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Estimation of the Spent Fuel Inventory for the DUPIC Fuel Cycle

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ABSTRACT

The spent fuel inventory was estimated for the DUPIC (Direct Use of Spent PWR Fuel in CANDU Reactors) fuel cycle using a dynamic analysis method. Through parametric calculations for the DUPIC fuel cycle deployment time and the fraction of the DUPIC fuel CANDU reactors, the environmental effect of the fuel cycle was estimated for important parameters such as the spent fuel inventory and the results were compared with those of the once-through LWR fuel cycle. The results of the parametric calculations showed that an early deployment of the DUPIC fuel cycle with a high fraction of the DUPIC fuel CANDU reactors can reduce the spent fuel inventory by up to 40%. Therefore it is expected that the implementation of the DUPIC fuel cycle will be beneficial from the viewpoint of the environmental effects.

I. Introduction

In the Generation-IV roadmap[1], the DUPIC[2,3] (Direct Use of Spent PWR Fuel in CANDU Reactors) fuel cycle is considered as one of the partial transuranic (TRU) recycling scenarios. In the DUPIC fuel cycle, the LWR spent fuel (SF) assembly is mechanically separated into two major parts: (i) the UO_2 with fission products and actinides and (ii) the structural materials. The UO_2 material with fission products and actinides is fabricated again as CANDU fuel bundles. These fuel bundles are burned in CANDU reactors and then disposed of as SF in a geological repository.

In this study, the environmental effect of the DUPIC fuel cycle was analyzed by a dynamic analysis code, DYMOND[4]. The important parameters considered in the environmental effect analysis are the amount of spent fuel, plutonium, minor actinides and fission products. Two variables were considered for the sensitivity calculations: the DUPIC fuel CANDU reactor deployment time and the reactor capacity. The fuel cycle calculations were performed under the assumption that the worldwide nuclear energy demand grows from 350 GWe in 2000 to 6000 GWe in 2100.

II. Sensitivity of the DUPIC fuel CANDU Reactor Deployment Time

II.1 Sensitivity Calculation

The LWR once-through fuel cycle scenario, used as the reference case in this study, is basically the same as that of the Generation-IV road map case. For the DUPIC scenario, it is assumed that between 2015 and 2100, CANDU reactors are built at a sufficient rate (for example, for achieving the reactor ratio of 2 PWRs and 1 CANDU reactor) so that almost all the LWR SF including the existing PWR and BWR spent fuels can be recycled into CANDU reactors from 2015. For the DUPIC fuel cycle deployment time, the sensitivity calculations were performed by changing the deployment time from 2015 to 2030 and the start of the DUPIC fuel fabrication from 2010 to 2025 accordingly, which are given in Table I.

II.2 Calculation Results

The results for the deployment time of 2015 are shown in Figs. 1 and 2. As shown in Fig. 1, the UO_2 SF inventory from the LWR will remain as a major part of the total SF and reaches a peak value around 2040. Beyond 2040, new DUPIC fuel CANDU reactors begin to consume the LWR SF at a rate greater than its production, and the pile of LWR SF starts to decrease. Gradually, the LWR SF contribution to the total SF decreases until 2052. Beyond that, the SF from the DUPIC reactors will be the major source of SF. Note that all the excess LWR SF will be consumed by 2085. Then the LWR SF will be generated at a rate similar to the recycling rate of the SF in the DUPIC reactors. In such a case, the LWR SF accumulating in the storage will be almost permanently eliminated. By 2100, the total amount of SF from the LWR and DUPIC fuel CANDU reactor will be about 2429 kt, which is ~40% less than the SF from the once-through LWR fuel cycle (4100 kt). The amount of SF uranium in 2100 is about 2310 kt, which is also ~60% of that of the once-through fuel cycle.

The reduction of the total SF waste inventory leads to reductions of the plutonium , MA and fission product (FP) inventory. The total plutonium inventory in 2100 is 24 kt, which is ~48% of that of the LWR once-through case. Compared to the once-through cycle, the MA and FP inventories are reduced to a level of 64% and 40%, respectively.

