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Preliminary assessment on the back end fuel cycle in PEACER

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Abstract

Preliminary assessment on the back end fuel cycle, in PEACER (Proliferation-resistant Environmental-friendly Accident-tolerant Continuable and Economical Reactor) that was designated as a new transmutation concept, was performed. Recovery system of uranium and TRU for PEACER is based on pyroprocessing. The result of actinide wastes analysis shows that the dominant radiotoxicity contributors are ^{238}Pu up to a few hundred years. In the assessment of long-lived fission products (LLFP) wastes, initially ^{90}Sr and ^{137}Cs are dominant contributor nuclides until 30 years and especially ^{90}Sr and ^{137}Cs have the highest activity and decay heat than other LLFP. In this study, recovery of ^{90}Sr and ^{137}Cs is recommended for reducing of wastes loading.

1. Introduction

The long-term hazard of radioactive wastes arising from nuclear energy production is a matter of continued discussion and public concern in many countries. By the use of partitioning and transmutation of the actinides and some of the long-lived fission products (LLFP), the radiotoxicity of the high-level waste and, possibly, the safety requirements for its geologic disposal can be reduced compared with the current once-through fuel cycle.

In Korea, KAERI is setting up a long-term research program called HYPER (Hybrid Power Extraction Reactor) and also SNU (Seoul National University) proposed a new transmutation concept designated as PEACER (Proliferation-resistant Environmental-friendly Accident-tolerant Continuable and Economical Reactor). Both of them include the concept of pyroprocess-based partitioning system and lead-bismuth cooled

transmutation reactor.

In this paper, it was preliminarily studied on the back end fuel cycle in PEACER and analyzed total wastes from pyroprocessing in PEACER.

2. Back end fuel cycle in PEACER

On the PEACER conceptual design, it is aimed to convert all the final waste into the class of low-level waste and it is also required to transmute two important fission products Tc-99 and I-129. Figure 1 shows the simplified flow sheet of back end fuel cycle in PEACER. A reference pyrochemical process for PEACER is based on LiCl-KCl molten salt and liquid cadmium cathode. LiCl-KCl based pyroprocess has been developed at ANL and recently has been redesigned for ATW system. LiCl-KCl based process has been also developed at CRIEPI. Key processes of Pyrochemical partitioning process are electrolysis process for TRU recovery that is electrorefining or electrowinning and salt purification including reductive extraction process for waste treatment Decontamination of TRU in LLW is subject to the combination of electrolysis and reductive extraction process. Decontamination factor (DF) is introduced for indication of process performance. Overall DF in pyrochemical partitioning is defined as the ratio of mass of TRU loaded into the process to TRU lost into waste stream expressed as follows;

$$DF_t = \frac{\text{The loaded TRU into pyrochemical process}}{\text{The lost TRU into waste stream}}$$

DF_t is a function of TRU loss fractions in electrorefining process and reductive extraction process. Asymptotically, DF_t is expressed as a reciprocal of a product of TRU loss fractions in electrorefining process and in reductive extraction process. In early study, PEACER pyroprocessing system that has 10^5 of DF_t was conceptually designed.

