COUPLING FUEL CYCLES WITH REPOSITORIES: HOW REPOSITORY INSTITUTIONAL CHOICES MAY IMPACT FUEL CYCLE DESIGN

Charles Forsberg[1] and Warren F. Miller, Jr[2]

[1]*Massachusetts Institute of Technology, 77 Massachusetts Ave., Room 24-207A*
Cambridge, Massachusetts 02139; Email: cforsber@mit.edu
[2]*Texas A & M University System, MS 3133*
College Station, TX 77843-3133

The United States repository for high-level waste (HLW) and spent nuclear fuel (SNF) is currently scheduled to open in 2048—more than a century after generation of the first HLW. This failure is a consequence of the cold war history and an institutional structure that provided insufficient confidence and incentives to states and communities to host a repository.

The U.S. government is now considering an alternative repository siting strategy based on voluntary agreements with state governments. If that occurs, state governments become key decision makers. They have different priorities. Those priorities may change the characteristics of the repository and the fuel cycle.

Historically the federal government has attempted to site repositories with a top-down approach driven by Administration and Congressional political considerations. This leads to siting fuel cycle facilities with associated jobs and taxes in different states.It follows that a repository will have less than optimum capabilities and benefits to the local community and state due to its geographic separation from related fuel cycle facilities.

State government priorities, when considering hosting a repository, are safety, financial incentives and jobs. It follows that states will demand that a repository be the center of the back end of the fuel cycle as a condition of hostingit. For example, states will push for collocation of transportation services, safeguards training, and navy/private SNF inspection at the repository site. Such activities would more than double local employment relative to what was planned for the Yucca Mountain (YM)-type repository. States may demand (1) the right to take future title of the SNF so if recycle became economic the reprocessing plant would be built at the repository site and (2) the right of a certain fraction of the repository capacity for foreign SNF. That would open the future option of leasing of fuel to foreign utilities with disposal of the SNF in the repository—but with the state-government condition that the front-end fuel-cycle enrichment and fuel fabrication facilities be located in that state.

Such a reorganization of the fuel cycle would reflect the end of the cold war as a major driver in fuel cycle decisions. If more than one state hosts a repository it could result in the development of a more traditional conventional industrial structure for the fuel cycle.

I. INTRODUCTION

The United States repository for high-level waste (HLW) and spent nuclear fuel (SNF) is currently scheduled [1] to open in 2048. Depending upon definitions, the failure of the proposed Yucca Mountain Repository (YMR) program is the 2^{ed} or 3^{ed} failure in a row. The U.S. Blue Ribbon Commission [2] last year recommended siting a repository using consent-based strategy. This reflects the international experience that the only successful repository programs have been those that have used a voluntary siting approach. This is a repeat of earlier recommendations ofU.S. repository siting approaches. Thirty years ago, the Office of Technology Assessment [3] made similar recommendations. Those recommendations were initially adopted and then later abandoned.

Like in previous decades, the repository program is caught in the center of partisan politics. However, there are pressures for solutions. The federal government signed contracts with utilities to take SNF for disposal starting in 1998 and now faces mounting financial penalties for failure to perform. Internationally, U.S. positions on fuel cycles relative to nonproliferation are losing their credibility because of the repository program failure. These challenges faced by the federal government create the possibility to more broadly consider what type of institutional structure is required to build a repository.

The central question is"who makes the key decisions?" The federal government has legal responsibility to dispose of the SNF. The utilities pay the bill via a levy on each kilowatt-hour of electricity generated from nuclear power plants with the oversight of state public service commissions. The state governments have a statutory role because the United States Constitution recognizes the State as an independent government entity. This is in contrast to countries such as

France with a national government with political subdivisions of the national government.

The constitutional structure of the United States and the experience of the YMP, where Nevada successfully opposed the federal government effort to site a repository,strongly suggest that state governments have effectively a veto power over the building of a repository.

We examine the consequences in terms of likelihood of siting a repository and impacts on the fuel cycle depending upon the level of government making the major repository decisions.

