Radioactivity Analysis for a Transmutation Fast Reactor, PEACER-300

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1. Introduction

One of the critical issues in the nuclear industry is how to treat the nuclear waste such that it has no significant effects on the natural environment. The nuclear waste is comprised of spent fuel from operating nuclear power plants – PWR, CANDU in Korea. It is well known that if the transuranic isotopes and long lived fission products which have small fraction in spent fuels are removed from the spent fuel destined for disposal, the toxicity of the spent fuel are dropped that of the natural uranium ore within several hundred years.

Therefore, GEN IV reactors are aimed for improvement in sustainability as well as reactor safety, reliability, proliferation resistance, economics. A university research center was formed in 2002 for Gen-IV reactor research, named as NUTRECK (Nuclear Transmutation energy Research Center of Korea) as a consortium center of three university members in Korea. As a long term option, a concept of integral system of transmutation fast reactor with collocated pyro-processing plants was proposed as PEACER (Proliferation-resistant, Environment-friendly, Accident-tolerant, Continuable-energy, and Economical Reactor) park.[1]

For 4 years, conceptual core design were modified to accept above mentioned objectives and neutronic characteristics were evaluated such as transmutation performance, proliferation-resistance and safety features.

As results of this study, it was confirmed that PEACER-300 core had good transmutation capability with support ratio of over 2.0. However, it was not confirmed that real radioactivity of spent fuels could be reduced half amount of fresh fuel by LLMA transmutation. Therefore, radioactivity of PEACER-300 was calculated and compared with different existing reactor in this paper.

2. Design Features of PEACER-300

A lead-bismuth coolant is circulating in a loop at the moderate temperature from 300°C to 400°C in order to reduce corrosion and erosion speed of core structure materials. A square lattice fuel assembly design is adopted to ensure a sufficient mass flow rate not only in normal operation but also in natural cooling under accidents. The core has fairly flat shape with 0.1 of the ratio of height to diameter. A metal fuel of (U,TRU)10%Zr is chosen because of high thermal conductivity. Cheap and small scale collocated pyro-processing is another feature of PEACER reactor complex. Recovery factors in reprocessing plant were controlled to dump low-level waste only to the repository within a level of US NRC class-C. [2]

In order to assess the performance of this core, the equilibrium cycle behavior was determined using REBUS-3 code under the parametric study results. Fuel assembly consists of 17 x 17 arrays with 2.2 of pitch to diameter ratio. Fuel cycle strategy with a cycle length of 330 days and 3 batches is adopted. As LWR feed spent fuel composition, the PWR spent fuel after 30 year cooling is used. However, following several assumptions were made for simplification of calculation procedures. Fission products were grouped into four lumped fission products by originating fissiles. In constructing the burnup chains, actinides heavier than Cm-245 and lighter than Th-232 were ignored and a few reactions which has short half-life were omitted. For equilibrium cycle, the excess reactivity was calculated by REBUS-3 and it was not exceed about 2.5% Δk at BOEC and 0.09% Δk at EOEC.

3. Radiotoxicity Evaluation

3.1 Radioactivity Change

In order to increase the transmutation rate, PEACER was designed with high TRU loading. However, it might also be increased the remained TRU amount in spent fuel even though the TRU transmutation amount can be increased. It caused the radioactivity of PEACER spent fuel to be larger than that of general SFR. That is against one of PEACER objective which is keeping the quality of waste under low level waste. To overcome disadvantage, ideal decontamination factors (DF) which have around 10 for F.P. and 10^4 for Actinide are adopted in pyroprocess.[3]

After reprocessing with these DFs, only 7.6 % of spent fuel mass was disposed and the radioactivity of unrecovered material could be reduced in inverse proportion. However, because most of actinides in discharged fuel are recycled, high radioactive recycled actinides might be a burden to radioactivity shielding in reprocessing process.

The time-dependent radioactivity changes of actinides were evaluated using the composition from reprocessing plant. The most of total radioactivity is depend on plutonium and curium isotopes. Fortunately, these isotopes are alpha particle emitter and a few percent of gamma-ray are produced in same time.

Therefore, it is expect that the sustainability of reprocessing plant can be maintained for lifetime because the radioactivity of fission products is similar to that of SFR and shielding about increased gamma-ray is considered.

3.2 Variations of Total Radioactivity

The cross-section library of ORIGEN-2 code consists of that for only commercial power plant – PWR, BWR, CANDU and LMFBR. Therefore, a new cross-section library needs for simulating accurate depletion calculation in the PEACER-300 core. From REBUS output, one group cross-sections about actinide isotopes – from thorium to curium were substituted to that of LMFBR cross-section.

Using this library, total radioactivity was calculated and compared with different reactor type. As shown figure 1, total activity of PEACER-300 fresh fuel is larger than PWR and LMFBR because larger amount of TRU was contained in PEACER fresh fuel by reprocessing process. After 3 year irradiation, total reactivity of PEACER-300 fuel was increased. However, the increased amount could be decreased in 1 month because this increased amount caused by fission products with short half-life time. The ratio of increased amount was less than that of other reactor type. It means that other reactor made total radioactivity increase by reactor operation but PEACER core had a capability to reduce total reactivity.

Table 1 showed that PEACER-300 had the smallest radiotoxicity increase with 12.5 times during 3 year irradiation time. After 100 year cooling, total radiotoxicity could be decrease up to 5.9 % of that of fresh fuel.

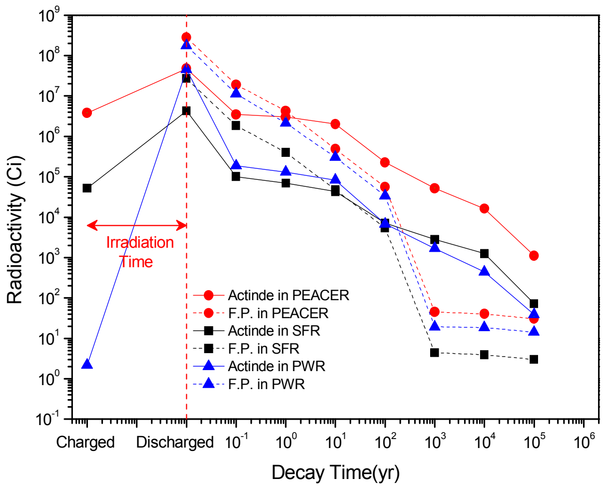

Fig. 1 Comparison of Radioactivity change

4. Conclusion

In order to confirm the decrease of radioactivity in PEACER-300 reactor, radioactivity calculations were performed by ORIGEN-2 code. For more accurate calculation, the ORIGEN-2 library was modified about actinide isotopes by REBUS output. The radioactivity of PEACER-300 spent fuels was dominant with plutonium and curium amount. By transmuting of TRU materials, the radioactivity of PEACER spent fuel could be reduced in a month decay time.

Acknowledgement

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Table 1. Radiotoxicity Variation

	Increase ratio (EOC / BOC) (Times)	Decrease ratio (100 yr / Initial) (Times)
PWR	2.09×10^7	3.08×10^3
SFR	83.1	0.1375
PEACER	12.5	0.0599