated March, 2016.

restart and construction/operation of other facilities in place than assumed in the MAX Path. Here, the nuclear industry starts 10 of its existing fleet of light water reactors in the next five years (beyond the two Sendai units restarted in 2015), with 15 more started by 2030. Reactor lifetimes are extended to sixty years, but only five of the new reactors that have been planned for construction on existing sites are built (by 2035). Decommissioning of Fukushima Daiichi units 1-6 continues, as does decommissioning of other older reactor units. BAU path nuclear capacity rises to a maximum of about 48 GWe in 2031-2033, falling thereafter to 26 GWe in 2050 as reactors are decommissioned. In the **MIN** path, in addition to the two Sendai reactors restarted in 2015, 10 reactors are restarted over a period of five years, focusing on those in areas of Japan that are most power-hungry, and restarting reactors that are relatively new.

In the **MIN** path, life extension is not applied to Japan's existing reactor fleet, and no new reactors are built. It is, however, assumed that the standard reactor operating lives are calculated such that the post-Fukushima outage period is not counted—that is, if, for example, a reactor was offline from 2011 through 2016, it would be decommissioned 45, not 40, years after it began initial operation. MIN path capacity falls steadily from about 44 GWe in 2015 to just over 2 GWe in 2050. The MIN path is thus, effectively, a nuclear phase-out path for Japan.

3.2 Nuclear Capacity Paths for the Republic of Korea

The **ROK** is in a slightly different position than Japan, in that its reactor fleet has gone through safety checks, but remained largely in operation post-Fukushima, and its program of reactor construction, though somewhat delayed, is continuing. In the **MAX** path, it is assumed that reactor additions largely follow those reported by the World Nuclear Association through about 2030, and that thereafter one 1425 MWe unit is added approximately every three years through 2045, when units are added annually through 2049 to replace units shut down after the expiration of (extended) 60-year operating lifetimes.[20] Under this path, nuclear capacity rises steadily through 2033 to about 37 GWe, then more slowly to about 41 GWe by 2050.

In the **BAU** path for the ROK, the units listed by the World Nuclear Association through about 2030 are assumed to be slightly delayed in commissioning. After 2030, new advanced reactors are added in 2035, 2040, and 2045, and older units are shut down as they reach an operating life of 60 years. The result is that capacity falls from a high of about 37 GWe in 2035 to about 33 GWe by 2050.

The **MIN** path for the ROK assumes that a combination of factors, including, for example, reduced electricity demand, difficulties in siting new nuclear units, and/or increased competition from other electricity sources, serve to progressively delay the installation of planned (but not already under-construction) plants such that the last new plants on the World Nuclear Association list are installed in 2035 and 2036, as opposed to 2029 and 2030 in the MAX path. Thereafter, no new units are installed through 2050, and as a result of older reactors being shut down after their nominal 40-year lifetimes, overall nuclear capacity remains in the 23 to 26 GWe range from 2022 through 2036, falling slowly thereafter to 20 GWe by 2045.

3.3 Nuclear Capacity Paths for China

[20] Existing and planned reactors after about 2013 from World Nuclear Association (2016), "Nuclear Power in South Korea", updated October 2016, available as http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx.

In any nuclear capacity path for the East Asia/Pacific region, **China's** nuclear capacity, and growth in nuclear capacity, dominates. In the MAX path, China's nuclear generation capacity is assumed to rise to about 241 GWe by 2050, meaning construction of more than 200 GWe between 2017 and 2050. This path assumes that plants for which the World Nuclear Association provides an estimated data of operation begin to operate as scheduled, that the reactors listed the reactors listed as "planned" by the World Nuclear Association but without a listed operating date are all phased in by 2026, and that about 80 percent of the 195 GWe of reactors listed by the World Nuclear Association as "proposed" (or replacements similar in total capacity) are all phased in by 2050.[21] The MAX path also assumes that PWRs and BWRs in China are operated for 50 years, meaning that only Daya Bay units-1 and 2 and Qinshan-1 are shuttered by 2050, along with China's two CANDU units (which operate for 30 years).

For the **BAU** path, capacity assumptions start with the World Nuclear Association roster of additions, but are tempered by a continuation of recent reported slowdowns in the Chinese nuclear industry,[22] such that some plants now under construction are delayed, plants listed as planned are spread out further into the future, and a much smaller fraction (less than a quarter) of the 195 GWe of capacity listed by the World Nuclear Association as "proposed" is actually built. In addition, more plants are decommissioned under the BAU path relative to the MAX path, because PWR and BWR plant lifetimes are assumed to be 40 years. The net result is that the operating nuclear capacity in China by 2050 is about 142 GWe in the BAU path, still more than 40 percent higher than the current nuclear capacity in the United States, which now leads the world.

The **MIN** path for China assumes that a combination of unfavorable economics, competition from other electricity sources (such as wind and solar power), civil opposition to nuclear power, and demand for electricity that grows more slowly than anticipated results in an even more significant delay in the commissioning of under-construction and planned and planned plants than in the BAU path, and that after 2035 only an average of about one (advanced) reactor unit per year is commissioned. Even so, and with an assumed 40-year lifetime for PWRs and BWRs, China's nuclear generation capacity rises to just under 100 GWe by 2050.

Readers should note that none of these paths account for potential shocks that might arise from a serious accident in a Chinese nuclear power plant, with potentially devastating consequences for large populations. The timing of such an event, should it occur, is not knowable in advance, although there is a strong argument that it is statistically likely over the time frame of these paths given historical rates of major accidents per year of reactor operation.[23]

3.4 Nuclear Capacity Paths for the Russian Far East

[21] Reference for under construction, planned, and proposed plants in China from the year 2014 onward: World Nuclear Association (2016), "Nuclear Power in China", updated October 2016, available as http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx.

[22] See, for example, Steve Thomas (2016), "China's Nuclear Power Plans Melting Down", *The Diplomat*, October 29, 2016, available as http://thediplomat.com/2016/10/chinas-nuclear-power-plans-melting-down/.

[23] See He Zuoxiu, "Chinese nuclear disaster "highly probable" by 2030," *China Dialogue*, March 19, 2013, at: https://www.chinadialogue.net/article/show/single/en/5808, and S. Wheatley, B. Sovacool, D. Sornette (2017), "Of Disasters and Dragon Kings: A Statistical Analysis of Nuclear Power Incidents and Accidents," *Risk Analysis*, Volume 37, #1, pages 99-115, available as http://onlinelibrary.wiley.com/doi/10.1111/risa.12587/epdf.

The vast territory of the **Russian Far East** (RFE) is sparsely settled (about 6 million people) but contains a wealth of energy and mineral resources. At present, the only nuclear plants in the region are the four small (12 MWe each) Bilibinskaya combined heat and power units installed in the city of Bilbino in the Chutotka Autonomous Okrug of the RFE. This plant has the distinction of being the smallest and the northernmost operating nuclear power plant in the world. In each of the three paths, the RFE adds some capacity through 2020 by replacing the Bilibinskaya units with a floating power plant located about 250 km away at Pevek on the Arctic seacoast, and by adding two additional floating power plants, based on icebreaker nuclear reactor technology, at two other coastal RFE locations. In the **BAU** case, the only other additions through 2050 are a pair of 300 MWe units added in the far southern Primorsky province of the RFE in 2030 and 2032, respectively, and listed as "proposed" by the World Nuclear Association.[24] This capacity would serve the cities of the region (Vladivostok, Nakhodka, and Khabarovsk, for example, and the region around them) and possibly provide some exports to China. BAU capacity thus rises to about 770 MWe by 2032, and remains at that level through 2050. In the **MAX** case, these two units are assumed to be completed earlier, in 2025 and 2027, respectively, and are augmented by four pairs of 1000 MWe reactors installed between 2030 and 2045, raising 2050 capacity to just under 9 GWe. These larger reactors would be designed to mostly serve export markets and/or to provide power for producing electricity-intensive export commodities such as aluminum. In the **MIN** case, only the under-construction floating power plants are completed, and nuclear capacity in the RFE is about 170 MWe from 2022 through 2050.

3.5 Nuclear Capacity Paths for Taiwan (Chinese Taipei)

In **Taiwan**, as in Japan and the ROK, limited space for new reactors and a declining population limit the extent to which nuclear capacity can increase. In the **BAU** case, the Lungmen reactors, which have long been under construction, and which have been a focus of political and social contention for many years, are assumed to be finally brought on line in 2019 and 2020, just as older units start to be decommissioned following the expiration of their 40-year operating lifetimes. One additional unit is brought on line in 2028, probably on an existing reactor site, following the decommissioning of Taiwan's remaining older units. The new unit brings 2028 through 2050 capacity to 3900 MWe.

In the **MAX** case, the Lungmen units are brought on line in 2016 and 2019, practically the earliest dates possible given a 2015 decision to "seal" the reactors for 3 years.[25] An addition 1300 MWe unit is added in 2025 in the MAX case, based on national utility Taipower's plans as reported by the World Nuclear Association.[26] The life of existing reactors is extended to 50

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[24] World Nuclear Association (2016), "Nuclear Power in Russia", updated 30 September 2016, and available as http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx.

[25] The completed (or nearly-completed) and under-testing Lungmen units were reportedly "sealed" for three years starting in mid-2015. The assumption here is that they will come on line in 2019 and 2020, respectively, for the BAU case, and a year earlier in the MAX case. See "Taiwan seals Lungmen No.1 nuclear reactor", *Taiwan Today*, dated July 1, 2015, available as http://taiwantoday.tw/ct.asp?xItem=232105&ctNode=2182.

[26] The World Nuclear Association (2016) "Nuclear Power in Taiwan", Updated 26 September 2016, reported that Taipower had "projected one further unit beyond Lungmen 1&2 being on line by 2025". Despite recent protests, we assume that for this MAX case the unit will not be delayed, and thus assume that it will come on line in 2025. See http://www.world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx.

years, and larger reactors are added at existing sites when older reactors are decommissioned, pushing capacity to 11.7 GWe in 9 units by 2050.

In the **MIN** case, older reactors are decommissioned after 40-year lifetimes and not replaced, and the Lungmen reactors are never commissioned, resulting in Taiwan's nuclear generation capacity falling to zero by 2026.

3.6 Nuclear Capacity Paths for the Democratic People's Republic of Korea

The nuclear energy future of the **DPRK** is highly dependent on the political and economic path that the country takes with respect to the international community. As a result, the DPRK's nuclear generation capacity could be anywhere between practically nothing, if the isolation related to its nuclear weapons program continues, to more than 10 GWe, if actual or de-facto (economic) reunification with the ROK occurs relatively soon.

In the **BAU** case for the DPRK, we assume that the "Experimental LWR" (see Figure 3-4), estimated at 25 MWe and now apparently largely complete, but reportedly not yet operational, [27] is brought on line in 2020 at an average capacity factor of 60 percent. With skills gained in developing the Experimental LWR, and perhaps, given a political opening, assistance from the ROK, in the BAU path the DPRK develops and commissions a series of "domestic" 100 MWe reactors suited to the size of its grid, with the first unit on line in 2023, and seven more units of the same size following by from 2027 through 2049. In addition, renewed cooperation with the ROK allows three 1050 MWe LWR units—full-size reactors—to be finished in 2025 through 2039, possibly at the existing Sinpo site where reactors built by the Korean Peninsula Energy Development Organization (KEDO) were under construction until 2003, when construction, later terminated, was first suspended.[28] These new (or completed, though doubtless with many safety and other upgrades, given the passage of time) reactors would be built using ROK designs and with ROK and international labor and oversight, as well as DPRK labor, and would be connected directly to the ROK grid, as they are too large to operate on a stand-alone DPRK grid. The resulting DPRK nuclear generation capacity by 2050 would be just under 4 GWe, of which more than 3 GWe would be directly connected to the ROK grid (and/or, though somewhat less likely, the Chinese or Russian grids).

In the **MAX** case for the DPRK, the experimental LWR is brought on line earlier, in 2019, the first 100 MWe domestic reactor follows shortly, in 2021, and ROK-connected units, possibly at Sinpo, are commissioned in 2022 and 2024. This path essentially requires an almost immediate (post-2016) rapprochement between the DPRK and the ROK. By 2050, the MAX path assumes that eight 100 MWe reactors are built between 2023 and 2049, and that six advanced 1400 MWe units are built in ROK/DPRK joint ventures, with international oversight, between 2028 and 2043, to serve first the ROK grid, and later, a united Korean grid, following refurbishment/replacement of the DPRK's existing grid and, likely, economic and possibly political reunification.

[27] See David Albright, Sarah Burkhard, Allison Lach, and Samta Savla 2016), "Monitoring Activities at the Yongbyon Nuclear Site", dated September 20, 2016 (Rev.1) and available as http://isis-online.org/uploads/isis-reports/documents/Sept_2016_Yongbyon_Update_20Sept2016_Final.pdf.

[28] See KEDO (2016?), "About Us: Our History", available as http://www.kedo.org/au_history.asp.

Figure 3-4: DPRK Experimental LWR as of Summer, 2016[29]

Operation of the Experimental LWR is delayed in the MIN case until 2023, and the DPRK adds three 100 MWe units in 2028, 2037, and 2045, respectively, operating at average annual capacity factors of 60 percent. Although the DPRK could receive some help from the ROK and/or other parties (perhaps Russia) in developing its 100 MWe model, the MIN case is consistent with the DPRK's economic isolation generally continuing. The MIN nuclear path might also, however, be consistent with other political/technical/economic paths, such as actual or effective reunification together with a Korea-wide decision to phase out nuclear power, and/or nuclear power losing market to innovative renewable energy technologies.

3.7 Nuclear Capacity Paths for Vietnam, Indonesia, and Australia

For **Vietnam**, **Indonesia,** and **Australia**, which do not have and are not yet building nuclear power capacity, the **BAU** case includes first reactors that come on line in the last years of the 2020s in Vietnam and Indonesia, with Vietnam's program being much more aggressive (9 units

[29] Image from Google Earth, https://www.google.com/maps/place/Yongbyon+Nuclear+Scientific+Research+Center/@39.7956293,125.7549256,295m/data=!3m1!1e3!4m5!3m4!1s0x0:0x47e303bb5423c566!8m2!3d39.7750261!4d125.7543813, as of 11/7/16.

totaling over 10 GWe by 2046) than in the other two nations.[30] Recent news suggests that this may in fact be an ambitious BAU—reports indicate that Vietnam's government is "scrapping plans" for its first two pairs of reactors, due to spiraling costs and lowered electricity demand forecasts—but given that construction on the first plants included in the BAU might not start until the mid-2020s, the possibility remains that Vietnam could come back to nuclear power by that time.[31] The BAU path for Indonesia totals 6.3 GWe of capacity by 2048. Australia is assumed not to adopt nuclear power in the BAU path.

The **MAX** path includes greater use of nuclear power for each nation by both 2030 and 2050, with Vietnam installing over 19 GWe of generation from 2024 through 2050, Indonesia installing its first reactor in 2025, and 10.5 GWe by 2047, and Australia making the decision to build a nuclear fleet, perhaps in part to export power to East Asia, with reactors starting to come on line in 2026, and 12 GWe built and operating by 2050.

In the **MIN** path only Vietnam adopts nuclear power, but builds only its first two reactors, which come on line in 2033 and 2035 (totaling 2.4 GWe), several years later than in the BAU path, and no further reactor construction, perhaps as a result of a national economic slowdown, high costs, competition with other electricity sources, and/or other factors. Neither Indonesia nor Australia ultimately adopts nuclear power in the MIN path.

[30] For Vietnam, the "BAU" path is based roughly on a combination of projections from Pham, K.T. (2007), "Vietnam Energy Review and Power Development Plan: Period 2006 - 2015 with outlook to 2025", prepared for the "Asian Energy Security Project Meeting", Beijing, PRC, October 31-November 2, 2007, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Vietnam-Energy.ppt; and World Nuclear Association (2016) "Nuclear Power in Vietnam", dated July, 2016, and available as http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/vietnam.aspx. Assumes capacity additions from 2030 through 2050 will be about twice additions by 2030. For Indonesia, we assume that the first set of reactors referenced in Indriyanto A.R.S., B. T. Wattimena, and F. V. C. Mulia (2007), "Indonesia Energy Overview" (prepared for the "Asian Energy Security Project Meeting", Beijing, PRC, October 31-November 2, 2007, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Indonesian-Energy.ppt), are delayed but ultimately built in the BAU case in 2028/2029. For Australia, the MAX path includes about 50 percent of the additions suggested by the "Zwitkowski taskforce", as quoted in Falk, J. (2007), "Energy in Australia", prepared for the 2007 Asian Energy Security Project Meeting "Energy Futures and Energy Cooperation in the Northeast Asia Region", Tsinghua University, Beijing, China, October 31 - November 2, 2007, and available at http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Australia-Nuclear.ppt.

[31] Associated Press (2016), "Vietnam scraps plans for its first nuclear power plants", dated Nov. 10, 2016, and available as http://bigstory.ap.org/article/544e8f5088b347f0bf71138bf3f1bdb3/vietnam-scraps-plans-its-first-nuclear-power-plants.

4 Regional Scenarios for Cooperation on Spent Fuel Management

Nautilus has worked with colleagues in the region to develop and analyze four cooperation "scenarios" for nuclear fuel enrichment and for spent fuel management. The scenarios, and some (but hardly all) of the key policy issues they suggest, are as follows:

1. "**National Enrichment, National Reprocessing**": In this scenario the major current nuclear energy users in East Asia (Japan, China, and the ROK), and perhaps others as well, each pursue their own enrichment and reprocessing programs. Disposal of high-level nuclear wastes from reprocessing would be up to each individual country, with attendant political and social issues in each nation. Security would be up to the individual country, and as a result, transparency in the actions of each country is not a given.
2. "**Regional Center(s)**": This scenario features the use of one or more regional centers for enrichment and reprocessing/waste management, drawn upon and shared by all of the nuclear energy users of the region. We avoid identifying particular country hosts for the facilities, but China and Russia are obvious candidates.
3. "**Fuel Stockpile/Market Reprocessing**": Here, the countries of the region purchase natural and enriched uranium internationally, but cooperate to create a fuel stockpile that the nations of the region can draw upon under specified market conditions. Reprocessing services are purchased from international sources, such as France's AREVA or from Russia, while some spent fuel continues to be stored in nations where nuclear generation is used.
4. "**Market Enrichment/Dry Cask Storage**": In this, likely the least expensive of the four scenarios for participants, countries in the region (with the possible exception of China) would continue to purchase enrichment services from international suppliers such as URENCO in Europe, the USEC in North America, and Russia. All spent fuel, after cooling in ponds at reactor sites, would be put into dry cask storage either at reactor sites or at intermediate storage facilities.

Cooperation on nuclear fuel cycle activities could take place between all of the countries of East Asia and the Pacific, or a narrower group of several countries within the region, or a broader group of countries that could include nations outside the region. At their least demanding (in terms of costs and institutional arrangements between nations), cooperation options can involve relatively modest types of activities such as straightforward scientific, educational, and technical exchanges, or collaborations—for example, through the International Atomic Energy Agency (IAEA) or other international agencies—on sharing of information on nuclear "best practices". More complex options include consortiums for purchasing of raw uranium or of enriched fuel. More complex still are arrangements to share enrichment and spent-fuel management facilities. An IAEA Expert Group in 2005 produced a generic review of multilateral approaches to the nuclear fuel cycle, and some of that group's observations and suggestions are reflected in the proposals by other groups summarized below, as well as in the regional cooperation scenarios elaborated and evaluated in this paper[32]. A few of the benefits—and challenges—of regional cooperation on nuclear fuel cycle issues are listed below,[33] along with a discussion of some of the previous global nuclear fuel cycle cooperation initiatives that have been discussed, more detailed descriptions of the nuclear fuel cycle scenarios summarized above, and a discussion of the key analytical approaches used in this report to evaluate the relative costs and benefits of the four cooperation scenarios.

4.1 Potential Benefits and Challenges of Cooperation

Some of the benefits of cooperation on nuclear fuel cycle issues could include:

- Scientific, educational, and technical exchanges on nuclear fuel cycle issues help to assure that countries have a common understanding and knowledge base with regard to fuel cycle issues.
- Sharing nuclear facilities, whether enrichment, reprocessing, or spent-fuel facilities, provides viable alternative for countries that may, due to political, social, geological, or other concerns, have few positive prospects for domestic siting of such facilities.
- Achieving economies-of-scale for enrichment facilities, reprocessing centers, or geologic repositories, though economies of scale likely are stronger for some types of facilities—such as enrichment plants or mined geologic repositories—than for others, such as spent-fuel storage based on dry-cask technologies.[34]
- Creating a new revenue source for a host country.
- Sharing nuclear facilities may help to assure that all countries maintain consistent practices and quality control standards in working with nuclear materials, as well as consistent levels of safeguards, monitoring, and verification in nuclear fuel cycle activities, helping to build confidence between nations.
- Sharing of spent-fuel and reprocessing facilities can help to reduce proliferation risks by avoiding unnecessary accumulation of separated plutonium.

Implementing regional or international facilities, including those for spent fuel/radioactive waste storage/disposal, also will likely involve overcoming obstacles such as:

- Ethical issues in the region. There is some public perception that countries that have the benefits of nuclear power generation should bear the burden of storing and disposing of their radioactive wastes. This argument raises ethical and fairness issues that would oppose the concept of a regional/international repository. To obtain public and political support, an

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[32] International Atomic Energy Agency (IAEA, 2005), *Multilateral Approaches to the Nuclear Fuel Cycle: Expert Group Report submitted to the Director General of the International Atomic Energy Agency*. Document # INFCIRC/640, dated 22 February 2005, and available as http://www.iaea.org/Publications/Documents/Infcircs/2005/infcirc640.pdf.

[33] Kang, J. (2007), *Regional Spent Fuel Management in Northeast Asia: Status, Initiatives, and Issues*. Prepared for the Nautilus Institute East Asia Science and Security Collaborative project

[34] Bunn, M. and et al. (2001), *Interim Storage of Spent Nuclear Fuel: A Safe, Flexible, and Cost-Effective Near-Term Approach to Spent Fuel Management*. A Joint Report from the Harvard University Project on Managing the Atom and the University of Tokyo Project on Sociotechnics of Nuclear Energy. June 2001. Available as http://www.whrc.org/resources/publications/pdf/BunnetalHarvardTokyo.01.pdf.

arrangement for the regional/international repository should be based on a fair and equitable sharing of benefits between a repository host and other participating countries.

- Complicating national policies in the management of spent fuel and high-level waste (HLW). A regional/international repository could distract national spent fuel and radioactive waste management programs with hopes for an international facility.
- Perceptions of attempts at coercion by nuclear supplier states felt by states that would potentially participate in fuel cycle cooperation—essentially, perceptions by the nuclear fuel cycle "have nots" that nuclear supplier states ("haves") are attempting to limit the activities of those that do not have enrichment and/or reprocessing in the guise of non-proliferation.[35]
- A tendency toward decision-making in the nuclear sectors that focuses on the requirements and concerns of a single group of nuclear actors, rather than taking a more holistic approach. For example, groups responsible for the security and profitability of nuclear reactors will likely reach different conclusions as to optimal policy paths than groups focusing on national security/non-proliferation or on nuclear waste management.[36]
- Increasing transportation requirements in the region. The regional/international repository will involve frequent transportation of spent fuel/radioactive waste from participating countries to a host country, and increasing concern over nuclear accidents during the transportation that may lead radioactive release to the environment. Proliferation risks due to diversion of materials during transport are also a concern.

4.2 Previous Global Nuclear Fuel Cycle Cooperation Proposals in East Asia

Regional (East Asia), and indeed, global nuclear fuel cycle cooperation proposals have been offered by a number of groups and individuals over the past two decades and earlier. Below we provide brief descriptions of selected prior proposals. Other authors have reviewed these and other proposals in greater detail than is possible here.[37]

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[35] Yudin, Y. (2011), *Multilateralization of the Nuclear Fuel Cycle A Long Road Ahead, United Nations Institute for Disarmament Research*, report number m UNIDIR/2011/5, available as http://www.unidir.org/files/publications/pdfs/multilateralization-of-the-nuclear-fuel-cycle-a-long-road-ahead-378.pdf, expresses this perception of coercion as follows:

> "A legacy of exclusiveness and coerciveness may make the future of multilateral approaches to the nuclear fuel cycle rather dim. Many non-supplier states have expressed concerns that suppliers may try to broaden the NPT division between nuclear-weapon states and non-nuclear-weapon states under the guise of non-proliferation. This suspicion can be traced, at least in part, to some early proposals for multilateral approaches—the 2004 Bush proposal, the Global Nuclear Energy Partnership, the six-country concept, and the World Nuclear Association proposal—that required non-supplier states to forgo domestic development of sensitive fuel-cycle technologies. Such preconditions were met with strong disapproval. These proposals can be blamed for giving rise to a false impression that multilateral fuel-cycle mechanisms necessarily imply discrimination between nuclear technology haves and have-nots."

[36] See, for example, Sharon Squassoni (2016), *Workshop Report, Nuclear Security And Regional Fuel Cycle Decisions: Northeast Asia*, Center for Strategic and International Studies, dated January 26, 2016, and available as https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/20160126_Sharon_Squassoni_Workshop_Report_Nuclear_Security_And_Regional_Fuel_Cycle_Decisions_Northeast_Asia%20.pdf.

[37] See Yudin, Y. (2009), *Multilateralization of the Nuclear Fuel Cycle: Assessing the Existing Proposals*, United Nations Institute for Disarmament Research, report # UNIDIR/2009/4, available as http://www.unidir.ch/pdf/ouvrages/pdf-1-978-92-9045-195-2-en.pdf; Yudin, Y. (2011), ibid; Suzuki, T. (1997),

- Interest in regional/international spent fuel/radioactive waste storage/disposal increased significantly in the 1970s and early 1980s. In 1977, the IAEA reported that regional fuel cycle centers were feasible and would offer considerable nonproliferation and economic advantages. In 1982, the IAEA concluded a project of the International Fuel Cycle Evaluation (INFCE) in which IAEA expert groups suggested an establishment of international plutonium storage and international spent fuel management.[38]

- In the mid-1990s, the concept of the International Monitored Retrievable Storage System (IMRSS) was proposed by Wolf Hafele. The IMRSS envisioned international sites where spent fuel, and possibly also excess separated plutonium, could be stored under monitoring for an extended period but could be retrieved at any time for peaceful use or disposal.[39]

- In the mid-1990s through the late 1990s, a number of proposals for nuclear power sector cooperation in the Asia-Pacific region, on topics ranging from safety to proliferation to waste management, were developed. Tatsujiro Suzuki[40] prepared a comparison of various proposals for regional nuclear cooperation offered during the period, and concluded that there are potential areas of cooperation where common needs and interests exist among the countries of Northeast Asia. At present, however, none of these proposals have been implemented to a significant degree.

- The past decade has seen a number of additional proposals for cooperation on uranium enrichment, management of nuclear spent fuels, or both, many involving East Asian and Pacific countries. Brief summarizes of just some of the cooperation proposals on international enrichment and/or low-enriched uranium (LEU) fuel supply and spent fuel management that have come forth in the last 10 years or so follow.[41]

- The **Global Nuclear Energy Partnership (GNEP)**, proposed by the United States during the George W. Bush administration (in 2006), had as its enrichment component a proposal to establish a group of enriched fuel supplier states, and a requirement that those states provide enriched fuel to non-supplier nations at a reasonable cost, while reducing the potential for proliferation of sensitive technologies, in part through cooperation with the IAEA on nuclear safeguards.[42] GNEP proposed coupling these fuel supply guarantees and with spent fuel "take back" arrangements. GNEP has received when the U.S. Congress cut funding to the program in 2008, and eliminated funding (except for a parallel but related "Advanced Fuel

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"Nuclear Power in Asia: Issues and Implications of "ASIATOM" Proposals", in: *United Nations Kanazawa Symposium on Regional Cooperation in Northeast Asia*, Kanazawa, Japan. June 2-5, 1997; and Tanabe, T. and Suzuki, T. (1998). "Institutional and Policy Issues for Cooperation Schemes in the Asia-Pacific Region", in *Pacific Basin Nuclear Conference*, Banff, Canada, May 3-7, 1998.

[38] Bunn et al., (2001), ibid.

[39] Hafele, W. (1996), "The Concept of an International Monitored Retrievable Storage System". In: *Uranium Institute Symposium*, London, UK, August 1996.

[40] Suzuki (1997), ibid.

[41] Suzuki, T. and T. Katsuta (2009), "A Proposal of Multilateral Nuclear Fuel Cycle Approach: 'International Nuclear Fuel Management Arrangements (INFA)'", presentation prepared *for A-MAD Project Mini Workshop on Policy Recommendations for Nuclear Disarmament and Non-proliferation*, September, 2009, and available as http://a-mad.org/download/MNA_Suzuki_Katsuta_AMAD_090930.pdf.

[42] Tomero, L., (2008), "The future of GNEP: The international partners", *Bulletin of the Atomic Scientists* web edition, dated 31 July 2008, available as http://www.thebulletin.org/web-edition/reports/the-future-of-gnep/the-future-of-gnep-the-international-partners.

Cycle Initiative" that funds reprocessing research and development) for 2009. GNEP has, however, been recast as the **International Framework for Nuclear Energy Cooperation (IFNEC)**, which "is a partnership of countries aiming to ensure that new nuclear in initiatives meet the highest standards of safety, security and non-proliferation" and "involves both political and technological initiatives, and extends to financing and infrastructure". [43]

- The **International Uranium Enrichment Center (IUEC) and LEU Nuclear Fuel Bank**, was proposed by Russia in 2006, and initiated by Russia shortly thereafter. The concept is for Russia to host the IUEC at its existing Angarsk Electrolytic Chemical Combine[44]. Membership in the enrichment center, intended to be on an "equal and non-discriminatory basis", requires charter states to forego developing their own enrichment facilities, and be in compliance with their nonproliferation obligations (including membership in the Treaty on the Non-Proliferation of Nuclear Weapons). Reserves of LEU were placed at Angarsk in late 2010, and the IUEC Agreement went into force in early 2011, after which "the LEU reserve in Angarsk has been available for IAEA Member States", constituting "the first proposals on nuclear fuel supply assurances to have been put into practice".[45]

- In 2006, **NTI (the Nuclear Threat Initiative)** pledged $50 million toward an **International Fuel Bank** to be run by the IAEA. Since then, $100 million in matching contributions have been pledged by other countries. Similar to the Russian proposal, but not affiliated with a specific enrichment center, the goal of the Fuel Bank concept by NTI "…is to help make fuel supplies from the international market more secure by offering customer states, that are in full compliance with their nonproliferation obligations, reliable access to a nuclear fuel reserve under impartial IAEA control should their supply arrangements be disrupted. In so doing, it is hoped that a state's sovereign choice to rely on this market will be made more secure"[46]. As of early 2010, the IAEA was planning to site the LEU repository at a remote site in Kazakhstan, at a metallurgical factory with existing storage infrastructure. IAEA member states voted in favor of the fuel bank in late 2010.[47]

- In April of 2007, **Germany** proposed to the IAEA the creation of **a multilateral enrichment facility**, established by a group of interested states, to be placed in a host states but on an

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[43] World Nuclear Association (2012), "International Framework for Nuclear Energy Cooperation (formerly Global Nuclear Energy Partnership)", updated July 2012, and available as http://www.world-nuclear.org/info/inf117_gnep.html.

[44] Loukianova, A. (2008), "The International Uranium Enrichment Center at Angarsk: A Step Towards Assured Fuel Supply?", NTI Issue Brief, updated November, 2008, available as http://www.nti.org/e_research/e3_93.html.

[45] See International Atomic Energy Agency (IAEA, 3011), "Assurance of Supply for Nuclear Fuel: IUEC and the LEU Guaranteed Reserve", dated 31 October, 2011, and available as http://www.iaea.org/OurWork/ST/NE/NEFW/Assurance-of-Supply/iuec.html.

[46] Nuclear Threat Initiative (NTI, 2009), "NTI/IAEA Fuel Bank Hits $100 Million Milestone; Kuwaiti Contribution Fulfills Buffett Monetary Condition", NTI press release dated March 5, 2009, available as http://www.nti.org/c_press/release_Kuwait_Fuel_Bank_030509.pdf; NTI (2010), "IAEA to Pursue Nuclear Fuel Bank in Kazakhstan". Global Security Newswire, dated Jan. 11, 2010, available as http://gsn.nti.org/gsn/nw_20100111_3105.php; and Horner, D. (2010), "IAEA Board Approves Russian Fuel Bank Plan", *Arms Control Today* January/February 2010, available as http://www.armscontrol.org/act/2010_01-02/FuelBank.

[47] Nuclear Threat Initiative (NTI, undated, but probably 2011), "International Nuclear Fuel Bank", available as http://www.nti.org/about/projects/international-nuclear-fuel-bank/.

"extraterritorial basis".[48] Like the Russian proposal, and similar to the Fuel Bank NTI proposal, the facility would help assure supplies of enriched fuels to nations that qualify based on adherence to their non-proliferation treaty commitments and related IAEA safeguards.[49]

- The so-called **"Six-Country" Proposal of a Nuclear Fuel Assurance Backup System**, offered in 2006 by the enriched fuel supplier nations France, Germany, the Netherlands, Russia, the United Kingdom, and the United States, proposed that enrichment suppliers would substitute enrichment services for each other to cover supply disruptions for enriched fuel consumers that have "chosen to obtain suppliers on the international market and not to pursue sensitive fuel cycle activities". Further, the proposal would provide "physical or virtual" reserves of LEU fuel for use in the event that other fuel assurances fail.[50]

- Also in 2006, **Japan** proposed an **IAEA Standby Arrangements System for the Assurance of Nuclear Fuel Supply**. This system would be managed by the IAEA and would offer information, provided voluntarily by nuclear fuel supplier countries, on the status of uranium ore, reserves, conversion, enrichment, and fuel fabrication in each country. The goal of this system is to help prevent disruption in international fuel supplies by acting as a kind of "early warning" system of impending supplier shortfalls for states purchasing fuel or fuel services. If a disruption in supply takes place, under this system, the IAEA acts as intermediary in helping a consumer country find a new supplier country.[51]

- In the 1990s, a commercial group called **Pangea** was looking for an **international geologic repository for both spent fuel and radioactive wastes**. Envisioning a facility for disposing of 75,000 MT heavy metal of spent fuel/HLW, Pangea initially selected Australia for its proposed repository, but is seeking other sites around the world after confronting political opposition in Australia.[52]

- During the late 1990s to early 2000s, two proposals involving depository sites in Russia were presented. One was a concept of the **Nonproliferation Trust** (NPT) that called for establishing a dry cask storage facility in Russia that would accept 10,000 MT heavy metal of spent fuel from abroad, and would include eventual spent fuel disposal. The other was a concept offered by **MINATOM (**Ministry for Atomic Energy of Russia) that suggested a plan for an international spent fuel service involving offering temporary storage with later return of the spent fuel, or reprocessing of spent fuel without return of plutonium or radioactive wastes for customer countries.[53]

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[48] Rauf, T., and Z. Vovchok (2007), "Fuel for Thought". *IAEA Bulletin* 49-2, March 2008, pages 59-63, available as http://www.iaea.org/Publications/Magazines/Bulletin/Bull492/49204845963.pdf.

[49] International Energy Agency (IAEA, 2007*), Communication received from the Resident Representative of Germany to the IAEA with regard to the German proposal on the Multilateralization of the Nuclear Fuel Cycle*, IAEA document # INFCIRC/704, dated 4 May 2007, and available as http://www.iaea.org/Publications/Documents/Infcircs/2007/infcirc704.pdf.

[50] United Nations Institute for Disarmament Research (2009), UNIDIR project "Multilateral Approaches to the Nuclear Fuel Cycle". Available as www.unidir.org/pdf/activites/pdf3-act396.pdf

[51] Rauf and Vovchok,(2007), ibid; Yudin (2009), ibid.

[52] Bunn and et al. (2001), ibid.

[53] Bunn and et al. (2001), ibid.

- In 2003, Dr. Mohamed El Baradei suggested multinational approaches to the management and disposal of spent fuel and radioactive waste[54]. In 2005, commissioned at Dr. M. El Baradei's suggestion in 2003, the IAEA published a report on Multilateral Approaches to the Nuclear Fuel Cycle in which the IAEA concluded that such approaches are needed and worth pursuing, on both security and economic grounds.[55]

- In January 2006, Russian President Vladimir Putin announced a **Global Nuclear Power Infrastructure** (GNPI) initiative to provide the benefits of nuclear energy to all interested countries in strict compliance with nonproliferation requirements, through a network of international nuclear fuel cycle centers (INFCC). INFCC are conceived as being related to the provision of enrichment services and to spent fuel management issues through the provision of reprocessing and the disposal of residual waste within the framework of INFCC, under IAEA safeguards.[56]

- In 2008, Tatsujiro Suzuki and Tadahiro Katsuta proposed the idea of an "**International Nuclear Fuel Management Association** (INFA)" as a multilateral nuclear fuel cycle approach[57]. The central principles of the INFA are universality, meaning avoiding discrimination between nuclear "haves" and "have nots", transparency, meaning that the IAEA "Additional Protocol" or equivalent safeguards arrangements should be applied for all facilities, and demand should come first before supply, and economic viability, meaning that the activities of the Association should be consistent with global nuclear fuel market activities, and that the economic rationale of the Association should be clearly defined to support nuclear fuel cycle programs.

- The Northeast Asia Peace and Cooperation Initiative, an ROK-led process that proposes to address several (often interrelated) topics of mutual concern to the countries of the region, one of which is "nuclear safety", through a gradual, stepwise process.[58] The Initiative is notable in the it explicitly seeks to include the DPRK, but it does not yet seem to have articulated specific goals or proposals for regional nuclear fuel cycle collaboration.

4.3 Scenarios for Nuclear Fuel Cycle Cooperation in Northeast Asia

The descriptions below update earlier Nautilus analyses of four cooperation "scenarios" for nuclear fuel enrichment and for spent fuel management. These generic scenarios borrow many concepts from earlier enrichment and spent-fuel management cooperation proposals, some of which are summarized above. Each scenario includes specific assumptions by country for each of several fuel-cycle "nodes": uranium mining and milling, uranium transport, uranium

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[54] El Baradei, M. (2003), "Toward a Safer World". *The Economist*, October 16, 2003.

[55] International Atomic Energy Agency (IAEA, 2005), *Multilateral Approaches to the Nuclear Fuel Cycle: Expert Group Report submitted to the Director General of the International Atomic Energy Agency*. Document # INFCIRC/640, dated 22 February 2005, and available as http://www.iaea.org/Publications/Documents/Infcircs/2005/infcirc640.pdf.

[56] Ruchkin, S.V. and Loginov, V.Y. (2006), "Securing the Nuclear Fuel Cycle: What Next?". *IAEA Bulletin* 48/1, September 2006.

[57] Suzuki, T. and T. Katsuta (2009), ibid.

[58] See, for example, ROK Ministry of Foreign Affairs (MOFA), Northeast Asia Peace and Cooperation Initiative, undated, but probably 2014 or 2015, available as http://www.mofa.go.kr/ENG/North_Asia/res/eng.pdf.

conversion and enrichment, fuel fabrication, transportation of fresh reactor fuel, electricity generation, spent fuel management (including reprocessing), spent fuel transport, and permanent disposal of nuclear wastes. Key attributes of the scenarios are as follows:

1. "**National Enrichment, National Reprocessing**": In this scenario the major current nuclear energy users in East Asia (Japan, China, and the ROK) each pursue their own enrichment and reprocessing programs, with all required enrichment in those countries accomplished domestically by 2025 or 2030. For Japan, domestic enrichment of all of its own uranium needs in the BAU or MAX nuclear capacity paths would require the construction of facilities beyond the total of 1.5 million SWU per year scheduled to be on line by 2022,[59] probably together with stockpiling some enriched uranium prior to the full restart of reactors. Note that enrichment and reprocessing activities by the ROK under this scenario would imply and require the assent of the United States under the "U.S.-Republic of Korea Nuclear Cooperation Agreement" revised and re-signed by the US and ROK in June, 2015.[60] Other countries may also pursue domestic enrichment, though this scenario assumes that other countries import enrichment services through 2050. Reprocessing uses 60 percent of newly cooled spent fuel (SF) in the ROK (and the DPRK) in each path.[61] In China, reprocessing uses 60 percent of newly cooled spent fuel in the BAU and MIN paths, and 80 percent in the MAX path.[62] In Japan, reprocessing operates at 85 percent of capacity in the MAX path, and 55 percent in the BAU path, but not at all in the MIN path, and is in place in Japan by 2020 (or, more accurately, the Rokkasho facility is assumed to be commissioned and operational by then). Reprocessing is in place in the ROK/China by 2030. Nuclear fuel is assumed to be fabricated where uranium is enriched and/or fuel is reprocessed. Half of the reactors in China and the ROK eventually use 20% mixed oxide fuel (fuel including mixed uranium and plutonium oxides, or MOx), with half of the reactors in Japan using 30 percent MOx fuel in the MAX and MIN paths, and 40 percent of reactors using MOx in the BAU path, but MOx use starts earlier in Japan than in the other nations. Japan, Taiwan, and the ROK import uranium; other nations in the region eventually produce half of their U needs domestically except Australia, which produces all of its needs, and the Russian Far East, which imports all of its modest needs from elsewhere in Russia. Arrangements for disposal of high-level nuclear wastes from reprocessing would be up to each individual country, with attendant political and social issues in each nation. Security would be up to the individual country, and

[59] World Nuclear Association (2016), "Japan's Nuclear Fuel Cycle", updated September 2016, available as http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-fuel-cycle.aspx, and Park Younwon, "Securing Nuclear Safety in Northeast Asia: ROK Proposal on Northeast Asia Nuclear Safety Mechanism", NAPSNet Special Reports, May 04, 2015, http://nautilus.org/napsnet/napsnet-special-reports/securing-nuclear-safety-in-northeast-asia-rok-proposal-on-northeast-asia-nuclear-safety-mechanism/

[60] See, for example, United States Congressional Research Service (CRS, 2015), CRS Insights, U.S.-Republic of Korea Nuclear Cooperation Agreement, dated June 30, 2015, and available as https://www.fas.org/sgp/crs/nuke/IN10304.pdf.

[61] For the DPRK, the assumption is that spent fuel from the large reactors in the DPRK that are connected to the ROK grid in the BAU and MAX paths, which would dominate the overall DPRK spent fuel production, would be reprocessed in an ROK facility (or an all-Korean facility in a unified Korea).

[62] The growth in China's nuclear generation, particularly in the MAX path, is such that without a higher fraction of the reprocessing of newly cooled (eight-year-old) spent fuel, insufficient plutonium will be available to supply MOx for Chinese reactors. In practice, it is likely that older cooled spent fuel and/or spent fuel from other nations (the latter in Scenarios 2 and 3) would be used to make up any gap between the amount of separated Pu needed to meet MOx fuel demand and Pu produced via reprocessing.

as a result, transparency in the actions of each country is not a given. Disposal of spent fuel and of high-level nuclear wastes from reprocessing is assumed to be carried out in each individual country, with interim storage or dry cask storage use assumed through 2050.

2. "**Regional Center(s)**": This scenario features the use of one or more regional centers for enrichment and reprocessing/waste management, drawn upon and shared by all of the nuclear energy users of the region. We avoid identifying particular country hosts for the facilities, but China and Russia are obvious candidates, though the potential involvement of other countries, including Mongolia, has been suggested.[63] The centers are assumed to be operated by an international consortium, and drawn upon and shared by all nuclear energy users in region. The consortium imports uranium for enrichment from the international market, and shares costs between participants. China limits its own production of uranium to current levels, which provides a progressively smaller share of China's uranium needs as the Chinese nuclear sector grows.[64] Nuclear fuel (including MOx) is fabricated at the regional center(s), with use of MOx by country the same as in Scenario 1. Reprocessing of spent fuel from the ROK, the DPRK, and China also occurs in the same amounts as in Scenario 1, but is accomplished in regional center(s) starting in 2025, with phase-in complete by 2030, and with reprocessing of half of the spent fuel from other nations carried out in regional centers by 2050. Japan's domestic reprocessing is initially the same by path as in Scenario 1, but transitions to regional centers starting in 2025 and ending in 2030 (still without reprocessing in the MIN path). Disposal of spent fuel and high-level nuclear wastes from reprocessing is done in coordinated regional interim storage facilities, pending development of permanent regional storage in the post-2050 period.

3. "**Fuel Stockpile/Market Reprocessing**": Here, the countries of the region purchase natural and enriched uranium internationally, but cooperate to create a fuel stockpile (the equivalent of one year's consumption of natural uranium and enriched fuel) that the nations of the region can draw upon under specified market conditions. Enrichment is purchased from international sources except for the existing modest Japanese and Chinese capacity. Reprocessing services are purchased from international sources, such as France's AREVA or from Russia, while some spent fuel continues to be stored in nations where nuclear generation is used. Nuclear fuel (**excluding** MOx) is fabricated where uranium is enriched. Reprocessing of spent fuel is done in the same amounts as in Scenario 2, but is carried out at international center(s), where MOx fuel is fabricated for use in the region (with MOx use as in Scenarios 1 and 2). The exception is in Japan, where, as in Scenario 2, domestic reprocessing operates starting in 2018 and ending by 2025, when international reprocessing is used. Management of spent fuel and high-level nuclear wastes from reprocessing is accomplished using international interim storage facilities, possibly including facilities in the region, pending development of permanent regional storage post-2050.

[63] Again, recent informal discussions with Mongolian officials suggest that participating in the regional nuclear fuel cycle was not at all of interest to the Mongolian government as of 2014/2015, despite the existence of substantial U resources in the country (see, for example, World Nuclear Organization, "Uranium in Mongolia", updated April 2016, and available as http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/mongolia.aspx), but we note that government positions can and do change over time, thus the mention of Mongolia here for the sake of completeness.

[64] Australia, as a major uranium supplier, is assumed to produce all of its domestic uranium needs in all scenarios, although that assumption is only relevant for the MAX path, which is the only path in which Australia adopts commercial nuclear generation.

4. "**Market Enrichment/Dry Cask Storage**": In this scenario, countries in the region (with the possible exception of China) would continue to purchase enrichment services from international suppliers such as URENCO in Europe (and the US), the USEC in North America, as well as from Russia, except that existing Chinese capacity enrichment capacity would continue to be used, and existing Japanese capacity would be used until it is closed after 2020. Uranium and enrichment services purchases would be through an international consortium, as in scenarios 2 and 3. Japan and China cease reprocessing in 2015, and no other countries reprocess spent fuel after that point either at international or in-region facilities. Japan's MOx use would be phased out by 2013 and no MOx use would occur elsewhere in the region. All spent fuel, after cooling in ponds at reactor sites, would be put into dry cask storage either at reactor sites or at intermediate storage facilities.[65] High-level wastes from reprocessing (before 2016) would also be placed in interim storage facilities.

These scenarios are not by any means intended to exhaust the universe of possible nuclear fuel cycle cooperation (or non-cooperation) options for the region. We believe that these scenarios do, however, represent a reasonable range of the different options that could be adopted.

4.4 Key Analytical Approaches and Assumptions

In order to the estimate the relative costs and benefits of the four nuclear fuel cycle cooperation scenarios summarized above, the following analytical approach was taken. What is presented here is necessarily a condensed description of the methods and data used; please see our more detailed 2010 report for further details, but please note that some model parameters have been updated consistent with the assumptions described here to prepare the results reported below.[66] Additional details of assumptions used in the analyses described here are available in the printouts provided in Annex 2A to this Report.

As a first step, nuclear paths specified by EASS country working groups, in some cases modified as noted above by the authors, served as the basis for calculating nuclear fuel requirements, and spent fuel arisings (including arisings from decommissioned plants). To these estimates of fuel requirements, calculated for each of the three nuclear "paths" in each country, as presented above, we overlaid the four scenarios of regional cooperation on nuclear fuel cycle issues over a timeline of 2000 through 2050. Simple stock and flow accounting was used to generate estimates of major required inputs to and outputs of the nuclear reactor fleet in each country, and of other nuclear facilities such as enrichment and reprocessing facilities. The fuel cycle nodes modeled were uranium mining and milling, uranium transportation and enrichment, fuel fabrication and reactor fuel transport, and reprocessing and spent fuel management. Key inputs

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[65] As noted in the Introduction to this Report, dry-cask storage of spent fuel appears much less vulnerable to release of radiation through accident or attack than storage in spent fuel pools. Release of radiation from fuel stored in dry casks essentially requires a concerted effort targeted specifically at the dry cask to not only break it open—requiring high explosives detonate essentially on the cask or physically drilling into the cask, requiring proximity of attackers—but to ignite the spent fuel assemblies stored in the cask. Zircaloy-clad fuel assemblies in dense-racked spent fuel pools, on the other hand, can ignite if water from the pool is lost, as dense-racked pools lack the ability to passively release sufficient heat through the air when coolant is lost, leading to rising temperatures and, eventually, ignition of fuel cladding, resulting in releases of radioactivity.

[66] von Hippel, D., T. Suzuki, T. Katsuta, J. Kang, A. Dmitriev, J. Falk, and P. Hayes (2010), *Future Regional Nuclear Fuel Cycle Cooperation in East Asia: Energy Security Costs and Benefits*, Nautilus Institute Report, June, 2010, available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/EASS_Report_6-2010_rev.pdf.

at each (applicable) node included the mass of uranium (in various forms) and plutonium, energy, enrichment services, transport services, and money, accounted for by country and by year. Key outputs at each node included uranium and plutonium, spent UOx (uranium oxide) and MOx fuel, and major radioactive waste products, again by country and year. Costs are presented and calculated in approximately 2009 dollars, except where noted.

Using this approach, quantitative results for 12 different regional cooperation scenario and nuclear power development path combinations were generated. These quantitative results were coupled with qualitative considerations to provide a side-by-side comparison of the energy security—broadly defined to include not just energy supply and price security, but technological, economic, environmental, social/cultural, and military security aspects as well[67]— attributes of four cooperation scenarios. As such, we used the energy security comparison methodology developed by Nautilus Institute and its partners under a series of initiatives starting in 1998.

Many of the parameters incorporated in the analysis described here are uncertain, with the future costs of nuclear materials and facilities perhaps the most uncertain. As such, numerous assumptions informed by a variety of literature sources were used in this analysis. Some of the key assumptions used in the analysis are as follows:

- Uranium Cost/Price: \$60/kgU in 2016,[68] escalating at 5.5%/yr through 2035 as demand increases and inventories are used up in the near term, and at 3.5 percent per year thereafter through 2050. Note that these prices are indicative of spot market prices. Long-term prices, associated with uranium purchased under long-term contracts, have historically been about \$25 more per kgU than spot market prices. This projection serves as a "medium" scenario, but uncertainties are, as noted, substantial. Just in the last decade, uranium prices "spiked" in 2007 at over \$260/kg, fell to about the \$120/kg level by 2009-2010, rose again in early 2011, then began to fall, particularly after the Fukushima accident, with continued decline, on average (though not in every year) over 2012 through September 2016 to about \$60 per kg, due to an international glut in uranium production and inventories. As alternative projections of uranium prices, we prepared a "High" projection that assumes 7.3 percent average annual growth through 2035, and 5 percent average growth per year thereafter, and a "Low" projection case below, we assume an increase in uranium costs of 3.0% annually through 2020 from the current (2016) very low U prices, and a modest 0.50% annual real increase in uranium costs thereafter.[69] It might be considered reasonable to pair the different projections of uranium prices with the different nuclear energy development paths, as we have done for enrichment prices (see below). We have decided against doing so, however, because it seems likely that uranium supply can respond to different levels of demand much more quickly than can enrichment capacity. We thus use the medium uranium price projection for all four scenarios of cooperation and for all three nuclear energy capacity paths, but use

[67] See, for example, von Hippel, David F., Suzuki, Tatsujiro, Williams, James H., Savage, Timothy, and Hayes, Peter (2011), "Energy Security and Sustainability in Northeast Asia", Asian Energy Security special section of *Energy Policy*, 39(11), 6719–6730; and von Hippel, David F., Suzuki, Tatsujiro, Williams, James H., Savage, Timothy, and Hayes, Peter (2011), "Evaluating the Energy Security Impacts of Energy Policies", in Benjamin K. Sovacool (Ed.), *The Routledge Handbook of Energy Security* (pp. 75–95), Oxon, UK: Routledge.
[68] Recent historical prices from Cameco "URANIUM PRICES, Uranium Spot Price History, though September, 2016, available as http://www.cameco.com/invest/markets/uranium-price.
[69] This is the same escalation rate used by a team of MIT researchers in preparing "Update of the MIT 2003 Future of Nuclear Power Study", dated 2009, and available as http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf.

alternative price projections to prepare sensitivity analyses.

- Average uranium (U) concentration in ore purchased from international market sources: 2.5%. Note that this estimated average, based mostly on 2011 output data, is heavily influenced by the uranium concentration of a single highly productive mine in Canada with an ore concentration of on the order of 20 percent. Excluding this mine, the global average U concentration in ore is about 0.1%, though in practice uranium concentrations in ore vary widely.[70]

- Thirty percent of the enriched uranium from the international market was produced in gaseous diffusion plants in 2007, with the remainder in centrifuge-based plants, but all enrichment was sourced from centrifuge-based plants by 2014 as gaseous diffusion capacity, mostly the Paducah plant in Kentucky in the United States, was retired.[71] Although some enriched uranium will continue to be sourced from highly enriched uranium from retired nuclear weapons, and it is possible that some laser enrichment will begin to be used in the international market, we assume that centrifuge-based plants will effectively continue to be the predominant supplier of enriched uranium for East Asia through 2050.

- Enrichment costs have fallen by well over 50 percent in the last five years, from about $160/kg per separative work unit (SWU) in 2008 through early 2010 to about $72 per kg in 2015, and to $51 in the first two-thirds of 2016, likely as a result of the combination of the global economic recession and the impacts on the nuclear industry of the Fukushima accident. We assume, for the BAU nuclear generation capacity expansion case, that costs per SWU rise at 2.0 percent annually in real terms from the 2016 level, meaning that real 2050 costs per SWU will be substantially lower than they were at the cost peak in 2008/2009. Since the MAX nuclear capacity expansion case results in higher demand for SWU, we assume that the costs per SWU will rise faster than for BAU capacity expansion, at an average rate of 3.0 percent annually. Conversely, a low rate of nuclear generation capacity expansion reduces SWU demand, so we assume a 1.0 percent annual real escalation of costs per SWU from (very low) 2016 levels is associated with scenarios in based on the MIN capacity expansion case. Associating particular enrichment cost trajectories with specific nuclear capacity expansion/use scenarios is admittedly a modeling decision in and of itself, and one that can be questioned. If the region being modeled represented a smaller part of the current and expected market for enrichment, then one could justifiably argue that world SWU market prices should be largely independent of changes in nuclear generation in the region. In this case, however, the converse is true, and changes in the region are likely to have a large impact on enrichment demand. The supply of enrichment services, on the other hand, is arguably fairly inelastic, as enrichment plants are expensive and take a long time to plan, site, and build. Still, over a 30-plus year time horizon one might expect more enrichment to come on line, and affect international prices. We thus use sensitivity analysis to look at the impacts of different enrichment price trajectories on different combinations of scenarios and nuclear capacity paths.

[70] World Nuclear Association (2012), "World Uranium Mining", last updated August, 2012, and available as http://www.world-nuclear.org/info/inf23.html.

[71] Roughly consistent with information in World Nuclear Association (2016), “Uranium Enrichment”, updated October 2016, and available as http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx.

- Raw uranium transport costs are set at roughly container-freight rates.
- The cost of U_3O_8 conversion to UF_6 (uranium hexafluoride, which is processed by enrichment plants) is $14/kg U.[72]
- The cost of UOx fuel fabrication is $270/kg heavy metal (HM, meaning uranium and plutonium).[73]
- The cost of MOx fuel blending and fabrication is $1800/kg heavy metal.[74]
- The fraction of plutonium (Pu) in (fresh) MOx fuel is 7%.[75]
- Spent fuel transport costs by ship are about $40/tHM-km.[76]
- The cost of reprocessing is $1200/kg HM[77] except in Japan, where it is $3400/kg HM based on the costs of the existing Rokkasho plant.[78]
- The effective average lag between placement of nuclear fuel in-service (in reactors) and its removal from spent fuel pools at reactors is 8 years.
- The cost of treatment and disposal of high-level wastes is $150/kg HM reprocessed, the mass of Pu separated during reprocessing is 11 kg/t HM in the original spent fuel, and the cost of storage and safeguarding of separated plutonium is $3000/kg Pu-yr.[79]
- The average capital cost of dry casks (for UOx or MOx spent fuel) is $0.8 million/cask and the operating cost of dry cask storage is $10,000 per /cask-yr.[80]
- The cost of interim spent fuel storage (total) is $360/kg HM placed in storage, and the cost of permanent storage of spent fuel is assumed to be $1000/kg HM placed in storage.[81] Permanent storage, however, is not implemented, and its costs are not charged, in any of the

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[72] The World Nuclear Association (2012), in "The Economics of Nuclear Power" (updated December, 2012, and available as http://www.world-nuclear.org/info/inf02.html), lists costs for UF_6 conversion as of March 2011 as $13 per kg UO_2. This is more than twice the cost listed in the earlier study Deutch, J., C. W. Forsberg, A.C. Kadak, M.S. Kazimi, E. J. Moniz, J.E. Parsons, Y. Du, and L. Pierpoint (2009), *Update of the MIT 2003 Future of Nuclear Power Study*. MIT Energy Initiative, available as http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf.
[73] World Nuclear Association (2012), in The Economics of Nuclear Power" (updated December, 2012, and available as http://www.world-nuclear.org/info/inf02.html), lists costs for fuel fabrication as of March 2011 as $240 per kg UO_2.
[74] Bunn, M., S. Fetter, J. P. Holdren, B. van der Zwaan (2003), *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel: Final Report*, 8/12/1999-7/30/2003. Project on Managing the Atom, Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, dated December 2003, Report number DE-FG26-99FT4028, and available as http://belfercenter.ksg.harvard.edu/files/repro-report.pdf.
[75] Massachusetts Institute of Technology (MIT, 2003), *The Future of Nuclear Power, An Interdisciplinary MIT Study*. Available as http://web.mit.edu/nuclearpower/pdf/nuclearpower-full.pdf.
[76] Organization for Economic Cooperation and Development Nuclear Energy Agency (OECD/NEA, 1994), *The Economics of the Nuclear Fuel Cycle*.
[77] MIT, 2003, ibid.
[78] Katsuta, T. (2010), personal communications.
[79] OECD/NEA, 1994, ibid.
[80] Capital and operating costs based very roughly on United States Department of Energy (US DOE, 1994), *Multi-purpose Canister Evaluation: A Systems Engineering Approach*, Report DOE/RW-0445, September, 1994l and TRW Environmental Safety Systems, Inc. (TRW, 1993), *At Reactor Dry Storage Issues*, Report # E00000000-01717-2200-00002, September, 1993..
[81] Based roughly on OECD/NEA, 1994, ibid.

scenarios above by 2050.

- The annual cost of storing cooled spent fuel, including both UOx and MOx spent fuel, in pools is $11,700 per tHM.[82] Note that this cost does not apply to spent fuel before it has cooled, as costs for at-reactor cooling for 8 years are assumed to be part of reactor operating and maintenance costs.

[82] A recent estimate for the operating costs of spent fuel pools was not immediately available, but an older (1991) US study, S.R. Rod (1991), *Cost Estimates of Operating Onsite Spent Fuel Pools After Final Reactor Shutdown*, Report Number PNL-7778, dated August, 1991, and available as http://www.osti.gov/scitech/servlets/purl/5349359/, lists an average (mean) cost of operating spent fuel pools of $7.41 per kg U-yr, presumably in 1991 dollars or similar, which implies $11.71 per kg U-yr in 2009 dollars.

5 Spent Fuel Management Cooperation Scenario Results

Results for the spent fuel management cooperation scenarios described above are provided in this section of this Project Summary Report. These results update Nautilus' previous work on the topic. Additional detailed results are available in Annex 2B to this Report.

5.1 Uranium Production and Enrichment

Over the period from 2000 through 2050, the countries of East Asia and the Pacific included in this study are projected to use a cumulative 1.37 to 1.46 million tonnes of natural uranium (as U) in the BAU capacity expansion case, with usage under Scenario 4 about 7 percent higher than in Scenarios 1 and 2. Producing these quantities of uranium will require the extraction of about 65 (Scenarios 2 through 4) to 270 million tonnes (Scenario 1)[83] of uranium ore, with extraction in Scenario 1 being much higher because more of the ore is mined domestically (mostly in China), rather than being sourced from higher-grade Canadian (and other) deposits. As large as these figures seem, they are dwarfed by the annual volume of coal extracted in China alone in a single year (over 3.5 billion tonnes in 2011,[84] although of course Chinese coal-fired power plants generated on the order of 10 times as much power during 2011 than did all of the reactors in the region combined). This comparison is, of course, inexact, because coal ash and other wastes have different disposal attributes and environmental impacts—and thus costs for disposal—than do uranium tailings. Milling the uranium needed for reactors in the region will require about 1.4 to 1.5 billion cubic meters of water over the period from 2000 through 2050, which, to put the level of resource use in perspective, is about half of one day's discharge of water from the Yangtze River to the ocean, or about a tenth of annual domestic water use in Japan.

The enrichment services requirements for the BAU paths across scenarios are about 40 to 41 million kg SWU in 2050 in Scenarios 1-3, and about 44 M for Scenario 4 (which includes no MOx use). For the MAX generation capacity expansion path, needs rise to about 81 M SWU/yr in 2050 in scenarios without substantial MOx use, and are about 8 to 13 percent less in scenarios with MOx use. For the MIN path, requirements are about 20-22 million SWU in the 2020s, rising slowly (on the strength of continued growth in the Chinese nuclear sector, offsetting declines elsewhere in the region to 23-25 million SWU in 2050.

Under Scenario 1, additional enrichment capacity in the countries of the region will be required under all nuclear capacity expansion paths, though under the MIN path Japan's maximum annual SWU demand (2020 – 2029) is quite close to the reported full capacity (1.5 million SWU/yr) of the Japan Nuclear Fuel Ltd (JNFL) commercial enrichment plant at Rokkasho.[85] Under other scenarios, global enrichment capacity by 2015 would need to be expanded to meet 2050 regional plus out-of-region enrichment demand under the BAU or MAX expansion paths. Under the MAX expansion path and Scenario 1, China alone would need to build new enrichment capacity

[83] In the MAX capacity expansion case, cumulative 2000 through 2050 uranium ore extraction is about 510 million tonnes in Scenario 1.

[84] British Petroleum (2012), Excel workbook "BP Statistical Review of World Energy June 2012", available as http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/spreadsheets/statistical_review_of_world_energy_full_report_2012.xlsx.

[85] See World Nuclear Association (2016), "Japan's Nuclear Fuel Cycle", updated September 2016, and available as http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-fuel-cycle.aspx.

by 2050 approximately equal to more than half of today's global capacity. Under the MIN expansion path, however, international enrichment facilities extant as of 2015 are likely sufficient to meet regional and out-of-region demand without significant expansion, assuming existing facilities (or replacement facilities) continue to operate. Figure 5-1 summarizes the required regional volume of enrichment service required, both in-country and out-of-country (that is, from regional or international facilities), for the period from 2000 through 2050 for each of the four scenarios. Figure 5-2 shows enrichment requirements over time by country. Though the ROK and Japan account for almost all enriched uranium needs pre-Fukushima, the rapid growth of China's nuclear power sector and the slow process of restarting Japan's reactors means that China's demand for enrichment will outstrip needs in the rest of the region well before 2020.