II. NATIONAL GOVERNMENT

As a consequence of the Manhattan Project duringWorld War II and the cold war, the United States built all the facilities needed for various fuel cycles before long-term, high level nuclear waste management was addressed. Separate facilities were built at different sites—partly to minimize the risk of a single event such as an attack, shutting down the entire system. Waste management systems were developed later. This led to the adoption of a model of the fuel cycle where wastes would be shipped from existing facilities to waste disposal facilities as they were developed. Economics was not a major consideration in the development of this system.

The federal government decision to be solely responsible for HLW and SNF disposal was a consequence of this history. Because the federal government generated large quantities of defense high level waste, the assumption was that it would be more efficient for government to be responsible for disposal of all wastes requiring geological disposal.

Another factor was nonproliferation. The first Indian nuclear detonation (1974) led to decisions by the U.S. government during the Ford and Carter administrations to adopt a once-through fuel cycle[4]. The idea was that if the U.S. set an example with a once-through fuel cycle, other countries would follow the U.S. and there would be greater barriers to nonproliferation.

This decision was made when gaseous diffusion was the primary technology for uranium enrichment—a technology that required very large plants to produce high enriched uranium suitable for construction of nuclear weapons. Consequently, it was believed that any proliferator would choose to build weapons using plutonium obtained from reprocessing SNF, as opposed to uranium enriched in gaseous diffusion plants. Since then the development of lower-cost centrifuge enrichment technology has made enriched uranium, not plutonium, the preferred route to weapons.

The non-proliferation policies contributed to a decision to establish a federal repository program that would take full responsibility and liability for defense waste as well as for utility SNF as it left the power reactor in exchange for a fee intended to cover the government's costs. This arrangement was financially attractive to the utilities and greatly reduced any utility interest in closed fuel cycles. While the change in fuel cycle directions was driven by the U.S. government, it is likely that utilities would have ultimately chosen the same fuel cycle when the greater availability of uranium and higher costs of reprocessing made the once-through fuel cycle the preferred economic choice.

The side effect was that these decisionsleft no one with a strong incentive to promptly build a repository. This is partly because the energy release from a kilogram of uranium is about a million times greater than from a kilogram of fossil fuel so the quantities of SNF are small and storable. This is in contrast to U.S. policies for disposal of other long-lived wastes. With hazardous wastes, the generator is responsible for disposal although many of these wastes include heavy metals that remain toxic forever. The chemical companies have powerful incentives to find disposal methods for their wastes.

The repository program was ultimately driven by Congressional politics where, of the candidate states, the state with the weakest Congressional delegation (Nevada) was chosen for the repository. This did not work because the balance of power between different groups in Congress (and Administrations) change faster than the time required to site, design, license, build and operate a repository. The local opposition to the repository has many roots: the major waste management problems from the weapons complex, the forced siting strategy, and a legacy of the cold war that limited benefits for the host state that accepted a repository.

The federal government (President and Congress) is now beginning a debate on the future of the repository program. Based on the recommendations of the Blue Ribbon Commission, there is a developing consensus that a voluntary repository siting strategy should be developed. If that is implemented, it makes the state (or tribal) government or governments hosting the repository, working with local communities, the key decision makers. A voluntary siting agreement would likely be implemented as a legally-binding compliance agreement in order to protect against subsequent state governments or the federal government having contrary positions.

In the following discussion, the authors assume that the candidate repositories discussed satisfy technical standards that are primarily driven by the geologic medium and geologic setting. Further, the authors make no assumptions concerning the eventual federal entity (e.g. a federal corporation) which manages the program on a national level.

III. STATE GOVERNMENTS

State governments place priorities on tax revenue and economic development (jobs). At the same time there is a

need to assure broad support across any state for industries that are recruited into that state. This leads to three challenges for a state that wants to host a geological repository: how to maximize revenue and jobs, how to assure acceptance, and how to organize the effort to achieve the above objectives.