The effects of the deployment time on the SF inventory are summarized in Table III. The total SF inventory varies from 2429 kt to 2576 kt and the amount of uranium in the SF increases from 2314 kt to 2444 kt when the deployment time is delayed from 2015 to 2030. Regarding the other parameters, the plutonium inventory increases from 24.3 kt to 26.5 kt, the MA inventory from 3.96 kt to 4.13 kt, and the FP inventory from 88.2 kt to 101.4 kt.

III. Sensitivities of the DUPIC Fuel CANDU Reactor Capacity

III.1 Sensitivity Calculation

For the deployment fraction of the CANDU reactors, the sensitivity calculations were performed by assuming that the fraction of electricity generation attributed to the CANDU reactors are 33%, 30%, 25% and 22% for the time periods 2015-2020, 2020-2029, 2030-2040 and 2041-2100, respectively. The initial large CANDU reactor capacity, which is greater than the equilibrium value of 22%, was to consume the existing pile of PWR SF. The constant rate of 22% is an equilibrium fraction that is based on the PWR spent fuel discharge rate, which is one half the DUPIC fuel discharge rate. For the sensitivity of the DUPIC fuel reactor capacity, the DUPIC fuel reactor capacity was changed from 22% to 18% of the total deployed capacity after

2040. Table II shows the cases used for the sensitivity calculation of the DUPIC fuel reactor capacity.

III.2 Calculation Results

Table IV compares the calculation results for the different deployment capacities. If the DUPIC fuel CANDU reactor fraction decreases from 22% to 18%, the total SF inventory increases from 2429 kt to 2579 kt in 2100. This amount of SF is ~62% of that of the once-through cycle. The amount of uranium in the SF in 2100 is ~2310 kt, which is also ~60% of that of the once-through cycle. Under the same condition, the amounts of plutonium, MA and FP increase from 24.0 kt to 26.3 kt, 3.96 kt to 4.15 kt and 88.2 kt to 99.6 kt, respectively.

IV. Summary and Conclusion

The environmental effects of the DUPIC fuel cycle were investigated for the sensitivities of the deployment time and capacity to the amount of SF, uranium, plutonium, MA and FP. The analysis results showed that if the deployment time is delayed from 2015 to 2030, the amount of total SF increases by 130 kt and that if the deployment capacity is decreased from 22% to 18%, the amount of total SF increases by 150 kt. Consequently, an early deployment of the DUPIC fuel cycle with a high CANDU reactor fraction can reduce the SF inventory by ~40% when compared with the once-through cycle. Therefore, a favorable environmental effect is expected when implementing the DUPIC fuel cycle.

REFERENCES

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Table I DUPIC Deployment Time

Case	DUPIC deployment time	DUPIC fuel fabrication time
1	2015	2010
2	2020	2015
3	2025	2020
4	2030	2025

Table II DUPIC Fuel Reactor Capacity (%)

Year	Case 1	Case 2	Case 3
2015 - 2019	33	33	33
2020 - 2029	30	30	30
2030 - 2044	25	25	25
2045 - 2100	22	20	18

Table III. Comparison of Spent Fuel Accumulation (kt) for Different DUPIC Reactor Deployment Time

Spent fuel	LWR once-through fuel cycle	DUPIC reactor deployment time			
		2015	2020	2025	2030
LWR spent fuel	4147.2	6.7	118.5	245.9	521.5
DUPIC spent fuel	0.0	2422.7	2317.9	2197.3	2054.4
Uranium	3877.6	2313.2	2318.0	2322.2	2443.9
Fission products	213.6	88.2	90.2	92.4	101.3
Plutonium + Minor Actinides	56.0	28.0	28.3	28.6	30.7
Total spent fuel	4147.2	2429.4	2436.4	2443.2	2575.9

Table IV. Comparison of Spent Fuel Accumulation (kt) for Different DUPIC Fuel Reactor Fractions

Spent fuel	LWR once-through fuel cycle	DUPIC reactor fraction		
		22%	20%	18%
LWR spent fuel	4147.2	6.7	203.5	396.2
DUPIC spent fuel	0.0	2422.7	2302.4	2183.2
Uranium	3877.6	2313.2	2382.7	2449.4
Fission products	213.6	88.2	94.0	99.6
Plutonium + Minor Actinides	56.0	28.0	29.2	30.4
Total spent fuel	4147.2	2429.4	2505.9	2579.4