Figure 5-1: Requirements for Enriched Uranium by Scenario, Adjusted for MOx Use, BAU Nuclear Capacity Expansion Path

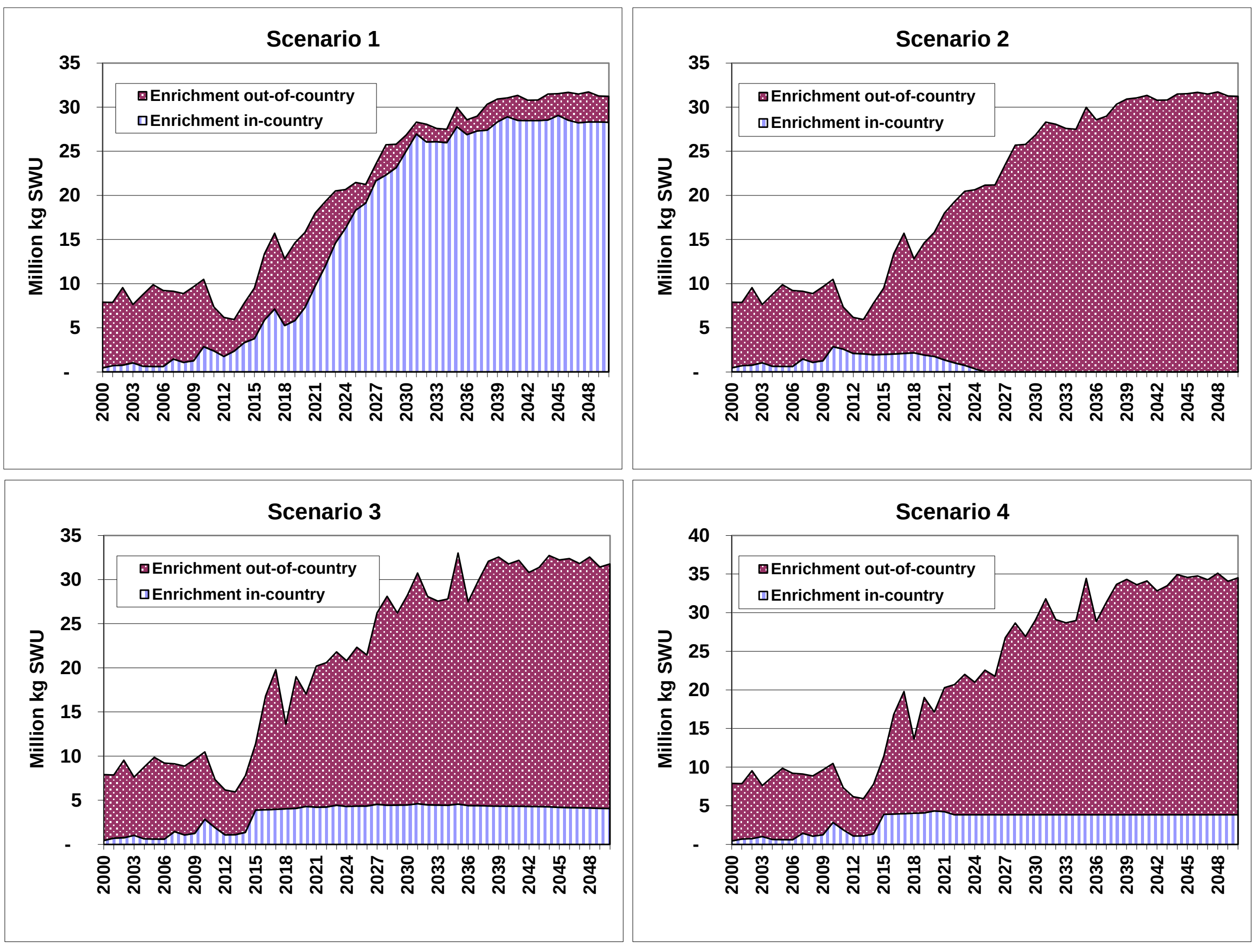
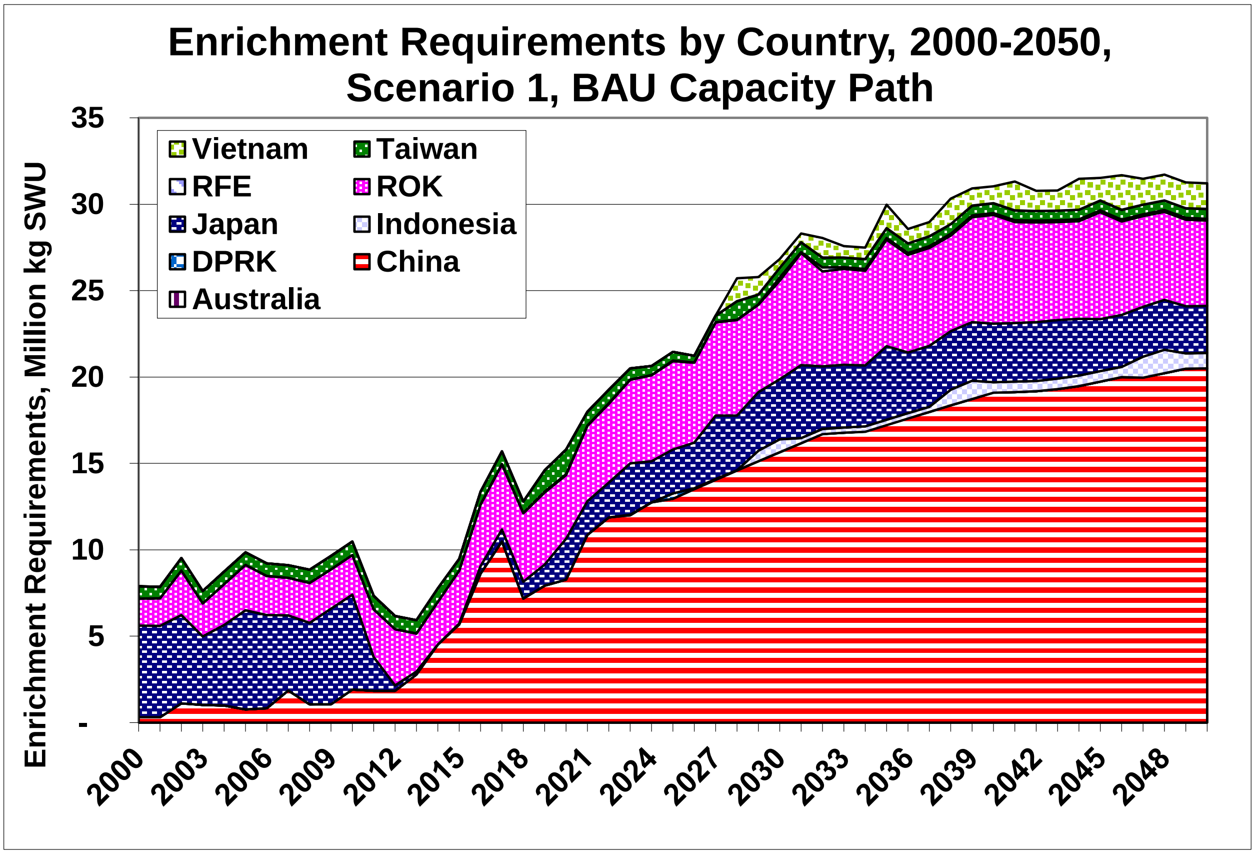


Figure 5-2: Requirements for Enriched Uranium by Country, Scenario 1, Adjusted for MOx Use, for the BAU Nuclear Capacity Expansion Path

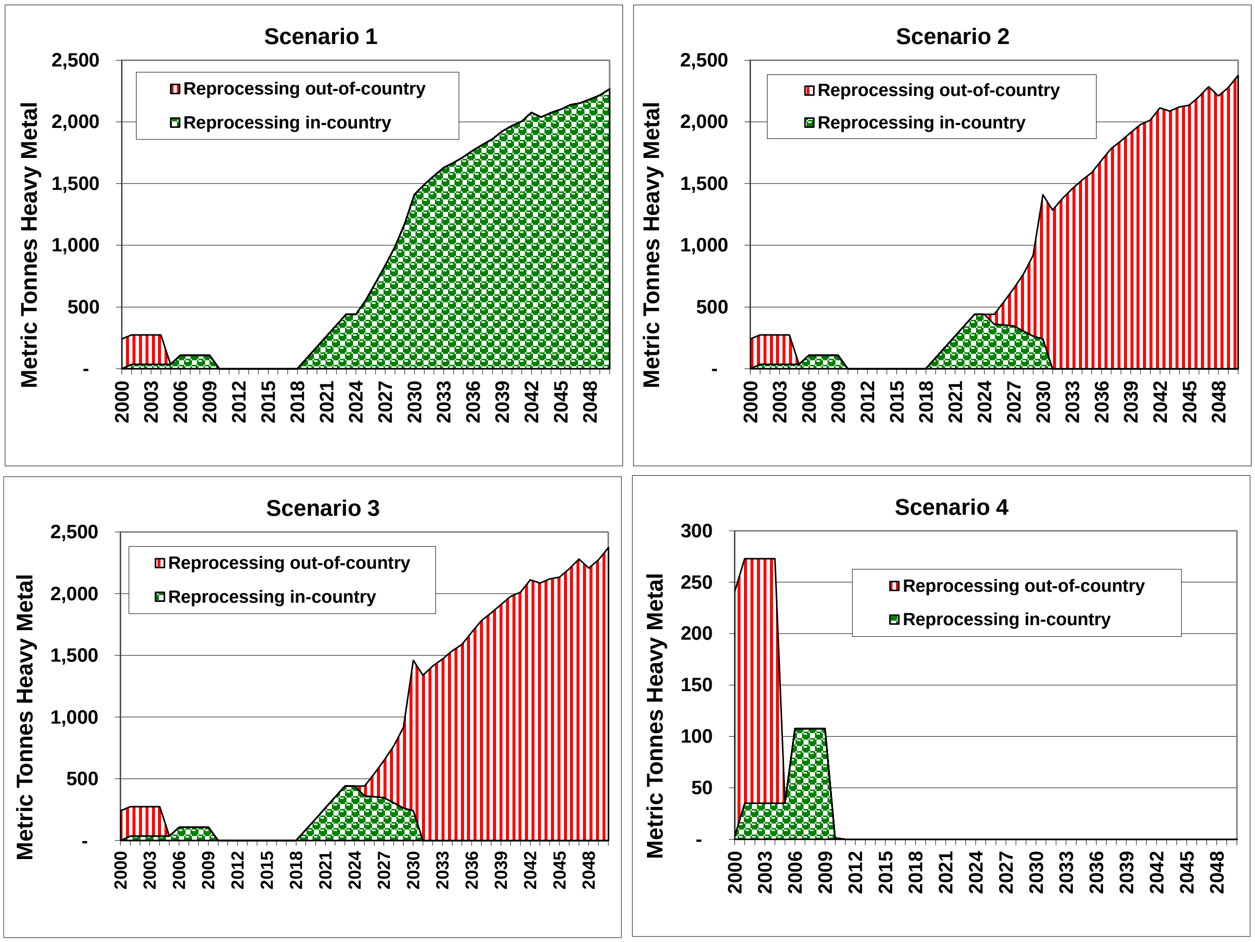


5.2 <u>Spent Fuel Management</u>

The increase in production of spent fuel has implications for the sufficiency of space for storage of spent fuel at reactors (spent fuel pools) and other facilities. In Scenario 1 under the BAU nuclear capacity expansion path, China, Japan, and the ROK will require new spent fuel storage capacity by the early 2020s or sooner in the ROK and possibly Japan, depending on whether spent fuel pools remain dense-racked, and the timeline for starting the Mutsu dry cask storage facility in Japan, and by the mid-2030s (China). By 2050, in the BAU case, storage, disposal, or reprocessing for about 3800 to 4100 tHM of spent fuel will need to be added annually, with about 60 percent of that requirement in China alone. In the absence of regional cooperation on spent fuel management, the countries of East Asia, and in particular Japan, the ROK, and China, will in the next 10 to 20 years need to begin opening a large amount of out-of-reactor-pool spent fuel storage or disposal space, or develop the same equivalent amount of storage space in reprocessing facilities (or a combination). This result is based, as noted above, on the assumption that new reactors will (mostly) be designed with 15 years of spent fuel storage capacity. Though it may be that new nuclear plants will be designed with larger spent fuel pools, the tendency to build larger spent fuel pools may be tempered by consideration of the risks of at-reactor pool storage of large quantities of spent fuel, particularly when, as in many existing plants in Northeast Asia (and elsewhere), spent fuel pools are “dense packed” with fuel rod assemblies. These risks were underscored by the damage to spent fuel in pool storage that occurred during the Fukushima Daiichi Plant accident in Japan starting in March 2011. Given the recent history of public opposition to new nuclear sites in Japan and the ROK, one would expect the process of developing new storage/disposal/reprocessing facilities to be difficult. China, with more lightly-populated areas than the ROK or Japan, and less of a tradition of civic involvement in security and environmental issues, may find an easier path to siting such facilities. On the other hand, in the twenty years between now and when China will need such facilities, and given the recent trend of a growing civil society voice in key issues, spent fuel management facilities may also become progressively harder to site in China as well.

Figure 5-3 summarizes the region-wide use of reprocessing over time in each of the four Scenarios. A similar amount of reprocessing takes place in each of Scenarios 1 through 3, rising to about 2200 tonnes of heavy metal annually by 2050, but reprocessing in Scenario 1 takes place mostly in the countries of the region, while in Scenarios 2 and 3 reprocessing is mostly done either outside the region, or in shared reprocessing facilities in the region. In Scenario 4, as a result of the scenario assumptions, no reprocessing takes place after about 2010. Note that the scale in the graph for Scenario 4 is much smaller than the scale in the other three panels of Figure 5-3. Combinations of active reprocessing programs and high or medium growth in nuclear generation capacity yield large, though transitional, inventories of plutonium—on the order of 75 to 95 tonnes. Scenario 1 coupled with the "MAX" capacity expansion path produces a maximum regional inventory of plutonium, at nearly 95 tonnes in 2038, but that inventory is more than used in MOx fuel by 2050, given Scenario 1 assumptions. Several scenario/path combinations actually result net negative plutonium stocks regionwide in the last two to four years of the modeling period (ending in 2050), implying that Pu from other international separation programs—or, perhaps, conversion of Plutonium originally produced for weapons—would be used to produce MOx fuel in those few years (and/or MOx fuel use would be decreased). Plutonium inventories remain at about 53 tonnes in all Scenario 4 capacity variants from about 2015 on. Placed in perspective, in almost all years any of these quantities of Pu are sufficient that diversion of even a few hundredths of one percent of the total regional stocks would be enough to produce one or more nuclear weapons.

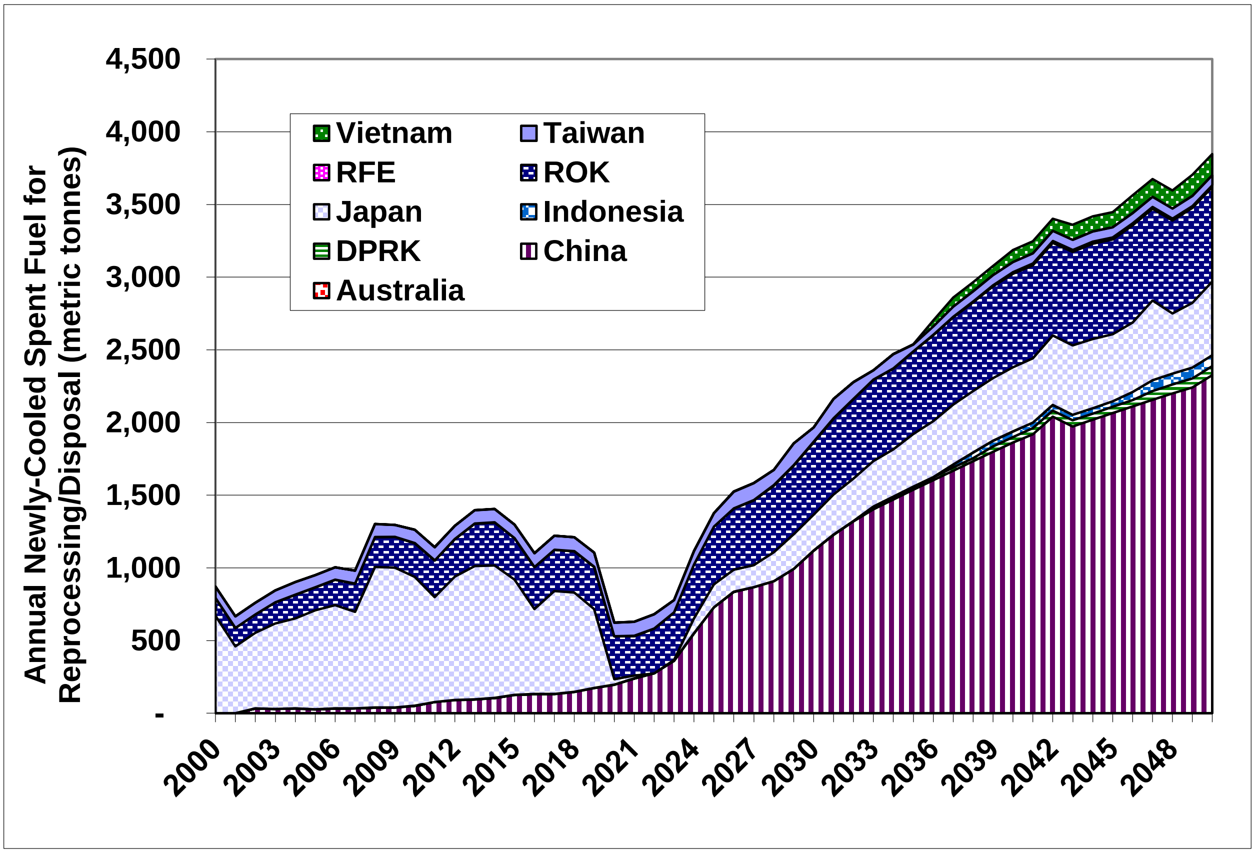
Figure 5-3: Region-wide Quantities of Spent Fuel Reprocessed by Year by Scenario, BAU Nuclear Capacity Expansion Path



5.3 <u>Spent Fuel Production</u>

Figure 5-4 summarizes cooled spent fuel (UOx fuel only) production by country in Scenario 1 for the BAU capacity expansion path. By 2050, an annual volume of somewhat under 4000 tonnes of spent fuel regionwide will be cooled and ready for storage, reprocessing, or disposal. An additional 280 tonnes per year of MOx spent fuel will be cooled and require further management—but likely somewhat different management than UOx fuel, due to its different radiological properties—in 2050, with all cooled MOx fuel coming from Japan, China, and the ROK. Note, in Figure 5-4, that the dip in cooled spent fuel production corresponds to the very low (or zero) capacity factors for nuclear power in Japan in the aftermath of the Fukushima accident. The actual cooled spent fuel production in the mid-to-late 2020s may be even lower, as the capacity factors used in this study for the post-Fukushima years in Japan may prove to be overstated.

Figure 5-4: Production of Cooled Spent UOx Fuel by Year and by Country, Scenario 1 and BAU Nuclear Capacity Expansion Path



5.4 Relative Costs of Scenarios

Along with the inputs to and outputs of nuclear fuel cycle facilities, the estimated costs of key elements of the nuclear fuel cycle have been evaluated for each combination of scenario and nuclear capacity expansion path. In general, though not in every case, "levelized" costs have been used, expressed, for example, on a per-tonne-heavy metal processed basis, to include a multitude of operating and maintenance as well as capital costs, often for very long-lived facilities. In other cases market trends in prices have been extrapolated, for example, for uranium prices and enrichment services, while providing for the option of modeling different price trends. All costs in the figures in this section are provided in 2009 dollars. The figures below focus on the results of the BAU nuclear capacity expansion path. As with other parameters, cost estimates are in many cases by their very nature quite speculative, as they often specify costs for technologies that have not yet been commercialized (permanent waste storage, for example), or are commercialized but practiced in only a few places in the world (reprocessing and high-level waste vitrification, for example), or are subject to regulatory oversight with the potential to considerably change costs, or for which specific costs were not immediately available for this analysis (such as most nuclear materials transport costs). As such, the costs estimates provided here should be taken as indicative only, for use primarily in comparing regional scenarios.

Not yet included in the cost analysis summarized here are the costs of nuclear generation, apart from fuel-related costs. These costs have been omitted (capital costs and O&M costs, for example) in analyses thus far because a full comparison of different nuclear paths also requires inclusion of the capital costs of other electricity generation sources and of other methods of providing energy services (such as energy efficiency improvements) that might be included in a given energy sector development path for a given country. It should be noted, however, that using MOx fuel in some of the region's reactors will require modifications in reactor design and operation that will vary in cost by plant, but will likely be in the range of tens of millions of dollars in capital costs and tens of millions of dollars in annual operations costs, per reactor (see, for example, Williams, 1999).[86] These costs would accrue to scenarios with substantial MOx use, but not to scenarios where reprocessing (and MOx use) is avoided.

Highlights of the cost results summarized as annual costs in 2050 for the BAU path (Figure 5-5) include:

- Uranium mining and milling costs for the region are estimated at $10.5 to $11.4 billion per year by 2050, with the inclusion of reprocessing in Scenarios 1 through 3 reducing costs only modestly (3 to 8 percent) relative to Scenario 4. It should be remembered that the BAU scenario uses a "Medium" international price trajectory for uranium, under which cost per kgU returns to near the historical (but transient) high price spike of 2007, in real terms, by 2050. Use of a lower uranium price forecast would substantially lower estimated mining and milling/purchase) costs.
- Natural uranium transport costs, at an estimated 1 to 5 million dollars per year in 2050, are a negligible fraction of overall costs.
- Uranium conversion costs range from 570 to 630 million dollars per year by 2050 for the countries of the region.
- Uranium enrichment costs for the region are about 30 percent of mining and milling costs, at an estimated at $3.2 to $3.5 billion per year by 2050, with the inclusion of reprocessing in scenarios again reducing costs only modestly. As noted above, enrichment costs, like uranium costs, have been historically volatile—decreasing by a factor of three between 2009 and 2016 alone—so use of a higher price trajectory could substantially increase this cost, relative to the medium enrichment price scenario (returning to only 2013 price levels by 2050) reflected in these results.
- UOx fuel fabrication costs are estimated at $1.2 to $1.3 billion annually by 2050.
- Though the quantity of MOx fuel used is much lower than that of UOx fuel, MOx fabrication costs are estimated at about $680-700 million annually by 2050 in Scenarios 1 through 3 where MOx is used.
- Reprocessing costs range from about $2.9 to 3.7 billion per year in those Scenarios (1 through 3) that feature reprocessing, with Scenario 1, with more (and more expensive) reprocessing in Japan having the highest reprocessing costs.
- Treatment of high-level wastes from reprocessing adds $340 to 360 million per year to the

[86] See, for example, Williams, K.A. (1999), *Life Cycle Costs for the Domestic Reactor-Based Plutonium Disposition Option*. Oak Ridge National Laboratory Report ORNL/TM-1999-257, Dated October, 1999, and available as http://www.ornl.gov/~webworks/cpr/rpt/105050.pdf.

costs of Scenarios 1 through 3, with treatment of medium-level, low-level, and solid wastes from reprocessing, and of uranium separated from spent fuel during reprocessing (less uranium used for MOx fuel) adding an aggregate $220 to 230 million per year to costs by 2050.

- Plutonium storage costs range from zero to $160 million/yr in 2050, with those scenarios that result in higher Pu inventories by 2050 (those where Pu is not substantially used up in MOx fuel) showing higher costs for that year.
- Interim storage of non-reprocessed spent fuels (and of MOx fuel), in Scenarios 1 through 3, has estimated costs in 2050 of $790 million to $850 billion per year. In Scenario 4, using Dry Cask Storage, estimated costs in 2050 are about $660 million per year, or somewhat lower, though the amount of spent fuel being handled in Scenario 4 includes the fuel that would otherwise have been sent to reprocessing in the other scenarios. Estimated costs for transportation of spent fuel in are about $70 million annually in 2050 in Scenario 1, about $210 million/yr in Scenarios 2 and 3, and $13 million/yr in Scenario 4.

Overall, the conclusion from the above—similar to the conclusion that a number of other researchers have reached using per-unit costs (not from regional scenarios), is that reprocessing of spent fuel results in much higher costs—higher by on the order of $4 billion per year (about 20-23 percent), region-wide, in 2050—than using dry-cask storage and avoiding reprocessing of spent fuel, as shown in Figure 5-5. Figure 5-6 shows net present value costs from 2010 through 2050 (calculated with three different discount rates) for the nuclear fuel cycle elements. Scenarios 1 through 3 yield total costs that are about 12 to 18 (at a discount rate of 5.0 percent/yr) to 16 to 21 percent (at a zero discount rate) higher overall than in the least expensive scenario (Scenario 4). The absolute cost difference between scenarios declines somewhat as the discount rate used increases. Results at three different real discount rates are shown to reflect a range of potential perspectives as to the time value of money in nuclear investments. Present interest rates in Japan, for example, are near zero (and in the negative range in real terms). In addition, one could argue that as investments with decidedly intergenerational implications, nuclear fuel cycle costs should be evaluated with a near-zero, zero, or even negative discount rate.[87]

[87] See, for example, Hellweg, S., T. B. Hofstetter, and K. Hungerbühler (2003), "Discounting and the Environment: Should Current Impacts be Weighted Differently than Impacts Harming Future Generations?". *International Journal of Life-Cycle Analysis* Volume 8 (1), pages 8 – 18. Available as http://www.lcaforum.ch/Portals/0/DF_Archive/DF22/Steffi.pdf.

Figure 5-5: Annual Regional Nuclear Fuel Cycle Costs in 2050

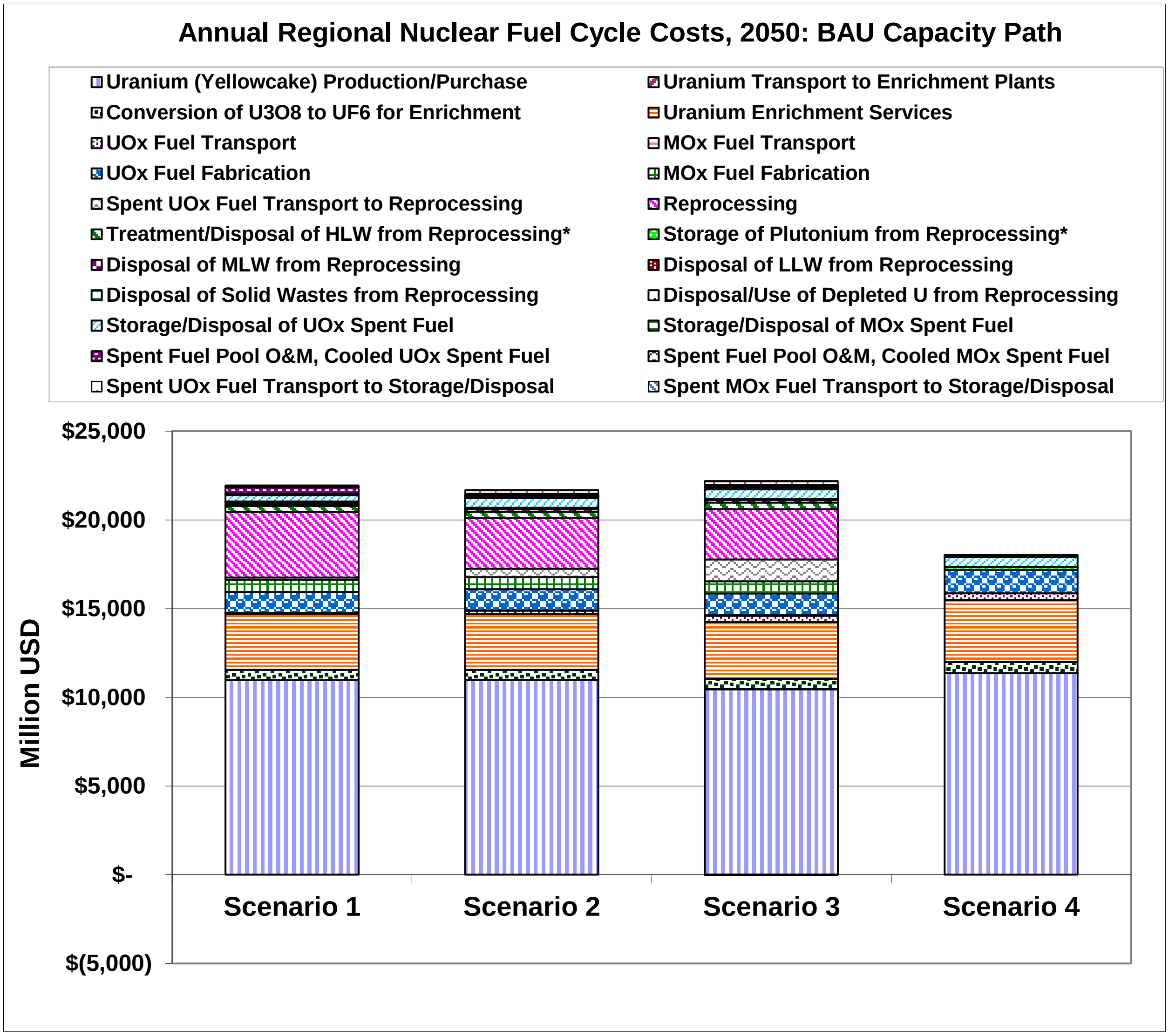
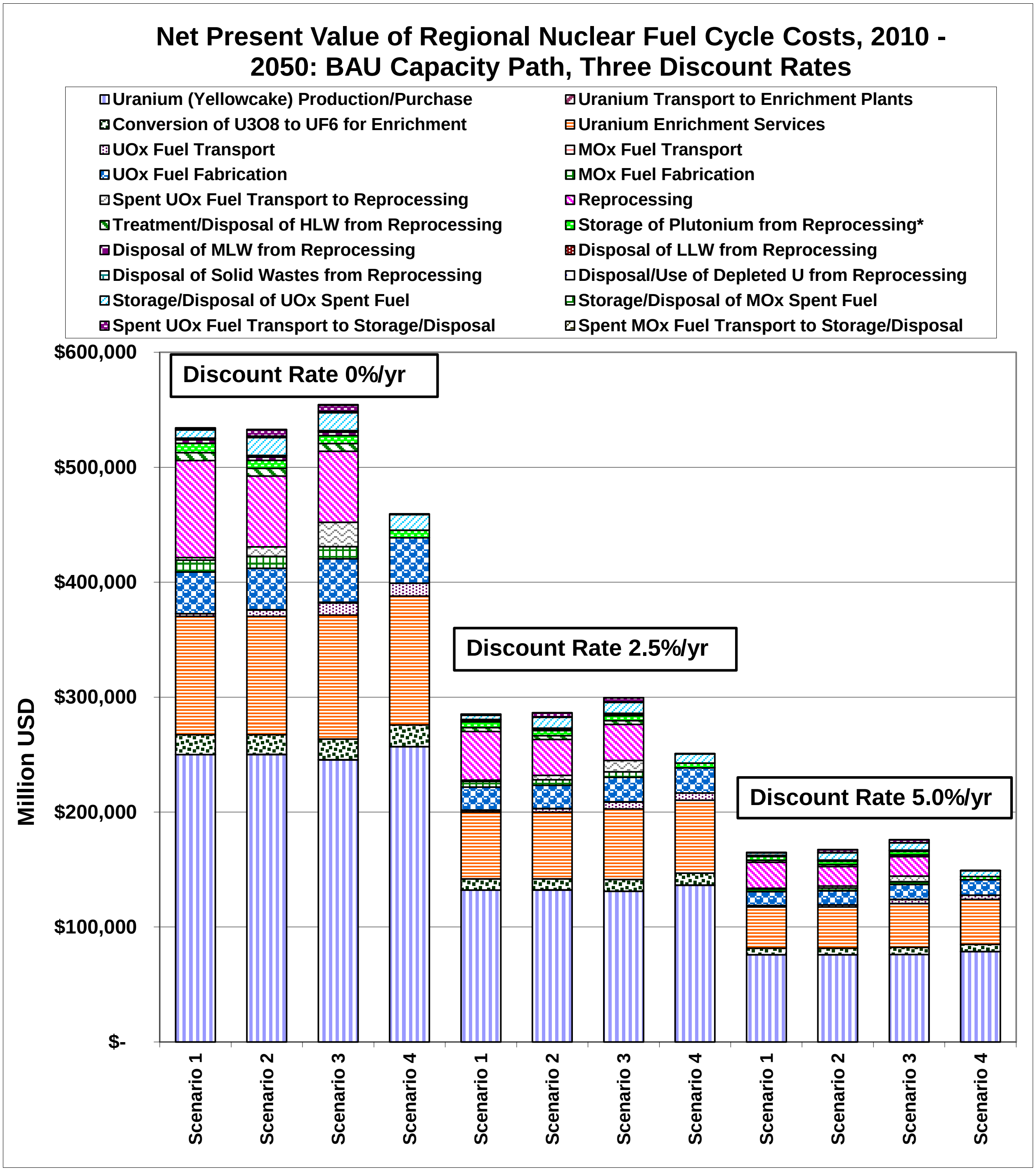


Figure 5-6: Net Present Value of Regional Nuclear Fuel Cycle Costs



5.5 Cooperation Scenario Costs in Context

Although significant, nuclear fuel cycle costs are only a portion of the overall costs of nuclear generation. In order to gauge the magnitude of fuel cycle costs relative to other costs, we prepared a rough estimate of the overall costs of nuclear power in each of the countries of the region over the period from 2010 through 2050. Table 5-1 shows our assumptions used in preparing an overall estimate of the costs of nuclear power in the region for major costs excluding fuel-cycle costs, which are covered above. The costs categories included here are capital costs (annualized using a cost recovery factor based on an interest rate of 5 percent/yr in real terms), annual fixed (O&M) operating and maintenance costs, variable (non-fuel-cycle) O&M costs (typically small for nuclear plants), and decommissioning costs. Capital and other costs for nuclear power plants are notoriously hard to estimate, particularly where future costs are involved, but the estimates below generally fall within the range of costs available from various literature sources.[88]

Table 5-1: Nuclear Power Cost Assumptions by Country and Component

Components of Nuclear Power Costs: Assumptions

All costs assumed to be in approximately 2009 dollars

Cost Component/Parameter	Units	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia
Fleet Average Initial Capital Cost, 2010	$/kW	$ 4,000	$ 2,200	$ 2,200	$ 2,200	$ 4,000	$ 2,200	$ 2,200	$ 2,200	$ 3,500
Fleet Average Initial Capital Cost, 2030	$/kW	$ 4,500	$ 2,600	$ 2,600	$ 2,600	$ 5,000	$ 2,600	$ 2,600	$ 4,000	$ 4,000
Fleet Average Initial Capital Cost, 2050	$/kW	$ 4,500	$ 3,000	$ 3,000	$ 3,000	$ 5,000	$ 3,000	$ 3,000	$ 5,000	$ 5,000
Interest Rate for Annualizing Capital Costs, 2010	%/yr	5%	5%	5%	5%	5%	5%	5%	5%	5%
Interest Rate for Annualizing Capital Costs, 2030	%/yr	5%	5%	5%	5%	5%	5%	5%	5%	5%
Interest Rate for Annualizing Capital Costs, 2050	%/yr	5%	5%	5%	5%	5%	5%	5%	5%	5%
Economic Lifetime	years	40	40	40	40	40	40	40	40	40
Implied Annualized Capital Costs, 2010	$/kW-yr	$233.11	$128.21	$128.21	$128.21	$233.11	$128.21	$128.21	$128.21	$203.97
Implied Annualized Capital Costs, 2030	$/kW-yr	$262.25	$151.52	$151.52	$151.52	$291.39	$151.52	$151.52	$233.11	$233.11
Implied Annualized Capital Costs, 2050	$/kW-yr	$262.25	$174.83	$174.83	$174.83	$291.39	$174.83	$174.83	$291.39	$291.39
Fixed Operating and Maintenance Costs, 2010	$/kW-yr	$ 160	$ 100	$ 100	$ 100	$ 140	$ 100	$ 100	$ 100	$ 100
Fixed Operating and Maintenance Costs, 2030	$/kW-yr	$ 160	$ 100	$ 100	$ 100	$ 140	$ 100	$ 100	$ 100	$ 100
Fixed Operating and Maintenance Costs, 2050	$/kW-yr	$ 160	$ 100	$ 100	$ 100	$ 140	$ 100	$ 100	$ 100	$ 100
Variable (non-fuel-cycle) O&M costs, 2010	$/MWh	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50
Variable (non-fuel-cycle) O&M costs, 2030	$/MWh	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50
Variable (non-fuel-cycle) O&M costs, 2050	$/MWh	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50
Decommissioning Costs, 2010	$/kW	$ 500	$ 350	$ 350	$ 350	$ 500	$ 350	$ 350	$ 350	$ 350
Decommissioning Costs, 2030	$/kW	$ 550	$ 400	$ 400	$ 400	$ 550	$ 400	$ 400	$ 400	$ 400
Decommissioning Costs, 2050	$/kW	$ 600	$ 450	$ 450	$ 450	$ 600	$ 450	$ 450	$ 450	$ 450

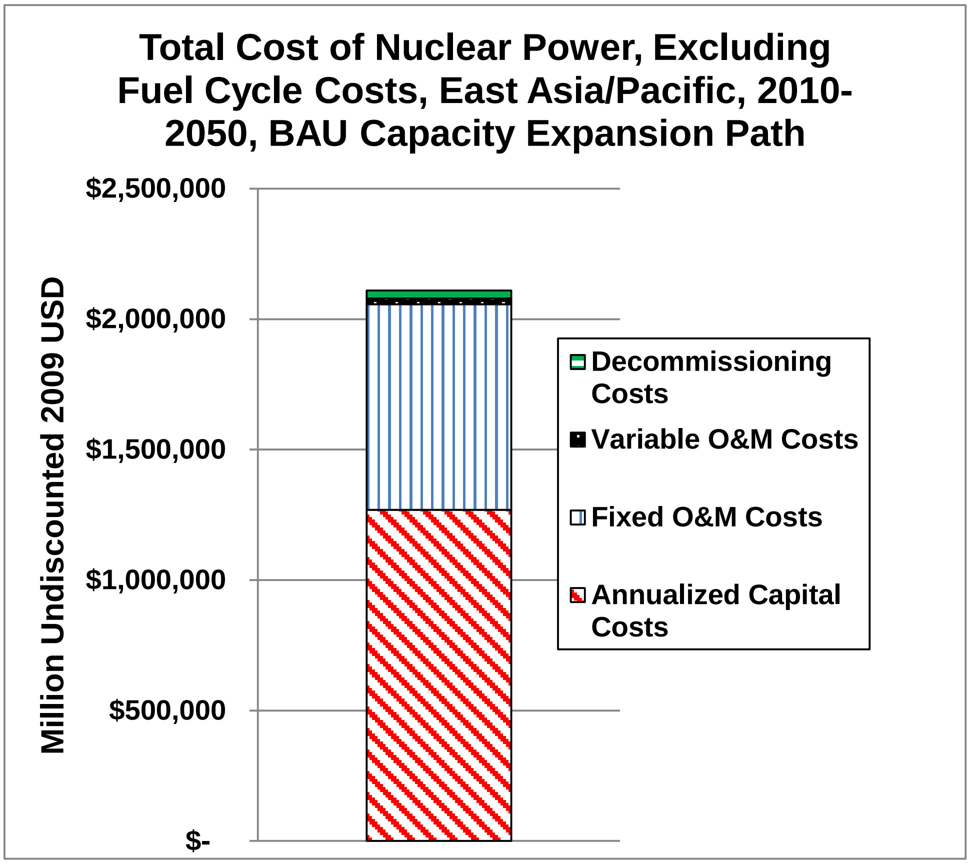
For the BAU capacity expansion path, as shown in Figure 5-7, we estimate the overall regional undiscounted cost of nuclear power in East Asia/Pacific over the period 2010 through 2050 to be about $2.1 trillion. This figure excludes fuel cycle costs, so the overall total cost for nuclear generation is about $2.5 to $2.6 trillion including the estimates (at a discount rate of zero) for fuel cycle costs shown for the four cooperation scenarios in Figure 5-6. The bulk of the non-fuel cycle costs are annualized capital costs (60 percent) and fixed O&M costs (37 percent), with non-fuel variable costs and decommissioning costs making up a much smaller fraction of the total.[89] Total non-fuel nuclear costs if all countries pursue MAX capacity expansion paths are estimated at $2.7 trillion over the same period, versus $1.5 trillion for the MIN capacity

[88] The rough estimates shown are based on a variety of literature sources, some country-specific, and some more general. See, for example, World Nuclear Association (2016), "The Economics of Nuclear Power", updated July 2016, and available as http://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx, and Dan Drollette Jr (2014), The rising cost of decommissioning a nuclear power plant, *Bulletin of the Atomic Scientists*, http://thebulletin.org/rising-cost-decommissioning-nuclear-power-plant7107.
28 April 2014

[89] For simplicity, decommissioning costs were treated as incurred in the first year of decommissioning. This is of course not entirely realistic, as decommissioning costs are typically spread over many years, and are often accumulated in advance from ratepayers. Decommissioning costs are much higher in countries with older reactor fleets (especially Japan), but still make up a small part of total nuclear costs.

expansion path. Additional detailed results related to this estimate are available in Annex 2C to this Report.

Figure 5-7: Total Estimated Cost of Nuclear Power in East Asia/Pacific, Excluding Nuclear Fuel Cycle Costs



Overall, the difference between the costs of the four cooperation scenarios—between $75 to $100 billion over the entire region from 2010 through 2050—represents only a few percent of the overall cost of nuclear power. Given the broad span of time and space over which these estimates are calculated, and the substantial uncertainties in many of the parameters involved, this result suggests that costs should not be the overriding factor in deciding between nuclear fuel cycle options. Rather, parameters that are difficult or impossible to accurately estimate quantitatively, such as the impacts of different fuel cycle options on radiological risks, security of the sector from attack, and/or the responses of local communities to different fuel cycle choices, should be regarded as more significant in informing nuclear fuel cycle decisions, as described below.

5.6 Energy Security Attributes Comparison of Scenarios

The broader energy security definition referred to earlier in section 4.4 of this report was used to develop a multiple-attribute method of compare national energy policy scenarios. This method was adapted to compare the energy security attributes of the four regional nuclear fuel cycle scenarios developed and evaluated as described above. It should be emphasized that while many different attributes and measures could be chosen for this analysis, the approach taken here has generally been to focus on attributes that are significantly different between scenarios, in order to provide guidance on the key policy trade-offs involved in choosing one scenario over another. Key results of this comparison are as follows:

Energy supply security: Arguably, Scenario 1, in which the major current nuclear energy nations of the region own and run their own enrichment and reprocessing facilities, provides greater energy supply security on a purely national level. On a regional level, depending on the strength of the agreements developed to structure regional cooperation on nuclear fuel cycle issues, Scenarios 2 and 3, and possibly 4, may offer better energy supply security. Scenarios 3 and 4 also offer the added security of shared fuel stockpiles.

Economic security: Scenarios including reprocessing have significantly higher annual costs, when viewed over the entire fuel cycle, than the scenario without reprocessing. The additional cost is still, however (as noted above), only a relatively small fraction of the cost of nuclear power as a whole. That said, the use of reprocessing and related required waste-management technologies may expose the countries of the region to additional economic risks if the technologies have costs that are unexpectedly high (as has been the case, for example, with Japan's Rokkasho reprocessing plant). In addition, the required additional investment, probably by governments or by companies backed by governments (tens of billions of dollars, at least) in facilities related to fuel reprocessing may divert investment from other activities, within the energy sector and in other sectors of potentially more benefit to the long-term health of the economies of the region. On the other hand, development of in-country and in-region nuclear facilities will have its own job-creation benefits in the nuclear industry and some related industries.

Technological security: Scenario 4, which depends on proven dry-cask storage, relies the least on the performance of complex technologies, but implicitly also depends on future generations to manage wastes generated today. Since all of the other scenarios, however, depend on interim storage of spent fuels, plutonium, and high-level wastes from reprocessing, and thus imply dependence on a future means of safe disposal, the scenarios are not so different in this long-term outlook.

Environmental security: Scenarios 1 through 3 as evaluated offer somewhat (on the order of several to 10 percent) less uranium mining and processing, with its attendant impacts and waste streams, relative to scenario 4. This reduction in mining is balanced by the additional environmental burden of the need to dispose of a range of solid, liquid, and radioactive reprocessing wastes from reprocessing, MOx fuel fabrication, and related processes related to the use of plutonium in nuclear fuels. Differences between the scenarios with regard to generation of greenhouse gases and more conventional air and water pollutants are likely to be relatively small, and are inconsequential when compared with overall emissions of such pollutants from the full electricity sectors and entire economies of the region.

Social-Cultural security: To the extent that some of the countries of the region have growing civil-society movements with concerns regarding nuclear power in general, reprocessing in particular, and local siting of nuclear fuel-cycle facilities, Scenario 4 arguably offers the highest level of social-cultural security. This advantage has likely been exacerbated by the social/political fallout from the Fukushima accident, although the different countries of the region are finding and will find that the Fukushima accident has impacts of different types and magnitudes on social and cultural issues related to nuclear power. In some cases current laws—in Japan, for example—would have to be changed to allow the long-term at-reactor storage included in Scenario 4, and changing those laws has its own risks.

Military security: From a national perspective, safeguarding in-country enrichment and reprocessing facilities in Scenario 1, including stocks of enriched uranium and (especially) plutonium, puts the largest strain on military (and/or police) resources. Those responsibilities are shifted largely to the regional level in Scenario 2, and to the international level in Scenario 3, with less stress on national resources, but more reliance on the strength of regional and international agreements. The level of military security (guards and safeguard protocols) required of Scenario 4 is arguably considerably less than in the other scenarios.

6 Summary of Results and Conclusions

Below we summarize the results of the cooperation scenarios analyses presented above, describe the implications of the analysis for how nuclear fuel cycle decisions should be considered, and describe how the conclusions regarding spent fuel cycle cooperation might interact with other issues related to nuclear power. We end this section with some thoughts on what types of projects might be undertaken to build on the work presented here.

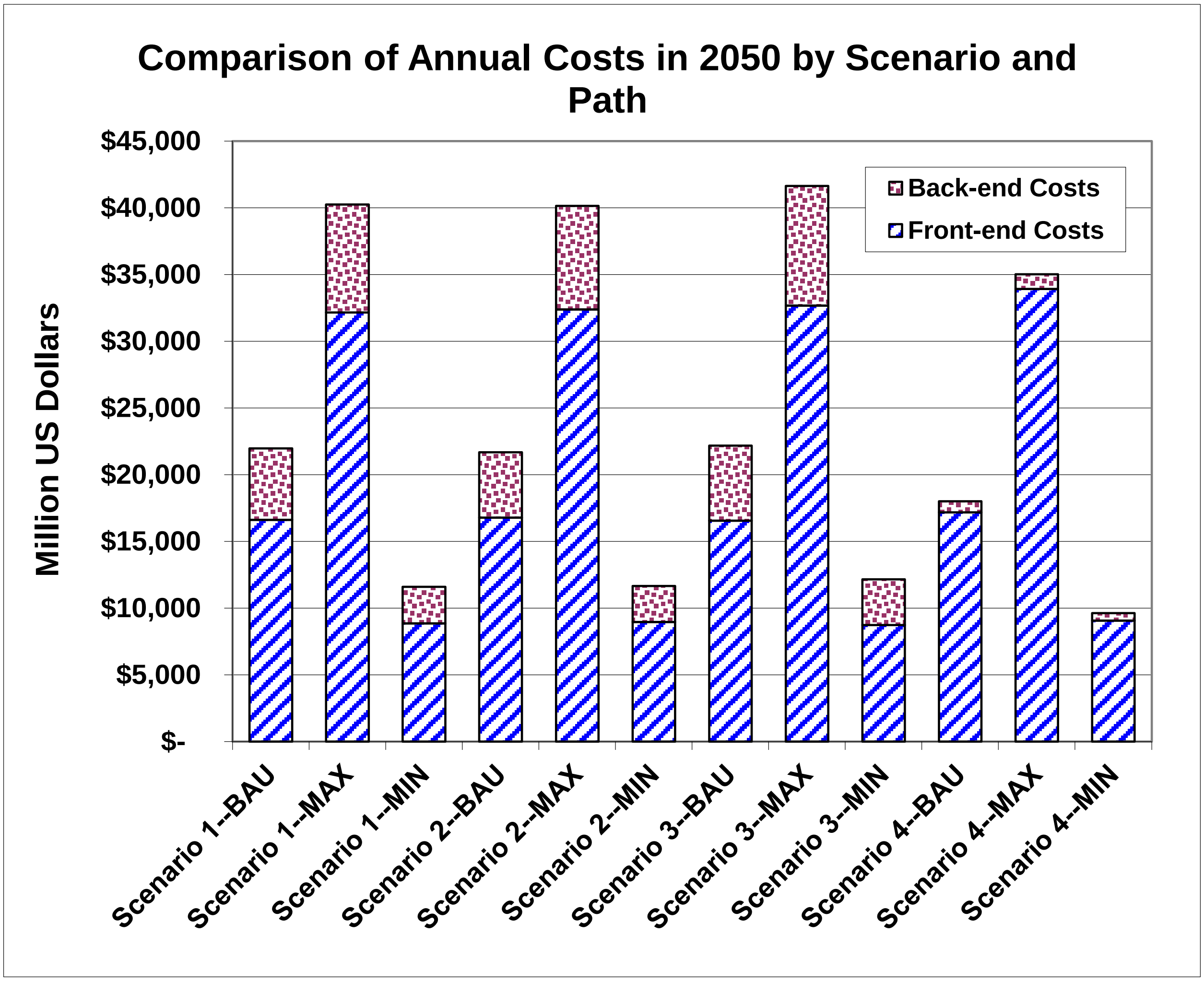
6.1 Cooperation Scenario Results Summary

The results of the regional scenario evaluation above indicate that Scenario 4, which focuses on at-reactor dry cask storage and coordinated fuel stockpiling, but largely avoids reprocessing and mixed-oxide fuel (MOx, that is, reactor fuel that uses a mixture of plutonium reprocessed from spent fuel and uranium and as its fissile material) use, results in lower fuel-cycle costs, and offers benefits in terms of social-cultural and military security. These results are consistent with (and, indeed, draw ideas and parameters from) broader studies by other research groups, including, for example, the joint work by the Harvard University Project on Managing the Atom and the University of Tokyo Project on Sociotechnics of Nuclear Energy.

That said, there are definite trade-offs between scenarios. Scenario 1, by using much more domestic enrichment and reprocessing than the other scenarios, arguably improves energy supply security for individual nations, but results in higher technological risk due to national reliance on one or a small number of enrichment and reprocessing plants, rather than the larger number of plants that constitute the international market. Scenario 1 would also raise significant proliferation concerns (not the least of which would be the DPRK's reaction to ROK enrichment and reprocessing). Scenario 1 also results in the at least transient build-up of stockpiles of plutonium (Pu) in each of the nations pursuing reprocessing. Though the magnitude of the plutonium stockpiles, and the rate at which they are used, varies considerably by nuclear path and scenario, the quantities accrued, ranging up to about 95 tonnes of Pu at a maximum in Scenario 1 in the late 2030s, are sufficient for tens of thousands of nuclear weapons, meaning that the misplacement or diversion of a very small portion of the stockpile becomes a serious proliferation issue, and thus requires significant security measures in each country where plutonium is produced or stored. Scenario 4, without additional reprocessing, maintains a stockpile of about 53 tonnes of Pu from about 2010 on. This still represents a serious proliferation risk, but does not add to existing stockpiles or create stockpile in new places.

Scenarios 1 through 3, which include reprocessing, result, as noted above, in higher annual costs-about \$3 to \$5 billion per year higher in 2050 relative to Scenario 4, over the entire region. Scenarios 1 through 3 reduce the amount of spent fuel to be managed substantially—by 50 percent or more over the period from 2000 through 2050, relative to Scenario 4—but imply additional production of more than 20-fold more high-level waste that must be managed instead (thousands versus hundreds of cubic meters). This in addition to medium- and low-level wastes from reprocessing, and wastes from MOx fuel fabrication that must be managed in significant quantities in Scenarios 1 through 3, but not in Scenario 4. Scenarios 1 through 3 offer a modest reduction—less than10 percent in the BAU nuclear capacity paths case—in the amount of natural uranium required region-wide, and in attendant needs for enriched uranium and enrichment services. This reduction is not very significant from a cost perspective unless uranium costs rise much, much higher in the next four decades. The quantities of electricity and fuel used for uranium mining and milling, as well as production of depleted uranium, are generally somewhat lower under Scenarios 1 through 3 than under Scenario 4, though results for Scenario 1 differ from Scenarios 2 and 3 because of the emphasis on sourcing uranium from domestic mines in the region. Figure 6-1 shows aggregated front-end (fuel preparation) and back-end (spent fuel management) costs by Scenario and for each of the three nuclear capacity paths for the region.

Figure 6-1: Summary of Year 2050 Annual Costs by Scenario and by Nuclear Capacity Expansion Path



Scenarios 2 and 3, though they include reprocessing, place more of the sensitive materials and technologies in the nuclear fuel cycle in regional and international facilities, and as a consequence, are likely to be superior to Scenario 1 in terms of reducing proliferation opportunities, reducing security costs, and increasing the transparency of (and thus international trust in) fuel cycle activities. The costs of Scenarios 2 and 3 shown in this analysis are not significantly different, overall, from those of Scenario 1, but a more detailed evaluation of the relative costs of nuclear facilities (particularly, enrichment and reprocessing facilities) in different countries, when available, might result in some differentiation in the costs of these three scenarios. Overall, however, although the total costs of the scenarios may vary by several billion dollars per year, it must be remembered that these costs are inconsequential to the overall annual costs of electricity generation in general, and modest even when compared to the cost of nuclear generation alone, as described in section 5.5. In considering the costs of electricity generation in general in the region, in round terms, if one assumes that the total electricity demand in East Asia in 2050 is on the order of 20,000 TWh, or about three times electricity demand in the countries in the region as of 2011, and that the per-unit total cost of electrical energy at that time is on the order of 10 US cents/kWh (perhaps somewhat greater than the average in the region today, but possibly an underestimate for 2050), then the implied total cost of electricity supplies in 2050 in the countries under consideration in this Working Paper is on the order of $2 trillion per year. The nuclear fuel cycle-related costs considered here are therefore just a percent or so of the total, and the differences between scenarios is a just a small fraction of a percent. Both of these values are easily lost in the margin of uncertainty regarding future power costs.

Scenarios 2 and 3 result in significantly more transport of nuclear materials—particularly spent fuel, enriched fuel, MOx fuel, and possibly high-level wastes around the globe, likely by ship, than Scenario 1, though there would be somewhat more transport of those materials inside the nations of East Asia in Scenario 1.

The scenarios described and evaluated above have, of necessity, to a certain extent suspended consideration of national and international political and legal constraints in order to focus on alternatives for regional fuel cycle management. It is more than clear, however, that there are substantial legal and political constraints to regional cooperation on nuclear fuel cycles, and that these constraints will either limit the opportunities for cooperation, or need to be overcome in some way, in order to allow regional arrangements to proceed. These constraints include (but are unlikely to be limited to) legal and/or political constraints on regional spent fuel management, enrichment, and integrated facilities. Specific and detailed discussion of these issues is beyond the scope of this Report, but will play a crucial role in determining the practicality of specific cooperation schemes, as discussed briefly below.

6.2 Implications of Cooperation Scenarios in Consideration of Other Project Findings

The key findings of the cooperation scenario analyses summarized in sections 4 and 5 of this Report, when combined with other findings of previous related Nautilus projects, have a number of ramifications.

First, it is clear that the costs of fuel cycles including reprocessing will be higher than those including alternative methods of spent fuel storage, including dry cask at-reactor or centralized storage, unless the costs of raw uranium and enrichment services rise far higher than levels of the recent past. Using base-case assumptions, scenarios involving reprocessing by 2050 are projected to cost several billion dollars per year, region-wide, more than “once through” scenarios in which spent fuel is simply placed in dry cask storage after a period of cooling in spent fuel pools.

That said, even several billion in the full context of the region’s electricity system as of 2050 is a relatively small sum of money. All of the fuel-cycle costs tracked in this analysis amount to on the order of a few percent of overall costs of power from all sources in the region, and are thus dwarfed by uncertainties in the future costs of electricity provision. Future electricity costs are rendered uncertain by potential changes in costs of generation technologies, costs associated with climate change mitigation (for example, carbon taxes) and pollution reduction, and/or costs related to regulatory compliance, particularly as civil society becomes more active in scrutinizing infrastructure plans in the region.

These findings with regard to the relative overall direct financial cost of different cooperation options suggest that decisions with regard to how spent fuel is managed, and whether cooperation is attractive for spent fuel management, largely boil down to political decisions that weigh proliferation and radiological risks with other, largely non-cost factors. This is not to say that certain nuclear sector actors—including nuclear plant operators, nuclear technology vendors, government regulators, and, ultimately, consumers—may be affected economically in different ways, but the overall unit costs of nuclear electricity generation to society will be affected relatively little by spent fuel management decisions.

If the conclusion holds that management of spent fuel will, or should, if incentives are properly structured, be decided by non-economic criteria, actual and perceived radiological risk from spent fuel management approaches becomes a more critical factor in the overall calculus, as does proliferation concerns. Both considerations point toward expanded use of dry cask storage in the near-term to reduce dense-packing in spent fuel pools in Japan and the ROK (and Taiwan), and to avoiding reprocessing. Getting spent fuel out of dense-packed pools and into much more attack- and accident-resistant dry casks is a key to reducing the radiological risk associated with accidents or non-state attack at nuclear energy facilities. Potential radiological risks associated with reprocessing facilities, though not a central topic of this project, would also be reduced by not moving forward with reprocessing, and by placing the spent fuel now in inventory at reprocessing plants into dry-cask storage.

Further, an emphasis on dry-cask storage in the near- and medium-term provides time for technologies for long-term storage and/or disposal of spent fuel and other similarly radioactive wastes (including high-level wastes from reprocessing and wastes from the Fukushima accident) to mature. This could include both geologic storage/disposal and deep borehole disposal, both of which will require decades for research, design, and siting.

The prompt movement of spent fuel now stored in dense-packed spent fuel pools to dry cask storage would also provide a form of insurance against the difficult-to-calculate but potentially considerable cost of damages caused by an accident at terrorist attack on a vulnerable spent fuel pool. The damages from such an event could vary considerably depending on the plant affected, the prevailing wind direction in the days following the incident, and the proximity and vulnerability of local populations and economic infrastructure, The worst case scenarios for such an event, for example, for the Tokyo area or for a reactor in South China, could cause damage to economic assets and human health due to radioactivity releases that could be on the order of hundreds of billions or trillions of dollars. As such, the relatively modest additional cost of moving to dry cask storage appears small in comparison with the potential benefits, even factoring in the considerable uncertainty of a worst-case event.   Moving to dry cask storage could also, if communicated appropriately to residents of the area, provide an additional benefit in the form of reassurance that the worst risks of a radiological incident due to accident or attack are being avoided. The value of such a benefit (reassurance of safety) is of course very difficult to estimate, but might be compared, for example with the peace of mind that residents and businesses purchase by measures designed to mitigate other risks, such as the risk of burglary or attack mitigated by guards and/or alarm and surveillance systems.

Regional cooperation in the nuclear fuel cycle could include shared uranium provision and enrichment services, but regional cooperation in spent fuel management pertains more directly to the current project. Regional cooperation could contribute to spent fuel management by establishing or strengthening regimes for the oversight of nuclear fuel cycle activities and accounting for nuclear materials. Given the difficulties that some nations, most notably Japan and the ROK (and Taiwan) face in siting interim or out-of-pool at-reactor storage of spent fuel, it is possible that regional cooperation could help to facilitate the establishment of intermediate, shared, away-from-reactor storage facilities. Further, international cooperation will be very helpful in undertaking deep borehole disposal of nuclear spent fuels, as it will both help to spread the costs of research and development on deep borehole disposal technologies, and will help to overcome reluctance on the part of nuclear sector actors in individual countries to explore new options for spent fuel management.

Additionally, in the long run, if deep borehole disposal is to be undertaken, it may be that its operation on a regional scale will offer benefits in terms of accounting for nuclear materials disposed of, and thus build confidence between the nations of the region in the transparency of nuclear sector activities in other nations. This will likely be particularly critical if, ultimately, existing (or, if reprocessing starts/continues in nations of the region, new) stocks of plutonium are disposed of by blending with other materials, followed by deep borehole disposal. The process of accounting for plutonium disposal is particularly critical, because diversion of even a small fraction of existing stocks poses the threat of proliferation of nuclear weapons and/or "dirty bombs", thus clear and open accounting for all of the nuclear materials disposed of in deep boreholes (or, for that matter, by other means) is crucial for maintaining the integrity of disposal practices from a non-proliferation perspective.

6.3 Conclusions and Interactions with Related Issues

Nuclear power will certainly continue to play a significant role in the economies of the countries of the East Asia and Pacific region for decades to come, but the extent of that role, and how the various cost, safety, environmental, and proliferation-risk issues surrounding nuclear power are and will be addressed on the national and regional levels, are not at all certain, and, in the wake of both the Fukushima accident and a host of recent and upcoming (for example, in the United States and the ROK) leadership changes, is perhaps more uncertain than it has been in decades.

Each of the nations in Northeast Asia has at least a general interest in international collaboration on spent fuel issues, but because of asymmetries between the nations, collaboration has been difficult to start. These asymmetries include China being a nuclear weapons state, while Japan and the ROK are not, and Japan having a reprocessing program and uranium enrichment capability, while the ROK does not, although it wishes to pursue a lightly-modified form of reprocessing called "pyroprocessing". Russia's expressed interest in hosting fuel cycle cooperation has failed to gain much traction internationally, in large part due to resistance, for reasons including concerns about whether Russia would reprocess spent fuel accepted from other countries, on the part of the United States.[90] In addition, longstanding regional rivalries likely impede the potential for cooperation on the sensitive issue of nuclear materials transfer.

The analysis summarized above indicates that different policy choices today, particularly with regard to cooperation between nations on nuclear fuel cycle issues, can lead to very different outcomes regarding the shape of the nuclear energy sector—and of related international security arrangements—over time. Regional cooperation on nuclear fuel cycle issues can help to enhance

[90] Whether the US stance on Russian reprocessing will change as the Trump Administration takes office is at this point (November, 2016) entirely unknown, though Mr. Trump's comments while campaigning suggest a more sympathetic approach to Russia may be in the cards.

energy security for the participating countries, relative to a scenario in which several nations pursue nuclear fuel cycle development on their own. From a number of energy security perspectives, however, a regional nuclear fuel cycle approach (such as that modeled in Scenario 4) that rapidly phases out reprocessing and MOx fuel use, and uses interim spent fuel storage in dry casks (or similar technologies) to manage spent fuel until indefinite storage facilities—potentially including "deep borehole disposal"[91]—has significant advantages. An approach that avoids reprocessing and MOx fuel use would be less expensive as well, though placed in perspective, the $3-4 billion or so saved annually in 2050 under Scenario 4 relative to other scenarios is just a small fraction of the overall cost of nuclear power, and a tiny fraction of the overall costs of power in general. What this means is that relative fuel cycle costs, at least for the range of LWR-based fuel cycles cooperation/non-cooperation options explored here, should in most cases play a very minor role in decisions about nuclear spent fuel management, and the other considerations described here should thus dominate the policy development process. Of these, it is likely to be the least quantifiable considerations—social and cultural factors, preventing nuclear weapons proliferation, nuclear safety, and military security issues—that are the most important to decisions regarding nuclear spent fuel policy. Unfortunately, these are the very issues that are some of the most difficult to address, particularly in the many instances where addressing those issues require a coordinated international, and intercultural, response.

Nuclear power choices intersect strongly with other energy policies and with security policy issues. As such, the exploration of the implications of different nuclear fuel cycle cooperation (or non-cooperation) options and opportunities in East Asia informs and potentially affects (and is affected by) issues such as deployment of new nuclear technologies, climate change, long-term storage/disposal of spent fuel and high-level wastes, management of radiological risk from spent fuel storage, and non-proliferation, but needs to be expanded to more fully address those issues.

6.3.1 New Reactor Technologies

A number of new types of reactors—including, for example, small, modular reactors, "fast" reactors using and producing plutonium fuels, and reactors based on a Thorium fuel cycle, to name just a few—have been proposed for implementation in the coming decades (typically after 2030, and often later). In addition, variants on the existing LEU/MOx fuel cycle, including a version of reprocessing called "pyroprocessing", have been proposed by various groups, including, most prominently, by ROK nuclear researchers and officials. How might the implementation of these new nuclear technologies affect the form or prospects of nuclear fuel cycle cooperation in East Asia? Given that, for example, small and medium reactors and "Gen IV" reactor designs are likely to be at least 15-20 years from commercialization[92], it seems clear that such reactors will play only a small role in the overall reactor fleet by 2050, or perhaps at most a moderate role in a "MAX" nuclear capacity expansion path. There is considerable uncertainty as to which next-generation reactors will be deployed, how much they will cost, and as to the implications their deployment may have for the region's nuclear fuel cycle. Given these

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[91] See, for example, von Hippel, D., and P. Hayes (2010), *Engaging the DPRK Enrichment and Small LWR Program: What Would it Take?* Nautilus Institute Special Report, dated December 23, 2010, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Deep-Borehole-Disposal-von-Hippel-Hayes-Final-Dec11-2010.pdf.

[92] See, for example, Goldberg, S.M, and R. Rosner (2011), *Nuclear Reactors: Generation to Generation*. American Academy of Arts and Sciences, available as http://www.amacad.org/pdfs/nuclearReactors.pdf.

uncertainties, consideration of the impact of next-generation reactors has been beyond the scope of this Report, but should be included in future work.

6.3.2 Climate Change Considerations

Climate change is a major and growing concern worldwide, with countries and sub-national jurisdictions making plans not just for reducing GHG emissions, but for adapting to impacts of climate change that seem inevitable. Nuclear power has to some degree enjoyed a resurgence of interest worldwide. As yet, however, with the significant exception of China, relatively little new reactor construction is underway worldwide.[93] A part of the interest in nuclear power is related to nuclear power's potential role in meeting energy needs without substantial GHG emissions. Some of the major issues associated with the linkages between nuclear power and climate change include the environmental implications of a "nuclear renaissance" for GHG emissions reduction, the economic, social, and political implications of a broad program of nuclear power development, relative to other GHG mitigation strategies, and the benefits and challenges posed by nuclear power in terms of adaptation to a changing climate, including, for example, the availability of water for reactor cooling as climates change, particularly at inland sites.

6.3.3 Long-term Storage/Disposal of Nuclear Wastes, Including Deep Borehole Disposal

Although not considered directly in the analysis presented here, the nations of the region, and indeed all nations using nuclear energy, will at some point within the next few decades have to make plans for long-term storage/disposal of nuclear wastes. Deep borehole disposal (DBD) of nuclear spent fuel and high-level wastes, which was the topic of an earlier Nautilus Institute project,[94] seems likely to be an attractive possibility, and there are areas within the Korean peninsula and China, as well as in other countries of the region, though possibly not in Japan, that would make good hosts for deep borehole facilities from a geological point of view. Deep borehole disposal facilities may well even have cost advantages over other forms of disposal (such as mined repositories). Deep borehole disposal, however, will require both technological advances to assure that key operational elements, such as emplacement of wastes, can be done safely and in a reliable manner, as well as domestic and possibly international policy agreements to allow the siting of deep borehole facilities. In addition, materials stored in deep boreholes should likely be considered essentially irretrievable, as a huge effort will be required to remove

[93] In the United States, for example, the recently completed Watts Bar 2 reactor, on which construction started in the 1970s and was halted for many years, is the first new US reactor to be commissioned in decades. Four additional units are under construction in the United States at present, representing about 4 percent of the total US reactor fleet. These additions will roughly offset the nuclear capacity decommissioned between 2010 and 2014 alone, and more US plants may be decommissioned in the next few years. See, for example, Chris Mooney (2016), "It's the first new U.S. nuclear reactor in decades. And climate change has made that a very big deal", *The Washington Post*, June 17, 2016, available as https://www.washingtonpost.com/news/energy-environment/wp/2016/06/17/the-u-s-is-powering-up-its-first-new-nuclear-reactor-in-decades/?utm_term=.10fe7a0a1db6, and World Nuclear Organization (2016), "
Nuclear Power in the USA", updated 27 October, 2016, and available as http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power.aspx.

[94] See, for example, participant papers related to deep borehole disposal of spent nuclear fuel prepared for the Nautilus Institute Security of Spent Nuclear Fuel (2012-2014) 2013 Working Group Meeting, available as http://nautilus.org/projects/by-name/security-of-spent-nuclear-fuel/2013-working-group-meeting/papers-and-presentations/.

emplaced materials from boreholes, not least because waste emplacement in boreholes would be between 3 and 5 kilometers underground. This isolation can well be considered a significant advantage, from a risk-of-diversion-of-nuclear materials point of view, but it brings up significant design considerations, and is of concern to those who see spent fuel as a potential future resource for energy production. Dr. Neil Chapman summarized the status of readiness of deep borehole technologies, despite their potential simplicity and low cost relative to mined repositories, as probably being 30 or so years from full-scale implementation, or about the same as other disposal options or, for that matter, the closed nuclear fuel cycle options involving the use of fast reactors that are under consideration in Japan, the ROK, and China.[95] What this means is that it is inevitable that intermediate spent fuel storage, and most likely dry cask storage, must be employed by most or all of the nations of the region in advance of any final disposal option.

Among the perceived favorable characteristics of deep borehole disposal of nuclear materials are its inherently modular nature, potentially lower costs, and widespread applicability. As a results, there is the possibility of sharing international R&D, and ultimately, of separately licensing the borehole technology and the disposal facility that allows nuclear waste to be disposed of in boreholes, analogous to generic reactor design licensing of different technologies.

Discussions on borehole operations focus on the need to understand drilling damage (extent and properties of the disturbed zone close to the borehole) and on the need for high integrity, low permeability seals to assure long-term isolation. Characteristics of the interface between the seals and the borehole wall will be particularly important. Potential operational problems during emplacement, including damage to canisters and waste during the trip down the borehole, should be minimized, and it may be desirable to line the hole for its entire length with steel casing. A reference design concept to provide a baseline for evaluating performance and impacts of alternative approaches may be useful. International cooperation, including, perhaps, cooperation between the countries of Northeast Asia, could help to move the concept forward through evaluation of the generic aspects of the technology. Such an effort would be amenable to an international co-operation project, and there is potentially sufficient interest from a number of countries to consider such a shared multinational project. The project would ultimately need a host country for the engineering trials. A first step in consideration of DBD by the countries of Northeast Asia, however, might be convening a regional meeting, attended by researchers and officials responsible for designing and managing nuclear waste disposal in the countries of the region, at which DBD concepts are described, and discussions are held on the specific barriers, especially institutional barriers, to DBD in the countries of the region.

In the China-Japan-ROK region, the amounts of radioactive material to be disposed of make shared disposal facilities look less attractive, for many reasons, but shared R&D could be highly appropriate, particularly given some of the potential institutional resistance to DBD (due to nuclear sector priorities) in many of the countries of the region. That is, it may be easier for a country to participate in a multi-nation project exploring DBD in than to negotiate internally for funding and support for a national DBD program.

[95] See Dr. Chapman's presentation "Deep Borehole Disposal of Spent Fuel and Other Radioactive Wastes: An International Overview", available as http://nautilus.org/wp-content/uploads/2013/08/Chapman-Nautilus-Beijing-May-2013.pdf.

Ultimately, if DBD proves to be an attractive and acceptable means of spent fuel disposal, the location of a shared site remains a key question. Several countries of the region, including nuclear weapons states Russia and China, almost certainly have suitable geology suitably remote from population centers. Mongolia has been mentioned as a potential participant in the nuclear fuel cycle, likely has suitable sites for DBD, and is considered a neutral party, though indications are that substantial nuclear sector development in Mongolia appears to be off the table from a political perspective.[96] As a consequence, a regional DBD facility, as with other shared nuclear facilities, would likely require years of patient international negotiation and institution building, as well as the types of technical research and development mentioned above, to come to fruition. Convening of an international workshop to begin to discuss these issues would therefore be a significant first step in this direction.

6.3.4 Management of Radiological Risk from Spent Fuel Pools

Another issue of potential intersection between international cooperation on fuel cycle management and spent fuel security is in the management of radiological risk from spent fuel pools. Reducing spent fuel density at existing and future reactors would require changes in design and operation, especially in BWRs (boiling water reactors). The resulting incremental cost of these changes per unit of electricity is highly likely to be tiny, but the benefits in terms of avoided risk of radiological emissions and damage could be huge, as could the benefits of avoided public anxiety. Conversely, the risks of not changing spent fuel pool practices could be catastrophic. Moreover, reducing pool density implies choices with regard to dry cask storage versus surface or underground spent fuel pools outside existing secure reactor containment buildings, posing different and new risks of technological accident and/or malevolent attack (in the ROK or Japan, of DPRK missile or bomb attack; in China, of non-state actor attack, in particular). The decision to reduce spent fuel pool density has ramifications for potential cooperation on spent fuel management, as an aggressive program to de-densify spent fuels means that much more spent fuel, particularly in Japan and the ROK, will need to find homes in dry cask interim storage sited somewhere, whether at local, national, or international facilities.