III.A. Jobs and Revenue

The goal of most state economic development programs is to recruit an entire industry, not just a single facility. Economists have long recognized that if a specific industry reaches a critical size in a single area, this brings added industry. For example, the largest concentration of chemical plants and refineries in the United States exists between the cities of Houston and New Orleans. This started with relatively small facilities. Once one begins to build port and pipeline facilities to supportrefineries and chemical plants, other refineries and chemical plants were built in the area because of the availability of the port and pipeline facilities. This was reinforced by the knowledgeable workforce and governments that work with industry to create the common infrastructure from roads to port facilities.

This economic impact and the resultant multiplier effect are seen in many industries: chemical (Gulf coast), insurance (Hartford), food (Minneapolis), and electronics (Silicon Valley). While these developments often were accidents, the development of the auto industry in southern states such as Tennessee was not. It was recognized that if one could lure the auto assembly plants into the state with incentives, the supplier industries would follow that would ultimately provide more jobs and revenue with fewer public incentives.

If a state government is the key decision maker on whether to host a repository, a major question quickly becomes “Can the repository be used as the starting point for industrial development?” There is evidence that such a strategy is viable given that the location of many nuclear fuel cycle facilities were based on defense needs that are no longer the driver for locating facilities. Let us thus examine hosting a repository from the perspective of a state government agency responsible for industrial development.

The traditional view is that a repository is a single-purpose facility for disposal of wastes. However, from an industrial development perspective it is a package of (at least) three multi-billion-dollar coupled facilities: (1) a world-class large SNF/HLW receiving facility, (2) a world-class large waste packaging facility, and (3) a large underground disposal facility. Along with these facilities is a set of commonbut expensive support services including security and health physics.

From this perspective, if a state hosts a repository the question is: Who are the other customers for these facilities? A starting list [5] of such customers has been identified where there would be economic incentives for collocation with the repository—including the following examples.

- *SNF inspection*. U.S. navy SNF is inspected to determine its behavior and make better estimates of reactor performance for the fleet. The existing facility consists of fuel receiving, inspection, and packaging for disposal. Collocating at a repository site eliminates added transportation after packaging and the need for separate SNF receiving and packaging facilities. The same applies to commercial SNF inspection. The total budgets for these facilities we estimate near $200 million per year.
- *Safeguards*. The United States trains people around the world on safeguards. A repository would be the preferred place for training because it will have the largest selection of SNF types. It is also the preferred location to test associated equipment. A staff of several hundred people would be associated with such facilities plus a large demand for hotel and other services for people in training.
- *Nuclear industrial facilities.* There are many nuclear related services from isotope production to waste treatment. In many of these operations, waste processing and treatment are a large fraction of total costs. Co-siting with the repository facilities enables use of common services and avoids the constraints associated with shipping radioactive wastes over public roads if private roads are developed from the repository to an industrial park.

The single-purpose Yucca Mountain repository was predicted to result in ~2300 jobs to the local communities and the state. Our estimate for an open fuel cycle repository operated as a multipurpose facility is that it would increase the total workforce to between 4000 and 6000 people. This is for existing related industries where there are economic incentives for collocation. It does not include future facilities such as pilot plant reprocessing facilities where there would also be incentives for collocation.

For a state government industrial recruiting program, a second question will be who has rights to the repository capacity [5]. Most of the capacity will belong to the federal government because it has responsibility for disposal of SNF and HLW generated in the U. S. However, the state government has an interest in control of some repository capacity to aid industrial development.

For a half a century the U.S. government has wanted to create a system for leasing nuclear fuel in foreign countries as part of its non-proliferation policy. Fuel would be produced in the U.S., leased to foreign utilities,

and the SNF returned to the U.S. for disposal. This policy goal has been a failure because no state government is willing to accept foreign SNF. In addition, at this point, this would violate federal law.

Economically fuel leasing would be very attractive to everyone. There are large economic benefits for countries with small nuclear programs to lease fuel and avoid the need to build repositories. There are massive economics of scale associated with repositories. That favors a global system with a few repositories worldwide to minimize costs. Fuel leasing would potentially be a profitable business for everyone.

