Session Sketches

Reprocessing and Disposal of Spent Nuclear Fuel

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Summary

Moderator Sharon Squassoni, director of the Proliferation Prevention Program at the Center for Strategic and International Studies (CSIS), opened the session by underscoring that the topic of reprocessing and disposal of spent nuclear fuel (SNF) was not only technical, but also highly political. She then introduced the panelists: Juhani Vira, senior vice president responsible for research at Posiva Oy in Finland; Andrew Orrell, director of Nuclear Energy Programs at Sandia National Laboratories; Alan Hanson, currently a visiting fellow at Stanford University's CISAC and executive vice president of Technologies and Used Fuel Management at AREVA, Inc; and Charles McCombie, president of the Association for Regional International Underground Storage (ARIUS) and a founding partner of MCM Consulting.

Juhani Vira:

In the 1970s, the first plans for SNF management in Finland did include reprocessing. Certain events in the late 1970s and early 1980s however lead Finland to go down the road towards the licensing of an SNF repository without reprocessing. These events included President Carter's ban of reprocessing in the United States and his encouragement of other countries to follow suit, as well as the Three Mile Island nuclear accident that caused uranium prices to drop quickly and dramatically in the early 1980s. Although these two events did not affect Finland directly, they certainly affected uranium markets and the way Finland considered the future of its nuclear policy, including the reprocessing option. At the time, Finnish nuclear company TVO, which was responsible for SNF management, decided not to sign any agreement with the reprocessing companies, and instead started preparing for direct disposal of SNF in Finland. The government of Finland was actually not in favor of the direct disposal option, because it preferred the arrangement that the other nuclear company, IVO, had with the Soviet Union, which took back Finland's SNF and reprocessed it for its own use. So the Finnish government originally wanted TVO to seek a similar arrangement for their SNF, but it eventually accepted TVO's decision and, in 1983, it set up a plan, including timeframes, for the way in which TVO should prepare for direct disposal. In 1994, the Nuclear Energy Act of Finland was changed in order to institute direct disposal as the only SNF management strategy for the country.

Today, Posiva Oy is in charge of SNF management in Finland, but it follows the same plan set up in 1983 and has maintained the same timeline for starting to dispose of the fuel—meant to happen in 2020, which would put Finland among the first countries to open a repository for SNF. The 1980s decision to go with direct disposal was taken mainly for economic reasons (see above), but there was an additional factor: many countries started putting restrictions on their fuel supply, including the requirement for prior consent before reprocessing their fuel. A decision to reprocess would therefore have been too risky for a country so dependent on foreign fuel. (Note that a number of assessments on the pros and cons, in terms of environmental impact and safety risk, of a once-through fuel cycle compared to a reprocessing one were inconclusive.) Finland's success with the repository strategy could nevertheless not have occurred if it had not been for Sweden. Swedish nuclear waste management company SKB had already embarked on the direct disposal route in the 1970s and had developed the famous KBS-3 disposal concept by the 1980s. Finland and Sweden have very similar geological properties and used the same nuclear fuel at the time, so Sweden's early progress in direct disposal gave Finland a model to follow. Finland's TVO adopted the KBS-3 concept and thus was able to draw on the extensive R&D Sweden had done for the technical aspects of disposal and focus instead on the siting process.

Finland foresaw that siting might be an issue, so it began a systematic, stepwise approach to siting in the 1980s, in order to ensure that it did not prevent direct disposal from happening. This approach began with a geological and safety survey to identify possible sites, but then let the public (both local and national) decide on the final site choice. The success of this approach is demonstrated by the fact that, ten years ago (2001), Finland was the first country to approve an SNF repository site. Once the site was approved, Posiva Oy began building its underground rock characterization facility, Onkalo, in 2004, in order to study the bedrock in preparation for disposal. Having reached about 420 meters of depth, Onkalo is now almost completed. To begin construction on the actual repository, Posiva Oy needs a construction license, which will be submitted at the end of 2012. Sweden's SKB has already submitted a similar application for their repository, but they will likely not be ready to operate their repository before 2025, because their licensing process will probably take more time than Finland's, they are still facing an ongoing political debate on the issue, and they have not yet begun to dig. France is also preparing for licensing, as it has a law that requires it to begin disposing of SNF by 2025—a deadline that France seems poised to meet. Still, Finland will likely be the first country to begin disposing of SNF by 2020. Despite concerns about long-term safety, Finns have agreed that there is no better alternative than direct disposal. There are of course some advocates of reprocessing in Finland (like Director General of the Finnish regulatory agency) but Posiva Oy's position is that, even if Finland eventually decides to reprocess, the country will still need a repository for *some* SNF, as well as reprocessing waste.