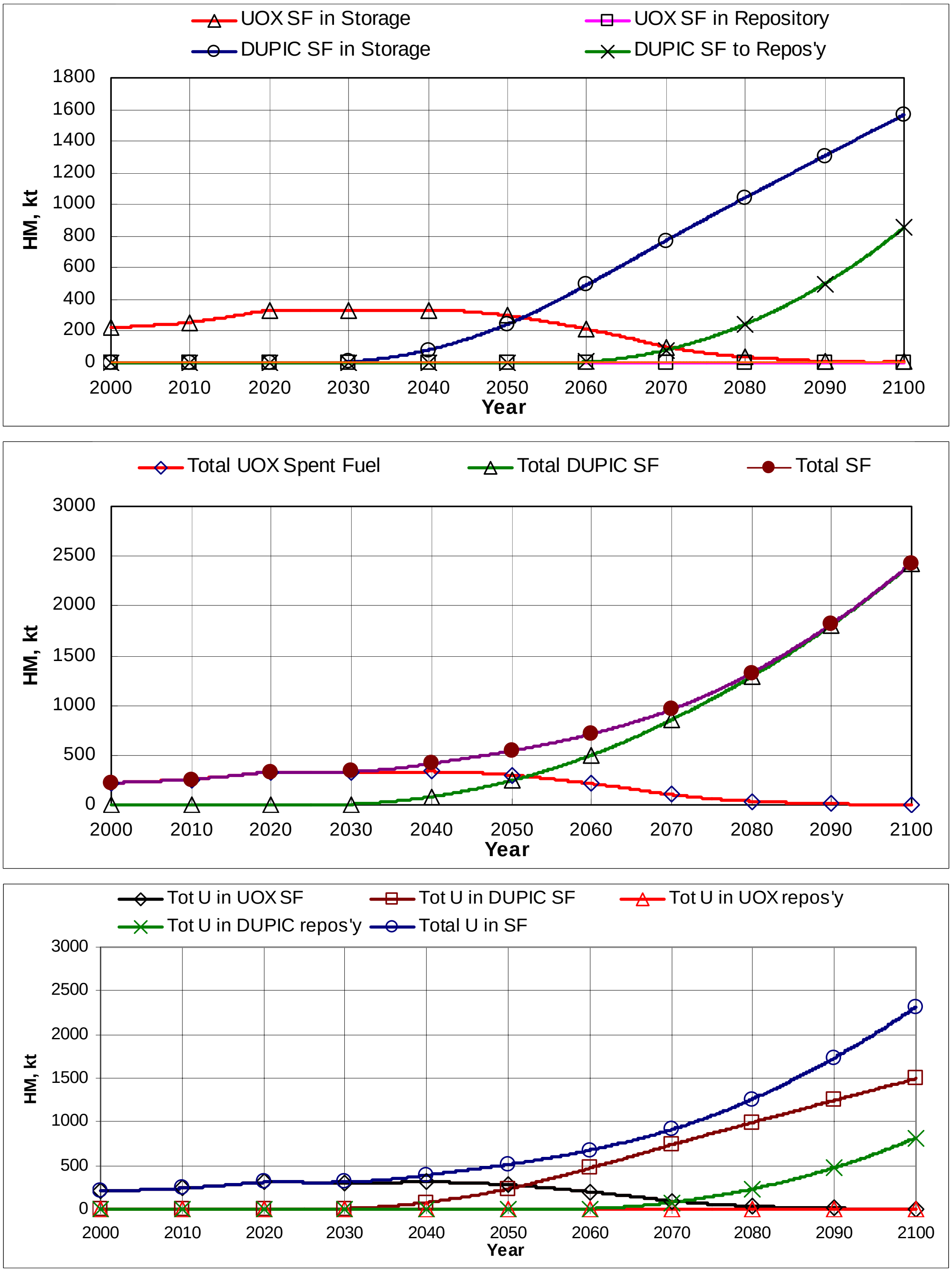

Fig. 1 (a) Amount of Heavy Elements with Deployment Time of 2015

