Yucca Mountain and the Global Nuclear Energy Partnership

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INTRODUCTION

Renewed U.S. interest in advanced nuclear fuel cycles involving reprocessing and recycling, embodied in the Global Nuclear Energy Partnership (GNEP) initiative, has raised questions about the role of a Yucca Mountain repository – what it will be used for, and when. While the repository is widely recognized as a key part of U.S. waste management strategy, the potential for advanced fuel cycles to improve the capacity and performance of a repository have led some to question whether its development can be deferred pending resolution of questions about the fuel cycle and the fate of commercial spent nuclear fuel (CSNF). This paper discusses the rationale for the Department of Energy’s (DOE’s) goal of completing the proposed Yucca Mountain repository by 2017 in parallel with pursuit of its goals for GNEP, as well as issues posed for the repository program by deployment of the initial facilities of an advanced fuel cycle.

YUCCA MOUNTAIN’S OTHER ROLE: TIMELY DISPOSAL OF THE DEFENSE WASTE INVENTORY

Before discussing the relationship of Yucca Mountain to GNEP, some perspective on the multiple roles of Yucca Mountain is needed. The focus on GNEP, the development of advanced fuel cycles, and the possible reuse of some or the entire current and projected inventory of commercial spent nuclear fuel (CSNF) may create an impression that the need and timing for operation of the proposed Yucca Mountain repository should be primarily or solely determined by its role in disposal of commercial waste. However, even if there were no commercial nuclear power industry at all, there would still be a need for a national repository to dispose of the high level waste and spent fuel from the nation’s defense nuclear activities – the legacy of nuclear weapons production during the Cold War, and the continued operation of the nuclear navy. As the DOE Strategic Plan points out, the proposed Yucca Mountain repository “is vital for moving temporarily stored legacy materials from former nuclear weapons sites to a safe, central storage location." [1] Nearly one third of the waste packages in the 70,000 MTHM inventory destined for the proposed Yucca Mountain repository will contain wastes from defense nuclear activities. (Even though the defense allocation is 10% of the 70,000 MTHM, it represents a large number of individual containers and waste packages into which they are placed.) Advanced commercial fuel cycle technologies would not benefit those materials, which require a repository regardless of what happens to the commercial waste. [2] Delaying repository development to wait for resolution of questions about the fate of CSNF could add substantial costs to the taxpayer for interim management of the defense wastes (including costs of delayed closure of the facilities in which they are now stored), with no associated benefit.

YUCCA MOUNTAIN PROGRESS SUPPORTS DEVELOPMENT OF ADVANCED FUEL CYCLES

Maintaining the pace of development of the proposed Yucca Mountain repository supports the GNEP initiative because it is needed to remove the waste disposal issue as an obstacle to new reactors, to allay concerns that interim spent fuel and high level waste storage or processing sites will become permanent, and to facilitate design of advanced fuel cycle facilities.

Enabling the crucial construction of new reactors

The Department of Energy's Strategic Plan concludes that the proposed Yucca Mountain repository is necessary for preserving the nuclear option for U.S. electricity generation. [1] Demonstrating that a repository can be licensed and operated for disposal of spent fuel is crucial to removing waste disposal as obstacle to near-term deployment of new reactors – the necessary first step towards a new fuel cycle. It will provide proof of the existence of working solution to the waste problem, and a basis for assurance that reactor sites will not be long-term waste repositories by default. Paradoxically, then, demonstrating that spent fuel can be disposed of directly will facilitate the start of a phase of construction of new nuclear plants, which in turn would pave the way for advanced fuel cycles in which high-level waste rather than spent fuel is sent to the proposed Yucca Mountain repository.

The extent of proof of disposal capability will depend on inventory initially approved for disposal. At present, that inventory is limited by law 70,000 MTHM until a second repository is in operation. (Legislation under consideration in Congress would remove that limit.) However, whatever the inventory initially approved for disposal, licensing and operation of the repository would provide a proof-in-principle that the technical and institutional issues of high level waste disposal have been or can be met. It would demonstrate the existence of a federal waste repository, as required by nuclear moratorium laws in some states, and would provide a basis for a continued finding of waste confidence by the NRC, ensuring that waste disposal would not become an issue in licensing new reactors or other fuel cycle facilities. (The current finding is predicated on the availability of a repository in the first quarter of this century. [3])