If the states hosting repositories have rights to some fraction of the repository capacity for foreign SNF, they could choose in the future to accept foreign SNF. The incentives for the state government to allow fuel leasing are large. The states would likely impose the condition that the fuel production (conversion, enrichment, fabrication, corporate headquarters) or other vendor facilities be located in the host state. From the state perspective, increasing the repository size by perhaps 20% could double or triple the repository benefits. Because there are no large economic incentives to build those facilities in the immediate vicinity of the repository, they could be located anywhere in the host state providing state-wide benefits.

Any foreign leasing of SNF would also require federal government approval because of import and export laws. Historically many in the federal government have viewed a state government role in foreign fuel leasing as unacceptable but the political reality is that the federal government does not have the ability to implement a fuel leasing program without state government approval. The federal government would retain its rights to site a repository over the objections of the state (current failed policy) or siting a repository offshore [6] in federal waters or on some of the island possessions that are not parts of states. In effect the federal government would not be giving up its authority but adding an alternative pathway to fuel leasing.

Last is the question of whether the U.S. will ultimately adopt a closed fuel cycle. Today the once-through fuel cycle appears to be more economic but that could change (Appendix A). Advances in technology and different regulatory structures can alter the economically preferred fuel cycle. Preliminary assessments [7] indicate that collocation and integration of reprocessing plants with the repository could lower fuel recycle costs by up to 30%; thus, states that host repositories would be the likely beneficiaries of adoption of a closed fuel cycle.

If recycle becomes economic or adopted for other reasons, there could be strong incentives to recover SNF from the repository. State governments would have strong incentives to assure any recycle facilities are built within the state and most likely at the repository site. As a consequence, there would be large incentives for any state hosting a repository as part of any agreement with the federal government to have the right to take title to the SNF in the future to assure that many of the benefits of recycle flow to the state.

III.B State Institutional Acceptance

There are many communities that expressed interest in hosting a repository. The difficulty has been obtaining state government acceptance. A question is how to get such acceptance.

A starting point is to examine social studies on public acceptance such as those by Jenkins-Smith [8] and others. These studies indicate greater acceptance of hosting a repository if (1) the repository is designed for SNF retrievability, (2) other fuel cycle facilities are collocated with the repository, and (3) research facilities are associated with the repository. These results have been interpreted respectively as providing (1) assurance of safety and maintaining future options, (2) providing jobs and revenue and (3) being part of the solution to solving national problems rather than a simply providing a "dump." Of course these issues are related since research facilities are likely to lead to jobs and revenue in both the near and the long term.

A state government would have incentives to insist that SNF retrievability be a design requirement to increase public acceptance and to keep open the option of a future closed fuel cycle that could enhance long-term economic benefits. The costs of such features appear to be small and consistent with obtaining public support for hosting a repository

TABLE 1. Change in Support for Repository Designs with Research Laboratory [8]

Initial Preference	Support (58%)	Neutral (26%)	Oppose (16%)
Support Increased	70%	55%	48%
Support Unchanged	20%	37%	21%
Support Decreased	10%	8%	31%

Public opinion polls show a strong increase in support for hosting a repository when coupled with a research laboratory. Table 1 shows the results of one poll where the question was asked "What would happen to your level of support if you learned that each of the sites also would contain a national research laboratory for studying ways to more safely and efficiently manage and dispose of nuclear materials?" This is most important to those who are neutral or are opposed to siting such a facility. Such a facility serves to both reduce the relevant

risks and provide high-prestige employment and other economic benefits.

In the context of a state hosting a repository, this has broader implications. A host state would have incentives to require, in any consent agreement, support for such a facility and support of a significant research and development program associated with its universities. The areas of interest would include fuel cycles, safeguards technologies, and geosciences. This would provide the state government with an independent source of expertise to provide assurance of repository performance, a stronger commitment to be part of the solution, a source of trained manpower, and a way to maximize local benefits of a multipurpose repository.

This is not a new role for either states or universities. From Stanford University that is the center of Silicon Valley to the large Midwestern land-grant universities that provide the technical support of American agriculture, there is a long tradition of universities supporting local industries, maximizing the local benefits from those industries, and acting as the technical experts that support state government

Lastly, any state government will want an oversight role to provide a level of confidence to its political constituents. There is a long history of states in this role at existing federal facilities and at the one operating repository in the U.S—the Waste Isolation Pilot Plant (WIPP) that disposes of transuranic wastes.