Andrew Orrell:

In 2008, with support from Sandia National Laboratories, the U.S. Department of Energy (DoE) submitted a license application to the Nuclear Regulatory Commission (NRC) to seek technical review and regulatory approval to construct a repository at Yucca Mountain. Then, the elections brought a Democratic Presidency and Congress. Immediately after being sworn in, the Obama administration moved to eliminate all funding for the Yucca Mountain project, suggesting a new strategy was needed. In addition, DoE moved to have the license application withdrawn, noting that it was the secretary of Energy's judgment, not that Yucca Mountain was unsafe or that the application was flawed, but rather that Yucca Mountain was "not a workable option and that alternatives will better serve the public interest." After a 10 billion dollar investment, repeatedly authorized by Congress since the Yucca Mountain site recommendation in 2002, the current efforts to cancel the projects without a clear alternative in place provoked a considerable reaction from Congress, the industry, and the public. There are legal suits by the states of South Carolina and Washington challenging DoE's authority to take such actions. The NRC's Atomic Safety and Licensing Board Panel ruled that the withdrawal of the application was not authorized. There have also been embarrassing inquiries and resolutions by congressional committees and objections by trade groups, among other signs of protest against the efforts to cancel the Yucca Mountain project.

As a result, the Secretary of Energy, acting on the direction of the president, called for the formation of a Blue Ribbon Commission to explore these issues and make recommendations on possible alternatives. By law, these commissions are limited to a maximum of 2 years, must have a membership that represents a diversity of opinion, must operate with transparency and seek public input. This Blue Ribbon Commission on America's Nuclear Future is comprised of 3 subcommittees. The Disposal Subcommittee addresses the question of how the United States can establish one or more disposal sites for high-level nuclear waste (HLW) in a manner that is technically, politically, and socially acceptable. The Transportation and Storage Subcommittee addresses the question of whether the United States should change the way in which it is currently storing SNF and HLW, while it works towards final disposal sites. The Reactor and Fuel Cycle Technology Subcommittee addresses the question of whether technical alternatives to today's once-through fuel cycle offer sufficient promise to warrant serious consideration and R&D investment, and whether these technologies hold significant potential to influence the way in which SNF is stored and disposed of. The draft recommendations of the three subcommittees were recently released, and among them are the following key findings: 1) a new entity (not DoE or other existing government agency) should be authorized to assume responsibility of all transportation, storage, and disposal 2) the United States should proceed with the siting of a centralized and consolidated interim storage facility, and simultaneously initiate a new repository siting program that is based on volunteer state adaptive management 3) the United States should continue R&D of advanced nuclear energy concepts. The BRC draft recommendations also explicitly argue that there is no rational for reprocessing at the moment (which is disappointing to those who defend that reprocessing holds certain benefits).

What does this all mean for SNF management in the United States? The United States already has the world's largest inventory of SNF with about 65, 000 metric tons of it at present, and will have a total of about 133, 000 metric tons at the end of the existing nuclear reactor fleet's 60-year life. If some new build, perhaps 5 to 8 new plants, occurs by the end of the decade, the country will accumulate even more SNF. Will there be interim, indefinite, or permanent storage of this inventory? Is inter-generational nuclear guardianship acceptable? Will the United States reprocess and recycle, and if so, for what benefit and at what cost? Or will the country proceed with direct disposal, either in mine repositories or deep borehole concepts? To address all these questions, the United States must answer the fundamental question of whether the SNF inventory is an asset to be stored and exploited or waste to be disposed of. In the current debate on reprocessing versus disposal, the question is regrettably often treated as an all-or-nothing issue: store and reprocess everything, or zero reprocessing and all direct disposal. The true answer may actually be both, for practical reasons.

On storage: The United States' inability to implement a geologic disposal or a reprocessing capability has led to a de facto interim and, at the moment, indefinite storage posture. The country has not and probably will not declare a nuclear guardianship policy of century-long storage before further action (as the Netherlands has rightly done at their HABOG facility). Due to the recent developments on Yucca Mountain, the United States nevertheless seems to be heading towards a default policy of century-long interim storage. The BRC has recognized this and has therefore called for an expedited repository program to begin anew.