Ensuring that interim processing sites are interim

Availability of an operating repository should facilitate siting and operation of advanced fuel cycle facilities by allaying fears that such sites would become *de facto* long-term high-level waste repositories by default – fears that have repeatedly been an obstacle to siting interim storage facilities. Indeed, the U.S Department of the Interior’s Bureau of Indian Affairs cited precisely this concern as one reason for disapproving the proposed lease for the Private Fuel Storage Facility in Utah. [4] In Minnesota, environmental groups have challenged a state regulatory decision to allow spent fuel storage at the Monticello plant, raising concerns about whether the storage would be interim or permanent, and whether or when the proposed Yucca Mountain repository would be able to accept the spent fuel. [5] Further, this objection has already been raised by opponents of consideration of locating a GNEP facility in Piketon, KY. [6] In other words, timely licensing and operation of a geologic repository may be needed to allow the siting and operation of reprocessing and other advanced fuel cycle facilities, not the other way around. [7]

Informing the design of advanced fuel cycle facilities

Advanced nuclear fuel cycles hold the promise of reducing (perhaps very substantially) the need for geologic disposal capacity and the technical demands on that capacity, by reducing the volume, toxicity, and long-term thermal output of the resulting high level waste requiring disposal. However, the design of the waste separations and processing facilities for advanced fuel cycles must recognize that beyond a certain point waste minimization efforts may increase waste treatment costs out of proportion to the waste management benefits. DOE’s call for expressions of interest in a Consolidated Fuel Treatment Center (CFTC) puts priority on waste minimization focused on reducing radiotoxicity, half-life, heat generation, and minimizing criticality concerns, but also emphasizes the CFTC must be designed as “an efficient component of an economical fuel cycle.” [8]

The analysis of the tradeoff between increased costs and benefits such as risk reduction associated with any treatment of waste must take into account the particular characteristics of the proposed Yucca Mountain repository. Theoretically, a program of extensive recycling and transmutation of the projected inventory of commercial spent fuel that might be disposed of at Yucca Mountain might reduce the long-term peak dose from that inventory (in the million year time frame) by as much as three orders of magnitude. However, because of the inventory of defense waste that is also planned for disposal in the proposed Yucca Mountain repository, the achievable reduction in total dose from the repository as a whole (taking both defense and commercial inventories into account) could be substantially less. As noted earlier, advanced commercial fuel cycle technologies would not benefit those materials, which are not candidates for reprocessing and recycling. This effect is apparent from analyses presented in the 1999 Roadmap for Developing Accelerator Transmutation of Waste (ATW) Technology, which compared the dose reductions at the proposed Yucca Mountain repository resulting from recycling and transmutation of the commercial SNF inventory both with and without inclusion of the contribution from the defense HLW and SNF. Considering the commercial spent fuel inventory alone, the dose reduction at one million years from full recycling and transmutation came to about three orders of magnitude. However, when the dose contribution from the defense HLW and SNF was added, the achievable dose reduction from recycling and transmutation of the CSNF was limited to about one order of magnitude. [9] In other words, the unprocessed waste inventory disposed of in the repository will set a performance “floor” – i.e. a lower bound to the projected dose level that cannot be improved significantly by reductions in the dose from the remaining inventory substantially below that level.

This “floor” to the projected releases from the proposed Yucca Mountain repository would be raised to the extent that some portion of the currently projected 63,000 MTHM inventory of CSNF is disposed of directly, without reprocessing and transmutation. This would depend on the magnitude and timing of reprocessing capability that might be constructed under the GNEP initiative. A recent paper on closing the U.S. fuel cycle prepared by the Boston Consulting Group for AREVA pointed out that the preferred spent fuel for reprocessing would be the most recently discharged fuel and estimated that some 50,000 MTHM of older “legacy” spent fuel would still be disposed of directly even with rapid construction and operation of a full-scale reprocessing plant. [10] Consistent with this conclusion, the high-level waste management bill introduced by Senator Pete Domenici (R-NM) provides for the Secretary of Energy to designate as legacy fuel, to be disposed of in the repository, any spent fuel for which reprocessing capability does not exist and is not expected to exist within a reasonable time. Even with relatively rapid deployment of reprocessing and recycling as part of an advanced fuel cycle, direct disposal of tens of thousands of tons of legacy spent fuel in the repository, in addition to the inventory of defense waste, would further limit the performance improvement that could be obtained by implementation of the highest technically achievable degree of waste minimization for that spent fuel and resulting waste that is reprocessed.

