Fuel Cycle Advantages Resulting from the Significant Inventory of U.S. Spent Fuel

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INTRODUCTION

Given the existing inventory of spent fuel and the present rate of fuel utilization, a second repository will be needed in just a few decades. The very large cost, between $31.5 billion and $42.8 billion in 2001 dollars [1], of a repository and the very difficult problem of finding a possible location offer a significant incentive to the development of cost-effective processing of the spent fuel to enhance the lifetime of the first repository. The goal is to separate from the spent fuel different components that could be recovered and recycled or disposed of more economically, thus leaving a much smaller fraction to be sent to the geological repository.

However, for overall cost savings to be realized, the treatment technologies must be cost-effective. An important factor in the deployment of treatment technologies is achieving the best match between the capacity of the plant, the rate of generation of the spent fuel, and the strategy for queuing spent fuel to the processing plant.

BACKGROUND

Reprocessing spent fuel has generally been analyzed on the basis of a 5-to10-year (or shorter) cooling period after removal from the reactor. Because of the very large inventory of spent fuel already accumulated, a different strategy having much longer cooling times (30–40 years) is possible. If a plant were designed, built, and ready to start up in the United States by the year 2015 with a capacity to process spent fuel equal to the present annual U.S. demand for new fuel (~ 2000 MTU) on an oldest-first basis, the plant would, during its anticipated 30–50-year lifetime, never process fuel that had been cooled less that 34 years. Further, given the very large inventory already at hand, the uncertainties regarding the spent fuel's burnup, composition, and assay are minimal. Assuming the stated 30–50-year lifetime and a rate of processing matching the rate of generation, the plant would process fuel generated in the period from 1969 to 2010 or 2030. Under this scenario, there is a 30-to 40-year gap between successive reprocessing cycles.

During this prolonged cooling period, there is a significant decay of fission products and heavy actinides that facilitates the processing of the spent fuel. Additionally, it offers the opportunity to introduce minor actinides into the fleet of thermal reactors for some limited transmutation, significantly delaying the need for specialized transmutation systems.

DESCRIPTION OF THE ACTUAL WORK

The strategy of processing older fuel first and closely matching the rate of generation so as to maintain a cooling period of about 30 years can offer both capital and operational cost savings.

A significant fraction of the construction costs should be proportional to the radiation field. Just as a relative indicator, the first three rows of Table I show the ratio of the activities (in curies) at different cooling times compared with the activities at 30 years for the unprocessed spent fuel and for the cladding and fission product fractions.

Obviously, extensive calculations are required to estimate actual shielding requirements; however, the significant decrease in the activities over time should translate into lower shielding requirements for the processing of older fuel. However, an educated guess would suggest that the savings in shielding should not be as important as those related to waste treatment, storage, and disposal.

The design capacities of several processing modules are also significantly affected by the age of the fuel: (1) Cs and Sr separation, treatment, storage, and cooling; (2) tritium separation and confinement; (3) Kr separation and storage; (4) dissolver off-gas treatment; (5) solvent treatment and recovery to remove radiolytic by-products; (6) HLW solidification, storage, and disposal; (7) fuel and miscellaneous waste storage; and (8) cladding disposal. Table I shows some of the relative indicators for some of the streams most affected by the age of the fuel. For most of these modules, the capital costs should be proportional to the respective quantities for a given throughput. Accordingly, there should be a substantial saving in capital equipment and operating costs for older fuel.

Table I. Relative indicators for spent fuel at different cooling times.[a]

Item	Values relative to a cooling period of 30 years					
	150 d	5 y	10 y	20 y	30 y	40 y
Activity from fuel elements	32.6	2.54	1.81	1.31	1.00	0.77
Activity from cladding	55.3	5.03	3.49	1.81	1.00	0.57
Activity of fission products	31.7	2.65	1.74	1.12	1.00	0.93
Heat from fuel elements	18.1	2.45	1.59	1.21	1.00	0.84
Amount of ^{3}H	5.26	4.07	3.07	1.75	1.00	0.57
Amount of ^{85}Kr	6.77	5.04	3.65	1.91	1.00	0.52
Amount of Cs and Sr	6.24	2.55	1.74	1.27	1.00	0.79

[a] Based on ratios for PWR fuel at a nominal burnup of 33000 MWd/MTIHM.

An adaptation of the capital cost analysis for a 1500-MTHM/year plant shows that the modules that will be most affected by the age of the fuel comprise about 60% of the capital costs [2, 3]. Consequently, the potential savings in capital costs can be quite significant when a strategy is used whereby the older fuel is processed first. However, only a very detailed sensitivity analysis could quantify the actual impact.

The same adaptation of the cost analysis for a 1500-MTHM/year plant shows that waste treatment, disposal, and storage totaled 56% of the operating costs. Each item in the operating costs for the waste treatment, disposal, and storage category should be linearly proportional to the respective quantities for a given throughput. Accordingly, the potential savings in operating costs can be quite significant for the HLW, Cs/Sr, and Kr portions when an oldest-first strategy is used.

About 690 MT/year of Zircalloy (64% PWR, 36% BWR) would be separated from the fuel in a 2000-MTHM/year processing plant. For older Zircalloy, a significant fraction of the activation products and surface-implanted species (caused by recoil and fuel cladding interactions) should have decayed. The main activation products remaining will be ^{93}Zr, ^{93m}Nb, and ^{94}Nb. Assuming that the cladding could be decontaminated from fuel residues, then old cladding might not be classified as HLW. Accordingly, its disposal should be significantly cheaper. In addition, the milder nature of the radiation field for old cladding could allow for recycling or alternative reuse.

RESULTS

The relative cost analysis shows the potential for significant savings in both capital and operational costs by using a strategy that enhances the cooling time of the spent fuel being processed and that conforms to the present reality. Other qualitative advantages of the older-fuel-first principle exist as well: (1) much lower heat load to the repository for a given separations efficiency, (2) significantly diminished growth of very heavy actinides from cycle to cycle, (3) very long time between fuel reprocessing cycles, (4) significantly reduced quantities of Cm, (5) somewhat less stringent separation efficiencies needed for heat-generating isotopes such as Cs and Sr, and (6) significantly lower growth of Am in the separated Pu.

REFERENCES

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2. M. JONATHAN HAIRE, "Nuclear Fuel Reprocessing Costs," to be presented at the American Nuclear Society Topical Meeting, Advances in Nuclear Fuel Management III, Hilton Head Island, South Carolina, October 5–8, 2003.
3. Adapted from W. D. BURCH, M. H. HAIRE, and W. E. UNGER, unpublished data, ca. 1982.