DEPLOYMENT OPTIONS FOR A SPENT FUEL TREATMENT FACILITY IN THE UNITED STATES

W. B. Boore, D. H. McGuire
Westinghouse Savannah River Company, LLC

ABSTRACT

The Department of Energy – Office of Nuclear Energy, Science and Technology (DOE-NE) is actively pursuing an Advanced Fuel Cycle Initiative (AFCI) to develop spent fuel treatment technologies to enhance the economic attractiveness of advanced nuclear fuel cycles. One alternative being evaluated is to operate a Spent Fuel Treatment Facility (SFTF) to recycle spent fuel from light water reactor (LWR) systems. The United States could consider such recycle if there proves to be a significant life cycle cost reduction compared to the once-through direct disposal option. Recycle of spent fuel would be the first step to enable a fuel cycle that holds promise to significantly reduce the volume, heat load and long-term radiotoxicity of waste sent to a High Level Waste repository.

INTRODUCTION

Whether to meet the demand for cleaner air, address rising costs of energy resources, supply the growing demand for electricity, support the evolution of a hydrogen economy, or some combination thereof, it appears reasonable that nuclear power will continue to play a vital role in supplying the energy needs of the United States. The U.S. plans to dispose of its spent nuclear fuel in a deep geologic repository located at Yucca Mountain, Nevada. The U.S., as with much of the rest of the world, continues to evaluate the potential to process the spent fuel in a manner that can be beneficial to both energy supply and, perhaps more importantly, repository capacity and performance. Energy demand and energy resources are the subject of numerous studies many of which advocate a renaissance of nuclear energy. Long-term disposal of nuclear waste continues to be a major deterrent to nuclear growth. Given the existing inventory of commercial nuclear spent fuel and the present rate of fuel utilization, additional repository space will be needed in just a few decades. Congress shall decide whether this will be at another location, through expansion of the existing location, or perhaps in conjunction with some expanded above ground dry storage.

A promising alternative to direct disposal would be to process the commercial spent nuclear fuel into key partitions permitting recovery of a portion of the energy value while providing vital flexibility to the repository operation in a manner to minimize and possibly defer the near-term need for future repositories. This paper has assumed that such a Spent Fuel Treatment Facility (SFTF) would provide significant benefit to the U.S. nuclear waste program and focuses on key options for deployment of such a facility. The SFTF could partition the spent fuel into manageable components that would be recovered, recycled, or dispositioned as economically beneficial to the overall fuel cycle and/or enhances the repository performance. The goal of the SFTF would be to reduce the high level waste volume sent to a repository, provide for more effective heat management, enhance the containment performance of the specific waste forms, and provide for energy recovery or transmutation as practical. Operation of a SFTF would enable options for plutonium management and other minor actinides that do not currently exist, and coupled with future Gen IV reactor operations holds promise for toxicity reduction of materials sent to the repository. Other nuclides also important to repository performance (e.g., Tc-99 and I-129), could be processed into waste forms with superior containment properties. The proliferation resistance and containment properties of Pu sent to the repository could be enhanced as well. The option would also exist to close the fuel cycle recovering energy value as a MOX fuel and/or ultimate destruction of the Pu via transmutation in Gas Cooled Reactors or Fast Reactors of the future.

Obviously, the cost of a SFTF would have to be justified relative to the overall benefit to, and life cycle cost for, the total fuel cycle. This paper has assumed that commercial spent nuclear fuel in the U.S. could be processed in a manner that provides broad cost and utilization benefit to the Nation's deep geologic repository program. Expediting such a facility could enable a positive impact on Yucca Mountain; however, due to the expected large capital investment and a need based on a modest nuclear growth scenario, timing would more likely be such as to have greatest impact on a second repository. The following discussion addresses potential deployment options for treatment technologies as relate to plant capacity, spent fuel generation rate, and overall strategy for queuing spent fuel to the processing plant and waste repository.