Without some basis for determining how much improvement in waste forms and amounts is enough, there could be a tendency to attempt to achieve performance objectives for waste reduction, radionuclide removal, waste form performance, and so on that would increase the cost of processing facilities greatly while providing only marginal improvements from the disposal perspective. The repository licensing process, starting in 2008, should provide that basis by clarifying performance requirements for a geologic repository (in terms of what is actually required in the licensing process to show compliance with regulations) and by establishing a projected long term performance “baseline” (in the form of a total system performance assessment of the current reference inventory that has been thoroughly reviewed and scrubbed in the licensing process) against which to measure the benefits of improvements in the characteristics of the waste inventory.

Not insignificantly, the licensing process – if successful – will demonstrate the disposability of one HLW waste form, borosilicate glass. As noted above, the inventory of waste to be included in the initial license application for the proposed Yucca Mountain repository already includes a large quantity of vitrified defense HLW (nearly one third of the waste packages), so the licensing process will evaluate, identify any issues associated with, and presumably approve the disposal of this material at the proposed Yucca Mountain repository, supporting disposal of similar waste from advanced fuel cycles. In the future, alternative waste forms with superior performance characteristics (e.g. lower solubility) might be considered (although they would need to be qualified for disposal at the proposed Yucca Mountain repository), particularly if advanced separations processes are used to produce different waste product streams that might benefit from waste forms tailored to specific waste streams. [11] The request for expressions of interest in a CFTC notes that the reference separations technology is UREX+1a where major products include high-purity uranium, cesium and strontium, transuranics, spent fuel cladding hulls, and fission products. However, it adds that “alternative separation technologies with different product streams (e.g., different actinide separation efficiencies or distributions) may be proposed.” [8]) Different product streams might warrant specialized waste forms. A comprehensive National Research Council review of the technology of geologic disposal pointed out the potential performance benefits resulting from waste forms with lower release rates than borosilicate glass, and of disposal of specific separated radionuclides (e.g. Iodine-129) in specially designed waste packages or waste forms. [12] However, it also noted that the manufacture of waste forms itself entails risks and produces processing and decommissioning wastes also requiring disposal, so that the analysis of waste forms should look at the entire waste management cycle from waste-form manufacture through disposal. The systems engineering program for the DOE spent fuel recycling program described in the May 2006 DOE *Spent Nuclear Fuel Recycling Program Plan* [11] would be the logical focal point for this analysis. The projected performance baseline established in the Yucca Mountain licensing process would contribute to such an analysis by providing a basis for assessing the significance of the potential performance benefits that might result from use of improved waste forms.

YUCCA MOUNTAIN SUPPORTS OPERATION OF ADVANCED FUEL CYCLES

Yucca Mountain design is compatible with advanced fuel cycles

Although the current planning basis for the proposed Yucca Mountain repository is direct disposal of the 63,000 MTHM of CSNF to be accepted under the 70,000 MTHM limit, from the statutory and technical perspectives the proposed Yucca Mountain repository could accommodate CSNF reprocessing and disposal of HLW waste forms instead. The Nuclear Waste Policy Act (NWPA) already requires that a repository be able to dispose of both high level waste and spent fuel and provides for contracts and fees for both types of waste. At the same time, the Act reflects uncertainty about the possible future reuse of spent fuel in the fact that it refers only to “such spent fuel as may be disposed of” and requires retrievability of spent fuel (but not of high-level waste) for possible economic reasons. The Act does *not* require disposal of spent fuel at all, much less rapid disposal. Instead, it requires that owners or generators of spent fuel *or high-level waste* sign disposal contracts with DOE, that disposal of the spent nuclear fuel or high-level waste in a repository begin by January 1998, and that DOE *take title* to spent fuel or high-level waste covered by contracts as expeditiously as practicable after the repository begins operation. The phrase “as expeditiously as practicable” applies to the acceptance of spent fuel or high-level waste, not its permanent disposal in the repository.