On reprocessing: Reprocessing does have real merit if energy security (assured supply of fissile material) is a concern. In that case, the economics of reprocessing may have to be assigned an intangible premium for energy security, which might make it worthwhile in a cost-benefit analysis. In the United States, however, with only 20% reliance on nuclear power for the foreseeable future, an assured supply of fissile material is not a main concern for the commercial industry. Proliferation, on the other hand, is a primary concern in U.S. policy. Regardless, in the United States, reprocessing is often promoted as having various benefits, especially for waste management and repository issues. For instance, proponents claim that reprocessing reduces the volume, heat, and radiotoxicity of the waste, and suggest that it will simplify the existing repository effort, avoid the need for a second repository, and somehow secure public acceptance. Yet, while new fuel cycles and/or reprocessing can affect the volume and characteristics of the resulting waste, they cannot prevent the need for substantial geologic disposal of high- and intermediate-level waste, nor reduce the societal barriers to opening a repository. Indeed, never did the state of Nevada say that only if the United States were to reprocess the SNF inventory, would it allow Yucca Mountain to proceed. Again, the U.S. debate on reprocessing versus disposal is often framed as an either-or proposition, but, given the large size of the U.S. SNF inventory, to suggest that reprocessing will remove the need for disposal is wishful thinking. Some simple calculations show that under most reasonable scenarios of nuclear generation and of potential availability and scale of reprocessing—even with significant reprocessing capacity beginning in the next 15 years—the backlog of SNF can never be practically consumed. Thus, at least some portion of the SNF inventory has no reprocessing value whatsoever and should be viewed as a waste appropriate for direct disposal now. One of the more common assertions about reprocessing is the reduction in radiotoxicity. Radiotoxicity of the waste form was widely used to evaluate the impact of alternative fuel cycle options on the waste stream, but it is not particularly useful for evaluating waste form for disposal system performance, which is evaluated and regulated based on dose and not on radiotoxicity. Radiotoxicity is dominated by the actinides, whereas the estimated dose of SNF is typically dominated by mobile fission and activation products. So, even if you do not separate the actinides by reprocessing, they still don't affect the repository performance. Another cited advantage of reprocessing is the reduction in heat or volume of the waste. Significant thermal benefits can be achieved if you also achieve substantial (greater than 99%) separation of short-lived fission products, but these will also require extended storage. However, waste volume and thermal output are inversely related: managing heat and volume is an engineering trade-off made in the repository design. As evidenced by the several national programs pursuing direct disposal of SNF, balancing heat and volume is readily achieved by combinations of aging, waste package, loading density, emplacement density, package placement (?), and ventilation. Additionally, volumes of low-level waste will increase with reprocessing, including Greater Than Class C (GTCC) or intermediate-level waste that may require geologic disposal as well—negating some of the above supposed benefits of reprocessing. Lastly, reprocessing has been promoted as extending the supply of uranium, which addresses the concerns of some about future uranium supply and availability, providing a sense of energy security. Yet, perhaps in response to the uranium price hike of 2007, exploration has increased immensely, leading to a commensurable increase in global recoverable uranium resources. According to the latest estimates, there are sufficient identified uranium resources to last another century. Nevertheless, available uranium resources do not mean that uranium is accessible to a particular program, and thus some countries may be willing to incur the economic cost of reprocessing for the assurance of energy security.

On disposal and repositories: It appears that the United States will be pursuing direct disposal for the foreseeable future. This may or may not be in parallel with siting a consolidated interim storage facility. In any case, Sandia National Laboratories have been giving the concept of deep borehole disposal more serious consideration as a practical cost-effective means to undertake high-confidence direct disposal in multiple locations and help address regional equity concerns. Moreover, the outcome of the Yucca Mountain situation is far from over. It is possible that U.S. courts and the next Congress after the 2012 elections will renew the efforts to develop a repository at Yucca Mountain, over the objection of the state of Nevada, but in compliance with current law. It is however unlikely that the issue will be resolved by Congress until well after the 2012 elections.

