# A Preliminary Study on the Reuse of the Recovered Uranium from the Spent CANDU Fuel Using Pyroprocessing

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## 1. Introduction

During the pyroprocessing[1], most of the uranium is gathered in metallic form around a solid cathode during an electro-refining process, which is composed of about 94 weight percent of the spent fuel. In the previous study, a feasibility study has been done to reuse the recovered uranium for the CANDU reactor fuel following the traditional DUPIC (direct use of spent pressurized water reactor fuel into CANDU reactor) fuel fabrication process.[2] However, the weight percent of U-235 in the recovered uranium is about 1 wt% and it is sufficiently re-utilized in a heavy water reactor which uses a natural uranium fuel. The reuse of recovered uranium will bring not only a huge economic profit and saving of uranium resources but also an alleviation of the burden on the management and the disposal of the spent fuel. The research on recycling of recovered uranium was carried out 10 years ago and most of the recovered uranium was assumed to be imported from abroad at that time.[3] The preliminary results showed there is the sufficient possibility to recycle recovered uranium in terms of a reactor's characteristics as well as the fuel performance.[4] However, the spent CANDU fuel is another issue in the storage and disposal problem. At present, most countries are considering that the spent CANDU fuel is disposed directly due to the low enrichment (~0.5 wt%) of the discharge fissile content and lots of fission products. If mixing the spent CANDU fuel and the spent PWR fuel, the estimated uranium fissile enrichment will be about 0.6 wt% ~ 1.0 wt% depending on the mixing ratio, which is sufficiently reusable in a CANDU reactor. Therefore, this paper deals with a feasibility study on the recovered uranium of the mixed spent fuel from the pyroprocessing. With the various mixing ratios between the PWR spent fuel and the CANDU spent fuel, a reactor characteristics including the safety parameters of the CANDU reactor was evaluated.

## 2. Methods and Results

In this research, the WIMS_AECL code[5] was used to estimate the discharge burnup and safety parameters when loaded in a CANDU reactor. The bundle for the lattice calculation is a CANFLEX[3] which contains 43 fuel rods and have a different radii between the inner and outer rods. The uranium enrichment varies as 1.04 wt%, 0.63 wt%, 0.76 wt%, and 0.83 wt% depending on the mixing ratios of the spent fuel of 1:0, 1:1, 2:1, and 3:1 for the spent PWR fuel and the spent CANDU fuel, respectively. It was assumed that any impurities do not exist in the recovered uranium from the pyroprocessing for simplicity. Discharge burnup, relative ring power, plutonium change, and fissile content change are evaluated from the lattice calculation. As the safety parameter in the CANDU reactor, fuel temperature coefficient, moderator temperature coefficient, coolant temperature coefficient, and void coefficient are considered in this study. The results are also compared with that of the natural uranium loaded CANDU reactor. The spent PWR fuel composition was adopted from the standard DUPIC fuel which has irradiated 30 GWD/tU with 3.0 wt% uranium enrichment and 20 years cooling.