From a technical perspective, the repository design has evolved in a way that makes it readily adaptable to evolution of the fuel cycle and waste management strategy that might substantially change the mix and timing of waste forms delivered for disposal at the proposed Yucca Mountain repository. In mid-2005, the Department of Energy undertook a broad review of the overall approach to designing, licensing, and operating the proposed Yucca Mountain repository to determine if there were ways to make it safer and simpler. That review led to significant changes in the waste management system design, the most significant being adoption of a new, predominantly clean-canistered approach to simplify the repository operational concepts. In this approach, a single canister would be used to transport, age, and dispose of nuclear waste without the canister ever being reopened. Current plans for operation of the repository assume that about 90% of the CSNF will arrive in such transport, aging, and disposal canisters (TADs).

In addition to adopting a canisterized approach for spent fuel, the Department has developed a repository design that differs markedly from the site recommendation design in its high degree of modularity and flexibility. The site recommendation design included one large integrated waste handling surface facility designed primarily for bare SNF and an underground repository with a single large emplacement area for the 70,000 MTHM inventory. This system design assumed direct disposal of all CSNF, with no reprocessing – consistent with general expectations at the time – and was optimized for that scenario, offering little flexibility to accommodate future changes of mission.

The new design (Figure 1) is based on a set of modules, or “building blocks,” that distribute the waste management functions among a set of smaller, simpler facilities for a primarily canister-based system that can be constructed and operated as needed and as funds are available to meet waste acceptance and disposal needs. (Handling most of the CSNF in large canisters rather than as bare fuel assemblies simplifies facility design and leads to incorporation of some modules that can readily handle either CSNF or HLW.) The new design includes three principal nuclear facility modules for handling spent nuclear fuel and high level waste on the surface before emplacement underground: a Canister Receipt and Closure Facility (CRCF) that receives canisters of waste (TADs with CSNF, or canisters of defense HLW and SNF) and loads and seals them into waste packages for disposal, a Wet Handling Facility (WHF) with a spent fuel pool for receiving and handling individual spent fuel assemblies and loading them into TADs for aging or disposal packaging at a CRCF, and a Receipt Facility (RF) that receives TADs and dual-purpose canisters and sends them to a Wet Handling Facility, aging or to a CRCF for disposal packaging. The suite of surface waste handling facilities also includes a small Initial Handling Facility (IHF) limited to receiving naval spent fuel and canisters of high-level waste and sealing them in waste packages, which simplifies the design and construction (compared to facilities that will handle CSNF) by reducing the need for important-to-safety systems. Finally, the surface facilities include an expandable aging area for TADs in storage overpacks (like those commonly used at reactor sites).