It is clear that further work is needed to identify technical means of reducing the risks associated with current common practices of spent fuel storage, to more rigorously estimate the relative costs and benefits of adopting risk-reduction approaches, to communicate the results of those assessments to decisionmakers, and to work with decisionmakers to develop policies that work toward risk reduction. One approach to accomplishing these tasks might be to convene an expert group on spent fuel management that includes both advocates of changed spent fuel management and critics and skeptics of the case that spent fuel pool density should be reduced. This might start in one country, probably Japan. Subsequently, the expert group could be broadened by convening a regional workshop involving representatives from the ROK, Taiwan, and China, as well as US and Japanese experts to address this issue, and ways to mitigate the different hazard events (natural disasters, aerial bombardment, non-state attack). In addition to expert meetings, synthesis, analysis, and summarizing of findings for policy input would be carried out.

In Japan, there is now a strong civil society and business constituency, as well as a well-informed nuclear-expert community, able and willing to address this issue in policy contexts, as part of the overall battle to reform the “nuclear village”, and to reconstitute the social pact that sustains the LWR-reprocessing-breeder reactor strategy in Japan. In Korea, there is less public interest, but

[96] Personal communications from a Mongolian official to D. von Hippel, 2013.

keen political and bureaucratic interest given the issue's salience of the US-ROK nuclear cooperation "123" negotiations.[97] There are key political and social constraints on fuel storage options in both nations that need further exploration in light of recent events. Policy options are less constrained and therefore more open in China, and we believe that Chinese experts and policymakers will respond to new data and analysis.

In short, it is critical to nuclear security to clarify whether reducing spent fuel pool density is justified to reduce the possible risk of inadvertent or malevolent radiological release from spent fuel pools and reactor sites.

Particularly in Japan and the ROK, dry cask storage at or away from reactor sites is clearly an attractive option for reducing radiological risks associated with spent fuel pools in the short-to-medium-term. There are, however, a host of legal, political, and institutional barriers preventing the wider use of this technology in both countries. Better understanding these barriers, and how to overcome them in each nation, is therefore a key need. To that end, working with colleagues and civil society groups in the region to better understand the challenges to siting at-reactor or away-from-reactor dry cask storage options that would reduce risks associated with spent fuel pools is an attractive activity that would build on the results of the current project, as well as other research efforts in the region.

6.3.5 Nuclear Fuel Cycle Choices and Nuclear Weapons Proliferation

Finally, there is a substantial link between nuclear fuel cycle choices and the risk of nuclear weapons proliferation, as indicated above. The presence of the DPRK in East Asia makes the proliferation issue especially pertinent in the region, as does the history of conflict between many of the region's nations, including ongoing territorial disputes among virtually all pairs of parties one could name (with the possible exception of Mongolia). Choices of nuclear fuel cycle approaches will affect national and international security arrangements. Specifically, if a Nuclear Weapons Free Zone in the region is to be developed, the future of nuclear fuel cycle development and cooperation in the region will be an integral part of the discussion[98].

[97] See, for example, World Nuclear News (2013)," US-Korea 123 extension is passed", dated September 19, 2013, and available as http://www.world-nuclear-news.org/NP-US-Korea_123_extension_is_passed-1909137.html.
[98] See, for example, Morton H. Halperin (2012), *Promoting Security in Northeast Asia: A New Approach*, presented at "A New Approach to Security in Northeast Asia: Breaking the Gridlock", October 9-10, 2012, Washington, DC, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/10/Halperin-New-approach-to-Northeast-Asian-Security-Oct8-2012.pdf.

6.4 Next Steps on Nuclear Fuel Cycle Cooperation, and Follow-on Activities

The development of cooperation arrangements will need to be built through follow-on activities that include a combination of expert analysis and input, through development of, for example, a report laying out the possible organization and activities of institutions for nuclear fuel cycle cooperation in the region, plus one or more workshops, attended by representative from the region, to discuss the political, organizational, institutional, and economic challenges that might be faced. The report on the potential organization of fuel cycle cooperation would build on previous work on the topic, but would also extend Nautilus' existing quantitative analysis to further describe the physical flows of materials and costs that would be involved, as well as use sensitivity analysis to examine the response of results to changes in key parameters. The workshop on barriers and challenges likely to be faced by nuclear sector cooperation would look at challenges faced on a national level in each country, as well as regionally and internationally, and would explore ways of overcoming those challenges.

The underpinnings of Nautilus' work on nuclear fuel cycle cooperation in general, and spent fuel management in particular, has been our work since 2000 with Country Teams on energy sector status, policy, and futures in the countries of the region. Continuing and deepening this work, including advanced full energy-sector and national/regional energy futures modeling, will continue to provide the full economic, environmental, political and social context for nuclear energy, and thus, nuclear spent fuel management and nuclear cooperation scenarios. Deepening this work to include more detailed non-nuclear (for example, renewable energy and energy efficiency) greenhouse gas emissions mitigation scenarios to compare and combine with nuclear scenarios will help to round out the consideration of nuclear energy paths, and to set the relative context for nuclear power and nuclear spent fuel management. A potential simultaneous activity could be to broaden, as Nautilus has done in years past (but has not been funded to do in recent years), the group of participating nations to include those in the East Asia and Pacific region with nascent or proposed nuclear energy programs, both to gain the insights of those groups and to explore the particular issues associated with building and operating the elements of a nuclear energy system (including spent fuel management) in nations without nuclear experience. The combination of representatives from nations with long nuclear experience and those from nations seeking to join the "nuclear club" offers significant opportunities for sharing of knowledge and perspectives, and for uncovering both challenges to and opportunities for cooperation in nuclear fuel cycle management.

ANNEX 1: Summary Graphics for Nuclear Capacity and Generation by Country and by Path

Figure A1- 1: Nuclear Capacity by Path for Japan, GWe

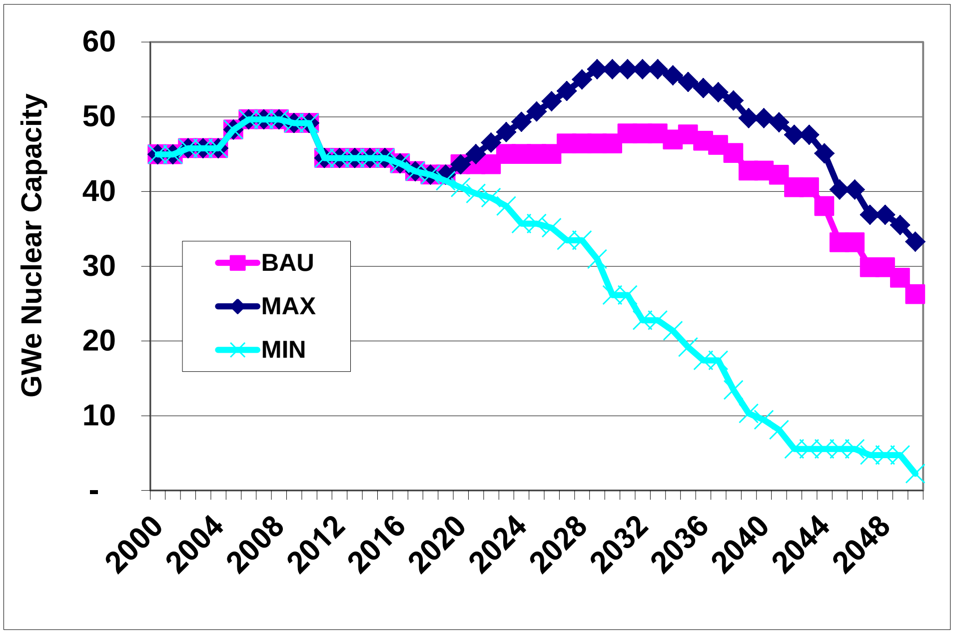


Figure A1- 2: Nuclear Output by Path for Japan, TWh

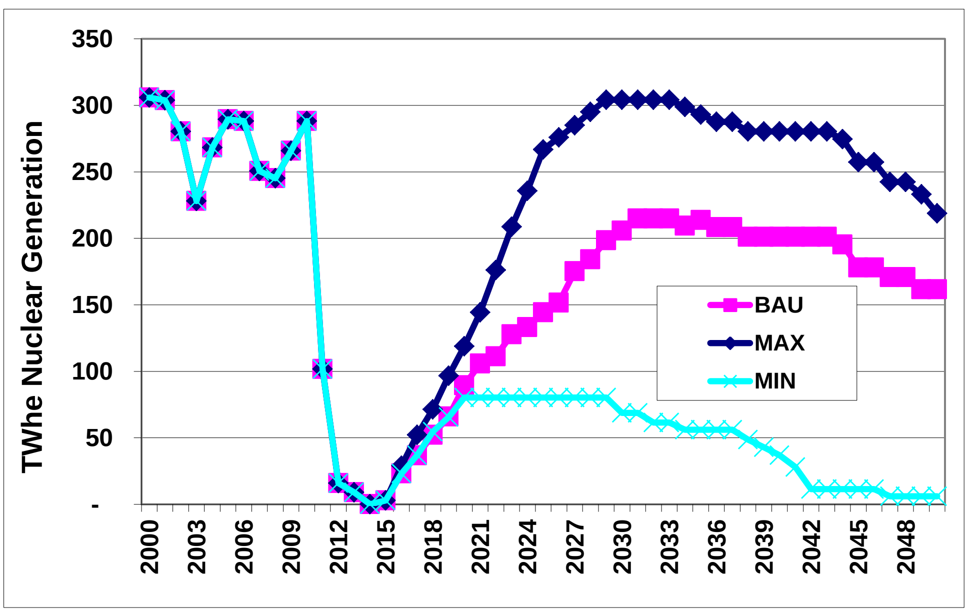


Figure A1- 3: Nuclear Capacity by Path for the ROK, GWe

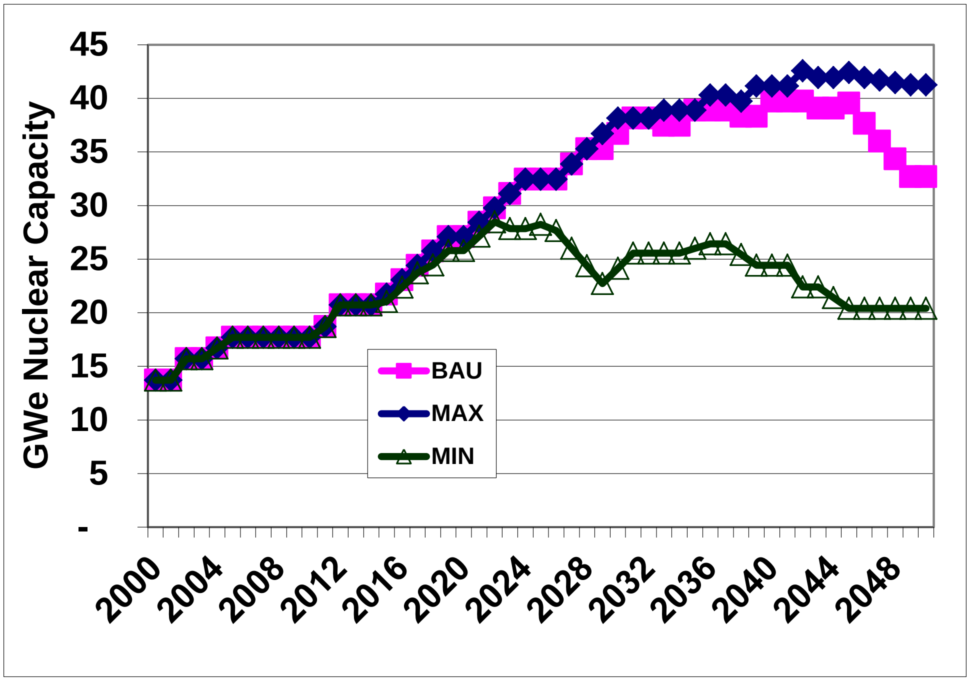


Figure A1- 4: Nuclear Output by Path for the ROK, TWh

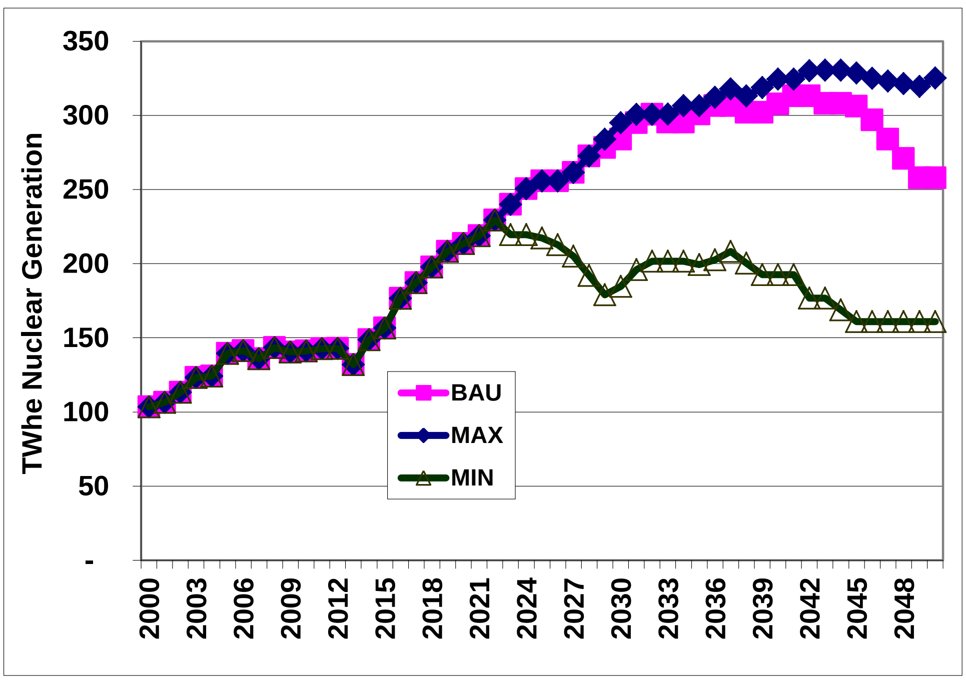


Figure A1- 5: Nuclear Capacity by Path for China, GWe

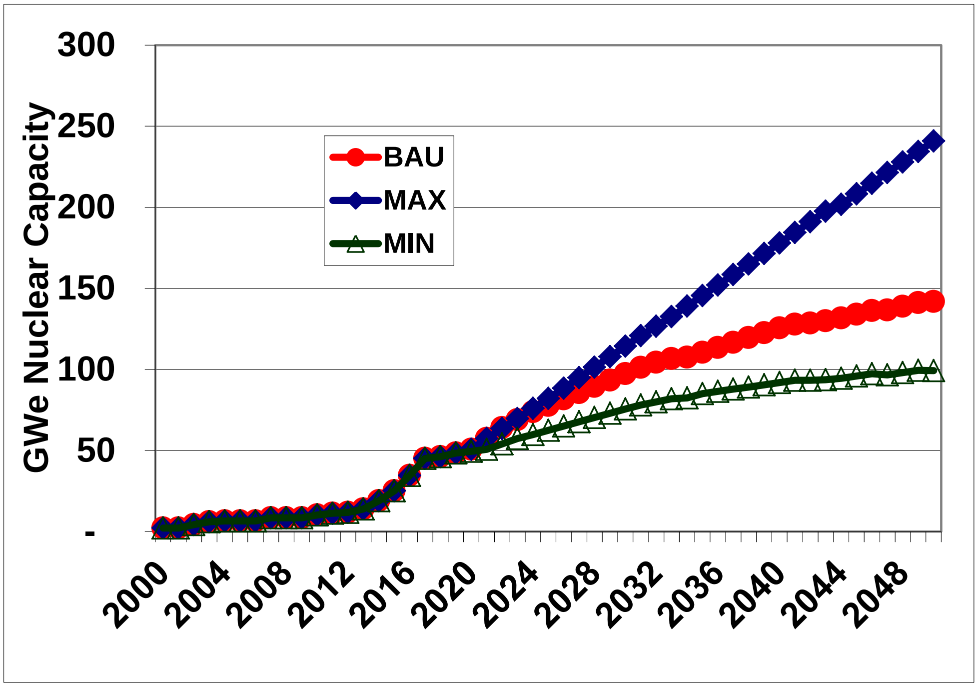


Figure A1- 6: Nuclear Output by Path for China, TWh

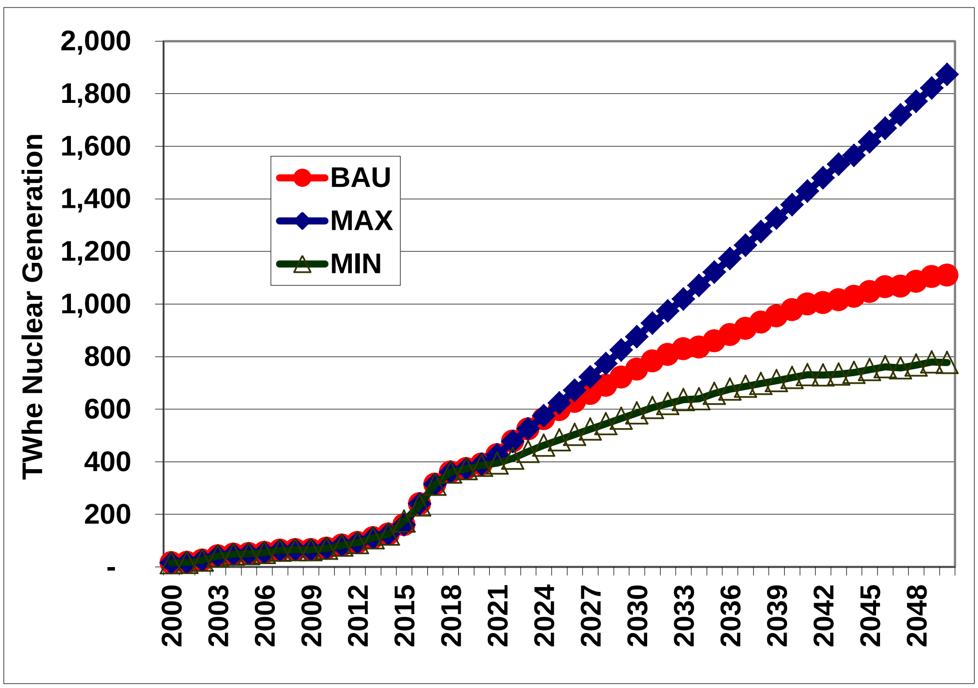


Figure A1- 7: Nuclear Capacity by Path for the Russian Far East, GWe

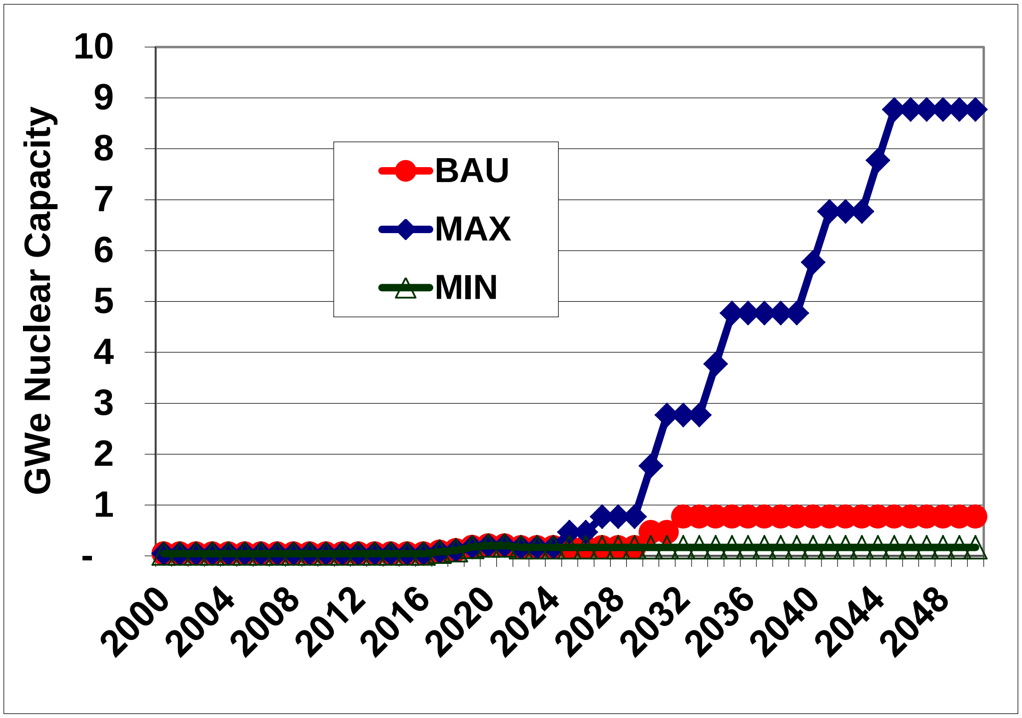


Figure A1- 8: Nuclear Output by Path for the Russian Far East, TWh

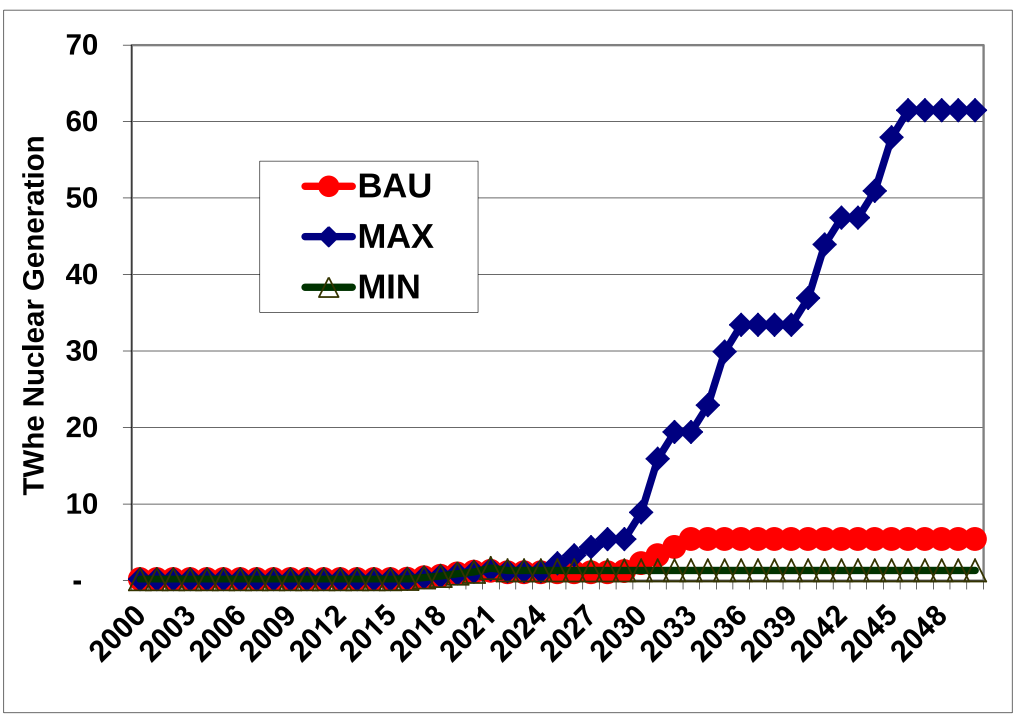


Figure A1- 9: Nuclear Capacity by Path for Taiwan (Chinese Taipei), GWe

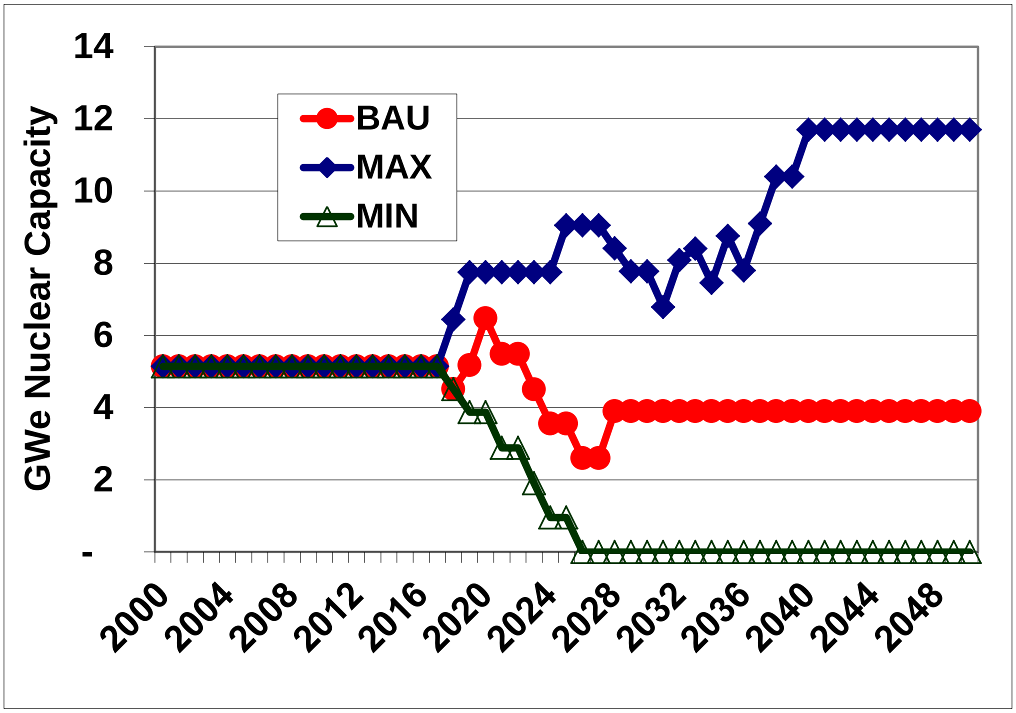


Figure A1- 10: Nuclear Output by Path for Taiwan (Chinese Taipei), TWh

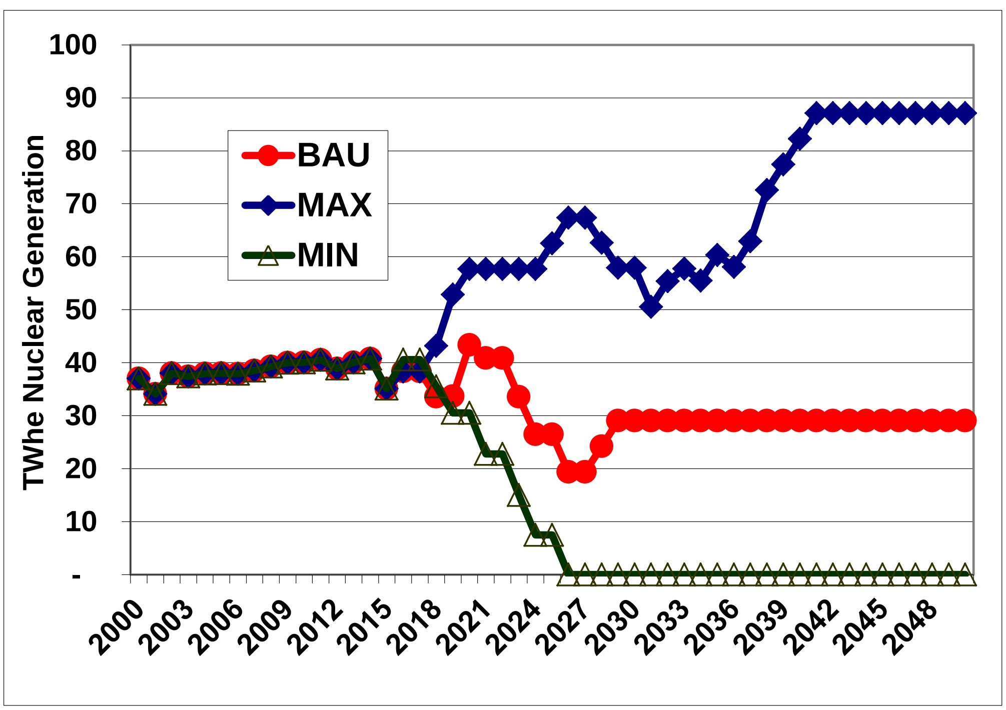


Figure A1- 11: Nuclear Capacity by Path for the DPRK, GWe

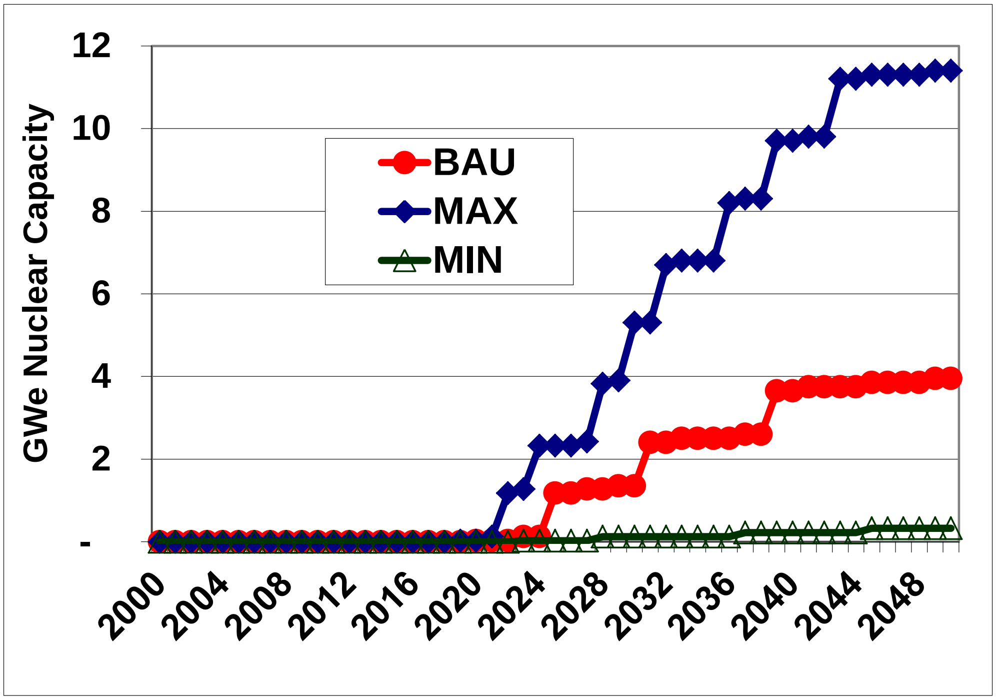


Figure A1- 12: Nuclear Output by Path for the DPRK, TWh

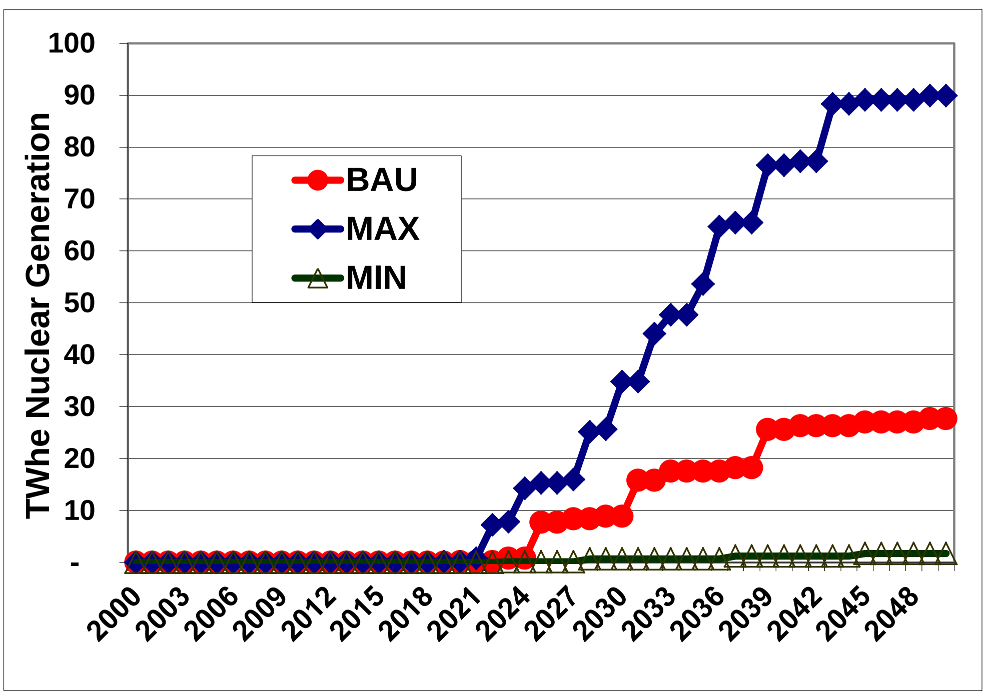


Figure A1- 13: Nuclear Capacity by Path for Vietnam, GWe

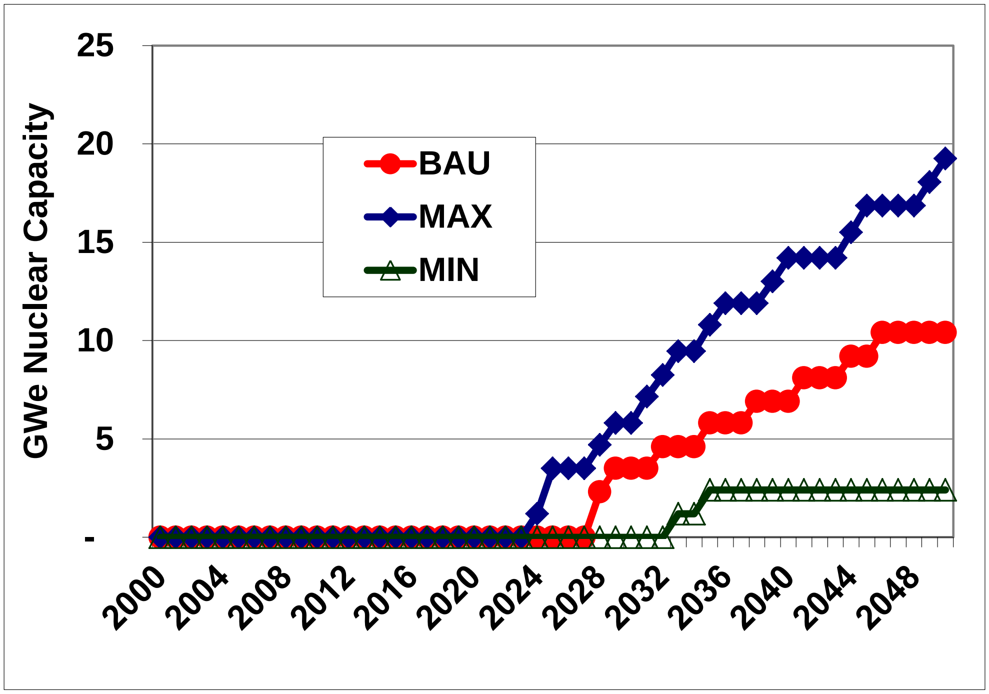


Figure A1- 14: Nuclear Output by Path for Vietnam, TWh

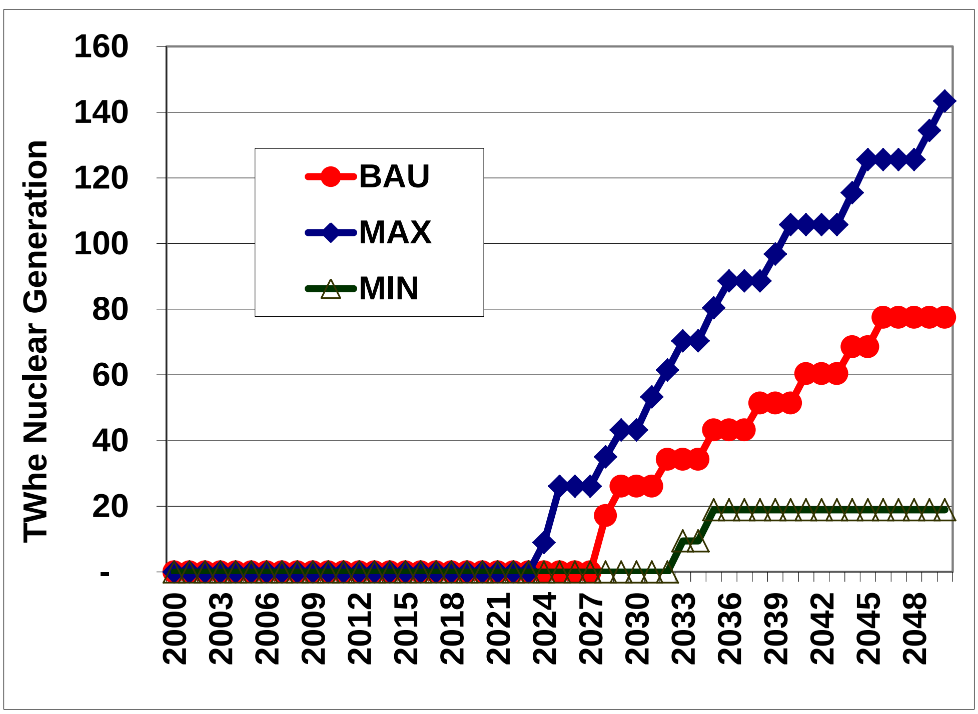


Figure A1- 15: Nuclear Capacity by Path for Indonesia, GWe

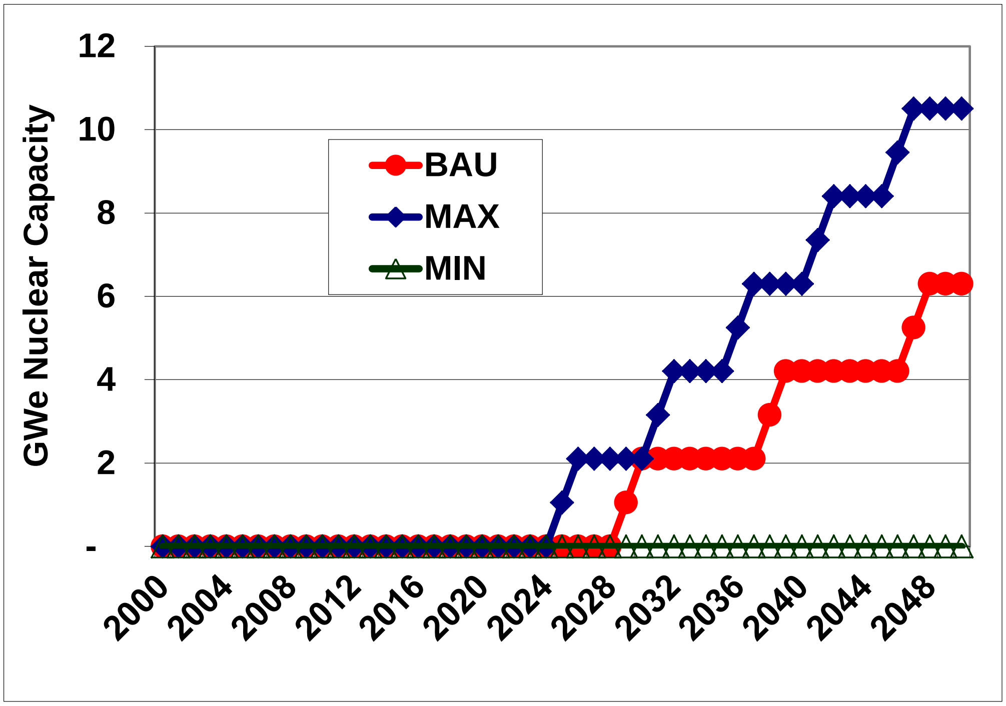


Figure A1- 16: Nuclear Output by Path for Indonesia, TWh

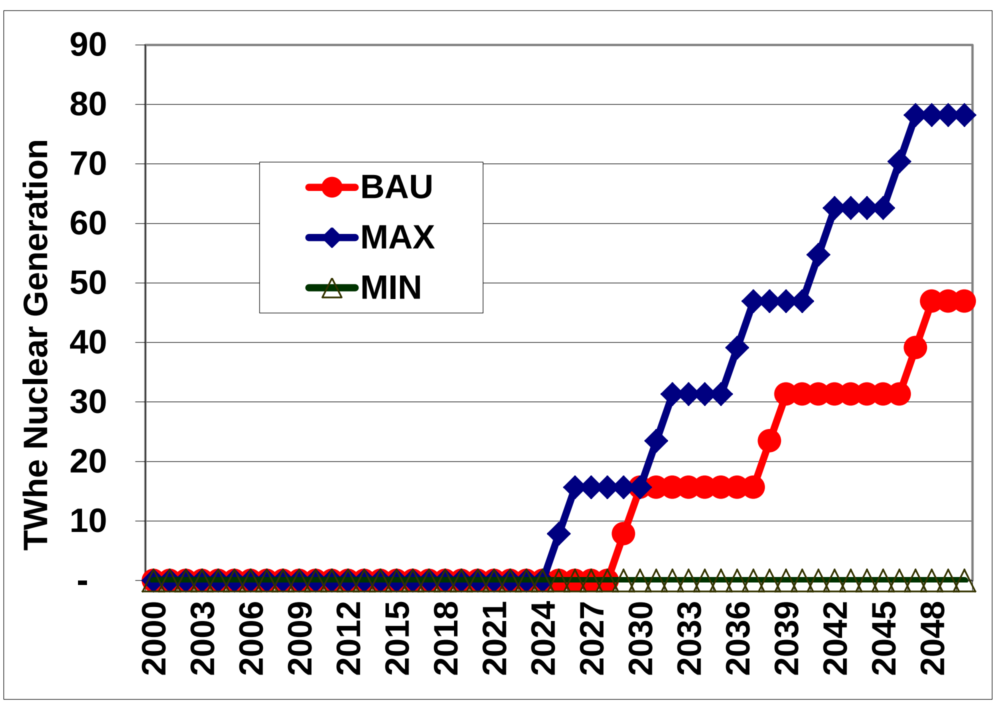


Figure A1- 17: Nuclear Capacity by Path for Australia, GWe

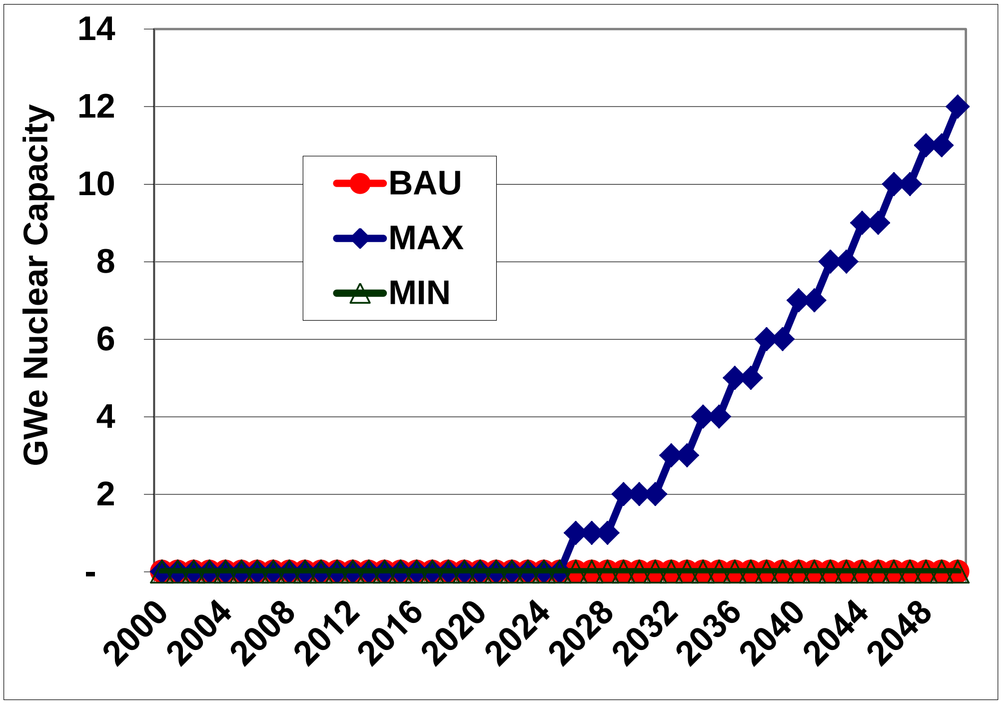
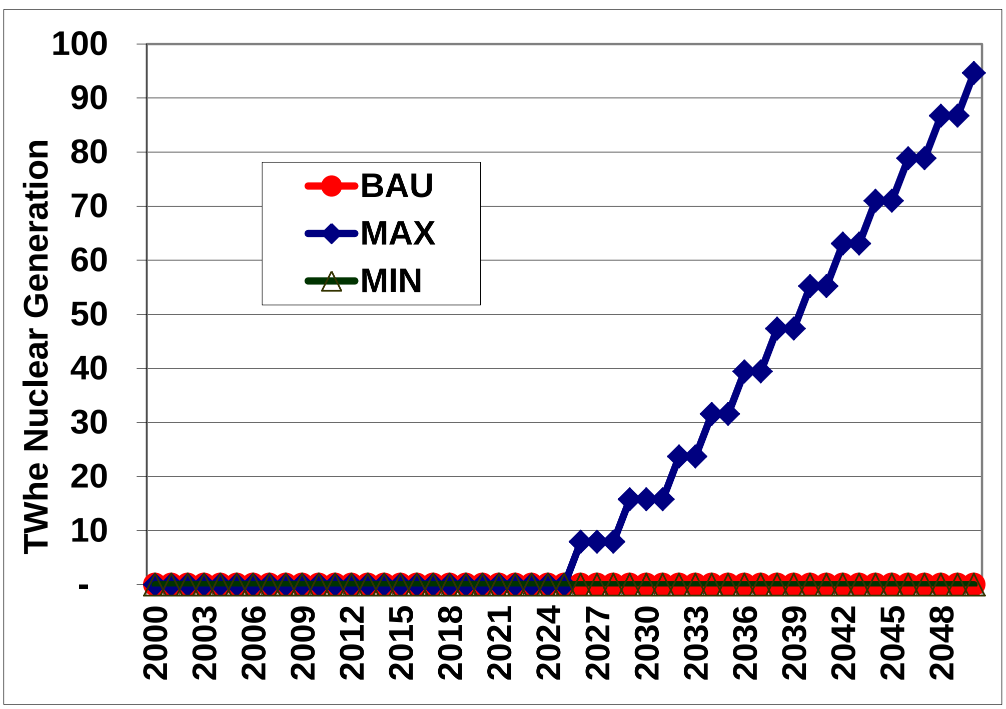


Figure A1- 18: Nuclear Output by Path for Australia, TWh



ANNEX 2: Selected Inputs, Assumptions, and Additional Results of Regional (East Asia) Nuclear Fuel Cycle Analysis

ANNEX 2A: Selected Inputs and Assumptions

FUTURE REGIONAL NUCLEAR FUEL CYCLE COOPERATION IN EAST ASIA:
ENERGY SECURITY COSTS AND BENEFITS

Calculations for East Asia Science and Security (EASS) and Related Follow-on (2012-2016) Projects, funded by MacArthur Foundation

Common Factors for Calculations

Prepared by:	David Von Hippel
Last Modified:	11/11/2016

Common Factors

Conversions:

Pounds per kg:	2.2	
Units U per unit U_3O_8	0.847993	
Becquerels (Bq) per Curie (Ci)	3.70E+10	(disintegrations per second)
Atomic Weight of Natural Uranium	238.0289	grams/mol
Units U per unit UF6	0.676012	
Assumed USD inflation rate post-2015:	2%	/yr

Inflation Factors (to 2009 US dollars)

1990	1.64
1991	1.58
1992	1.53
1993	1.48
1994	1.45
1995	1.41
1996	1.37
1997	1.34
1998	1.32
1999	1.29
2000	1.26
2001	1.22
2002	1.20
2003	1.17
2004	1.14
2005	1.11
2006	1.07
2007	1.04
2008	1.00
2009	1.00
2010	0.98
2011	0.95
2012	0.93
2013	0.92
2014	0.91
2015	0.91
2016	0.89
2017	0.87
2018	0.85
2019	0.84
2020	0.82

Through 2016, from U.S. Bureau of Labor Statistics Inflation Calculator, http://www.bls.gov/data/inflation_calculator.htm; 2016-on based on assumed inflation rate.

Discount Rate	5%	;yr (real basis)

FUTURE REGIONAL NUCLEAR FUEL CYCLE COOPERATION IN EAST ASIA: ENERGY SECURITY COSTS AND BENEFITS

Calculations for East Asia Science and Security (EASS) and Related Follow-on (2012-2016) Projects, funded by MacArthur Foundation

Estimates of Uranium Prices

Prepared by:	David Von Hippel
Last Modified:	10/25/2016

Historical Uranium Spot Prices

Conversions:

Pounds per kg:	2.2
Units U per unit U_3O_8	0.847993

Historical prices below from Cameco "URANIUM PRICES, Uranium Spot Price History, though September, 2016,
available as http://www.cameco.com/invest/markets/uranium-price.
except 2011 - 2012 from "Uranium Miner", available as http://www.uraniumminer.net/market_price.htm. Values from these two data sets appear reasonably consistent.
As of 2016, Cameco's "long term prices" were $10-$15 per lb higher than spot prices, with the larger differences in the later months of the year.
Prices shaded green are "UxC Uranium U3O8 Futures Quotes", available from http://www.cmegroup.com/trading/metals/other/uranium.html.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Unweighted Average	
													$/lb$U_3O_8$	$/kg U
2021	$23.90	$23.90	$23.90	$24.05	$24.05	$24.05	$24.20	$24.20	$24.20				$24.05	$ 62.39
2020	$23.20	$23.20	$23.20	$23.40	$23.40	$23.40	$23.60	$23.60	$23.60	$23.75	$23.75	$23.75	$23.49	$ 60.94
2019	$22.20	$22.20	$22.20	$22.60	$22.60	$22.60	$22.80	$22.80	$22.80	$23.00	$23.00	$23.00	$22.65	$ 58.76
2018	$21.00	$21.00	$21.10	$21.20	$21.20	$21.30	$21.40	$21.40	$21.40	$21.80	$21.80	$21.80	$21.37	$ 55.43
2017	$20.05	$20.05	$20.05	$20.10	$20.15	$20.20	$20.40	$20.45	$20.50	$20.60	$20.80	$20.90	$20.35	$ 52.81
2016	$34.70	$32.15	$28.70	$27.50	$27.25	$26.70	$25.45	$25.25	$23.00	$20.00	$20.00	$20.00	$25.89	$ 67.17
2015	$37.00	$38.63	$38.36	$37.13	$35.00	$36.38	$35.50	$36.75	$36.38	$36.13	$36.00	$34.23	$36.46	$ 94.58
2014	$35.45	$35.38	$34.00	$30.43	$28.25	$28.23	$28.50	$31.50	$35.40	$36.38	$39.50	$35.50	$33.21	$ 86.16
2013	$43.88	$42.00	$42.25	$40.50	$40.45	$39.60	$34.75	$34.50	$35.00	$34.50	$36.08	$34.50	$38.17	$ 99.02
2012	$52.00	$52.00	$51.00	$51.75	$52.00	$51.00	$49.25	$48.50	$46.50	$42.50	$42.00	$43.50	$48.50	$ 125.83
2011	$72.00	$69.25	$62.50	$55.50	$57.50	$54.25	$51.75	$49.00	$52.50	$52.00	$51.75	$51.75	$56.65	$ 146.96
2010	$42.38	$41.13	$41.88	$41.75	$40.75	$41.75	$45.63	$45.25	$46.63	$52.00	$60.63	$62.25	$46.84	$ 121.51
2009	$47.50	$44.50	$42.00	$44.50	$49.00	$51.50	$47.00	$46.00	$42.88	$48.00	$45.38	$44.50	$46.06	$ 119.50
2008	$78.00	$73.00	$71.00	$65.00	$60.00	$59.00	$64.50	$64.50	$53.00	$45.00	$55.00	$52.50	$61.71	$ 160.09
2007	$75.00	$85.00	$95.00	$113.00	$125	$136.00	$120.00	$90.00	$85.00	$85.00	$93.00	$90.00	$99.33	$ 257.71
2006	$37.50	$38.63	$40.75	$41.50	$43.00	$45.75	$47.38	$50.25	$54.88	$60.13	$63.50	$72.00	$49.61	$ 128.70
2005	$21.10	$21.75	$22.55	$25.00	$29.00	$29.00	$29.50	$30.10	$31.63	$33.25	$34.75	$36.38	$28.67	$ 74.37
2004	$15.55	$16.63	$17.63	$17.68	$17.80	$18.50	$18.50	$19.63	$20.00	$20.23	$20.50	$20.60	$18.60	$ 48.27
2003	$10.15	$10.15	$10.10	$10.88	$10.95	$10.90	$11.05	$11.30	$12.23	$12.73	$13.75	$14.45	$11.55	$ 29.97
2002	$9.70	$9.93	$9.83	$9.90	$9.90	$9.90	$9.85	$9.85	$9.75	$9.90	$9.88	$10.20	$9.88	$ 25.64
2001	$7.23	$7.95	$8.20	$8.85	$8.85	$8.83	$8.93	$9.10	$9.40	9.48	$9.50	$9.55	$8.82	$ 22.89
2000	$9.45	$9.38	$9.20	$8.85	$8.43	$8.13	$8.08	$7.75	$7.43	$7.20	$7.13	$7.10	$8.18	$ 21.22
1999	$10.50	$10.50	$10.85	$10.85	$10.63	$10.35	$10.25	$10.05	$9.83	$9.73	$9.68	$9.60	$10.24	$ 26.55
1998	$11.90	$10.88	$10.73	$10.78	$10.83	$10.83	$10.50	$10.23	$9.83	$9.20	$8.75	$8.75	$10.27	$ 26.64
1997	$14.25	$13.70	$13.00	$12.18	$11.45	$10.60	$10.50	$10.25	$10.93	$12.63	$12.75	$12.10	$12.03	$ 31.21
1996	$12.95	$15.33	$15.83	$16.13	$16.50	$16.55	$16.50	$16.35	$15.90	$15.45	$14.95	$14.70	$15.60	$ 40.46
1995	$9.68	$10.38	$11.08	$11.55	$11.78	$11.83	$11.88	$11.80	$11.75	$11.75	$11.83	$12.23	$11.46	$ 29.74
1994	$9.50	$9.48	$9.48	$9.35	$9.25	$9.25	$9.33	$9.15	9.08	$9.08	9.48	9.6	$9.34	$ 24.22
1993	$9.75	$10.05	$10.10	$10.20	$10.08	$10.15	$9.90	$10.05	$10.25	$10.23	$9.95	$9.88	$10.05	$ 26.07
1992	$7.95	$8.00	$7.88	$7.83	$7.73	$7.83	$7.83	$8.08	$8.68	$10.38	$10.40	$9.98	$8.55	$ 22.18
1991	$9.15	$9.45	$9.35	$9.05	$9.23	$9.08	$8.65	$8.88	$8.33	$7.38	$7.40	$8.75	$8.73	$ 22.64
1990	$8.88	$8.75	$8.80	$8.85	$9.30	$11.30	$11.73	$11.48	$10.30	$8.43	$9.65	9.75	$9.77	$ 25.34
1989	$11.55	$11.23	$10.73	$10.15	$9.80	$9.73	$9.73	$9.65	$9.60	$9.40	9.25	$9.00	$9.99	$ 25.90
1988	$16.40	$16.20	$15.95	$15.88	$15.45	$15.18	$14.65	$14.13	$13.80	$13.18	$12.85	$11.88	$14.63	$ 37.95

Projections of Uranium Costs

No recent long-term projections of Uranium costs were immediately available, and the recent glut of uranium on the international market, and very low spot prices, complicates the task of attempting to project Uranuim prices over the long term. An older (2001) IAEA report (Analysis of Uranium Supply to 2050, (May 2001, STI/PUB/1104), suggests that in a medium nuclear fuels demand scenario, uranium resources with production costs of $130 would become economic in 2034 (assuming known resource development only), and in a high demand scenario, those resources would become economic in 2026. Converting this cost to 2009 dollars yields $ 163.80 per kg U (inflation from 2000 to 2009 from http://data.bls.gov/cgi-bin/cpicalc.pl).

Starting with actual 2001 Uranium spot prices, which were presumably the operative prices when the projections were made, these estimates suggest an annual average growth rate in Uranium prices of 5.51% under a medium demand scenario through the original end date of the forecast, moderating to 3.5% annually from 2035 through 2050.

The IAEA projections implied growth of 7.33% under a high demand scenario through 2026. We assume that this projection continues through 2034, after which growth in the high case moderates to 5.0% annually from 2035 through 2050.

These very rough estimates, extrapolated to 2050, yield the following Uranium price trends.

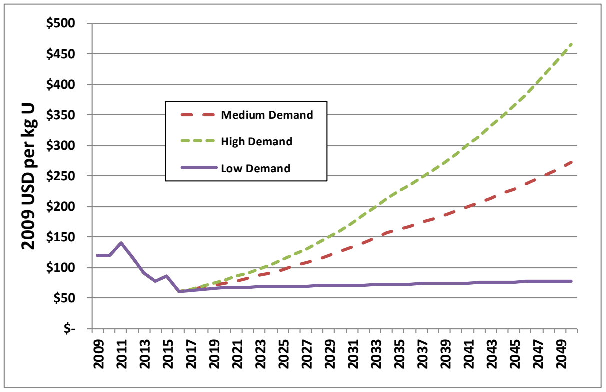
Note that in the high demand case, by 2050 Uranium prices approach earlier estimates of the costs of extracting uranium from seawater ($300-$600 kgU), though more recent estimates of U from seawater costs are apparently higher (see, for example, "Extraction of uranium from seawater: a few facts", Joel Guidez and Sophie Gabriel, *EPJ Nuclear Sci. Technol* .2, 10 (2016), available as http://www.epj-n.org/articles/epjn/pdf/2016/01/epjn150059.pdf. For the low price trajectory case below, we assume an increase in uranium costs of 3.0% per year from their current (2016) very low levels through 2020, and thereafter assume a modest 0.50% annual real increase in Uranium costs, which is the same escalation rate used by a team of MIT researchers in preparing "Update of the MIT 2003 Future of Nuclear Power Study", dated 2009, and available as http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf.

For 2016-2020, the medium demand case assumptions yield growth rates fairly close to those for 2015-2020 projections by the Minerals Council of Australia (see table at right).

Year	Medium Demand	High Demand	Low Demand
2009	$ 119.50	$ 119.50	$ 119.50
2010	$ 119.08	$ 119.08	$ 119.08
2011	$ 139.61	$ 139.61	$ 139.61
2012	$ 117.02	$ 117.02	$ 117.02
2013	$ 91.19	$ 91.19	$ 91.19
2014	$ 78.08	$ 78.08	$ 78.08
2015	$ 85.62	$ 85.62	$ 85.62
2016	$ 59.69	$ 59.69	$ 59.69
2017	$ 62.98	$ 64.07	$ 61.48
2018	$ 66.44	$ 68.76	$ 63.32
2019	$ 70.10	$ 73.81	$ 65.22
2020	$ 73.97	$ 79.22	$ 67.18
2021	$ 78.04	$ 85.03	$ 67.52
2022	$ 82.34	$ 91.26	$ 67.85
2023	$ 86.87	$ 97.96	$ 68.19
2024	$ 91.66	$ 105.14	$ 68.53
2025	$ 96.70	$ 112.85	$ 68.88
2026	$ 102.03	$ 121.12	$ 69.22
2027	$ 107.65	$ 130.01	$ 69.57
2028	$ 113.58	$ 139.54	$ 69.92
2029	$ 119.83	$ 149.77	$ 70.27
2030	$ 126.43	$ 160.75	$ 70.62
2031	$ 133.39	$ 172.54	$ 70.97
2032	$ 140.74	$ 185.19	$ 71.32
2033	$ 148.49	$ 198.78	$ 71.68
2034	$ 156.67	$ 213.35	$ 72.04
2035	$ 162.15	$ 224.02	$ 72.40
2036	$ 167.83	$ 235.22	$ 72.76
2037	$ 173.70	$ 246.98	$ 73.13
2038	$ 179.78	$ 259.33	$ 73.49
2039	$ 186.08	$ 272.30	$ 73.86
2040	$ 192.59	$ 285.91	$ 74.23
2041	$ 199.33	$ 300.21	$ 74.60
2042	$ 206.30	$ 315.22	$ 74.97
2043	$ 213.53	$ 330.98	$ 75.35
2044	$ 221.00	$ 347.53	$ 75.72
2045	$ 228.73	$ 364.90	$ 76.10
2046	$ 236.74	$ 383.15	$ 76.48
2047	$ 245.03	$ 402.31	$ 76.87
2048	$ 253.60	$ 422.42	$ 77.25
2049	$ 262.48	$ 443.54	$ 77.64
2050	$ 271.66	$ 465.72	$ 78.02

Year	Historical Uranium Price (2009 $/kg U)*
2000	$ 26.73
2001	$ 27.92
2002	$ 30.77
2003	$ 35.07
2004	$ 55.02
2005	$ 82.55
2006	$ 137.70
2007	$ 268.01
2008	$ 160.09
2009	$ 119.50
2010	$ 119.08
2011	$ 139.61
2012	$ 117.02
2013	$ 91.19
2014	$ 78.08
2015	$ 85.62
2016	$ 59.69
2017	$ 46.00
2018	$ 47.34
2019	$ 49.20
2020	$ 50.02

*Values for 2016-2020 and from August 2015 based on UxC Uranium Futures Quotes (see above).



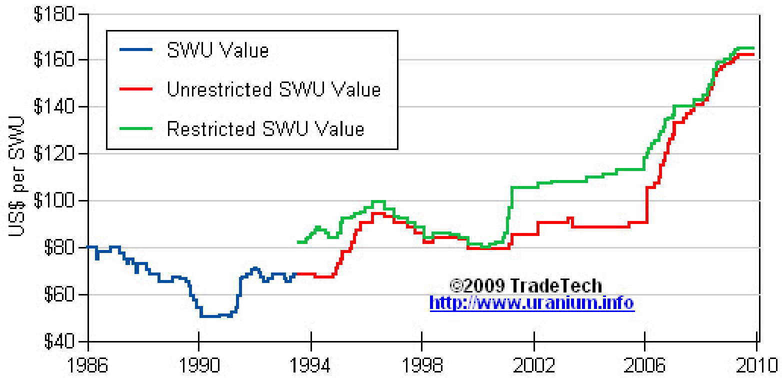
Projections of Uranium Enrichment Costs

No recent long-term projections of Uranium enrichment costs were immediately available. We use the historical data below with three assumed growth rates to produce three candidate cost trajectories.

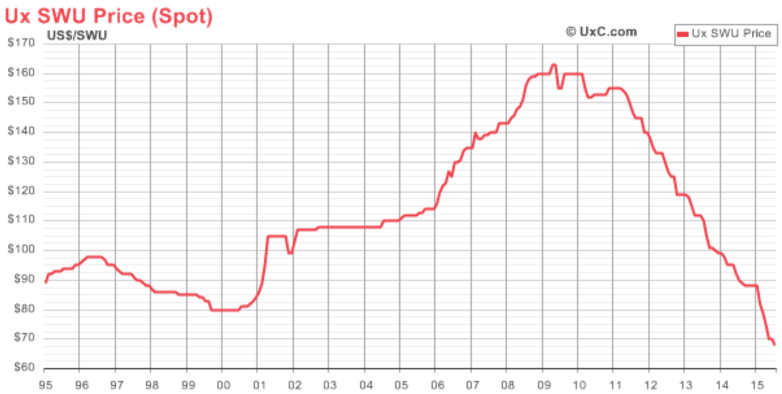
The following data are from "TradeTech and its Web site, http://www.uranium.info", accessed as of 2009 via http://www.uranium.info/index.cfm?go=c.page&id=34

For the years 2000-2009, average SWU values (arithmetic averages of restricted and unrestricted mid-year values) were estimated from the table and graph below. These data imply an average real escalation in SWU value from 2000-2009 of 5.27% percent annually. Given that this time period spans an era when enriched uranium from nuclear weapons programs was used for power reactors in large quantities, this growth rate is probably not suitable for use as a future long-term growth rate, even in a high case. If more recent years are included in the calculation (see UCx graphs, below), much lower average real escalation rates, for example, 1.40% percent annually from 2000 through 2012, is implied, but if calculated using post-Fukushima SWU values, even negative growth rates are implied.

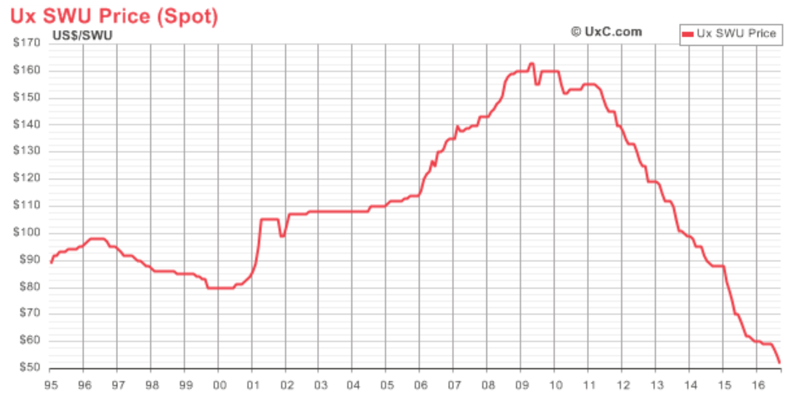
We use an average real escalation rate of 2.00% annually as a reference case (medium demand) assumption, with 3.00% annually for a high demand case, and 1.00% annual growth used as a low-case projection of enrichment value, but we acknowledge that given recent volatility in the enrichment market and the many uncertainties in uranium and enriched uranium demand in coming years, the projection of these costs is a highly uncertain exercise.



For graph below Source: The Ux Consulting Company, LLC, http://www.uxc.com/, accessed 8-14-15.



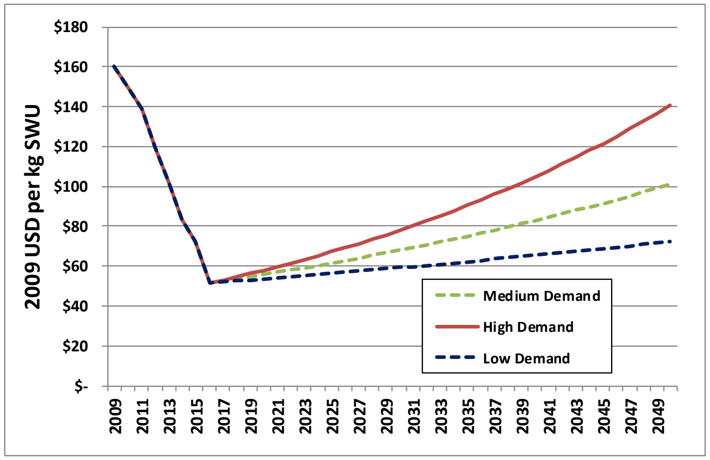
For graph below Source: The Ux Consulting Company, LLC, https://www.uxc.com/p/prices/UxCPriceChart.aspx?chart=spot-swu-full, accessed 10-26-16.



Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prices from 1986-2001, and 2007-present are available to clients only.												
2002												
Unrestricted	85	85	90	90	90	90	90	90	90	90	90	90
Restricted	105	105	107	107	107	107	107	107	108	108	108	108
2003												
Unrestricted	90	90	90	92	92	88	88	88	88	88	88	88
Restricted	108	108	108	108	108	108	108	108	108	108	108	110
2004												
Unrestricted	88	88	88	88	88	88	88	88	88	88	88	88
Restricted	110	110	110	110	110	110	111	111	111	111	111	111
2005												
Unrestricted	88	88	88	88	88	90	90	90	90	90	90	90
Restricted	113	113	113	113	113	113	113	113	113	113	113	113
2006												
Unrestricted	90	105	105	105	107	107	110	115	117	120	124	126
Restricted	118	120	122	124	125	125	128	129	131	134	135	135
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Year	Medium Demand	High Demand	Low Demand
2009	$ 160.00	$ 160.00	$ 160.00
2010	$ 148.96	$ 148.96	$ 148.96
2011	$ 138.70	$ 138.70	$ 138.70
2012	$ 119.04	$ 119.04	$ 119.04
2013	$ 102.22	$ 102.22	$ 102.22
2014	$ 83.37	$ 83.37	$ 83.37
2015	$ 72.42	$ 72.42	$ 72.42
2016	$ 51.54	$ 51.54	$ 51.54
2017	$ 52.57	$ 53.08	$ 52.05
2018	$ 53.62	$ 54.68	$ 52.57
2019	$ 54.69	$ 56.32	$ 53.10
2020	$ 55.79	$ 58.01	$ 53.63
2021	$ 56.90	$ 59.75	$ 54.17
2022	$ 58.04	$ 61.54	$ 54.71
2023	$ 59.20	$ 63.39	$ 55.26
2024	$ 60.39	$ 65.29	$ 55.81
2025	$ 61.59	$ 67.25	$ 56.37
2026	$ 62.83	$ 69.26	$ 56.93
2027	$ 64.08	$ 71.34	$ 57.50
2028	$ 65.36	$ 73.48	$ 58.08
2029	$ 66.67	$ 75.69	$ 58.66
2030	$ 68.00	$ 77.96	$ 59.24
2031	$ 69.36	$ 80.30	$ 59.83
2032	$ 70.75	$ 82.70	$ 60.43
2033	$ 72.17	$ 85.19	$ 61.04
2034	$ 73.61	$ 87.74	$ 61.65
2035	$ 75.08	$ 90.37	$ 62.26
2036	$ 76.58	$ 93.08	$ 62.89
2037	$ 78.12	$ 95.88	$ 63.52
2038	$ 79.68	$ 98.75	$ 64.15
2039	$ 81.27	$ 101.72	$ 64.79
2040	$ 82.90	$ 104.77	$ 65.44
2041	$ 84.55	$ 107.91	$ 66.10
2042	$ 86.25	$ 111.15	$ 66.76
2043	$ 87.97	$ 114.48	$ 67.42
2044	$ 89.73	$ 117.92	$ 68.10
2045	$ 91.52	$ 121.45	$ 68.78
2046	$ 93.36	$ 125.10	$ 69.47
2047	$ 95.22	$ 128.85	$ 70.16
2048	$ 97.13	$ 132.72	$ 70.86
2049	$ 99.07	$ 136.70	$ 71.57
2050	$ 101.05	$ 140.80	$ 72.29

Year	Historical Enrichment Value (2009 $/kg SWU)	
2000	100.80	
2001	97.60	
2002	118.20	
2003	125.19	
2004	113.43	
2005	112.67	
2006	127.33	
2007	135.20	
2008	140.00	
2009	160.00	
2010	148.96	Rough estimate of annual average from UCx graph above
2011	138.70	Rough estimate of annual average from UCx graph above
2012	119.04	Rough estimate of annual average from UCx graph above
2013	102.22	Rough estimate of annual average from UCx graph above
2014	83.37	Rough estimate of annual average from UCx graph above
2015	72.42	Rough estimate of annual average from UCx graph above
2016	51.54	Rough estimate of annual average from UCx graph above



FUTURE REGIONAL NUCLEAR FUEL CYCLE COOPERATION IN EAST ASIA: ENERGY SECURITY COSTS AND BENEFITS

Calculations for East Asia Science and Security (EASS) and Related Follow-on (2012-2016) Projects, funded by MacArthur Foundation

Estimates of Average Uranium Ore Concentrations

Prepared by:	David Von Hippel
Last Modified:	1/9/2013

WORLD URANIUM OUTPUT AND CALCULATION OF AVERAGE ORE GRADE

Following data from World Nuclear Association (2012), "World Uranium Mining", last updated August, 2012, and available as http://www.world-nuclear.org/info/inf23.html

Production from mines (tonnes U)

Country	2002	2003	2004	2005	2006	2007	**2008**	**2009**	**2010**	**2011**	Estimated Average Ore % U
Canada	11604	10457	11597	11628	9862	9476	9000	10173	9783	9145	14.500
Kazakhstan	2800	3300	3719	4357	5279	6637	8521	14020	17803	19451	0.072
Australia	6854	7572	8982	9516	7593	8611	8430	7982	5900	5983	0.121
Niger	3075	3143	3282	3093	3434	3153	3032	3243	4198	4351	0.167
Namibia	2333	2036	3038	3147	3067	2879	4366	4626	4496	3258	0.033
Russia (est)	2900	3150	3200	3431	3262	3413	3521	3564	3562	2993	0.142
Uzbekistan	1860	1598	2016	2300	2260	2320	2338	2657	2874	3000	0.140
USA	919	779	878	1039	1672	1654	1430	1453	1660	1537	0.149
Ukraine (est)	800	800	800	800	800	846	800	840	850	890	0.140
China (est)	730	750	750	750	750	712	769	1200	1350	1500	0.132
Malawi								104	670	846	
South Africa	824	758	755	674	534	539	655	104	670	846	0.035
Brazil	270	310	300	110	190	299	330	563	583	582	0.250
India (est)	230	230	230	230	177	270	271	290	400	400	0.020
Czech Repub.	465	452	412	408	359	306	263	345	148	265	0.308
Romania (est)	90	90	90	90	90	77	77	258	254	229	
Germany	221	104	77	94	65	41	0	75	77	77	
Pakistan (est)	38	45	45	45	45	45	45	0	0	52	
France	20	0	7	7	5	4	5	50	45	45	
Total of Above	36,033	35,574	40,178	41,719	39,444	41,282	43,853	51,547	55,323	55,450	
total world	**36 072**	**35 574**	**40 178**	**41 719**	**39 444**	**41 282**	**43 853**	**51 450**	**54 660**	**54 610**	
tonnes U_3O_8	42 529	41 944	47 382	49 199	46 516	48 683	51 716	60 675	64 461	64 402	
percentage of world demand				65%	63%	64%	68%	78%	78%	85%	
Estimated Global Weighted-average Ore grade (% as U) for countries where grade estimates available											2.49
Estimated Global Weighted-average Ore grade (% as U) for countries where grade estimates available, less Canada											0.10

ORE GRADE AND PRODUCTION/RESERVES/CAPACITY DATA BY COUNTRY

Production data in yellow highlights from same World Nuclear Association source as table above, and used as more up-to-date, when available.

Country	Mine Name	Ore %	Output (te Ore)	Output (te U)	Implied country weighted average Ore %	Notes
Argentina	Cachocira	0.3	340		0.3	Mine-specific data from Selected Countries extracted from Wikipedia, "List of uranium mines", available as http://en.wikipedia.org/wiki/List_of_uranium_mines. Production data in yellow highlights is for 2011 from same World Nuclear Association source as table above (except Canada, which is from World Nuclear Association (2013), "Uranium in Canada", last updated January 2013, and available as , used as more up-to-date than Wikipedia source, when available.
Australia	Olympic Dam	0.05		3353	0.121	
	Ranger	0.2		2240		
	Beverley	0.18		1064		
Brazil	Caetité	0.25		400	0.25	
Canada	MacArthur River	18.33		7686	14.500	
	McClean Lake	0.53		666		
	Rabbit Lake	0.76		1463		
China	[See below]	0.132		1500	0.132	
Czech Republic	Rozna	0.378		400	0.308	Ore % estimated from NEA 2007, page 171--see ***Source 2***.
	Straz	0.030		100		Output figures are nominal annual U production per year.
DPRK		0.200			0.200	Rough estimate; see ***Note 5***
India	All	0.0196		271	0.020	Ore % estimated from NEA 2007, page 211--see ***Source 2***.
Indonesia	Remaja-Hitam Ore Body	0.2	*7500*		0.228	See ***Note 1***; figures shown are reserves, not output
	Rirang-Tanah Merah Ore Body	0.65	*500*			See ***Note 1***; figures shown are reserves, not output
Kazakhstan	All	0.072		19451	0.072	Ore % estimated from NEA 2007 based on planned nominal capacities and ore % by "Centre", pages 242-243--see Source 2. Almost all Centres use or will use ISL.
Namibia	Rossing	0.03	*40000*	1822	0.033	Ore % estimated from NEA 2007, page 264--see ***Source 2***.
	Langer Heinrich	0.06	*4500*			Output figures are ore production per day.
Niger	Arlit (operating)	0.28	*1900*		0.167	Ore % estimated from NEA 2007, page 273--see ***Source 2***.
	Arlit (planned)	0.07	*3800*			Output figures are ore production per day.
	Akouta	0.4	*1800*			
Russia	PPGHO	0.18		3500	0.142	Ore % estimated from NEA 2007, page 297--see ***Source 2***.
	Dalur	0.04		800		Output figures are nominal annual U production per year.
	Khiagda	0.05		1000		
	Elkon	0.15		5000		
	Gornoe	0.2		600		
	Orlov	0.082		600		
South Africa	All	0.035		846	0.035	Ore % estimate--See ***Note 3***
Ukraine	All	0.1		890	0.100	Ore % estimated from NEA 2007, page 346--see ***Source 2***.
United States	Canon City	0.160		*210*	0.149	Ore % estimated from NEA 2007, page 346--see ***Source 2***.
	Sweetwater	0.035		350		Output figures are nominal annual U production per year.
	White Mesa	0.181		1200		ISL "Centres" not included (no ore % data available for those).
Uzbekistan		0.14		3000	0.140	Ore % estimate--See ***Note 4***
Vietnam	An Diem Deposit	0.034		500	0.099	Recoverable te U, page 375, NEA 2007, see ***Source 2***.
	Khe Hoa-Khe Cao deposit	0.104		6744		Ore % estimate--See ***Note 6***

MacArthur River Data from World Nuclear Association 2013

	Te U	Ore % U
Probable	77,780	23.81%
Proven	70,800	12.30%
Weighted Average		18.33%

China's Operating Uranium Mines (from World Nuclear Association (2010), "China's Nuclear Fuel Cycle", updated March, 2010, and available as http://www.world-nuclear.org/info/inf63b_china_nuclearfuelcycle.html, except as noted).

Mine	Province	Type	Nominal capacity (tonnes U per year)	Started	Ore %	Source for Ore % data
Fuzhou	Jiangxi	Underground & open pit	300	1966	0.12%	Derived from ore output and tU output data from NEA (Nuclear Energy Agency) "Redbook" 2007, page 159 (***Source 2***).
Chongyi	Jiangxi	Underground & open pit	120	1979	0.09%	
Yining	Xinjiang	In-situ leach (ISL)	200	1993		
Lantian	Shaanxi	Underground	100	1993	0.14%	
Benxi	Liaoning	Underground	120	1996	0.20%	
Weighted average of mines with ore % available					0.13%	
Fraction of production from Underground Mines					76.2%	

Additional Notes and Sources

1. Indonesian mines are thought to be dormant. Figures in "Output" column are actually central estimates of range of reserves, and "Ore %" data are central values for range of Uranium "grades" (assumed to be %) provided. Source, Countries of Strategic Nuclear Concern: Indonesia, Carolyn Taylor, Yana Feldman, Charles Mahaffey, Brett Marvin, Jack Boureston, SIPRI, 2004, quoted in Natilus Institute "Muria peninsula nuclear power proposal: Uranium Mining", at http://www.globalcollab.org/Nautilus/australia/reframing/aust-ind-nuclear/ind-np/muria/uranium-mining.

2. NEA (Nuclear Energy Agency, 2008), Uranium 2007--Resources, Production, and Demand (also called "Red Book") available ("Read only version") as http://www.oecdbookshop.org/oecd/get-it.asp?REF=6608031E.PDF&TYPE=browse.

3. Ore concentration for South Africa is a very rough estimate based on data in Wise Uranium Project -- Mine Ownership, Africa, available as http://www.wise-uranium.org/uoafr.html#EASTRANDT.

4. No specific estimate for the average grade of Uranium ore in Uzbekistan was immediately available. J. W. S. van Leeuwen (2006), of Oxford Research Group, in Energy from Uranium, dated July 2006 (available as http://www.stormsmith.nl/publications/Energy%20from%20Uranium%20-%20July%202006.pdf), ascribes a value of 0.14 % for Uzbek ore based on an average value for sandstone ores globally.

5. P. Hayes (2004), in "North Korea's Uranium Exports: Much Ado About Something", Nautilus Institute Northeast Asia Peace and Security Network Special Report, dated May 25, 2004, and available as http://www.nautilus.org/archives/pub/ftp/napsnet/special_reports/Hayes-DPRKuranium.txt), describes DPRK uranium resources as "The deposits are uraniferous black shale occurrences (perhaps similar to that at Ok'chon in South Korea) occurring at a depth about 200 meters. The ore grades are about 0.2%". "North Korea’s Nuclear Weapons Programme", by the International Institute for Strategic Studies, 2006, available as http://www.iiss.org/publications/strategic-dossiers/north-korean-dossier/north-koreas-weapons-programmes-a-net-asses/north-koreas-nuclear-weapons-programme, states "“It has been estimated that, at its peak in the early 1990s, North Korea was able to produce about 300 tonnes of yellow cake [U3O8] annually, equal to approximately 30,000 tonnes of uranium ore.”. The latter would imply an ore grade of about 0.1% U. At present, we use the 0.2% value.

6. In Chapter 16, "Vietnam", the book Uranium Resources of the World cites a measurement for the Uranium content of "unweathered sandstone" in the Nong Son Basin where Vietnam's major Uranium resources lie of 0.104%. This value is just a measurement, not a basin-wide average but is the only figure immediately available to characterize this deposit, and is in the range of typical values for sandstone Uranium deposits. F.J. Dahlkamp (2009), Uranium Deposits of the Word: Asia, Springer-Verlag.

FUTURE REGIONAL NUCLEAR FUEL CYCLE COOPERATION IN EAST ASIA:
ENERGY SECURITY COSTS AND BENEFITS
Calculations for East Asia Science and Security (EASS) and Related Follow-on (2012-2016) Projects, funded by MacArthur Foundation

Estimates of Uranium Mining and Milling Volumes: "National Enrichment, National Reprocessing" Scenario (Regional Scenario 1)

Using Nuclear Fuel Requirements Estimates from "Business-as-Usual" Capacity Expansion Case

Prepared by:	David Von Hippel
Last Modified:	11/8/2016

General Assumptions

All costs in approximately **2009 US Dollars** unless otherwise noted

Average tons ore mined per kg U metal extracted, imported Uranium	0.040	*See **Note 7**. Corresponds to a U content in ore of*	2.493%
Fraction of imported Uranium from conventional underground & open pit mines	62%	as of 2008 (*See **Note 1**).*	
Fraction of imported Uranium from conventional underground & open pit mines	62%	as of 2050	
Fraction of imported Uranium from in-situ leaching operations	28%	as of 2008 (*See **Note 1**).*	
Fraction of imported Uranium from in-situ leaching operations	28%	as of 2050	
Average % of imported U from conventional mines that is from underground mines	56%	(See ***Note 6***)	
Fossil fuel used in open pit mining per te ore	407	MJ (See ***Note 2***)	
Fossil fuel used in underground mining per te ore	58	MJ (See ***Note 2***)	
Electricity used in open pit mining per te ore	2.68	kWhe (See ***Note 2***)	
Electricity used in underground mining per te ore	70.6	kWhe (See ***Note 2***)	
Electricity used in in-isitu leaching (ISL) per kg Uranium	26	kWhe (See ***Note 3***)	
Fossil fuel used in in-isitu leaching (ISL) per kg Uranium	0	MJ *Placeholder*	
Fossil fuel used in milling Uranium per te ore	483	MJ (See ***Note 2***)	
Electricity used in milling Uranium per te ore	18.6	kWhe (See ***Note 2***)	
Water use in Uranium milling per tonne U produced	1,000	cubic m. (See ***Note 4***)	
2009 Average Uranium Price	$ 120	$/kg U (2009 USD)	
2050 Average Uranium Price	272	assuming Medium	price trajectory (see "Uranium_Prices" worksheet in this workbook)
Radioactivity in tailings from Uranium Milling	1.30	GBq per tonne ore assuming concentration of	1% U in ore. (See ***Note 5***)

	Australia	China	DPRK	Indonesia	Japan	ROK	RFE	Taiwan	Vietnam	Notes and Sources
Target fraction of Uranium from in-country mines	100%	50%	50%	50%	0%	0%	100%	0%	50%	
Year in-country mining starts	2000	2000	2020	2025	2000	2000	2000	2000	2025	
Year in-country mining reaches target level	2000	2000	2030	2030	2000	2000	2000	2000	2030	
Average tons ore mined per kg U metal, domestic Uranium	0.825	0.759	0.500	0.438	0.994	0.500	0.705	0.994	1.008	(See ***Note 8***)
% of domestic U from conventional underground & open pit mines	91%	76%	100%	100%	100%	100%	82.8%	100%	100%	All Placeholders
% of domestic U from in-situ leaching mines	9.2%	24%	0%	0%	0%	0%	17%	0%	0%	except Australia, China,
Ave. % of domestic U from conventional mines that is from underground mines	0%	100%	100%	100%	100%	100%	100%	100%	100%	Russia (see ***Note 9***)
Notes and Sources										

NOTES AND SOURCES

1. World Nuclear Association (2009), "World Uranium Mining". Available as http://www.world-nuclear.org/info/inf23.html. As of 2008, 62% of uranium was mined in conventional underground and open pit mines, 28% was removed through in situ leaching (ISL), and 10% of Uranium was extracted as a by-product of other metals mining in the Olympic Dam mine in Australia.

2. WISE Uranium Project (2009), "Nuclear Fuel Energy Balance Calculator - HELP", available as http://www.wise-uranium.org/nfceh.html, notes:with regard to fossil fuel use in Uranium mining, "Values vary in wide ranges, depending on ore deposit and mining technique used. Typical values are per t ore for open pit mines, and 57.7 MJ per t ore for underground mines in the US." Regarding electricity use in Uranium mining, the same source states "Values vary in wide ranges, depending on ore deposit and mining technique used. Typical values are 2.68 kWhe per t ore for open pit mines, and 70.6 kWhe per t ore for underground mines in the US".

3. World Nuclear Association (2009), "In Situ Leach (ISL) Mining of Uranium", dated June, 2009, and available as http://www.world-nuclear.org/info/inf27.html, lists examples of electricity consumption during ISL Uranium mining as: "Unit power consumption is about 19 kWh/kgU (16 kWh/kg U3O8) in Australia and around 33 kWh/kgU in Kazakhstan." The average of these values is used here.

4. Down the Yellowcake Road (2008), "Uranium Milling Explained", available as http://downtheyellowcakeroad.org/html/Milling.html, lists a US Uranium mill proposed for reopening as potentially using 1.3 million gallons of water per day to process peak production of 1200 tons of ore per day. This converts to 4.50 cubic meters water per metric ton ore processed. Water consumption for Uranium production in Namibia, which produces about 10 percent of the world's Uranium, is estimated at 10 Million cubic meters annually as of 2008, when production was 5104 tonnes of Uranium, or about 1,959 cubic meters per (metric) ton U, from J.S. lita (2009), "URANIUM PRODUCTION PROSPECTS AND CHALLENGES –NAMIBIA", presented at IAEA, VIENNA, AUSTRIA-SEPTEMBER 2009. Available as http://www.iaea.org/OurWork/ST/NE/NEFW/documents/RawMaterials/GCRoundTable2009/NAMIBIA_URANIUM%20PRODUCTION%20PROSPECTS%20AND%20CHALLENGES%20.pdf. A survey of water consumption in a number of mines around the world yielded a wide range of results from about 46 to 860 cubic meters of water per metric ton U_3O_8. The same survey cites a much higher average of about 7,700 cubic meters per te U_3O_8 for an Australian mine that uses the in situ leaching production method. Source: G. M Mudd and M. Diesendorf (2007), "Sustainability Aspects of Uranium Mining : Towards Accurate Accounting ?", 2nd International Conference on Sustainability Engineering & Science, Auckland, New Zealand - 20-23 February 2007, Available as http://civil.eng.monash.edu.au/about/staff/muddpersonal/2007-SustEngSci-Sust-v-Uranium-Mining.pdf. Given this wide range of estimates, and the fact that it is difficult to determine whether all of these estimates consistently include all water requirements in U mining and milling, we adopt a placeholder value of 1000 cubic meters per metric ton Uranium produced pending receipt of more definitive studies.

5. Based on results from Wise Uranium Project, "Uranium Decay Calculator" (http://www.wise-uranium.org/rccu.html) assuming Uranium ore with U concentration of 1%, natural Uranium in equilibrium with its projeny in the mill tailing, and including all activities. The value shown is estimated activity for roughly the period 1 to 10,000 years after mining. Based on the results of the Calculator, tailings activity varies roughly linearly with Uranium content of ore in the typical range of U contents found in economically exploitable ores.

6. The World Nuclear Association web page "Uranium Mining" (http://www.world-nuclear.org/education/mining.htm, accessed 4/2010) lists Uranium sources by type of mine as "[a]bout half of the world's uranium now comes from underground mines, about 30% from open cut mines and over 20% from ISL" These figures are somewhat different from those provided by the same group in source 1, above. To try and reconcile these figures, however, we assume that 40% of the 72% of Uranium listed in source 1 as coming from underground mines, surface mines, or as a by-product from the Olympic Dam metals mine in Australia comes from (dedicated Uranium) underground mines, meanin 55.6% of total Uranuim not from ISL is from underground mining.

7. Current global average for Uranium ore grade as estimated in "Uranium_Production" worksheet in this workbook. Although most Uranium mines in the world have ore concentrations in range from 0.03 to 0.4 percent Uranium, the global average is brought up significantly by the exceedingly high quality (and quantity) Uranium mined at MacArthur River, Canada. Mining in the rest of the world uses ores averaging on the order of 0.1 percent Uranium.

8. Estimateds as prepared in "Uranium_Production" worksheet in this workbook. Values for Japan and Taiwan, which have very limited Uranium resources. (and will not mine Uranium under any of the scenarios considered) are set at the world average excluding Canada. The value for the ROK, which also has limited resources (but is apparently considering exploring some areas) is set at present at the estimate used for the DPRK.

9. Estimates of fractions of ore mined by type for China, Russia, and Australia are rough estimates based on production data for recent years (Russia, Australia) or production capacity data (China) from the document below, some of which is presented in the "Uranium_Production" worksheet in this workbook.
NEA (Nuclear Energy Agency, 2008), Uranium 2007--Resources, Production, and Demand (also called "Red Book")
available ("Read only version") as http://www.oecdbookshop.org/oecd/get-it.asp?REF=6608031E.PDF&TYPE=browse.

FUTURE REGIONAL NUCLEAR FUEL CYCLE COOPERATION IN EAST ASIA: ENERGY SECURITY COSTS AND BENEFITS

Calculations for East Asia Science and Security (EASS) and Related Follow-on (2012-2016) Projects, funded by MacArthur Foundation

Estimates of Uranium Transport, Conversion, and Enrichment Requirements: "National Enrichment, National Reprocessing" Scenario (Regional Scenario 1)

Using Nuclear Fuel Requirements Estimates from "Business-as-Usual" Capacity Expansion Case

Prepared by:	David Von Hippel
Last Modified:	11/8/2016

General Assumptions

All costs in approximately **2009 US Dollars** unless otherwise noted

Fraction of imported enrichment services from gas diffusion plants as of 2007	30%	(*See* ***Note 1***).	
Target fraction of imported enrichment services from gaseous diffusion plants	0%		
Year that target fraction of imported enrichment services from gaseous diffusion plants reached	2014	Closure of last US Plant	
Average distance from mining area to enrichment facility for imported uranium or domestic uranium not enriched in-country (km)	10,000	Very rough estimate of average distance between major Uranium producers and enrichment facilities in Europe	
Average cost of uranium (yellowcake) transport, rail ($/tonne-km U_3O_8)	$ 0.0209	(*See* ***Note 6***).	
Average cost of uranium (yellowcake) transport, ocean freight ($/tonne-km U_3O_8)	$ 0.0127	Estimated from container freight average rates--see ***Note 7***	
Fossil fuel used in uranium conversion (to UF_6)	2.39	MJ/kg U	(See ***Note 3***)
Electricity used in uranium conversion (to UF_6)	1	kWhe/kg U	Placeholder only
Losses in uranium conversion (to UF_6)	0.5%	of incoming natural uranum feed (as in country workbooks)	
Electricity use in gaseous diffusion enrichment plants per (kg) SWU	2,400	kWhe	(See ***Note 2***)
Electricity use in centrifuge-based enrichment plants per (kg) SWU	50	kWhe	(See ***Note 2***)
Tails assay for enrichment plants (fraction as U_{235})	0.24%		(See ***Note 2***)
Fraction U_{235} in natural Uranium	0.71%		(See ***Note 2***)
Tonnes depleted Uranium produced (as U) per unit natural Uranium feed	88.98%	Assuming	4.51% enrichment
Average cost of uranium conversion (to UF_6) per kg U	$ 14.01		(See ***Note 4***)
Solid waste from uranium conversion (to UF_6)	0.7	t/t U	(See ***Note 5***)
Liquid waste from uranium conversion (to UF_6)	6.5	m^3/t U	(See ***Note 5***)
2012 Average enrichment costs (per kg SWU)	$ 119	(2009 USD)	
2050 Average enrichment costs (per kg SWU)	101	assuming	Medium price trajectory (see "Uranium_Prices" worksheet in this workbook)

	Australia	China	DPRK	Indonesia	Japan	ROK	RFE	Taiwan	Vietnam	
Average distance from mining area to enrichment facility (km)	2500	1000	300	1000	8000	500	2000	500	500	All Rough Estimates-- For Japan, see ***Note 10***
Predominant transport mode for domestic Uranium production	Ship	Rail	Rail	Ship	Ship	Ship	Rail	Ship	Ship	Assumptions
Target fraction of Uranium needs enriched in-country	0%	100%	100%	0%	100%	100%	100%	0%	0%	Assumptions
Year in-country enrichment starts	2030	2000	2020	2025	2010	2020	2000	2025	2025	(See ***Note 8***)
Year in-country enrichment reaches target level	2030	2025	2030	2030	2015	2030	2000	2030	2030	(See ***Note 8***)
Average electricity use for in-country enrichment	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	kWhe/SWU
Average level of enrichment before 2008 (% U_{235})	4.34%	4.34%	4.34%	4.34%	3.46%	4.34%	4.34%	4.34%	4.34%	from country workbooks
Average level of enrichment after 2007 (% U_{235})	4.51%	4.51%	4.51%	4.51%	4.51%	4.51%	4.51%	4.51%	4.51%	from country workbooks
Implied Separative Work Units (SWU) for level of enrichment before 2008 (kg SWU/kg U in enriched product)	6.68	6.68	6.68	6.68	4.83	6.68	6.68	6.68	6.68	Calculated based on Equation from
Implied Separative Work Units (SWU) for level of enrichment after 2007 (kg SWU/kg U in enriched product)	7.05	7.05	7.05	7.05	7.05	7.05	7.05	7.05	7.05	MIT Study (see ***Note 1***)

NOTES AND SOURCES

1. "The Future of Nuclear Power," An Interdisciplinary MIT Study, Massachusetts Institute of Technology (2003), available as http://web.mit.edu/nuclearpower/pdf/nuclearpower-full.pdf. SWU equation referenced is shown on page 146.
   Note that it is assumed that all enrichment carried out in the countries in this study is assumed to be in centrifuge plants, though some of the enrichment services imported by the countries of the region were in gaseous diffusion plants prior to 2014.

2. Estimate of "tails assay" and U_{235} content of natural uranium from study referenced in Note 1, page 145 was 0..3%.
   An update to the MIT study, "Update of the MIT 2003 Future of Nuclear Power Study", dated 2009, and available as http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf, uses an "optimal tails assay" calculated based on current uranium prices of 0.24%, which we use here.
   Typical values for the fraction of U_{235} in enrichment tails from centrifuge enrichment plants range from 0.25% to 0.3%, suggests WISE Uranium Project (2009), "Nuclear Fuel Energy Balance Calculator - HELP", available as http://www.wise-uranium.org/nfceh.html.
   The WISE source also lists the electricity requirements for gaseous diffusion enrichment to be between 2300 and 2500 kWhe/kg SWU, and for centrifuge enrichment as "less than 50 kWhe/kg SWU", though the document ACP & World Enrichment Market Final, USEC, dated September 5, 2013 by Edward Kee and Jennifer Cascone Fauver of NERA Consulting, available as http://www.centrusenergy.com/sites/default/files/NERA_ACP_And_World_Enrichment_Market_0.pdf, suggests a range from 50 to 300 kWhe/kg SWU for centrifuge enrichment in general.

3. A direct estimate of the fuel used in UF6 production from Uranium Oxide was not immediately available, but the World Nuclear Association document "Some Chemistry of Uranium" (2009), available as http://www.world-nuclear.org/education/chem.htm, includes the following passage:

> Refining and Conversion to UF6 prior to Enrichment
>
> (in Europe and North America)
>
> The mixed uranium oxide concentrate U3O8 received by the refinery is dissolved in nitric acid. The resulting solution of uranium nitrate UO2(NO3)2.6H2O is fed into a countercurrent solvent extraction process, using tributyl phosphate dissolved in kerosene or dodecane. The uranium is collected by the organic extractant, from which it can be washed out by dilute nitric acid solution and then concentrated by evaporation. The solution is then calcined (heated strongly) to produce pure UO3.
>
> Most nuclear reactors require uranium to be enriched from its natural isotopic composition of 0.7% U-235 (most of the rest being U-238) to 3.5-4% U-235. The uranium therefore needs to be in a gaseous form and the most convenient way of achieving this is to convert the uranium oxides to uranium hexafluoride.
>
> After purification, the uranium oxide UO3 is reduced in a kiln by hydrogen to UO2.
>
> UO3 + H2 ====> UO2 + H2O .... delta H = -109 kJ/mole
>
> This reduced oxide is then reacted with gaseous hydrogen fluoride in another kiln to form uranium tetrafluoride, UF4, though in some places this is made with aqueous HF by a wet process.
>
> UO2 + 4HF ====> UF4 + 2H2O .... delta H = -176 kJ/mole
>
> The tetrafluoride is then fed into a fluidised bed reactor with gaseous fluorine to produce uranium hexafluoride, UF6. Hexafluoride is condensed and stored.
>
> UF4 + F2 ====> UF6

This implies that the minimum energy for reducing and converting Uranium oxide to Uranium tetrafluoride is 285 kJ per mole of Uranium, or 1.20 MJ per kg Uranium metal. As a starting value, we assume that inefficiencies in the kilns used in these processes, plus the energy cost of converting UF_4 to UF_6, mean that the total energy needed for converting U_3O_8 to UF_6 is approximately 200% of the theoretical minimum, or about 2.39 MJ per kg Uranium metal.

4. The 2009 update to the "MIT Report" described in note 2 uses a conversion cost of $6 per kg U in 2007 dollars. The World Nuclear Association (2012), in "The Economics of Nuclear Power" (updated December, 2012, and available as http://www.world-nuclear.org/info/inf02.html), lists costs for UF6 conversion as of March 2011 as $13 per kg UO_2.

5. The WISE Uranium Project's (2009), "Nuclear Fuel Material Balance Calculator", available as http://www.wise-uranium.org/nfcm.html, lists default estimates for the amount of solid and liquid waste per unit Uranium metal handled in conversion plants as shown.

6. Initital estimate based on US 2006 reported average rail freight revenue, updated to 2009 dollars. Original data from Research and Innovative Technology Administration, U.S. Bureau of Transportation Statistics, U.S. Department of Transportation (US DOT), "Table 3-17: Average Freight Revenue Per Ton-mile", available as http://www.bts.gov/publications/national_transportation_statistics/html/table_03_17.html.

7. Initital estimate based on description of uranium oxide concentrate (UOC, or U_3O_8) shipping practices from Australia from Australian Government Department of Toursim, Industry and Resources brochure "SAFE AND EFFECTIVE TRANSPORT OF URANIUM", dated October, 2007, and available as www.ret.gov.au/.../uranium/.../Safe_and_Effective_Transport_of_Uranium.pdf.
This document suggests that UOC is shipped in standard 20-foot shipping containers in 205-liter drums. Photos in the brochure suggest that about 48 drums fit in a standard container. According to http://www.powderandbulk.com/resources/bulk_density/material_bulk_density_chart_u.htm, the bulk density of uranum oxide is 1.73 kg/liter, which suggests that each drum would hold 354.65 kg of product, and a shipping container would hold 17.02 metric tons of yellowcake.
Other sources give a range of bulk densities for U_3O_8 of 1.5 to 4.0 kg/liter, but several sources cited the same figure used in this calculation.
Shipping rates are difficult to estimate, and according to at least one reference, have varied by a factor of four just between 2005 and 2009. We use an average 2008 leasing rate for Panamax ships of about $ 26,000 per day for ships with capacity of 3500 TEU, with one "TEU" equaling the space for a standard 20-foot container unit.
Based on the document "Propulsion Trends in Container Vessels", by MAN B&W Diesel A/S, Copenhagen, Denmark, undated but probably about 2005, and available as http://www.manbw.com/files/news/filesof4672/P9028.pdf, the average design speed of a panamax ship is in the range of 20 knots, or 37.1 km/hr.
Assuming that the average speed of a ship during a voyage is 80% of design speed, and assuming that the ship operates at an average of 80% of capacity, and a tare (empty) weight for eac drum of 17 kg (e.g. from http://www.colyerfehr.com.au/logisticsAndTransport.html), the cost per tonne-km for shipping of U_3O_8 would be estimated at $ 0.00077 per tonne-km of yellowcake transported.
An alternative, and perhaps more accurate, way of estimating this cost is to base the cost roughly on published freight rates per container (TEU).
The Review of Maritime Transport 2008, published by the United Nations, United Nations Conference in Trade and Development Staff, and available to read through Google Books, includes in Table 34 the following data:

Table 34

Freight rates (market averages) per TEU on the three major liner trade routes
($ per TEU and percentage change)

	Transpacific		Europe–Asia		Transatlantic	
	Asia–USA	USA–Asia	Europe–Asia	Asia–Europe	USA–Europe	Europe–USA
2006						
First quarter	1 836	815	793	1 454	995	1 829
Change (%)	- 2	- 1	- 4	- 15	- 1	1
Second quarter	1 753	828	804	1 408	1 010	1 829
Change (%)	- 5	2	1	- 3	2	0
Third quarter	1 715	839	806	1 494	1 041	1 854
Change (%)	- 2	1	0	6	3	1
Fourth quarter	1 671	777	792	1 545	1 066	1 762
Change (%)	- 3	- 7	- 2	3	2	- 5
2007						
First quarter	1 643	737	755	1 549	1 032	1 692
Change (%)	- 2	- 5	- 5	0	- 3	- 4
Second quarter	1 675	765	744	1 658	1 067	1 653
Change (%)	2	4	- 1	7	3	- 2
Third quarter	1 707	780	777	1 952	1 115	1 725
Change (%)	2	2	4	18	4	4
Fourth quarter	1 707	794	905	2 054	1 147	1 766
Change (%)	0	2	16	5	3	2
2008						
First quarter	1 725	861	968	2 021	1 193	1 700
Change (%)	1	8	7	- 2	4	- 4
Second quarter	1 837	999	1 061	1 899	1 326	1 652
Change (%)	6	16	10	- 6	11	- 3

Source: UNCTAD secretariat based upon *Containerisation International Online*, www.ci-online.co.uk.

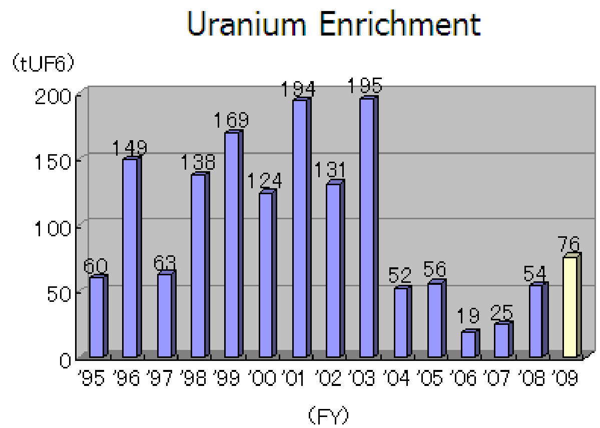
Notes: The freight rates shown are all-in, that is they include currency adjustment factors and bunker adjustment factors, plus terminal handling charges where gate/gate rates have been agreed, and inland haulage where container yard/container yard rates have been agreed. All rates are average rates of all commodities carried by major carriers. Rates to and from the United States refer to the average for all three coasts.

Assuming, as an example, that Uranium bound for Northeast Asia is mined in Canada and enriched in France, a cross-Atlantic transport distance of about 6000 km is implied, which, at a per-container rate of $1,300, would imply a shipment cost per metric tonne of Uranium of $ 0.0127. We use this rough estimate in the calculations above.

8. See text of EASS Report for this scenario. Calculations assume that all DPRK enrichment takes place in the ROK, that Chinese enrichment ramps up from an assumed 10 percent of requirements in 2000 (which should be checked) to 1.5 million SWU/yr in 2009 and 3 million SWU/yr in 2015, that Japan's enrichment averages 300,000 SWU/yr through 2010, and that that the ROK begins enriching fuel in 2015. Assumptions for Japan and China based on http://www.world-nuclear.org/info/inf79.html ("Nuclear Power in Japan", World Nuclear Association, January, 2010) and World Nuclear Association (2015), "Uranium Enrichment", available as http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Conversion-Enrichment-and-Fabrication/Uranium-Enrichment/, The latter lists enrichment capacity in China at "Hanzhun & Lanzhou" as 2200, 4220, and 7520 thousand SWU in 2013, 2015 and 2020, respectively.

9. The graph below, from Japan Nuclear Fuel Limited (JNFL) "Operational Progress (As of end of February 28, 2010)", available as http://www.jnfl.co.jp/english/progress.html, indicates the problems with centrifuge technologies encountered by Japan in the past decade. Data from this graph are used to calculate the fractions of enrichment provided in-country from 2000 through 2009, as shown above. Conversion of units (enriched fuel as UF_6 to enriched fuel as U) follow.

Year	te UF_6	te U	Natural U equivalent
2000	124	83.83	572.28
2001	194	131.15	895.35
2002	131	88.56	604.59
2003	195	131.82	899.96
2004	52	35.15	239.99
2005	56	37.86	258.45
2006	19	12.84	87.69
2007	25	16.90	115.38
2008	54	36.50	249.22
2009	76	51.38	350.75



10 Japan sources its uranium from a number of different countries, most notably Australia, Kazakhstan, and Canada. We assume most of this uranium is carried by ship, and an average shipping distance is 8000 km. For U origin for Japan, see, for example, World Nuclear Organization (2016), "Japan's Nuclear Fuel Cycle", dated January, 2016, and available as http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-fuel-cycle.aspx.

FUTURE REGIONAL NUCLEAR FUEL CYCLE COOPERATION IN EAST ASIA: ENERGY SECURITY COSTS AND BENEFITS

Calculations for East Asia Science and Security (EASS) and Related Follow-on (2012-2016) Projects, funded by MacArthur Foundation

Estimates of Reactor Fuel Fabrication and Transport Requirements: "National Enrichment, National Reprocessing" Scenario (Regional Scenario 1)

Using Nuclear Fuel Requirements Estimates from "Business-as-Usual" Capacity Expansion Case

Prepared by:	David Von Hippel
Last Modified:	11/8/2016

General Assumptions

All costs in approximately **2009 US Dollars** unless otherwise noted

Fraction of mixed-oxide (MOx) fuel used in first reactor cores using MOx	20%	(See ***Note 1***), except	30%	in Japan
Fraction of mixed-oxide (MOx) fuel used in reactors using MOx by target year	20%	(See ***Note 1***), except	30%	in Japan
Year that target fraction of MOx fuel in reactor cores using MOx is reached	2030	(See ***Note 1***).		
Average distance from fuel fabrication facility for imported fuel assemblies made of uranium (and MOx) not enriched in-country (km)	13,000	Rough Estimate (See ***Note 11***)		
Average cost of UOx fabricated fuel transport, rail ($/tonne-km heavy metal)	$ 2.75	(See ***Note 7***).		
Average cost of UOx fabricated fuel transport, ocean freight ($/tonne-km heavy metal)	$ 6.88	(See ***Note 7***).		
Average cost of MOx fabricated fuel transport, rail ($/tonne-km heavy metal)	$ 4.13	(See ***Note 7***).		
Average cost of MOx fabricated fuel transport, ocean freight ($/tonne-km heavy metal)	$ 10.32	(See ***Note 7***).		
Cost of Uranium Oxide (UOx) fuel fabrication	$ 272	per kg heavy metal (See ***Note 6***)		
Cost of Uranium/Plutonium Blending and MOx fuel fabrication	$ 1,800	per kg heavy metal (See ***Note 5***)		
Fraction of MOx fuel as Plutonium (% of Heavy Metals)	9.5%	(See ***Note 4***)		
Losses in uranium conversion (from UF_6 to UO_2) and fuel fabrication	1.0%	(total) of incoming enriched UF_6 (as in country workbooks)		
Solid waste from Uranium Oxide (UOx) fuel fabrication	0.5	t/t U (See ***Note 3***)		
Liquid waste from Uranium Oxide (UOx) fuel fabriction	9	m^3/t U (See ***Note 3***)		
Solid waste from Mixed Oxide (MOx) fuel fabrication	0.5	t/t heavy metal (See ***Note 8***)		
Liquid waste from Mixed Oxide (MOx) fuel fabrication	9	m^3/t heavy metal (See ***Note 8***)		
Fossil fuel use in Uranium Oxide (UOx) fuel fabrication	2709	GJ/t U (See ***Note 9***)		
Electricity use in Uranium Oxide (UOx) fuel fabrication	300.9	MWhe/t U (See ***Note 9***)		
Fossil fuel use in Mixed Oxide (MOx) fuel fabrication	2709	GJ/t heavy metal (See ***Note 10***)		
Electricity use in Mixed Oxide (MOx) fuel fabrication	300.9	MWhe/t heavy metal (See ***Note 10***)		

	Australia	China	DPRK	Indonesia	Japan	ROK	RFE	Taiwan	Vietnam	
Average distance from domestic fuel fabrication facilities to reactors (km)	1000	1000	300	1000	500	500	2000	500	500	All Placeholders
Predominant transport mode for domestic fuel assemblies	Ship	Rail	Rail	Ship	Ship	Ship	Rail	Ship	Ship	All Placeholders
Ultimate target fraction of reactors that will use mixed-oxide (MOx) Fuel	0%	40%	50%	0%	40%	50%	0%	0%	0%	(See ***Note 2***)
Year use of MOx fuel starts	2025	2025	2025	2025	2010	2025	2025	2025	2025	(See ***Note 2***)
Year use of MOx fuel reaches target level	2050	2050	2050	2050	2030	2050	2050	2050	2050	(See ***Note 2***)

NOTES AND SOURCES

1. Our understanding, based on conversations with US and European experts (F.N. von Hippel and K. Janberg, personal communications, 2009) is that the use of MOx fuel in current light-water reactor cores is limited by the characteristics of MOx fuel to 20% of the reactor core for safety and reactor control reasons.
The information from these experts is contradicted somewhat by a passage in the "MIT Report" (see referece below), page 121, which reads (in part), "In practice, current reactors employing UOX and MOX are fueled with a 2:1 ratio of UOX to MOX fuel".
Other references suggest that France is currently using approximately 30% MOx in some of its reactors, that the US DOE calls for reactors using 40% MOx cores, and that future reactors capable of using 50% (Europe) and 100% (Japan) MOx cores are under design. See, for example,
A. Sowder (2009), "Readiness of Current and New U.S. Reactors for MOX Fuel", presentation at North Carolina and Virginia Health Physics Societies Joint 2009 Spring Meeting, New Bern, North Carolina, 13 March 2009 (Sowder is from the US Electric Power Research Institute, or EPRI), available as http://hpschapters.org/northcarolina/spring2009/FAM.4.pdf.
Although at present we have no reason to believe that the 20% limit described above will increase in the future as an average across reactors in the region, we include in this worksheet algorithms for increasing the limit gradually over time in case technological improvements allow higher fractions of MOx to be used.

2 See text of EASS Report for this scenario for a description of these assumptions. Calculations assume that DPRK use of MOx fuel is tha same as in the ROK, because the ROK is essentially operating the DPRK's reactors.

3. The WISE Uranium Project's (2009), "Nuclear Fuel Material Balance Calculator", available as http://www.wise-uranium.org/nfcm.html, lists default estimates for the amount of solid and liquid waste per unit Uranium metal handled in fuel fabrication plants as shown.

4. 7 % is reported in "MIT Report", <u>The Future of Nuclear Power, An Interdisciplinary MIT Study</u>, 2003, compiled by a team of researchers mostly from the Massachusetts Institute of Technology (MIT), Cambridge, MA USA. Data from page 121. Report available as http://web.mit.edu/nuclearpower/pdf/nuclearpower-full.pdf. http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Fuel-Recycling/Mixed-Oxide-Fuel-MOX/ reports an average of 9.5% Pu in MOX fuel.

5. Initial value from lecture notes from 2004 MIT course "Nuclear Energy Economics and Policy Analysis", available as
http://ocw.mit.edu/NR/rdonlyres/Nuclear-Engineering/22-812JSpring2004/55ABD4F2-4FF8-4386-9055-D8F1C38A2193/0/lec15note.pdf
Original source probably Matthew Bunn et al, “The Economics of Reprocessing vs. the Direct Disposal of Spent Fuel”, Project on Managing the Atom, Kennedy School of Government, Harvard University, December 2003, but the latter document hasn't been consulted yet.
The same value has been found in the MIT Report (see reference above), page 147, where the reference seems to be to 2002 costs.
We therefore assume that the cost in 2009 dollars is about $ 1,800
For Japan, the CINC (Citizens' Nuclear Information Center) entitled "Rokkasho Reprocessing Plant and other Nuclear Facilities", available as http://www.cnic.jp/english/topics/cycle/rokkasho/rokkashodata.html, citing a JNFL press release from April, 2009, lists the cost (assumedly in 2009) of the MOX fuel fabrication facility at Rokkasho as 190 billion Yen, with a capacity of 130 tonnes of MOX fuel per year. At an interest rate of 5% annually and an assumed facility lifetime of 30 years, this would imply annualized capital costs (only) of 95,075 Yen per kg processed, or, at the then-prevailing exchange rates of about 95 Yen per dollar, about $ 1,001 for annualized capital costs alone. This appears reasonably consistent with the MIT figure referenced above, since additional operating costs would also be incurred.

6. Initial value, based on World Nuclear Association (2010) "The Economics of Nuclear Power", available as http://www.world-nuclear.org/info/inf02.html.
Quoted cost of $240 per kg UO_2 fuel as of January 2010 was converted to a $ per kg heavy metal (U) basis.
This value is in the range of the "$200 to $400/kg" indicated in the WISE Uranium Project (2009), "Nuclear Fuel Energy Balance Calculator - HELP", available as http://www.wise-uranium.org/nfceh.html, but substantially less than the value of $460/kg U calculated with the WISE Uranium Project (2009) "Nuclear Fuel Cost Calculator", available as http://www.wise-uranium.org/nfcc.html.
The MIT Report (see reference above), gives, on page 146, an estimate for fuel fabrication costs of $275 per kg heavy metal, probably in 2002 dollars, which would imply a cost of $ 330.00 in 2009 dollars.

7. These values are pure guesses at present. It is assumed that due to requirements for specialized ships, shipping containers, and handling procedures, the costs of transporting UOx fuel will be much higher than the costs of transporting yellowcake, which can travel in fairly standard cargo vessels and containers. It is assumed that costs for transporting MOx fuels will be higher still, due to the added security and radiological hazards associated with MOx. Research is needed to better estimate these costs.
As a order of magnitude estimate, assume that a ship carries an average of 10 transport casks, each of which cost $2 million and can hold 16 BWR assemblies of 0.183 tHM each. Assume that each ship has a capital cost of $30 million, and an operating life of. 30 years.
(Might be a ship similar to those used by Nuclear Fuel Transport Limited of Japan, see http://www.nft.co.jp/yusou/english/business/vessels.html.)
Assume an interest rate of 7% per year, and 40 trips per year. Then the annualized capital cost per tonne of spent fuel for a journey of 500 km (as in Japan) would be $4.03 million per year, or $100,733 per trip, or $ 3,440 per tonne of fuel or $ 6.88 per tonne-km of fuel transported. Fuel, personnel, and related costs would also apply, but are assumed to be small relative to capital costs for these specialized transport modes and containers. As noted, this is a very rough estimate at best.
For rail transport (or road) transport, a rough calculation based on the capital cost of a transport cask, with otherwise the same assumptions as above, would yield $ 161,173 dollars per year per cask, or $ 4,029 per trip, or $ 1,376 per tHM, or $ 2.75 per tHM-km.

8. No specific data on waste generation from MOx fuel preparation and fabrication is available at present, so values for UOx fuel preparation (see Note 3) are used as a placeholder. It seems likely that MOx fuel preparation will generate at least as much waste as UOx fuel fabrication, given the additional blending step required.

9. The WISE Uranium Project's (2009), "Nuclear Fuel Energy Balance Calculator", available as http://www.wise-uranium.org/nfce.html lists default estimates for the amount of fossil fuel and electricity needed per unit Uranium metal handled in fuel fabrication plants as shown.

10. No specific data for fuels and electricity use in MOx fuel fabrication were immediately available, so values for UOx fuel fabrication from source above (WISE Uranium Project) are used as placeholders.

11. Rough estimate assuming that imported enriched fuel would come from Eastern North America or Western Europe (about 16,000 km by sea) or from Russia (Urals region or Irkutsk region), which is a shorter distance, and partially overland.

FUTURE REGIONAL NUCLEAR FUEL CYCLE COOPERATION IN EAST ASIA: ENERGY SECURITY COSTS AND BENEFITS

Calculations for East Asia Science and Security (EASS) and Related Follow-on (2012-2016) Projects, funded by MacArthur Foundation

Estimates of Reprocessing and Spent Fuel Management Requirements: "National Enrichment, National Reprocessing" Scenario (Regional Scenario 1)

Using Nuclear Fuel Requirements Estimates from "Business-as-Usual" Capacity Expansion Case

Prepared by:	David Von Hippel
Last Modified:	11/7/2016

General Assumptions

All costs in approximately **2009 US Dollars** unless otherwise noted

Effective average lag time between when fabricated fuel is placed in service in reactor and when it is removed from at-reactor spent-fuel pool for reprocessing, storage, and/or disposal	8	years	(See ***Note 8***).
Average loading of spent fuel pools (relative to capacity) before fuel is discharged to storage and/or disposal	90%	Assumption	
Average distance from reactors to international reprocessing facility (km)	13,000	Rough Estimate (See ***Note 20***)	
Average distance from reactors to regional spent fuel storage or disposal facility (km)	3,000	Placeholder only	
Average mass of spent fuel per shipping cask--ocean or rail transport	6.71	t HM	(See ***Note 3***).
Average number of shipping casks per shipload in ocean transport	20		(See ***Note 3***).
Average cost of spent fuel transport, rail ($/tonne-km heavy metal)	$ 79.00	(See ***Note 4***).	
Average cost of spent fuel transport, ocean freight ($/tonne-km heavy metal)	$ 39.50	(See ***Note 4***).	
Average cost of reprocessing at international facilities	$ 1,200	per kg heavy metal	(See ***Notes 1, 9, and 15***)
Volume of high-level waste (as vitrified) from reprocessing operations	0.115	m^3/t HM processed	(See ***Note 1***)
Cost of treatment and disposal of high-level waste (via vitrification) from reprocessing operations	$ 150,000	$/t HM processed	(See ***Note 1***)
Fossil fuel requirements for treatment/disposal of high level wastes from reprocessing	1.00	GJ/t HM processed	Placeholder only
Electricity requirements for treatment/disposal of high level wastes from reprocessing	3.45	MWhe/t HM processed	(Very rough estimate, see ***Note 19***)
Volume of medium-level waste from reprocessing operations	0.2	m^3/t HM processed	(See ***Note 1***)
Cost of disposal of medium-level waste from reprocessing operations	$ 62,179	$/t HM processed	Rough estimate (See ***Note 22***)
Volume of low-level waste from reprocessing operations	1.4	m^3/t HM processed	(See ***Note 1***)
Cost of disposal of low-level waste from reprocessing operations	$ 26,500	$/t HM processed	Rough estimate (See ***Note 21***)
Volume of solid wastes from reprocessing operations	0.15	m^3/t HM processed	(See ***Note 1***)
Cost of disposal of solid wastes from reprocessing operations	$ 144	$/t HM processed	Rough estimate (See ***Note 23***)
Mass of Plutonium separated from reprocessing operations	11.00	kg/t HM processed	(See ***Note 1***)
Cost of storage/safeguarding/disposal of plutonium from reprocessing operations (fraction not used as MOx)	$ 3,000	$/kg Pu-yr	(See ***Note 5***)

(Depleted) Uranium separated during reprocessing operations	0.94	t/t HM processed	(See ***Note 1***)
Cost of disposal of depleted Uranium from reprocessing operations (fraction not used in MOx)	$ 8,572	$/t U	Rough estimate (See ***Note 24***)
Fossil fuel requirements for reprocessing	26,736.00	GJ/t HM processed	(See ***Note 27***)
Electricity requirements for reprocessing	1,110.00	MWhe/t HM processed	(See ***Note 27***)
Average cost of cask for dry cask storage of spent nuclear fuel (UOx)	$ 800,000	per cask	Rough estimate (See ***Note 17***), except Japan (See ***Note 28***)
Average cost of cask for dry cask storage of spent nuclear fuel (MOx)	$ 800,000	per cask	Placeholder only--Assumed same as UOx for now
Average capacity of cask for dry cask storage, spent UOx Fuel	10.00	t HM processed	Rough estimate--capacity varies by cask design
Average capacity of cask for dry cask storage, spent MOx Fuel	10.00	t HM processed	Placeholder only--Assumed same as UOx for now
Average cost of permanent disposal of spent fuel (UOx or MOx)	$ 1,000,000	$/t HM processed	(See ***Note 6***)
Average operating and maintenance costs for dry cask storage of spent UOx Fuel	$ 10,000	per cask-yr	Order-of-magnitude estimate (See ***Note 18***), except Japan (See ***Note 28***)
Average operating and maintenance costs for dry cask storage of spent MOx Fuel	$ 10,000	per cask-yr	Placeholder only--Assumed same as UOx for now
Average cost of interim storage of spent fuel	$ 360,000	$/t HM processed	(See ***Note 7***)
Annual Cost of Storing Spent Cooled UOx Fuel in Pools	$ 11,708	$/t HM processed	(See ***Note 29***)
Annual Cost of Storing Spent Cooled MOx Fuel in Pools	$ 11,708	$/t HM processed	Placeholder only--Assumed same as UOx for now, though could be higher

	Australia	China	DPRK	Indonesia	Japan	ROK	RFE	Taiwan	Vietnam	
Average distance from reactors to domestic reprocessing facilities (km)	1000	1000	300	1000	500	500	2000	500	500	All Placeholders
Predominant transport mode to domestic reprocessing facilities	Ship	Rail	Rail	Ship	Ship	Ship	Rail	Ship	Ship	All Placeholders
Inventory of LWR spent fuel as of 2000 (metric tons heavy metal--MTHM)	-	225	-	-	7,242	2,058	9	1,434	-	From national workbooks for this nuclear path--year 2000 values
Inventory of CANDU spent fuel as of 2000 (metric tons heavy metal--MTHM)	-	-	-	-	-	2,206	-	-	-	From national workbooks for this nuclear path--year 2000 values
Inventory of plutonium from spent fuel reprocessed internationally or domestically, as of 2000 (MTHM)	0	0	0	0	34.00	0	0	0	0	(See ***Note 10***)
Inventory of high level wastes from spent fuel reprocessed internationally as of 2000 (m^3 as vitrified solid)	0	0	0	0	355.45	0	0	0	0	(See ***Note 13***)
Year reprocessing at international facilities starts	2030	2030	2030	2030	2000	2030	2030	2030	2030	(See ***Note 14***)
Initial fraction of spent fuel reprocessed at international facilities	0%	0%	0%	0%	50%	0%	0%	0%	0%	(See ***Note 16*** for
Ultimate target fraction of annual cooled spent UOx reactor fuel that is reprocessed internationally	0%	0%	0%	0%	0%	0%	0%	0%	0%	(See ***Note 16*** for estimated Japan value)
Year international reprocessing of spent fuel reaches target level	2050	2050	2050	2050	2005	2050	2050	2050	2050	(See ***Note 16*** for estimated Japan value)
Ultimate target fraction of spent UOx reactor fuel that is reprocessed domestically	0%	60%	60%	0%	80%	60%	25%	0%	0%	*(Assumption)*
Year domestic fuel reprocessing starts	2025	2025	2025	2025	2018	2025	2021	2025	2025	*(Assumption)*
Year domestic reprocessing of fuel reaches target level	2050	2030	2030	2050	2020	2030	2022	2050	2050	*(Assumption)*

Average cost of reprocessing at domestic facilities ($/kg U in incoming spent fuel)	$ 1,200	$ 1,200	$ 1,200	$ 1,200	$ 3,400	$ 1,200	$ 1,200	$ 1,200	$ 1,200	(See ***Note 11***)
Average cost of direct disposal at domestic facilities ($/kg HM in incoming spent fuel)	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	(See ***Note 12***)
Average distance from reactors to domestic spent fuel storage/disposal facilities (km)	1000	1000	300	1000	500	500	2000	500	500	All Placeholders
Predominant transport mode to domestic fuel storage/disposal facilities	Ship	Rail	Rail	Ship	Ship	Ship	Rail	Ship	Ship	All Placeholders
Average cost of interim domestic storage of spent fuel	$ 360,000	$ 360,000	$ 360,000	$ 360,000	$ 360,000	$ 360,000	$ 360,000	$ 360,000	$ 360,000	$/t HM processed--Placeholder assuming same as international costs for now
Average cost of permanent domestic disposal of spent fuel (UOx or MOx)	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$1,000,000	$ 1,000,000	$ 1,000,000	$/t HM processed--Placeholder assuming same as international costs for now

Type of Spent Fuel Storage or Disposal Used for Cooled Fuel Not Reprocessed (and Cooled Spent MOx Fuel), by Country				
	Australia	Dry Cask Storage	China	Domestic Interim Storage
	DPRK	Dry Cask Storage	Indonesia	Dry Cask Storage
	Japan	Dry Cask Storage	ROK	Domestic Interim Storage
	RFE	Domestic Interim Storage	Taiwan	Dry Cask Storage
	Vietnam	Dry Cask Storage		

NOTES AND SOURCES

1. The following data were prepared and compiled by T. Katsuta for the EASS project and are used as the source for several initial estimates in the calculations above. Note that these data have not been thoroughly cross-checked against other, more recent, sources, and need to be updated to reflect more recent currency years or for updated technologies. Source, memo "EASSC: Estimation of the unit cost and the material flow", by Tadahiro KATSUTA, dated 5/1/2009.

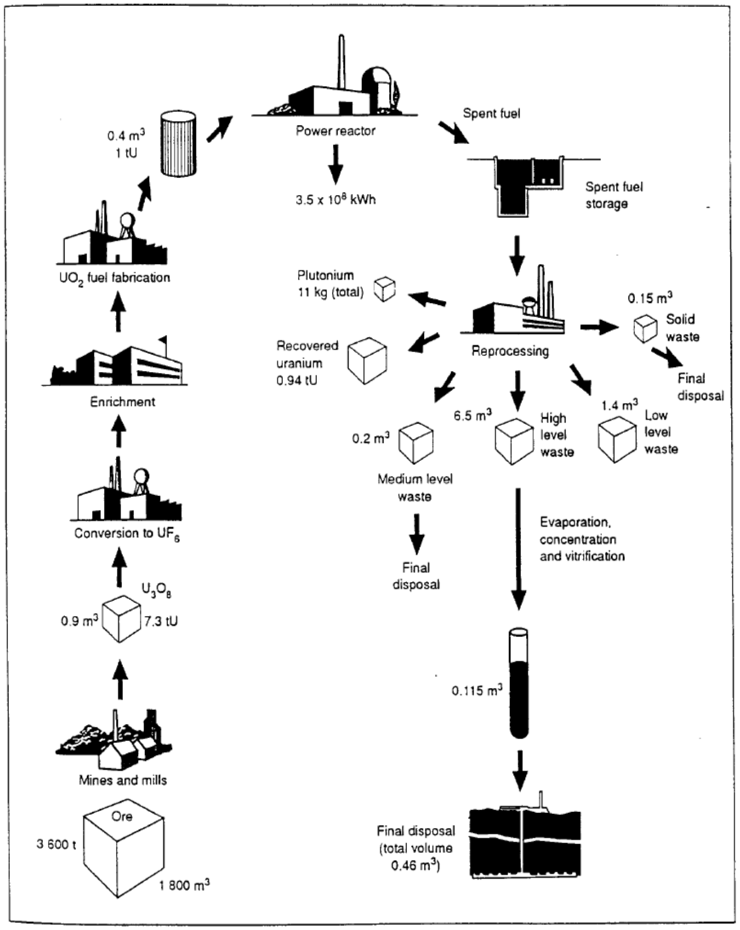
	Case 1	Case 2, 3 or 4[1]
(Frontend)		
Uranium ore purchase	$50/kgU	
Conversion	$8kgU	
Enrichment	$110/SWU	
UOX Fabrication	$275/kgU	
(Backend)		
Reprocessing option		
Transport	$50/kgU	
Reprocessing	$3,400/kgU [2]	$720/kgU
HLW disposal	$90/kgU	
MOX fuel fabrication	$1,100/kgU	
Direct disposal option		
Transport/Storage	$600/kgU[3]	$230/kgU
Disposal	$610/kgU	

Values in this table that are from OECD/NEA (1994) are in "early-1991" US dollars.

[1] Nuclear Energy Agency of the Organization for Economic Cooperation and Development, The Economics of the Nuclear Fuel Cycle, OECD/NEA (1994)
[2] In the case of Rokkasho plant, 32,000tons of spent fuel is reprocessed using 110 US billion $.
[3] In the case of Mutsu intrim storage, 24,000 tons of spent fuel is transported and stored using 60US billion $

Figure at right is source of initial estimates of material flows from reprocessing, as included in the Katsuta memo referenced above. Original source is OECD/NEA 1994 reference noted above.

Figure 3.1 **Material flow of the PWR reprocessing option**
(the figure is an example and the numbers are approximate only)



Recovered uranium and plutonium can be recycled.
Source: COGEMA, HORIZON 2000.

2. These values are pure guesses at present. It is assumed that due to requirements for specialized ships, shipping containers, and handling procedures, the costs of transporting UOx fuel will be much higher than the costs of transporting yellowcake, which can travel in fairly standard cargo vessels and containers. We may ultimately wish to use a transport cost estimate that is not based on distance, or only partially based on distance, if that is appropriate and cost data are available.

3. Assumptions for fuel transport by rail or ocean freight assume the use of shipping casks similar to those produced/used by Japan's Nuclear Fuel Transport Company Ltd..
These casks, which weigh on the order of 100 tons empty, and 115-120 tons full, hold 38 BWR or 14 PWR fuel assemblies
(see http://www.nft.co.jp/english/business/packages_1.html).
Other casks are in use in reactor fuel transport (generic casks shown in documents from the US Nuclear Regulatory Commission for use in rail--and presumably ship--transport as shown in http://www.nrc.gov/waste/spent-fuel-storage/diagram-typical-trans-cask-system-2.pdf, for example, have similar dimensions, but capacity for more fuel assemblies) but the Japanese casks are used as an example here because they are provided and presumably in use by a company in the region.
Japan's Nuclear Fuel Transport Company Ltd., also lists two dedicated ships for handling spent fuel. The vessel with higher capacity (the "ROKUEI MARU"), can handle a maximum of 20 spent fuel packages (casks). We assume that this is a reasonable average for ship capacity in the coming decades.
(Data on ships from http://www.nft.co.jp/english/business/vessels.html).
The website http://www.nucleartourist.com/basics/hlwaste.htm, using data from the USDOE, reports the following information on the contents of PWR and BWR fuel assemblies:

Characteristics	**BWR**[a]	**PWR**[b]
Overall assembly length, m	4.47	4.059
Cross section, cm	13.9 x 13.9	21.4 x 21.4
Fuel rod length, m	4.064	3.851
Active fuel height, m	3.759	3.658
Fuel rod outer diameter, cm	1.252	0.95
Fuel rod array	8 x 8	17 x 17
Fuel rods per assembly	63	264
Assembly total weight, kg	319.9	657.9
Uranium/assembly, kg	183.3	461.4
UO_2/assembly, kg	208	523.4
Zircaloy/assembly, kg	103.3[c]	108.4[d]
Hardware/assembly, kg	8.6[e]	26.1[f]
Total metal/assembly, kg	111.9	134.5
Nominal volume/assembly, m^3	0.0864[g]	0.186[g]

[a] Ref. 5. U.S. Environmental Protection Agency, "*Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*," Code of Federal Regulations, 40 CFR Part 191 (July 1, 1996).

[b] Ref. 6. U.S. Department of Energy, DOE Order 5820.2A, *Radioactive Waste Management*, Washington, D.C., Sept. 26, 1988.

[c] Includes Zircaloy fuel-rod spacers and fuel channel.

[d] Includes Zircaloy control-rod guide thimbles.

[e] Includes stainless steel tie-plates, Inconel springs, and plenum springs.

[f] Includes stainless steel nozzles and Inconel-718 grids.

[g] Based on overall outside dimension. Includes spacing between the stacked fuel rods of an assembly.

These data, together with the data above, suggest a mass of 6.46 t HM per PWR cask, or
6.97 t HM per BWR cask.
At present, PWRs dominate the reactor fleet in the ROK, while BWRs make up about two thirds of the reactor fleets in Japan and Taiwan. We make the rough approximation that 50% of spent fuel is/will be of the PWR type in the period under study, implying an average of 6.71 t HM per cask.

4. As a first approximation of the costs of shipping spent nuclear fuel, we use the estimate of shipping costs of $50 kg U (or heavy metal) from the 1994 OECD/NEA study referenced in note 1, above. In 2009 dollars, this is $ 79.00 kg U (or heavy metal). The 1994 OECD/NEA study indicates (section 4.3.2.1) that this cost is indicative of transport within the (Western) European area, which we assume means an average transport distance of about 1000 km, and also means transport predominantly by rail. This implies a transport cost of abou $ 79.00 per t (HM)-km. If we assume that ocean shipping costs about 50% as much, that cost would be $ 39.50 per t (HM)-km, which, with an average capacity as indicated in note 3, above, and an average ship speed of 20 km/hr, implies a daily transport cost of $ 2,545,380 This seems somewhat high, but is perhaps reasonable given the special nature of the materials shipped. It is also somewhat unclear whether this cost includes elements such as preparation of fuel for transport, loading of casks, and the casks themselves (if they are not reusable)..

5. As an initial estimate, the 1994 OECD/NEA study referenced in note 1, above, includes (section 4.3.2.6) an estimate that costs of storing plutonium are "in the region of $1 to $2 per gram of total plutonium [Pu(t)] per year" in 1991 dollars. We use the higher end of this estimate, and update to 2009 dollars, pending receipt of more up-to-date data.

6. As an initial estimate, the 1994 OECD/NEA study referenced in note 1, above, includes (table 5.5) provides an estimate that costs of a "Direct disposal option, encapsulation & disposal" are $610/kg U in 1991 dollars. We use this figure, converted (roughly) to 2009 dollars, as an initial estimate pending receipt of more up-to-date information. An alternative figure for the cost of spent fuel disposal of $400 per kg HM was used in the study <u>THE ECONOMICS OF REPROCESSING VS. DIRECT DISPOSAL OF SPENT NUCLEAR FUEL</u> Final Report, 8/12/1999-7/30/2003, by Matthew Bunn, Steve Fetter, John P. Holdren, and Bob van der Zwaan, available as http://belfercenter.ksg.harvard.edu/publication/2089/economics_of_reprocessing_vs_direct_disposal_of_spent_nuclear_fuel.html This cost in 2009 dollars would equate to $ 468,000 per t HM processed.

7. As an initial estimate, the 1994 OECD/NEA study referenced in note 1, above, includes (table 5.5) provides an estimate that costs of a "Direct disposal option, spent fuel transport & storage" are $230/kg U in 1991 dollars. We use this figure, converted (roughly) to 2009 dollars, as an initial estimate pending receipt of more up-to-date information.

8. Rough, initial estimate based on a number of sources, including the 1994 OECD/NEA study referenced in note 1 above (table 5.3). In practice, spent fuel needs to be placed in reactor fuels for a minimum of 5 years, but can stay much longer, and the amount of time a fuel element spends in a typical LWR seems to be 1 to 2 years.

9. The "MIT Report", <u>The Future of Nuclear Power, An Interdisciplinary MIT Study</u>, 2003, compiled by a team of researchers mostly from the Massachusetts Institute of Technology (MIT), Cambridge, MA USA, lists an estimated reprocessing cost of $1000 per kg heavy metal, presumably in approximately 2002 dollars (p. 147). Available as http://web.mit.edu/nuclearpower/pdf/nuclearpower-full.pdf. This value, equivalent to $ 1,200 in 2009 dollars, is very simlar to (in comparable dollars) to the value from the OECD/NEA 1994 document referred to in Note 1.