In conclusion, each nation's nuclear energy policy will dictate its approach to storage, reprocessing, and disposal. Smaller national nuclear energy programs, such as those in Mexico or Slovenia, may benefit from direct disposal and securing their fuel supply by other means than reprocessing. While, on its face, reprocessing may not offer substantial benefits to the U.S. nuclear waste management situation (as the BRC also concludes), the world is an uncertain place—so, even if the United States chooses not to pursue reprocessing today, it may be prudent to develop a policy whereby the country keeps in 'strategic reserve' some fraction of the U.S. SNF that could be reprocessed, should the future need arise. The remainder of SNF should be disposed of. This strategic reserve would be (like the U.S. strategic petroleum reserve) a security measure, and could actually coincide with the consolidated interim storage site—with a fixed capacity that the host community would know could not be exceeded. Fresher fuel would be continually brought in to the reserve (thus keeping some economic activity at the site) and older fuel would be disposed of directly and permanently. All of this requires Congress to change the laws, now mandating a repository at Yucca Mountain, to enact some or all of the recommendations put forth by the BRC.

Alan Hanson:

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The following is not by any means a sales pitch for reprocessing. Reprocessing should not be undertaken by every country in the world, and especially not just because some countries (like France) do it or just to obtain a sense of prestige.

Why do some countries embark on reprocessing programs?

- Resource conservation: Recovery of the unburned uranium and of the plutonium from SNF displaces the need to mine more virgin uranium and to do more enrichment. The new material savings resulting from reprocessing are in the order of 25%, which is not a negligible value. Since the largest environmental impact of nuclear power comes from mining (except for when there is a nuclear reactor accident), reducing the amount of mining is a plus. Reprocessing also lowers the secondary carbon generation associated with nuclear power: nuclear energy itself does not produce carbon, but there are carbon emissions that come along with the mining and enrichment stages of the fuel cycle.
- Energy security: If a country is not rich in uranium resources, then it needs to obtain its uranium from another country. Yet, a country with light-water reactors (LWR) and reprocessing can effectively turn purchased and imported foreign uranium into a domestic resource—the uranium and plutonium recovered by reprocessing from the LWR's SNF. This added energy security explains why some countries, dependent on foreign uranium, may be ready to pay the cost of reprocessing. Nevertheless, the value of the recovered products from reprocessing does not completely offset the cost of the reprocessing operation necessary to recover them.
- Waste management: This factor depends on the linkage between the waste disposal strategy of a country and its fuel cycle strategy, as well as on the geologic environment and the availability of land for siting. Therefore, to answer the question of whether reprocessing is helpful for waste management in a given country, one must examine the specific situation in that country. Reprocessing can enable an important reduction in the volume of nuclear waste, but it is more difficult to obtain a reduction in heat, which is often the driving force in repository size and design. Thus, if reprocessing does not lead to sufficient heat reduction, there is very little overall benefit for repository design. Dose, mentioned by Andrew Orrell, is a determining factor in U.S. waste management decision-making, but it is not so in every country. Radiotoxity can also be a factor in making these decisions and reprocessing can have some advantages in reducing the amount of actinides. Doing *early* reprocessing in

particular, dramatically reduces the amount of plutonium in the waste (the largest actinide in the mix), which in turn reduces the amount of americium and neptunium (because they result from the decay of plutonium-241). If, however, reprocessing is *not* done early (and there are the advantages of a lower heat load and lower criticality concerns in doing it later), all of the plutonium-241 decays into americium and neptunium, leading to a hotter mix of isotopes to deal with in the waste.

- Nonproliferation: Although this is not a common position, it is arguable that reprocessing has both positive and negative consequences in terms of nonproliferation. The fact that reprocessing destroys plutonium atoms and denatures the remaining plutonium atoms (so that they are less useful for explosive purposes) is a benefit for nonproliferation. The negative consequence is that, in order to get that benefit, there is a period of time during which there is separated material that could potentially be diverted for weapons purposes. This period of time therefore creates the need for expensive safeguards and security that might not be necessary otherwise (since, at least for the first century, un-reprocessed SNF is nominally self-protecting).

No single one of the above reasons, taken alone, should be sufficient to justify undertaking reprocessing. A combination of two or three of these reasons is required to drive a country to reprocess, rather than dispose of SNF.