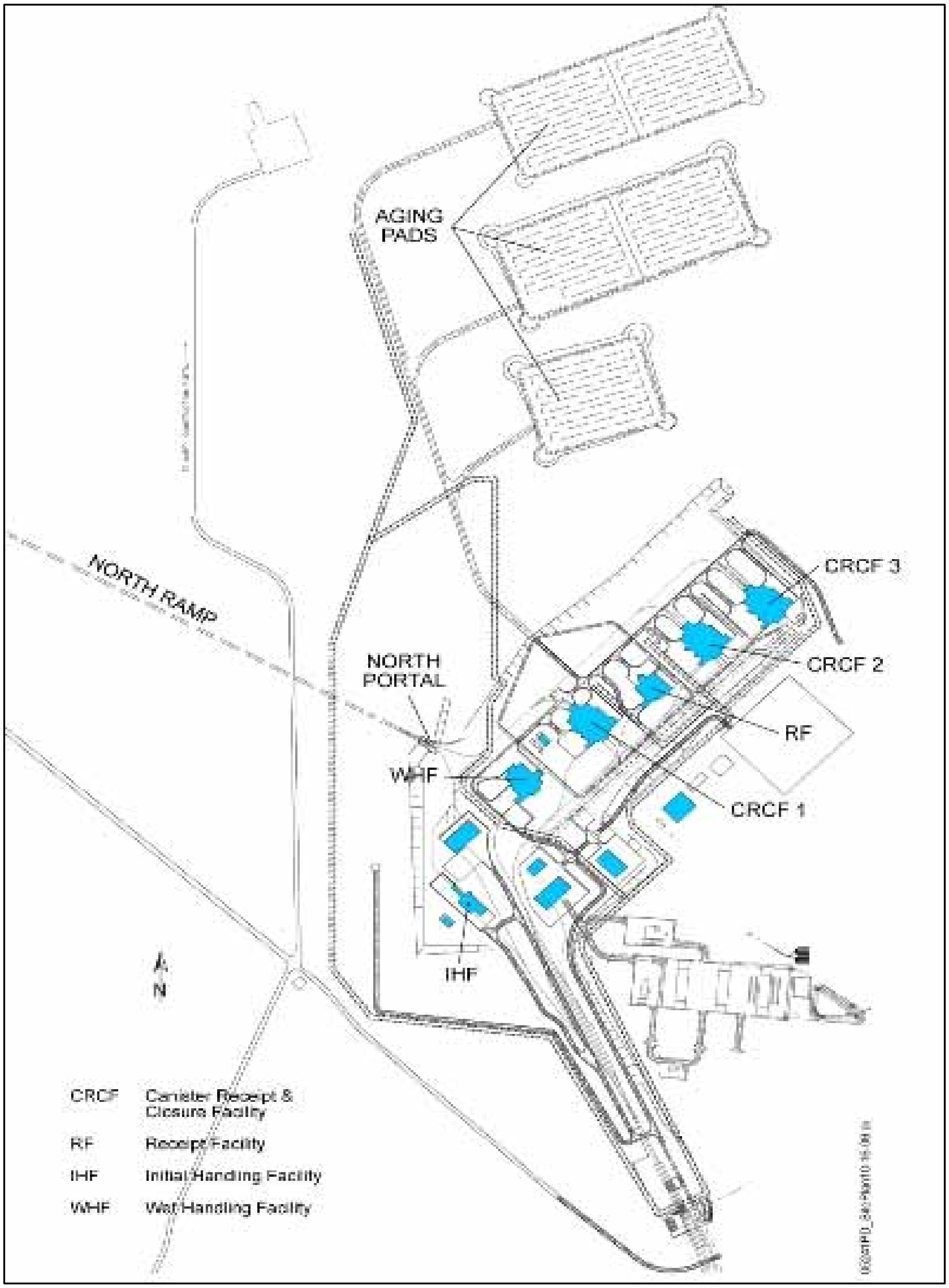

Fig. 1. Modular surface facility design provides flexibility for repository development

These modules offer flexibility to adjust to changing circumstances or policies, since they can be combined as needed to meet any desired sequence of receipt, aging, and disposal, and the design of later modules can be modified prior to construction to accommodate different waste streams, subject to revised safety analyses and approval by the Nuclear Regulatory Commission. In the reference plan for receipt and disposal of the 70,000 MTHM inventory, one Wet Handling Facility, one Receipt Facility, and three Canister Receipt and Closure Facilities would be built in a sequence that allows receipt of all of the 67,000 MTHM of commercial spent fuel (10 percent in uncanistered form) within the first 25 years of operation and emplacement of most of it underground as soon thereafter as thermal management considerations allow. However, if it were deemed desirable to defer disposal of the commercial spent fuel for an extended period (e.g., to preserve a reprocessing option for a GNEP nuclear development scenario), the second and third Canister Receipt and Closure Facilities could be delayed, with an additional Receipt Facility being constructed early to allow spent fuel to be received for aging pending resolution of questions about its ultimate fate. If the fuel cycle developed in a way that led to a substantial shift in the ratio of HLW to SNF to be disposed of, the design of the later waste handling facilities for processing the HLW instead of SNF might be modified to resemble the simpler and less expensive IHF design, benefiting from the experience that will have been gained in licensing and operating that facility.

The underground facilities have also evolved in a way that facilitates adaptation to future changes in waste forms and quantities. At the time of the site recommendation, the underground design involved a single large panel. The design that will be presented in the license application is highly modular, involving five smaller independent waste emplacement panels (Figure 2). This reduces the front-end investment required before emplacement begins and allows for changes in the design and layout, if required, during the operational period. For example, this approach could accommodate a change to zoned disposal of different waste forms similar to the French approach. [13], if that proved to be desirable. Current plans are to integrate the disposal of the high level waste and spent fuel in the same drifts. However , the lower integrated heat output of HLW might allow much denser emplacement – e.g. in drifts that are much closer together than the 81 meters now planned – thereby increasing the efficiency of use of repository disposal area. (Of course, any changes to the layout that affect safety would require approval of the Nuclear Regulatory Commission.) In such an approach, some panels might be optimized for direct disposal of CSNF that is not reprocessed and others optimized for disposal of HLW.