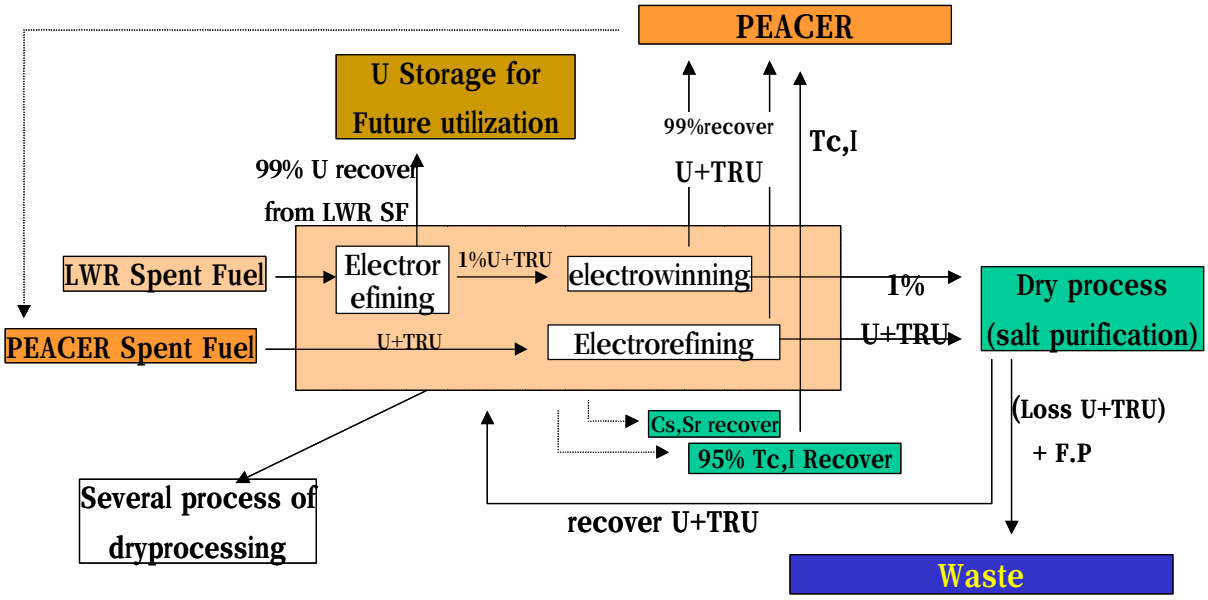

Figure 1. Flow sheet of back end fuel cycle in PEACER

3. Actinide waste production

In order to evaluate the produced total wastes from pyroprocessing, we assumed that LWR has 1 GWe capacity, 40 years lifetime with spent fuels discharged at 33,000 MWD/MTU burnup and 30 years cooling time. And as it can see Figure 1, by the PEACER pyrochemical partitioning process, about 99% of uranium in the spent LWR fuel is recovered and stored in the metallic form for the future utilization. The nuclide inventory of LWR was obtained by ORIGEN2 code. And the actinide mass in case of PEACER is analyzed in equilibrium state by REBUS code. Table 1 shows total actinide waste production from pyroprocessing when the value of DF=10^3 was applied instead of DF=10^5 of PEACER conceptual designed.

Important features of this balance are illustrated in Figure 2. The unique features of the reactor appear, again, in the isotopic composition presented in Figure 3. The plutonium vector is strongly dominated by ^{239}Pu except ^{238}U. Therefore the small abundance of higher plutonium isotopes in the fuel explains the low minor actinide content of the waste.

Table 1. Total produced actinide waste from pyroprocessing in the case of DF=10^3

Nuclide	LWR[g/TWhe]	PEACER[g/TWhe]	TOTAL[g/TWhe]
U234	0.01	0.03	0.04
U235	0.25	0.59	0.84
U236	0.12	0	0.12
U238	29.39	635.45	664.84
NP237	1.47	9.17	10.64
PU238	0.35	9	9.35
PU239	15.7	124.28	139.98
PU240	7.21	115.56	122.77
PU241	0.88	24.88	25.76
PU242	1.41	27.67	29.08
AM241	2.93	1.31	4.24
AM243	0.27	11.64	11.91
CM244	0.02	4.81	4.83
U	29.77	636.07	665.84
Pu	25.55	301.39	326.94
Np	1.47	9.17	10.64
Am	3.2	12.95	16.15
Cm	0.02	4.81	4.83
TRU	30.24	328.32	358.56
HM	60.01	964.39	1024.4

