Safety Parameters for the Recycled Uranium Loaded into a CANDU Reactor

Chang Je Park, Kweon Ho Kang, Sang Ho Na, Young Hee Kim, Ho Jin Ryu, Geun Il Park and Kee Chan Song
Korea Atomic Energy Research Institute, P.O. Box 105, Yuseong, Daejeon, Korea, 305-600
cjpark@kaeri.re.kr

1. Introduction

In order to recover uranium and TRU from spent nuclear fuels, a pyroprocessing has been developed through a dry and metallurgical reprocess technology using a series of electrolyses such as an electro-reduction, an electro-refining, and an electro-winning.[1] When the spent fuel is being fed into the pyroprocess, most of the uranium is gathered in metallic form around a solid cathode during an electro-refining process. It is expected that the recovered uranium will be sent to a spent fuel storage site after converting it into a metal ingot form to reduce its storage space and transportation burden. However, the weight percent of U-235 in the recovered uranium is about 0.9 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 economical profit and save of uranium resources but also an alleviation of burden on the management and disposal of the spent fuel. A previous research on recycling of recovered uranium was carried out and most of the recovered uranium was assumed to be imported from abroad at that time.[2] The preliminary results showed there is a sufficient possibility to recycle recovered uranium in terms of a reactor's characteristics as well as the fuel performance. And the DUPIC (direct use of spent pressurized water reactor fuel into CANDU reactor) program has also been performed and demonstrated the fundamental technologies.[3] The recovered uranium from a pyroprocess contains some TRU as an impurity and it will exhibit a slightly different behavior from the previous recycling options.[4] In this paper, the reactor's characteristics including safety parameters are investigated based on the lattice calculations which are performed for the CANFELX bundle.

2. Method and results

The recovered uranium and TRU inventories were estimated from the ORIGEN-ARP calculation,[4] The initial enrichment was assumed as 3.0 wt% and the discharge burnup was set at 30 GWD/tHM, and the cooling period was taken as 10 years. Total 27 of neutron groups and 18 gamma groups were used for the depletion calculation. Based on the inventories obtained from the ORIGEN-ARP, a simple lattice calculation was performed with the WIMS code[5] for the CANDU reactor. The lattice geometry of the CANFLEX bundle which contains 43 rods was taken into consideration for the lattice calculation and several reactor characteristics data was obtained including the discharge burnup and the effective multiplication factor, and the relative bundle peak power. The discharge burnup was estimated based on a previous work which modified the thermal cross section of a reactivity device.[6] Some safety parameters were obtained using the perturbation options. Sensitivity tests were also performed for the composition of the TRU in the recovered uranium in the pyroprocess. The target of the uranium recovery rate in the pyroprocessing technology is about 99.9% and 0.05% TRU and 0.05% FP still remains as an impurity. Thus in this study, the weights of TRU and FP vary from 0.0% to 0.05%.

3. Conclusion

Table I shows the results of the lattice calculation and shielding analysis based on reference recovered uranium inventories. The discharge burnup of the recovered uranium was estimated at about two times higher than a conventional CANDU reactor. However the relative bundle power exhibited a similar behavior. The effect of fission product as an impurity in the recovered uranium is insignificant in view of the reactor characteristics due to its small contents, but it has a big effect on the radioactivity and it may need an additional shielding wall in the case of the existence of some fission products. Fig. 1 shows the safety parameters for the various cases including moderator temperature coefficient, fuel temperature coefficient, coolant temperature coefficient, and void reactivity. The results show that all parameters increase as an irradiation proceeds. However, considering the unit of the parameters, μk/K, the variation does not have a significant effect on the reactor states. But, the void reactivity is still positive throughout the irradiation period. At the beginning of cycle, the RU+TRU fuel shows a similar behavior in the void reactivity to the NU fuel and the end of cycle, the RU+TRU fuel exhibits similar to the DUPIC fuel. The main difference of safety parameters results from the initial compositions of different fuels and they change the spectrum characteristics in the reactor. Form the results, the RU+TRU fuel does not show that different a behavior in the safety parameters compared with the NU and DUPIC fuels. It provides similar values of the temperature coefficients throughout the irradiation in the CANDU reactor. In the near future, the whole core analysis will be performed using RU+TRU fuel for the CANDU reactor.

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REFERENCES

[1] J.J. Laidler, J.E. Battles, W.E. Miller, J.P. Ackerman, and E.L. Carls, "Development of Pyroprocessing Technology," Prog. in Nucl. Energy, 31 131-140 (1997).

[2] H.C. Suk, "Current Status and Future Prospect of CANDU Fuel Research and Development in Korea," 7th International Conference on CANDU Fuel, 2001.9.23-27, Canada (2001).

