Sensitivity of Transmutation Capability to Recycling Scenarios in KALIMER-600 TRU Burner

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1. Introduction

For the development of sodium-cooled fast reactor(SFR) technology, prototype KALIMER plant is now under R&D stage in Korea. For the future application of SFR for waste transmutation, KALIMER core was designed for TRU burner by KAERI.[1] Feasibility of TRU burner cannot be evaluated exactly because overall functional parameters in pyro-processing recycling process has not been verified yet. There is great possibility to accept undesirable process functions in pyro-processing. The purpose of this study is to test transmutation and design feasibility of KALIMER burner caused from many limitations in recycling options; such as low recovery factors and external feed. Design impact from many recycling options will be tested as a sensitivity to various recycling process parameters under many recycling scenarios.

2. Reference Core Design Concept

The SFR core concept in this study is based on KALIMER-600 TRU burner(KALIMER-KAERI) that is being developed by KAERI. Because of proprietary data, a new core was designed based published report.[1] Nuclear design was done with code system of TRANSX, TWODANT, REBUS-3 with KAFAX library recently modified with ENDF/B-VII. Figure 1 is the Kyung Hee University design concept (KALIMER-KHU) with minor differences with assumed detail design specifications.

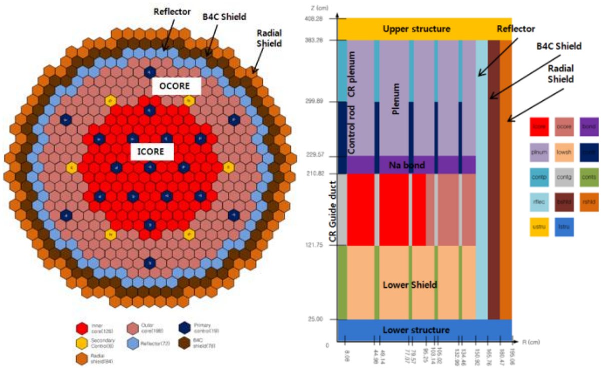

Fig.1 Radial and Axial configuration of the KALIMER-KHU

One of major differences in KALIMER-KHU are design parameters about In-Vessel Storage(IVS). IVS is excluded from the geometry for simplified analysis. Structure materials for cladding, duct, reflector and radial shield rods is assumed to be Mod. HT-9. The cycle length of the reactor is assumed to be 332 days and the number of batches at inner and outer core be 5.

3. Recycling Scenarios

Reference recycling system is shown in Fig.2. The materials, uranium, TRU and rare earth isotopes recovered from the PWR spent fuel(SF), is used as External Feed. The EF is always supplied with the others recovered from the SFR SF per each cycle to make fuels to be loaded on SFR.

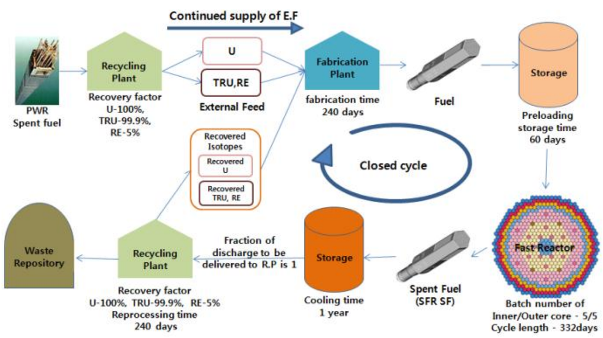

Fig.2 Reference Recycling Scenario diagram

Process time in fabrication, preloading storage and recovering materials are to be the same with KALIMER-KAERI. TRU and RE recovery factors are 99.9% and 5%. The comparison of equilibrium cycle analysis between KALIMER-KHU and KALIMER-KAERI showed reasonably low differences as shown in Table 1.

3.1 Change of External Feed Composition

The TRU, RE and U composition of EF are divided into two cases; the use of SF from PWR and CANDU.

3.2 Change of recovery factors of TRU and RE

Concerning the unsuccessful achievement in pyro-processing. Recovery factors for TRU are tested with value of 99%, 99.9%, 99.99%, 99.999% and RE's are tested from 5% to 65% at an interval of 10%.

3.3 Change of the cycle length of SFR

Extending the cycle length of SFR is able to consume more TRU nuclides and reduce them contained in the waste. And operating ratio increases if overhaul period is constant. But this scenario can get a problem that may not control the excess reactivity at BOC when the cycle length is too long.

