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Coupling repositories with fuel cycles

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Siting a reprocessing plant with a waste disposal facility can improve the economics, efficiency, and public acceptance of both.

IN THE UNITED States, the way the nuclear fuel cycle is currently arranged is a legacy of World War II and the Cold War. Fuel cycle facilities were quickly developed and deployed without consideration being given to the waste management implications, leading to the fuel cycle model of a geological repository as a separate facility at a separate site. There are, however, many ways to organize a fuel cycle, including (1) traditional repositories; (2) repositories with spent nuclear fuel (SNF) retrievability for recycle or as insurance against unforeseen repository failure; (3) collocation and integration of reprocessing facilities and repositories; and (4) collocated specialized disposal facilities for different types of wastes.

System design choices have major impacts on fuel cycle economics, accident risks, repository performance, nonproliferation, repository siting, and public acceptance. While the fuel cycle is a small fraction of the cost of nuclear power, waste treatment and waste management account for a significant portion of the cost of the fuel cycle. Fuel cycle choices also have an impact on proliferation and waste management. How fuel cycles are coupled with repositories can drive fuel cycle choices, including whether to reprocess light-water reactor SNF, and yet this dimension of fuel cycle design has not been examined.

The evidence suggests that a repository as a disposal-only site (the system currently supported in the United States) is the least favorable option[1]. There are large incentives to develop repository sites that collocate and integrate all back-end fuel cycle facilities with the repository, independent of the choice of fuel cycles or how these fuel cycles evolve over time. Collocation and integration change the interface between facilities by eliminating many storage and transport requirements, such as the need for waste forms with high waste loadings (that is, high concentrations of radionuclides in the inert waste matrix to minimize shipping volumes). That in turn can result in cost and risk reductions and in improved repository performance. For closed fuel cycles, collocation and integration can eliminate the need for long-term repository safeguards, which suggests that a new repository business model is needed.

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Where we stand today

Because the United States does not have a repository site for commercial spent fuel/high-level radioactive waste, there are choices available.

The United States has not selected a long-term fuel cycle or cycles. The Massachusetts Institute of Technology's report, *The Future of the Nuclear Fuel Cycle,* examined alternative nuclear futures in the context of a greatly expanded use of nuclear energy. A key conclusion was that today, it is not known whether LWR SNF is—or will be—a *waste* or a *resource.* Also, economically accessible uranium resources are larger than originally estimated. In the long term, fast reactors may be preferred because they use uranium 20 to 50 times more efficiently than LWRs. Fast reactors, however, can be started on low-enriched uranium (LEU) with fast reactor SNF recycled back to fast reactors—an option that may be more economical than processing LWR SNF to recover plutonium for the startup of fast reactors.

The economic challenge with LWR SNF recycling is the low fissile content of the SNF. Eight LWR SNF assemblies must be reprocessed to obtain the fissile fuel required for one new LWR assembly. A dozen or more LWR SNF assemblies are required to create the equivalent of one fast reactor fuel assembly. In contrast, only one fast reactor SNF assembly has to be reprocessed to produce one new fast reactor fuel assembly. Fast reactor SNF may be economical to recycle, while LWR SNF becomes a waste, depending on what the future costs of reprocessing might be. These factors suggest a long-term storage policy for LWR SNF so that options can be maintained.

The options

Noted earlier were the following four options for coupling repositories with fuel cycles:

1. *Traditional repository*—The traditional repository is a stand-alone disposal site and is the only option that the United States has investigated. The concept of a stand-alone repository, also as noted earlier, is a legacy of the Cold War. Fuel cycle facilities were built before the development of waste management technologies such as repositories, and so sites were not selected to allow for the co-siting of a repository.
2. *Repositories with SNF retrievability*—Whether LWR SNF is—or will be—a valuable resource or a waste is yet to be determined. Given this uncertainty, one option is to dispose of SNF in a repository but to design the repository to allow for the recovery of SNF in the future, if it is needed. The repository becomes a fuel vault and a disposal facility—a different way to couple fuel cycles with the repository. The repository as a storage facility has the following advantages relative to storage at reactor sites or centralized facilities:

■ *Greater public acceptance of the nuclear enterprise.* Because of U.S. waste management failures, a policy of SNF surface storage appears to the public as kicking the can down the road and not addressing waste management challenges.

■ *Intergenerational equity.* A reversible repository both maintains options for and minimizes costs to future generations if SNF is ultimately deemed a waste.