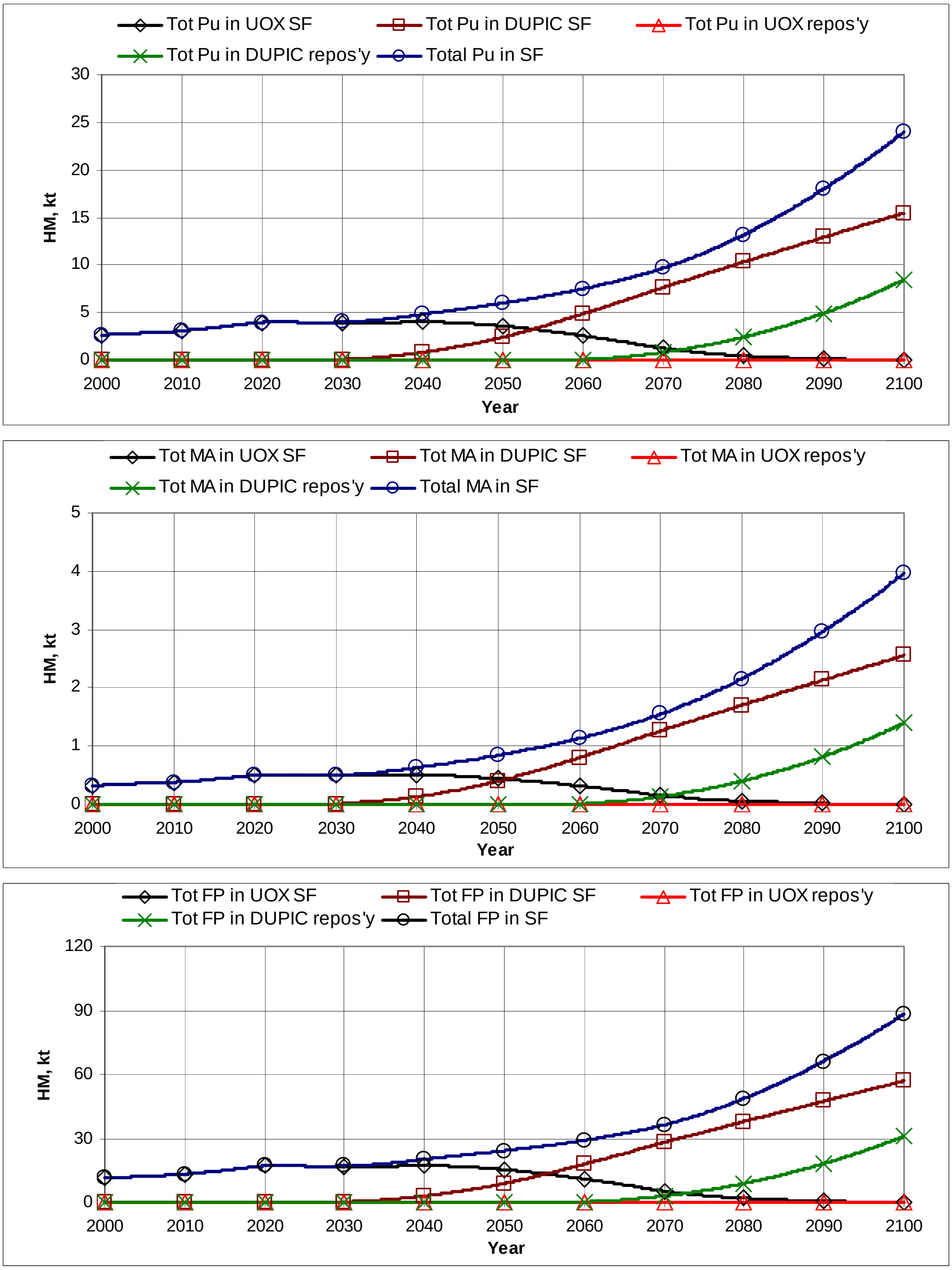

Fig. 1(b) Amount of Heavy Elements with Deployment Time of 2015