10. Estimated based on Figures 3.3 and 3.4 in "Japan's Civilian Nuclear Fuel Cycle and Nuclear Spent Fuel Management Issue", by Tadahiro Katsuta1 and Tatsujiro Suzuki, dated June 2006 Prepared for the INTERNATIONAL PANEL ON FISSILE MATERIAL. Of the total mass of Pu, approximately 7 tonnes was at Tokai, with the remainder at international reprocessing facilities in the UK and France. Available as http://nautilus.org/wp-content/uploads/2012/01/copy_of_IPFMFact200606b13.pdf.

11. Japan value is assumed for now to be similar to the estimate prepared by Katsuta (see Note 1, above). Reprocessing at other countries is assumed, pending country-specific information, to be at similar cost to international reprocessing.

12. Cost of domestic direct disposal of spent fuels is assumed, pending country-specific information, to be at similar cost to international disposal.

13. Japan value is estimated, at present, based on mass of Plutonium in inventories and average production of plutonium and vitrified high-level wastes from international reprocessing operations (factors assumed in this worksheet).

14. Reprocessing of Japanese spent fuel at international facilities in France and the UK was ongoing as of 2000. Values for other years are placeholders, and do not affect results since no international reprocessing of spent fuels from countries other than Japan is assumed to take place in this scenario.

15. F. N. von Hippel, in "Why reprocessing persists in some countries and not in others:The Costs and Benefits of Reprocessing" (prepared 9 April 2009, and available as http://www.npec-web.org/Essays/vonhippel%20-%20TheCostsandBenefits.pdf, notes that the cost of reprocessing of Japanese spent fuel (and, other spent fuel) in France as "..perhaps $2 million per ton..", which would be significantly higher than the values cited in notes 1 and 9, above.

16. A straightforward statement of the amount of Japanese spent fuel reprocessed internationally (in the UK and France) was not immediately available. The World Nuclear Association (2010), in "Japanese Waste and MOX Shipments From Europe", (available as http://www.world-nuclear.org/info/inf39.html, updated January, 2010), notes that "From 1969-1990, some 2940 tonnes of used fuel in total was shipped (in over 160 shipments) by these utilities to France for reprocessing. Shipments of about 4100 tonnes were to the UK, and by mid 2007 more than 2600 tonnes of oxide fuel had been reprocessed there, plus a small amount of Japanese Magnox used fuel."
This suggests that at least 7000 tonnes of spent fuel had been sent to Europe for reprocessing by 2007, and possibly more.
This represents about 107% of the cooled spent fuel available by 2007, or possibly slightly less, since the World Nuclear Association figures seem to be in terms of Uranium oxides, as opposed to tonnes of heavy metal. Since Japanese shipments to reprocessing centers in Europe were winding down in the 2000s, we use 50 percent reprocessing as a starting value for approximately 2000, pending receipt of better data, and an end date for European reprocessing of Japanese spent fuel of 2012.

17. An older reference, US Department of Energy (1994), Multi-purpose Canister Evaluation: A Systems Engineering Approach. Report DOE/RW-0445, September, 1994, describes a multipurpose canister (interim storage, transport, and final disposal) designed for PWR spent fuel, costing about $350,000 in (presumably) 1994 US dollars. Escalated to 2009 dollars, this would be about $500,000. Pending receipt of more definitive costs, we increase this estimate to $800,000 per cask to reflect increases in materials costs (steel and concrete) as well as other refinements. This is consistent with references to costs of "about $1 million each" for dry casks that we have seen in other summary descriptions of the technology.

18. Rough, order-of-magnitude estimate, pending development of more up-to-date information, based on older data descrbed as "Midrange" estimates for costs of O&M of dry storage facilities at operating and shut-down reactors from TRW Environmental Safety Systems, Inc., At Reactor Dry Storage Issues, Report # E00000000-01717-2200-00002, September, 1993.

19. Though electricity is a key input to the process of vitrifying high-level nuclear wastes (HLW), firm figures on the electricity requirements for HLW vitrification have been difficult to find. Electricity is used in numerous operations in HLW processing, but seems to be used most intensively in the process of "calcining"--reducing liquid HLW to a powder for mixture with glass, and "melting", in which the powdered HLW is melted together with glass "frit" to form molten glass, which is then poured into steel flaskes for indefinite storage. The melting step requires the most electricity.
Of the many documents reviewed to date on HLW vitrification, few provide sufficient data to calculate a per-unit electricity consumption for the process.
One document with potentially applicable data is the Pacific Northwest National Laboratory (report # PNNL-13582) report High-Level Waste Melter Study Report, by J.M. Perez, et al, dated July 2001, and available as http://www.osti.gov/bridge/servlets/purl/786808-mi2P3c/native/786808.pdf.
In a discussion of a German HLW pilot test included in this document (e.g., page 6-16), "installed electrical power" to the test melter is described as being 80 kVA, with average glass output of 7 kg/hr. Assuming (in a full production facility) a mass ratio of 25% HLW oxides within the final glass product (the German test actually used a lower value, 16%, but 25% seems more common in the literature), this implies an average power input of 45.71 kWh per kg heavy metal oxides, or somewhat more than that per kg heavy metal.
This calculation is highly approximate, as 1) the "installed electrical power" is highly likely to have been greater then the average draw on the system, but 2) this only counts power to the melter, not to the calciner or to the many other processes that are required for HLW vitrification.
Another (imperfect) point of reference for this parameter is a report on a pilot project for a different type of vitrification system: "AVS ADVANCED VITRIFICATION SYSTEM Additional Testing Project DE-AC26-00NT40801", Presentation to Industry Partnerships for Environmental Science and Technology Conference, November 1 [2001] at NETL, Morgantown WV, by James Powell, available as www.netl.doe.gov/publications/proceedings/01/indpartner/em5-1.pdf.
The "AVS" system involves heating a sludge-like mixture of glass and concentrated HLW directly in a crucible, which also ultimately serves as the disposal vessel. Slide 8 of the Powell presentation lists electricity input of 10 MWh to produce 2100 kg of glass. In the AVS test, higher ratios of HLW to glass were used than is typical in the literature. If one takes the same 25% HLW oxides used above (rather than the 35% to 62% for the AVS system), the estimated use of electricity per unit input HLW (mostly heavy metal oxides) woul 19.05 kWh per kg heavy metal oxides, or somewhat more than that per kg heavy metal.
The average electricity use for vitrification in existing and operating facilities is known to someone, and can doubtless be divined through further research. For the time being We take the above as indicative that electricity input to HLW vitrification is in the range of tens of kWh per tonne HLW oxides, and use the value 40 kWh per kg HLW solids in the incoming HLW feed. Assuming a glass density 3 kg/liter (from Powell presentation), and the vitrified HLW volume of 0.115 m^3/t HM processed, as assumed above, or 0.08625 tonnes HLW solids (presumably mostly oxides) per t HM processed, this implies about 3.45 MWh for HLW vitrification per t HM processed in a reprocessing center. Again, this is at best a crude estimate.

20. Rough estimate assuming that imported reprocessing centers accepting spent fuel would be in Eastern North America or Western Europe (about 16,000 km by sea) or in Russia (Urals region or Siberia region), which is a shorter distance, and partially overland.

21. Recent estimates of the U.S. costs of disposal of low-level radioactive wastes were not immediately available, but cost figures provided in Porter, R.C (2002), The Economics of Waste, Resources for the Future, Table 16-2, shows estimates by other authors ranging from \$91 to \$218 per cubic foot of waste (1997 dollars).
The U.S. DOE (1998) document Report to Congress: Equity of Commercial Low-Level Radioactive Waste Disposal Fees, dated February, 1998, and available as http://www.osti.gov/bridge/servlets/purl/587909-T8VLO4/webviewable/587909.pdf, lists a range of costs for disposing of a hypothetical shipment of LLRW at several existing and (then) proposed US sites of \$111 to \$613 per cubic foot (Table 2--presumably also in 1997 dollars). Assuming escalation of LLW disposal costs in the decade-plus since these estimates were published, we take a value at the higher end of the range, \$400 per cubic foot in 1997 dollars, or \$ 18,929 2009 dollars per cubic meter LLW. In an extract from the book Nukenomics: The commercialisation of Britain's nuclear industry, available as "Radwaste management:Buried costs", in Nuclear Engineering International, 27 March, 2008, available as http://www.neimagazine.com/story.asp?storyCode=2049209, I. Jackson states that the "price for disposal of low-level waste at the NDA's Low Level Waste Repository (LLWR) at Drigg in Cumbria is only around £2000/m3".
This would be about \$ 4,145 2009 dollars per cubic meter LLW. For the moment, we assume that the US estimate is more applicable, as it averages in newer facilities, so we assume a cost of \$26,500 per t heavy metal processed.

22. The conclusion to the article by I. Jackson cited in Note 21 reads" The bottom line is that nuclear energy utilities probably need fixed waste disposal 'prices' for repository disposal capped somewhere in the range from £12,200 to £24,400/m3, but the NDA's true marginal 'cost' is nearer to £67,000/m3, and the commercial 'value' of the repository asset could approach £201,000m3 if operated as a fully private sector venture." This passage, which refers to the costs of Intermediate-level waste disposal in the United Kingdom, suggests a range of costs from true marginal costs of disposal to the value to foreign (mostly Asian, in this case) utilities of waste disposal services of 67 to 201 thousand British pounds per cubic meter. As an order-of magnitude estimate, we choose a value at the upper end ot this scale as probably representative of either commercial or Asian disposal costs, at 150,000 2007 British pounds per cubic meter of ILW, \$ 62,179 per t heavy metal processed.

23. A U.S. commercial provider of solid waste disposal services lists a cost for disposing of industrial waste of $200 per 55-gallon drum.
(See http://www.accpwasteremoval.com/COST.html.) This equates to a cost of $ 962.00 per cubic meter.
Y. Nakamura (2007), WASTE MANAGEMENT AND RECYCLING BUSINESS IN THE UNITED STATES AND JAPAN, USJP (Harvard University) Occasional Paper 07-09, cites a range of disposal costs in "highly regulated landfills" of "from ¥20,000 ($169) to ¥40,000 ($338) per ton".
(Source available as www.wcfia.harvard.edu/us-japan/research/pdf/07-09.Nakamura.pdf). If the wastes were refered to in the Nakamura article were, for example, a mixture of paper, cloth, sludges, and other components, a bulk density of 0.2 to 0.4 per liter might not be unreasonable, which would suggest that the Japanese costs are of a similar magnitude, on a per unit volume basis, as the costs from the US. We therefore use the latter as a rough estimate. The U.S. estimate equates to $ 144 per t heavy metal processed.

24. No specific cost estimate for the disposal of deplete Uranium from reprocessing operations was immediately available, but it stands to reason that the cost of disposal of depleted U cannot be less, on a volumetric basis, than the cost of low-level radioactive waste, since it is, after all, such a waste. Assuming a bulk density for depleted Uranium of about 3.0 (as, for example, U3O8, UF4, or UO2F2--see http://www.eoearth.org/article/uranium), then the cost of disposing of depleted U would be about $ 8,572 per tonne U.

25. Various sources, including "Construction and Operation Experience of Rokkasho Reprocessing Plant", presented at the conference "2009 Fuel Cycle Information Exchange (FCIX)", June 25, 2009, by Kazuhiko Hiruta and Toshiyuki Zama of Japan Nuclear Fuel Limited, report that 430 tonnes of spent fuel were used in a trial reprocessing run at Japan's Rokkasho plant between 2006 and 2009. It is somewhat unclear whether the 430 tonnes refers to the total mass of spent fuel, or just to the heavy metals content, but we assume the latter. The source document is available (via Google search) on www.nrc.gov.
We model the use of the 430 tonnes of spent fuel in Rokkasho as occuring in equal portions over the four years of the trial.

26. An estimate of the amount of spent fuel reprocessed each year at the experimental Tokai plant in the year 2000 through its closure in early 2006 was not immediately available, but we estimate the annual amounts as follows: For 2000 and 2001, specific annual data are available from IAEA (2005), Status and trends in spent fuel reprocessing, Report # IAEA-TECDOC-1467, dated September, 2005, and available as www-pub.iaea.org/MTCD/publications/PDF/te_1467_web.pdf (page 68). For other years, the amount of spent fuel reprocessed was estimated by assuming that a similar amount of spent fuel was reprocessed in 2002 through 2005 as was reported reprocessed in 2001. This assumption is more or less consistent with the amount of spent fuel reported as transported or to be transport to Tokai over the period 2000 through 2005, (spent fuel data and projections from M. Mori (2001?), "Spent Fuel Transport Experience in Japan", figure 3, available as www-pub.iaea.org/MTCD/publications/PDF/te_1467_web.pdf)

27. The document NETL Life Cycle Inventory Data Process Documentation File, by the US DOE National Energy Technology Laboratory, for "Spent Fuel Reprocessing", dated August 11, 2011, and available as http://www.netl.doe.gov/File%20Library/Research/Energy%20Analysis/Life%20Cycle%20Analysis/UP_Library/DF_Stage3_O_Spent_Fuel_Reprocessing_2011-01.pdf, includes the following data:

Electricity consumption by reprocessing (PUREX) process:	1.11	MWh per kgHM				
Thermal enenergy use (gas)	5.57	MWh per kgHM or	20.05	GJ per kgHM, which assuming a	75%	boiler efficiency
suggests an estimated	26.74	GJ natural gas per kgHM				
Water requirements for cooling	631,000	liters per kgHM, 99% of which is returned to the source, meaning that				
Water consumption for cooling is	6310	liters per kgHM				

28. At a cost for casks of $800,000 each, annual O&M costs of $ 10,000 per cask/yr, cask capacity of 10.00 tHM, and an assumed storage period of 40 years, and a discount rate of 5% annually, the implied discounted cost of dry cask storage is $ 97,159 per tHM, of which $ 17,159 , or about 17.7% , are O&M costs. This is roughly consistent with the proportion of dry cask storage costs accounted for by O&M costs as included in "Metal Cask Storage as Compared with Pool Storage of Spent Nuclear Fuel in Japan", prepared by Toshiari Saegusa (CRIEPI) for a Nautilus Institute Workshop in September, 2015.
Although the year in which the overall costs presented in the Dr. Saegusa's paper is unclear, assuming that it is 2015, the overall discounted storage cost per tHM presented, about 30 million Y per tHM, assuming an exchange rate of 118 Y per $, is the equivalent of $ 254,237 per THM in 2015 dollars, or $ 230,136 in 2009, a factor of 2.37 higher than the international/basis costs calculated above. It is possible that Dr. Saegusa's study used figures from around 1999, and it is not clear that they have been adjusted for inflation, though inflation in Japan has been limited. Also, dry cask costs may have changed in the interim. Lacking additional information on dry cask costs in Japan, we use the calculated ratio of costs above to increase dry cask costs for Japan.
An alternative estimate for dry cask storage cost in Japan can be derived based on the cost of the Mustu dry storage facility built in 2010-2013, and scheduled to be put in service in 2016.
Based on the World Nuclear Association (2015) document "Japan's Nuclear Fuel Cycle", dated October, 2015, and available as http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Japan--Nuclear-Fuel-Cycle/, the Mustu spent storage facility cost 100 billion yen, of which 70% was said to be cost for casks, with a total capacity of 3000 THM. This implies a cask cost of 23,333,333 Yen per metric tonne or about 233,333,333 Yen per Cask. At 2013 exchange rates of about 93 Yen per USD, this would be $ 2,508,961 per cask, significantly higher than the international cost above, but close to the cost estimated above based on the presentation by Dr. Saegusa.

29 A recent estimate for the operating costs of spent fuel pools was not immediately available, but an older (1991) US study, S.R. Rod (1991), *Cost Estimates of Operating Onsite Spent Fuel Pools After Final Reactor Shutdown* , Report Number PNL-7778, dated August, 1991, and available as http://www.osti.gov/scitech/servlets/purl/5349359/, lists an average (mean) cost of operating spent fuel pools of $7.41 per kg U-yr, presumably in 1991 dollars or similar, which imp $ 11.71 per kg U-yr in 2009 dollars.
By way of comparison, the operating costs for spent fuel pools implied by data in Dr. Saegusa's study, as referenced in *Note 28* above, was appro 25000 Yen per kg U for a storage volume of 3000 tU (see Figure 11 of Dr. Saegusa's paper), which is the capacity of the Rokkasho spent fuel pools, and similar to the aggregate size of the largest at-reactor pools in Japan for a single complex.
Assuming that the total cost per unit storage was calculated based on a storage t 50 years and using a discount rate of 5% /yr, the value above implies an annual cost of 1,369.42 Yen per kg U/yr, which, assuming the exchange rates above, implies $ 11.61 per kg U in 2015 dollars or $ 10.51 per kg U-yr in 2009 dollars, that is, very close to the PNL estimate provided above when expressed in comparble units. The value for operating costs estimated from Dr. Saegusa's paper includes "administration", "maintenance", "personnel", and "utilities".

30 A recent article by Hui Zhang (2015), "Reprocessing in China: A long, risky journey", *Bulletin of the Atomic Scientists* , dated 10 April 2015, and available as http://thebulletin.org/reprocessing-poised-growth-or-deaths-door/reprocessing-china-long-risky-journey indicates that China produced less than 14 kg of Pu during a hot test of its pilot civilian reprocessing plant at the Jiuquan nuclear complex in Gansu province during 2010, but as of early 2015, reprocessing at the (nominally) 50 tHM/yr facility had not resumed.

ANNEX 2B: Selected Additional Results for Cooperation Scenarios

FUTURE REGIONAL NUCLEAR FUEL CYCLE COOPERATION IN EAST ASIA: ENERGY SECURITY COSTS AND BENEFITS

Calculations for East Asia Science and Security (EASS) and Related Follow-on (2012-2016) Projects, funded by MacArthur Foundation

Cost Totals: Summaries for All Regional Scenarios

Prepared by:	David Von Hippel
Last Modified:	11/11/2016

All costs in millions of 2009 US Dollars. Cumulative costs are not discounted.

Results for BAU Nuclear Capacity Expansion Path 96.6%

	Annual Costs in 2050				Cumulative Costs, 2000-2050			
Cost Category	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Uranium (Yellowcake) Production/Purchase	$ 10,972	$ 10,972	$ 10,452	$ 11,360	$262,029	$262,028	$ 257,362	$268,861
Uranium Transport to Enrichment Plants	$ 1	$ 5	$ 5	$ 5	$ 71	$ 167	$ 158	$ 164
Conversion of U_3O_8 to UF_6 for Enrichment	$ 566	$ 566	$ 576	$ 625	$ 18,840	$ 18,830	$ 19,643	$ 20,394
Uranium Enrichment Services	$ 3,154	$ 3,154	$ 3,208	$ 3,486	$113,927	$113,864	$ 118,863	$123,219
UOx Fuel Transport	$ 49	$ 181	$ 349	$ 387	$ 3,591	$ 5,918	$ 11,717	$ 12,415
MOx Fuel Transport	$ 2	$ 24	$ 45	$ -	$ 28	$ 354	$ 664	$ 1
UOx Fuel Fabrication	$ 1,194	$ 1,194	$ 1,214	$ 1,320	$ 40,345	$ 40,324	$ 42,038	$ 43,622
MOx Fuel Fabrication	$ 683	$ 683	$ 697	$ -	$ 10,316	$ 10,315	$ 10,478	$ 12
Spent UOx Fuel Transport to Reprocessing	$ 128	$ 469	$ 1,219	$ -	$ 2,964	$ 8,437	$ 21,873	$ 623
Reprocessing	$ 3,686	$ 2,851	$ 2,848	$ -	$ 87,794	$ 65,162	$ 65,326	$ 3,495
Treatment/Disposal of HLW from Reprocessing*	$ 340	$ 356	$ 356	$ -	$ 7,641	$ 7,444	$ 7,464	$ 733
Storage of Plutonium from Reprocessing*	$ 48	$ 4	$ (17)	$ 159	$ 9,608	$ 8,409	$ 8,297	$ 7,949
Disposal of MLW from Reprocessing	$ 141	$ 148	$ 148	$ -	$ 2,975	$ 2,893	$ 2,902	$ 112
Disposal of LLW from Reprocessing	$ 60	$ 63	$ 63	$ -	$ 1,268	$ 1,233	$ 1,237	$ 48
Disposal of Solid Wastes from Reprocessing	$ 0	$ 0	$ 0	$ -	$ 7	$ 7	$ 7	$ 0
Disposal/Use of Depleted U from Reprocessing	$ 15	$ 16	$ 16	$ -	$ 341	$ 330	$ 331	$ 14
Storage/Disposal of UOx Spent Fuel	$ 355	$ 529	$ 529	$ 569	$ 7,336	$ 19,123	$ 19,059	$ 16,437
Storage/Disposal of MOx Spent Fuel	$ 84	$ 101	$ 102	$ -	$ 759	$ 1,095	$ 1,109	$ 2
Spent Fuel Pool O&M, Cooled UOx Spent Fuel	$ 339	$ 90	$ 90	$ 90	$ 11,189	$ 4,607	$ 4,607	$ 4,607
Spent Fuel Pool O&M, Cooled MOx Spent Fuel	$ 71	$ 71	$ 72	$ 0	$ 548	$ 548	$ 553	$ 5
Spent UOx Fuel Transport to Storage/Disposal	$ 59	$ 175	$ 174	$ 13	$ 913	$ 6,655	$ 6,628	$ 530
Spent MOx Fuel Transport to Storage/Disposal	$ 13	$ 33	$ 34	$ -	$ 111	$ 360	$ 365	$ 0
TOTAL of Above	$ 21,960	$ 21,686	$ 22,179	$ 18,015	$582,601	$578,106	$ 600,685	$503,242

* Note: Includes Pu and HLW stocks accumulated by Japan by 2000, mostly from fuel reprocessed internationally.

Total of U/Enrichment/Transport Costs	$ 16,621	$ 16,779	$ 16,546	$ 17,183	$449,146	$451,801	$ 460,925	$468,687

Net Present Value Cost Results for BAU Nuclear Capacity Expansion Path, 2010-2050

	Real Discount Rate:		**0%**	**/yr**	**Real Discount Rate:**		**2.5%**	**/yr**	**Real Discount Rate:**		**5.0%**	**/yr**
Cost Category	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Uranium (Yellowcake) Production/Purchase	$249,975	$249,974	$ 245,308	$ 256,807	$132,142	$132,141	$ 131,043	$136,257	$ 75,777	$ 75,776	$ 76,039	$ 78,520
Uranium Transport to Enrichment Plants	$ 56	$ 153	$ 143	$ 149	$ 34	$ 84	$ 80	$ 83	$ 23	$ 50	$ 48	$ 50
Conversion of U_3O_8 to UF_6 for Enrichment	$ 17,162	$ 17,152	$ 17,965	$ 18,716	$ 9,560	$ 9,553	$ 10,084	$ 10,433	$ 5,783	$ 5,779	$ 6,147	$ 6,317
Uranium Enrichment Services	$103,000	$102,938	$ 107,937	$ 112,293	$ 58,258	$ 58,216	$ 61,516	$ 63,549	$ 35,828	$ 35,800	$ 38,107	$ 39,105
UOx Fuel Transport	$ 2,350	$ 5,343	$ 10,477	$ 11,174	$ 1,570	$ 2,933	$ 5,814	$ 6,151	$ 1,136	$ 1,742	$ 3,501	$ 3,673
MOx Fuel Transport	$ 28	$ 354	$ 664	$ 1	$ 13	$ 165	$ 308	$ 1	$ 7	$ 80	$ 150	$ 1
UOx Fuel Fabrication	$ 36,205	$ 36,184	$ 37,899	$ 39,482	$ 20,167	$ 20,153	$ 21,274	$ 22,008	$ 12,200	$ 12,191	$ 12,968	$ 13,327
MOx Fuel Fabrication	$ 10,316	$ 10,315	$ 10,478	$ 12	$ 4,797	$ 4,797	$ 4,868	$ 11	$ 2,348	$ 2,348	$ 2,380	$ 11
Spent UOx Fuel Transport to Reprocessing	$ 2,342	$ 8,190	$ 21,251	$ 0	$ 1,111	$ 3,819	$ 9,894	$ 0	$ 554	$ 1,861	$ 4,810	$ 0
Reprocessing	$ 84,300	$ 61,669	$ 61,833	$ 2	$ 42,390	$ 31,279	$ 31,379	$ 1	$ 22,561	$ 16,863	$ 16,923	$ 1
Treatment/Disposal of HLW from Reprocessing	$ 6,908	$ 6,711	$ 6,731	$ 0	$ 3,366	$ 3,233	$ 3,245	$ 0	$ 1,729	$ 1,642	$ 1,650	$ 0
Storage of Plutonium from Reprocessing*	$ 8,198	$ 6,998	$ 6,886	$ 6,539	$ 4,983	$ 4,409	$ 4,367	$ 4,062	$ 3,280	$ 2,994	$ 2,979	$ 2,758
Disposal of MLW from Reprocessing	$ 2,863	$ 2,782	$ 2,790	$ 0	$ 1,395	$ 1,340	$ 1,345	$ 0	$ 717	$ 681	$ 684	$ 0
Disposal of LLW from Reprocessing	$ 1,220	$ 1,186	$ 1,189	$ 0	$ 595	$ 571	$ 573	$ 0	$ 305	$ 290	$ 291	$ 0
Disposal of Solid Wastes from Reprocessing	$ 7	$ 6	$ 6	$ 0	$ 3	$ 3	$ 3	$ 0	$ 2	$ 2	$ 2	$ 0
Disposal/Use of Depleted U from Reprocessing	$ 327	$ 316	$ 316	$ (0)	$ 160	$ 153	$ 153	$ (0)	$ 83	$ 78	$ 78	$ (0)
Storage/Disposal of UOx Spent Fuel	$ 7,156	$ 15,596	$ 15,533	$ 13,659	$ 3,691	$ 9,513	$ 9,477	$ 7,857	$ 2,086	$ 6,447	$ 6,426	$ 5,060
Storage/Disposal of MOx Spent Fuel	$ 759	$ 1,095	$ 1,109	$ 2	$ 319	$ 474	$ 479	$ 2	$ 138	$ 213	$ 215	$ 2
Spent Fuel Pool O&M, Cooled UOx Spent Fuel	$ 10,429	$ 3,704	$ 3,704	$ 3,704	$ 6,124	$ 2,300	$ 2,300	$ 2,300	$ 3,937	$ 1,562	$ 1,562	$ 1,562
Spent Fuel Pool O&M, Cooled MOx Spent Fuel	$ 548	$ 548	$ 553	$ 5	$ 228	$ 228	$ 230	$ 3	$ 98	$ 98	$ 99	$ 2
Spent UOx Fuel Transport to Storage/Disposal	$ 903	$ 5,494	$ 5,467	$ 389	$ 416	$ 3,374	$ 3,360	$ 246	$ 205	$ 2,289	$ 2,281	$ 175
Spent MOx Fuel Transport to Storage/Disposal	$ 111	$ 360	$ 365	$ 0	$ 46	$ 156	$ 158	$ 0	$ 20	$ 70	$ 71	$ 0
TOTAL of Above	$545,163	$537,069	$ 558,607	$ 462,933	$291,368	$288,894	$ 301,951	$252,964	$ 168,816	$168,856	$ 177,412	$ 150,564

* Note: "Storage of Plutonium from Reprocessing" Includes Pu and HLW stocks accumulated by Japan by 2000, mostly from fuel reprocessed internationally.

Total of U/Enrichment/Transport Costs	$419,093	$422,413	$ 430,872	$ 438,633	$226,540	$ 228,041	$ 234,986	$238,492	$ 133,102	$133,766	$ 139,342	$ 141,004
Fraction of total cost of highest-cost scenario	97.6%	96.1%	100.0%	82.9%	96.5%	95.7%	100.0%	83.8%	95.2%	95.2%	100.0%	84.9%
Fraction of total cost of lowest-cost scenario	117.8%	116.0%	120.7%	100.0%	115.2%	114.2%	119.4%	100.0%	112.1%	112.1%	117.8%	100.0%

Results for MAX Nuclear Capacity Expansion Path

	Annual Costs in 2050				Cumulative Costs, 2000-2050			
Cost Category	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Uranium (Yellowcake) Production/Purchase	$ 19,778	$ 19,778	$ 19,129	$ 20,660	$375,754	$375,747	$ 372,578	$390,760
Uranium Transport to Enrichment Plants	$ 3	$ 9	$ 9	$ 10	$ 97	$ 231	$ 230	$ 240
Conversion of U_3O_8 to UF_6 for Enrichment	$ 1,020	$ 1,020	$ 1,065	$ 1,150	$ 25,966	$ 25,934	$ 27,649	$ 28,852
Uranium Enrichment Services	$ 7,922	$ 7,922	$ 8,269	$ 8,930	$188,715	$188,489	$ 200,837	$209,812
UOx Fuel Transport	$ 129	$ 326	$ 686	$ 750	$ 4,814	$ 8,186	$ 17,159	$ 18,269
MOx Fuel Transport	$ 3	$ 39	$ 81	$ -	$ 43	$ 559	$ 1,100	$ 1
UOx Fuel Fabrication	$ 2,152	$ 2,152	$ 2,246	$ 2,426	$ 55,377	$ 55,308	$ 58,927	$ 61,466
MOx Fuel Fabrication	$ 1,145	$ 1,145	$ 1,188	$ -	$ 16,276	$ 16,275	$ 16,794	$ 12
Spent UOx Fuel Transport to Reprocessing	$ 237	$ 805	$ 2,088	$ -	$ 4,389	$ 12,842	$ 33,240	$ 623
Reprocessing	$ 6,126	$ 4,889	$ 4,879	$ -	$136,262	$102,964	$ 103,177	$ 3,495
Treatment/Disposal of HLW from Reprocessing*	$ 579	$ 611	$ 610	$ -	$ 11,373	$ 11,243	$ 11,270	$ 733
Storage of Plutonium from Reprocessing*	$ (75)	$ (103)	$ (180)	$ 159	$ 9,422	$ 8,194	$ 7,676	$ 7,949
Disposal of MLW from Reprocessing	$ 240	$ 253	$ 253	$ -	$ 4,522	$ 4,469	$ 4,480	$ 112
Disposal of LLW from Reprocessing	$ 102	$ 108	$ 108	$ -	$ 1,927	$ 1,904	$ 1,909	$ 48
Disposal of Solid Wastes from Reprocessing	$ 1	$ 1	$ 1	$ -	$ 10	$ 10	$ 10	$ 0
Disposal/Use of Depleted U from Reprocessing	$ 26	$ 28	$ 28	$ -	$ 516	$ 509	$ 508	$ 14
Storage/Disposal of UOx Spent Fuel	$ 192	$ 574	$ 572	$ 824	$ 1,631	$ 17,465	$ 17,359	$ 19,929
Storage/Disposal of MOx Spent Fuel	$ 104	$ 155	$ 160	$ -	$ 902	$ 1,686	$ 1,728	$ 2
Spent Fuel Pool O&M, Cooled UOx Spent Fuel	$ 418	$ 90	$ 90	$ 90	$ 11,015	$ 4,607	$ 4,607	$ 4,607
Spent Fuel Pool O&M, Cooled MOx Spent Fuel	$ 110	$ 110	$ 112	$ 0	$ 884	$ 884	$ 899	$ 5
Spent UOx Fuel Transport to Storage/Disposal	$ 22	$ 192	$ 188	$ 28	$ 50	$ 6,456	$ 6,392	$ 719
Spent MOx Fuel Transport to Storage/Disposal	$ 19	$ 51	$ 53	$ -	$ 141	$ 555	$ 569	$ 0
TOTAL of Above	$ 40,251	$ 40,155	$ 41,634	$ 35,028	$850,090	$844,519	$ 889,098	$747,649

* Note: Includes Pu and HLW stocks accumulated by Japan by 2000, mostly from fuel reprocessed internationally.

Results for MIN Nuclear Capacity Expansion Path

	Annual Costs in 2050				Cumulative Costs, 2000-2050			
Cost Category	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Uranium (Yellowcake) Production/Purchase	$ 6,181	$ 6,181	$ 5,873	$ 6,399	$173,424	$173,424	$ 169,977	$176,483
Uranium Transport to Enrichment Plants	$ 0	$ 3	$ 2	$ 3	$ 47	$ 116	$ 103	$ 106
Conversion of U_3O_8 to UF_6 for Enrichment	$ 319	$ 319	$ 318	$ 347	$ 13,191	$ 13,190	$ 13,538	$ 13,959
Uranium Enrichment Services	$ 1,271	$ 1,271	$ 1,268	$ 1,382	$ 69,969	$ 69,966	$ 72,027	$ 73,940
UOx Fuel Transport	$ 12	$ 102	$ 177	$ 194	$ 2,699	$ 4,115	$ 7,660	$ 7,958
MOx Fuel Transport	$ 1	$ 14	$ 24	$ -	$ 16	$ 202	$ 353	$ 1
UOx Fuel Fabrication	$ 672	$ 672	$ 671	$ 731	$ 28,427	$ 28,426	$ 29,158	$ 30,047
MOx Fuel Fabrication	$ 397	$ 397	$ 397	$ -	$ 5,891	$ 5,891	$ 5,891	$ 12
Spent UOx Fuel Transport to Reprocessing	$ 87	$ 232	$ 692	$ -	$ 2,246	$ 4,559	$ 13,467	$ 623
Reprocessing	$ 1,591	$ 1,412	$ 1,618	$ -	$ 34,268	$ 29,693	$ 33,511	$ 3,495
Treatment/Disposal of HLW from Reprocessing*	$ 199	$ 177	$ 202	$ -	$ 4,580	$ 4,008	$ 4,485	$ 733
Storage of Plutonium from Reprocessing*	$ 75	$ (51)	$ 54	$ 159	$ 7,784	$ 5,992	$ 7,154	$ 7,949
Disposal of MLW from Reprocessing	$ 82	$ 73	$ 84	$ -	$ 1,706	$ 1,469	$ 1,667	$ 112
Disposal of LLW from Reprocessing	$ 35	$ 31	$ 36	$ -	$ 727	$ 626	$ 711	$ 48
Disposal of Solid Wastes from Reprocessing	$ 0	$ 0	$ 0	$ -	$ 4	$ 3	$ 4	$ 0
Disposal/Use of Depleted U from Reprocessing	$ 9	$ 8	$ 9	$ -	$ 196	$ 165	$ 191	$ 14
Storage/Disposal of UOx Spent Fuel	$ 256	$ 456	$ 395	$ 322	$ 7,710	$ 20,563	$ 19,417	$ 13,386
Storage/Disposal of MOx Spent Fuel	$ 53	$ 54	$ 54	$ -	$ 505	$ 635	$ 635	$ 2
Spent Fuel Pool O&M, Cooled UOx Spent Fuel	$ 254	$ 90	$ 90	$ 90	$ 9,555	$ 4,607	$ 4,607	$ 4,607
Spent Fuel Pool O&M, Cooled MOx Spent Fuel	$ 41	$ 41	$ 41	$ 0	$ 330	$ 330	$ 330	$ 5
Spent UOx Fuel Transport to Storage/Disposal	$ 40	$ 150	$ 130	$ 4	$ 773	$ 6,772	$ 6,392	$ 427
Spent MOx Fuel Transport to Storage/Disposal	$ 9	$ 18	$ 18	$ -	$ 81	$ 209	$ 209	$ 0
TOTAL of Above	$ 11,584	$ 11,651	$ 12,154	$ 9,631	$364,130	$374,961	$ 391,486	$333,908

* Note: Includes Pu and HLW stocks accumulated by Japan by 2000, mostly from fuel reprocessed internationally.

Aggregated Results for BAU Nuclear Capacity Expansion Path

	Annual Costs in 2050				Cumulative Costs, 2000-2050			
Cost Category	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Uranium Production/Purchase	$ 10,972	$ 10,972	$ 10,452	$ 11,360	$262,029	$262,028	$ 257,362	$268,861
Uranium/Fuel/SF Transport	$ 252	$ 887	$ 1,825	$ 405	$ 7,678	$ 21,892	$ 41,406	$ 13,731
Uranium Conversion/Enrichment	$ 3,720	$ 3,720	$ 3,783	$ 4,112	$132,767	$132,695	$ 138,507	$143,613
Fuel Fabrication	$ 1,877	$ 1,877	$ 1,911	$ 1,320	$ 50,661	$ 50,639	$ 52,517	$ 43,633
Reprocessing	$ 3,686	$ 2,851	$ 2,848	$ -	$ 87,794	$ 65,162	$ 65,326	$ 3,495
Waste Treatment/Pu Storage*	$ 604	$ 588	$ 566	$ 159	$ 21,840	$ 20,317	$ 20,238	$ 8,857
Spent Fuel Storage/Disposal	$ 848	$ 791	$ 793	$ 660	$ 19,833	$ 25,373	$ 25,329	$ 21,052
TOTAL of Above	$ 21,960	$ 21,686	$ 22,179	$ 18,015	$582,601	$578,106	$ 600,685	$503,242
* Note: Includes Pu and HLW stocks accumulated by Japan by 2000, mostly from fuel reprocessed internationally.								
Total Uranium/fuel supply costs	$ 16,821	$ 17,456	$ 17,972	$ 17,196	$453,135	$467,253	$ 489,792	$469,839

Aggregated Results for MAX Nuclear Capacity Expansion Path

	Annual Costs in 2050				Cumulative Costs, 2000-2050			
Cost Category	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Uranium Production/Purchase	$ 19,778	$ 19,778	$ 19,129	$ 20,660	$375,754	$375,747	$ 372,578	$390,760
Uranium/Fuel/SF Transport	$ 412	$ 1,423	$ 3,105	$ 789	$ 9,535	$ 28,830	$ 58,690	$ 19,852
Uranium Conversion/Enrichment	$ 8,942	$ 8,942	$ 9,333	$ 10,080	$214,682	$214,423	$ 228,486	$238,664
Fuel Fabrication	$ 3,296	$ 3,296	$ 3,434	$ 2,426	$ 71,653	$ 71,583	$ 75,721	$ 61,477
Reprocessing	$ 6,126	$ 4,889	$ 4,879	$ -	$136,262	$102,964	$ 103,177	$ 3,495
Waste Treatment/Pu Storage*	$ 873	$ 898	$ 819	$ 159	$ 27,772	$ 26,330	$ 25,853	$ 8,857
Spent Fuel Storage/Disposal	$ 824	$ 929	$ 935	$ 914	$ 14,432	$ 24,642	$ 24,593	$ 24,543
TOTAL of Above	$ 40,251	$ 40,155	$ 41,634	$ 35,028	$850,090	$844,519	$ 889,098	$747,649

* Note: Includes Pu and HLW stocks accumulated by Japan by 2000, mostly from fuel reprocessed internationally.

Aggregated Results for MIN Nuclear Capacity Expansion Path

	Annual Costs in 2050				Cumulative Costs, 2000-2050			
Cost Category	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Uranium Production/Purchase	$ 6,181	$ 6,181	$ 5,873	$ 6,399	$173,424	$173,424	$ 169,977	$176,483
Uranium/Fuel/SF Transport	$ 149	$ 519	$ 1,044	$ 200	$ 5,862	$ 15,973	$ 28,184	$ 9,115
Uranium Conversion/Enrichment	$ 1,590	$ 1,590	$ 1,586	$ 1,728	$ 83,160	$ 83,156	$ 85,564	$ 87,899
Fuel Fabrication	$ 1,070	$ 1,070	$ 1,068	$ 731	$ 34,318	$ 34,317	$ 35,049	$ 30,059
Reprocessing	$ 1,591	$ 1,412	$ 1,618	$ -	$ 34,268	$ 29,693	$ 33,511	$ 3,495
Waste Treatment/Pu Storage*	$ 400	$ 238	$ 385	$ 159	$ 14,998	$ 12,264	$ 14,211	$ 8,857
Spent Fuel Storage/Disposal	$ 604	$ 641	$ 580	$ 412	$ 18,100	$ 26,135	$ 24,989	$ 18,000
TOTAL of Above	$ 11,584	$ 11,651	$ 12,154	$ 9,631	$364,130	$374,961	$ 391,486	$333,908

* Note: Includes Pu and HLW stocks accumulated by Japan by 2000, mostly from fuel reprocessed internationally.

Comparison of Further Aggregated Annual Costs in 2050 by Scenario and Path

Cost Category	Scenario 1--BAU	Scenario 1--MAX	Scenario 1--MIN	Scenario 2--BAU	Scenario 2--MAX	Scenario 2--MIN	Scenario 3--BAU	Scenario 3--MAX	Scenario 3--MIN	Scenario 4--BAU	Scenario 4--MAX	Scenario 4--MIN
Front-end Costs	$ 16,621	$ 32,151	$ 8,853	$ 16,779	$ 32,391	$ 8,959	$ 16,546	$ 32,673	$ 8,732	$ 17,183	$ 33,926	$ 9,055
Back-end Costs	$ 5,339	$ 8,100	$ 2,731	$ 4,907	$ 7,764	$ 2,692	$ 5,633	$ 8,961	$ 3,422	$ 832	$ 1,102	$ 576
TOTAL	$ 21,960	$ 40,251	$ 11,584	$ 21,686	$ 40,155	$ 11,651	$ 22,179	$ 41,634	$ 12,154	$ 18,015	$ 35,028	$ 9,631

Comparison of Further Aggregated Cumulative 2000 - 2050 Costs by Scenario and Path

Cost Category	Scenario 1--BAU	Scenario 1--MAX	Scenario 1--MIN	Scenario 2--BAU	Scenario 2--MAX	Scenario 2--MIN	Scenario 3--BAU	Scenario 3--MAX	Scenario 3--MIN	Scenario 4--BAU	Scenario 4--MAX	Scenario 4--MIN
Front-end Costs	$ 449,146	$ 667,044	$ 293,663	$ 451,801	$ 670,730	$ 295,331	$ 460,925	$ 695,274	$ 298,706	$ 468,687	$ 709,412	$ 302,507
Back-end Costs	$ 133,455	$ 183,046	$ 70,467	$ 126,305	$ 173,789	$ 79,630	$ 139,760	$ 193,824	$ 92,780	$ 34,556	$ 38,237	$ 31,402
TOTAL	$582,601	$850,090	$ 364,130	$ 578,106	$844,519	$ 374,961	$ 600,685	$889,098	$ 391,486	$503,242	$ 747,649	$ 333,908

FUTURE REGIONAL NUCLEAR FUEL CYCLE COOPERATION IN EAST ASIA: ENERGY SECURITY COSTS AND BENEFITS

Calculations for East Asia Science and Security (EASS) and Related Follow-on (2012-2016) Projects, funded by MacArthur Foundation

Estimates of Uranium Mining and Milling Volumes: Summaries for All Regional Scenarios

Prepared by:	David Von Hippel
Last Modified:	11/8/2016

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as U) Mined In-country for Use in Domestic Reactors	2010	1,320	1,136	1,136	1,136
	2030	11,195	1,105	1,107	1,140
	2050	15,128	1,049	1,049	1,140
	Cumulative, 2000-2050	408,284	52,559	52,577	54,041
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as U) Mined In-country for Use in Domestic Reactors	2010	1,320	1,136	1,136	1,136
	2030	14,879	1,475	1,477	1,532
	2050	31,193	3,740	3,741	4,041
	Cumulative, 2000-2050	628,441	85,847	85,928	89,440
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as U) Mined In-country for Use in Domestic Reactors	2010	1,320	1,136	1,136	1,136
	2030	7,781	1,109	1,111	1,140
	2050	9,486	1,046	1,046	1,140
	Cumulative, 2000-2050	294,961	52,621	52,627	54,041

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as U) Imported for Use in Domestic Reactors	2010	12,788	12,971	12,971	12,971
	2030	24,070	34,160	35,714	36,788
	2050	25,260	39,339	39,396	42,817
	Cumulative, 2000-2050	957,498	1,313,217	1,357,061	1,408,726

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as U) Imported for Use in Domestic Reactors	2010	12,788	12,971	12,971	12,971
	2030	30,022	43,427	44,685	46,345
	2050	41,609	69,063	70,181	75,798
	Cumulative, 2000-2050	1,244,283	1,786,838	1,865,206	1,945,556

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as U) Imported for Use in Domestic Reactors	2010	12,788	12,971	12,971	12,971
	2030	14,650	21,322	22,477	23,069
	2050	13,265	21,704	21,656	23,596
	Cumulative, 2000-2050	661,208	903,548	928,339	957,063

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as U) Imported plus Domestic Production	2010	14,107	14,107	14,107	14,107
	2030	35,265	35,265	36,820	37,928
	2050	40,388	40,388	40,445	43,957
	Cumulative, 2000-2050	1,365,783	1,365,775	1,409,638	1,462,767

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as U) Imported plus Domestic Production	2010	14,107	14,107	14,107	14,107
	2030	44,902	44,902	46,162	47,877
	2050	72,803	72,803	73,923	79,839
	Cumulative, 2000-2050	1,872,723	1,872,685	1,951,134	2,034,996

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as U) Imported plus Domestic Production	2010	14,107	14,107	14,107	14,107
	2030	22,432	22,432	23,588	24,209
	2050	22,751	22,751	22,702	24,736
	Cumulative, 2000-2050	956,169	956,168	980,966	1,011,103

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Thousand te Uranium Ore to Supply Uranium Mined In-country for Use in Domestic Reactors	2010	763	657	657	657
	2030	6,537	639	640	659
	2050	9,032	607	607	659
	Cumulative, 2000-2050	241,456	30,400	30,410	31,257
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Thousand te Uranium Ore to Supply Uranium Mined In-country for Use in Domestic Reactors	2010	763	657	657	657
	2030	8,807	917	919	953
	2050	19,143	2,621	2,622	2,831
	Cumulative, 2000-2050	378,096	55,337	55,390	57,763
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Thousand te Uranium Ore to Supply Uranium Mined In-country for Use in Domestic Reactors	2010	763	657	657	657
	2030	4,500	642	642	659
	2050	5,578	605	605	659
	Cumulative, 2000-2050	172,472	30,436	30,439	31,257

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Thousand Metric Tons Uranium Ore (from In-country and outside mines) to Supply All Domestic Uranium Needs	2010	1,081	980	980	980
	2030	7,136	1,489	1,528	1,574
	2050	9,660	1,585	1,587	1,724
	Cumulative, 2000-2050	265,271	63,063	64,164	66,296
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Thousand Metric Tons Uranium Ore (from In-country and outside mines) to Supply All Domestic Uranium Needs	2010	1,081	980	980	980
	2030	9,554	1,997	2,030	2,106
	2050	20,178	4,338	4,367	4,717
	Cumulative, 2000-2050	409,044	99,780	101,782	106,154
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Thousand Metric Tons Uranium Ore (from In-country and outside mines) to Supply All Domestic Uranium Needs	2010	1,081	980	980	980
	2030	4,865	1,172	1,202	1,233
	2050	5,908	1,145	1,144	1,246
	Cumulative, 2000-2050	188,918	52,909	53,530	55,062

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used (Mining and Milling) for Uranium Produced In-country for Use in Domestic Reactors (GWh)	2010	63	54	54	54
	2030	533	53	53	54
	2050	732	50	50	54
	Cumulative, 2000-2050	19,678	2,511	2,512	2,582

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used (Mining and Milling) for Uranium Produced In-country for Use in Domestic Reactors (GWh)	2010	63	54	54	54
	2030	694	54	54	56
	2050	1,395	64	64	69
	Cumulative, 2000-2050	28,779	2,679	2,682	2,764

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used (Mining and Milling) for Uranium Produced In-country for Use in Domestic Reactors (GWh)	2010	63	54	54	54
	2030	372	53	53	54
	2050	458	50	50	54
	Cumulative, 2000-2050	14,191	2,514	2,514	2,582

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used (Mining and Milling) for Uranium Imported In-country for Use in Domestic Reactors (GWh)	2010	115	117	117	117
	2030	217	309	323	332
	2050	228	355	356	387
	Cumulative, 2000-2050	8,648	11,860	12,256	12,723
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used (Mining and Milling) for Uranium Imported In-country for Use in Domestic Reactors (GWh)	2010	115	117	117	117
	2030	271	392	404	419
	2050	376	624	634	685
	Cumulative, 2000-2050	11,238	16,138	16,845	17,571
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used (Mining and Milling) for Uranium Imported In-country for Use in Domestic Reactors (GWh)	2010	115	117	117	117
	2030	132	193	203	208
	2050	120	196	196	213
	Cumulative, 2000-2050	5,972	8,160	8,384	8,644

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used (Mining and Milling) for Domestic and Imported Production (GWh)	2010	179	171	171	171
	2030	751	361	375	387
	2050	960	405	406	441
	Cumulative, 2000-2050	28,326	14,371	14,768	15,304

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used (Mining and Milling) for Domestic and Imported Production (GWh)	2010	179	171	171	171
	2030	965	447	458	475
	2050	1,770	688	698	754
	Cumulative, 2000-2050	40,017	18,817	19,527	20,335

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used (Mining and Milling) for Domestic and Imported Production (GWh)	2010	179	171	171	171
	2030	504	246	256	263
	2050	578	246	246	268
	Cumulative, 2000-2050	20,162	10,674	10,898	11,225

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Fossil Fuel (likely mostly diesel) Used (Mining and Milling) for Uranium Produced In-country for Use in Domestic Reactors (TJ)	2010	70	60	60	60
	2030	594	58	58	60
	2050	814	55	55	60
	Cumulative, 2000-2050	21,843	2,772	2,773	2,851

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Fossil Fuel (likely mostly diesel) Used (Mining and Milling) for Uranium Produced In-country for Use in Domestic Reactors (TJ)	2010	70	60	60	60
	2030	895	180	180	187
	2050	2,411	926	926	1,000
	Cumulative, 2000-2050	42,718	13,581	13,595	14,324

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Fossil Fuel (likely mostly diesel) Used (Mining and Milling) for Uranium Produced In-country for Use in Domestic Reactors (TJ)	2010	70	60	60	60
	2030	410	59	59	60
	2050	506	55	55	60
	Cumulative, 2000-2050	15,667	2,776	2,776	2,851

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Total Fossil Fuel (likely mostly diesel) Used (Mining and Milling) for Uranium Imported In-country for Use in Domestic Reactors (TJ)	2010	316	320	320	320
	2030	594	843	881	908
	2050	623	971	972	1,056
	Cumulative, 2000-2050	23,625	32,401	33,483	34,758

		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Total Fossil Fuel (likely mostly diesel) Used (Mining and Milling) for Uranium Imported In-country for Use in Domestic Reactors (TJ)	2010	316	320	320	320
	2030	741	1,071	1,103	1,143
	2050	1,027	1,704	1,732	1,870
	Cumulative, 2000-2050	30,700	44,087	46,021	48,003

		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Total Fossil Fuel (likely mostly diesel) Used (Mining and Milling) for Uranium Imported In-country for Use in Domestic Reactors (TJ)	2010	316	320	320	320
	2030	361	526	555	569
	2050	327	536	534	582
	Cumulative, 2000-2050	16,314	22,293	22,905	23,614

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Total Fossil Fuel (likely mostly diesel) Used (Mining and Milling) for Domestic and Imported Uranium Production (TJ)	2010	385	380	380	380
	2030	1,188	901	940	968
	2050	1,437	1,026	1,027	1,117
	Cumulative, 2000-2050	45,468	35,174	36,256	37,608
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Total Fossil Fuel (likely mostly diesel) Used (Mining and Milling) for Domestic and Imported Uranium Production (TJ)	2010	385	380	380	380
	2030	1,636	1,252	1,283	1,331
	2050	3,438	2,630	2,658	2,871
	Cumulative, 2000-2050	73,418	57,668	59,616	62,327
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Total Fossil Fuel (likely mostly diesel) Used (Mining and Milling) for Domestic and Imported Uranium Production (TJ)	2010	385	380	380	380
	2030	772	585	613	629
	2050	833	591	590	642
	Cumulative, 2000-2050	31,981	25,069	25,681	26,464

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Water Use for Milling (including in-situ leaching) of Uranium Produced In-country for Use in Domestic Reactors (million cubic meters)	2010	1.3	1.1	1.1	1.1
	2030	11.2	1.1	1.1	1.1
	2050	15.1	1.0	1.0	1.1
	Cumulative, 2000-2050	408	53	53	54
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Water Use for Milling (including in-situ leaching) of Uranium Produced In-country for Use in Domestic Reactors (million cubic meters)	2010	1.3	1.1	1.1	1.1
	2030	14.9	1.5	1.5	1.5
	2050	31.2	3.7	3.7	4.0
	Cumulative, 2000-2050	628	86	86	89
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Water Use for Milling (including in-situ leaching) of Uranium Produced In-country for Use in Domestic Reactors (million cubic meters)	2010	1.3	1.1	1.1	1.1
	2030	7.8	1.1	1.1	1.1
	2050	9.5	1.0	1.0	1.1
	Cumulative, 2000-2050	295	53	53	54

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Water Use for Milling (including in-situ leaching) of Uranium Imported In-country for Use in Domestic Reactors (million cubic meters)	2010	13	13	13	13
	2030	24	34	36	37
	2050	25	39	39	43
	Cumulative, 2000-2050	957	1,313	1,357	1,409

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Water Use for Milling (including in-situ leaching) of Uranium Imported In-country for Use in Domestic Reactors (million cubic meters)	2010	13	13	13	13
	2030	30	43	45	46
	2050	42	69	70	76
	Cumulative, 2000-2050	1,244	1,787	1,865	1,946

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Water Use for Milling (including in-situ leaching) of Uranium Imported In-country for Use in Domestic Reactors (million cubic meters)	2010	13	13	13	13
	2030	15	21	22	23
	2050	13	22	22	24
	Cumulative, 2000-2050	661	904	928	957

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Water Use for Milling (including in-situ leaching) for Production of Domestic and Imported Uranium (million cubic meters)	2010	14	14	14	14
	2030	35	35	37	38
	2050	40	40	40	44
	Cumulative, 2000-2050	1,366	1,366	1,410	1,463
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Water Use for Milling (including in-situ leaching) for Production of Domestic and Imported Uranium (million cubic meters)	2010	14	14	14	14
	2030	45	45	46	48
	2050	73	73	74	80
	Cumulative, 2000-2050	1,873	1,873	1,951	2,035
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Water Use for Milling (including in-situ leaching) for Production of Domestic and Imported Uranium (million cubic meters)	2010	14	14	14	14
	2030	22	22	24	24
	2050	23	23	23	25
	Cumulative, 2000-2050	956	956	981	1,011

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost (or value) of Uranium Produced In-country for Use in Domestic Reactors (Million 2009 dollars)	2010	$ 161	$ 139	$ 139	$ 139
	2030	$ 2,037	$ 201	$ 201	$ 207
	2050	$ 4,110	$ 285	$ 285	$ 310
	Cumulative, 2000-2050	$ 83,466	$ 9,277	$ 9,280	$ 9,609
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost (or value) of Uranium Produced In-country for Use in Domestic Reactors (Million 2009 dollars)	2010	$ 161	$ 139	$ 139	$ 139
	2030	$ 2,708	$ 268	$ 269	$ 279
	2050	$ 8,474	$ 1,016	$ 1,016	$ 1,098
	Cumulative, 2000-2050	$ 134,162	$ 16,969	$ 16,986	$ 17,795
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost (or value) of Uranium Produced In-country for Use in Domestic Reactors (Million 2009 dollars)	2010	$ 161	$ 139	$ 139	$ 139
	2030	$ 1,416	$ 202	$ 202	$ 207
	2050	$ 2,577	$ 284	$ 284	$ 310
	Cumulative, 2000-2050	$ 58,705	$ 9,289	$ 9,290	$ 9,609

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost (or value) of Uranium Imported for Use in Domestic Reactors (Million 2009 dollars)	2010	$ 1,559	$ 1,581	$ 1,581	$ 1,581
	2030	$ 4,381	$ 6,217	$ 6,175	$ 6,360
	2050	$ 6,862	$ 10,687	$ 10,167	$ 11,050
	Cumulative, 2000-2050	$ 178,563	$ 252,751	$ 248,082	$ 259,252
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost (or value) of Uranium Imported for Use in Domestic Reactors (Million 2009 dollars)	2010	$ 1,559	$ 1,581	$ 1,581	$ 1,581
	2030	$ 5,464	$ 7,903	$ 7,726	$ 8,013
	2050	$ 11,304	$ 18,762	$ 18,112	$ 19,562
	Cumulative, 2000-2050	$ 241,591	$ 358,778	$ 355,592	$ 372,965
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost (or value) of Uranium Imported for Use in Domestic Reactors (Million 2009 dollars)	2010	$ 1,559	$ 1,581	$ 1,581	$ 1,581
	2030	$ 2,666	$ 3,881	$ 3,886	$ 3,988
	2050	$ 3,604	$ 5,896	$ 5,589	$ 6,090
	Cumulative, 2000-2050	$ 114,720	$ 164,136	$ 160,687	$ 166,874

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost (or value) of Uranium Produced Domestically or Imported for Use in Reactors in the Region (Million 2009 dollars)	2010	$ 1,720	$ 1,720	$ 1,720	$ 1,720
	2030	$ 6,418	$ 6,418	$ 6,376	$ 6,568
	2050	$ 10,972	$ 10,972	$ 10,452	$ 11,360
	Cumulative, 2000-2050	$ 262,029	$ 262,028	$ 257,362	$ 268,861
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost (or value) of Uranium Produced Domestically or Imported for Use in Reactors in the Region (Million 2009 dollars)	2010	$ 1,720	$ 1,720	$ 1,720	$ 1,720
	2030	$ 8,172	$ 8,172	$ 7,995	$ 8,292
	2050	$ 19,778	$ 19,778	$ 19,129	$ 20,660
	Cumulative, 2000-2050	$ 375,754	$ 375,747	$ 372,578	$ 390,760
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost (or value) of Uranium Produced Domestically or Imported for Use in Reactors in the Region (Million 2009 dollars)	2010	$ 1,720	$ 1,720	$ 1,720	$ 1,720
	2030	$ 4,082	$ 4,082	$ 4,088	$ 4,196
	2050	$ 6,181	$ 6,181	$ 5,873	$ 6,399
	Cumulative, 2000-2050	$ 173,424	$ 173,424	$ 169,977	$ 176,483

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Radioactivity in Mill Tailings from Uranium Produced In-country for Use in Domestic Reactors (TBq)	2010	131	113	113	113
	2030	1,139	109	110	113
	2050	1,553	104	104	113
	Cumulative, 2000-2050	41,444	5,206	5,208	5,353

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Radioactivity in Mill Tailings from Uranium Produced In-country for Use in Domestic Reactors (TBq)	2010	131	113	113	113
	2030	1,535	153	153	159
	2050	3,273	421	422	455
	Cumulative, 2000-2050	65,130	9,136	9,145	9,531

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Radioactivity in Mill Tailings from Uranium Produced In-country for Use in Domestic Reactors (TBq)	2010	131	113	113	113
	2030	771	110	110	113
	2050	947	104	104	113
	Cumulative, 2000-2050	29,374	5,212	5,213	5,353

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Radioactivity in Mill Tailings from Uranium Imported for Use in Domestic Reactors (TBq)	2010	1,161	1,158	1,158	1,158
	2030	3,079	2,863	2,988	3,078
	2050	3,589	3,275	3,279	3,564
	Cumulative, 2000-2050	118,618	111,051	114,587	118,896

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Radioactivity in Mill Tailings from Uranium Imported for Use in Domestic Reactors (TBq)	2010	1,161	1,158	1,158	1,158
	2030	3,955	3,653	3,755	3,895
	2050	6,627	5,988	6,078	6,565
	Cumulative, 2000-2050	165,420	153,155	159,480	166,342

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Radioactivity in Mill Tailings from Uranium Imported for Use in Domestic Reactors (TBq)	2010	1,161	1,158	1,158	1,158
	2030	1,952	1,828	1,922	1,972
	2050	2,016	1,853	1,849	2,015
	Cumulative, 2000-2050	82,667	78,038	80,037	82,492

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Radioactivity in Mill Tailings from Uranium Produced Domestically and Imported for Use in Reactors in the Region (TBq)	2010	1,292	1,271	1,271	1,271
	2030	4,217	2,972	3,098	3,191
	2050	5,142	3,379	3,383	3,677
	Cumulative, 2000-2050	160,062	116,257	119,794	124,249
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Radioactivity in Mill Tailings from Uranium Produced Domestically and Imported for Use in Reactors in the Region (TBq)	2010	1,292	1,271	1,271	1,271
	2030	5,489	3,807	3,909	4,054
	2050	9,900	6,409	6,500	7,020
	Cumulative, 2000-2050	230,550	162,291	168,625	175,873
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Radioactivity in Mill Tailings from Uranium Produced Domestically and Imported for Use in Reactors in the Region (TBq)	2010	1,292	1,271	1,271	1,271
	2030	2,723	1,938	2,032	2,085
	2050	2,963	1,957	1,953	2,128
	Cumulative, 2000-2050	112,041	83,250	85,249	87,844

TABLES BELOW ALL FOR BAU CAPACITY EXPANSION CASE

		Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Parameter	YEAR	Uranium Mined In-Country	Uranium Imported	Uranium Mined In-Country	Uranium Imported	Uranium Mined In-Country	Uranium Imported	Uranium Mined In-Country	Uranium Imported
Annual Total Metric Tons Natural Uranium (as U) Mined for Use in Domestic Reactors	2010	1,321	12,782	1,138	12,965	1,138	12,965	1,138	12,965
	2030	11,170	24,828	1,140	34,160	1,101	35,746	1,140	36,788
	2050	15,003	27,447	1,140	39,339	1,042	39,432	1,140	42,817
	Cumulative, 2000-2050	406,541	991,920	53,969	1,313,239	52,444	1,357,838	54,041	1,408,722
Annual Total Thousand Metric Tons Uranium Ore Mined for Use in Domestic Reactors*	2010	764	318	658	322	658	322	658	322
	2030	6,522	618	659	850	637	889	659	915
	2050	8,957	683	659	978	603	981	659	1,065
	Cumulative, 2000-2050	240,419	24,672	31,216	32,664	30,334	33,773	31,257	35,039

* Excludes Uranium mined via in-situ leaching.