DEPLOYMENT OVERVIEW

The recommended deployment strategy would be to build a multi-purpose SFTF to be located on an existing federally-owned site. The location should accommodate not only a standalone spent fuel treatment plant, but also ancillary facilities in support of the broader Advanced Fuel Cycle Initiative (AFCI) program such as Mixed Oxide (MOX) or advanced fuel/transmutation target fabrication facilities. The SFTF would have an initial capacity of ~2500 MT/yr, but with an inherent capability to expand its capacity to >3000 MT/yr. Such a SFTF could only be merited in the case where current nuclear power is sustained and the nuclear industry experiences a reasonable growth in the period of 2010 – 2050. A moderate 25-50% growth in nuclear power was assumed as a basis for evaluating facility requirements. A capacity of 2500 MT/Yr would appear adequate to meet the needs of such a growth scenario without need for a second such facility for 15-20 yrs. This seems prudent as nuclear technology would surely continue to evolve and a second generation spent fuel facility would be needed to adapt to the economic fuel cycle that would emerge to meet the needs of the future.

The SFTF should be designed in a modular and/or multi-line fashion to support a cost-effective expansion to 3000 MT/yr if desired. The recommended capacity range reflects two major objectives. The first would be to process spent fuel that has aged as long as possible (25–30+ years out of the reactor). This opportunity would present itself due to the fact that the U.S. has maintained in-situ storage since the inception of commercial nuclear power. This could enable significant reduction in the life cycle costs of operation [including repository operation]. The second objective would be to support a cost-effective capital project to build a SFTF. Evaluations of flat to moderate nuclear growth scenarios suggest that a 2500 MT/yr plant could support a 25-year old feed strategy. Capacity much less than 1500 MT/yr, while providing opportunity for much older feed, would rapidly increase the unit cost basis and would not be recommended. World-wide reprocessing experience would suggest that a 2500 MT/yr capacity addressed in a modular or multi-line fashion reflects a reasonable extension of existing technology. Modest expansion capability could address a more aggressive growth in nuclear power or provide an option to help expedite reduction of existing in-situ spent fuel inventories.

The process envisioned for the SFTF would receive spent fuel shipments from nuclear power sites, or other interim storage areas, and produce products whose value is based upon energy recovery, or direct cost or performance benefit to the national repository program. If economics support, uranium could be recovered with sufficient purity for recycle to enrichment facilities or alternatively disposed as LLW. Plutonium (Pu) and Neptunium (Np) would be recovered and could be used in the short term as a mixed oxide (MOX) fuel in LWRs or gas-cooled reactors when available. Ultimately, the recovered Pu would be consumed in the fast reactors of the future. Alternatively, the Pu could be combined with recovered metals and other nuclides to enhance both its longer term proliferation resistance and repository containment performance. Relatively short-lived fission products such as Cs and Sr would be partitioned into a separate product stream providing a significant cost effective alternative for heat management of these radionuclides at YM or future repositories. Minor actinides such as Am and Cm would be partitioned and the small volume either processed into an enhanced containment waste form or stored for future transmutation in thermal or fast reactor systems. Remaining fission products and the metal cladding wastes would be treated for volume reduction and disposal. The net effect would be a much smaller volume of material going to the repository with a significant flexibility and reduction in heat management requirements as well as enhancing the containment performance of the repository. The SFTF would utilize the experience of world-wide commercial spent fuel reprocessing as well as the U.S. experience in both experimental and weapons program reprocessing to establish initial process baselines. The specific design for the SFTF would be the result of technology evolution, demonstration and value engineering.

DEPLOYMENT STRATEGY

The optimum deployment strategy for recycle of commercial spent fuel would be one that best meets AFCI program objectives of repository benefit, energy recovery, Pu destruction, and support for the future operation of Generation IV nuclear energy systems. The following strategy topics relate to meeting AFCI program objectives based upon a SFTF operation.

