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LOW LEVEL WASTE GENERATION FROM VARIOUS FUEL CYCLE OPTIONS

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The United States (U.S.) currently utilizes a once-through fuel cycle where used nuclear fuel (UNF) is stored on-site in either wet pools or in dry storage systems with ultimate disposal in a deep mined geologic repository envisioned. This strategy of minimal fuel handling generates only small quantities of low level waste. Within the Department of Energy's (DOE) Office of Nuclear Energy (DOE-NE), the Fuel Cycle Technology (FCT) Program develops options to the current commercial fuel cycle management strategy to enable the safe, secure, economic, and sustainable expansion of nuclear energy while minimizing proliferation risks by conducting research and development of advanced fuel cycles, including modified open and closed cycles. These advanced cycles, requiring some level of handling and rework of used fuel, inherently have the potential to increase low level waste generation – in some cases substantially.

This study analyzes the quantities of various low level waste streams as a function of a variety of potential fuel cycle alternatives including:

- *Geologic disposal of commercial UNF generated by uranium fuel light water reactors (LWR).*
- *Four alternative LWR used fuel recycling processes that differ in the reprocessing method (aqueous vs. electro-chemical), complexity (Pu only or full transuranic (TRU) recovery) and waste forms generated.*
- *Reprocessing of fuels derived from recovered TRU utilizing multiple reactor passes.*

I. INTRODUCTION

The safe management and disposition of used nuclear fuel and/or nuclear waste is a fundamental aspect of any nuclear fuel cycle; however, the routine disposal of used nuclear fuel and radioactive waste remains problematic. Advanced fuel cycles will generate different quantities and forms of waste than the current light water reactor (LWR) fleet. This study analyzes the quantities and characteristics of potential secondary wastes from facility operational and maintenance activities as a function of a variety of potential fuel cycles. The information presented in this paper is more completely investigated in references 1 and 2.

II. Secondary Waste

Secondary waste streams will be generated from the disposition of used fuel regardless of the fuel cycle utilized. Secondary waste streams are non-process waste streams typically consisting of contaminated items such as protective clothing, other job control waste, maintenance waste and failed equipment. Secondary waste estimates have been prepared for the following used fuel disposition activities:

- geologic disposal of LWR used fuel
- aqueous and electrochemical recycling of LWR used fuel
- aqueous and electrochemical recycling of sodium fast reactor (SFR) used fuel

Estimates of Class A/B/C low level waste (hereinafter referred to as LLW), greater than Class C low level waste (GTCC waste), mixed Class A/B/C low level waste (hereinafter referred to as mixed LLW) and mixed greater than Class C low level waste (mixed GTCC waste) are provided.

II.A. Secondary Waste from Geologic Disposal of LWR Used Fuel

Secondary waste estimates were prepared as part of the Environmental Impact Statement for a geologic repository at Yucca Mountain.[3] The waste estimates prepared for the Yucca Mountain repository form the basis for the secondary waste estimates reported here.

Repository operations are expected to generate only LLW. GTCC waste, mixed LLW and mixed GTCC waste are not expected to be generated by repository operations. Estimates of LLW generation for operations at a geologic repository range from 0.8 m^3 per metric ton of heavy metal (m^3/MTHM) of used fuel disposed to 3.7 m^3/MTHM depending on the fraction of used fuel that is prepackaged in canisters that are suitable for direct disposal at the repository. Figure I shows the waste generation rate with respect to the fraction of used fuel that is prepackaged in directly disposable canisters.