■ *Security.* Repositories are the ultimate in safe storage because they are far underground where even catastrophic events have little impact.

The technology to build repositories that allow for the recovery of SNF has been developed for most geologies, including tuff, salt, granite, and clay. The proposed French repository in clay and the planned Finnish repository in granite both have legal requirements for long-term retrieval. The proposed U.S. repository in tuff at Yucca Mountain, in Nevada, was designed to allow SNF recovery for several decades. A series of studies by the Office of Nuclear Waste Isolation in the early 1980s indicated that the recovery of SNF in salt would be relatively easy for centuries. Most of the studies on retrievability were to allow waste retrieval in the event of unforeseen problems with the repository, but the same designs with minor modifications are suitable for repositories that will allow for the long-term economical recovery of SNF.

If all back-end facilities are collocated, the community and state accepting a repository will benefit from thousands of added jobs.

3. *Collocation and integration of reprocessing facilities and repositories*—If a repository is sited before a closed fuel cycle is selected for deployment, the option exists to collocate and integrate reprocessing, fabrication, and waste disposal into a single back-end fuel-cycle facility. The functional requirements are to produce fuel elements for reactors using fissile and fertile materials recovered from SNF and to safely dispose of all wastes. This option has received almost no attention. The single exception was in Germany, where in the 1970s the collocation of reprocessing and repository facilities at Gorleben was proposed.

Collocation may ease the siting of geological repositories. A traditional repository implies a few hundred long-term jobs. If all back-end facilities are collocated, the community and state accepting a repository will benefit from the thousands of added jobs associated with reprocessing and fuel fabrication.

Collocating and integrating reprocessing and a repository also can result in major reductions in the cost of recycling SNF. In a reprocessing plant, less than 7 percent of the facility's cost is associated with the separation of fissile and fertile materials from SNF, which is the purpose of a reprocessing facility, and about half the cost is associated with waste management. Therefore, the economics of recycling depends on waste management. Collocation and integration with a repository can reduce those costs.

There is historical evidence to support this conclusion. During peak operations, the Hanford Purex reprocessing plant throughput was 7000 metric tons of defense SNF per year. In comparison, the commercial LaHague reprocessing plant in France—a much larger facility and the largest commercial reprocessing plant in the world—has a capacity of just 1700 metric tons per year. The main technical difference is that the Hanford defense complex used on-site disposal, which simplified and reduced the cost of reprocessing and waste management operations. Because of improper disposal of wastes at the Hanford Site, however, a massive cleanup effort has been under way there for a number of years. Nevertheless, a comparison of facility sizes strongly suggests that the economics of collocation and integration—with proper repository waste management—would result in large reductions in closed fuel cycle costs.

An example can clarify this. SNF cladding and hardware typically make up a third of the mass of an SNF assembly, which means that the removal, treatment, and storage for shipment of the cladding are major cost components of reprocessing plants. Cladding can be separated from fuel materials by mechanical or chemical methods. Chemical decladding of Zircaloy-clad SNF has been done on an industrial scale for defense SNF at the Hanford Site. The higher waste volumes, however, have made chemical decladding nonviable for facilities that ship wastes off site to repositories. If waste volumes are not a constraint, chemical decladding becomes a viable option, with reductions in reprocessing plant capital costs and simpler operations.

For the repository, larger waste volumes are not a cost or technical constraint. The United States' Waste Isolation Pilot Plant for defense transuranic wastes, Sweden's underground SFR (final repository for short-lived radioactive wastes), and Germany's Herfa Neurode geological repository for chemical wastes all show that the incremental disposal costs of low-heat–generating wastes (everything but high-level waste and SNF) are small.

The impacts of integrating and collocating reprocessing facilities and repositories also include the following:

■ *Repository performance.* Waste forms can be designed for the specific repository, an option that significantly improves repository performance while reducing costs.

■ *Safeguards termination.* If wastes contain significant quantities of plutonium and other fissile materials, there is a requirement for multigenerational long-term repository safeguards. Dilution of such wastes, however, can make the fissile materials "not practically recoverable," allowing for safeguards to be terminated before disposal. The economic requirement for safeguards termination is co-siting facilities so that one can afford waste forms with fissile concentrations that are below the International Atomic Energy Agency's safeguards termination limits.