Operational Flexibility

Due to uncertainty surrounding the magnitude of future nuclear power expansion in the U.S. and the inevitable budget constraints, a successful SFTF would have to offer operational flexibility while striving to minimize the project capital cost. To achieve these dual objectives, a modular (or multi-line process) concept for a reprocessing facility would be recommended. In the modular scenario, the initial reprocessing modules would be built to a process throughput scale consistent with facilities successfully operated in France and the U.K. (800 – 1000 MT/yr). The reprocessing plant would be located on a site large enough to accommodate a large multi-line (or modular) facility or multiple plants of smaller scale, a [MOX] fuel fabrication facility, ample interim storage area, as well as facilities for transmutation target fabrication (as needed). The advantages of a multiple line plant have been demonstrated by the successful industrial practice by the French at LaHague. For instance, two parallel process lines could be interconnected such that the plant could continue to operate at half-capacity while significant systems in both lines were undergoing maintenance. To be successful and provide maximum benefit to a repository, a SFTF must also be capable of both high yield and high availability operation to minimize the generation of unique secondary wastes that would have to be packaged for repository disposal. Based on the IAEA data summarized by Prince [1], a dual-line plant was estimated to cost ~50% more than a single-line plant. A value based systems engineering approach would be used to define the best approach for a SFTF design. However, it is believed the multi-line approach would be required to meet the requirements and provide the necessary flexibility in operations.

In the multi-line facility approach, it may be advantageous to build the critical infrastructure but only populate the process equipment for the capacity needed for the shorter term, leaving room for expansion and/or conversion to evolved technology as market conditions or cost-effectiveness warrants. Implementing a phased approach to achieve the ultimate facility capacity would permit economies of scale to be achieved in the design, procurement and construction, while minimizing as practical the initial project capital cost. Longer-term project capital requirements could be partially offset by the economic gains realized through reprocessing, electrical generation, and the cost avoidance relative to repository operations and deferred need for a second repository.

Siting

The reprocessing facility should be collocated with any planned fuel/target fabrication facility to take advantage of cost, safety and security advantages of shared services, infrastructure, and operating staff. Additional efficiencies could be gained by siting the SFTF on an existing federal site in conjunction with ancillary facilities and to take advantage of existing operations, storage capability, and other macro-infrastructure as applicable. The factors of integrated transportation and required interim storage would require significant consideration relative to the cost impact on the spent fuel processing as well as distribution of the various SFTF and related MOX products. While siting involves many factors (many of which are not technology based), there would be two obvious geographic locations to consider. A location at or near the repository site could provide opportunity to utilize shared interim storage space and minimize transport of HLW to the repository from the SFTF. Under such a Yucca Mountain scenario, a co-located fuel fabrication plant would then have to transport the MOX fuel and the recovered uranium across the country to where most of the nuclear reactors and current enrichment facilities are located. A SFTF with a relative eastern location would be in closer proximity to the reactor and enrichment end-users, but would have to address the cost of shipping the processed HLW to YM for disposition, albeit at a much smaller volume.

Functional Collaboration (with Repository and/or Fuel Fabrication facilities)

Due to the massive scale of the facilities and large number of personnel required to operate them, significant cost avoidances could be realized by sharing of common infrastructure including consideration of integrated processing within common structures. Close coupling of processes could also permit the flexibility to reduce interim storage requirements and minimize any duplication of process functionality between the facilities. Such strategies would have the potential to reduce both capital and life cycle costs especially relative to safeguards and security requirements, control strategy, interim storage, licensing/permitting, waste operations, transportation, basic balance of plant facilities including complex laboratories, and required functions such as emergency response, etc.

Spent Fuel Feed Strategy

Both Yucca Mountain (YM) and the SFTF would share a common objective to utilize the spent fuel in a manner that minimizes operating cost and capital expenditure. Both facilities could benefit from handling "well-aged" spent fuel (25-30+ years since reactor discharge), while facing the necessity of blending a range of aged fuels for consistency in heat management, design application and/or processing. Aged fuel has much less high energy radiation and would present opportunity for simpler design, lower cost and less waste relative to SFTF operations. Therefore a common strategy for parallel operation of the SFTF and on-going repository operations would have to be developed such that both spent fuel feed to the SFTF and "waste" to YM are well defined with appropriate schedules developed. Regardless of long range planning, it would be desirable to begin the first few years of SFTF operations using very old feed such that startup operations, and any necessary process revisions, could be completed without excessive exposure and/or with reduced need for remote operations.

