Reuse in LWRs of Uranium Recovered from Spent Fuel: Neutronic Evaluation of Multiple Cycles of Re-enrichment and Reactor Irradiation

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INTRODUCTION

The uranium component is the largest fraction of spent fuel, representing about 66 wt % of the fuel assembly mass or 95 wt % of the spent fuel itself.[1] One of the goals of the DOE Global Nuclear Energy Partnership (GNEP) program is to minimize the amount of wastes requiring geological disposal.

Only a small amount of the recovered uranium (RU) from spent fuel can be used as part of the transmutation fuels. The surface disposal path for uranium, even if purified to a level comparable to a low level class C waste, is uncertain.

This paper presents a neutronic analysis of the repeated reuse of RU by re-enrichment and re-irradiation in light-water reactors (LWRs). Of the many possible reuse scenarios, the one chosen in this paper is such that the RU from a given amount of spent fuel is fed along with sufficient natural U to produce the same amount of fresh fuel for the next reactor pass. The tails exit the enrichment process at 0.2 wt % for ^{235}U.

BACKGROUND

Naturally occurring uranium contains only the three isotopes: ^{234}U, ^{235}U and ^{238}U. Reprocessed uranium contains several radioactive isotopes: ^{232}U, ^{233}U, ^{236}U and ^{237}U.

The concentration of residual fissile ^{235}U in the spent fuel is in the range of 0.8 to 1.3 wt %, depending on initial fuel enrichment, irradiation neutron flux level and fuel burnup level at discharge. Other significant uranium isotope concentrations include ^{232}U (< 12 ng/g U), ^{234}U (0.02 to 0.04 wt %), and ^{236}U (0.3 to 0.7 wt %).

The ^{236}U isotope is formed by neutron capture in ^{235}U. During the re-enrichment of the recovered uranium, about 60% of ^{236}U remains in the re-enriched product. Because of the non-fission capture in ^{236}U, the fuel at a given ^{235}U enrichment has a slightly smaller neutronic reactivity with ^{236}U present than without. The reactivity loss persists late in the life of the fuel so that the initial enrichment will have to be slightly higher to compensate for the ^{236}U content or alternatively the fuel assemblies will have to be replaced earlier than would ones that were free of ^{236}U. The additional ^{235}U needed to compensate is termed the "^{236}U penalty factor." The ^{236}U penalty factors, determined in the 1970s and 1980s in the U.S. enrichment industry, ranged from 0.25 to 0.33. That is, 0.25 to 0.33 units of additional ^{235}U are needed to compensate for 1 unit of initial ^{236}U in the reactor fuel [2]. Similar studies by the NEA [3] used a compensation factor of 0.28. A recent report by the IAEA [4] studied the use of RU in fuel with ^{235}U assays ranging from 3.25 to 3.70 wt %. While the report did not explicitly state the penalty factor used (or derived), one can deduce a value of 0.24 from their results.

DESCRIPTION OF THE ACTUAL WORK

To analyze the effect of ^{236}U in fuels that have higher initial-enrichments and achieve higher-burnups, including multiple re-enrichments, two-dimensional reactor lattice neutronic calculations were performed using the HELIOS computer code [5] (using 47 neutron group cross-sections). In the core lattice calculations, each fuel assembly consisted of 264 fuel rods and 25 guide tubes that were arranged into a 17 × 17 square lattice. Cases for two different final average fuel burnups were studied: 33,000 MWd/MTU representing the average burnup of the U.S. inventory and 55,000 MWd/MTU representing high burnup fuels. In the defined RU reuse scenarios it was assumed that there would be a fleet of PWR reactors requiring 3,000 MTU of enriched fuel per year. After decay following fuel discharge, the fuel was assumed to be reprocessed and the resulting RU was fed along with sufficient natural uranium to produce the required amount of enriched product to feed the next reactor pass.

RESULTS

The enrichment model and the neutronic model were integrated to allow tracking of masses and isotopic compositions of all the U isotopes.

In summary, the concentration of ^{236}U in U in the enriched uranium product were calculated as a function of the reactor pass numbers for this scenario, extended to 7 reactor passes. The estimated asymptotic constant value of the ^{236}U concentration in U in the loaded enriched product is approximately 0.85 wt %. Figure 1 displays the additional ^{235}U in U required to compensate for the presence of ^{236}U in the loaded enriched product as a function of reactor passes.

For the scenario represented in Figure 1, the ^{236}U penalty factor was determined to be 0.259 for the second reactor re-enrichment pass, and 0.247 for the third pass.

The isotope ^{232}U has no effect on the neutronic performance of a reactor because of the very low concentrations involved. However, ^{232}U is radiologically the most important of the uranium isotopes, not because of ^{232}U itself, but because of the radiological hazard of the decay daughters of ^{232}U. The current American Society for Testing and Materials (ASTM) limit for ^{232}U in reprocessed UF6 feed is 5 nanogr/grU. The calculated values for the combined feed (RU + natural feed) do not exceed this limit.

The total ^{238}Pu generation is approximately 50% higher in the RU cases than in the non-RU enrichment cases, which benefit somewhat the transmutation value of the plutonium and also provides some additional proliferation resistance.

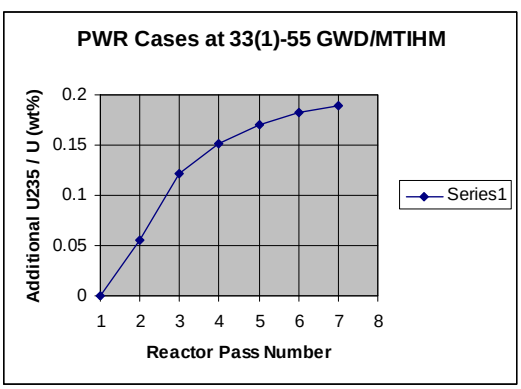

Fig. 1. Additional ^{235}U required to compensate for the ^{236}U in U of the loaded enriched product as a function of reactor passes for the combined 33,000 MWD/MTHM (reactor pass 1) and 55,000 MWD/MTHM (reactor passes 2 to 7) cases.

REFERENCES

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