FUTURE REGIONAL NUCLEAR FUEL CYCLE COOPERATION IN EAST ASIA: ENERGY SECURITY
Calculations for East Asia Science and Security (EASS) and Related Follow-on (2012-2016) Projects, funded by MacArthur Foundation

Estimates of Uranium Transport and Enrichment Parameters: Summaries for All Regional Scenarios

Prepared by:	David Von Hippel
Last Modified:	11/11/2016

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as UF6, but expressed as U) Enriched In-country for Use in Domestic Reactors	2010	3,643	3,643	3,643	3,643
	2030	32,280	-	5,769	4,925
	2050	36,695	-	5,267	4,925
	Cumulative, 2000-2050	1,027,334	45,550	220,888	201,296
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Tons Natural Uranium (as UF6, but expressed as U) Enriched In-country for Use in Domestic Reactors	2010	3,643	3,643	3,643	3,643
	2030	40,984	-	6,199	4,925
	2050	62,083	-	5,562	4,925
	Cumulative, 2000-2050	1,428,116	46,584	234,039	202,162
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Tons Natural Uranium (as UF6, but expressed as U) Enriched In-country for Use in Domestic Reactors	2010	3,643	3,643	3,643	3,643
	2030	22,140	-	5,130	4,925
	2050	22,207	-	4,548	4,925
	Cumulative, 2000-2050	702,782	45,111	201,384	200,943

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as UF6, but expressed as U) Enriched Outside the Country for Use in Domestic Reactors	2010	9,841	9,841	9,841	9,841
	2030	2,264	34,544	30,541	32,477
	2050	3,491	40,186	35,606	39,496
	Cumulative, 2000-2050	309,976	1,291,753	1,174,137	1,247,027
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as UF6, but expressed as U) Enriched Outside the Country for Use in Domestic Reactors	2010	9,841	9,841	9,841	9,841
	2030	3,153	44,137	40,803	43,823
	2050	10,355	72,439	70,049	76,737
	Cumulative, 2000-2050	415,956	1,795,173	1,729,546	1,846,883
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as UF6, but expressed as U) Enriched Outside the Country for Use in Domestic Reactors	2010	9,841	9,841	9,841	9,841
	2030	0	22,140	18,159	18,977
	2050	430	22,637	18,041	19,687
	Cumulative, 2000-2050	234,007	891,643	760,031	790,410

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as UF6, but expressed as U) Enriched Inside and Outside the Country for Use in Domestic Reactors	2010	13,484	13,484	13,484	13,484
	2030	34,544	34,544	36,310	37,403
	2050	40,186	40,186	40,873	44,421
	Cumulative, 2000-2050	1,337,310	1,337,303	1,395,025	1,448,323
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as UF6, but expressed as U) Enriched Inside and Outside the Country for Use in Domestic Reactors	2010	13,484	13,484	13,484	13,484
	2030	44,137	44,137	47,002	48,748
	2050	72,439	72,439	75,611	81,662
	Cumulative, 2000-2050	1,844,072	1,841,757	1,963,585	2,049,045
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Metric Tons Natural Uranium (as UF6, but expressed as U) Enriched Inside and Outside the Country for Use in Domestic Reactors	2010	13,484	13,484	13,484	13,484
	2030	22,140	22,140	23,290	23,903
	2050	22,637	22,637	22,589	24,613
	Cumulative, 2000-2050	936,789	936,754	961,414	991,353

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Million Tonne-km U3O8 Transport to In-country Enrichment for Use in Domestic Reactors	2010	12.0	12.0	12.0	12.0
	2030	63.7	-	12.7	13.1
	2050	59.3	-	10.5	11.4
	Cumulative, 2000-2050	1,969	108	466	482
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Million Tonne-km U3O8 Transport to In-country Enrichment for Use in Domestic Reactors	2010	12	12	12	12
	2030	88	-	16	17
	2050	93	-	13	14
	Cumulative, 2000-2050	2,827	117	573	594
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Million Tonne-km U3O8 Transport to In-country Enrichment for Use in Domestic Reactors	2010	12	12	12	12
	2030	31	-	7	8
	2050	21	-	5	5
	Cumulative, 2000-2050	984	105	307	315

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Million Tonne-km U3O8 Transport to Out-of-country Enrichment for Use in Domestic Reactors	2010	99	99	99	99
	2030	23	347	307	316
	2050	35	404	358	389
	Cumulative, 2000-2050	3,122	12,982	11,800	12,260
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Million Tonne-km U3O8 Transport to Out-of-country Enrichment for Use in Domestic Reactors	2010	99	99	99	99
	2030	32	444	410	425
	2050	104	728	704	760
	Cumulative, 2000-2050	4,180	18,042	17,382	18,158
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Million Tonne-km U3O8 Transport to Out-of-country Enrichment for Use in Domestic Reactors	2010	99	99	99	99
	2030	0	223	183	187
	2050	4	228	181	198
	Cumulative, 2000-2050	2,352	8,961	7,638	7,876

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Million Tonne-km U3O8 Transport to In-country and Out-of-country Enrichment for Use in Domestic Reactors	2010	111	111	111	111
	2030	86	347	320	329
	2050	94	404	368	400
	Cumulative, 2000-2050	5,091	13,091	12,266	12,742

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Million Tonne-km U3O8 Transport to In-country and Out-of-country Enrichment for Use in Domestic Reactors	2010	111	111	111	111
	2030	120	444	427	442
	2050	197	728	717	774
	Cumulative, 2000-2050	7,007	18,159	17,955	18,752

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Million Tonne-km U3O8 Transport to In-country and Out-of-country Enrichment for Use in Domestic Reactors	2010	111	111	111	111
	2030	31	223	190	195
	2050	26	228	186	203
	Cumulative, 2000-2050	3,336	9,066	7,946	8,191

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Cost (Million 2009 USD) of U3O8 Transport to In-country Enrichment for Use in Domestic Reactors	2010	$ 0.17	$ 0.17	$ 0.17	$ 0.17
	2030	$ 0.98	$ -	$ 0.20	$ 0.21
	2050	$ 0.97	$ -	$ 0.17	$ 0.19
	Cumulative, 2000-2050	$ 30.79	$ 1.68	$ 7.46	$ 7.71
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Cost (Million 2009 USD) of U3O8 Transport to In-country Enrichment for Use in Domestic Reactors	2010	$ 0.17	$ 0.17	$ 0.17	$ 0.17
	2030	$ 1.33	$ -	$ 0.25	$ 0.26
	2050	$ 1.59	$ -	$ 0.20	$ 0.21
	Cumulative, 2000-2050	$ 44.28	$ 1.79	$ 8.82	$ 9.14
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Cost (Million 2009 USD) of U3O8 Transport to In-country Enrichment for Use in Domestic Reactors	2010	$ 0.17	$ 0.17	$ 0.17	$ 0.17
	2030	$ 0.52	$ -	$ 0.13	$ 0.14
	2050	$ 0.42	$ -	$ 0.10	$ 0.11
	Cumulative, 2000-2050	$ 16.93	$ 1.63	$ 5.44	$ 5.59

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Cost (Million 2009 USD) of U3O8 Transport to Out-of-country Enrichment for Use in Domestic Reactors	2010	$ 1.26	$ 1.26	$ 1.26	$ 1.26
	2030	$ 0.29	$ 4.42	$ 3.91	$ 4.02
	2050	$ 0.45	$ 5.14	$ 4.55	$ 4.95
	Cumulative, 2000-2050	$ 39.74	$ 165.24	$ 150.19	$ 156.05
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Cost (Million 2009 USD) of U3O8 Transport to Out-of-country Enrichment for Use in Domestic Reactors	2010	$ 1.26	$ 1.26	$ 1.26	$ 1.26
	2030	$ 0.40	$ 5.65	$ 5.22	$ 5.41
	2050	$ 1.32	$ 9.27	$ 8.96	$ 9.68
	Cumulative, 2000-2050	$ 53.21	$ 229.63	$ 221.24	$ 231.11
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Cost (Million 2009 USD) of U3O8 Transport to Out-of-country Enrichment for Use in Domestic Reactors	2010	$ 1.26	$ 1.26	$ 1.26	$ 1.26
	2030	$ 0.00	$ 2.83	$ 2.32	$ 2.38
	2050	$ 0.05	$ 2.90	$ 2.31	$ 2.51
	Cumulative, 2000-2050	$ 29.93	$ 114.06	$ 97.22	$ 100.24

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Cost (Million 2009 USD) of U3O8 Transport to In-country and Out-of-country Enrichment for Use in Domestic Reactors	2010	$ 1.43	$ 1.43	$ 1.43	$ 1.43
	2030	$ 1.27	$ 4.42	$ 4.11	$ 4.23
	2050	$ 1.42	$ 5.14	$ 4.72	$ 5.14
	Cumulative, 2000-2050	$ 70.53	$ 166.92	$ 157.65	$ 163.76
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Cost (Million 2009 USD) of U3O8 Transport to In-country and Out-of-country Enrichment for Use in Domestic Reactors	2010	$ 1.43	$ 1.43	$ 1.43	$ 1.43
	2030	$ 1.73	$ 5.65	$ 5.47	$ 5.67
	2050	$ 2.91	$ 9.27	$ 9.16	$ 9.89
	Cumulative, 2000-2050	$ 97.49	$ 231.42	$ 230.06	$ 240.25
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Cost (Million 2009 USD) of U3O8 Transport to In-country and Out-of-country Enrichment for Use in Domestic Reactors	2010	$ 1.43	$ 1.43	$ 1.43	$ 1.43
	2030	$ 0.52	$ 2.83	$ 2.46	$ 2.52
	2050	$ 0.48	$ 2.90	$ 2.41	$ 2.62
	Cumulative, 2000-2050	$ 46.86	$ 115.69	$ 102.66	$ 105.84

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Fossil Fuel Used in Converting U3O8 to UF6 for Uranium Enriched In-country (TJ)	2010	9	9	9	9
	2030	78	-	14	14
	2050	88	-	13	14
	Cumulative, 2000-2050	2,472	110	532	550
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Fossil Fuel Used in Converting U3O8 to UF6 for Uranium Enriched In-country (TJ)	2010	9	9	9	9
	2030	99	-	15	15
	2050	149	-	13	14
	Cumulative, 2000-2050	3,437	112	563	583
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Fossil Fuel Used in Converting U3O8 to UF6 for Uranium Enriched In-country (TJ)	2010	9	9	9	9
	2030	53	-	12	13
	2050	53	-	11	12
	Cumulative, 2000-2050	1,691	109	485	500

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Fossil Fuel Used in Converting U3O8 to UF6 for Uranium Enriched Out-of-country (TJ)	2010	24	24	24	24
	2030	5	83	74	76
	2050	8	97	86	93
	Cumulative, 2000-2050	748	3,109	2,826	2,936
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Fossil Fuel Used in Converting U3O8 to UF6 for Uranium Enriched Out-of-	2010	24	24	24	24
	2030	8	106	98	102
	2050	25	174	169	182
	Cumulative, 2000-2050	1,001	4,320	4,163	4,348
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Fossil Fuel Used in Converting U3O8 to UF6 for Uranium Enriched Out-of-	2010	24	24	24	24
	2030	0	53	44	45
	2050	1	54	43	47
	Cumulative, 2000-2050	563	2,146	1,829	1,886

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Fossil Fuel Used in Converting U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (TJ)	2010	32	32	32	32
	2030	83	83	87	90
	2050	97	97	98	107
	Cumulative, 2000-2050	3,220	3,218	3,357	3,486

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Fossil Fuel Used in Converting U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (TJ)	2010	32	32	32	32
	2030	106	106	113	117
	2050	174	174	182	197
	Cumulative, 2000-2050	4,438	4,433	4,726	4,931

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Fossil Fuel Used in Converting U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (TJ)	2010	32	32	32	32
	2030	53	53	56	58
	2050	54	54	54	59
	Cumulative, 2000-2050	2,255	2,254	2,314	2,386

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used in Converting U3O8 to UF6 for Uranium Enriched In-country (GWh)	2010	4	4	4	4
	2030	32	-	6	6
	2050	37	-	5	6
	Cumulative, 2000-2050	1,032	46	222	230

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used in Converting U3O8 to UF6 for Uranium Enriched In-country (GWh)	2010	4	4	4	4
	2030	41	-	6	6
	2050	62	-	6	6
	Cumulative, 2000-2050	1,435	47	235	244

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used in Converting U3O8 to UF6 for Uranium Enriched In-country (GWh)	2010	4	4	4	4
	2030	22	-	5	5
	2050	22	-	5	5
	Cumulative, 2000-2050	706	45	202	209

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used in Converting U3O8 to UF6 for Uranium Enriched Out-of-country (GWh)	2010	10	10	10	10
	2030	2	35	31	32
	2050	4	40	36	39
	Cumulative, 2000-2050	312	1,298	1,180	1,226
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used in Converting U3O8 to UF6 for Uranium Enriched Out-of-country (GWh)	2010	10	10	10	10
	2030	3	44	41	43
	2050	10	73	70	76
	Cumulative, 2000-2050	418	1,804	1,738	1,816
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used in Converting U3O8 to UF6 for Uranium Enriched Out-of-country (GWh)	2010	10	10	10	10
	2030	0	22	18	19
	2050	0	23	18	20
	Cumulative, 2000-2050	235	896	764	788

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Electricity Used in Converting U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (GWhe)	2010	14	14	14	14
	2030	35	35	36	38
	2050	40	40	41	45
	Cumulative, 2000-2050	1,345	1,344	1,402	1,456
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Electricity Used in Converting U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (GWhe)	2010	14	14	14	14
	2030	44	44	47	49
	2050	73	73	76	82
	Cumulative, 2000-2050	1,853	1,851	1,973	2,059
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Electricity Used in Converting U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (GWhe)	2010	14	14	14	14
	2030	22	22	23	24
	2050	23	23	23	25
	Cumulative, 2000-2050	941	941	966	996

Parameter	YEAR	BAU Capacity Expansion Paths Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Conversion of U3O8 to UF6 for Uranium Enriched In-country (million dollars)	2010	$ 51	$ 51	$ 51	$ 51
	2030	$ 455	$ -	$ 81	$ 84
	2050	$ 517	$ -	$ 74	$ 81
	Cumulative, 2000-2050	$ 14,466	$ 641	$ 3,110	$ 3,216

Parameter	YEAR	MAX Capacity Expansion Paths Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Conversion of U3O8 to UF6 for Uranium Enriched In-country (million dollars)	2010	$ 51	$ 51	$ 51	$ 51
	2030	$ 577	$ -	$ 87	$ 91
	2050	$ 874	$ -	$ 78	$ 85
	Cumulative, 2000-2050	$ 20,109	$ 656	$ 3,295	$ 3,412

Parameter	YEAR	MIN Capacity Expansion Paths Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Conversion of U3O8 to UF6 for Uranium Enriched In-country (million dollars)	2010	$ 51	$ 51	$ 51	$ 51
	2030	$ 312	$ -	$ 72	$ 74
	2050	$ 313	$ -	$ 64	$ 70
	Cumulative, 2000-2050	$ 9,896	$ 635	$ 2,836	$ 2,924

Parameter	YEAR	BAU Capacity Expansion Paths Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Conversion of U3O8 to UF6 for Uranium Enriched Out-of-country (million dollars)	2010	$ 139	$ 139	$ 139	$ 139
	2030	$ 32	$ 486	$ 430	$ 443
	2050	$ 49	$ 566	$ 501	$ 545
	Cumulative, 2000-2050	$ 4,375	$ 18,189	$ 16,533	$ 17,177

Parameter	YEAR	MAX Capacity Expansion Paths Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Conversion of U3O8 to UF6 for Uranium Enriched Out-of-country (million dollars)	2010	$ 139	$ 139	$ 139	$ 139
	2030	$ 44	$ 621	$ 575	$ 596
	2050	$ 146	$ 1,020	$ 986	$ 1,065
	Cumulative, 2000-2050	$ 5,857	$ 25,278	$ 24,354	$ 25,440

Parameter	YEAR	MIN Capacity Expansion Paths Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Conversion of U3O8 to UF6 for Uranium Enriched Out-of-country (million dollars)	2010	$ 139	$ 139	$ 139	$ 139
	2030	$ 0	$ 312	$ 256	$ 262
	2050	$ 6	$ 319	$ 254	$ 277
	Cumulative, 2000-2050	$ 3,295	$ 12,555	$ 10,702	$ 11,035

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Conversion of U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (million dollars)	2010	$ 190	$ 190	$ 190	$ 190
	2030	$ 486	$ 486	$ 511	$ 527
	2050	$ 566	$ 566	$ 576	$ 625
	Cumulative, 2000-2050	$ 18,840	$ 18,830	$ 19,643	$ 20,394
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Conversion of U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (million dollars)	2010	$ 190	$ 190	$ 190	$ 190
	2030	$ 621	$ 621	$ 662	$ 686
	2050	$ 1,020	$ 1,020	$ 1,065	$ 1,150
	Cumulative, 2000-2050	$ 25,966	$ 25,934	$ 27,649	$ 28,852
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Conversion of U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (million dollars)	2010	$ 190	$ 190	$ 190	$ 190
	2030	$ 312	$ 312	$ 328	$ 337
	2050	$ 319	$ 319	$ 318	$ 347
	Cumulative, 2000-2050	$ 13,191	$ 13,190	$ 13,538	$ 13,959

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched In-country (metric tons)	2010	2,563	2,563	2,563	2,563
	2030	22,710	-	4,059	4,181
	2050	25,816	-	3,705	4,027
	Cumulative, 2000-2050	722,748	32,046	155,399	160,703
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched In-country (metric tons)	2010	2,563	2,563	2,563	2,563
	2030	28,833	-	4,361	4,523
	2050	43,677	-	3,913	4,226
	Cumulative, 2000-2050	1,004,705	32,773	164,651	170,488
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched In-country (metric tons)	2010	2,563	2,563	2,563	2,563
	2030	15,576	-	3,609	3,704
	2050	15,623	-	3,199	3,486
	Cumulative, 2000-2050	494,420	31,736	141,677	146,114

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched Out-of-country (metric tons)	2010	6,924	6,924	6,924	6,924
	2030	1,592	24,302	21,486	22,133
	2050	2,456	28,272	25,049	27,224
	Cumulative, 2000-2050	218,570	908,771	826,026	858,217
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched Out-of-country (metric tons)	2010	6,924	6,924	6,924	6,924
	2030	2,218	31,051	28,706	29,772
	2050	7,285	50,962	49,281	53,225
	Cumulative, 2000-2050	292,632	1,262,936	1,216,766	1,271,051
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched Out-of-country (metric tons)	2010	6,924	6,924	6,924	6,924
	2030	0	15,576	12,775	13,112
	2050	302	15,925	12,692	13,830
	Cumulative, 2000-2050	164,628	627,286	534,695	551,320

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (metric tons)	2010	9,486	9,486	9,486	9,486
	2030	24,302	24,302	25,545	26,314
	2050	28,272	28,272	28,755	31,251
	Cumulative, 2000-2050	941,318	940,816	981,425	1,018,921
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
[illegible] Produced in Converting U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (metric tons)	2010	9,486	9,486	9,486	9,486
	2030	31,051	31,051	33,067	34,295
	2050	50,962	50,962	53,194	57,451
	Cumulative, 2000-2050	1,297,337	1,295,708	1,381,417	1,441,539
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
[illegible] Produced in Converting U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (metric tons)	2010	9,486	9,486	9,486	9,486
	2030	15,576	15,576	16,385	16,816
	2050	15,925	15,925	15,892	17,315
	Cumulative, 2000-2050	659,048	659,023	676,372	697,434

Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched In-country (cubic meters)	2010	23,796	23,796	23,796	23,796
	2030	210,876	-	37,689	38,823
	2050	239,717	-	34,408	37,395
	Cumulative, 2000-2050	6,711,227	297,565	1,442,990	1,492,246
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched In-country (cubic meters)	2010	23,796	23,796	23,796	23,796
	2030	267,733	-	40,497	42,001
	2050	405,568	-	36,334	39,242
	Cumulative, 2000-2050	9,329,403	304,316	1,528,899	1,583,100
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched In-country (cubic meters)	2010	23,796	23,796	23,796	23,796
	2030	144,630	-	33,515	34,397
	2050	145,074	-	29,707	32,369
	Cumulative, 2000-2050	4,591,039	294,696	1,315,572	1,356,775

Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched Out-of-country (cubic meters)	2010	64,291	64,291	64,291	64,291
	2030	14,787	225,662	199,514	205,516
	2050	22,804	262,521	232,600	252,794
	Cumulative, 2000-2050	2,029,579	8,438,584	7,670,241	7,969,162
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched Out-of-country (cubic meters)	2010	64,291	64,291	64,291	64,291
	2030	20,599	288,332	266,554	276,455
	2050	67,649	473,217	457,608	494,228
	Cumulative, 2000-2050	2,717,300	11,727,262	11,298,543	11,802,619
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched Out-of-country (cubic meters)	2010	64,291	64,291	64,291	64,291
	2030	0	144,630	118,629	121,751
	2050	2,806	147,879	117,859	128,417
	Cumulative, 2000-2050	1,528,690	5,824,800	4,965,024	5,119,402

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liguid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (cubic meters)	2010	88,087	88,087	88,087	88,087
	2030	225,662	225,662	237,203	244,340
	2050	262,521	262,521	267,007	290,189
	Cumulative, 2000-2050	8,740,806	8,736,150	9,113,231	9,461,408

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liguid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (cubic meters)	2010	88,087	88,087	88,087	88,087
	2030	288,332	288,332	307,051	318,457
	2050	473,217	473,217	493,942	533,470
	Cumulative, 2000-2050	12,046,703	12,031,578	12,827,442	13,385,719

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liguid Waste Produced in Converting U3O8 to UF6 for Uranium Enriched In-country or Out-of-country (cubic meters)	2010	88,087	88,087	88,087	88,087
	2030	144,630	144,630	152,144	156,148
	2050	147,879	147,879	147,566	160,786
	Cumulative, 2000-2050	6,119,730	6,119,496	6,280,596	6,476,177

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enriched Fuel Requirements for Uranium Enriched In-country for Domestic Use (metric tons enriched fuel as U)	2010	401	401	401	401
	2030	3,557	-	636	655
	2050	4,044	-	580	631
	Cumulative, 2000-2050	113,368	5,174	24,497	25,328
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enriched Fuel Requirements for Uranium Enriched In-country for Domestic Use (metric tons enriched fuel as U)	2010	401	401	401	401
	2030	4,516	-	683	709
	2050	6,842	-	613	662
	Cumulative, 2000-2050	157,535	5,288	25,946	26,860
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enriched Fuel Requirements for Uranium Enriched In-country for Domestic Use (metric tons enriched fuel as U)	2010	401	401	401	401
	2030	2,440	-	565	580
	2050	2,447	-	501	546
	Cumulative, 2000-2050	77,602	5,126	22,347	23,042

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enriched Fuel Requirements for Uranium Enriched Out-of-country for Domestic Use (metric tons enriched fuel as U)	2010	1,085	1,085	1,085	1,085
	2030	249	3,807	3,366	3,467
	2050	385	4,429	3,924	4,264
	Cumulative, 2000-2050	36,309	144,424	131,463	136,506

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enriched Fuel Requirements for Uranium Enriched Out-of-country for Domestic Use (metric tons enriched fuel as U)	2010	1,085	1,085	1,085	1,085
	2030	347	4,864	4,497	4,664
	2050	1,141	7,983	7,720	8,337
	Cumulative, 2000-2050	47,910	199,902	192,670	201,174

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enriched Fuel Requirements for Uranium Enriched Out-of-country for Domestic Use (metric tons enriched fuel as U)	2010	1,085	1,085	1,085	1,085
	2030	0	2,440	2,001	2,054
	2050	47	2,495	1,988	2,166
	Cumulative, 2000-2050	27,859	100,332	85,828	88,432

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enriched Fuel Requirements for Uranium Enriched In-country or Out-of-country for Domestic Use (metric tons enriched fuel as U)	2010	1,486	1,486	1,486	1,486
	2030	3,807	3,807	4,001	4,122
	2050	4,429	4,429	4,504	4,895
	Cumulative, 2000-2050	149,677	149,599	155,960	161,833
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enriched Fuel Requirements for Uranium Enriched In-country or Out-of-country for Domestic Use (metric tons enriched fuel as U)	2010	1,486	1,486	1,486	1,486
	2030	4,864	4,864	5,180	5,372
	2050	7,983	7,983	8,332	8,999
	Cumulative, 2000-2050	205,445	205,190	218,616	228,034
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enriched Fuel Requirements for Uranium Enriched In-country or Out-of-country for Domestic Use (metric tons enriched fuel as U)	2010	1,486	1,486	1,486	1,486
	2030	2,440	2,440	2,567	2,634
	2050	2,495	2,495	2,489	2,712
	Cumulative, 2000-2050	105,461	105,457	108,175	111,474

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enrichment Requirements for Uranium Enriched In-country for Domestic Use (Million kg SWU)	2010	2.8	2.8	2.8	2.8
	2030	25.1	-	4.5	4.6
	2050	28.5	-	4.1	4.4
	Cumulative, 2000-2050	798	35	171	177
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enrichment Requirements for Uranium Enriched In-country for Domestic Use (Million kg SWU)	2010	2.8	2.8	2.8	2.8
	2030	31.8	-	4.8	5.0
	2050	48.2	-	4.3	4.7
	Cumulative, 2000-2050	1,109	36	181	188
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enrichment Requirements for Uranium Enriched In-country for Domestic Use (Million kg SWU)	2010	3	3	3	3
	2030	17	-	4	4
	2050	17	-	4	4
	Cumulative, 2000-2050	546	35	156	161

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enrichment Requirements for Uranium Enriched Out-of-country for Domestic Use (Million kg SWU)	2010	8	8	8	8
	2030	2	27	24	24
	2050	3	31	28	30
	Cumulative, 2000-2050	237	999	908	943
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enrichment Requirements for Uranium Enriched Out-of-country for Domestic Use (Million kg SWU)	2010	8	8	8	8
	2030	2	34	32	33
	2050	8	56	54	59
	Cumulative, 2000-2050	319	1,390	1,339	1,399
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enrichment Requirements for Uranium Enriched Out-of-country for Domestic Use (Million kg SWU)	2010	8	8	8	8
	2030	0	17	14	14
	2050	0	18	14	15
	Cumulative, 2000-2050	178	689	586	605

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enrichment Requirements for Uranium Enriched In-country or Out-of-country for Domestic Use (Million kg SWU)	2010	10	10	10	10
	2030	27	27	28	29
	2050	31	31	32	35
	Cumulative, 2000-2050	1,035	1,034	1,079	1,121
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enrichment Requirements for Uranium Enriched In-country or Out-of-country for Domestic Use (Million kg SWU)	2010	10	10	10	10
	2030	34	34	37	38
	2050	56	56	59	63
	Cumulative, 2000-2050	1,428	1,426	1,521	1,587
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Enrichment Requirements for Uranium Enriched In-country or Out-of-country for Domestic Use (Million kg SWU)	2010	10	10	10	10
	2030	17	17	18	19
	2050	18	18	18	19
	Cumulative, 2000-2050	723	723	742	766

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Uranium Enrichment In-country for Fuel Used in Domestic Reactors (Million 2009 dollars)	2010	$ 421	$ 421	$ 421	$ 421
	2030	$ 2,762	$ -	$ 494	$ 508
	2050	$ 2,880	$ -	$ 413	$ 449
	Cumulative, 2000-2050	$ 86,041	$ 4,335	$ 19,038	$ 19,656
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Uranium Enrichment In-country for Fuel Used in Domestic Reactors (Million 2009 dollars)	2010	$ 421	$ 421	$ 421	$ 421
	2030	$ 4,103	$ -	$ 621	$ 644
	2050	$ 6,789	$ -	$ 608	$ 657
	Cumulative, 2000-2050	$ 147,596	$ 4,543	$ 23,698	$ 24,563
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Uranium Enrichment In-country for Fuel Used in Domestic Reactors (Million 2009 dollars)	2010	$ 421	$ 421	$ 421	$ 421
	2030	$ 1,616	$ -	$ 375	$ 384
	2050	$ 1,247	$ -	$ 255	$ 278
	Cumulative, 2000-2050	$ 49,093	$ 4,196	$ 15,053	$ 15,458

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Uranium Enrichment Services Imported for Fuel Used in Domestic Reactors (Million 2009 dollars)	2010	$ 1,139	$ 1,139	$ 1,139	$ 1,139
	2030	$ 194	$ 2,955	$ 2,613	$ 2,692
	2050	$ 274	$ 3,154	$ 2,795	$ 3,037
	Cumulative, 2000-2050	$ 27,886	$ 109,529	$ 99,826	$ 103,563
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Uranium Enrichment Services Imported for Fuel Used in Domestic Reactors (Million 2009 dollars)	2010	$ 1,139	$ 1,139	$ 1,139	$ 1,139
	2030	$ 316	$ 4,419	$ 4,085	$ 4,237
	2050	$ 1,132	$ 7,922	$ 7,660	$ 8,273
	Cumulative, 2000-2050	$ 41,120	$ 183,947	$ 177,139	$ 185,249
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Uranium Enrichment Services Imported for Fuel Used in Domestic Reactors (Million 2009 dollars)	2010	$ 1,139	$ 1,139	$ 1,139	$ 1,139
	2030	$ 0	$ 1,616	$ 1,326	$ 1,361
	2050	$ 24	$ 1,271	$ 1,013	$ 1,104
	Cumulative, 2000-2050	$ 20,876	$ 65,770	$ 56,974	$ 58,482

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Uranium Enrichment Services In-country or Imported for Fuel Used in Domestic Reactors (Million 2009 dollars)	2010	$ 1,560	$ 1,560	$ 1,560	$ 1,560
	2030	$ 2,955	$ 2,955	$ 3,106	$ 3,200
	2050	$ 3,154	$ 3,154	$ 3,208	$ 3,486
	Cumulative, 2000-2050	$ 113,927	$ 113,864	$ 118,863	$ 123,219
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Uranium Enrichment Services In-country or Imported for Fuel Used in Domestic Reactors (Million 2009 dollars)	2010	$ 1,560	$ 1,560	$ 1,560	$ 1,560
	2030	$ 4,419	$ 4,419	$ 4,705	$ 4,880
	2050	$ 7,922	$ 7,922	$ 8,269	$ 8,930
	Cumulative, 2000-2050	$ 188,715	$ 188,489	$ 200,837	$ 209,812
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Cost of Uranium Enrichment Services In-country or Imported for Fuel Used in Domestic Reactors (Million 2009 dollars)	2010	$ 1,560	$ 1,560	$ 1,560	$ 1,560
	2030	$ 1,616	$ 1,616	$ 1,700	$ 1,745
	2050	$ 1,271	$ 1,271	$ 1,268	$ 1,382
	Cumulative, 2000-2050	$ 69,969	$ 69,966	$ 72,027	$ 73,940

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used for Uranium Enrichment In-country for Fuel Used in Domestic Reactors (GWh)	2010	141	141	141	141
	2030	1,254	-	224	231
	2050	1,425	-	205	222
	Cumulative, 2000-2050	39,881	1,754	8,563	8,856
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used for Uranium Enrichment In-country for Fuel Used in Domestic Reactors (GWh)	2010	141	141	141	141
	2030	1,592	-	241	250
	2050	2,411	-	216	233
	Cumulative, 2000-2050	55,446	1,794	9,074	9,396
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used for Uranium Enrichment In-country for Fuel Used in Domestic Reactors (GWh)	2010	141	141	141	141
	2030	860	-	199	204
	2050	862	-	177	192
	Cumulative, 2000-2050	27,277	1,737	7,806	8,051

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used for Uranium Enrichment	2010	3,462	3,462	3,462	3,462
	2030	88	1,341	1,186	1,222
	2050	136	1,561	1,383	1,503
Out-of-country for Fuel Used in Domestic Reactors (GWh)	Cumulative, 2000-2050	71,494	109,499	105,431	107,207
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used for Uranium Enrichment	2010	3,462	3,462	3,462	3,462
	2030	122	1,714	1,585	1,643
	2050	402	2,813	2,720	2,938
Out-of-country for Fuel Used in Domestic Reactors (GWh)	Cumulative, 2000-2050	75,987	129,050	127,000	129,996
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used for Uranium Enrichment	2010	3,462	3,462	3,462	3,462
	2030	0	860	705	724
	2050	17	879	701	763
Out-of-country for Fuel Used in Domestic Reactors (GWh)	Cumulative, 2000-2050	68,921	93,961	89,349	90,266

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used for Uranium Enrichment	2010	3,603	3,603	3,603	3,603
	2030	1,341	1,341	1,410	1,453
	2050	1,561	1,561	1,587	1,725
In-country or Out-of-country for Fuel Used in Domestic Reactors (GWh)	Cumulative, 2000-2050	111,376	111,253	113,994	116,063
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used for Uranium Enrichment	2010	3,603	3,603	3,603	3,603
	2030	1,714	1,714	1,825	1,893
	2050	2,813	2,813	2,936	3,171
In-country or Out-of-country for Fuel Used in Domestic Reactors (GWh)	Cumulative, 2000-2050	131,432	130,844	136,074	139,392
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Electricity Used for Uranium Enrichment	2010	3,603	3,603	3,603	3,603
	2030	860	860	904	928
	2050	879	879	877	956
In-country or Out-of-country for Fuel Used in Domestic Reactors (GWh)	Cumulative, 2000-2050	96,198	95,698	97,155	98,317

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Depleted Uranium Produced from Uranium Enrichment In-country for Fuel Used in Domestic Reactors (metric tons U)	2010	3,241	3,241	3,241	3,241
	2030	28,723	-	5,134	5,288
	2050	32,651	-	4,687	5,093
	Cumulative, 2000-2050	913,966	40,376	196,392	203,101
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Depleted Uranium Produced from Uranium Enrichment In-country for Fuel	2010	3,241	3,241	3,241	3,241
	2030	36,467	-	5,516	5,721
	2050	55,241	-	4,949	5,345
	Cumulative, 2000-2050	1,270,581	41,296	208,093	215,476
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Depleted Uranium Produced from Uranium Enrichment In-country for Fuel	2010	3,241	3,241	3,241	3,241
	2030	19,700	-	4,565	4,685
	2050	19,760	-	4,046	4,409
	Cumulative, 2000-2050	625,180	39,985	179,037	184,649

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Depleted Uranium Produced from Uranium Enrichment Out-of-country for Fuel Used in Domestic Reactors (metric tons U)	2010	8,757	8,757	8,757	8,757
	2030	2,014	30,737	27,175	27,993
	2050	3,106	35,757	31,682	34,433
	Cumulative, 2000-2050	274,373	1,147,328	1,042,674	1,083,389
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Depleted Uranium Produced from Uranium Enrichment Out-of-country for Fuel Used in Domestic Reactors (metric tons U)	2010	8,757	8,757	8,757	8,757
	2030	2,806	39,273	36,307	37,655
	2050	9,214	64,456	62,330	67,318
	Cumulative, 2000-2050	368,046	1,595,271	1,536,876	1,605,535
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Depleted Uranium Produced from Uranium Enrichment Out-of-country for Fuel Used in Domestic Reactors (metric tons U)	2010	8,757	8,757	8,757	8,757
	2030	0	19,700	16,158	16,583
	2050	382	20,142	16,053	17,491
	Cumulative, 2000-2050	206,148	791,311	674,203	695,230

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Depleted Uranium Produced from Uranium Enrichment In-country or Out-of-country for Fuel Used in Domestic Reactors (metric tons U)	2010	11,998	11,998	11,998	11,998
	2030	30,737	30,737	32,309	33,281
	2050	35,757	35,757	36,368	39,526
	Cumulative, 2000-2050	1,188,339	1,187,704	1,239,066	1,286,490

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Depleted Uranium Produced from Uranium Enrichment In-country or Out-of-country for Fuel Used in Domestic Reactors (metric tons U)	2010	11,998	11,998	11,998	11,998
	2030	39,273	39,273	41,823	43,376
	2050	64,456	64,456	67,279	72,663
	Cumulative, 2000-2050	1,638,627	1,636,567	1,744,969	1,821,011

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Total Depleted Uranium Produced from Uranium Enrichment In-country or Out-of-country for Fuel Used in Domestic Reactors (metric tons U)	2010	11,998	11,998	11,998	11,998
	2030	19,700	19,700	20,723	21,268
	2050	20,142	20,142	20,100	21,900
	Cumulative, 2000-2050	831,328	831,296	853,239	879,879

FUTURE REGIONAL NUCLEAR FUEL CYCLE COOPERATION IN EAST ASIA: ENERGY SECURITY COSTS AND BENEFITS

Calculations for East Asia Science and Security (EASS) and Related Follow-on (2012-2016) Projects, funded by MacArthur Foundation

Estimates of Fuel Fabrication and Transport Parameters: Summaries for All Regional Scenarios

Prepared by:	David Von Hippel
Last Modified:	11/11/2016

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	398	398	398	398
	2030	3,514	-	626	537
	2050	3,970	-	571	537
	Cumulative, 2000-2050	111,755	5,120	24,176	22,114

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	398	398	398	398
	2030	4,458	-	668	537
	2050	6,682	-	595	537
	Cumulative, 2000-2050	154,776	5,230	25,417	22,209

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	398	398	398	398
	2030	2,415	-	560	537
	2050	2,419	-	497	537
	Cumulative, 2000-2050	76,737	5,073	22,152	22,076

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated Outside the Country for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	1,073	1,073	1,073	1,073
	2030	255	3,769	3,335	3,543
	2050	414	4,384	3,888	4,309
	Cumulative, 2000-2050	36,426	142,983	130,224	138,100

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated Outside the Country for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	1,073	1,073	1,073	1,073
	2030	357	4,815	4,460	4,781
	2050	1,221	7,903	7,654	8,372
	Cumulative, 2000-2050	48,615	197,908	191,012	203,545

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated Outside the Country for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	1,073	1,073	1,073	1,073
	2030	0	2,415	1,981	2,070
	2050	51	2,470	1,967	2,148
	Cumulative, 2000-2050	27,670	99,330	84,941	88,284

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Requirements for UOx Fuel (excluding MOx) from All Sources (Metric tonnes heavy metal in fabricated fuel)	2010	1,471	1,471	1,471	1,471
	2030	3,769	3,769	3,961	4,081
	2050	4,384	4,384	4,459	4,846
	Cumulative, 2000-2050	148,180	148,103	154,400	160,215

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Requirements for UOx Fuel (excluding MOx) from All Sources (Metric tonnes heavy metal in fabricated fuel)	2010	1,471	1,471	1,471	1,471
	2030	4,815	4,815	5,128	5,318
	2050	7,903	7,903	8,249	8,909
	Cumulative, 2000-2050	203,391	203,138	216,430	225,753

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Requirements for UOx Fuel (excluding MOx) from All Sources (Metric tonnes heavy metal in fabricated fuel)	2010	1,471	1,471	1,471	1,471
	2030	2,415	2,415	2,541	2,608
	2050	2,470	2,470	2,464	2,685
	Cumulative, 2000-2050	104,407	104,403	107,093	110,360

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for MOx Fuel Blended and Fabricated In-Country for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	1	1	1	1
	2030	119	-	22	-
	2050	380	-	53	-
	Cumulative, 2000-2050	5,720	11	900	1
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for MOx Fuel Blended and Fabricated In-Country for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	1	1	1	1
	2030	187	-	33	-
	2050	636	-	61	-
	Cumulative, 2000-2050	9,031	19	1,176	1
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for MOx Fuel Blended and Fabricated In-Country for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	1	1	1	1
	2030	67	-	14	-
	2050	221	-	43	-
	Cumulative, 2000-2050	3,264	9	661	1

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for MOx Fuel Blended and Fabricated Out-of-Country for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	4	4	4	4
	2030	(0)	119	97	-
	2050	0	380	334	-
	Cumulative, 2000-2050	11	5,720	4,922	5

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for MOx Fuel Blended and Fabricated Out-of-Country for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	4	4	4	4
	2030	-	187	157	-
	2050	0	636	599	-
	Cumulative, 2000-2050	12	9,023	8,154	5

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for MOx Fuel Blended and Fabricated Out-of-Country for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	4	4	4	4
	2030	0	67	53	-
	2050	(0)	221	177	-
	Cumulative, 2000-2050	9	3,264	2,612	5

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for MOx Fuel Blended and Fabricated from All Sources for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	5	5	5	5
	2030	119	119	119	-
	2050	380	380	387	-
	Cumulative, 2000-2050	5,731	5,731	5,821	7
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for MOx Fuel Blended and Fabricated from All Sources for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	5	5	5	5
	2030	187	187	190	-
	2050	636	636	660	-
	Cumulative, 2000-2050	9,042	9,042	9,330	7
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Requirements for MOx Fuel Blended and Fabricated from All Sources for Use in Domestic Reactors (Metric tonnes heavy metal in fabricated fuel)	2010	5	5	5	5
	2030	67	67	67	-
	2050	221	221	221	-
	Cumulative, 2000-2050	3,273	3,273	3,273	7

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Use of Plutonium for MOx Fuel Blended and Fabricated In-Country for Use in Domestic Reactors (Metric tonnes Pu in fabricated fuel)	2010	0.1	0.1	0.1	0.1
	2030	11.3	-	2.1	-
	2050	36.1	-	5.1	-
	Cumulative, 2000-2050	543.4	1.0	85.5	0.1

		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Plutonium for MOx Fuel Blended and Fabricated In-Country for Use in Domestic Reactors (Metric tonnes Pu in fabricated fuel)	2010	0.1	0.1	0.1	0.1
	2030	17.7	-	3.2	-
	2050	60.4	-	5.8	-
	Cumulative, 2000-2050	857.9	1.8	111.7	0.1

		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Use of Plutonium for MOx Fuel Blended and Fabricated In-Country for Use in Domestic Reactors (Metric tonnes Pu in fabricated fuel)	2010	0.1	0.1	0.1	0.1
	2030	6.4	-	1.3	-
	2050	21.0	-	4.1	-
	Cumulative, 2000-2050	310.1	0.9	62.8	0.1

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Use of Plutonium for MOx Fuel Blended and Fabricated Out-of-Country for Use in Domestic Reactors (Metric tonnes Pu in fabricated fuel)	2010	0.4	0.4	0.4	0.4
	2030	(0.0)	11.3	9.2	-
	2050	0.0	36.1	31.7	-
	Cumulative, 2000-2050	1	543	468	0

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Use of Plutonium for MOx Fuel Blended and Fabricated Out-of-Country for Use in Domestic Reactors (Metric tonnes Pu in fabricated fuel)	2010	0	0	0	0
	2030	-	18	15	-
	2050	0	60	57	-
	Cumulative, 2000-2050	1	857	775	0

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Use of Plutonium for MOx Fuel Blended and Fabricated Out-of-Country for Use in Domestic Reactors (Metric tonnes Pu in fabricated fuel)	2010	0	0	0	0
	2030	0	6	5	-
	2050	(0)	21	17	-
	Cumulative, 2000-2050	1	310	248	0

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Use of Plutonium for MOx Fuel Blended and Fabricated from All Sources for Use in Domestic Reactors (Metric tonnes Pu in fabricated fuel)	2010	0.4	0.4	0.4	0.4
	2030	11.3	11.3	11.3	-
	2050	36.1	36.1	36.8	-
	Cumulative, 2000-2050	544	544	553	0.6

		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Use of Plutonium for MOx Fuel Blended and Fabricated from All Sources for Use in Domestic Reactors (Metric tonnes Pu in fabricated fuel)	2010	0	0	0	0
	2030	18	18	18	-
	2050	60	60	63	-
	Cumulative, 2000-2050	859	859	886	1

		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Use of Plutonium for MOx Fuel Blended and Fabricated from All Sources for Use in Domestic Reactors (Metric tonnes Pu in fabricated fuel)	2010	0	0	0	0
	2030	6	6	6	-
	2050	21	21	21	-
	Cumulative, 2000-2050	311	311	311	1

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Million dollars)	2010	$ 1.18	$ 1.18	$ 1.18	$ 1.18
	2030	$ 10.63	$ -	$ 1.79	$ 1.48
	2050	$ 11.71	$ -	$ 1.62	$ 1.48
	Cumulative, 2000-2050	$ 332.92	$ 14.92	$ 69.11	$ 61.63
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Million dollars)	2010	$ 1.18	$ 1.18	$ 1.18	$ 1.18
	2030	$ 13.68	$ -	$ 1.94	$ 1.48
	2050	$ 19.89	$ -	$ 1.71	$ 1.48
	Cumulative, 2000-2050	$ 465.79	$ 15.30	$ 73.38	$ 61.95
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Million dollars)	2010	$ 1.18	$ 1.18	$ 1.18	$ 1.18
	2030	$ 7.16	$ -	$ 1.56	$ 1.48
	2050	$ 6.95	$ -	$ 1.37	$ 1.48
	Cumulative, 2000-2050	$ 223.90	$ 14.76	$ 62.14	$ 61.50

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated Out-of-Country for Use in Domestic Reactors (Million dollars)	2010	$ 96.00	$ 44.31	$ 96.00	$ 96.00
	2030	$ 22.79	$ 155.59	$ 298.31	$ 316.94
	2050	$ 37.02	$ 181.00	$ 347.79	$ 385.44
	Cumulative, 2000-2050	$ 3,258	$ 5,903	$ 11,648	$ 12,353
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated Out-of-Country for Use in Domestic Reactors (Million dollars)	2010	$ 96.00	$ 44.31	$ 96.00	$ 96.00
	2030	$ 31.97	$ 198.80	$ 398.92	$ 427.66
	2050	$ 109.19	$ 326.27	$ 684.68	$ 748.86
	Cumulative, 2000-2050	$ 4,349	$ 8,170	$ 17,086	$ 18,207
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated Out-of-Country for Use in Domestic Reactors (Million dollars)	2010	$ 96.00	$ 44.31	$ 96.00	$ 96.00
	2030	$ 0.00	$ 99.72	$ 177.16	$ 185.20
	2050	$ 4.57	$ 101.96	$ 175.98	$ 192.13
	Cumulative, 2000-2050	$ 2,475	$ 4,101	$ 7,598	$ 7,897

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated for Use in Domestic Reactors, All Sources (Million dollars)	2010	$ 97.18	$ 45.49	$ 97.18	$ 97.18
	2030	$ 33.42	$ 155.59	$ 300.10	$ 318.42
	2050	$ 48.72	$ 181.00	$ 349.41	$ 386.91
	Cumulative, 2000-2050	$ 3,591	$ 5,918	$ 11,717	$ 12,415
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated for Use in Domestic Reactors, All Sources (Million dollars)	2010	$ 97.18	$ 45.49	$ 97.18	$ 97.18
	2030	$ 45.65	$ 198.80	$ 400.85	$ 429.14
	2050	$ 129.08	$ 326.27	$ 686.39	$ 750.34
	Cumulative, 2000-2050	$ 4,814	$ 8,186	$ 17,159	$ 18,269
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated for Use in Domestic Reactors, All Sources (Million dollars)	2010	$ 97.18	$ 45.49	$ 97.18	$ 97.18
	2030	$ 7.16	$ 99.72	$ 178.73	$ 186.68
	2050	$ 11.51	$ 101.96	$ 177.35	$ 193.60
	Cumulative, 2000-2050	$ 2,699	$ 4,115	$ 7,660	$ 7,958

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for MOx Fuel for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Million dollars)	2010	$ 0.00	$ 0.00	$ 0.00	$ 0.00
	2030	$ 0.58	$ -	$ 0.10	$ -
	2050	$ 1.70	$ -	$ 0.23	$ -
	Cumulative, 2000-2050	$ 26.49	$ 0.06	$ 4.07	$ 0.01
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for MOx Fuel for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Million dollars)	2010	$ 0.00	$ 0.00	$ 0.00	$ 0.00
	2030	$ 0.92	$ -	$ 0.16	$ -
	2050	$ 2.83	$ -	$ 0.27	$ -
	Cumulative, 2000-2050	$ 41.92	$ 0.10	$ 5.49	$ 0.01
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for MOx Fuel for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Million dollars)	2010	$ 0.00	$ 0.00	$ 0.00	$ 0.00
	2030	$ 0.32	$ -	$ 0.06	$ -
	2050	$ 0.96	$ -	$ 0.18	$ -
	Cumulative, 2000-2050	$ 14.66	$ 0.05	$ 2.84	$ 0.01

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for MOx Fuel for Fuel Enriched and Fabricated Out-of-Country for Use in Domestic Reactors (Million dollars)	2010	$ 0.52	$ 0.24	$ 0.52	$ 0.52
	2030	$ (0.00)	$ 7.35	$ 13.05	$ -
	2050	$ 0.00	$ 23.51	$ 44.77	$ -
	Cumulative, 2000-2050	$ 1.42	$ 354.22	$ 660.36	$ 0.69

		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for MOx Fuel for Fuel Enriched and Fabricated Out-of-Country for Use in Domestic Reactors (Million dollars)	2010	$ 0.52	$ 0.24	$ 0.52	$ 0.52
	2030	$ -	$ 11.57	$ 21.10	$ -
	2050	$ 0.00	$ 39.38	$ 80.43	$ -
	Cumulative, 2000-2050	$ 1.56	$ 558.76	$ 1,094.09	$ 0.69

		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for MOx Fuel for Fuel Enriched and Fabricated Out-of-Country for Use in Domestic Reactors (Million dollars)	2010	$ 0.52	$ 0.24	$ 0.52	$ 0.52
	2030	$ 0.00	$ 4.14	$ 7.07	$ -
	2050	$ (0.00)	$ 13.67	$ 23.79	$ -
	Cumulative, 2000-2050	$ 1.19	$ 202.10	$ 350.39	$ 0.69

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for MOx Fuel for Fuel Enriched and Fabricated for Use in Domestic Reactors, All Sources (Million dollars)	2010	$ 0.53	$ 0.24	$ 0.53	$ 0.53
	2030	$ 0.58	$ 7.35	$ 13.15	$ -
	2050	$ 1.70	$ 23.51	$ 45.01	$ -
	Cumulative, 2000-2050	$ 27.91	$ 354.27	$ 664.42	$ 0.69
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for MOx Fuel for Fuel Enriched and Fabricated for Use in Domestic Reactors, All Sources (Million dollars)	2010	$ 0.53	$ 0.24	$ 0.53	$ 0.53
	2030	$ 0.92	$ 11.57	$ 21.26	$ -
	2050	$ 2.83	$ 39.38	$ 80.70	$ -
	Cumulative, 2000-2050	$ 43.48	$ 558.86	$ 1,099.58	$ 0.69
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for MOx Fuel for Fuel Enriched and Fabricated for Use in Domestic Reactors, All Sources (Million dollars)	2010	$ 0.53	$ 0.24	$ 0.53	$ 0.53
	2030	$ 0.32	$ 4.14	$ 7.14	$ -
	2050	$ 0.96	$ 13.67	$ 23.97	$ -
	Cumulative, 2000-2050	$ 15.85	$ 202.15	$ 353.23	$ 0.69

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated In-country (metric tons)	2010	199	199	199	199
	2030	1,757	-	313	269
	2050	1,985	-	286	269
	Cumulative, 2000-2050	55,877	2,560	12,088	11,057
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated In-country (metric tons)	2010	199	199	199	199
	2030	2,229	-	334	269
	2050	3,341	-	297	269
	Cumulative, 2000-2050	77,388	2,615	12,709	11,104
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated In-country (metric tons)	2010	199	199	199	199
	2030	1,208	-	280	269
	2050	1,209	-	249	269
	Cumulative, 2000-2050	38,368	2,537	11,076	11,038

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated Out-of-country (metric tons)	2010	537	537	537	537
	2030	127	1,884	1,667	1,772
	2050	207	2,192	1,944	2,155
	Cumulative, 2000-2050	18,213	71,491	65,112	69,050
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated Out-of-country (metric tons)	2010	537	537	537	537
	2030	179	2,408	2,230	2,391
	2050	610	3,952	3,827	4,186
	Cumulative, 2000-2050	24,308	98,954	95,506	101,772
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated Out-of-country (metric tons)	2010	537	537	537	537
	2030	0	1,208	990	1,035
	2050	26	1,235	984	1,074
	Cumulative, 2000-2050	13,835	49,665	42,471	44,142

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated, All Sources (metric tons)	2010	736	736	736	736
	2030	1,884	1,884	1,981	2,040
	2050	2,192	2,192	2,230	2,423
	Cumulative, 2000-2050	74,090	74,051	77,200	80,107
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated, All Sources (metric tons)	2010	736	736	736	736
	2030	2,408	2,408	2,564	2,659
	2050	3,952	3,952	4,125	4,455
	Cumulative, 2000-2050	101,695	101,569	108,215	112,877
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated, All Sources (metric tons)	2010	736	736	736	736
	2030	1,208	1,208	1,270	1,304
	2050	1,235	1,235	1,232	1,343
	Cumulative, 2000-2050	52,203	52,201	53,547	55,180

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated In-country (cubic meters)	2010	3,581	3,581	3,581	3,581
	2030	31,626	-	5,638	4,836
	2050	35,734	-	5,140	4,836
	Cumulative, 2000-2050	1,005,793	46,079	217,587	199,030
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated In-country (cubic meters)	2010	3,581	3,581	3,581	3,581
	2030	40,122	-	6,014	4,836
	2050	60,141	-	5,352	4,836
	Cumulative, 2000-2050	1,392,980	47,069	228,757	199,880
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated In-country (cubic meters)	2010	3,581	3,581	3,581	3,581
	2030	21,739	-	5,043	4,836
	2050	21,768	-	4,474	4,836
	Cumulative, 2000-2050	690,630	45,658	199,369	198,684

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated Out-of-country (cubic meters)	2010	9,659	9,659	9,659	9,659
	2030	2,293	33,918	30,015	31,890
	2050	3,724	39,459	34,993	38,781
	Cumulative, 2000-2050	327,830	1,286,844	1,172,014	1,242,904
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated Out-of-country (cubic meters)	2010	9,659	9,659	9,659	9,659
	2030	3,216	43,338	40,137	43,030
	2050	10,986	71,127	68,890	75,348
	Cumulative, 2000-2050	437,538	1,781,176	1,719,111	1,831,901
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated Out-of-country (cubic meters)	2010	9,659	9,659	9,659	9,659
	2030	0	21,739	17,826	18,634
	2050	459	22,227	17,706	19,331
	Cumulative, 2000-2050	249,029	893,967	764,469	794,552

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated, All Sources (cubic meters)	2010	13,240	13,240	13,240	13,240
	2030	33,918	33,918	35,653	36,726
	2050	39,459	39,459	40,133	43,617
	Cumulative, 2000-2050	1,333,623	1,332,923	1,389,600	1,441,934

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated, All Sources (cubic meters)	2010	13,240	13,240	13,240	13,240
	2030	43,338	43,338	46,152	47,866
	2050	71,127	71,127	74,242	80,184
	Cumulative, 2000-2050	1,830,519	1,828,246	1,947,869	2,031,781

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating UOx Fuel for Fuel Enriched and Fabricated, All Sources (cubic meters)	2010	13,240	13,240	13,240	13,240
	2030	21,739	21,739	22,868	23,470
	2050	22,227	22,227	22,180	24,167
	Cumulative, 2000-2050	939,659	939,624	963,839	993,236

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated In-country (metric tons)	2010	0.4	0.4	0.4	0.4
	2030	59.4	-	11.0	-
	2050	189.8	-	26.7	-
	Cumulative, 2000-2050	2,860.2	5.4	449.8	0.7
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated In-country (metric tons)	2010	0.4	0.4	0.4	0.4
	2030	93.4	-	16.6	-
	2050	317.9	-	30.3	-
	Cumulative, 2000-2050	4,515.4	9.3	587.9	0.7
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated In-country (metric tons)	2010	0.4	0.4	0.4	0.4
	2030	33.4	-	7.1	-
	2050	110.4	-	21.7	-
	Cumulative, 2000-2050	1,632.0	4.6	330.7	0.7

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated Out-of-country (metric tons)	2010	1.9	1.9	1.9	1.9
	2030	(0.0)	59.4	48.6	-
	2050	0.0	189.8	166.9	-
	Cumulative, 2000-2050	5	2,860	2,461	3

		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated Out-of-country (metric tons)	2010	2	2	2	2
	2030	-	93	79	-
	2050	0	318	300	-
	Cumulative, 2000-2050	6	4,512	4,077	3

		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated Out-of-country (metric tons)	2010	2	2	2	2
	2030	0	33	26	-
	2050	(0)	110	89	-
	Cumulative, 2000-2050	4	1,632	1,306	3

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated, All Sources (metric tons)	2010	2.3	2.3	2.3	2.3
	2030	59.4	59.4	59.6	-
	2050	189.8	189.8	193.6	-
	Cumulative, 2000-2050	2,865	2,865	2,911	3.3

		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated, All Sources (metric tons)	2010	2	2	2	2
	2030	93	93	95	-
	2050	318	318	330	-
	Cumulative, 2000-2050	4,521	4,521	4,665	3

		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Solid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated, All Sources (metric tons)	2010	2	2	2	2
	2030	33	33	33	-
	2050	110	110	110	-
	Cumulative, 2000-2050	1,636	1,636	1,636	3

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated In-country (cubic meters)	2010	7	7	7	7
	2030	1,068	-	197	-
	2050	3,417	-	481	-
	Cumulative, 2000-2050	51,483	97	8,097	13
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated In-country (cubic meters)	2010	7.0	7.0	7.0	7.0
	2030	1,681.5	-	298.9	-
	2050	5,723.1	-	546.2	-
	Cumulative, 2000-2050	81,277.5	168.1	10,583.0	13.1
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated In-country (cubic meters)	2010	7.0	7.0	7.0	7.0
	2030	601.8	-	127.5	-
	2050	1,987.0	-	391.3	-
	Cumulative, 2000-2050	29,376.7	83.4	5,952.7	13.1

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated Out-of-country (cubic meters)	2010	35	35	35	35
	2030	(0)	1,068	875	-
	2050	0	3,417	3,003	-
	Cumulative, 2000-2050	95	51,480	44,295	46
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated Out-of-country (cubic meters)	2010	35	35	35	35
	2030	-	1,681	1,415	-
	2050	0	5,723	5,395	-
	Cumulative, 2000-2050	105	81,208	73,389	46
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated Out-of-country (cubic meters)	2010	35	35	35	35
	2030	0	602	474	-
	2050	(0)	1,987	1,596	-
	Cumulative, 2000-2050	80	29,373	23,504	46

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated, All Sources (cubic meters)	2010	42	42	42	42
	2030	1,068	1,068	1,073	-
	2050	3,417	3,417	3,484	-
	Cumulative, 2000-2050	51,579	51,577	52,392	59

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated, All Sources (cubic meters)	2010	42	42	42	42
	2030	1,681	1,681	1,714	-
	2050	5,723	5,723	5,941	-
	Cumulative, 2000-2050	81,382	81,376	83,972	59

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Liquid Waste Produced in Fabricating MOx Fuel for Fuel Blended and Fabricated, All Sources (cubic meters)	2010	42	42	42	42
	2030	602	602	602	-
	2050	1,987	1,987	1,987	-
	Cumulative, 2000-2050	29,456	29,456	29,456	59

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Million dollars)	2010	$ 108	$ 108	$ 108	$ 108
	2030	$ 957	$ -	$ 171	$ 146
	2050	$ 1,081	$ -	$ 155	$ 146
	Cumulative, 2000-2050	$ 30,427	$ 1,394	$ 6,582	$ 6,021

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Million dollars)	2010	$ 108	$ 108	$ 108	$ 108
	2030	$ 1,214	$ -	$ 182	$ 146
	2050	$ 1,819	$ -	$ 162	$ 146
	Cumulative, 2000-2050	$ 42,141	$ 1,424	$ 6,920	$ 6,047

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Million dollars)	2010	$ 108	$ 108	$ 108	$ 108
	2030	$ 658	$ -	$ 153	$ 146
	2050	$ 659	$ -	$ 135	$ 146
	Cumulative, 2000-2050	$ 20,893	$ 1,381	$ 6,031	$ 6,011

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated Out-of-Country for Use in Domestic Reactors (Million dollars)	2010	$ 292	$ 292	$ 292	$ 292
	2030	$ 69	$ 1,026	$ 908	$ 965
	2050	$ 113	$ 1,194	$ 1,059	$ 1,173
	Cumulative, 2000-2050	$ 9,918	$ 38,930	$ 35,456	$ 37,600
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated Out-of-Country for Use in Domestic Reactors (Million dollars)	2010	$ 292	$ 292	$ 292	$ 292
	2030	$ 97	$ 1,311	$ 1,214	$ 1,302
	2050	$ 332	$ 2,152	$ 2,084	$ 2,279
	Cumulative, 2000-2050	$ 13,236	$ 53,884	$ 52,007	$ 55,419
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated Out-of-Country for Use in Domestic Reactors (Million dollars)	2010	$ 292	$ 292	$ 292	$ 292
	2030	$ 0	$ 658	$ 539	$ 564
	2050	$ 14	$ 672	$ 536	$ 585
	Cumulative, 2000-2050	$ 7,534	$ 27,044	$ 23,127	$ 24,037

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated, All Sources, for Use in Domestic Reactors (Million dollars)	2010	$ 401	$ 401	$ 401	$ 401
	2030	$ 1,026	$ 1,026	$ 1,079	$ 1,111
	2050	$ 1,194	$ 1,194	$ 1,214	$ 1,320
	Cumulative, 2000-2050	$ 40,345	$ 40,324	$ 42,038	$ 43,622

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated, All Sources, for Use in Domestic Reactors (Million dollars)	2010	$ 401	$ 401	$ 401	$ 401
	2030	$ 1,311	$ 1,311	$ 1,396	$ 1,448
	2050	$ 2,152	$ 2,152	$ 2,246	$ 2,426
	Cumulative, 2000-2050	$ 55,377	$ 55,308	$ 58,927	$ 61,466

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for UOx Fuel (excluding MOx) for Fuel Enriched and Fabricated, All Sources, for Use in Domestic Reactors (Million dollars)	2010	$ 401	$ 401	$ 401	$ 401
	2030	$ 658	$ 658	$ 692	$ 710
	2050	$ 672	$ 672	$ 671	$ 731
	Cumulative, 2000-2050	$ 28,427	$ 28,426	$ 29,158	$ 30,047

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for MOx Fuel for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Million dollars)	2010	$ 1.4	$ 1.4	$ 1.4	$ 1.4
	2030	$ 214	$ -	$ 39	$ -
	2050	$ 683	$ -	$ 96	$ -
	Cumulative, 2000-2050	$ 10,297	$ 19	$ 1,619	$ 2.6

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for MOx Fuel for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Million dollars)	2010	$ 1.4	$ 1.4	$ 1.4	$ 1.4
	2030	$ 336	$ -	$ 60	$ -
	2050	$ 1,145	$ -	$ 109	$ -
	Cumulative, 2000-2050	$ 16,256	$ 34	$ 2,117	$ 3

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for MOx Fuel for Fuel Enriched and Fabricated In-Country for Use in Domestic Reactors (Million dollars)	2010	$ 1.4	$ 1.4	$ 1.4	$ 1.4
	2030	$ 120	$ -	$ 25	$ -
	2050	$ 397	$ -	$ 78	$ -
	Cumulative, 2000-2050	$ 5,875	$ 17	$ 1,191	$ 3

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for MOx Fuel for Fuel Enriched and Fabricated Out-of-Country for Use in Domestic Reactors (Million dollars)	2010	$ 7.0	$ 7.0	$ 7.0	$ 7.0
	2030	$ (0)	$ 214	$ 175	$ -
	2050	$ 0	$ 683	$ 601	$ -
	Cumulative, 2000-2050	$ 19	$ 10,296	$ 8,859	$ 9
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for MOx Fuel for Fuel Enriched and Fabricated Out-of-Country for Use in Domestic Reactors (Million dollars)	2010	7	7	7	7
	2030	-	336	283	-
	2050	0	1,145	1,079	-
	Cumulative, 2000-2050	21	16,242	14,678	9
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for MOx Fuel for Fuel Enriched and Fabricated Out-of-Country for Use in Domestic Reactors (Million dollars)	2010	7	7	7	7
	2030	0	120	95	-
	2050	(0)	397	319	-
	Cumulative, 2000-2050	16	5,875	4,701	9

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for MOx Fuel, All Sources, for Use in Domestic Reactors (Million dollars)	2010	$ 8	$ 8	$ 8	$ 8
	2030	$ 214	$ 214	$ 215	$ -
	2050	$ 683	$ 683	$ 697	$ -
	Cumulative, 2000-2050	$ 10,316	$ 10,315	$ 10,478	$ 12
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for MOx Fuel, All Sources, for Use in Domestic Reactors (Million dollars)	2010	$ 8	$ 8	$ 8	$ 8
	2030	$ 336	$ 336	$ 343	$ -
	2050	$ 1,145	$ 1,145	$ 1,188	$ -
	Cumulative, 2000-2050	$ 16,276	$ 16,275	$ 16,794	$ 12
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Fuel Fabrication Costs for MOx Fuel, All Sources, for Use in Domestic Reactors (Million dollars)	2010	$ 8	$ 8	$ 8	$ 8
	2030	$ 120	$ 120	$ 120	$ -
	2050	$ 397	$ 397	$ 397	$ -
	Cumulative, 2000-2050	$ 5,891	$ 5,891	$ 5,891	$ 12

Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		BAU Capacity Expansion Paths			
Annual Fossil Fuel Use in Fabricating UOx Fuel for Fuel Enriched and Fabricated In-country (TJ)	2010	1,078	1,078	1,078	1,078
	2030	9,519	-	1,697	1,456
	2050	10,756	-	1,547	1,456
	Cumulative, 2000-2050	302,744	13,870	65,494	59,908
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating UOx Fuel for Fuel Enriched and Fabricated In-country (TJ)	2010	1,078	1,078	1,078	1,078
	2030	12,077	-	1,810	1,456
	2050	18,102	-	1,611	1,456
	Cumulative, 2000-2050	419,287	14,168	68,856	60,164
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating UOx Fuel for Fuel Enriched and Fabricated In-country (TJ)	2010	1,078	1,078	1,078	1,078
	2030	6,543	-	1,518	1,456
	2050	6,552	-	1,347	1,456
	Cumulative, 2000-2050	207,880	13,743	60,010	59,804

Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		BAU Capacity Expansion Paths			
Annual Fossil Fuel Use in Fabricating UOx Fuel for Fuel Enriched and Fabricated Out-of-country (TJ)	2010	2,907	2,907	2,907	2,907
	2030	690	10,209	9,035	9,599
	2050	1,121	11,877	10,533	11,673
	Cumulative, 2000-2050	98,677	387,340	352,776	374,114
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating UOx Fuel for Fuel Enriched and Fabricated Out-of-country (TJ)	2010	2,907	2,907	2,907	2,907
	2030	968	13,045	12,081	12,952
	2050	3,307	21,409	20,736	22,680
	Cumulative, 2000-2050	131,699	536,134	517,453	551,402
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating UOx Fuel for Fuel Enriched and Fabricated Out-of-country (TJ)	2010	2,907	2,907	2,907	2,907
	2030	0	6,543	5,365	5,609
	2050	138	6,690	5,330	5,819
	Cumulative, 2000-2050	74,958	269,084	230,105	239,160

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating UOx Fuel, All Sources (TJ)	2010	3,985	3,985	3,985	3,985
	2030	10,209	10,209	10,732	11,054
	2050	11,877	11,877	12,080	13,129
	Cumulative, 2000-2050	401,420	401,210	418,270	434,022
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating UOx Fuel, All Sources (TJ)	2010	3,985	3,985	3,985	3,985
	2030	13,045	13,045	13,892	14,408
	2050	21,409	21,409	22,347	24,135
	Cumulative, 2000-2050	550,986	550,302	586,308	611,566
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating UOx Fuel, All Sources (TJ)	2010	3,985	3,985	3,985	3,985
	2030	6,543	6,543	6,883	7,064
	2050	6,690	6,690	6,676	7,274
	Cumulative, 2000-2050	282,837	282,827	290,115	298,964

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating UOx Fuel for Fuel Enriched and Fabricated In-country (GWh)	2010	120	120	120	120
	2030	1,057	-	189	162
	2050	1,195	-	172	162
	Cumulative, 2000-2050	33,627	1,541	7,275	6,654
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating UOx Fuel for Fuel Enriched and Fabricated In-country (GWh)	2010	120	120	120	120
	2030	1,341	-	201	162
	2050	2,011	-	179	162
	Cumulative, 2000-2050	46,572	1,574	7,648	6,683
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating UOx Fuel for Fuel Enriched and Fabricated In-country (GWh)	2010	120	120	120	120
	2030	727	-	169	162
	2050	728	-	150	162
	Cumulative, 2000-2050	23,090	1,526	6,666	6,643

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating UOx Fuel for Fuel Enriched and Fabricated Out-of-country (GWh)	2010	323	323	323	323
	2030	77	1,134	1,004	1,066
	2050	125	1,319	1,170	1,297
	Cumulative, 2000-2050	10,960	43,023	39,184	41,554
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating UOx Fuel for Fuel Enriched and Fabricated Out-of-country (GWh)	2010	323	323	323	323
	2030	108	1,449	1,342	1,439
	2050	367	2,378	2,303	2,519
	Cumulative, 2000-2050	14,628	59,551	57,476	61,247
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating UOx Fuel for Fuel Enriched and Fabricated Out-of-country (GWh)	2010	323	323	323	323
	2030	0	727	596	623
	2050	15	743	592	646
	Cumulative, 2000-2050	8,326	29,888	25,559	26,565

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating UOx Fuel for Fuel Enriched and Fabricated, All Sources (GWh)	2010	443	443	443	443
	2030	1,134	1,134	1,192	1,228
	2050	1,319	1,319	1,342	1,458
	Cumulative, 2000-2050	44,587	44,564	46,459	48,209
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating UOx Fuel for Fuel Enriched and Fabricated, All Sources (GWh)	2010	443	443	443	443
	2030	1,449	1,449	1,543	1,600
	2050	2,378	2,378	2,482	2,681
	Cumulative, 2000-2050	61,200	61,124	65,124	67,929
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating UOx Fuel for Fuel Enriched and Fabricated, All Sources (GWh)	2010	443	443	443	443
	2030	727	727	765	785
	2050	743	743	742	808
	Cumulative, 2000-2050	31,416	31,415	32,224	33,207

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating MOx Fuel for Fuel Enriched and Fabricated In-country (TJ)	2010	2.1	2.1	2.1	2.1
	2030	321.6	-	59.4	-
	2050	1,028.6	-	144.8	-
	Cumulative, 2000-2050	15,496.5	29.1	2,437.2	3.9
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating MOx Fuel for Fuel Enriched and Fabricated In-country (TJ)	2010	2.1	2.1	2.1	2.1
	2030	506.1	-	90.0	-
	2050	1,722.6	-	164.4	-
	Cumulative, 2000-2050	24,464.5	50.6	3,185.5	3.9
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating MOx Fuel for Fuel Enriched and Fabricated In-country (TJ)	2010	2.1	2.1	2.1	2.1
	2030	181.1	-	38.4	-
	2050	598.1	-	117.8	-
	Cumulative, 2000-2050	8,842.4	25.1	1,791.8	3.9

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating MOx Fuel for Fuel Enriched and Fabricated Out-of-country (TJ)	2010	10.5	10.5	10.5	10.5
	2030	(0.0)	321.6	263.5	-
	2050	0.0	1,028.6	904.0	-
	Cumulative, 2000-2050	28.6	15,495.5	13,332.8	13.9

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating MOx Fuel for Fuel Enriched and Fabricated Out-of-country (TJ)	2010	10.5	10.5	10.5	10.5
	2030	-	506.1	426.0	-
	2050	0.0	1,722.6	1,623.9	-
	Cumulative, 2000-2050	31.5	24,443.6	22,090.0	13.9

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating MOx Fuel for Fuel Enriched and Fabricated Out-of-country (TJ)	2010	10.5	10.5	10.5	10.5
	2030	0.0	181.1	142.8	-
	2050	(0.0)	598.1	480.3	-
	Cumulative, 2000-2050	24.0	8,841.2	7,074.6	13.9

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating MOx Fuel, All Sources (TJ)	2010	13	13	13	13
	2030	322	322	323	-
	2050	1,029	1,029	1,049	-
	Cumulative, 2000-2050	15,525	15,525	15,770	18

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating MOx Fuel, All Sources (TJ)	2010	13	13	13	13
	2030	506	506	516	-
	2050	1,723	1,723	1,788	-
	Cumulative, 2000-2050	24,496	24,494	25,275	18

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Fossil Fuel Use in Fabricating MOx Fuel, All Sources (TJ)	2010	13	13	13	13
	2030	181	181	181	-
	2050	598	598	598	-
	Cumulative, 2000-2050	8,866	8,866	8,866	18

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating MOx Fuel for Fuel Enriched and Fabricated In-country (GWh)	2010	0	0	0	0
	2030	36	-	7	-
	2050	114	-	16	-
	Cumulative, 2000-2050	1,721	3	271	0

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating MOx Fuel for Fuel Enriched and Fabricated In-country (GWh)	2010	0	0	0	0
	2030	56	-	10	-
	2050	191	-	18	-
	Cumulative, 2000-2050	2,717	6	354	0

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating MOx Fuel for Fuel Enriched and Fabricated In-country (GWh)	2010	0	0	0	0
	2030	20	-	4	-
	2050	66	-	13	-
	Cumulative, 2000-2050	982	3	199	0

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating MOx Fuel for Fuel Enriched and Fabricated Out-of-country (GWh)	2010	1.2	1.2	1.2	1.2
	2030	(0.0)	35.7	29.3	-
	2050	0.0	114.2	100.4	-
	Cumulative, 2000-2050	3.2	1,721.2	1,480.9	1.5
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating MOx Fuel for Fuel Enriched and Fabricated Out-of-country (GWh)	2010	1.2	1.2	1.2	1.2
	2030	-	56.2	47.3	-
	2050	0.0	191.3	180.4	-
	Cumulative, 2000-2050	3.5	2,715.1	2,453.6	1.5
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating MOx Fuel for Fuel Enriched and Fabricated Out-of-country (GWh)	2010	1	1	1	1
	2030	0	20	16	-
	2050	(0)	66	53	-
	Cumulative, 2000-2050	3	982	786	2

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating MOx Fuel from All Sources (GWh)	2010	1	1	1	1
	2030	36	36	36	-
	2050	114	114	116	-
	Cumulative, 2000-2050	1,724	1,724	1,752	2
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating MOx Fuel from All Sources (GWh)	2010	1	1	1	1
	2030	56	56	57	-
	2050	191	191	199	-
	Cumulative, 2000-2050	2,721	2,721	2,807	2
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Electricity Used in Fabricating MOx Fuel from All Sources (GWh)	2010	1	1	1	1
	2030	20	20	20	-
	2050	66	66	66	-
	Cumulative, 2000-2050	985	985	985	2