Table.1 Performance parameters of KALIMER-KHU

Parameter	KALIMER-KAERI	KALIMER-KHU
Burnup reactivity swing (pcm)	4,002	4031
Average/peak fuel discharge burnup (MWD/kg)	139.4/219.5	141.6/192.6
Charged driver fuel enrichment (wt.%)		
Fissile Pu in U-TRU	14.40	14.13
Total Pu in U-TRU	26.14	26.62
Total TRU in U-TRU	29.42	30.80
Driver fuel enrichment (BOEC/EOEC) (TRU wt.%)	28.67/28.32	28.87/28.51
Fissile Pu inventory (BOEC/EOEC) (kg)	2213.2/2088.6	2210.2/2093.0
TRU inventory (BOEC/EOEC) (kg)	4663.9/4461.1	4730.6/4521.1
Average power density (BOEC) (W/cc)		
Inner/Outer/Total	274.4/207.0/233.2	300.7/223.5/253.5
Power peaking factors for driver fuel		
Inner/Outer/Total (BOEC)	1.20/1.69/1.50	1.28/1.77/1.56
Inner/Outer/Total (EOEC)	1.18/1.62/1.46	1.36/1.70/1.57

4. Sensitivity Test Results

4.1 Change of External Feed Composition

Material flow inside the core is checked to confirm the TRU transmutation ratio. Transmutation ratios in PWR SF feed and CANDU SF feed are 20.21% and 20.23%. But amount of transmuted Pu in CANDU case is larger than PWR case because the Pu content in TRU of CANDU SF is larger than PWR case. But the amount of transmuted TRU is larger in PWR case as shown in Fig.3.

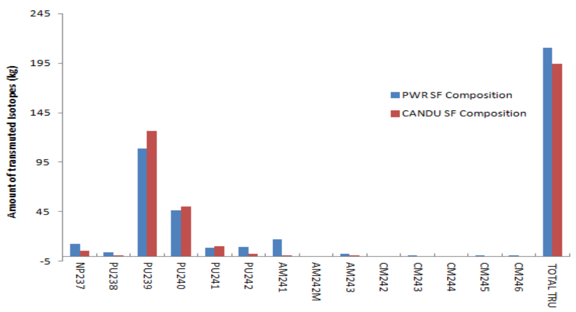

Fig.3 Amount of transmuted nuclides

The TRU support ratio in PWR's case is 1.48 and CANDU's case is 0.99. The TRU content of the waste of each case is 0.25% in PWR's and 0.16% in CANDU's and MA content in PWR's is three times larger than CANDU's.

4.2 Change of recovery factors of TRU and RE

The performance parameters are almost same due to small change in the recovery factor(RF) for TRU within 1%. But the TRU content in the waste is considerably changed once TRU RF changes from 99% to 99.9%. It is expected that the TRU content is exponentially reduced by 1 to 0.001% but actually not.

Table.2 Performance Parameters of different recovery factor for TRU

Parameters	**TRU recovery factor (%)**			
	99	**99.9**	**99.99**	**99.999**
Reactivyty swing (pcm)	**4039**	**4031**	**4030**	**4029**
Amount of TRU transmutation (kg/cycle)	**219.04**	**219.06**	**219.06**	**219.11**
TRU transmutation ratio	**20.325**	**20.296**	**20.293**	**20.294**
Charged driver fuel enrichment (TRU wt.%)	**30.752**	**30.799**	**30.804**	**30.808**
TRU feed (kg/cycle)	**228.39**	**220.68**	**219.91**	**219.87**
U feed (kg/cycle)	**309.63**	**309.66**	**309.67**	**309.62**
TRU/total waste (%)	**1.5845**	**0.2486**	**0.1476**	**0.1389**

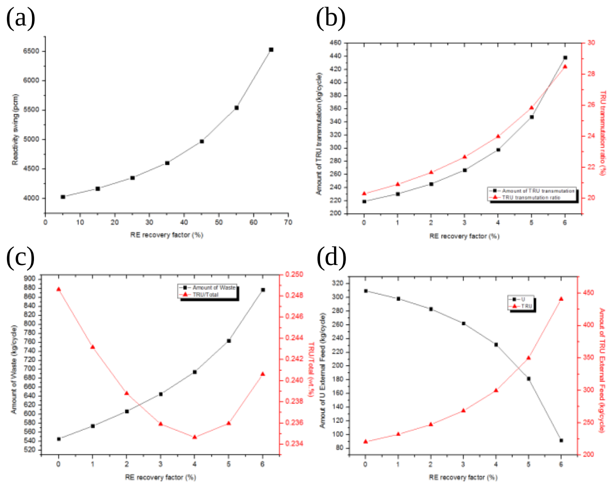

Fig.4 Change of performance parameter of different recovery factor for RE

(a) Reactivity swing(B) (B:black line, R:red line)
(b) Amoumt of TRU transmutation(B) and Transmutation ratio(R)
(c) Amount of Waste(B) and TRU content in the Waste(R)
(d) Amount of U(B) and TRU(R) External feed

RF of RE is changed from 5 to 65%. Reactivity swing increases about 2,500pcm. Therefore this scenario needs analysis on safety impact. The amount of waste is increases, but TRU content is smallest at 45% of RF. The amount of using TRU EF per each cycle also increases.

5. Conclusion

Through this study, possibilities when Pyro-processing is realized with SFR can be expected in the recycling scenarios. Only TRU nuclides composition a little differs between PWR SF and CANDU SF so first scenario has no problem operating SFR. In second scenario, the radiotoxicity of waste at 99% of TRU RF have to be confirmed whether it is proper level to reposit as Low and Intermediate Level Wastes or not. And the reactor safety at high RF of RE must be inspected. Not only third scenario but also several scenarios for good measure are being calculated and will be evaluated.

REFERENCES

[1] Y. I. Kim, Establishment of Advanced SFR Concepts, KAERI/TR-4063/2010.