Impact of Partitioning and Transmutation on Repository Design

Carter D. "Buzz" Savage

U.S. Department of Energy, Office of Nuclear Energy, Science and Technology:
1000 Independence Avenue SW, Washington, DC 20585
Buzz.savage@nuclear.energy.gov

Abstract *– The U.S. Department of Energy's Advanced Fuel Cycle Initiative (AFCI) program is investigating spent nuclear fuel treatment technologies that have the potential to improve the performance of the proposed geologic repository at Yucca Mountain. Separating actinides and selected fission products from spent fuel, storing some of them as low level waste and transmuting them in thermal and/or fast reactors has the potential to reduce the volume, short and long-term heat load and radiotoxicity of the high level waste destined for the repository, effectively increasing its capacity by a factor of 50 or more above the current legislative limit.*

INTRODUCTION

The Advanced Fuel Cycle Initiative (AFCI) program was initiated by the U.S. Department of Energy (DOE) Office of Nuclear Energy, Science and Technology (NE) in Fiscal Year (FY) 2000 as an accelerator-based transmutation research and development (R&D) program to develop the capability to transmute the transuranic actinides and selected fission products from spent nuclear fuel that are the most important contributors to the heat generation and radiotoxicity of the high level waste (HLW) in the geologic repository. The program shifted focus from accelerators to reactors over the next three years and had two name changes in the process. The current AFCI program is conducting research into advanced spent fuel separations, fuel development, and transmutation technologies in order to provide options for future spent fuel management and complete the development of Generation IV nuclear energy systems.

The capacity of the U.S. geologic repository proposed for Yucca Mountain in the state of Nevada is legislated at 70,000 metric tons of initial heavy metal (MTIHM), of which 63,000 MTIHM is from commercial spent fuel and the remainder from defense spent fuel and high level waste. This capacity is a legal limit, not a technical limit. There was an inventory of about 45,000 MT of commercial spent fuel in storage at the sites of the nuclear power plants in 2003, and the 103 operating plants are generating about 2000 MT additional spent fuel per year. At this rate, the legal limit of Yucca Mountain will be reached by 2010, the year in which it is currently scheduled to open.

LIMITS ON YUCCA MOUNTAIN REPOSITORY CAPACITY

If the currently operating nuclear plants in the U.S. were to operate to the end of their license periods (no additional license extensions), the total spent fuel inventory is expected to reach 90,000 MT. Most if not all of the plant owners are expected to apply to the Nuclear Regulatory Commission (NRC) for license extensions for the rest of the reactor fleet, according to the Energy Information Administration (EIA) of DOE and the Nuclear Energy Institute. This will result in a final inventory of about 120,000 MT of spent fuel. Thus, with no changes in legislation or spent fuel management schemes, at least one additional geologic repository will be required in the U.S. just to handle the spent fuel from existing light water reactors.

Analyses conducted by the DOE Office of Civilian Radioactive Waste Management (OCRWM) indicate the capacity of the mountain itself is probably much larger than the legislated limit. The Yucca Mountain Final Environmental Impact Statement included alternative analyses that conclude a technical capacity of at least 105,000 MT exists [1]. More recent analysis suggests a technical capacity of 129,000 MT. This implies that with legislative changes the Yucca Mountain repository could quite possibly accommodate all the spent fuel from the current generation of nuclear plants in the U.S. even if all operating plants apply for and are granted a twenty year license extension.

U.S. NUCLEAR FUTURE

If this is true, why should we detour from the current once through fuel cycle policy and develop technologies to recycle spent fuel components? The reason is that we do not expect nuclear power to remain stagnant in the U.S. The DOE has two research programs that focus on development and deployment of advanced nuclear reactors in the U.S. These are the Nuclear Power 2010 program, which seeks to work with Industry to site and build an advanced light water reactor in the U.S. in the next decade; and the Generation IV nuclear energy initiative (GEN IV), which will, in an international collaborative effort, develop advanced thermal and fast reactor systems for the future. AFCI supports both programs by conducting R&D into advanced fuel and fuel recycle technologies.

A team of AFCI technical experts led by the Idaho National Engineering and Environmental Laboratory (INEEL) and Argonne National Laboratory (ANL) has been conducting analyses of various nuclear energy growth scenarios and the potential impact of AFCI technologies on future repository requirements [2,3]. This paper acknowledges their ongoing work and reports the conclusions the AFCI program has reached to date based on their analysis.

The AFCI Team chose three U.S. nuclear growth scenarios for the 21^{st} century to analyze, attempting to cover the full range of possible nuclear futures. The first is maintaining nuclear generation capacity constant at 100 GWe, the current capacity. This means each operating plant that shuts down would be replaced by a new reactor with approximately the same capacity. This would result in an inventory of about 250,000 MT of spent fuel by 2100.

The second scenario assumes an expansion of nuclear energy to maintain 20 percent of the electricity market share, which equates to a 1.8% compounded market growth (Electricity market growth rate from *EIA Annual Energy Outlook 2004 with Projections to 2025,* Table A8). This scenario would result in about 600,000 MT of spent fuel generated by 2100.