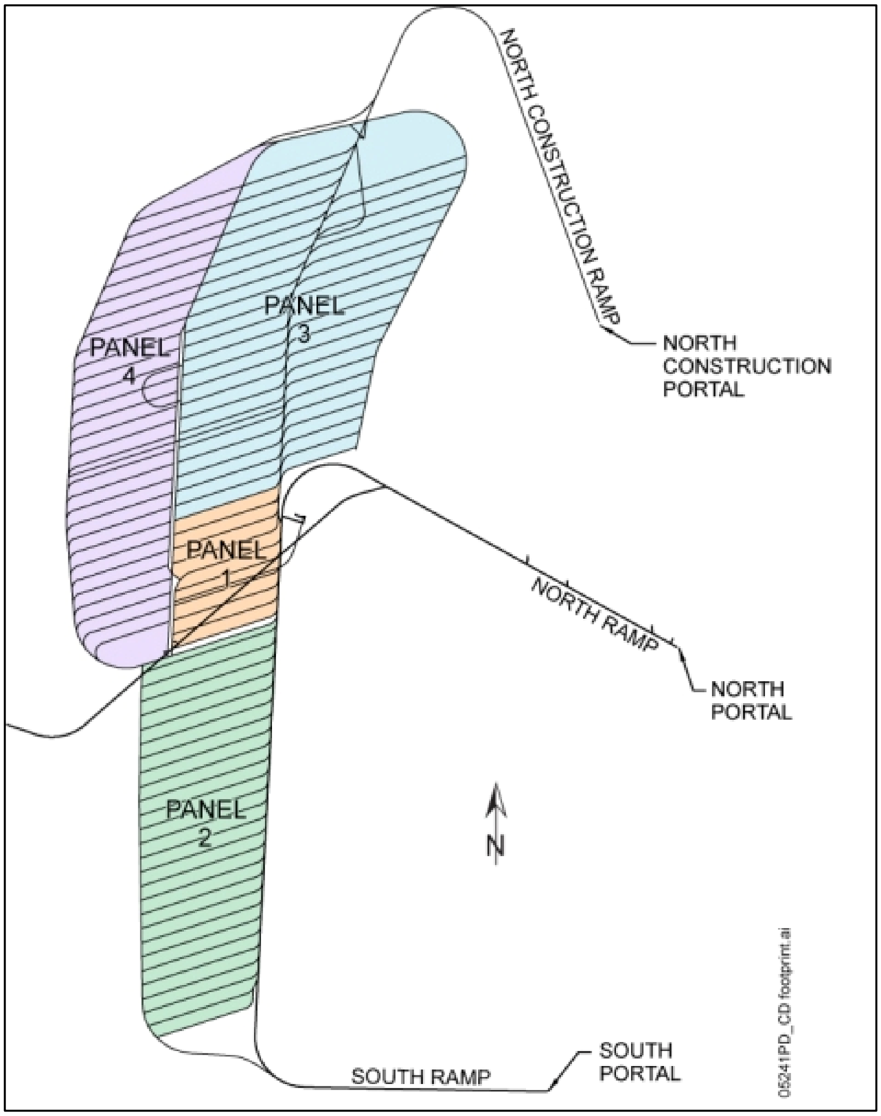

Fig. 2. Zoned underground layout provides flexibility for disposal of different waste types.

Yucca Mountain, GNEP, and Interim Spent Fuel Storage perform complementary functions

Recent statements by key members of both Houses of Congress show clear recognition that there are three key pieces to the waste management puzzle: Yucca Mountain, GNEP, and interim spent fuel storage. The question under debate is how they fit together, and the relative emphasis to be placed on each. The preceding discussion shows that these pieces are indeed complementary. The main aspects of the interrelationships are shown in Figure 3. Notice that storage is a function that can and likely will be provided in a variety of locations -- reactors, independent interim storage facilities, GNEP facilities, or even at the repository. Storage is an inevitable part of waste management because of delays in availability of either a repository or a reprocessing facility and because of the need for in-process buffer storage even after such facilities are in operation. Every commercial reactor (both operating and shut down) is currently storing its spent fuel, and will continue to have some fuel in storage at the site until 5 years after shutdown. Any CFTF is expected to provide adequate storage for both spent fuel prior to processing and for the resulting HLW. [8] The repository will have capability to provide up to 20,000 MTHM of storage in modular increments, for thermal management or other reasons. (The EIS covers 40,000 MTHM.) Finally, legislation under consideration would provide for the possibility of independent interim storage facilities.