There are two fundamental approaches to reprocessing: aqueous (chemical separation) method, which were developed during the Cold War and were also used for weapons, and electro-metallurgical separation ("pyroprocessing") method, which are far less developed than the aqueous one. Both of these methods separate isotopes. From the perspective of nonproliferation, if a country has technology that makes it possible to move one set of isotopes in one direction and another set in another direction, then there is cause for proliferation concerns. Consequently, both aqueous and electro-metallurgical reprocessing methods require additional safeguards and security. Pyroprocessing is not a solution to the proliferation problems associated with reprocessing in general. Furthermore, pyroprocessing still needs to be developed and proved effective on a commercial scale, as it has for now shown promise only on the laboratory scale—including through a joint U.S.-South Korean R&D program. (General Electric, for instance, had developed a brand new reprocessing method, to avoid PUREX, called Aquaflor that worked very well in the laboratory, but could not be scaled up.)

Note that France's AREVA has been doing reprocessing successfully for about 40 years (thus minimizing the quantity of plutonium and actinides in its nuclear waste), and its La Hague reprocessing facility has about 40-45% unused capacity at present. Hence, a country that is looking to reprocess its SNF does not need to do so domestically; it can purchase reprocessing services from France—or conceivably from the United Kingdom or Russia. Indeed, it does not make sense for every country that has a nuclear energy program to have its own reprocessing facility. The investment in a reprocessing complex is so large (of the order 4 to 5 nuclear power plants, which are already a big investment individually) that it can only be justified if the country has a very large domestic nuclear program (of the order of 20 to 40 reactors) that will provide enough SNF to guarantee use of the reprocessing facility. Otherwise, the country will be making a huge investment on which it will never get a return. (Contrarily to the business model that could be drawn up for an enrichment facility, a reprocessing facility cannot count on foreign reprocessing demands to be economical.) The nuclear energy programs in countries like Finland and Sweden, for example, are not large enough to justify a domestic reprocessing complex. Again, each country's unique situation needs to be examined to determine whether a domestic facility is justified. Lastly, it must be underlined that reprocessing does not remove the need to site a repository for nuclear waste.

Charles McCombie:

On storage: Storage is a necessity for any country with a nuclear energy program, but the type of storage that is most suitable varies with each case. The nuclear accident at Fukushima has had an impact on the question of wet versus dry storage. In the past, advising countries with a single-reactor program to build one big storage pool, as the cheapest and easiest way to store all of their SNF for 60 years, was possible. Following Fukushima, one big SNF pool is no longer regarded as a safe option. Storing SNF (in wet or dry storage) does maintain a country's options open, but it can sometimes push back the impetus to address the need for a permanent repository—which, as Alan Hanson underscored, is always necessary. Yet, it may be argued that if a country does not have a credible permanent disposal strategy in place, efforts to implement storage can be more complicated (if, for instance, the community near the storage site feels storage will be indefinite).

On reprocessing: Conservation of uranium, which can be aided by reprocessing, is important (just as conservation of any energy source is). Also, sending SNF away for reprocessing is sometimes the only near-term solution available to some countries, as is the case for Italy that cannot keep its SNF onsite and therefore sends it to the United Kingdom for reprocessing. Nevertheless, every country must eventually find a way to open a nuclear waste repository, regardless of whether it reprocesses its SNF (domestically or abroad). It must be noted that the technical advantages and disadvantages of reprocessing for waste management, as discussed by Andrew Orrell and Alan Hanson above, can be debated at length. The main reasons for which most countries are not currently seeking to undertake reprocessing is that it is very expensive and that it can be postponed (via storage).

On geological disposal: This cannot be emphasized enough: a *credible* geological disposal strategy is needed for every fuel cycle that we have—for long-term safety and security reasons, as well as for public acceptance of national nuclear energy and waste management programs. For a disposal strategy to be credible, the country needs to have the technology (and this has been proven to be possible by some countries, like Sweden), the funding set aside and available (not being used for other things, as is the case in the United States), and a viable strategy to identify a repository site (which can of course be politically difficult). Countries that have new, smaller nuclear energy programs, in particular, can have a national strategy towards disposal (if their programs are large enough to warrant it, since a repository costs roughly as much as one reactor), but they can also partner with a larger country that can take back their SNF, or participate in a multilateral option (perhaps along the lines of the European Repository Development Organisation project). The United Arab Emirates, for instance, has declared that it is pursuing a dual-track strategy in preparing to dispose of its SNF: it will explore the possibility of a national repository as well as multilateral approaches. Deep borehole disposal may also be an attractive option for countries with new nuclear energy programs.

* The views expressed herein do not necessarily reflect the views of the Asan Institute for Policy Studies.