FUTURE REGIONAL NUCLEAR FUEL CYCLE COOPERATION IN EAST ASIA: ENERGY SECURITY COSTS AND BENEFITS

Calculations for East Asia Science and Security (EASS) and Related Follow-on (2012-2016) Projects, funded by MacArthur Foundation

Estimates of Reprocessing and Spent Fuel Managment Parameters: Summaries for All Regional Scenarios

Prepared by:	David Von Hippel
Last Modified:	11/11/2016

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual New Spent LWR Fuel Cooled and Available for Reprocessing, Storage, or Disposal (excluding MOx spent fuel), Metric Tonnes Heavy Metal	2010	1,261	1,261	1,261	1,261
	2030	1,966	1,966	1,966	1,982
	2050	3,846	3,846	3,841	4,125
	Cumulative, 2000-2050	97,634	99,654	99,614	102,689
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual New Spent LWR Fuel Cooled and Available for Reprocessing, Storage, or Disposal (excluding MOx spent fuel), Metric Tonnes Heavy Metal	2010	1,261	1,261	1,261	1,261
	2030	2,151	2,151	2,151	2,190
	2050	5,670	5,670	5,656	6,099
	Cumulative, 2000-2050	118,359	120,379	120,263	125,056
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual New Spent LWR Fuel Cooled and Available for Reprocessing, Storage, or Disposal (excluding MOx spent fuel), Metric Tonnes Heavy Metal	2010	1,261	1,261	1,261	1,261
	2030	1,742	1,742	1,742	1,756
	2050	2,444	2,444	2,444	2,593
	Cumulative, 2000-2050	78,729	80,749	80,749	82,506

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Spent MOx Fuel Cooled and Available for Storage or Disposal, Metric Tonnes Heavy Metal	2010	-	-	-	-
	2030	17	17	17	-
	2050	279	279	284	-
	Cumulative, 2000-2050	3,042	3,042	3,081	7
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Spent MOx Fuel Cooled and Available for Storage or Disposal, Metric Tonnes Heavy Metal	2010	-	-	-	-
	2030	39	39	39	-
	2050	429	429	444	-
	Cumulative, 2000-2050	4,684	4,683	4,799	7
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual Spent MOx Fuel Cooled and Available for Storage or Disposal, Metric Tonnes Heavy Metal	2010	-	-	-	-
	2030	14	14	14	-
	2050	149	149	149	-
	Cumulative, 2000-2050	1,763	1,763	1,763	7

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Amount of Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (Metric tonnes heavy metal; based on annual amount of newly-cooled spent fuel available by year)	2010	1	1	1	1
	2030	1,410	241	241	-
	2050	2,265	-	-	-
	Cumulative, 2000-2050	46,658	4,238	4,238	609

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Amount of Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (Metric tonnes heavy metal; based on annual amount of newly-cooled spent fuel available by year)	2010	1	1	1	1
	2030	1,880	375	375	-
	2050	3,859	-	-	-
	Cumulative, 2000-2050	71,542	7,604	7,604	609

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Amount of Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (Metric tonnes heavy metal; based on annual amount of newly-cooled spent fuel available by year)	2010	1	1	1	1
	2030	882	-	-	-
	2050	1,326	-	-	-
	Cumulative, 2000-2050	26,254	609	609	609

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Amount of Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (Metric tonnes heavy metal; based on annual amount of newly-cooled spent fuel available by year)	2010	-	-	-	-
	2030	-	1,168	1,218	-
	2050	-	2,376	2,373	-
	Cumulative, 2000-2050	1,189	42,296	42,433	1,189

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Amount of Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (Metric tonnes heavy metal; based on annual amount of newly-cooled spent fuel available by year)	2010	-	-	-	-
	2030	-	1,504	1,574	-
	2050	-	4,074	4,066	-
	Cumulative, 2000-2050	1,189	64,262	64,439	1,189

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Amount of Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (Metric tonnes heavy metal; based on annual amount of newly-cooled spent fuel available by year)	2010	-	-	-	-
	2030	-	785	909	-
	2050	-	1,177	1,348	-
	Cumulative, 2000-2050	1,189	23,020	26,203	1,189

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Amount of Spent LWR Fuel (UOx only) Reprocessed in Total for Use in Domestic Reactors (Metric tonnes heavy metal)	2010	1	1	1	1
	2030	1,410	1,409	1,459	-
	2050	2,265	2,376	2,373	-
	Cumulative, 2000-2050	47,847	46,534	46,671	1,798

		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Amount of Spent LWR Fuel (UOx only) Reprocessed in Total for Use in Domestic Reactors (Metric tonnes heavy metal)	2010	1	1	1	1
	2030	1,880	1,879	1,949	-
	2050	3,859	4,074	4,066	-
	Cumulative, 2000-2050	72,731	71,866	72,043	1,798

		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Amount of Spent LWR Fuel (UOx only) Reprocessed in Total for Use in Domestic Reactors (Metric tonnes heavy metal)	2010	1	1	1	1
	2030	882	785	909	-
	2050	1,326	1,177	1,348	-
	Cumulative, 2000-2050	27,443	23,630	26,812	1,798

Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		BAU Capacity Expansion Paths			
Implied Transport Costs for Cooled Spent LWR Fuel (UOx only)	2010	$ 0.10	$ 0.10	$ 0.10	$ 0.10
	2030	$ 67.75	$ 4.76	$ 4.76	$ -
	2050	$ 127.98	$ -	$ -	$ -
Reprocessed In-country for Use in Domestic Reactors (Million dollars)	Cumulative, 2000-2050	$ 2,354	$ 84	$ 84	$ 12
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for Cooled Spent LWR Fuel (UOx only)	2010	$ 0.10	$ 0.10	$ 0.10	$ 0.10
	2030	$ 90.13	$ 7.40	$ 7.40	$ -
	2050	$ 236.79	$ -	$ -	$ -
Reprocessed In-country for Use in Domestic Reactors (Million dollars)	Cumulative, 2000-2050	$ 3,778	$ 150	$ 150	$ 12
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for Cooled Spent LWR Fuel (UOx only)	2010	$ 0.10	$ 0.10	$ 0.10	$ 0.10
	2030	$ 51.76	$ -	$ -	$ -
	2050	$ 87.14	$ -	$ -	$ -
Reprocessed In-country for Use in Domestic Reactors (Million dollars)	Cumulative, 2000-2050	$ 1,636	$ 12	$ 12	$ 12

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 230.67	$ 625.36	$ -
	2050	$ -	$ 469.23	$ 1,218.51	$ -
	Cumulative, 2000-2050	$ 611	$ 8,354	$ 21,789	$ 611
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 297.12	$ 808.46	$ -
	2050	$ -	$ 804.67	$ 2,087.76	$ -
	Cumulative, 2000-2050	$ 611	$ 12,692	$ 33,090	$ 611
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 155.01	$ 466.97	$ -
	2050	$ -	$ 232.45	$ 692.26	$ -
	Cumulative, 2000-2050	$ 611	$ 4,547	$ 13,455	$ 611

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (Million dollars)	2010	$ 0.10	$ 0.10	$ 0.10	$ 0.10
	2030	$ 67.75	$ 235.42	$ 630.11	$ -
	2050	$ 127.98	$ 469.23	$ 1,218.51	$ -
	Cumulative, 2000-2050	$ 2,964	$ 8,437	$ 21,873	$ 623
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (Million dollars)	2010	$ 0.10	$ 0.10	$ 0.10	$ 0.10
	2030	$ 90.13	$ 304.52	$ 815.86	$ -
	2050	$ 236.79	$ 804.67	$ 2,087.76	$ -
	Cumulative, 2000-2050	$ 4,389	$ 12,842	$ 33,240	$ 623
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Transport Costs for All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (Million dollars)	2010	$ 0.10	$ 0.10	$ 0.10	$ 0.10
	2030	$ 51.76	$ 155.01	$ 466.97	$ -
	2050	$ 87.14	$ 232.45	$ 692.26	$ -
	Cumulative, 2000-2050	$ 2,246	$ 4,559	$ 13,467	$ 623

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Number of Ocean Voyages Annually for Transport of Cooled Spent LWR Fuel (UOx only) to In-country Reprocessing Centers	2010	-	-	-	-
	2030	5.50	1.79	1.79	-
	2050	6.18	-	-	-
	Cumulative, 2000-2050	165.05	31.56	31.56	4.53
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Number of Ocean Voyages Annually for Transport of Cooled Spent LWR Fuel (UOx only) to In-country Reprocessing Centers	2010	-	-	-	-
	2030	7	3	3	-
	2050	8	-	-	-
	Cumulative, 2000-2050	229	57	57	5
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Number of Ocean Voyages Annually for Transport of Cooled Spent LWR Fuel (UOx only) to In-country Reprocessing Centers	2010	-	-	-	-
	2030	2	-	-	-
	2050	2	-	-	-
	Cumulative, 2000-2050	55	5	5	5

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Number of Ocean Voyages Annually for Transport of Cooled Spent LWR Fuel (UOx only) to Out-of-country Reprocessing Centers	2010	-	-	-	-
	2030	-	8.70	9.07	-
	2050	-	17.70	17.68	-
	Cumulative, 2000-2050	8.86	315.06	316.08	8.86
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Number of Ocean Voyages Annually for Transport of Cooled Spent LWR Fuel (UOx only) to Out-of-country Reprocessing Centers	2010	-	-	-	-
	2030	-	11.21	11.73	-
	2050	-	30.35	30.28	-
	Cumulative, 2000-2050	8.86	478.68	480.00	8.86
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Number of Ocean Voyages Annually for Transport of Cooled Spent LWR Fuel (UOx only) to Out-of-country Reprocessing Centers	2010	-	-	-	-
	2030	-	5.85	6.77	-
	2050	-	8.77	10.04	-
	Cumulative, 2000-2050	8.86	171.47	195.18	8.86

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Number of Ocean Voyages Annually for Transport of Cooled Spent LWR Fuel (UOx only) to All Reprocessing Centers	2010	-	-	-	-
	2030	5.5	10.5	10.9	-
	2050	6.2	17.7	17.7	-
	Cumulative, 2000-2050	173.9	346.6	347.6	13.4
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Number of Ocean Voyages Annually for Transport of Cooled Spent LWR Fuel (UOx only) to All Reprocessing Centers	2010	-	-	-	-
	2030	7.3	14.0	14.5	-
	2050	8.1	30.3	30.3	-
	Cumulative, 2000-2050	237.9	535.3	536.6	13.4
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Number of Ocean Voyages Annually for Transport of Cooled Spent LWR Fuel (UOx only) to All Reprocessing Centers	2010	-	-	-	-
	2030	2.3	5.8	6.8	-
	2050	2.2	8.8	10.0	-
	Cumulative, 2000-2050	64.0	176.0	199.7	13.4

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (Million dollars)	2010	$ 2	$ 2	$ 2	$ 2
	2030	$ 2,660	$ 819	$ 819	$ -
	2050	$ 3,686	$ -	$ -	$ -
	Cumulative, 2000-2050	$ 86,367	$ 14,407	$ 14,407	$ 2,068

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (Million dollars)	2010	$ 2	$ 2	$ 2	$ 2
	2030	$ 3,752	$ 1,274	$ 1,274	$ -
	2050	$ 6,126	$ -	$ -	$ -
	Cumulative, 2000-2050	$ 134,835	$ 25,849	$ 25,849	$ 2,068

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (Million dollars)	2010	$ 2	$ 2	$ 2	$ 2
	2030	$ 1,059	$ -	$ -	$ -
	2050	$ 1,591	$ -	$ -	$ -
	Cumulative, 2000-2050	$ 32,842	$ 2,068	$ 2,068	$ 2,068

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 1,402	$ 1,461	$ -
	2050	$ -	$ 2,851	$ 2,848	$ -
	Cumulative, 2000-2050	$ 1,427	$ 50,756	$ 50,920	$ 1,427
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 1,805	$ 1,889	$ -
	2050	$ -	$ 4,889	$ 4,879	$ -
	Cumulative, 2000-2050	$ 1,427	$ 77,115	$ 77,327	$ 1,427
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 942	$ 1,091	$ -
	2050	$ -	$ 1,412	$ 1,618	$ -
	Cumulative, 2000-2050	$ 1,427	$ 27,625	$ 31,443	$ 1,427

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for All Reprocessing of Cooled Spent LWR Fuel (UOx only) for Use in Domestic Reactors (Million dollars)	2010	$ 2	$ 2	$ 2	$ 2
	2030	$ 2,660	$ 2,221	$ 2,281	$ -
	2050	$ 3,686	$ 2,851	$ 2,848	$ -
	Cumulative, 2000-2050	$ 87,794	$ 65,162	$ 65,326	$ 3,495
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for All Reprocessing of Cooled Spent LWR Fuel (UOx only) for Use in Domestic Reactors (Million dollars)	2010	$ 2	$ 2	$ 2	$ 2
	2030	$ 3,752	$ 3,080	$ 3,164	$ -
	2050	$ 6,126	$ 4,889	$ 4,879	$ -
	Cumulative, 2000-2050	$ 136,262	$ 102,964	$ 103,177	$ 3,495
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for All Reprocessing of Cooled Spent LWR Fuel (UOx only) for Use in Domestic Reactors (Million dollars)	2010	$ 2	$ 2	$ 2	$ 2
	2030	$ 1,059	$ 942	$ 1,091	$ -
	2050	$ 1,591	$ 1,412	$ 1,618	$ -
	Cumulative, 2000-2050	$ 34,268	$ 29,693	$ 33,511	$ 3,495

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of High-level Waste (as vitrified) from Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	162	28	28	-
	2050	261	-	-	-
	Cumulative, 2000-2050	5,366	487	487	70

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of High-level Waste (as vitrified) from Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	216	43	43	-
	2050	444	-	-	-
	Cumulative, 2000-2050	8,227	874	874	70

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of High-level Waste (as vitrified) from Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	101	-	-	-
	2050	152	-	-	-
	Cumulative, 2000-2050	3,019	70	70	70

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of High-level Waste (as vitrified) from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (cubic meters)	2010	-	-	-	-
	2030	-	134	140	-
	2050	-	273	273	-
	Cumulative, 2000-2050	137	4,864	4,880	137

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of High-level Waste (as vitrified) from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (cubic meters)	2010	-	-	-	-
	2030	-	173	181	-
	2050	-	469	468	-
	Cumulative, 2000-2050	137	7,390	7,411	137

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of High-level Waste (as vitrified) from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (cubic meters)	2010	-	-	-	-
	2030	-	90	105	-
	2050	-	135	155	-
	Cumulative, 2000-2050	137	2,647	3,013	137

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of High-level Waste (as vitrified) from All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	162	162	168	-
	2050	261	273	273	-
	Cumulative, 2000-2050	5,502	5,351	5,367	207

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of High-level Waste (as vitrified) from All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	216	216	224	-
	2050	444	469	468	-
	Cumulative, 2000-2050	8,364	8,265	8,285	207

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of High-level Waste (as vitrified) from All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	101	90	105	-
	2050	152	135	155	-
	Cumulative, 2000-2050	3,156	2,717	3,083	207

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of High-level Wastes from Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 212	$ 36	$ 36	$ -
	2050	$ 340	$ -	$ -	$ -
	Cumulative, 2000-2050	$ 6,999	$ 636	$ 636	$ 91

		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of High-level Wastes from Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 282	$ 56	$ 56	$ -
	2050	$ 579	$ -	$ -	$ -
	Cumulative, 2000-2050	$ 10,731	$ 1,141	$ 1,141	$ 91

		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of High-level Wastes from Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 132	$ -	$ -	$ -
	2050	$ 199	$ -	$ -	$ -
	Cumulative, 2000-2050	$ 3,938	$ 91	$ 91	$ 91

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of High-level Wastes from Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 175	$ 183	$ -
	2050	$ -	$ 356	$ 356	$ -
	Cumulative, 2000-2050	$ 178	$ 6,344	$ 6,365	$ 178

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of High-level Wastes from Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 226	$ 236	$ -
	2050	$ -	$ 611	$ 610	$ -
	Cumulative, 2000-2050	$ 178	$ 9,639	$ 9,666	$ 178

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of High-level Wastes from Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 118	$ 136	$ -
	2050	$ -	$ 177	$ 202	$ -
	Cumulative, 2000-2050	$ 178	$ 3,453	$ 3,930	$ 178

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of High-level Wastes from All Reprocessing of Cooled Spent LWR Fuel (UOx only) for Use in Domestic Reactors (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 212	$ 211	$ 219	$ -
	2050	$ 340	$ 356	$ 356	$ -
	Cumulative, 2000-2050	$ 7,177	$ 6,980	$ 7,001	$ 270
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of High-level Wastes from All Reprocessing of Cooled Spent LWR Fuel (UOx only) for Use in Domestic Reactors (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 282	$ 282	$ 292	$ -
	2050	$ 579	$ 611	$ 610	$ -
	Cumulative, 2000-2050	$ 10,910	$ 10,780	$ 10,806	$ 270
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of High-level Wastes from All Reprocessing of Cooled Spent LWR Fuel (UOx only) for Use in Domestic Reactors (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 132	$ 118	$ 136	$ -
	2050	$ 199	$ 177	$ 202	$ -
	Cumulative, 2000-2050	$ 4,116	$ 3,544	$ 4,022	$ 270

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Electricity Use for Treatment of High-level Wastes from Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (GWh)	2010	0.0	0.0	0.0	0.0
	2030	4.9	0.8	0.8	-
	2050	7.8	-	-	-
	Cumulative, 2000-2050	161.0	14.6	14.6	2.1

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Electricity Use for Treatment of High-level Wastes from Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (GWh)	2010	0.0	0.0	0.0	0.0
	2030	6.5	1.3	1.3	-
	2050	13.3	-	-	-
	Cumulative, 2000-2050	246.8	26.2	26.2	2.1

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Electricity Use for Treatment of High-level Wastes from Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (GWh)	2010	0.0	0.0	0.0	0.0
	2030	3.0	-	-	-
	2050	4.6	-	-	-
	Cumulative, 2000-2050	90.6	2.1	2.1	2.1

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Electricity Use for Treatment of High-level Wastes from Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (GWh)	2010	-	-	-	-
	2030	-	4.0	4.2	-
	2050	-	8.2	8.2	-
	Cumulative, 2000-2050	4.1	145.9	146.4	4.1

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Electricity Use for Treatment of High-level Wastes from Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (GWh)	2010	-	-	-	-
	2030	-	5.2	5.4	-
	2050	-	14.1	14.0	-
	Cumulative, 2000-2050	4.1	221.7	222.3	4.1

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Electricity Use for Treatment of High-level Wastes from Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (GWh)	2010	-	-	-	-
	2030	-	2.7	3.1	-
	2050	-	4.1	4.7	-
	Cumulative, 2000-2050	4.1	79.4	90.4	4.1

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Electricity Use for Treatment of High-level Wastes from All Reprocessing of Cooled Spent LWR Fuel (UOx only) for Use in Domestic Reactors (GWh)	2010	0.0	0.0	0.0	0.0
	2030	4.9	4.9	5.0	-
	2050	7.8	8.2	8.2	-
	Cumulative, 2000-2050	165.1	160.5	161.0	6.2
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Electricity Use for Treatment of High-level Wastes from All Reprocessing of Cooled Spent LWR Fuel (UOx only) for Use in Domestic Reactors (GWh)	2010	0.0	0.0	0.0	0.0
	2030	6.5	6.5	6.7	-
	2050	13.3	14.1	14.0	-
	Cumulative, 2000-2050	250.9	247.9	248.5	6.2
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Electricity Use for Treatment of High-level Wastes from All Reprocessing of Cooled Spent LWR Fuel (UOx only) for Use in Domestic Reactors (GWh)	2010	0.0	0.0	0.0	0.0
	2030	3.0	2.7	3.1	-
	2050	4.6	4.1	4.7	-
	Cumulative, 2000-2050	94.7	81.5	92.5	6.2

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Medium-level Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	282	48	48	-
	2050	453	-	-	-
	Cumulative, 2000-2050	9,332	848	848	122

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Medium-level Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (cubic meters)	2010	0.3	0.3	0.3	0.3
	2030	376.1	75.0	75.0	-
	2050	771.7	-	-	-
	Cumulative, 2000-2050	14,308.4	1,520.7	1,520.7	121.8

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Medium-level Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (cubic meters)	2010	0.3	0.3	0.3	0.3
	2030	176.4	-	-	-
	2050	265.1	-	-	-
	Cumulative, 2000-2050	5,250.7	121.8	121.8	121.8

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Medium-level Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (cubic meters)	2010	-	-	-	-
	2030	-	234	244	-
	2050	-	475	475	-
	Cumulative, 2000-2050	238	8,459	8,487	238
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Medium-level Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (cubic meters)	2010	-	-	-	-
	2030	-	301	315	-
	2050	-	815	813	-
	Cumulative, 2000-2050	238	12,852	12,888	238
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Medium-level Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (cubic meters)	2010	-	-	-	-
	2030	-	157	182	-
	2050	-	235	270	-
	Cumulative, 2000-2050	238	4,604	5,241	238

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Medium-level Waste from All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	282	282	292	-
	2050	453	475	475	-
	Cumulative, 2000-2050	9,569	9,307	9,334	360

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Medium-level Waste from All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	376	376	390	-
	2050	772	815	813	-
	Cumulative, 2000-2050	14,546	14,373	14,409	360

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Medium-level Waste from All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	176	157	182	-
	2050	265	235	270	-
	Cumulative, 2000-2050	5,489	4,726	5,362	360

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Low-level Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (cubic meters)	2010	2	2	2	2
	2030	1,974	337	337	-
	2050	3,171	-	-	-
	Cumulative, 2000-2050	65,321	5,933	5,933	853

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Low-level Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (cubic meters)	2010	2	2	2	2
	2030	2,633	525	525	-
	2050	5,402	-	-	-
	Cumulative, 2000-2050	100,159	10,645	10,645	853

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Low-level Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (cubic meters)	2010	2	2	2	2
	2030	1,235	-	-	-
	2050	1,856	-	-	-
	Cumulative, 2000-2050	36,755	853	853	853

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Low-level Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (cubic meters)	2010	-	-	-	-
	2030	-	1,635	1,705	-
	2050	-	3,326	3,322	-
	Cumulative, 2000-2050	1,665	59,215	59,406	1,665

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Low-level Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (cubic meters)	2010	-	-	-	-
	2030	-	2,106	2,204	-
	2050	-	5,704	5,692	-
	Cumulative, 2000-2050	1,665	89,967	90,215	1,665

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Low-level Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (cubic meters)	2010	-	-	-	-
	2030	-	1,099	1,273	-
	2050	-	1,648	1,887	-
	Cumulative, 2000-2050	1,665	32,229	36,684	1,665

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Low-level Waste from All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (cubic meters)	2010	2	2	2	2
	2030	1,974	1,972	2,042	-
	2050	3,171	3,326	3,322	-
	Cumulative, 2000-2050	66,986	65,148	65,340	2,517

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Low-level Waste from All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (cubic meters)	2010	2	2	2	2
	2030	2,633	2,631	2,729	-
	2050	5,402	5,704	5,692	-
	Cumulative, 2000-2050	101,823	100,612	100,860	2,517

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Low-level Waste from All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (cubic meters)	2010	2	2	2	2
	2030	1,235	1,099	1,273	-
	2050	1,856	1,648	1,887	-
	Cumulative, 2000-2050	38,420	33,081	37,537	2,517

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Solid Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	212	36	36	-
	2050	340	-	-	-
	Cumulative, 2000-2050	6,999	636	636	91
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Solid Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	282	56	56	-
	2050	579	-	-	-
	Cumulative, 2000-2050	10,731	1,141	1,141	91
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Solid Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed In-country for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	132	-	-	-
	2050	199	-	-	-
	Cumulative, 2000-2050	3,938	91	91	91

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Solid Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (cubic meters)	2010	-	-	-	-
	2030	-	175	183	-
	2050	-	356	356	-
	Cumulative, 2000-2050	178	6,344	6,365	178
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Solid Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (cubic meters)	2010	-	-	-	-
	2030	-	226	236	-
	2050	-	611	610	-
	Cumulative, 2000-2050	178	9,639	9,666	178
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Solid Waste from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Use in Domestic Reactors (cubic meters)	2010	-	-	-	-
	2030	-	118	136	-
	2050	-	177	202	-
	Cumulative, 2000-2050	178	3,453	3,930	178

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Solid Waste from All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	212	211	219	-
	2050	340	356	356	-
	Cumulative, 2000-2050	7,177	6,980	7,001	270
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Solid Waste from All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	282	282	292	-
	2050	579	611	610	-
	Cumulative, 2000-2050	10,910	10,780	10,806	270
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Volume of Solid Waste from All Cooled Spent LWR Fuel (UOx only) Reprocessed for Use in Domestic Reactors (cubic meters)	2010	0	0	0	0
	2030	132	118	136	-
	2050	199	177	202	-
	Cumulative, 2000-2050	4,116	3,544	4,022	270

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from Cooled Spent LWR Fuel (UOx only) Reprocessed in Domestic Plants, Less Plutonium Used to make MOx Fuel (metric tonnes heavy metal)	2010	(0.06)	(0.06)	(0.06)	(0.06)
	2030	4.23	2.65	0.57	-
	2050	(11.15)	-	(5.08)	-
	Cumulative, 2000-2050	(30.20)	45.60	(38.85)	6.56
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from Cooled Spent LWR Fuel (UOx only) Reprocessed in Domestic Plants, Less Plutonium Used to make MOx Fuel (metric tonnes heavy metal)	2010	(0)	(0)	(0)	(0)
	2030	3	4	1	-
	2050	(18)	-	(6)	-
	Cumulative, 2000-2050	(71)	82	(28)	7
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from Cooled Spent LWR Fuel (UOx only) Reprocessed in Domestic Plants, Less Plutonium Used to make MOx Fuel (metric tonnes heavy metal)	2010	(0)	(0)	(0)	(0)
	2030	3	-	(1)	-
	2050	(6)	-	(4)	-
	Cumulative, 2000-2050	(21)	6	(56)	7

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally, Less Plutonium Used to make MOx Fuel (metric tonnes heavy metal)	2010	(0.37)	(0.37)	(0.37)	(0.37)
	2030	0.00	1.57	4.16	-
	2050	(0.00)	(9.94)	(5.60)	-
	Cumulative, 2000-2050	12.08	(78.14)	(0.80)	12.59

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally, Less Plutonium Used to make MOx Fuel (metric tonnes heavy metal)	2010	(0)	(0)	(0)	(0)
	2030	-	(1)	2	-
	2050	(0)	(16)	(12)	-
	Cumulative, 2000-2050	12	(150)	(66)	13

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally, Less Plutonium Used to make MOx Fuel (metric tonnes heavy metal)	2010	(0)	(0)	(0)	(0)
	2030	(0)	2	5	-
	2050	0	(8)	(2)	-
	Cumulative, 2000-2050	12	(57)	40	13

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from All Cooled Spent LWR Fuel (UOx only) Reprocessed, Less Plutonium Used to make MOx Fuel (metric tonnes heavy metal)	2010	(0.43)	(0.43)	(0.43)	(0.43)
	2030	4.23	4.22	4.72	-
	2050	(11.15)	(9.94)	(10.68)	-
	Cumulative, 2000-2050	(18.12)	(32.54)	(39.65)	19.15
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from All Cooled Spent LWR Fuel (UOx only) Reprocessed, Less Plutonium Used to make MOx Fuel (metric tonnes heavy metal)	2010	(0)	(0)	(0)	(0)
	2030	3	3	3	-
	2050	(18)	(16)	(18)	-
	Cumulative, 2000-2050	(59)	(68)	(94)	19
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from All Cooled Spent LWR Fuel (UOx only) Reprocessed, Less Plutonium Used to make MOx Fuel (metric tonnes heavy metal)	2010	(0)	(0)	(0)	(0)
	2030	3	2	4	-
	2050	(6)	(8)	(6)	-
	Cumulative, 2000-2050	(9)	(51)	(16)	19

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from Cooled Spent LWR Fuel (UOx only) Reprocessed in Domestic Plants (metric tonnes heavy metal)	2010	0.01	0.01	0.01	0.01
	2030	15.51	2.65	2.65	-
	2050	24.92	-	-	-
	Cumulative, 2000-2050	513.24	46.62	46.62	6.70
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from Cooled Spent LWR Fuel (UOx only) Reprocessed in Domestic Plants (metric tonnes heavy metal)	2010	0.01	0.01	0.01	0.01
	2030	20.68	4.12	4.12	-
	2050	42.45	-	-	-
	Cumulative, 2000-2050	786.96	83.64	83.64	6.70
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from Cooled Spent LWR Fuel (UOx only) Reprocessed in Domestic Plants (metric tonnes heavy metal)	2010	0.01	0.01	0.01	0.01
	2030	9.70	-	-	-
	2050	14.58	-	-	-
	Cumulative, 2000-2050	288.79	6.70	6.70	6.70

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally (metric tonnes heavy metal)	2010	-	-	-	-
	2030	-	12.85	13.40	-
	2050	-	26.13	26.10	-
	Cumulative, 2000-2050	13.08	465.26	466.76	13.08
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally (metric tonnes heavy metal)	2010	-	-	-	-
	2030	-	17	17	-
	2050	-	45	45	-
	Cumulative, 2000-2050	13	707	709	13
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally (metric tonnes heavy metal)	2010	-	-	-	-
	2030	-	9	10	-
	2050	-	13	15	-
	Cumulative, 2000-2050	13	253	288	13

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from All Cooled Spent LWR Fuel (UOx only) Reprocessed (metric tonnes heavy metal)	2010	0.01	0.01	0.01	0.01
	2030	15.51	15.50	16.05	-
	2050	24.92	26.13	26.10	-
	Cumulative, 2000-2050	526.32	511.88	513.38	19.78

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from All Cooled Spent LWR Fuel (UOx only) Reprocessed (metric tonnes heavy metal)	2010	0	0	0	0
	2030	21	21	21	-
	2050	42	45	45	-
	Cumulative, 2000-2050	800	791	792	20

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Mass of Plutonium Separated from All Cooled Spent LWR Fuel (UOx only) Reprocessed (metric tonnes heavy metal)	2010	0	0	0	0
	2030	10	9	10	-
	2050	15	13	15	-
	Cumulative, 2000-2050	302	260	295	20

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost/Benefit of Storage/ safeguarding/ disposal of Plutonium from Reprocessing Operations (fraction not used as MOx) (Million dollars)	2010	$ 160	$ 160	$ 160	$ 160
	2030	$ 245	$ 215	$ 216	$ 159
	2050	$ 48	$ 4	$ (17)	$ 159
	Cumulative, 2000-2050	$ 9,608	$ 8,409	$ 8,297	$ 7,949
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost/Benefit of Storage/ safeguarding/ disposal of Plutonium from Reprocessing Operations (fraction not used as MOx) (Million dollars)	2010	$ 160	$ 160	$ 160	$ 160
	2030	$ 252	$ 219	$ 219	$ 159
	2050	$ (75)	$ (103)	$ (180)	$ 159
	Cumulative, 2000-2050	$ 9,422	$ 8,194	$ 7,676	$ 7,949
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost/Benefit of Storage/ safeguarding/ disposal of Plutonium from Reprocessing Operations (fraction not used as MOx) (Million dollars)	2010	$ 160	$ 160	$ 160	$ 160
	2030	$ 155	$ 115	$ 125	$ 159
	2050	$ 75	$ (51)	$ 54	$ 159
	Cumulative, 2000-2050	$ 7,784	$ 5,992	$ 7,154	$ 7,949

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost of Disposal of High-level Wastes from Reprocessing Operations (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 212	$ 211	$ 219	$ -
	2050	$ 340	$ 356	$ 356	$ -
	Cumulative, 2000-2050	$ 7,641	$ 7,444	$ 7,464	$ 733
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost of Disposal of High-level Wastes from Reprocessing Operations (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 282	$ 282	$ 292	$ -
	2050	$ 579	$ 611	$ 610	$ -
	Cumulative, 2000-2050	$ 11,373	$ 11,243	$ 11,270	$ 733
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost of Disposal of High-level Wastes from Reprocessing Operations (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 132	$ 118	$ 136	$ -
	2050	$ 199	$ 177	$ 202	$ -
	Cumulative, 2000-2050	$ 4,580	$ 4,008	$ 4,485	$ 733

(Note: Includes in 2000 value costs for HLW stocks accumulated by Japan by 2000, mostly from fuel reprocessed internationally)

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Mass of Uranium Separated during Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Domestically for Domestic Reactors (metric tonnes)	2010	1	1	1	1
	2030	1,325	226	226	-
	2050	2,129	-	-	-
	Cumulative, 2000-2050	43,859	3,984	3,984	573
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Mass of Uranium Separated during Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Domestically for Domestic Reactors (metric tonnes)	2010	1	1	1	1
	2030	1,768	352	352	-
	2050	3,627	-	-	-
	Cumulative, 2000-2050	67,249	7,147	7,147	573
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Mass of Uranium Separated during Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Domestically for Domestic Reactors (metric tonnes)	2010	1	1	1	1
	2030	829	-	-	-
	2050	1,246	-	-	-
	Cumulative, 2000-2050	24,678	573	573	573

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Mass of Uranium Separated during Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Domestic Reactors (metric tonnes)	2010	-	-	-	-
	2030	-	1,098	1,145	-
	2050	-	2,233	2,231	-
	Cumulative, 2000-2050	1,118	39,758	39,887	1,118
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Mass of Uranium Separated during Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Domestic Reactors (metric tonnes)	2010	-	-	-	-
	2030	-	1,414.1	1,479.9	-
	2050	-	3,829.8	3,821.8	-
	Cumulative, 2000-2050	1,117.7	60,406.5	60,573.1	1,117.7
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Mass of Uranium Separated during Reprocessing of Cooled Spent LWR Fuel (UOx only) Reprocessed Internationally for Domestic Reactors (metric tonnes)	2010	-	-	-	-
	2030	-	738	855	-
	2050	-	1,106	1,267	-
	Cumulative, 2000-2050	1,118	21,639	24,631	1,118

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Mass of Uranium Separated during All Reprocessing of Cooled Spent LWR Fuel (UOx only) for Domestic Reactors (metric tonnes)	2010	1	1	1	1
	2030	1,325	1,324	1,371	-
	2050	2,129	2,233	2,231	-
	Cumulative, 2000-2050	44,976	43,742	43,871	1,690
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Mass of Uranium Separated during All Reprocessing of Cooled Spent LWR Fuel (UOx only) for Domestic Reactors (metric tonnes)	2010	1	1	1	1
	2030	1,768	1,766	1,832	-
	2050	3,627	3,830	3,822	-
	Cumulative, 2000-2050	68,367	67,554	67,720	1,690
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Mass of Uranium Separated during All Reprocessing of Cooled Spent LWR Fuel (UOx only) for Domestic Reactors (metric tonnes)	2010	1	1	1	1
	2030	829	738	855	-
	2050	1,246	1,106	1,267	-
	Cumulative, 2000-2050	25,796	22,212	25,203	1,690

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Number of Casks Required for Dry Cask Storage of Cooled Spent LWR Fuel (UOx only) for Storage/Disposal, Net of Reprocessing (units)	2010	28	126	126	126
	2030	20	56	51	198
	2050	112	147	147	413
	Cumulative, 2000-2050	2,383	5,312	5,294	10,089

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Number of Casks Required for Dry Cask Storage of Cooled Spent LWR Fuel (UOx only) for Storage/Disposal, Net of Reprocessing (units)	2010	28	126	126	126
	2030	-	27	20	219
	2050	90	160	159	610
	Cumulative, 2000-2050	1,293	4,851	4,822	12,326

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Number of Casks Required for Dry Cask Storage of Cooled Spent LWR Fuel (UOx only) for Storage/Disposal, Net of Reprocessing (units)	2010	28	126	126	126
	2030	28	96	83	176
	2050	71	127	110	259
	Cumulative, 2000-2050	3,258	5,712	5,394	8,071

Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		BAU Capacity Expansion Paths			
Total Annual Number of Casks Required for Dry Cask Storage of Cooled Spent LWR MOx Fuel for Storage/Disposal (units)	2010	-	-	-	-
	2030	2	2	2	-
	2050	28	28	28	-
	Cumulative, 2000-2050	304	304	308	1
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Number of Casks Required for Dry Cask Storage of Cooled Spent LWR MOx Fuel for Storage/Disposal (units)	2010	-	-	-	-
	2030	3.9	3.9	3.9	-
	2050	42.9	42.9	44.4	-
	Cumulative, 2000-2050	468.4	468.3	479.9	0.7
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Number of Casks Required for Dry Cask Storage of Cooled Spent LWR MOx Fuel for Storage/Disposal (units)	2010	-	-	-	-
	2030	1	1	1	-
	2050	15	15	15	-
	Cumulative, 2000-2050	176	176	176	1

Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		BAU Capacity Expansion Paths			
Total Annual Number of Casks Required for Cooled Spent LWR Fuel, UOx and MOx, for Domestic Reactors (units)	2010	28	126	126	126
	2030	22	57	52	198
	2050	140	175	175	413
	Cumulative, 2000-2050	2,688	5,616	5,602	10,090
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Number of Casks Required for Cooled Spent LWR Fuel, UOx and MOx, for Domestic Reactors (units)	2010	28	126	126	126
	2030	4	31	24	219
	2050	133	203	203	610
	Cumulative, 2000-2050	1,761	5,320	5,302	12,326
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Number of Casks Required for Cooled Spent LWR Fuel, UOx and MOx, for Domestic Reactors (units)	2010	28	126	126	126
	2030	30	97	85	176
	2050	85	142	124	259
	Cumulative, 2000-2050	3,434	5,888	5,570	8,071

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost of Casks Required for Dry Cask Storage of Cooled Spent LWR Fuel (UOx only) for Storage/Disposal, Not Including Spent Fuel Reprocessed Domestically or Internationally (Million dollars)	2010	$ 23	$ 101	$ 101	$ 101
	2030	$ 16	$ 45	$ 41	$ 159
	2050	$ 89	$ 118	$ 117	$ 330
	Cumulative, 2000-2050	$ 1,907	$ 4,250	$ 4,235	$ 8,071

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost of Casks Required for Dry Cask Storage of Cooled Spent LWR Fuel (UOx only) for Storage/Disposal, Not Including Spent Fuel Reprocessed Domestically or Internationally (Million dollars)	2010	$ 23	$ 101	$ 101	$ 101
	2030	$ -	$ 22	$ 16	$ 175
	2050	$ 72	$ 128	$ 127	$ 488
	Cumulative, 2000-2050	$ 1,034	$ 3,881	$ 3,858	$ 9,861

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost of Casks Required for Dry Cask Storage of Cooled Spent LWR Fuel (UOx only) for Storage/Disposal, Not Including Spent Fuel Reprocessed Domestically or Internationally (Million dollars)	2010	$ 23	$ 101	$ 101	$ 101
	2030	$ 23	$ 77	$ 67	$ 140
	2050	$ 56	$ 101	$ 88	$ 207
	Cumulative, 2000-2050	$ 2,606	$ 4,570	$ 4,315	$ 6,457

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost of Casks Required for Dry Cask Storage of Cooled Spent LWR MOx Fuel for Storage/Disposal (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ 1.33	$ 1.33	$ 1.33	$ -
	2050	$ 22.34	$ 22.34	$ 22.73	$ -
	Cumulative, 2000-2050	$ 243.37	$ 243.35	$ 246.50	$ 0.53
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost of Casks Required for Dry Cask Storage of Cooled Spent LWR MOx Fuel for Storage/Disposal (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ 3.13	$ 3.13	$ 3.13	$ -
	2050	$ 34.36	$ 34.36	$ 35.49	$ -
	Cumulative, 2000-2050	$ 374.73	$ 374.68	$ 383.95	$ 0.53
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost of Casks Required for Dry Cask Storage of Cooled Spent LWR MOx Fuel for Storage/Disposal (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ 1.16	$ 1.16	$ 1.16	$ -
	2050	$ 11.91	$ 11.91	$ 11.91	$ -
	Cumulative, 2000-2050	$ 141.05	$ 141.05	$ 141.05	$ 0.53

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost of Casks Required for Dry Cask Storage of Cooled Spent LWR UOx and MOx Fuel for Storage/Disposal (Million dollars)	2010	$ 23	$ 101	$ 101	$ 101
	2030	$ 17	$ 46	$ 42	$ 159
	2050	$ 112	$ 140	$ 140	$ 330
	Cumulative, 2000-2050	$ 2,150	$ 4,493	$ 4,482	$ 8,072
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost of Casks Required for Dry Cask Storage of Cooled Spent LWR UOx and MOx Fuel for Storage/Disposal (Million dollars)	2010	23	101	101	101
	2030	3	25	19	175
	2050	107	162	163	488
	Cumulative, 2000-2050	1,409	4,256	4,242	9,861
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Cost of Casks Required for Dry Cask Storage of Cooled Spent LWR UOx and MOx Fuel for Storage/Disposal (Million dollars)	2010	23	101	101	101
	2030	24	78	68	140
	2050	68	113	100	207
	Cumulative, 2000-2050	2,748	4,711	4,456	6,457

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Operating and Maintenance Cost for Casks Required for Dry Cask Storage of Cooled Spent LWR Fuel (UOx only) for Storage/Disposal Beyond Spent Fuel Pool Capacity, Not Including Spent Fuel Reprocessed Domestically or Internationally (Million dollars)	2010	$ 1	$ 11	$ 11	$ 11
	2030	$ 12	$ 30	$ 29	$ 36
	2050	$ 31	$ 53	$ 53	$ 101
	Cumulative, 2000-2050	$ 544	$ 1,314	$ 1,311	$ 1,861

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Operating and Maintenance Cost for Casks Required for Dry Cask Storage of Cooled Spent LWR Fuel (UOx only) for Storage/Disposal Beyond Spent Fuel Pool Capacity, Not Including Spent Fuel Reprocessed Domestically or Internationally (Million	2010	$ 1	$ 11	$ 11	$ 11
	2030	$ 11	$ 26	$ 26	$ 37
	2050	$ 17	$ 49	$ 48	$ 123
	Cumulative, 2000-2050	$ 391	$ 1,192	$ 1,187	$ 2,044

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Operating and Maintenance Cost for Casks Required for Dry Cask Storage of Cooled Spent LWR Fuel (UOx only) for Storage/Disposal Beyond Spent Fuel Pool Capacity, Not Including Spent Fuel Reprocessed Domestically or Internationally (Million	2010	$ 1	$ 11	$ 11	$ 11
	2030	$ 29	$ 34	$ 34	$ 36
	2050	$ 56	$ 57	$ 54	$ 81
	Cumulative, 2000-2050	$ 1,160	$ 1,440	$ 1,405	$ 1,691

		BAU Capacity Expansion Paths							
Parameter	YEAR	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Total Annual Operating and Maintenance Cost for Casks Required for Dry Cask Storage of Cooled Spent LWR MOx Fuel for Storage/Disposal (Million dollars)	2010	$	-	$	-	$	-	$	-
	2030	$	0.06	$	0.06	$	0.06	$	0.01
	2050	$	3.04	$	3.04	$	3.08	$	0.01
	Cumulative, 2000-2050	$	23.42	$	23.41	$	23.63	$	0.21

		MAX Capacity Expansion Paths							
Parameter	YEAR	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Total Annual Operating and Maintenance Cost for Casks Required for Dry Cask Storage of Cooled Spent LWR MOx Fuel for Storage/Disposal (Million dollars)	2010	$	-	$	-	$	-	$	-
	2030	$	0.11	$	0.11	$	0.11	$	0.01
	2050	$	4.68	$	4.68	$	4.80	$	0.01
	Cumulative, 2000-2050	$	37.76	$	37.75	$	38.39	$	0.21

		MIN Capacity Expansion Paths							
Parameter	YEAR	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Total Annual Operating and Maintenance Cost for Casks Required for Dry Cask Storage of Cooled Spent LWR MOx Fuel for Storage/Disposal (Million dollars)	2010	$	-	$	-	$	-	$	-
	2030	$	0.06	$	0.06	$	0.06	$	0.01
	2050	$	1.76	$	1.76	$	1.76	$	0.01
	Cumulative, 2000-2050	$	14.10	$	14.10	$	14.10	$	0.21

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Operating and Maintenance Cost for Casks Required for Dry Cask Storage of All Cooled Spent LWR Fuel for Storage/Disposal (Million dollars)	2010	$ 1	$ 11	$ 11	$ 11
	2030	$ 12	$ 30	$ 30	$ 36
	2050	$ 34	$ 56	$ 56	$ 101
	Cumulative, 2000-2050	$ 567	$ 1,337	$ 1,334	$ 1,861

		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Operating and Maintenance Cost for Casks Required for Dry Cask Storage of All Cooled Spent LWR Fuel for Storage/Disposal (Million dollars)	2010	$ 1	$ 11	$ 11	$ 11
	2030	$ 11	$ 26	$ 26	$ 37
	2050	$ 22	$ 53	$ 53	$ 123
	Cumulative, 2000-2050	$ 429	$ 1,230	$ 1,226	$ 2,044

		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Operating and Maintenance Cost for Casks Required for Dry Cask Storage of All Cooled Spent LWR Fuel for Storage/Disposal (Million dollars)	2010	$ 1	$ 11	$ 11	$ 11
	2030	$ 29	$ 34	$ 34	$ 36
	2050	$ 58	$ 59	$ 56	$ 81
	Cumulative, 2000-2050	$ 1,174	$ 1,454	$ 1,419	$ 1,691

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Storage/Disposal of Cooled Spent LWR Fuel (UOx only), Not Including Spent Fuel Reprocessed Domestically or Internationally (Million dollars)	2010	$ 102	$ 454	$ 454	$ 353
	2030	$ 24	$ 200	$ 182	$ 254
	2050	$ 355	$ 529	$ 529	$ 569
	Cumulative, 2000-2050	$ 7,336	$ 19,123	$ 19,059	$ 16,437
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Storage/Disposal of Cooled Spent LWR Fuel (UOx only), Not Including Spent Fuel Reprocessed Domestically or Internationally (Million dollars)	2010	$ 24	$ 454	$ 454	$ 353
	2030	$ 11	$ 98	$ 73	$ 314
	2050	$ 192	$ 574	$ 572	$ 824
	Cumulative, 2000-2050	$ 1,631	$ 17,465	$ 17,359	$ 19,929
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Storage/Disposal of Cooled Spent LWR Fuel (UOx only), Not Including Spent Fuel Reprocessed Domestically or Internationally (Million dollars)	2010	$ 102	$ 454	$ 454	$ 353
	2030	$ 47	$ 344	$ 300	$ 226
	2050	$ 256	$ 456	$ 395	$ 322
	Cumulative, 2000-2050	$ 7,710	$ 20,563	$ 19,417	$ 13,386

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Storage/Disposal of Cooled Spent MOx Fuel (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ 1	$ 6	$ 6	$ -
	2050	$ 84	$ 101	$ 102	$ -
	Cumulative, 2000-2050	$ 759	$ 1,095	$ 1,109	$ 2
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Storage/Disposal of Cooled Spent MOx Fuel (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ 3	$ 14	$ 14	$ -
	2050	$ 104	$ 155	$ 160	$ -
	Cumulative, 2000-2050	$ 902	$ 1,686	$ 1,728	$ 2
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Storage/Disposal of Cooled Spent MOx Fuel (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ 1	$ 5	$ 5	$ -
	2050	$ 53	$ 54	$ 54	$ -
	Cumulative, 2000-2050	$ 505	$ 635	$ 635	$ 2

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Storage/Disposal of All Cooled Spent Fuel (Million dollars)	2010	$ 102	$ 454	$ 454	$ 353
	2030	$ 25	$ 206	$ 188	$ 254
	2050	$ 439	$ 630	$ 631	$ 569
	Cumulative, 2000-2050	$ 8,095	$ 20,218	$ 20,169	$ 16,440
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Storage/Disposal of All Cooled Spent Fuel (Million dollars)	2010	$ 24	$ 454	$ 454	$ 353
	2030	$ 14	$ 112	$ 87	$ 314
	2050	$ 296	$ 729	$ 732	$ 824
	Cumulative, 2000-2050	$ 2,533	$ 19,151	$ 19,087	$ 19,931
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Storage/Disposal of All Cooled Spent Fuel (Million dollars)	2010	$ 102	$ 454	$ 454	$ 353
	2030	$ 48	$ 350	$ 305	$ 226
	2050	$ 309	$ 510	$ 448	$ 322
	Cumulative, 2000-2050	$ 8,215	$ 21,198	$ 20,052	$ 13,388

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Operating and Maintenance Costs of Storing Cooled Spent LWR Fuel (UOx only) Remaining in Spent Fuel Pools (Million dollars)	2010	$ 131	$ 90	$ 90	$ 90
	2030	$ 257	$ 90	$ 90	$ 90
	2050	$ 339	$ 90	$ 90	$ 90
	Cumulative, 2000-2050	$ 11,189	$ 4,607	$ 4,607	$ 4,607
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Operating and Maintenance Costs of Storing Cooled Spent LWR Fuel (UOx only) Remaining in Spent Fuel Pools (Million dollars)	2010	$ 131	$ 90	$ 90	$ 90
	2030	$ 219	$ 90	$ 90	$ 90
	2050	$ 418	$ 90	$ 90	$ 90
	Cumulative, 2000-2050	$ 11,015	$ 4,607	$ 4,607	$ 4,607
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Operating and Maintenance Costs of Storing Cooled Spent LWR Fuel (UOx only) Remaining in Spent Fuel Pools (Million dollars)	2010	$ 131	$ 90	$ 90	$ 90
	2030	$ 224	$ 90	$ 90	$ 90
	2050	$ 254	$ 90	$ 90	$ 90
	Cumulative, 2000-2050	$ 9,555	$ 4,607	$ 4,607	$ 4,607

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Operating and Maintenance Costs of Storing Cooled Spent LWR Fuel (MOx only) Remaining in Spent Fuel Pools (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ 1	$ 1	$ 1	$ 0
	2050	$ 71	$ 71	$ 72	$ 0
	Cumulative, 2000-2050	$ 548	$ 548	$ 553	$ 5

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Operating and Maintenance Costs of Storing Cooled Spent LWR Fuel (MOx only) Remaining in Spent Fuel Pools (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ 3	$ 3	$ 3	$ 0
	2050	$ 110	$ 110	$ 112	$ 0
	Cumulative, 2000-2050	$ 884	$ 884	$ 899	$ 5

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Annual Implied Operating and Maintenance Costs of Storing Cooled Spent LWR Fuel (MOx only) Remaining in Spent Fuel Pools (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ 1	$ 1	$ 1	$ 0
	2050	$ 41	$ 41	$ 41	$ 0
	Cumulative, 2000-2050	$ 330	$ 330	$ 330	$ 5

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Operating and Maintenance Cost of Spent Fuel Pool Storage of All Cooled Fuel after Other Storage/Disposal Implemented (Million dollars)	2010	$ 131	$ 90	$ 90	$ 90
	2030	$ 259	$ 92	$ 92	$ 90
	2050	$ 410	$ 162	$ 162	$ 90
	Cumulative, 2000-2050	$ 11,737	$ 5,155	$ 5,160	$ 4,612
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Operating and Maintenance Cost of Spent Fuel Pool Storage of All Cooled Fuel after Other Storage/Disposal Implemented (Million dollars)	2010	$ 131	$ 90	$ 90	$ 90
	2030	$ 222	$ 93	$ 93	$ 90
	2050	$ 527	$ 200	$ 203	$ 90
	Cumulative, 2000-2050	$ 11,900	$ 5,491	$ 5,506	$ 4,612
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Operating and Maintenance Cost of Spent Fuel Pool Storage of All Cooled Fuel after Other Storage/Disposal Implemented (Million dollars)	2010	$ 131	$ 90	$ 90	$ 90
	2030	$ 225	$ 92	$ 92	$ 90
	2050	$ 295	$ 132	$ 132	$ 90
	Cumulative, 2000-2050	$ 9,886	$ 4,937	$ 4,937	$ 4,612

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Transport to Storage/Disposal for LWR Fuel (UOx only), Not Including Spent Fuel Reprocessed Domestically or Internationally (Million dollars)	2010	$ 6	$ 149	$ 149	$ 18
	2030	$ -	$ 89	$ 83	$ 6
	2050	$ 59	$ 175	$ 174	$ 13
	Cumulative, 2000-2050	$ 913	$ 6,655	$ 6,628	$ 530

	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Transport to Storage/Disposal for LWR Fuel (UOx only), Not Including Spent Fuel Reprocessed Domestically or Internationally (Million dollars)	2010	$ 0	$ 149	$ 149	$ 18
	2030	$ -	$ 68	$ 59	$ 9
	2050	$ 22	$ 192	$ 188	$ 28
	Cumulative, 2000-2050	$ 50	$ 6,456	$ 6,392	$ 719

	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Transport to Storage/Disposal for LWR Fuel (UOx only), Not Including Spent Fuel Reprocessed Domestically or Internationally (Million dollars)	2010	$ 6	$ 149	$ 149	$ 18
	2030	$ -	$ 114	$ 99	$ 5
	2050	$ 40	$ 150	$ 130	$ 4
	Cumulative, 2000-2050	$ 773	$ 6,772	$ 6,392	$ 427

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Transport to Storage/Disposal for Cooled Spent MOx Fuel (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 2.0	$ 2.0	$ -
	2050	$ 13.4	$ 33.1	$ 33.7	$ -
	Cumulative, 2000-2050	$ 111.0	$ 360.5	$ 365.1	$ 0.1
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Transport to Storage/Disposal for Cooled Spent MOx Fuel (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 4.6	$ 4.6	$ -
	2050	$ 18.8	$ 50.9	$ 52.6	$ -
	Cumulative, 2000-2050	$ 141.1	$ 555.0	$ 568.7	$ 0.1
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Transport to Storage/Disposal for Cooled Spent MOx Fuel (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 1.7	$ 1.7	$ -
	2050	$ 9.5	$ 17.6	$ 17.6	$ -
	Cumulative, 2000-2050	$ 81.2	$ 208.9	$ 208.9	$ 0.1

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Transport to Storage/Disposal for All Cooled Spent Fuel (Million dollars)	2010	$ 6	$ 149	$ 149	$ 18
	2030	$ -	$ 91	$ 85	$ 6
	2050	$ 72	$ 208	$ 208	$ 13
	Cumulative, 2000-2050	$ 1,024	$ 7,016	$ 6,993	$ 530
		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Transport to Storage/Disposal for All Cooled Spent Fuel (Million dollars)	2010	$ 0	$ 149	$ 149	$ 18
	2030	$ -	$ 72	$ 64	$ 9
	2050	$ 41	$ 243	$ 241	$ 28
	Cumulative, 2000-2050	$ 191	$ 7,011	$ 6,961	$ 719
		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Total Cost of Transport to Storage/Disposal for All Cooled Spent Fuel (Million dollars)	2010	$ 6	$ 149	$ 149	$ 18
	2030	$ -	$ 115	$ 100	$ 5
	2050	$ 49	$ 168	$ 148	$ 4
	Cumulative, 2000-2050	$ 854	$ 6,981	$ 6,600	$ 427

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Medium-level Wastes from Reprocessing In-country (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 88	$ 15	$ 15	$ -
	2050	$ 141	$ -	$ -	$ -
	Cumulative, 2000-2050	$ 2,901	$ 264	$ 264	$ 38
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Medium-level Wastes from Reprocessing In-country (Million dollars)	2010	0	0	0	0
	2030	117	23	23	-
	2050	240	-	-	-
	Cumulative, 2000-2050	4,448	473	473	38
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Medium-level Wastes from Reprocessing In-country (Million dollars)	2010	0	0	0	0
	2030	55	-	-	-
	2050	82	-	-	-
	Cumulative, 2000-2050	1,632	38	38	38

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Medium-level Wastes from Reprocessing Out-of--country (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 73	$ 76	$ -
	2050	$ -	$ 148	$ 148	$ -
	Cumulative, 2000-2050	$ 74	$ 2,630	$ 2,638	$ 74
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Medium-level Wastes from Reprocessing Out-of--country (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 94	$ 98	$ -
	2050	$ -	$ 253	$ 253	$ -
	Cumulative, 2000-2050	$ 74	$ 3,996	$ 4,007	$ 74
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Medium-level Wastes from Reprocessing Out-of--country (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 49	$ 57	$ -
	2050	$ -	$ 73	$ 84	$ -
	Cumulative, 2000-2050	$ 74	$ 1,431	$ 1,629	$ 74

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Medium-level Wastes from All Reprocessing (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 88	$ 88	$ 91	$ -
	2050	$ 141	$ 148	$ 148	$ -
	Cumulative, 2000-2050	$ 2,975	$ 2,893	$ 2,902	$ 112
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Medium-level Wastes from All Reprocessing (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 117	$ 117	$ 121	$ -
	2050	$ 240	$ 253	$ 253	$ -
	Cumulative, 2000-2050	$ 4,522	$ 4,469	$ 4,480	$ 112
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Medium-level Wastes from All Reprocessing (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 55	$ 49	$ 57	$ -
	2050	$ 82	$ 73	$ 84	$ -
	Cumulative, 2000-2050	$ 1,706	$ 1,469	$ 1,667	$ 112

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Low-level Wastes from Reprocessing In-country for Use in Domestic Reactors (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 37	$ 6	$ 6	$ -
	2050	$ 60	$ -	$ -	$ -
	Cumulative, 2000-2050	$ 1,236	$ 112	$ 112	$ 16
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Low-level Wastes from Reprocessing In-country for Use in Domestic Reactors (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 50	$ 10	$ 10	$ -
	2050	$ 102	$ -	$ -	$ -
	Cumulative, 2000-2050	$ 1,896	$ 201	$ 201	$ 16
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Low-level Wastes from Reprocessing In-country for Use in Domestic Reactors (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 23	$ -	$ -	$ -
	2050	$ 35	$ -	$ -	$ -
	Cumulative, 2000-2050	$ 696	$ 16	$ 16	$ 16

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Low-level Wastes from Reprocessing Out-of-country (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 31	$ 32	$ -
	2050	$ -	$ 63	$ 63	$ -
	Cumulative, 2000-2050	$ 32	$ 1,121	$ 1,124	$ 32
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Low-level Wastes from Reprocessing Out-of-country (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 40	$ 42	$ -
	2050	$ -	$ 108	$ 108	$ -
	Cumulative, 2000-2050	$ 32	$ 1,703	$ 1,708	$ 32
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Low-level Wastes from Reprocessing Out-of-country (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 21	$ 24	$ -
	2050	$ -	$ 31	$ 36	$ -
	Cumulative, 2000-2050	$ 32	$ 610	$ 694	$ 32

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Low-level Wastes from All Reprocessing (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 37	$ 37	$ 39	$ -
	2050	$ 60	$ 63	$ 63	$ -
	Cumulative, 2000-2050	$ 1,268	$ 1,233	$ 1,237	$ 48
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Low-level Wastes from All Reprocessing (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 50	$ 50	$ 52	$ -
	2050	$ 102	$ 108	$ 108	$ -
	Cumulative, 2000-2050	$ 1,927	$ 1,904	$ 1,909	$ 48
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Low-level Wastes from All Reprocessing (Million dollars)	2010	$ 0	$ 0	$ 0	$ 0
	2030	$ 23	$ 21	$ 24	$ -
	2050	$ 35	$ 31	$ 36	$ -
	Cumulative, 2000-2050	$ 727	$ 626	$ 711	$ 48

Parameter	YEAR	BAU Capacity Expansion Paths Scenario 1	 Scenario 2	 Scenario 3	 Scenario 4
Implied Costs for Treatment and Disposal/Storage of Solid Wastes from Reprocessing In-country (Million dollars)	2010	$ 0.0	$ 0.0	$ 0.0	$ 0.0
	2030	$ 0.2	$ 0.0	$ 0.0	$ -
	2050	$ 0.3	$ -	$ -	$ -
	Cumulative, 2000-2050	$ 6.7	$ 0.6	$ 0.6	$ 0.1

Parameter	YEAR	MAX Capacity Expansion Paths Scenario 1	 Scenario 2	 Scenario 3	 Scenario 4
Implied Costs for Treatment and Disposal/Storage of Solid Wastes from Reprocessing In-country (Million dollars)	2010	$ 0.0	$ 0.0	$ 0.0	$ 0.0
	2030	$ 0.3	$ 0.1	$ 0.1	$ -
	2050	$ 0.6	$ -	$ -	$ -
	Cumulative, 2000-2050	$ 10.3	$ 1.1	$ 1.1	$ 0.1

Parameter	YEAR	MIN Capacity Expansion Paths Scenario 1	 Scenario 2	 Scenario 3	 Scenario 4
Implied Costs for Treatment and Disposal/Storage of Solid Wastes from Reprocessing In-country (Million dollars)	2010	$ 0.0	$ 0.0	$ 0.0	$ 0.0
	2030	$ 0.1	$ -	$ -	$ -
	2050	$ 0.2	$ -	$ -	$ -
	Cumulative, 2000-2050	$ 3.8	$ 0.1	$ 0.1	$ 0.1

Parameter	YEAR	BAU Capacity Expansion Paths Scenario 1	 Scenario 2	 Scenario 3	 Scenario 4
Implied Costs for Treatment and Disposal/Storage of Solid Wastes from Reprocessing Out-of-country (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 0.2	$ 0.2	$ -
	2050	$ -	$ 0.3	$ 0.3	$ -
	Cumulative, 2000-2050	$ 0.2	$ 6.1	$ 6.1	$ 0.2

Parameter	YEAR	MAX Capacity Expansion Paths Scenario 1	 Scenario 2	 Scenario 3	 Scenario 4
Implied Costs for Treatment and Disposal/Storage of Solid Wastes from Reprocessing Out-of-country (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 0.2	$ 0.2	$ -
	2050	$ -	$ 0.6	$ 0.6	$ -
	Cumulative, 2000-2050	$ 0.2	$ 9.3	$ 9.3	$ 0.2

Parameter	YEAR	MIN Capacity Expansion Paths Scenario 1	 Scenario 2	 Scenario 3	 Scenario 4
Implied Costs for Treatment and Disposal/Storage of Solid Wastes from Reprocessing Out-of-country (Million dollars)	2010	$ -	$ -	$ -	$ -
	2030	$ -	$ 0.1	$ 0.1	$ -
	2050	$ -	$ 0.2	$ 0.2	$ -
	Cumulative, 2000-2050	$ 0.2	$ 3.3	$ 3.8	$ 0.2

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Solid Wastes from All Reprocessing (Million dollars)	2010	$ 0.0	$ 0.0	$ 0.0	$ 0.0
	2030	$ 0.2	$ 0.2	$ 0.2	$ -
	2050	$ 0.3	$ 0.3	$ 0.3	$ -
	Cumulative, 2000-2050	$ 6.9	$ 6.7	$ 6.7	$ 0.3
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Solid Wastes from All Reprocessing (Million dollars)	2010	$ 0.0	$ 0.0	$ 0.0	$ 0.0
	2030	$ 0.3	$ 0.3	$ 0.3	$ -
	2050	$ 0.6	$ 0.6	$ 0.6	$ -
	Cumulative, 2000-2050	$ 10.5	$ 10.4	$ 10.4	$ 0.3
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Solid Wastes from All Reprocessing (Million dollars)	2010	$ 0.0	$ 0.0	$ 0.0	$ 0.0
	2030	$ 0.1	$ 0.1	$ 0.1	$ -
	2050	$ 0.2	$ 0.2	$ 0.2	$ -
	Cumulative, 2000-2050	$ 4.0	$ 3.4	$ 3.9	$ 0.3

	BAU Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Uranium Separated During from Reprocessing In-country (Million dollars)	2010	$ 0.0	$ 0.0	$ 0.0	$ 0.0
	2030	$ 10.4	$ 1.9	$ 1.8	$ -
	2050	$ 15.3	$ -	$ (0.4)	$ -
	Cumulative, 2000-2050	$ 331.6	$ 34.1	$ 27.2	$ 4.9
	MAX Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Uranium Separated During from Reprocessing In-country (Million dollars)	2010	0.0	0.0	0.0	0.0
	2030	13.7	3.0	2.8	-
	2050	26.2	-	(0.5)	-
	Cumulative, 2000-2050	506.4	61.1	52.1	4.9
	MIN Capacity Expansion Paths				
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Uranium Separated During from Reprocessing In-country (Million dollars)	2010	0.0	0.0	0.0	0.0
	2030	6.6	-	(0.1)	-
	2050	9.0	-	(0.3)	-
	Cumulative, 2000-2050	186.2	4.8	(0.2)	4.9

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Uranium Separated During from Reprocessing Out-of-country (Million dollars)	2010	$ (0.0)	$ (0.0)	$ (0.0)	$ (0.0)
	2030	$ 0.0	$ 8.5	$ 9.1	$ -
	2050	$ (0.0)	$ 16.2	$ 16.5	$ -
	Cumulative, 2000-2050	$ 9.5	$ 296.4	$ 303.7	$ 9.5

		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Uranium Separated During from Reprocessing Out-of-country (Million dollars)	2010	$ (0.0)	$ (0.0)	$ (0.0)	$ (0.0)
	2030	$ -	$ 10.7	$ 11.5	$ -
	2050	$ (0.0)	$ 27.9	$ 28.1	$ -
	Cumulative, 2000-2050	$ 9.5	$ 447.8	$ 456.0	$ 9.5

		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Uranium Separated During from Reprocessing Out-of-country (Million dollars)	2010	$ (0.0)	$ (0.0)	$ (0.0)	$ (0.0)
	2030	$ (0.0)	$ 5.8	$ 6.9	$ -
	2050	$ 0.0	$ 7.8	$ 9.5	$ -
	Cumulative, 2000-2050	$ 9.5	$ 160.2	$ 190.9	$ 9.5

		BAU Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Uranium Separated During from All Reprocessing (Million dollars)	2010	$ (0.0)	$ (0.0)	$ (0.0)	$ (0.0)
	2030	$ 10.4	$ 10.4	$ 10.8	$ -
	2050	$ 15.3	$ 16.2	$ 16.1	$ -
	Cumulative, 2000-2050	$ 341.1	$ 330.5	$ 330.9	$ 14.4

		MAX Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Uranium Separated During from All Reprocessing (Million dollars)	2010	$ (0.0)	$ (0.0)	$ (0.0)	$ (0.0)
	2030	$ 13.7	$ 13.7	$ 14.2	$ -
	2050	$ 26.2	$ 27.9	$ 27.6	$ -
	Cumulative, 2000-2050	$ 515.9	$ 508.9	$ 508.1	$ 14.4

		MIN Capacity Expansion Paths			
Parameter	YEAR	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Implied Costs for Treatment and Disposal/Storage of Uranium Separated During from All Reprocessing (Million dollars)	2010	$ (0.0)	$ (0.0)	$ (0.0)	$ (0.0)
	2030	$ 6.6	$ 5.8	$ 6.8	$ -
	2050	$ 9.0	$ 7.8	$ 9.1	$ -
	Cumulative, 2000-2050	$ 195.7	$ 165.0	$ 190.6	$ 14.4

ANNEX 2C: Inputs and Selected Results: Estimate of Non-Fuel Cycle Nuclear Power Costs

FUTURE REGIONAL NUCLEAR FUEL CYCLE COOPERATION IN EAST ASIA: ENERGY SECURITY COSTS AND BENEFITS

Calculations for East Asia Science and Security (EASS) and Related Follow-on (2012-2016) Projects, funded by MacArthur Foundation

