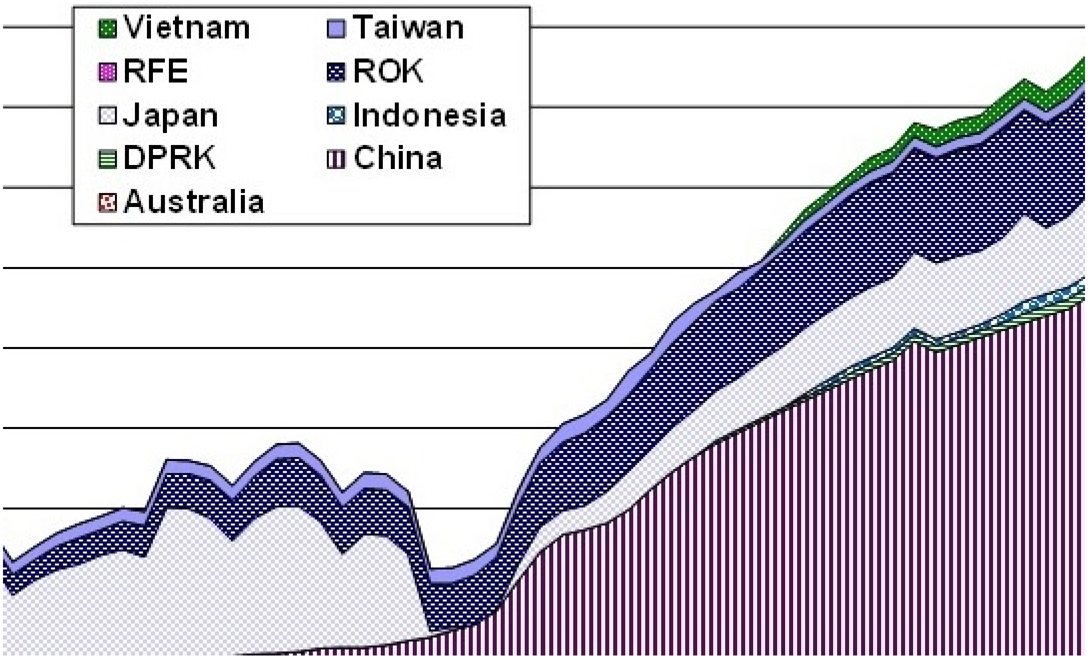
CONCERTED STRATEGIES FOR MANAGEMENT OF SPENT NUCLEAR FUEL IN NORTHEAST ASIA



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David F. von Hippel and Peter Hayes

August 17, 2017

I. INTRODUCTION

In this essay, David von Hippel and Peter Hayes conclude 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 expanding the 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 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."

David von Hippel is Nautilus Institute Senior Associate. Peter Hayes is Director of the Nautilus Institute and Honorary Professor at the Centre for International Security Studies at the University of Sydney.

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The full report including the full technical analysis and workbooks is available as a PDF file here. (3.0MB)

Banner image: spent fuel per year by country from the authors' full technical report here.

II. NAPSNET SPECIAL REPORT BY DAVID F. VON HIPPEL AND PETER HAYES

CONCERTED STRATEGIES FOR MANAGEMENT OF SPENT NUCLEAR FUEL IN NORTHEAST ASIA

August 17, 2017

This special report updates 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) region wide, 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 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 result 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.

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 key policy issues that arise therefrom, 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[1]. A few of the benefits—and challenges—of regional cooperation on nuclear fuel cycle issues are listed below,[2] 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.

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.[3]
- 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 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.[4]
- 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.[5]
- 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.

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 raises 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 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.

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 of the full report. 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 study 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.

Implications of Cooperation Scenarios

The key findings of the cooperation scenario analyses summarized above, 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 expanding the 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 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.

III. ENDNOTES

[1] 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-pub.iaea.org/MTCD/publications/PDF/mna-2005_web.pdf

[2] 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

[3] 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.belfercenter.org/publication/interim-storag--spent-nuclear-fuel-safe-flexible-and-cost-effective-near-term-approach

[4] 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."

[5] 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 here.

IV. NAUTILUS INVITES YOUR RESPONSE

The Nautilus Asia Peace and Security Network invites your responses to this report. Please send responses to: nautilus@nautilus.org. Responses will be considered for redistribution to the network only if they include the author's name, affiliation, and explicit consent

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Nautilus Institute
608 San Miguel Ave., Berkeley, CA 94707-1535 | Phone: (510) 423-0372 | Email: nautilus@nautilus.org