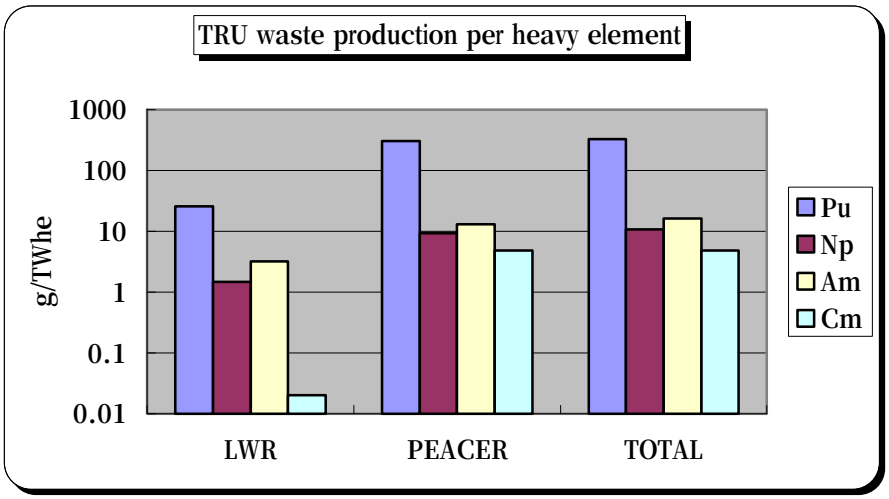

Figure 2. TRU waste production per heavy element

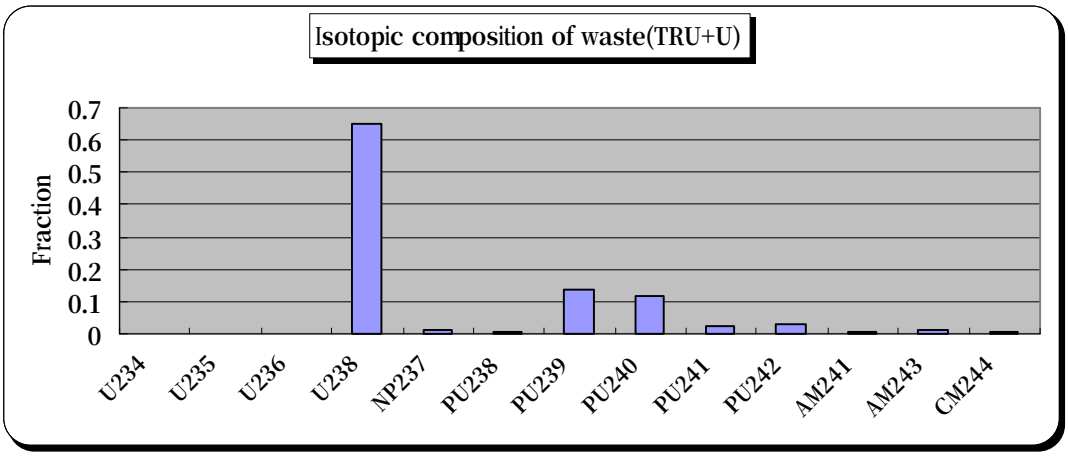

Figure 3. Isotopic composition of actinide waste

To understand the strategy-dependent trends in the time evolution of the radiotoxicity, decomposition into nuclide contributions is necessary. Figure 4 shows that the dominant radiotoxicity contributors are ^{238}Pu up to a few hundred year, ^{240}Pu and ^{239}Pu in the range 10^3 to 10^5 years, and ^{226}Ra(including daughter products) in the range 10^5 to 10^6 years. The latter is predominantly produced by the decay of ^{238}Pu. As this applies to all transmutation schemes, one can expect the trends to be correlated with the ^{238}Pu-to ^{239}Pu ratio of the fuel. An inspection of the plutonium isotopic composition of the fuels confirms the existence of such a correlation.