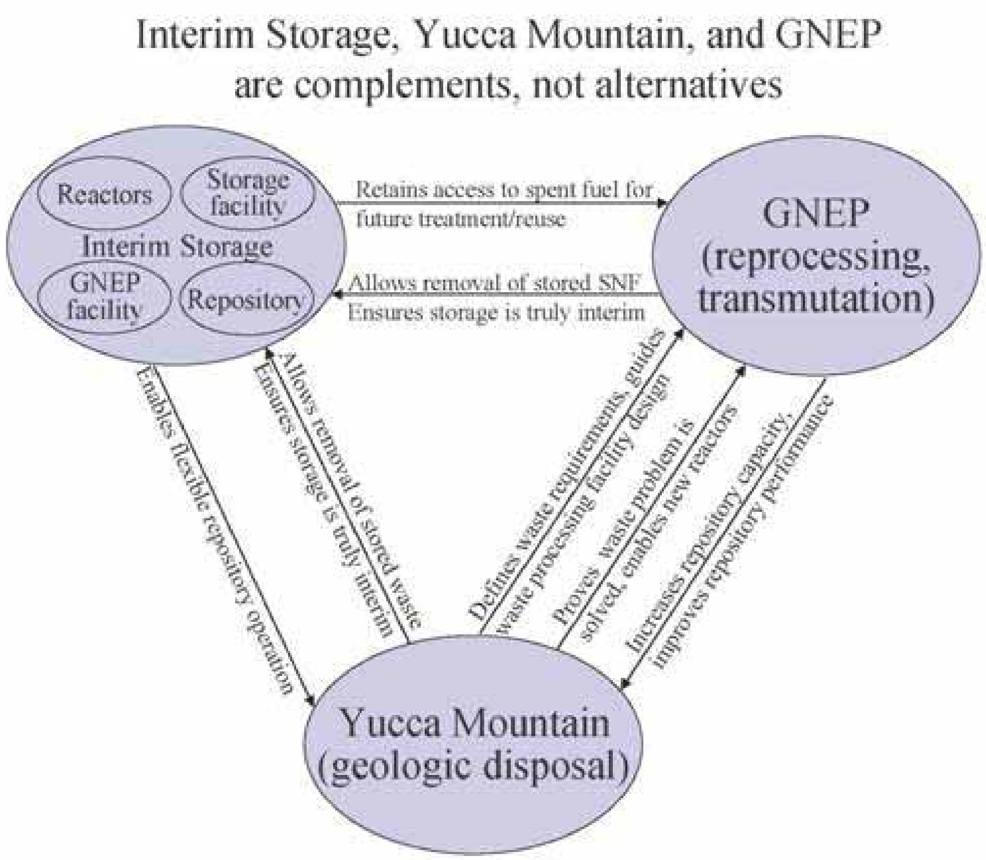

Fig. 3. Relationship of Yucca Mountain, GNEP, and interim storage.

INSTITUTIONAL CONSIDERATIONS

Future reprocessing may have implications for program funding and fee adequacy analyses related to the NWPA’s contractual fee-for-service system. Past analyses have assumed disposal of a fixed proportion of CSNF and HLW (from defense programs), with no reprocessing of CSNF (except for the small amount reprocessed at West Valley.) While a reprocessing plant might not affect the first 63,000 MTHM of CSNF destined for the repository, it would affect the relative amounts of CSNF and HLW disposed of after that. Removing the 70,000 MTHM limit on the proposed Yucca Mountain repository could substantially change the ratio of HLW to SNF disposed of in the future, with implications for the design and cost of the later phases of the repository that could raise issues affecting Waste Fund and fee adequacy analyses.