Rough Estimates of Non-Fuel-Cycle Nuclear Power Costs by Nation and Region

Prepared by:	David Von Hippel
Last Modified:	11/14/2016

Components of Nuclear Power Costs: Assumptions

All costs assumed to be in approximately 2009 dollars

Cost Component/Parameter	Units	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia
Fleet Average Initial Capital Cost, 2010	$/kW	$ 4,000	$ 2,200	$ 2,200	$ 2,200	$ 4,000	$ 2,200	$ 2,200	$ 2,200	$ 3,500
Fleet Average Initial Capital Cost, 2030	$/kW	$ 4,500	$ 2,600	$ 2,600	$ 2,600	$ 5,000	$ 2,600	$ 2,600	$ 4,000	$ 4,000
Fleet Average Initial Capital Cost, 2050	$/kW	$ 4,500	$ 3,000	$ 3,000	$ 3,000	$ 5,000	$ 3,000	$ 3,000	$ 5,000	$ 5,000
Interest Rate for Annualizing Capital Costs, 2010	%/yr	5%	5%	5%	5%	5%	5%	5%	5%	5%
Interest Rate for Annualizing Capital Costs, 2030	%/yr	5%	5%	5%	5%	5%	5%	5%	5%	5%
Interest Rate for Annualizing Capital Costs, 2050	%/yr	5%	5%	5%	5%	5%	5%	5%	5%	5%
Economic Lifetime	years	40	40	40	40	40	40	40	40	40
Implied Annualized Capital Costs, 2010	$/kW-yr	$233.11	$128.21	$128.21	$128.21	$233.11	$128.21	$128.21	$128.21	$203.97
Implied Annualized Capital Costs, 2030	$/kW-yr	$262.25	$151.52	$151.52	$151.52	$291.39	$151.52	$151.52	$233.11	$233.11
Implied Annualized Capital Costs, 2050	$/kW-yr	$262.25	$174.83	$174.83	$174.83	$291.39	$174.83	$174.83	$291.39	$291.39
Fixed Operating and Maintenance Costs, 2010	$/kW-yr	$ 160	$ 100	$ 100	$ 100	$ 140	$ 100	$ 100	$ 100	$ 100
Fixed Operating and Maintenance Costs, 2030	$/kW-yr	$ 160	$ 100	$ 100	$ 100	$ 140	$ 100	$ 100	$ 100	$ 100
Fixed Operating and Maintenance Costs, 2050	$/kW-yr	$ 160	$ 100	$ 100	$ 100	$ 140	$ 100	$ 100	$ 100	$ 100
Variable (non-fuel-cycle) O&M costs, 2010	$/MWh	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50
Variable (non-fuel-cycle) O&M costs, 2030	$/MWh	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50
Variable (non-fuel-cycle) O&M costs, 2050	$/MWh	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50
Decommissioning Costs, 2010	$/kW	$ 500	$ 350	$ 350	$ 350	$ 500	$ 350	$ 350	$ 350	$ 350
Decommissioning Costs, 2030	$/kW	$ 550	$ 400	$ 400	$ 400	$ 550	$ 400	$ 400	$ 400	$ 400
Decommissioning Costs, 2050	$/kW	$ 600	$ 450	$ 450	$ 450	$ 600	$ 450	$ 450	$ 450	$ 450

Components of Nuclear Power Costs: Detailed Results

Net Present Values Calculated at Discount Rate of 5% /yr (real basis)

		BAU Nuclear Capacity Expansion Path									
Annualized Capital Costs (million 2009 USD)	YEAR	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
	2010	$ 11,568	$ 2,271	$ 1,105	$ 6	$ 1,199	$ -	$ -	$ -	$ -	$ 16,150
	2011	$ 11,636	$ 2,290	$ 1,114	$ 6	$ 1,213	$ -	$ -	$ -	$ -	$ 16,260
	2012	$ 11,595	$ 2,310	$ 1,124	$ 6	$ 1,226	$ -	$ -	$ -	$ -	$ 16,260
	2013	$ 11,663	$ 2,329	$ 1,349	$ 6	$ 1,240	$ -	$ -	$ -	$ -	$ 16,588
	2014	$ 10,611	$ 2,481	$ 1,497	$ 6	$ 1,254	$ -	$ -	$ -	$ -	$ 15,849
	2015	$ 10,674	$ 2,769	$ 1,592	$ 6	$ 1,268	$ -	$ -	$ -	$ -	$ 16,310
	2016	$ 10,737	$ 2,793	$ 1,881	$ 6	$ 1,282	$ -	$ -	$ -	$ -	$ 16,699
	2017	$ 10,800	$ 2,816	$ 2,591	$ 7	$ 1,297	$ -	$ -	$ -	$ -	$ 17,510
	2018	$ 10,864	$ 2,977	$ 3,451	$ 7	$ 1,311	$ -	$ -	$ -	$ -	$ 18,610
	2019	$ 10,757	$ 3,187	$ 4,792	$ 7	$ 1,326	$ -	$ -	$ -	$ -	$ 20,068
	2020	$ 10,559	$ 3,400	$ 6,291	$ 11	$ 1,341	$ -	$ -	$ -	$ -	$ 21,602
	2021	$ 10,507	$ 3,617	$ 6,497	$ 16	$ 1,188	$ -	$ -	$ -	$ -	$ 21,824
	2022	$ 10,569	$ 3,837	$ 6,869	$ 25	$ 1,378	$ -	$ -	$ -	$ -	$ 22,678
	2023	$ 10,979	$ 3,870	$ 7,246	$ 29	$ 1,744	$ 4	$ -	$ -	$ -	$ 23,872
	2024	$ 11,044	$ 4,095	$ 8,266	$ 29	$ 1,495	$ 4	$ -	$ -	$ -	$ 24,933
	2025	$ 11,109	$ 4,324	$ 9,301	$ 24	$ 1,512	$ 4	$ -	$ -	$ -	$ 26,275
	2026	$ 11,527	$ 4,557	$ 10,103	$ 25	$ 1,255	$ 18	$ -	$ -	$ -	$ 27,484
	2027	$ 11,595	$ 4,793	$ 10,918	$ 25	$ 1,001	$ 18	$ -	$ -	$ -	$ 28,350
	2028	$ 11,663	$ 4,833	$ 11,591	$ 25	$ 1,012	$ 175	$ -	$ -	$ -	$ 29,299
	2029	$ 11,732	$ 4,874	$ 12,274	$ 25	$ 749	$ 177	$ -	$ -	$ -	$ 29,831
	2030	$ 12,165	$ 5,131	$ 12,968	$ 25	$ 758	$ 193	$ -	$ -	$ -	$ 31,239
	2031	$ 12,165	$ 5,385	$ 13,656	$ 26	$ 1,136	$ 195	$ -	$ 542	$ -	$ 33,105
	2032	$ 12,165	$ 5,424	$ 14,354	$ 26	$ 1,136	$ 208	$ 161	$ 834	$ -	$ 34,307
	2033	$ 12,165	$ 5,683	$ 15,060	$ 72	$ 1,136	$ 209	$ 325	$ 844	$ -	$ 35,495
	2034	$ 12,525	$ 5,946	$ 15,777	$ 73	$ 1,136	$ 374	$ 327	$ 853	$ -	$ 37,012
	2035	$ 12,525	$ 5,989	$ 16,396	$ 121	$ 1,136	$ 377	$ 330	$ 1,134	$ -	$ 38,007
	2036	$ 12,525	$ 5,925	$ 16,881	$ 121	$ 1,136	$ 395	$ 332	$ 1,147	$ -	$ 38,462
	2037	$ 12,308	$ 5,967	$ 17,132	$ 122	$ 1,136	$ 398	$ 335	$ 1,159	$ -	$ 38,558
	2038	$ 12,483	$ 6,239	$ 17,736	$ 123	$ 1,136	$ 401	$ 337	$ 1,478	$ -	$ 39,934
	2039	$ 12,267	$ 6,283	$ 18,348	$ 124	$ 1,136	$ 404	$ 339	$ 1,495	$ -	$ 40,397
	2040	$ 12,118	$ 6,329	$ 18,968	$ 125	$ 1,136	$ 423	$ 342	$ 1,512	$ -	$ 40,953
	2041	$ 11,830	$ 6,278	$ 19,596	$ 126	$ 1,136	$ 426	$ 516	$ 1,819	$ -	$ 41,727
	2042	$ 11,213	$ 6,323	$ 20,232	$ 127	$ 1,136	$ 603	$ 693	$ 1,839	$ -	$ 42,167
	2043	$ 11,213	$ 6,605	$ 20,877	$ 128	$ 1,136	$ 607	$ 698	$ 1,860	$ -	$ 43,124
	2044	$ 11,067	$ 6,653	$ 21,412	$ 129	$ 1,136	$ 628	$ 703	$ 2,207	$ -	$ 43,935
	2045	$ 10,630	$ 6,700	$ 21,692	$ 130	$ 1,136	$ 633	$ 708	$ 2,232	$ -	$ 43,862
	2046	$ 10,630	$ 6,638	$ 22,080	$ 130	$ 1,136	$ 637	$ 714	$ 2,257	$ -	$ 44,222
	2047	$ 9,971	$ 6,686	$ 22,527	$ 131	$ 1,136	$ 642	$ 719	$ 2,593	$ -	$ 44,404
	2048	$ 8,704	$ 6,816	$ 23,085	$ 132	$ 1,136	$ 664	$ 724	$ 2,622	$ -	$ 43,883
	2049	$ 8,704	$ 6,535	$ 23,650	$ 133	$ 1,136	$ 668	$ 729	$ 2,997	$ -	$ 44,553
	2050	$ 7,823	$ 6,293	$ 23,876	$ 134	$ 1,136	$ 673	$ 918	$ 3,030	$ -	$ 43,884
Undiscounted Total Costs, 2010 - 2050		$ 459,380	$ 198,251	$ 506,157	$ 2,558	$ 48,776	$ 10,157	$ 9,952	$ 34,453	$ -	$ 1,269,684
Discounted Total Costs, 2010 - 2050		$ 194,585	$ 68,861	$ 142,265	$ 633	$ 21,168	$ 2,172	$ 1,948	$ 6,823	$ -	$ 438,455

	Maximum Nuclear Capacity Expansion Path									
YEAR	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
2010	$ 11,568	$ 2,271	$ 1,105	$ 6	$ 1,199	$ -	$ -	$ -	$ -	$ 16,150
2011	$ 11,636	$ 2,290	$ 1,114	$ 6	$ 1,213	$ -	$ -	$ -	$ -	$ 16,260
2012	$ 11,595	$ 2,310	$ 1,124	$ 6	$ 1,226	$ -	$ -	$ -	$ -	$ 16,260
2013	$ 11,663	$ 2,329	$ 1,349	$ 6	$ 1,240	$ -	$ -	$ -	$ -	$ 16,588
2014	$ 10,611	$ 2,481	$ 1,497	$ 6	$ 1,254	$ -	$ -	$ -	$ -	$ 15,849
2015	$ 10,674	$ 2,769	$ 1,592	$ 6	$ 1,268	$ -	$ -	$ -	$ -	$ 16,310
2016	$ 10,737	$ 2,793	$ 1,881	$ 6	$ 1,282	$ -	$ -	$ -	$ -	$ 16,699
2017	$ 10,800	$ 2,816	$ 2,591	$ 7	$ 1,297	$ -	$ -	$ -	$ -	$ 17,510
2018	$ 10,864	$ 2,977	$ 3,451	$ 7	$ 1,311	$ -	$ -	$ -	$ -	$ 18,610
2019	$ 10,757	$ 3,187	$ 4,792	$ 7	$ 1,326	$ -	$ -	$ -	$ -	$ 20,068
2020	$ 10,559	$ 3,400	$ 6,291	$ 11	$ 1,341	$ -	$ -	$ -	$ -	$ 21,602
2021	$ 10,507	$ 3,617	$ 6,497	$ 16	$ 1,698	$ -	$ -	$ -	$ -	$ 22,335
2022	$ 10,569	$ 3,837	$ 6,869	$ 25	$ 2,064	$ 4	$ -	$ -	$ -	$ 23,367
2023	$ 10,979	$ 3,870	$ 7,246	$ 29	$ 2,087	$ 4	$ -	$ -	$ -	$ 24,215
2024	$ 11,392	$ 4,095	$ 8,266	$ 29	$ 2,110	$ 18	$ -	$ -	$ -	$ 25,910
2025	$ 11,851	$ 4,324	$ 9,236	$ 24	$ 2,134	$ 171	$ -	$ -	$ -	$ 27,740
2026	$ 12,275	$ 4,557	$ 10,222	$ 25	$ 2,158	$ 187	$ -	$ -	$ -	$ 29,424
2027	$ 12,705	$ 4,793	$ 11,224	$ 25	$ 2,182	$ 344	$ -	$ 256	$ -	$ 31,528
2028	$ 13,136	$ 4,833	$ 12,242	$ 70	$ 2,577	$ 346	$ 156	$ 769	$ -	$ 34,129
2029	$ 13,571	$ 4,874	$ 13,276	$ 70	$ 2,606	$ 349	$ 316	$ 792	$ 232	$ 36,086
2030	$ 14,014	$ 5,131	$ 14,372	$ 116	$ 2,635	$ 367	$ 318	$ 816	$ 233	$ 38,004
2031	$ 14,418	$ 5,385	$ 15,468	$ 117	$ 2,450	$ 584	$ 320	$ 1,108	$ 236	$ 40,086
2032	$ 14,780	$ 5,643	$ 16,578	$ 118	$ 2,265	$ 599	$ 323	$ 1,383	$ 477	$ 42,165
2033	$ 14,780	$ 5,904	$ 17,703	$ 274	$ 2,265	$ 820	$ 325	$ 1,398	$ 482	$ 43,951
2034	$ 14,780	$ 5,946	$ 18,844	$ 432	$ 1,978	$ 826	$ 491	$ 1,743	$ 488	$ 45,527
2035	$ 14,780	$ 5,989	$ 19,893	$ 435	$ 2,356	$ 1,052	$ 660	$ 2,034	$ 739	$ 47,938
2036	$ 14,780	$ 6,150	$ 20,957	$ 438	$ 2,448	$ 1,076	$ 664	$ 2,355	$ 748	$ 49,616
2037	$ 14,563	$ 6,194	$ 22,143	$ 600	$ 2,171	$ 1,083	$ 669	$ 2,382	$ 1,008	$ 50,814
2038	$ 14,335	$ 6,239	$ 23,345	$ 765	$ 2,550	$ 1,091	$ 674	$ 2,753	$ 1,020	$ 52,771
2039	$ 14,118	$ 6,514	$ 24,563	$ 771	$ 2,273	$ 1,325	$ 848	$ 3,067	$ 1,289	$ 54,768
2040	$ 13,970	$ 6,560	$ 25,797	$ 776	$ 2,652	$ 1,351	$ 1,025	$ 3,101	$ 1,303	$ 56,536
2041	$ 13,681	$ 6,511	$ 27,048	$ 782	$ 3,030	$ 1,361	$ 1,033	$ 3,136	$ 1,581	$ 58,164
2042	$ 13,065	$ 6,793	$ 28,316	$ 787	$ 3,030	$ 1,602	$ 1,040	$ 3,465	$ 1,599	$ 59,697
2043	$ 13,065	$ 6,842	$ 29,600	$ 959	$ 3,409	$ 1,613	$ 1,048	$ 3,827	$ 1,886	$ 62,250
2044	$ 12,919	$ 6,891	$ 30,901	$ 1,134	$ 3,409	$ 1,641	$ 1,231	$ 3,870	$ 1,908	$ 63,903
2045	$ 12,482	$ 7,181	$ 32,219	$ 1,142	$ 3,409	$ 1,653	$ 1,417	$ 3,913	$ 2,205	$ 65,621
2046	$ 12,482	$ 7,122	$ 33,555	$ 1,150	$ 3,409	$ 1,903	$ 1,427	$ 3,957	$ 2,229	$ 67,235
2047	$ 11,822	$ 7,173	$ 34,534	$ 1,329	$ 3,409	$ 1,917	$ 1,437	$ 4,369	$ 2,536	$ 68,528
2048	$ 10,556	$ 7,307	$ 35,902	$ 1,511	$ 3,409	$ 1,948	$ 1,448	$ 4,803	$ 2,565	$ 69,448
2049	$ 10,556	$ 7,277	$ 37,289	$ 1,522	$ 3,409	$ 1,962	$ 1,640	$ 4,857	$ 2,882	$ 71,393
2050	$ 9,674	$ 7,290	$ 38,693	$ 1,533	$ 3,409	$ 1,976	$ 1,836	$ 4,911	$ 2,914	$ 72,236
TOTAL	$ 508,066	$ 204,467	$ 659,584	$ 17,078	$ 92,951	$ 29,172	$ 20,348	$ 65,064	$ 30,558	$ 1,627,288
NPV	$ 207,169	$ 70,007	$ 172,279	$ 3,406	$ 32,474	$ 6,284	$ 4,125	$ 13,513	$ 5,885	$ 515,142

	Minimum Nuclear Capacity Expansion Path									
YEAR	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
2010	$ 11,568	$ 2,271	$ 1,105	$ 6	$ 1,199	$ -	$ -	$ -	$ -	$ 16,150
2011	$ 11,636	$ 2,290	$ 1,114	$ 6	$ 1,213	$ -	$ -	$ -	$ -	$ 16,260
2012	$ 11,595	$ 2,310	$ 1,124	$ 6	$ 1,226	$ -	$ -	$ -	$ -	$ 16,260
2013	$ 11,663	$ 2,329	$ 1,349	$ 6	$ 1,240	$ -	$ -	$ -	$ -	$ 16,588
2014	$ 10,611	$ 2,481	$ 1,497	$ 6	$ 1,254	$ -	$ -	$ -	$ -	$ 15,849
2015	$ 10,674	$ 2,769	$ 1,592	$ 6	$ 1,268	$ -	$ -	$ -	$ -	$ 16,310
2016	$ 10,737	$ 2,793	$ 1,881	$ 6	$ 1,282	$ -	$ -	$ -	$ -	$ 16,699
2017	$ 10,800	$ 2,816	$ 2,591	$ 7	$ 1,297	$ -	$ -	$ -	$ -	$ 17,510
2018	$ 10,864	$ 2,884	$ 3,451	$ 7	$ 1,311	$ -	$ -	$ -	$ -	$ 18,517
2019	$ 10,757	$ 3,093	$ 4,792	$ 7	$ 1,326	$ -	$ -	$ -	$ -	$ 19,974
2020	$ 10,559	$ 3,306	$ 6,291	$ 11	$ 1,341	$ -	$ -	$ -	$ -	$ 21,507
2021	$ 10,507	$ 3,439	$ 6,497	$ 16	$ 1,188	$ -	$ -	$ -	$ -	$ 21,647
2022	$ 10,362	$ 3,658	$ 6,869	$ 25	$ 1,032	$ -	$ -	$ -	$ -	$ 21,946
2023	$ 10,204	$ 3,689	$ 7,086	$ 29	$ 1,044	$ -	$ -	$ -	$ -	$ 22,052
2024	$ 10,056	$ 3,913	$ 7,307	$ 29	$ 787	$ -	$ -	$ -	$ -	$ 22,092
2025	$ 9,971	$ 4,140	$ 7,852	$ 24	$ 796	$ -	$ -	$ -	$ -	$ 22,783
2026	$ 9,748	$ 4,080	$ 8,405	$ 25	$ 530	$ 4	$ -	$ -	$ -	$ 22,791
2027	$ 9,200	$ 4,114	$ 8,859	$ 25	$ 268	$ 4	$ -	$ -	$ -	$ 22,470
2028	$ 9,254	$ 4,207	$ 9,321	$ 25	$ 271	$ 4	$ -	$ -	$ -	$ 23,082
2029	$ 9,163	$ 4,158	$ 9,790	$ 25	$ -	$ 4	$ -	$ -	$ -	$ 23,140
2030	$ 8,780	$ 3,943	$ 10,266	$ 25	$ -	$ 4	$ -	$ -	$ -	$ 23,018
2031	$ 8,780	$ 3,719	$ 10,737	$ 26	$ -	$ 19	$ -	$ -	$ -	$ 23,281
2032	$ 8,121	$ 3,492	$ 11,213	$ 26	$ -	$ 19	$ -	$ -	$ -	$ 22,872
2033	$ 6,854	$ 3,738	$ 11,696	$ 26	$ -	$ 19	$ -	$ -	$ -	$ 22,334
2034	$ 6,854	$ 3,987	$ 12,186	$ 26	$ -	$ 19	$ -	$ -	$ -	$ 23,073
2035	$ 5,973	$ 4,016	$ 12,575	$ 26	$ -	$ 20	$ -	$ -	$ -	$ 22,610
2036	$ 5,973	$ 4,044	$ 12,969	$ 27	$ -	$ 20	$ -	$ 299	$ -	$ 23,333
2037	$ 5,606	$ 4,073	$ 13,129	$ 27	$ -	$ 20	$ -	$ 302	$ -	$ 23,158
2038	$ 5,029	$ 4,171	$ 13,640	$ 27	$ -	$ 20	$ -	$ 612	$ -	$ 23,499
2039	$ 4,568	$ 4,270	$ 13,964	$ 27	$ -	$ 20	$ -	$ 619	$ -	$ 23,468
2040	$ 4,568	$ 4,300	$ 14,292	$ 27	$ -	$ 37	$ -	$ 626	$ -	$ 23,850
2041	$ 3,530	$ 4,167	$ 14,624	$ 28	$ -	$ 37	$ -	$ 633	$ -	$ 23,019
2042	$ 2,699	$ 4,032	$ 14,961	$ 28	$ -	$ 37	$ -	$ 640	$ -	$ 22,396
2043	$ 2,483	$ 4,061	$ 15,301	$ 28	$ -	$ 37	$ -	$ 647	$ -	$ 22,557
2044	$ 2,127	$ 4,090	$ 15,645	$ 28	$ -	$ 38	$ -	$ 654	$ -	$ 22,582
2045	$ 1,462	$ 3,782	$ 15,733	$ 28	$ -	$ 38	$ -	$ 661	$ -	$ 21,704
2046	$ 1,462	$ 3,809	$ 15,924	$ 29	$ -	$ 38	$ -	$ 669	$ -	$ 21,931
2047	$ 1,462	$ 3,665	$ 16,174	$ 29	$ -	$ 39	$ -	$ 676	$ -	$ 22,045
2048	$ 1,462	$ 3,519	$ 16,531	$ 29	$ -	$ 56	$ -	$ 684	$ -	$ 22,281
2049	$ 1,462	$ 3,545	$ 16,893	$ 29	$ -	$ 56	$ -	$ 692	$ -	$ 22,677
2050	$ 1,246	$ 3,570	$ 16,913	$ 29	$ -	$ 57	$ -	$ 699	$ -	$ 22,514
TOTAL	$ 300,434	$ 146,733	$ 394,138	$ 873	$ 19,871	$ 665	$ -	$ 9,112	$ -	$ 871,826
NPV	$ 157,676	$ 56,882	$ 116,231	$ 289	$ 13,410	$ 137	$ -	$ 1,714	$ -	$ 346,339

		BAU Nuclear Capacity Expansion Path									
Fixed O&M Costs (million 2009 USD)	YEAR	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
	2010	$ 7,940	$ 1,772	$ 862	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,298
	2011	$ 7,940	$ 1,772	$ 862	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,298
	2012	$ 7,865	$ 1,772	$ 862	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,223
	2013	$ 7,865	$ 1,772	$ 1,026	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,388
	2014	$ 7,114	$ 1,872	$ 1,129	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 10,839
	2015	$ 7,114	$ 2,072	$ 1,191	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,101
	2016	$ 7,114	$ 2,072	$ 1,395	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,306
	2017	$ 7,114	$ 2,072	$ 1,906	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,816
	2018	$ 7,114	$ 2,172	$ 2,518	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 12,528
	2019	$ 7,002	$ 2,306	$ 3,467	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 13,499
	2020	$ 6,833	$ 2,440	$ 4,514	$ 8	$ 720	$ -	$ -	$ -	$ -	$ 14,514
	2021	$ 6,759	$ 2,574	$ 4,622	$ 11	$ 631	$ -	$ -	$ -	$ -	$ 14,597
	2022	$ 6,759	$ 2,708	$ 4,846	$ 18	$ 724	$ -	$ -	$ -	$ -	$ 15,055
	2023	$ 6,980	$ 2,708	$ 5,070	$ 20	$ 906	$ 3	$ -	$ -	$ -	$ 15,687
	2024	$ 6,980	$ 2,842	$ 5,735	$ 20	$ 768	$ 3	$ -	$ -	$ -	$ 16,348
	2025	$ 6,980	$ 2,976	$ 6,400	$ 17	$ 768	$ 3	$ -	$ -	$ -	$ 17,144
	2026	$ 7,200	$ 3,110	$ 6,894	$ 17	$ 630	$ 13	$ -	$ -	$ -	$ 17,863
	2027	$ 7,200	$ 3,244	$ 7,388	$ 17	$ 497	$ 13	$ -	$ -	$ -	$ 18,358
	2028	$ 7,200	$ 3,244	$ 7,778	$ 17	$ 497	$ 118	$ -	$ -	$ -	$ 18,853
	2029	$ 7,200	$ 3,244	$ 8,168	$ 17	$ 364	$ 118	$ -	$ -	$ -	$ 19,110
	2030	$ 7,422	$ 3,386	$ 8,558	$ 17	$ 364	$ 128	$ -	$ -	$ -	$ 19,874
	2031	$ 7,422	$ 3,529	$ 8,948	$ 17	$ 546	$ 128	$ -	$ 230	$ -	$ 20,819
	2032	$ 7,422	$ 3,529	$ 9,338	$ 17	$ 546	$ 135	$ 105	$ 350	$ -	$ 21,441
	2033	$ 7,422	$ 3,671	$ 9,728	$ 47	$ 546	$ 135	$ 210	$ 350	$ -	$ 22,109
	2034	$ 7,641	$ 3,814	$ 10,118	$ 47	$ 546	$ 240	$ 210	$ 350	$ -	$ 22,966
	2035	$ 7,641	$ 3,814	$ 10,441	$ 77	$ 546	$ 240	$ 210	$ 460	$ -	$ 23,428
	2036	$ 7,641	$ 3,746	$ 10,673	$ 77	$ 546	$ 250	$ 210	$ 460	$ -	$ 23,602
	2037	$ 7,509	$ 3,746	$ 10,754	$ 77	$ 546	$ 250	$ 210	$ 460	$ -	$ 23,552
	2038	$ 7,616	$ 3,888	$ 11,054	$ 77	$ 546	$ 250	$ 210	$ 580	$ -	$ 24,221
	2039	$ 7,484	$ 3,888	$ 11,354	$ 77	$ 546	$ 250	$ 210	$ 580	$ -	$ 24,389
	2040	$ 7,393	$ 3,888	$ 11,654	$ 77	$ 546	$ 260	$ 210	$ 580	$ -	$ 24,608
	2041	$ 7,217	$ 3,830	$ 11,954	$ 77	$ 546	$ 260	$ 315	$ 690	$ -	$ 24,889
	2042	$ 6,841	$ 3,830	$ 12,254	$ 77	$ 546	$ 365	$ 420	$ 690	$ -	$ 25,023
	2043	$ 6,841	$ 3,972	$ 12,554	$ 77	$ 546	$ 365	$ 420	$ 690	$ -	$ 25,465
	2044	$ 6,752	$ 3,972	$ 12,784	$ 77	$ 546	$ 375	$ 420	$ 810	$ -	$ 25,736
	2045	$ 6,485	$ 3,972	$ 12,859	$ 77	$ 546	$ 375	$ 420	$ 810	$ -	$ 25,544
	2046	$ 6,485	$ 3,907	$ 12,996	$ 77	$ 546	$ 375	$ 420	$ 810	$ -	$ 25,616
	2047	$ 6,083	$ 3,907	$ 13,165	$ 77	$ 546	$ 375	$ 420	$ 920	$ -	$ 25,492
	2048	$ 5,310	$ 3,955	$ 13,395	$ 77	$ 546	$ 385	$ 420	$ 920	$ -	$ 25,007
	2049	$ 5,310	$ 3,765	$ 13,625	$ 77	$ 546	$ 385	$ 420	$ 1,040	$ -	$ 25,167
	2050	$ 4,773	$ 3,600	$ 13,657	$ 77	$ 546	$ 385	$ 525	$ 1,040	$ -	$ 24,601
Undiscounted Total Costs, 2010 - 2050		$ 288,982	$ 128,341	$ 318,497	$ 1,582	$ 24,992	$ 6,178	$ 5,985	$ 12,820	$ -	$ 787,378
Discounted Total Costs, 2010 - 2050		$ 125,021	$ 46,752	$ 92,726	$ 404	$ 11,285	$ 1,339	$ 1,183	$ 2,581	$ -	$ 281,291

	Maximum Nuclear Capacity Expansion Path									
YEAR	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
2010	$ 7,940	$ 1,772	$ 862	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,298
2011	$ 7,940	$ 1,772	$ 862	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,298
2012	$ 7,865	$ 1,772	$ 862	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,223
2013	$ 7,865	$ 1,772	$ 1,026	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,388
2014	$ 7,114	$ 1,872	$ 1,129	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 10,839
2015	$ 7,114	$ 2,072	$ 1,191	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,101
2016	$ 7,114	$ 2,072	$ 1,395	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,306
2017	$ 7,114	$ 2,072	$ 1,906	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,816
2018	$ 7,114	$ 2,172	$ 2,518	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 12,528
2019	$ 7,002	$ 2,306	$ 3,467	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 13,499
2020	$ 6,833	$ 2,440	$ 4,514	$ 8	$ 720	$ -	$ -	$ -	$ -	$ 14,514
2021	$ 6,759	$ 2,574	$ 4,622	$ 11	$ 902	$ -	$ -	$ -	$ -	$ 14,868
2022	$ 6,759	$ 2,708	$ 4,846	$ 18	$ 1,084	$ 3	$ -	$ -	$ -	$ 15,417
2023	$ 6,980	$ 2,708	$ 5,070	$ 20	$ 1,084	$ 3	$ -	$ -	$ -	$ 15,865
2024	$ 7,200	$ 2,842	$ 5,735	$ 20	$ 1,084	$ 13	$ -	$ -	$ -	$ 16,894
2025	$ 7,446	$ 2,976	$ 6,355	$ 17	$ 1,084	$ 118	$ -	$ -	$ -	$ 17,995
2026	$ 7,668	$ 3,110	$ 6,975	$ 17	$ 1,084	$ 128	$ -	$ -	$ -	$ 18,981
2027	$ 7,889	$ 3,244	$ 7,595	$ 17	$ 1,084	$ 233	$ -	$ 120	$ -	$ 20,182
2028	$ 8,109	$ 3,244	$ 8,215	$ 47	$ 1,266	$ 233	$ 105	$ 350	$ -	$ 21,568
2029	$ 8,329	$ 3,244	$ 8,835	$ 47	$ 1,266	$ 233	$ 210	$ 350	$ 100	$ 22,613
2030	$ 8,550	$ 3,386	$ 9,485	$ 77	$ 1,266	$ 243	$ 210	$ 350	$ 100	$ 23,667
2031	$ 8,796	$ 3,529	$ 10,135	$ 77	$ 1,177	$ 383	$ 210	$ 470	$ 100	$ 24,877
2032	$ 9,017	$ 3,671	$ 10,785	$ 77	$ 1,088	$ 390	$ 210	$ 580	$ 200	$ 26,018
2033	$ 9,017	$ 3,814	$ 11,435	$ 177	$ 1,088	$ 530	$ 210	$ 580	$ 200	$ 27,051
2034	$ 9,017	$ 3,814	$ 12,085	$ 277	$ 950	$ 530	$ 315	$ 715	$ 200	$ 27,903
2035	$ 9,017	$ 3,814	$ 12,668	$ 277	$ 1,132	$ 670	$ 420	$ 825	$ 300	$ 29,122
2036	$ 9,017	$ 3,888	$ 13,250	$ 277	$ 1,176	$ 680	$ 420	$ 945	$ 300	$ 29,953
2037	$ 8,885	$ 3,888	$ 13,900	$ 377	$ 1,043	$ 680	$ 420	$ 945	$ 400	$ 30,538
2038	$ 8,746	$ 3,888	$ 14,550	$ 477	$ 1,225	$ 680	$ 420	$ 1,080	$ 400	$ 31,466
2039	$ 8,614	$ 4,031	$ 15,200	$ 477	$ 1,092	$ 820	$ 525	$ 1,190	$ 500	$ 32,448
2040	$ 8,523	$ 4,031	$ 15,850	$ 477	$ 1,274	$ 830	$ 630	$ 1,190	$ 500	$ 33,304
2041	$ 8,347	$ 3,972	$ 16,500	$ 477	$ 1,456	$ 830	$ 630	$ 1,190	$ 600	$ 34,002
2042	$ 7,971	$ 4,115	$ 17,150	$ 477	$ 1,456	$ 970	$ 630	$ 1,300	$ 600	$ 34,668
2043	$ 7,971	$ 4,115	$ 17,800	$ 577	$ 1,638	$ 970	$ 630	$ 1,420	$ 700	$ 35,820
2044	$ 7,882	$ 4,115	$ 18,450	$ 677	$ 1,638	$ 980	$ 735	$ 1,420	$ 700	$ 36,596
2045	$ 7,615	$ 4,257	$ 19,100	$ 677	$ 1,638	$ 980	$ 840	$ 1,420	$ 800	$ 37,327
2046	$ 7,615	$ 4,192	$ 19,750	$ 677	$ 1,638	$ 1,120	$ 840	$ 1,420	$ 800	$ 38,052
2047	$ 7,213	$ 4,192	$ 20,181	$ 777	$ 1,638	$ 1,120	$ 840	$ 1,551	$ 900	$ 38,411
2048	$ 6,440	$ 4,240	$ 20,831	$ 877	$ 1,638	$ 1,130	$ 840	$ 1,686	$ 900	$ 38,581
2049	$ 6,440	$ 4,192	$ 21,481	$ 877	$ 1,638	$ 1,130	$ 945	$ 1,686	$ 1,000	$ 39,388
2050	$ 5,902	$ 4,170	$ 22,131	$ 877	$ 1,638	$ 1,130	$ 1,050	$ 1,686	$ 1,000	$ 39,583
TOTAL	$ 318,747	$ 132,046	$ 410,697	$ 10,282	$ 46,390	$ 17,755	$ 12,285	$ 24,467	$ 11,300	$ 983,969
NPV	$ 132,724	$ 47,442	$ 110,970	$ 2,082	$ 16,799	$ 3,883	$ 2,522	$ 5,190	$ 2,212	$ 323,825

	Minimum Nuclear Capacity Expansion Path									
YEAR	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
2010	$ 7,940	$ 1,772	$ 862	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,298
2011	$ 7,940	$ 1,772	$ 862	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,298
2012	$ 7,865	$ 1,772	$ 862	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,223
2013	$ 7,865	$ 1,772	$ 1,026	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,388
2014	$ 7,114	$ 1,872	$ 1,129	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 10,839
2015	$ 7,114	$ 2,072	$ 1,191	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,101
2016	$ 7,114	$ 2,072	$ 1,395	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,306
2017	$ 7,114	$ 2,072	$ 1,906	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 11,816
2018	$ 7,114	$ 2,104	$ 2,518	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 12,460
2019	$ 7,002	$ 2,238	$ 3,467	$ 5	$ 720	$ -	$ -	$ -	$ -	$ 13,431
2020	$ 6,833	$ 2,372	$ 4,514	$ 8	$ 720	$ -	$ -	$ -	$ -	$ 14,446
2021	$ 6,759	$ 2,447	$ 4,622	$ 11	$ 631	$ -	$ -	$ -	$ -	$ 14,471
2022	$ 6,627	$ 2,581	$ 4,846	$ 18	$ 542	$ -	$ -	$ -	$ -	$ 14,614
2023	$ 6,488	$ 2,581	$ 4,958	$ 20	$ 542	$ -	$ -	$ -	$ -	$ 14,589
2024	$ 6,356	$ 2,715	$ 5,070	$ 20	$ 404	$ -	$ -	$ -	$ -	$ 14,565
2025	$ 6,265	$ 2,849	$ 5,403	$ 17	$ 404	$ -	$ -	$ -	$ -	$ 14,938
2026	$ 6,089	$ 2,784	$ 5,735	$ 17	$ 266	$ 3	$ -	$ -	$ -	$ 14,894
2027	$ 5,713	$ 2,784	$ 5,995	$ 17	$ 133	$ 3	$ -	$ -	$ -	$ 14,645
2028	$ 5,713	$ 2,823	$ 6,255	$ 17	$ 133	$ 3	$ -	$ -	$ -	$ 14,944
2029	$ 5,624	$ 2,767	$ 6,515	$ 17	$ -	$ 3	$ -	$ -	$ -	$ 14,925
2030	$ 5,357	$ 2,602	$ 6,775	$ 17	$ -	$ 3	$ -	$ -	$ -	$ 14,754
2031	$ 5,357	$ 2,437	$ 7,035	$ 17	$ -	$ 13	$ -	$ -	$ -	$ 14,859
2032	$ 4,955	$ 2,272	$ 7,295	$ 17	$ -	$ 13	$ -	$ -	$ -	$ 14,551
2033	$ 4,182	$ 2,415	$ 7,555	$ 17	$ -	$ 13	$ -	$ -	$ -	$ 14,181
2034	$ 4,182	$ 2,557	$ 7,815	$ 17	$ -	$ 13	$ -	$ -	$ -	$ 14,584
2035	$ 3,644	$ 2,557	$ 8,008	$ 17	$ -	$ 13	$ -	$ -	$ -	$ 14,238
2036	$ 3,644	$ 2,557	$ 8,200	$ 17	$ -	$ 13	$ -	$ 120	$ -	$ 14,550
2037	$ 3,420	$ 2,557	$ 8,241	$ 17	$ -	$ 13	$ -	$ 120	$ -	$ 14,368
2038	$ 3,068	$ 2,600	$ 8,501	$ 17	$ -	$ 13	$ -	$ 240	$ -	$ 14,438
2039	$ 2,787	$ 2,642	$ 8,641	$ 17	$ -	$ 13	$ -	$ 240	$ -	$ 14,339
2040	$ 2,787	$ 2,642	$ 8,781	$ 17	$ -	$ 23	$ -	$ 240	$ -	$ 14,489
2041	$ 2,154	$ 2,542	$ 8,921	$ 17	$ -	$ 23	$ -	$ 240	$ -	$ 13,896
2042	$ 1,647	$ 2,442	$ 9,061	$ 17	$ -	$ 23	$ -	$ 240	$ -	$ 13,429
2043	$ 1,515	$ 2,442	$ 9,201	$ 17	$ -	$ 23	$ -	$ 240	$ -	$ 13,437
2044	$ 1,298	$ 2,442	$ 9,341	$ 17	$ -	$ 23	$ -	$ 240	$ -	$ 13,360
2045	$ 892	$ 2,242	$ 9,326	$ 17	$ -	$ 23	$ -	$ 240	$ -	$ 12,740
2046	$ 892	$ 2,242	$ 9,373	$ 17	$ -	$ 23	$ -	$ 240	$ -	$ 12,786
2047	$ 892	$ 2,142	$ 9,452	$ 17	$ -	$ 23	$ -	$ 240	$ -	$ 12,765
2048	$ 892	$ 2,042	$ 9,592	$ 17	$ -	$ 33	$ -	$ 240	$ -	$ 12,815
2049	$ 892	$ 2,042	$ 9,732	$ 17	$ -	$ 33	$ -	$ 240	$ -	$ 12,955
2050	$ 760	$ 2,042	$ 9,674	$ 17	$ -	$ 33	$ -	$ 240	$ -	$ 12,765
TOTAL	$ 191,862	$ 96,674	$ 249,652	$ 562	$ 10,978	$ 403	$ -	$ 3,360	$ -	$ 553,491
NPV	$ 102,437	$ 39,246	$ 76,418	$ 194	$ 7,498	$ 84	$ -	$ 638	$ -	$ 226,514

Variable O&M Costs (million 2009 USD)	YEAR	BAU Nuclear Capacity Expansion Path									
		Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
	2010	$ 144	$ 71	$ 35	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 270
	2011	$ 51	$ 71	$ 41	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 184
	2012	$ 8	$ 71	$ 46	$ 0	$ 19	$ -	$ -	$ -	$ -	$ 145
	2013	$ 5	$ 66	$ 55	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 146
	2014	$ -	$ 74	$ 62	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 157
	2015	$ 1	$ 78	$ 80	$ 0	$ 18	$ -	$ -	$ -	$ -	$ 177
	2016	$ 12	$ 88	$ 120	$ 0	$ 19	$ -	$ -	$ -	$ -	$ 239
	2017	$ 18	$ 94	$ 157	$ 0	$ 19	$ -	$ -	$ -	$ -	$ 289
	2018	$ 26	$ 99	$ 180	$ 0	$ 17	$ -	$ -	$ -	$ -	$ 322
	2019	$ 33	$ 104	$ 187	$ 0	$ 17	$ -	$ -	$ -	$ -	$ 341
	2020	$ 45	$ 107	$ 195	$ 1	$ 22	$ 0	$ -	$ -	$ -	$ 369
	2021	$ 53	$ 109	$ 213	$ 1	$ 20	$ 0	$ -	$ -	$ -	$ 396
	2022	$ 56	$ 115	$ 239	$ 1	$ 20	$ 0	$ -	$ -	$ -	$ 430
	2023	$ 64	$ 120	$ 262	$ 1	$ 17	$ 0	$ -	$ -	$ -	$ 464
	2024	$ 67	$ 125	$ 282	$ 1	$ 13	$ 0	$ -	$ -	$ -	$ 487
	2025	$ 72	$ 128	$ 299	$ 1	$ 13	$ 4	$ -	$ -	$ -	$ 517
	2026	$ 76	$ 128	$ 314	$ 1	$ 10	$ 4	$ -	$ -	$ -	$ 532
	2027	$ 88	$ 131	$ 330	$ 1	$ 10	$ 4	$ -	$ -	$ -	$ 562
	2028	$ 92	$ 136	$ 345	$ 1	$ 12	$ 4	$ -	$ 9	$ -	$ 599
	2029	$ 99	$ 139	$ 360	$ 1	$ 15	$ 4	$ 4	$ 13	$ -	$ 635
	2030	$ 103	$ 142	$ 376	$ 1	$ 15	$ 4	$ 8	$ 13	$ -	$ 662
	2031	$ 107	$ 148	$ 391	$ 2	$ 15	$ 8	$ 8	$ 13	$ -	$ 691
	2032	$ 107	$ 150	$ 404	$ 2	$ 15	$ 8	$ 8	$ 17	$ -	$ 711
	2033	$ 107	$ 148	$ 415	$ 3	$ 15	$ 9	$ 8	$ 17	$ -	$ 721
	2034	$ 105	$ 148	$ 418	$ 3	$ 15	$ 9	$ 8	$ 17	$ -	$ 721
	2035	$ 107	$ 150	$ 430	$ 3	$ 15	$ 9	$ 8	$ 22	$ -	$ 743
	2036	$ 104	$ 153	$ 442	$ 3	$ 15	$ 9	$ 8	$ 22	$ -	$ 754
	2037	$ 104	$ 153	$ 453	$ 3	$ 15	$ 9	$ 8	$ 22	$ -	$ 767
	2038	$ 101	$ 151	$ 465	$ 3	$ 15	$ 9	$ 12	$ 26	$ -	$ 781
	2039	$ 101	$ 151	$ 477	$ 3	$ 15	$ 13	$ 16	$ 26	$ -	$ 800
	2040	$ 101	$ 154	$ 489	$ 3	$ 15	$ 13	$ 16	$ 26	$ -	$ 815
	2041	$ 101	$ 157	$ 499	$ 3	$ 15	$ 13	$ 16	$ 30	$ -	$ 833
	2042	$ 101	$ 157	$ 502	$ 3	$ 15	$ 13	$ 16	$ 30	$ -	$ 836
	2043	$ 101	$ 154	$ 508	$ 3	$ 15	$ 13	$ 16	$ 30	$ -	$ 838
	2044	$ 98	$ 154	$ 514	$ 3	$ 15	$ 13	$ 16	$ 34	$ -	$ 846
	2045	$ 89	$ 153	$ 523	$ 3	$ 15	$ 13	$ 16	$ 34	$ -	$ 846
	2046	$ 89	$ 148	$ 533	$ 3	$ 15	$ 13	$ 16	$ 39	$ -	$ 855
	2047	$ 85	$ 142	$ 534	$ 3	$ 15	$ 13	$ 20	$ 39	$ -	$ 850
	2048	$ 85	$ 135	$ 543	$ 3	$ 15	$ 13	$ 23	$ 39	$ -	$ 857
	2049	$ 81	$ 129	$ 552	$ 3	$ 15	$ 14	$ 23	$ 39	$ -	$ 855
	2050	$ 81	$ 129	$ 555	$ 3	$ 15	$ 14	$ 23	$ 39	$ -	$ 857
Undiscounted Total Costs, 2010 - 2050		$ 3,065	$ 5,160	$ 13,827	$ 60	$ 646	$ 255	$ 293	$ 593	$ -	$ 23,899
Discounted Total Costs, 2010 - 2050		$ 1,062	$ 1,916	$ 4,227	$ 16	$ 292	$ 59	$ 61	$ 128	$ -	$ 7,761

	Maximum Nuclear Capacity Expansion Path									
YEAR	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
2010	$ 144	$ 71	$ 35	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 270
2011	$ 51	$ 71	$ 41	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 184
2012	$ 8	$ 71	$ 46	$ 0	$ 19	$ -	$ -	$ -	$ -	$ 145
2013	$ 5	$ 66	$ 55	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 146
2014	$ -	$ 74	$ 62	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 157
2015	$ 1	$ 78	$ 80	$ 0	$ 18	$ -	$ -	$ -	$ -	$ 177
2016	$ 14	$ 88	$ 120	$ 0	$ 19	$ -	$ -	$ -	$ -	$ 242
2017	$ 26	$ 94	$ 157	$ 0	$ 19	$ -	$ -	$ -	$ -	$ 296
2018	$ 36	$ 99	$ 180	$ 0	$ 22	$ -	$ -	$ -	$ -	$ 336
2019	$ 48	$ 104	$ 187	$ 0	$ 26	$ 0	$ -	$ -	$ -	$ 366
2020	$ 59	$ 107	$ 195	$ 1	$ 29	$ 0	$ -	$ -	$ -	$ 391
2021	$ 72	$ 109	$ 213	$ 1	$ 29	$ 0	$ -	$ -	$ -	$ 424
2022	$ 88	$ 115	$ 238	$ 1	$ 29	$ 4	$ -	$ -	$ -	$ 474
2023	$ 104	$ 120	$ 263	$ 1	$ 29	$ 4	$ -	$ -	$ -	$ 520
2024	$ 118	$ 125	$ 287	$ 1	$ 29	$ 7	$ -	$ 4	$ -	$ 571
2025	$ 133	$ 128	$ 312	$ 1	$ 31	$ 8	$ 4	$ 13	$ -	$ 630
2026	$ 138	$ 128	$ 336	$ 2	$ 34	$ 8	$ 8	$ 13	$ 4	$ 670
2027	$ 142	$ 131	$ 361	$ 2	$ 34	$ 8	$ 8	$ 13	$ 4	$ 703
2028	$ 148	$ 136	$ 387	$ 3	$ 31	$ 13	$ 8	$ 17	$ 4	$ 746
2029	$ 152	$ 142	$ 412	$ 3	$ 29	$ 13	$ 8	$ 22	$ 8	$ 788
2030	$ 152	$ 148	$ 438	$ 4	$ 29	$ 17	$ 8	$ 22	$ 8	$ 826
2031	$ 152	$ 150	$ 464	$ 8	$ 25	$ 17	$ 12	$ 27	$ 8	$ 863
2032	$ 152	$ 150	$ 487	$ 10	$ 28	$ 22	$ 16	$ 31	$ 12	$ 907
2033	$ 152	$ 150	$ 509	$ 10	$ 29	$ 24	$ 16	$ 35	$ 12	$ 937
2034	$ 149	$ 153	$ 535	$ 11	$ 28	$ 24	$ 16	$ 35	$ 16	$ 967
2035	$ 146	$ 153	$ 561	$ 15	$ 30	$ 27	$ 16	$ 40	$ 16	$ 1,004
2036	$ 144	$ 156	$ 586	$ 17	$ 29	$ 32	$ 20	$ 44	$ 20	$ 1,048
2037	$ 144	$ 159	$ 612	$ 17	$ 31	$ 33	$ 23	$ 44	$ 20	$ 1,083
2038	$ 140	$ 157	$ 638	$ 17	$ 36	$ 33	$ 23	$ 44	$ 24	$ 1,111
2039	$ 140	$ 159	$ 663	$ 17	$ 39	$ 38	$ 23	$ 48	$ 24	$ 1,152
2040	$ 140	$ 162	$ 689	$ 18	$ 41	$ 38	$ 23	$ 53	$ 28	$ 1,193
2041	$ 140	$ 162	$ 714	$ 22	$ 44	$ 39	$ 27	$ 53	$ 28	$ 1,229
2042	$ 140	$ 165	$ 740	$ 24	$ 44	$ 39	$ 31	$ 53	$ 32	$ 1,267
2043	$ 140	$ 165	$ 766	$ 24	$ 44	$ 44	$ 31	$ 53	$ 32	$ 1,298
2044	$ 137	$ 165	$ 783	$ 25	$ 44	$ 44	$ 31	$ 58	$ 35	$ 1,323
2045	$ 129	$ 164	$ 808	$ 29	$ 44	$ 45	$ 31	$ 63	$ 35	$ 1,348
2046	$ 129	$ 162	$ 834	$ 31	$ 44	$ 45	$ 35	$ 63	$ 39	$ 1,381
2047	$ 121	$ 162	$ 860	$ 31	$ 44	$ 45	$ 39	$ 63	$ 39	$ 1,402
2048	$ 121	$ 161	$ 885	$ 31	$ 44	$ 45	$ 39	$ 63	$ 43	$ 1,431
2049	$ 117	$ 160	$ 911	$ 31	$ 44	$ 45	$ 39	$ 67	$ 43	$ 1,456
2050	$ 109	$ 163	$ 936	$ 31	$ 44	$ 45	$ 39	$ 72	$ 47	$ 1,486
TOTAL	$ 4,384	$ 5,384	$ 18,388	$ 436	$ 1,288	$ 803	$ 575	$ 1,113	$ 579	$ 32,949
NPV	$ 1,485	$ 1,958	$ 5,171	$ 92	$ 470	$ 184	$ 125	$ 252	$ 120	$ 9,858

	Minimum Nuclear Capacity Expansion Path									
YEAR	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
2010	$ 144	$ 71	$ 35	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 270
2011	$ 51	$ 71	$ 41	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 184
2012	$ 8	$ 71	$ 46	$ 0	$ 19	$ -	$ -	$ -	$ -	$ 145
2013	$ 5	$ 66	$ 55	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 146
2014	$ -	$ 74	$ 62	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 157
2015	$ 1	$ 78	$ 87	$ 0	$ 18	$ -	$ -	$ -	$ -	$ 185
2016	$ 12	$ 88	$ 118	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 238
2017	$ 18	$ 94	$ 157	$ 0	$ 20	$ -	$ -	$ -	$ -	$ 290
2018	$ 27	$ 99	$ 180	$ 0	$ 18	$ -	$ -	$ -	$ -	$ 324
2019	$ 33	$ 104	$ 187	$ 0	$ 15	$ -	$ -	$ -	$ -	$ 339
2020	$ 40	$ 107	$ 193	$ 1	$ 15	$ -	$ -	$ -	$ -	$ 356
2021	$ 40	$ 109	$ 198	$ 1	$ 11	$ -	$ -	$ -	$ -	$ 359
2022	$ 40	$ 115	$ 206	$ 1	$ 11	$ -	$ -	$ -	$ -	$ 373
2023	$ 40	$ 110	$ 220	$ 1	$ 7	$ 0	$ -	$ -	$ -	$ 378
2024	$ 40	$ 110	$ 231	$ 1	$ 4	$ 0	$ -	$ -	$ -	$ 386
2025	$ 40	$ 109	$ 241	$ 1	$ 4	$ 0	$ -	$ -	$ -	$ 395
2026	$ 40	$ 106	$ 252	$ 1	$ -	$ 0	$ -	$ -	$ -	$ 399
2027	$ 40	$ 103	$ 262	$ 1	$ -	$ 0	$ -	$ -	$ -	$ 405
2028	$ 40	$ 96	$ 272	$ 1	$ -	$ 0	$ -	$ -	$ -	$ 409
2029	$ 40	$ 90	$ 282	$ 1	$ -	$ 0	$ -	$ -	$ -	$ 413
2030	$ 34	$ 92	$ 293	$ 1	$ -	$ 0	$ -	$ -	$ -	$ 420
2031	$ 34	$ 98	$ 303	$ 1	$ -	$ 0	$ -	$ -	$ -	$ 436
2032	$ 31	$ 101	$ 311	$ 1	$ -	$ 0	$ -	$ -	$ -	$ 443
2033	$ 31	$ 101	$ 318	$ 1	$ -	$ 0	$ -	$ 5	$ -	$ 455
2034	$ 28	$ 101	$ 320	$ 1	$ -	$ 0	$ -	$ 5	$ -	$ 454
2035	$ 28	$ 100	$ 330	$ 1	$ -	$ 0	$ -	$ 9	$ -	$ 468
2036	$ 28	$ 101	$ 338	$ 1	$ -	$ 0	$ -	$ 9	$ -	$ 478
2037	$ 28	$ 104	$ 343	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 486
2038	$ 24	$ 100	$ 349	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 484
2039	$ 21	$ 96	$ 354	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 483
2040	$ 18	$ 96	$ 360	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 485
2041	$ 14	$ 96	$ 365	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 486
2042	$ 6	$ 88	$ 365	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 470
2043	$ 6	$ 88	$ 367	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 472
2044	$ 6	$ 84	$ 370	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 471
2045	$ 6	$ 80	$ 375	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 473
2046	$ 6	$ 80	$ 381	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 478
2047	$ 3	$ 80	$ 379	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 473
2048	$ 3	$ 80	$ 384	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 479
2049	$ 3	$ 80	$ 390	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 484
2050	$ 3	$ 80	$ 389	$ 1	$ -	$ 1	$ -	$ 9	$ -	$ 483
TOTAL	$ 1,061	$ 3,801	$ 10,710	$ 22	$ 244	$ 13	$ -	$ 161	$ -	$ 16,013
NPV	$ 543	$ 1,575	$ 3,448	$ 7	$ 177	$ 3	$ -	$ 33	$ -	$ 5,786

		BAU Nuclear Capacity Expansion Path									
Decommissioning Costs (million 2009 USD)	YEAR	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
	2010	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	2011	$ 2,359	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,359
	2012	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	2013	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	2014	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	2015	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	2016	$ 359	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 359
	2017	$ 547	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 547
	2018	$ 239	$ -	$ -	$ -	$ 330	$ -	$ -	$ -	$ -	$ 569
	2019	$ -	$ -	$ -	$ -	$ 332	$ -	$ -	$ -	$ -	$ 332
	2020	$ -	$ -	$ -	$ 4	$ -	$ -	$ -	$ -	$ -	$ 4
	2021	$ -	$ -	$ -	$ -	$ 519	$ -	$ -	$ -	$ -	$ 519
	2022	$ -	$ -	$ -	$ 14	$ -	$ -	$ -	$ -	$ -	$ 14
	2023	$ -	$ -	$ -	$ -	$ 524	$ -	$ -	$ -	$ -	$ 524
	2024	$ -	$ -	$ -	$ -	$ 508	$ -	$ -	$ -	$ -	$ 508
	2025	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	2026	$ -	$ -	$ -	$ -	$ 513	$ -	$ -	$ -	$ -	$ 513
	2027	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	2028	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	2029	$ -	$ -	$ -	$ -	$ -	$ 10	$ -	$ -	$ -	$ 10
	2030	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	2031	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	2032	$ -	$ -	$ 274	$ -	$ -	$ -	$ -	$ -	$ -	$ 274
	2033	$ -	$ 276	$ 276	$ -	$ -	$ -	$ -	$ -	$ -	$ 552
	2034	$ 462	$ -	$ 895	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,358
	2035	$ 489	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 489
	2036	$ 466	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 466
	2037	$ 321	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 321
	2038	$ 626	$ 246	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 873
	2039	$ 1,344	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,344
	2040	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	2041	$ 323	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 323
	2042	$ 965	$ -	$ 665	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,630
	2043	$ -	$ 281	$ 405	$ -	$ -	$ -	$ -	$ -	$ -	$ 686
	2044	$ 1,470	$ -	$ 265	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,735
	2045	$ 2,836	$ 415	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 3,251
	2046	$ -	$ 835	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 835
	2047	$ 1,990	$ 729	$ 875	$ -	$ -	$ -	$ -	$ -	$ -	$ 3,595
	2048	$ -	$ 734	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 734
	2049	$ 836	$ 738	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,574
	2050	$ 1,320	$ -	$ 741	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,061
Undiscounted Total Costs, 2010 - 2050		$ 16,952	$ 4,255	$ 4,396	$ 18	$ 2,727	$ 10	$ -	$ -	$ -	$ 28,358
Discounted Total Costs, 2010 - 2050		$ 5,489	$ 736	$ 935	$ 10	$ 1,439	$ 4	$ -	$ -	$ -	$ 8,612

	Maximum Nuclear Capacity Expansion Path									
YEAR	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
2010	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2011	$ 2,359	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,359
2012	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2013	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2014	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2015	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2016	$ 359	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 359
2017	$ 547	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 547
2018	$ 239	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 239
2019	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2020	$ -	$ -	$ -	$ 4	$ -	$ -	$ -	$ -	$ -	$ 4
2021	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2022	$ -	$ -	$ -	$ 14	$ -	$ -	$ -	$ -	$ -	$ 14
2023	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2024	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2025	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2026	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2027	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2028	$ -	$ -	$ -	$ -	$ 346	$ -	$ -	$ -	$ -	$ 346
2029	$ -	$ -	$ -	$ -	$ 348	$ 10	$ -	$ -	$ -	$ 358
2030	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2031	$ -	$ -	$ -	$ -	$ 544	$ -	$ -	$ -	$ -	$ 544
2032	$ -	$ -	$ 274	$ -	$ -	$ -	$ -	$ -	$ -	$ 274
2033	$ -	$ 276	$ 276	$ -	$ 549	$ -	$ -	$ -	$ -	$ 1,101
2034	$ 462	$ -	$ -	$ -	$ 532	$ -	$ -	$ -	$ -	$ 995
2035	$ 489	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 489
2036	$ 466	$ -	$ -	$ -	$ 537	$ -	$ -	$ -	$ -	$ 1,003
2037	$ 321	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 321
2038	$ 626	$ 246	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 873
2039	$ 1,344	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,344
2040	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2041	$ 323	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 323
2042	$ 965	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 965
2043	$ -	$ 281	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 281
2044	$ 1,470	$ -	$ 950	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,419
2045	$ 2,836	$ 415	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 3,251
2046	$ -	$ 835	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 835
2047	$ 1,990	$ 729	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,719
2048	$ -	$ 734	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 734
2049	$ 836	$ 738	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,574
2050	$ 1,320	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,320
TOTAL	$ 16,952	$ 4,255	$ 1,500	$ 18	$ 2,857	$ 10	$ -	$ -	$ -	$ 25,592
NPV	$ 5,489	$ 736	$ 347	$ 10	$ 925	$ 4	$ -	$ -	$ -	$ 7,511

	Minimum Nuclear Capacity Expansion Path									
YEAR	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
2010	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2011	$ 2,359	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,359
2012	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2013	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2014	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2015	$ -	$ 246	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 246
2016	$ 359	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 359
2017	$ 547	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 547
2018	$ 239	$ 217	$ -	$ -	$ 330	$ -	$ -	$ -	$ -	$ 786
2019	$ 431	$ -	$ -	$ -	$ 332	$ -	$ -	$ -	$ -	$ 763
2020	$ 456	$ -	$ -	$ 4	$ -	$ -	$ -	$ -	$ -	$ 461
2021	$ 435	$ -	$ -	$ -	$ 519	$ -	$ -	$ -	$ -	$ 954
2022	$ 300	$ -	$ -	$ 14	$ -	$ -	$ -	$ -	$ -	$ 313
2023	$ 585	$ 248	$ -	$ -	$ 524	$ -	$ -	$ -	$ -	$ 1,357
2024	$ 1,256	$ -	$ -	$ -	$ 508	$ -	$ -	$ -	$ -	$ 1,764
2025	$ -	$ 368	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 368
2026	$ 302	$ 740	$ -	$ -	$ 513	$ -	$ -	$ -	$ -	$ 1,555
2027	$ 903	$ 647	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,550
2028	$ -	$ 651	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 651
2029	$ 1,376	$ 656	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,032
2030	$ 2,657	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,657
2031	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2032	$ 1,864	$ -	$ 274	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,139
2033	$ -	$ -	$ 276	$ -	$ -	$ -	$ -	$ -	$ -	$ 276
2034	$ 783	$ -	$ 895	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,678
2035	$ 1,237	$ 412	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,649
2036	$ 993	$ 414	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,407
2037	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2038	$ 2,253	$ 419	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,673
2039	$ 1,813	$ 422	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,235
2040	$ 474	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 474
2041	$ 782	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 782
2042	$ 1,470	$ 859	$ 665	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,993
2043	$ -	$ -	$ 405	$ -	$ -	$ -	$ -	$ -	$ -	$ 405
2044	$ -	$ 434	$ 265	$ -	$ -	$ -	$ -	$ -	$ -	$ 699
2045	$ -	$ 437	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 437
2046	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2047	$ 489	$ -	$ 875	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,364
2048	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2049	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2050	$ 1,488	$ -	$ 741	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,229
TOTAL	$ 25,851	$ 7,169	$ 4,396	$ 18	$ 2,727	$ -	$ -	$ -	$ -	$ 40,161
NPV	$ 9,990	$ 2,465	$ 935	$ 10	$ 1,439	$ -	$ -	$ -	$ -	$ 14,838

Components of Nuclear Power Costs: Costs Summaries

Total Cost by Component and Country, 2010 - 2050

	BAU Nuclear Capacity Expansion Path									
Undiscounted Costs	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
Annualized Capital Costs	$ 459,380	$ 198,251	$ 506,157	$ 2,558	$ 48,776	$ 10,157	$ 9,952	$ 34,453	$ -	$ 1,269,684
Fixed O&M Costs	$ 288,982	$ 128,341	$ 318,497	$ 1,582	$ 24,992	$ 6,178	$ 5,985	$ 12,820	$ -	$ 787,378
Variable O&M Costs	$ 3,065	$ 5,160	$ 13,827	$ 60	$ 646	$ 255	$ 293	$ 593	$ -	$ 23,899
Decommissioning Costs	$ 16,952	$ 4,255	$ 4,396	$ 18	$ 2,727	$ 10	$ -	$ -	$ -	$ 28,358
Total	$ 768,379	$ 336,006	$ 842,877	$ 4,219	$ 77,141	$ 16,599	$ 16,230	$ 47,867	$ -	$ 2,109,319
Fraction of Total										
Annualized Capital Costs	59.8%	59.0%	60.1%	60.6%	63.2%	61.2%	61.3%	72.0%	#DIV/0!	60.2%
Fixed O&M Costs	37.6%	38.2%	37.8%	37.5%	32.4%	37.2%	36.9%	26.8%	#DIV/0!	37.3%
Variable O&M Costs	0.4%	1.5%	1.6%	1.4%	0.8%	1.5%	1.8%	1.2%	#DIV/0!	1.1%
Decommissioning Costs	2.2%	1.3%	0.5%	0.4%	3.5%	0.1%	0.0%	0.0%	#DIV/0!	1.3%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	#DIV/0!	100.0%
Implied Cost per MWh Generation										
Annualized Capital Costs	$ 74.95	$ 19.21	$ 18.30	$ 21.24	$ 37.74	$ 19.94	$ 16.97	$ 29.03	#DIV/0!	$ 26.56
Fixed O&M Costs	$ 47.15	$ 12.44	$ 11.52	$ 13.14	$ 19.34	$ 12.13	$ 10.21	$ 10.80	#DIV/0!	$ 16.47
Variable O&M Costs	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	#DIV/0!	$ 0.50
Decommissioning Costs	$ 2.77	$ 0.41	$ 0.16	$ 0.15	$ 2.11	$ 0.02	$ -	$ -	#DIV/0!	$ 0.59
Total	$ 125.36	$ 32.56	$ 30.48	$ 35.03	$ 59.69	$ 32.58	$ 27.68	$ 40.33	#DIV/0!	$ 44.13

	Maximum Nuclear Capacity Expansion Path									
Undiscounted Costs	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
Annualized Capital Costs	$ 508,066	$ 204,467	$ 659,584	$ 17,078	$ 92,951	$ 29,172	$ 20,348	$ 65,064	$ 30,558	$ 1,627,288
Fixed O&M Costs	$ 318,747	$ 132,046	$ 410,697	$ 10,282	$ 46,390	$ 17,755	$ 12,285	$ 24,467	$ 11,300	$ 983,969
Variable O&M Costs	$ 4,384	$ 5,384	$ 18,388	$ 436	$ 1,288	$ 803	$ 575	$ 1,113	$ 579	$ 32,949
Decommissioning Costs	$ 16,952	$ 4,255	$ 1,500	$ 18	$ 2,857	$ 10	$ -	$ -	$ -	$ 25,592
Total	$ 848,150	$ 346,153	$ 1,090,168	$ 27,814	$ 143,485	$ 47,740	$ 33,207	$ 90,644	$ 42,438	$ 2,669,798
Fraction of Total										
Annualized Capital Costs	59.9%	59.1%	60.5%	61.4%	64.8%	61.1%	61.3%	71.8%	72.0%	61.0%
Fixed O&M Costs	37.6%	38.1%	37.7%	37.0%	32.3%	37.2%	37.0%	27.0%	26.6%	36.9%
Variable O&M Costs	0.5%	1.6%	1.7%	1.6%	0.9%	1.7%	1.7%	1.2%	1.4%	1.2%
Decommissioning Costs	2.0%	1.2%	0.1%	0.1%	2.0%	0.0%	0.0%	0.0%	0.0%	1.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Implied Cost per MWh Generation										
Annualized Capital Costs	$ 57.94	$ 18.99	$ 17.94	$ 19.60	$ 36.09	$ 18.17	$ 17.70	$ 29.24	$ 26.37	$ 24.69
Fixed O&M Costs	$ 36.35	$ 12.26	$ 11.17	$ 11.80	$ 18.01	$ 11.06	$ 10.69	$ 11.00	$ 9.75	$ 14.93
Variable O&M Costs	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50
Decommissioning Costs	$ 1.93	$ 0.40	$ 0.04	$ 0.02	$ 1.11	$ 0.01	$ -	$ -	$ -	$ 0.39
Total	$ 96.72	$ 32.14	$ 29.64	$ 31.92	$ 55.71	$ 29.73	$ 28.89	$ 40.74	$ 36.62	$ 40.51

	Minimum Nuclear Capacity Expansion Path									
Undiscounted Costs	Japan	ROK	China	RFE	Taiwan	DPRK	Indonesia	Vietnam	Australia	TOTAL
Annualized Capital Costs	$ 300,434	$ 146,733	$ 394,138	$ 873	$ 19,871	$ 665	$ -	$ 9,112	$ -	$ 871,826
Fixed O&M Costs	$ 191,862	$ 96,674	$ 249,652	$ 562	$ 10,978	$ 403	$ -	$ 3,360	$ -	$ 553,491
Variable O&M Costs	$ 1,061	$ 3,801	$ 10,710	$ 22	$ 244	$ 13	$ -	$ 161	$ -	$ 16,013
Decommissioning Costs	$ 25,851	$ 7,169	$ 4,396	$ 18	$ 2,727	$ -	$ -	$ -	$ -	$ 40,161
Total	$ 519,209	$ 254,377	$ 658,897	$ 1,476	$ 33,820	$ 1,081	$ -	$ 12,633	$ -	$ 1,481,491
Fraction of Total										
Annualized Capital Costs	57.9%	57.7%	59.8%	59.2%	58.8%	61.5%	#DIV/0!	72.1%	#DIV/0!	58.8%
Fixed O&M Costs	37.0%	38.0%	37.9%	38.1%	32.5%	37.2%	#DIV/0!	26.6%	#DIV/0!	37.4%
Variable O&M Costs	0.2%	1.5%	1.6%	1.5%	0.7%	1.2%	#DIV/0!	1.3%	#DIV/0!	1.1%
Decommissioning Costs	5.0%	2.8%	0.7%	1.2%	8.1%	0.0%	#DIV/0!	0.0%	#DIV/0!	2.7%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	#DIV/0!	100.0%	#DIV/0!	100.0%
Implied Cost per MWh Generation										
Annualized Capital Costs	$ 141.53	$ 19.30	$ 18.40	$ 19.80	$ 40.67	$ 25.31	#DIV/0!	$ 28.33	#DIV/0!	$ 27.22
Fixed O&M Costs	$ 90.38	$ 12.72	$ 11.66	$ 12.75	$ 22.47	$ 15.32	#DIV/0!	$ 10.45	#DIV/0!	$ 17.28
Variable O&M Costs	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	#DIV/0!	$ 0.50	#DIV/0!	$ 0.50
Decommissioning Costs	$ 12.18	$ 0.94	$ 0.21	$ 0.41	$ 5.58	$ -	#DIV/0!	$ -	#DIV/0!	$ 1.25
Total	$ 244.59	$ 33.46	$ 30.76	$ 33.46	$ 69.23	$ 41.12	#DIV/0!	$ 39.27	#DIV/0!	$ 46.26