NUCLEAR INDUSTRY INVOLVEMENT

Participation and acceptance of program objectives are important to the overall successful implementation of the AFCI program. The nuclear power industry would be challenged with two main issues for which acceptable alternatives and/or incentives will be necessary. To utilize a strategy of "well-aged" feed would require that a substantial inventory of spent fuel be maintained. This would create a challenge to consider continued in-situ storage at the utility locations and/or new storage to be defined and located. From a nuclear industry basis, there would be a desire to remove spent fuel from the utility location to either make room for fresh discharge or to support site closure activities. From a SFTF cost basis, it would be desirable to minimize the size of the interim storage to provide an appropriate blend of feed. In any case, the logistics of interim storage and transportation would hold opportunity for significant cost avoidance but take cooperative planning and policy/regulations by the nuclear industry, Department of Energy - Office of Civilian Radioactive Waste Management, AFCI program personnel, as well as Congressional and regulatory agency interaction. The second issue would be that of developing a significant MOX market to utilize the recovered Pu from the SFTF if that is the desired route for Pu utilization. The nuclear industry would have to become willing participants having weighed risks and benefits to develop a viable market (e.g., 30+ LWRs using MOX and consideration for new GCRs to use a full Pu core or new LWRs to use a full MOX core). This would surely invoke significant resistance and stockholder concerns. A major program that defines acceptable risk management and proactively addresses the major public relations concerns would have to be developed with involvement of the major stakeholders.

PROJECT CONSIDERATIONS (Schedule, Budget, Technical Feasibility)

The Yucca Mountain Repository currently has a goal to begin operation in 2010 [2]. Thus the YM must license the facility based upon a baseline operation that appropriately could not consider a SFTF operation. If a SFTF could prove to be of significant benefit to the repository operation, then design and construction of the SFTF should begin as soon as practical such that YM could consider more cost effective operations based upon actual performance of a SFTF. While schemes could be envisioned to temporarily place the oldest spent fuel in YM with plans for short term retrieval as part of an overall SFTF feed strategy, the most cost-effective approach would likely be to minimize the placement of untreated spent fuel in YM. Processing spent fuel before the "waste" is sent for final disposition in the repository would maximize both the volume and heat management benefits resulting from the operation.

PRODUCT END-USE CONSIDERATIONS

Decisions relative to "product" end-use such as recycle of uranium vs. waste, use of Pu for fuel value vs. waste, and enhanced containment waste forms would drive the selection of applied technologies for the SFTF. Although major production scale reprocessing facilities exist in foreign countries, a U.S. plan to separate Pu and Np as well as the minor actinides (Am, Cm) for re-use in reactor systems would drive the need to consider several processing alternatives. Project alternatives such as phased capacity installation and co-process/collocation considerations with MOX could minimize initial construction capital requirements while locking-in the economies of scale relative to building and infrastructure cost. Such decisions on end-use including flexibility to change direction based upon economics and technology evolution would dictate the overall facility scope.

CONCLUSION

A SFTF would be a key element for the DOE's AFCI mission to develop and implement spent fuel treatment technologies that enhance the performance of the high level waste repository and reduce the cost of geological disposal. A successful SFTF operation would depend upon cooperation between civilian and government agencies as well as with private industry with emphasis on effective collaboration between SFTF, repository authorities and the nuclear industry. Close coupling of the AFCI and Gen IV Nuclear Energy programs would appear essential to enabling an expanded role for nuclear power as a sustainable resource that could address long-term U.S. energy security, environmental and economic concerns. A major challenge would obviously exist to gain public recognition and acceptance of the value and benefits of such an approach.

REFERENCES

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