While reprocessing and recycling may reduce the costs of disposal of the HLW compared to direct disposal of the CSNF, the current statutory fee structure does not allow any such cost reductions to be reflected back specifically to the owners and generators of the HLW resulting from those activities. As noted, the NWPA does require that contracts with owners and generators of waste cover both spent fuel and high-level waste from reprocessing. However, the NWPA also establishes a single, uniform fee (per kilowatt-hour of electricity generation) to be charged to all contract holders, independent of which type of waste they deliver for disposal. The amount paid by each contract holder each year is tied to the amount of electricity generation that produced the waste, not to any specific characteristics of that waste. The Act requires the adequacy of the fee to be reviewed regularly, and that the fee be adjusted as needed to ensure recovery of the full costs of management and disposal activities under the Act. As a result, any substantial reduction in projected disposal costs resulting from a shift towards disposal of HLW instead of SNF would benefit all contract holders paying the fee, rather than only those who are delivering HLW instead of SNF for disposal. Since any disposal cost benefits from disposal of HLW cannot be fully recaptured by the generators of the CSNF that is reprocessed to produce that HLW, their economic incentive for bearing the costs of reprocessing is thereby reduced. (From perspective of contract holder, he would pay the full costs of processing, but would receive only a small fraction of the waste disposal benefits, which would be shared by all contract holders. In economic terms, the benefits from disposal of improved waste forms are public goods benefiting all waste generators because of the statutory fee structure.)

It is worth noting that the net impact of reprocessing and recycling on the total cost of disposal of the resulting waste will depend significantly on the extend and duration of the recycling of the MOX fuel produced after the first recycle of LWR fuel. Direct disposal of the used MOX (which is substantially hotter than LWR spent fuel) after a few recycles could essentially offset the disposal benefits from reprocessing the CSNF in the first place. [10] The challenge for determining the adequacy of the nuclear waste fee in the event of the initiation of large scale reprocessing of CSNF would be to project what the actual waste stream would be over the life of the repository so that disposal costs could be estimated. Analysis of a range of waste management scenarios might be required as a basis for a fee adequacy analysis in the event of initiation of reprocessing and recycling.

There have been suggestions that the Nuclear Waste Fund might be used to pay for reprocessing CSNF. However, language in the House-passed version of the FY07 Energy and Water Development Appropriations bill specifically prohibits the use of amounts made available by that specific Act from the Nuclear Waste Fund to carry out the Global Nuclear Energy Partnership program. [14] Nonetheless, if it were possible to use the Waste Fund to finance reprocessing and recycling of spent fuel, there could be a significant impact on the adequacy of the current nuclear waste fee, particularly if appropriations from the Fund were used to pay for up front construction of processing facilities. Fee adequacy analyses assume that a large unused balance remains in the Fund accumulating interest for an extended period, leaving a positive balance at the end of emplacement: "Sufficient capital in the NWF at the end of the emplacement period is the equivalent of a sinking fund that will provide future decision-makers with the flexibility to defer prompt closure. A sinking fund in excess of the net present value of the future costs provides a margin of safety for uncertainties and changes in program scope, costs, revenues, and economic assumptions." [15]

The analysis suggesting possible financing of a reprocessing facility from the Fund before construction and operation of the proposed Yucca Mountain repository, with the repository starting operation in 2030, noted that the cumulative program expenditures under that scenario would not equal the cumulative receipts in the Waste Fund (including both fee payments and accrued interest on the unspent balance) until about 2048.[10] While this might be true from a near term cash flow perspective, complete depletion of the balance in the Fund far earlier than currently anticipated in order to construct major capital facilities that are not now contemplated as part of the waste disposal system would likely have a major impact on fee adequacy calculations, possibly requiring a substantial increase in the fee to ensure that all of the costs of processing and disposal are recovered and that there is a sufficient sinking fund remaining at the end of repository loading. This problem could arise even if processing the CSNF before disposal led to substantial reductions in disposal costs, because of the mismatch in timing of the expenditures (before disposal begins) and the cost reductions (spread out over the entire disposal period). Since fee adequacy analysis considers the discounted present value of revenues and expenditures, added costs up front are more heavily weighted than cost reductions later. (As an example of the importance of the timing of expenditures, the 2001 fee adequacy report shows that addition of several billion dollars of cost to emplace titanium drip shields just before repository closure had little effect on fee adequacy.) [15]

CONCLUSIONS

The proposed Yucca Mountain repository is needed to allow removal of legacy materials from former nuclear weapons sites and preserve the nuclear electricity option. Repository licensing will contribute to near term design decisions for the GNEP reprocessing plant and associated waste separations and solidification facilities. While the repository can accommodate recycling scenarios, issues concerning waste disposal contracts, fees, and waste fund management may need to be addressed.

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