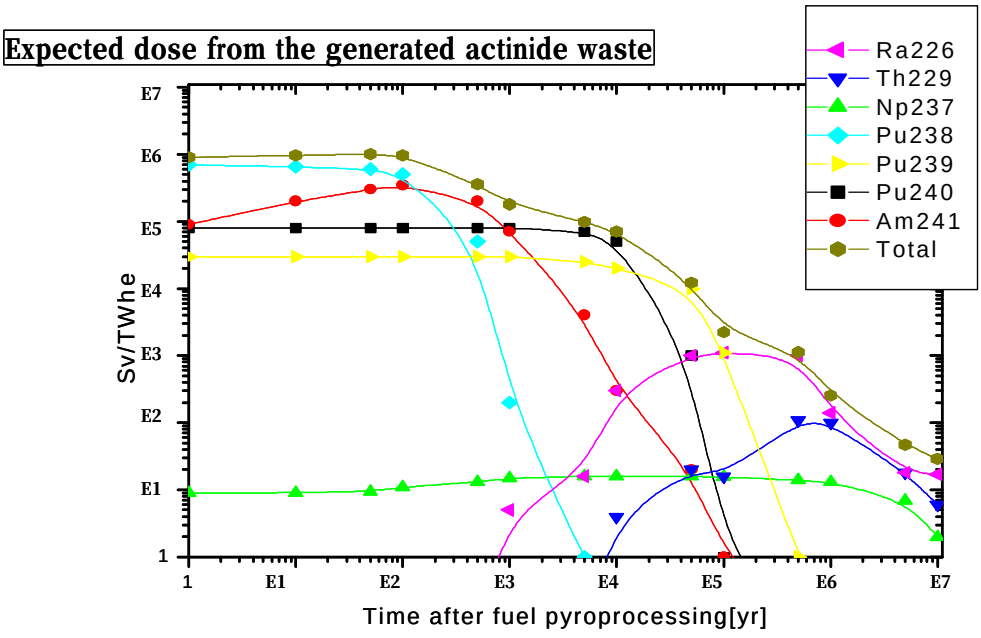

Figure 4. Expected dose from the generated actinide waste

4. Waste production of long-lived fission products

Table 2 shows that the total waste production of long-lived fission products (LLFP) that are generated from 20 LWR's with total electricity of 800 Gwe-yr. It was also obtained by ORIGEN2 code. To improve repository performance, ^{99}Tc and ^{129}I need to be separated from waste stream and to be transmuted to stable nuclides. According to early conceptual PEACER design, these two fission products are assumed to be recovered with 95% efficiency.

Table 2. Total waste production generated from LLFP

Nuclide	Mass [g]	Activity [Ci]	Heat load [watts]
SE 79	2.05E+05	1.43E+04	3.55E+00
SR 90	9.33E+06	1.24E+09	5.13E+06
ZR 93	2.51E+07	6.30E+04	7.33E+00
TC 99	1.35E+06	2.28E+04	1.14E+01
PD107	7.62E+06	3.92E+03	2.32E-01
SN126	9.56E+05	2.71E+04	3.38E+01
I129	3.12E+05	5.51E+01	2.55E-02
CS135	1.05E+07	1.21E+04	4.02E+00
CS137	1.79E+07	1.87E+09	1.11E+06
SM151	3.79E+05	9.97E+06	1.17E+03
TOTAL	7.36E+07	3.11E+09	1.34E+07

In the sense of low-level wastes (LLW) disposal site, heat load must be one of the most important factors as much as concentrations of nuclides. IAEA has classified LLW as wastes with less than 2 kW/m^3 heat load. Figure 5 shows decay heat that was generated from each long-lived fission products. As it can see Figure 5, initially ^{90}Sr and ^{137}Cs have the highest heat load. The most important thing that was required to meet the regulation for LLW disposal is concentration of nuclides, also known as activity. Figure 6 shows the trends of activity in time evolution. Initially ^{90}Sr, ^{137}Cs and ^{151}Sm are dominant contributor nuclides until 30 years and especially ^{90}Sr and ^{137}Cs have the highest activity than other LLFPs. It will be required very large dilution volume to meet the regulation for LLW disposal site due to high activity and heat of these two nuclides if it could be wanted to dispose initially all of LLFPs in LLW disposal

site. If ^{90}Sr and ^{137}Cs are separated from waste for cooling, the dilution volume that was required to dispose in LLW disposal site will be reduced as a large amount. Therefore in this study, recovery of ^{90}Sr and ^{137}Cs as well as ^{99}Tc and ^{129}I is recommended for reducing of wastes loading.