III.C. Repository Institutional Structure

If the benefits to the state hosting the repository are to be maximized, an appropriate institutional structure is required. In the context of the United States, the closest public/private institution to what may be required is the airport authority and the airport runways—a business and institutional model that combines public and private facilities [7, 9, 10]. Airport authorities own the runways, some of the terminals, and some other facilities. However connected to the runway are taxiways to a variety of public and private facilities, from terminals (passenger, air freight, etc.) to aircraft maintenance facilities to aircraft manufacturing facilities. All are collocated to take advantage of the central runway asset.

For example, the Minneapolis St. Paul International Airport, the 15th largest airport in terms of travelers each year, in 2010 generated 10.6 billion dollars in business revenue, 1.3 billion dollars in local purchases, and 626 million dollars in state and local taxes. That large revenue stream and associated taxes is a consequence of the Metropolitan Airports Commission (MAC)—a state chartered organization with the goals of providing high-quality air service to the Twin Cities while maximizing local benefits.

The structure of the commission [10] is designed to assure support for the airport by providing a mechanism for local input into the decision making process and aid economic development. Commissioners are appointed by the governor and the mayors of Minneapolis and St. Paul and represent specific nearby areas. Most of the commission members are from areas near the airport. However, four of the commissioners are appointed to represent those parts of the state that are far from the airport. It is a governing strategy that addresses local concerns while considering the economic development needs of the entire state.

A repository authority could operate in a similar manner. Some customers (SNF inspection, safeguards, etc.) would need to be connected to SNF receiving pools and hot cells by SNF transfer systems. Other customers (radioisotope production, etc.) would be connected to the repository by private heavy-haul roads or on-site rail systems. All would take advantage of the common facilities and services.

Airport authorities are larger, technologically more complex, and handle a wider range of security challenges than would be required for a repository authority. Some airports, such as Albuquerque, involve both civilian and military aviation. In such cases there are various agreements on ownership and use of the runways. The institutional models exist and have records of success.

If a repository authority was created, there would be one for each repository site. Different states have different political cultures that would result in different types of repository authorities. There would be a federal waste management authority but its activities would depend upon federal-state agreements. If more than one waste repository was built, the federal-state agreements could be significantly different with different states.

IV. UTILITIES

There is a history of waste generators being responsible for disposal of their wastes. In the United States, chemical companies are responsible for disposal of hazardous chemical wastes—including heavy metals that remain toxic forever. In Germany, the chemical companies operate geological repositories for the disposal of hazardous chemical wastes. The best known of these facilities is Herfa-Neurode, the first geological repository for hazardous wastes that has been in operation since the 1970s.

The most successful SNF repository programs are those of Sweden and Finland where the reactor owners are responsible for siting, building, and operating the repositories. Both countries have sites with local and national approval and are proceeding through licensing.

From a technical and management perspective, there is no question that an alternative to the “airport model”, a utility structure, could be assembled to operate a repository program. The issues are institutional. Unlike hazardous waste programs or the Scandinavian SNF

repository programs, U.S. policies in waste management have been partly driven by nuclear weapons programs and national nonproliferation goals. It is this connection that has made waste management a federal program.

V. OTHER CONSIDERATIONS

There is the question of how many repositories the United States should build. History supports a policy of siting and building at least two repositories. This provides a contingency option if there are unexpected technical or institutional difficulties with one site. Equally important, any voluntary siting strategy with one host state results in a monopoly. The costs of such a monopoly in the long run are likely to exceed the costs of a second repository.

There is the potential for significant cost savings if state governments are key decision makers.