[3] M.S. Yang, H. Choi, C.J. Jeong, K.C. Song, "The Status and Prospect of DUPIC Fuel Technology," Nucl. Eng. Tech., 38, 359 (2006).

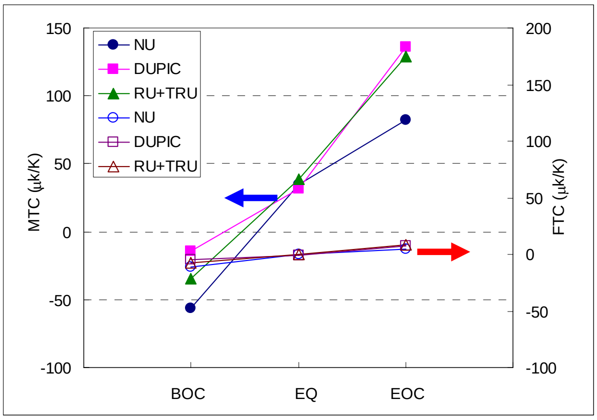
[4] C.J. Park, K.H. Kang, H.J. Ryu, G.I. Park, K.C. Song, "Feasibility Study on the Reuse of Recovered Uranium from a Pyroprocess into CANDU Reactors," American Nuclear Society Annual Meeting, 2008.6.8-12, U.S.A.(2008)

[5] I.G. Gauld, S.M. Bowman, J.E. Horwedel, and L.C. Leal, ORIGEN-ARP: Automatic Rapid Processing for Spent Fuel Depletion, Decay, and Source Term Analysis, ORNL/NUREG/CSD-2/V1/R7, 2004.

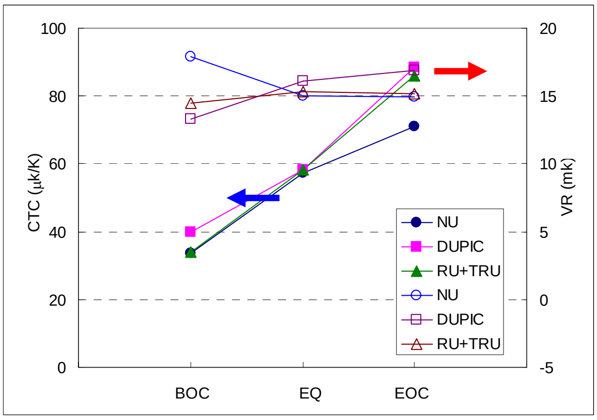
[6] J.V. Donnelly, "WIMS-CRNL: A User's Manual for the Chalk River Version of WIMS", AECL-8955, Atomic Energy of Canada Limited, 1986.

[7] H. Choi and C.J. Park, "A Physics Study on the Thorium Fuel Recycling in a CANDU Reactor by Dry Process Technology," Nuclear Technology, 153, 132 (2004).

[8] R.J. McEachern and P. Taylor, "A Review of the Oxidation of Uranium Dioxide at Temperatures below 400oC," J. Nucl. Mater., 254, 87 (1998).



(a) Moderator temperature coefficient and fuel temperature coefficient



(b) Coolant temperature coefficient and void reactivity

Fig. 1 Safety parameters for various cases.

Table I. Calculation Results for Various Cases with Recycled Uranium Loaded into a CANDU Reactor

TRU(wt%)	0	0.05	0.05	0.00	NU
Rare Earth Fission Product (wt%)	0	0	0.05	0.05	
Burnup (MWD/tHM)	12,824	14,315	13,141	11,582	7,058
Relative ring power at equilibrium state	1.05,1.10 0.88,1.05	1.05,1.10 0.88,1.04	1.04,1.10 0.88,1.05	1.04,1.09 0.88,1.05	1.03,1.09 0.88, 1.05
Pu (kg/bundle) (charge,discharge)	0.0/0.09	0.013/0.10	0.013/0.09	0.0/0.08	0.0/0.07
Fissile (wt%) (charge,discharge)	0.88/0.45	0.93/0.44	0.91/0.45	0.86/0.47	0.71/0.50
Radioactivity (Ci/bundle)	3.43E-03	8.33E+01	1.10E+02	2.62E+01	0.0
Fuel Temp. Coef. (μk/K) (charge/equilibrium/discharge)	-9.6/0.3/8.3	-7.7/0.4/9.4	-7.7/0.1/8.4	-9.7/0.0/7.2	-11/0.2/4.5
Coolant Temp. Coef. (μk/K) (charge/equilibrium/discharge)	32/60/85	33/61/88	34/58/86	32/59/81	33/57/71
Moderator Temp. Coef. (μk/K) (charge/equilibrium/discharge)	-51/40/128	-34/42/140	-34/39/129	-52/36/116	-56/35/82
Void Reactivity (mk) (charge/equilibrium/discharge)	16/15/15	14/15/15	15/15/15	16/15/15	18/15/15