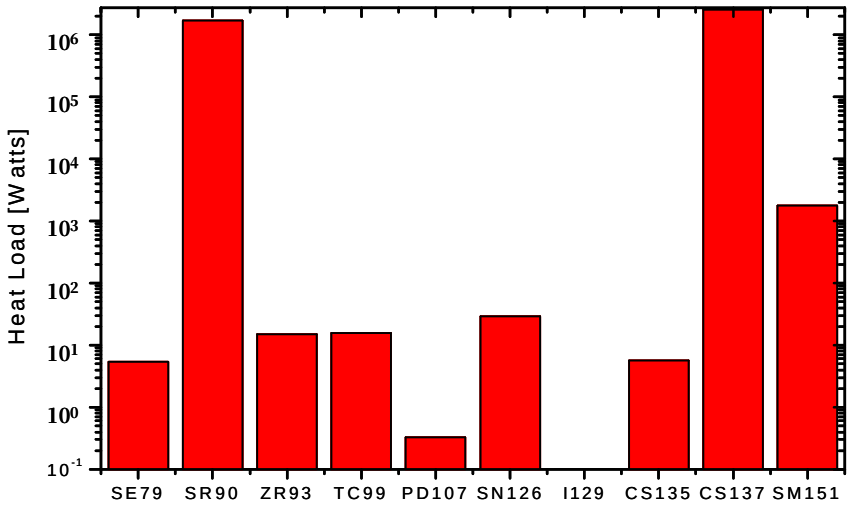

Figure 5. Decay heat generated from LLFP

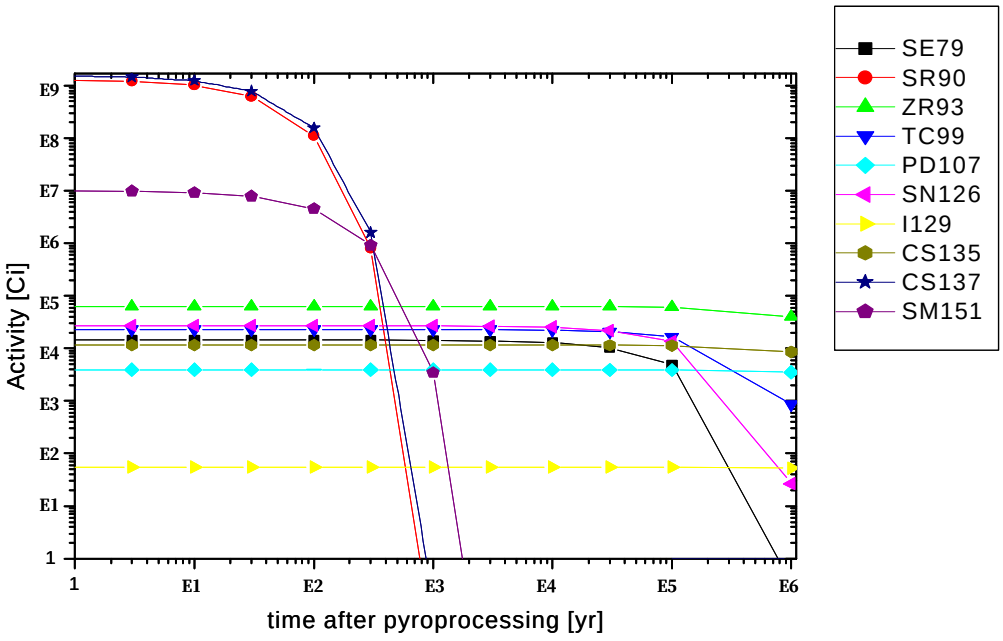

Figure 6. Activity generated from LLFP

5. Conclusion

Preliminary assessment on the back end fuel cycle, in PEACER (Proliferation-resistant Environmental-friendly Accident-tolerant Continuable and Economical Reactor) that was designated as a new transmutation concept, was performed. A reference pyrochemical process for PEACER is based on LiCl-KCl molten salt and liquid cadmium cathode. The result of actinide wastes analysis shows that the dominant radiotoxicity contributors are ^{238}Pu up to a few hundred years. In the assessment of long-lived fission products (LLFP) wastes, initially ^{90}Sr and ^{137}Cs are dominant contributor nuclides until 30 years and especially ^{90}Sr and ^{137}Cs have the highest activity and decay heat than other LLFP. If ^{90}Sr and ^{137}Cs are separated from waste for cooling, the dilution volume that was required to dispose in LLW disposal site will be reduced as a large amount. Therefore in this study, recovery of ^{90}Sr and ^{137}Cs is recommended for reducing of wastes loading.

Acknowledgement

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