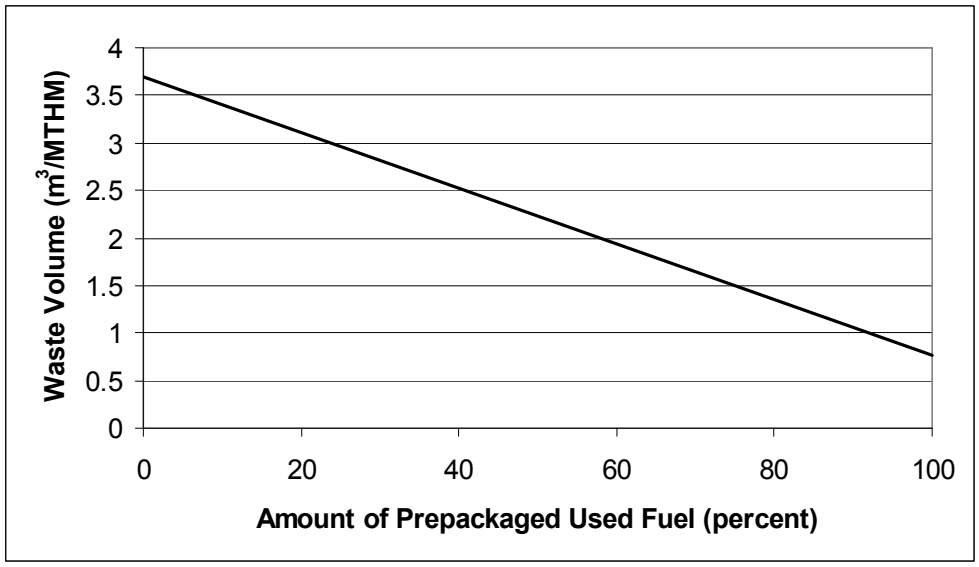

Figure I. LLW Generated by Disposal of Used Fuel at a Geologic Repository

II.B. Secondary Waste from Recycling of LWR Used Fuel

Secondary waste from a variety of aqueous recycling operations has been estimated relative to facility capacity. Commercial LWR used fuel reprocessing methods vary in process complexity and technical maturity. Generally the objective of additional complexity is to lessen the potential environmental impact of the resulting waste disposition activities. Three aqueous reprocessing methods and one electro-chemical reprocessing method were selected.

Co-Extraction represents the simplest and most technically mature aqueous reprocessing method evaluated. The process envisioned is similar to the current generation of deployed reprocessing technology (e.g., the Rokkasho Reprocessing Facility). Uranium and plutonium are recovered together (no pure plutonium separation). The principle fission product wastes including the minor actinides are combined with the undissolved solids (UDS) and recovered Tc into a single borosilicate glass wasteform. The gaseous radionuclides I-129 and H-3 released during reprocessing are captured and converted to waste forms suitable for disposal while C-14 and Kr-85 are assumed to be released to the atmosphere.

New Extraction is an advanced aqueous process which recovers all of the transuranic (TRU) elements for re-use. The process envisioned includes Transuranic Extraction (TRUEX) and the Trivalent Actinide Lanthanide Separation by Phosphorus-based Aqueous Komplexes [*sic.*] (TALSPEAK) process for complete TRU recovery. The principle fission product wastes are combined with the UDS and separated Tc into a single borosilicate glass wasteform. The principle gaseous radionuclides I-129, Kr-85, C-14 and H-3 released during reprocessing are captured and converted to waste forms suitable for disposal.

Uranium Extraction (UREX) is an advanced aqueous process which also recovers all of the TRU and in addition separates the fission product waste components into three segments. The Fission Product Extraction (FPEX) process is added to separate the Cs/Sr/Ba/Rb, which is converted to a solid ceramic waste form. The Tc and Undissolved Solids (UDS) are combined with a portion of the zirconium hulls/stainless steel hardware to form a metal alloy, and the remaining fission products are converted to a borosilicate glass. UREX is the most complex of the three aqueous processes evaluated.

Electro-chemical processing is a dry process using conductive molten salt baths to recover all the TRU elements. In this process the fission products are split between three waste streams. Elements which are more noble (as measured by electro-chemical potential) than uranium, such as fuel cladding and noble metal fission products, remain as metals and are incorporated into a metal alloy waste form. Elements less noble than uranium are converted to chloride salts. The lanthanide elements are recovered from the salt by electrolysis and converted to a lanthanide glass. Excess salt is purged; the chloride is adsorbed by zeolite and bonded with glass to make the final waste form. The principle gaseous radionuclides I-129, Kr-85, C-14 and H-3 released during reprocessing are captured and converted to a wasteform suitable for disposal, although most of the I-129 in this process is not released to the gaseous phase but is converted to a molten salt and purged with the excess salt.

Data related to the co-extraction process proposed by AREVA, the new extraction (NUEX) process proposed by Energy*Solutions* and the UREX+1a process as evaluated by the Engineering Alternative Studies (EAS) were used as a basis for the estimates.[4,5,6] Curves were generated based on the available data to provide consistent estimates for subsequent analysis of future fuel cycles. Curves for LLW and GTCC waste are shown in Figures II and III respectively. Similar curves for mixed wastes are provided in reference 2.