- *Liabilities*. The Federal government faces significant financial liabilities for future storage of commercial SNF because of the failure to dispose of that SNF as required by contracts with the utilities. Those liabilities stop once a repository becomes operational. The time to develop a repository assuming the host state is supportive could be comparatively short.
- *Facility savings*. Making full use of the multiple facilities associated with a repository has the potential for large cost savings for several national programs.
- *Geological choices*. Work in the last decade has led to a better understanding of the costs of repositories in different geological media. There appear to be very large differences in repository costs depending upon the geology [11-12]. It implies that a new repository site may have lower total costs going forward than completion of the proposed Yucca Mountain site. There is seems to be little economic basis to select or not select Yucca Mountain as a preferred site.

VI. FUEL CYCLE IMPACTS

Which governmental entity makes which decisions on the repository will have major impacts on fuel cycledesign. Federal decision-making is likely to result ina disposal-only facility that would reflect long-termAdministration and Congressional views on the organization of the fuel cycle.

State government decision-making would likely result in a major effort to maximize use of the repository for commercial benefit. In the long-term this may include international fuel leasing with front-end fuel cycle facilities in the states hosting repositories. It also would imply a major rethinking about collocation and integration of closed fuel cycles with repository facilities.

VII. CONCLUSIONS

The historical repository siting strategy in the United States has been a top-down approach driven by federal government decision making. The Blue Ribbon Commission has recommended a voluntary siting strategy. A voluntary agreement implies state governments would become major decision makers. Such an approach is more likely to succeed. It also implies different decision makers with different priorities—jobs and revenue for the host state.

The fuel cycle structure and the concept of a stand-alone repository are legacies of World War II and the cold war. Changing the decision paradigm changes the fuel cycle. If the state governments become major decision makers, many fuel cycle facilities are likely to be located at or near the repository site for economic and political reasons. There will be an emphasis to understand the implications of collocation and integration of reprocessing with the repository versus the current model of isolated separated facilities. The decision making will more closely resemble that of other industrial sectors—particularly if more than one repository is ultimately built.

APPENDIX A: REPROCESSING AND CLOSED FUEL CYCLES

To reprocess is to treat—but for what purpose? At one time reprocessing was to produce nuclear weapons materials. At another time the U.S. began to recycle light-water reactor (LWR) SNF into mixed oxide (MOX) fuel assemblies for LWRs. In the last decade the U.S. government has processed SNF for nonproliferation reasons. High-enriched research-reactor SNF was reprocessed and the high-enriched uranium was blended with low-enriched uranium to produce low-enriched uranium that was sent to fuel fabricators to produce fuel for LWRs. In each case there are three objectives.

- Receive and store SNF from reactors
- Produce a high quality product (purified plutonium, low-enriched uranium, or MOX fuel assembly)
- Treat and dispose of wastes.

The legacy of the World War II Manhattan Project and the cold war is that separate facilities were built. However, SNF receiving and storage is a major cost. Waste management is about half the cost of reprocessing. Transportation is an important cost component and places major constraints on system design. The consequences of this [7, 13] is that there is at least a 30% cost savings by integrating these operations with the repository. This may be an underestimate but only limited studies have been done because of the historic assumptions about how to organize a fuel cycle.

Going forward we make several observations.

- If fuel is reprocessed for any reason, there are large incentives to do it at the repository site and take advantage of combined facilities and avoidance of the cost and restrictions associated with over-the-road transport of wastes.
- If fuel reprocessing is at the repository, the fuel fabrication facility should also be at the repository to avoid the shipping of plutonium between the reprocessing plant and fabrication plant, allow sharing of processing facilities, and enable use of common support operations (security, analytical laboratories, etc.). Collocation allows recycle of any off-specification MOX fuel to be easily recycled using the adjacent reprocessing plant. It also allows the use of many common waste treatment facilities. This implies major economic savings.
- With existing technologies, an integrated site with repository, reprocessing facilities, and fuel fabrication facilities could employ up to 10,000 people.
- The current economics are unfavorable [14] and the U.S. does not have the institutional structure (regulation, national policies) to implement reprocessing. However, the cost, safety, and environmental advantages of collocation are so large that a repository site should be designed to maintain the future option to build such facilities at the repository site. This would be consistent with the recommendations [2] of the Blue Ribbon Commission to maintain options.

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