4. *Collocated specialized disposal facilities*—This repository system consists of at least two disposal facilities, such as a conventional repository for high-volume wastes and a collocated borehole (or equivalent) disposal facility for enhanced isolation capabilities. A borehole is a drilled well where waste is typically buried 4–5 kilometers underground. The practical diameter of drilled wells limits the waste volumes that can be disposed of. Such a facility would be suitable for SNF, vitrified HLW, and other selected wastes such as minor actinides, but not for the higher-volume wastes (with much less radioactivity) requiring disposal.

While borehole disposal has been considered for decades, it is not currently a demonstrated technology, but advances in drilling technologies have begun to convert it into a viable option. A borehole disposal facility could be located directly under a repository for low-heat wastes. The expectation would be that any site suitable for a low-heat geological repository is likely to be suitable for borehole disposal at greater depths, because the upper geology alone has the capability to isolate radionuclides. Borehole disposal would reduce the footprint of the conventional repository because that footprint is determined primarily by heat-generating wastes.

A redesign of the back end

It is not known what fuel cycle or fuel cycles the United States will adopt in the future. The fuel cycle will evolve over time, but because there will always be some wastes requiring disposal, the need for a repository will remain a constant. These considerations, plus the benefits of collocation, lead to the conclusion that we should site integrated back-end facilities with the future capability to serve all four functions described above.

Collocation and integration of back-end facilities imply that a new business model needs to be developed, similar to that of airport authorities, which own the airport runways. Collocated with those runways are public and private airline terminals, aircraft maintenance bases, and related operations, all of which are enabled by and benefit from the high-value runway asset. Because of the characteristics of radioactive wastes, there are large economic, risk, and nonproliferation incentives for collocating and integrating all back-end fuel cycle facilities—the runway equivalent of the airport—with the repository.

Such a business model could include both civilian and defense/government facilities. Again using the airport analogy, there are many airports that are both commercial airports and air force bases, with shared runways. In the context of a repository in the United States, one likely government facility would be a small reprocessing plant to process troublesome materials such as high-enriched SNF for downblending and recycling as LEU, and to develop the technologies and site-specific waste forms to enable an integrated, collocated commercial reprocessing repository facility.

In the context of repositories with the option of SNF retrievability, there is one unique incentive for accepting such a facility, besides jobs and tax revenue. Future recycling of SNF from a repository most likely would imply that the SNF has acquired significant value, raising the question of who has title to it (ownership). In the United States, with a federal system, the option exists to provide the government of states where repositories are located the first right to take title to the SNF in the repository at any time in the future. This would provide a mechanism to guarantee that if a state government agreed to the construction of a repository within its boundaries, any future reprocessing plant using that SNF would be built in that state.

Public opinion polls indicate greater acceptance of a repository if it is designed for SNF retrievability and if other fuel cycle facilities are collocated with the repository. By a two-to-one margin, the U.S. public prefers repositories that are designed to allow for SNF retrieval, thereby maintaining future options (recycling) and the ability to recover SNF if problems with the facility are identified. This conclusion has been reinforced by other polls and studies conducted in the United States, Finland, and France. Support for a repository also increases if it is collocated with other facilities, such as waste management research facilities and reprocessing plants. The accompanying table shows that support for a repository—particularly from those initially neutral or opposed to geological repositories—increases dramatically if a reprocessing plant is collocated with the repository.

CHANGE IN SUPPORT FOR BASE REPOSITORY DESIGNS WITH REPROCESSING FACILITIES (BASE CASE ASSUMES TWO NATIONAL FACILITIES)[2]

Initial Preference	Support (58%)	Neutral (26%)	Opposed (16%)
Support Increase	66%	47%	48%
Support Unchanged	21%	43%	16%
Support Decreased	13%	10%	36%

The reconsideration of waste options today in the United States, particularly by the Blue Ribbon Commission on America's Nuclear Future, presents an opportunity to rethink how we organize the back end of the fuel cycle. It's time to take advantage of that opportunity to design a system for the future that has better economics, maintains fuel cycle options, and is considered an asset by the local community and the state hosting the back-end facility.

References

1. C. W. Forsberg, "Alternative Fuel-Cycle Repository Designs," International High-Level Radioactive Waste Management Conference, Paper 3213, Albuquerque, N.M. (April 10–14, 2011).

2. H. C. Jenkins-Smith, C. L. Silva, K. G. Herron, and R. P. Rechard, "Enhancing Acceptability and Credibility of Repository Development for Spent Nuclear Fuel," International High Level Radioactive Waste Management Conference, Paper 3459, Albuquerque, N.M. (April 10–14, 2011). NN