From the simulation, the recovered uranium fuel from the mixed spent fuel provides quite different behaviors depending on the mixing ratio which is related with the initial uranium enrichment. The discharge burnup of the recovered uranium from the spent PWR fuel only (mixing ratio = 1:0 for PWR and CANDU) was estimated as about 18 GWD/tU. When mixing the CANDU spent fuel which has a low uranium enrichment, the discharge burnup were estimated as 6.1 GWD/tU, 9.4 GWD/tU, and 12 GWD/tU for the ratios of 1:1, 2:1, and 3:1 for the spent PWR fuel and the spent CANDU fuel, respectively. Considering the discharge burnup of the typical CANDU reactor with natural uranium, 7.1 GWD/tU, more the spent PWR fuel is added than the spent CANDU fuel. In particular, the discharge burnup of the mixed spent fuel with the mixing ratio of 2:1 for the PWR and the CANDU fuel was 32% higher than the typical CANDU reactor. The obtained relative ring powers for the various cases were almost flattened between 0.88 to 1.09 at the equilibrium state. The fuel temperature coefficient of the mixing ratio of 1:0 exhibited -8.6 μk/K, 0.4 μk/K, and 11.4 μk/K for the charge, equilibrium, and the discharge states, respectively. For the mixing ration of 2:1, the fuel temperature coefficient exhibited -10.2 μk/K, 0.0 μk/K, and 5.3 μk/K for the charge, equilibrium, and the discharge states, respectively. And at the discharge state of the mixing ratio of 1:0, the moderator and coolant temperature coefficients were estimated as 162.9 μk/K and 94.9 μk/K, respectively, whereas those of the typical CANDU reactor were 82.6 μk/K and 70.9 μk/K. However, the mixing ratio of 1:0 at the discharge state showed the moderator temperature coefficient of 96.6 μk/K and the coolant temperature coefficient of 77.2 μk/K. It shows that the temperature coefficient of various recovered uranium for the mixed spent fuel does not reveal a significantly different behavior compared to that of the normal CANDU fuel. Furthermore, considering the unit of temperature coefficient, 1E-06 k/K, most temperature coefficients are nearly zero, which means that they have a negligible effect on the safety of the reactor as a temperature variation. However, the void coefficients of the recovered uranium with a mixing ratio of 1:0 were calculated as 14.4 mk, 15.6 mk, and 15.0 mk for the charge, equilibrium, and discharge states, respectively. And the other cases showed that the positive void coefficient around 15 mk ~ 19 mk and this positive void coefficient is one of the inherent problems of the CANDU reactor. The void coefficient of the recovered uranium from the various mixing ratios showed a similar trend to that of the natural uranium and DUPIC fuels.

## 3. Conclusions

It is concluded that it is to be expected that when the recovered uranium from the pyroprocess mixed with the spent PWR fuel, and the spent CANDU fuel is loaded in the CANDU reactor, the reactor characteristics provided similar behavior compared to a typical CANDU reactor and more spent PWR fuel ratio is needed to obtain an extended discharge burnup. A further investigation will be performed for the whole core calculation for the CANDU reactor with the mixed spent fuels.

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Table I. Results of Lattice Calculations for the Mixed Spent Fuel in a CANDU Reactor

| Fuel type | Recovered Uranium with Mixed Spent Fuel | | | | NU |
|---|---|---|---|---|---|
| Mixing Ratio (PWR:CANDU) | 1:0 | 1:1 | 2:1 | 3:1 | |
| Burnup (MWD/tHM) | 18,100 | 6,100 | 9,400 | 12,000 | 7,100 |
| Relative ring power at equilibrium state | 1.09,1.13<br>0.88,1.04 | 1.05,1.10<br>0.88,1.05 | 1.04,1.09<br>0.88,1.05 | 1.06,1.10<br>0.87,1.05 | 1.03,1.08<br>0.86,1.05 |
| Pu (kg/bundle) (charge,discharge) | 0.0/0.10 | 0.0/0.06 | 0.0/0.09 | 0.0/0.10 | 0.0/0.07 |
| Fissile (wt%) (charge,discharge) | 1.04/0.41 | 0.63/0.48 | 0.76/0.48 | 0.83/0.46 | 0.71/0.50 |
| Fuel temperature coefficient(μk/K) | -8.6/0.4/11.4 | -11.8/1.5/5.0 | -10.2/0.0/5.3 | -9.7/0.1/6.9 | -10.9/0.3/4.5 |
| Moderator temperature coefficient(μk/K) | -46.1/44.0/162.9 | -61.5/47.3/86.7 | -57.6/35.2/96.6 | -54.7/38.2/116.1 | -56.1/35.0/82.6 |
| Coolant temperature coefficient(μk/K) | 29.8/61.1/94.9 | 36.0/61.8/72.8 | 34.5/60.0/77.2 | 33.7/60.7/83.2 | 33.5/57.5/70.9 |
| Void coefficient (mk) | 14.4/15.6/15.0 | 19.3/15.0/14.8 | 17.4/15.8/16.0 | 16.6/16.0/16.2 | 17.8/15.0/14.9 |