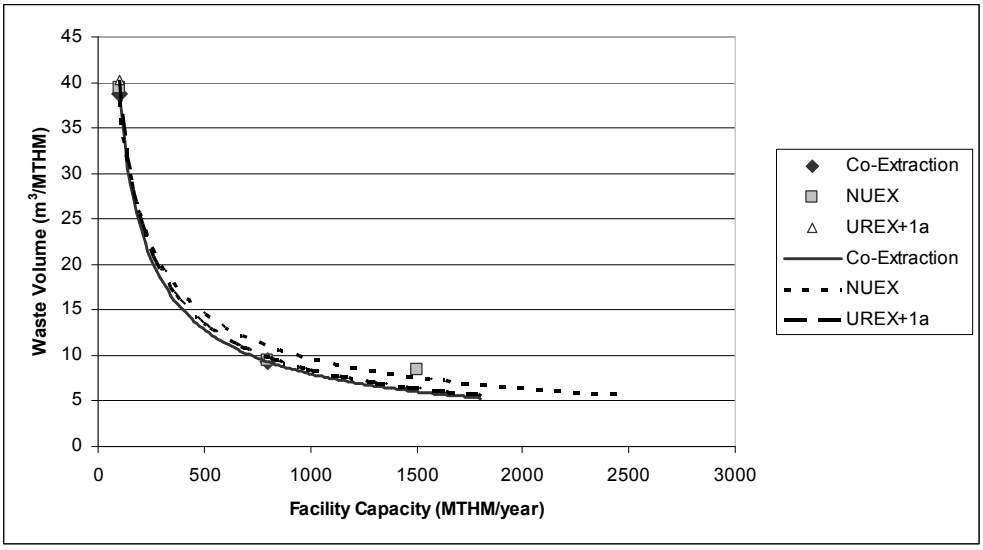

Figure II. LLW Generated by Aqueous Recycling of LWR Used Fuel

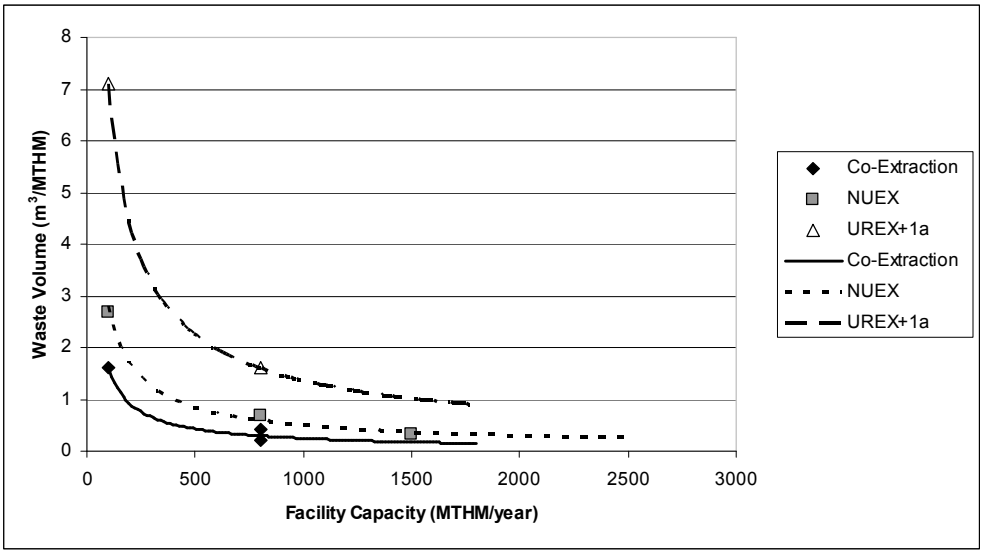

Figure III. GTCC Waste Generated by Aqueous Recycling of LWR Used Fuel

Secondary waste from electrochemical recycling of LWR used fuel has also been estimated. Table I shows the estimated waste volume expected from a 300 MTHM/year electrochemical recycling facility based on data developed for the Engineering Alternative Studies. Secondary wastes from electrochemical recycling of LWR used fuel are investigated more completely in reference 2.

Table I. LLW Generated by Electrochemical Recycling of LWR Used Fuel

Facility Capacity (MTHM/yr)	Volume	LLW	GTCC	Mixed LLW	Mixed GTCC
300	m^3/year	2,616.1	919	29	43.6
	m^3/MTHM	8.7	3.1	0.1	0.15

I.C. Secondary Waste from Recycling of SFR Used Fuel

Secondary wastes from recycling of SFR used fuel does not differ substantially from the estimates for LWR used fuel. The primary differences in the estimates relate to the quantity of fuel assemblies recycled which is driven primarily by the physical configuration and the radionuclide content of the fuel assemblies. Secondary wastes from recycling SFR used fuel are investigated more completely in reference 2.

II. FUTURE ACTIVITIES

Efforts will continue in 2011 to evaluate other fuel cycle activities including secondary wastes from the fabrication of mixed oxide fuel. Work is also planned in conjunction with industrial partners to refine the process and secondary waste estimates already prepared for aqueous recycling of used fuel.

REFERENCES

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