The third scenario assumes a 3.2% growth in nuclear energy representing a 1.5% total energy market growth (all energy, not just electricity – from *EIA Annual Energy Outlook 2004 with Projections to 2025,* Table A1) and 1.7% share growth. This share growth results in tripling nuclear's market share by 2100 from its current 8.4% to 25%, equivalent to continuing the average market growth of the last 50 years for an additional 100 years. Such a scenario would result in over 1,400,000 MT of spent fuel by 2100.

AFCI TECHNOLOGIES AND REPOSITORY CAPACITY

The AFCI program has developed a phased approach for the implementation of advanced fuel cycles through R&D and demonstrations of spent fuel separations and transmutation technologies. This phased approach will be described in detail by Dr. James Laidler of ANL in his talk later in this conference on the development of separations technologies. For purposes of this discussion, we can briefly summarize them. Phase 1 would separate the uranium from spent light water reactor fuel with a high purity such that it could be classified as low level waste for disposal or future reuse. Cesium and strontium, the major contributors to the short term heat load in the Yucca Mountain repository, would also be separated and stored separately for decay to low level waste. With each of these fission products having 30 year half lives, this would require 200-300 years. The transuranic actinides would be put into a stable waste form that could be placed in the repository either temporarily or permanently. The remainder of the fission products would be put in a waste form for permanent storage in the repository. In Phase 2, plutonium, neptunium and perhaps americium would be recovered and recycled in thermal reactors. In Phase 3, the americium and curium, plus transuranics recovered from recycled thermal reactor transmutation fuel, would be sent to dedicated fast spectrum transmuters. Finally, in Phase 4 Generation IV fast spectrum reactors with closed fuel cycles would be introduced, and all actinides recycled.

Each of these phases, if implemented, would have a benefit on repository performance and permit more high level waste to be placed into the first repository, possible negating the need for an additional repository in the next 100 years.

The removal of uranium from spent fuel would reduce the volume of high level waste going to the repository. This in itself would not improve the capacity of the repository since the decay heat from cesium, strontium, plutonium and americium drive the loading requirements. Removing the uranium would permit alternative storage containers for the remaining waste, possibly improving the economics of storage of the remainder of the waste.

Removal of cesium and strontium would take away the major contributor to the short term (a few hundred years) heat load in the repository. Removal of plutonium and americium would remove the major contribution to the long term heat load. Dose rates from spent fuel are not limiting during the repository licensing period and so are neglected in this analysis. Recycling the transuranics in thermal and/or fast reactors would reduce the inventory of each species by a differing amount, depending on numerous factors such as age of the spent fuel, separations efficiency, fuel fabrication losses, and others. Weigland et al [3] have studied the effect on long term heat generation in the repository if these components were not present. The analyses performed so far indicate a significant improvement on repository performance can be achieved by implementation of the AFCI separations and recycling technologies.

Figure 1 presents the different nuclear energy scenarios through 2100 described above, and the impact of implementation of legislative changes and AFCI technologies in high level waste management. This chart was developed by Dixon [2] and is being continually updated as the analyses are improved upon.

CONCLUSION

From Figure 1, one can see that if the current repository capacity were expanded to its potential technical capacity, it would be able to handle all the spent fuel expected to be generated from the current fleet of light water reactors. Under any nuclear growth scenario, however, additional repositories would be required unless separations and recycle technologies are developed and implemented. Only with the introduction of thermal and fast spectrum reactor recycling can the U.S. possibly avoid the need for at least a second and potentially many additional repositories.

Nuclear Futures		**Legislative Limit**	**Existing License Completion**	**Extended License Completion**	**Continuing Level Energy Generation**	**Continuing Market Share Generation**	**Growing Market Share Generation**
Cumulative discharged fuel in 2100 (MTiHM)		63,000	90,000	120,000	250,000	600,000	1,400,000
		Existing Reactors Only <-----			-----> Existing and New Reactors		
Fuel Management Approach		**Number of Repositories Needed**					
---> No Recycle	Current Management Approach (under existing repository legislation)	1	2	2	4	9	21
	Expanded Repository Capacity	1	1	1	2	5	11
Reprocess and Recycle <-----	Separations, Limited Thermal Recycle, Repository Capacity Expansion	1	1	1	1	2	5
	Separations, Repeated Combined Thermal and Fast Recycle	1	1	1	1	1	1
	Separations, Repeated Fast Recycle	1	1	1	1	1	1

Fig. 1. Nuclear Futures in the U.S. for Various Fuel Management Approaches

REFERENCES

1. *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*, DOE-EIS-0250 (2002).
2. B. DIXON, Idaho National Engineering and Environmental Laboratory, "Nuclear Futures versus Spent Fuel Management", presentation to the Advanced Nuclear Transformation Subcommittee of the Nuclear Energy Research Advisory Committee, U.S. DOE (February 2004)
3. R.A. WEIGLAND, T. H. BAUER, T.H. FANNING, E.A. MORRIS, Argonne National Laboratory, "Spent Nuclear Fuel Separations and Transmutation Criteria for Benefit to a Geologic Repository", Proceedings of Waste Management 2004 Conference, Tucson, AZ (March 2004)