# Core Design Optimization of Transmutation Fast Reactor, PEACER-300

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## 1. Introduction

Design concept of a Pb-Bi cooled transmutation fast reactor, PEACER is the maximization of the Gen-IV design goals; proliferation resistance, transmutation capability, accident-tolerance, energy & environment sustainability and economics. To satisfy above objectives, core design has been changed since 1999 when the first design of PEACER was proposed.[1] Some of design features have been fixed to maintain the characteristics of PEACER reactor. A lead-bismuth coolant is circulating in a loop at the moderate temperature from 300 $^{o}$C to 400 $^{o}$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. Core size was reduced from 50 cm high, flat pan-cake shape core to the smaller one as rated power was decreased from 1,560 MWt (850MWe) to 850 MWt (300MWe) to ensure a natural convection capability.[2]

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 USNRC class C.[3]

In this paper, results from a parametric study were summarized. The objective of design optimization is to enhance a transmutation performance. Parameters were evaluated for the core average by standard codes, REBUS-3 and MCNP-4/c2. [4, 5]

## 2. Parametric Study for Evaluation of Transmutation Performance

### *2.1 Change of Pitch to Diameter*

A neutron energy spectrum is one of the major factors to change the transmutation speed of long-lived minor actinides (LLMA). In a thermal reactor, main transmutation process is the fission of daughter isotopes which were produced by neutron capture of mother LLMA. However, direct fission reaction is a principal process in a fast reactor. In a lead-bismuth liquid metal coolant core, most probable neutron flux ranges in keV energy band.

Under the lead-bismuth coolant, Pitch to diameter ratio was adjusted to change neutron energy spectrum. To evaluate transmutation performance, an extended effective fission half-life time($T_{EX}$) which was required for reduction to a half of initial minor actinides amount by fission of themselves and their daughters was used.[6]

$$T_{EX} = \frac{\ln 2}{\sigma_f^i \phi + \sum_j f_j \sigma_c^i \frac{\sigma_f^j \phi}{\sigma_t^j \phi + \lambda} \phi + \sum_k \lambda_i^{i \to k} \frac{\sigma_f^k \phi}{\sigma_t^k \phi + \lambda}}$$

As shown figure 1, when pitch to diameter ratio is increased, namely softer spectrum, $T_{EX}$ changes of Am-241, Am-243 are insignificant. However, those of Np-237 and Cm-244 are contrary to the others and k-infinite values are deceased. It means that the growth of the transmutation performance of all LLMA isotopes is not possible at the same time. The optimized pitch to diameter was chosen to 2.2 which facilitate large coolant volume.

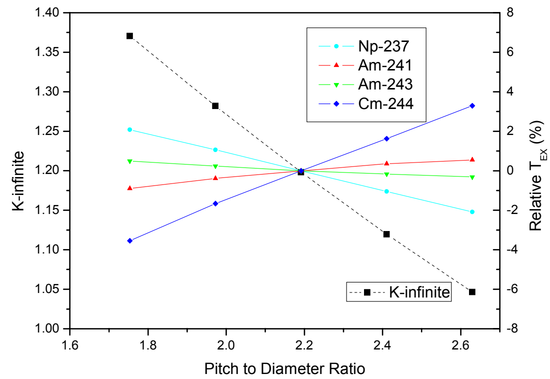


Fig. 1. Change of K-inf and relative $T_{EX}$ to P/D Ratio

### *2.2 Change of Core Shape*

Change of transmutation performance was checked by adjusting the core height under the same condition - fixed fuel composition, thermal power with same core volume, and equilibrium calculation with same cycle length.

As shown in figure 2, when core height is decreased, axial neutron leakage is increased because of flatten core shape. The conversion ratio of this core shape is decreased by decreasing capture reaction rate of fertile. Therefore, a large amount of TRU is required to the core in order to compensate criticality loss and an increase of fast flux level resulting in increased transmutation of LLMA.

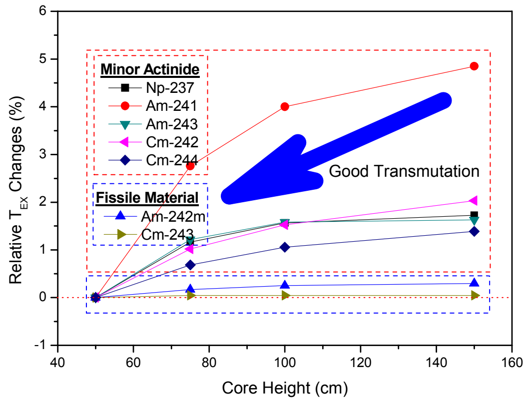


Fig. 2 Change in relative $T_{EX}$ to core height

*2.3 Change of Cycle Length and Batch*

The extension of irradiation time by cycle length and batch was considered to improve transmutation performance because HT-9 which could be endured long irradiation condition was used as cladding and the structure material of PEACER core.

As mentioned chapter 2.2, extending the irradiation time makes the opportunity and the time to spare for a direct fission step up. As shown table 1, TRU mass fraction could be increased by 30% from 1 year - 3 batch operation to 6 year - 1 batch operation in order to guarantee criticality for whole cycle length. Irradiation time limit was restricted until 6 year because high k-effective value at BOEC might not be controlled.

When the number of batch is decreased and cycle length is increased, TRU mass fraction is increased by 10 % and the value of support ratio(SR) which is one of transmutation performance index is increased by 10% proportionally. When cycle length is increased under same batch number, TRU mass fraction is increased by 15 % and the value of SR is increased by 12%. However, high k-effective value at BOEC has to be suppressed for safety and shutdown margin in order to irradiate during high burnup period.

## 3. Conclusion

In this paper the parametric studies about PEACER core were accomplished to search good transmutation performance for long-lived radiotoxic isotopes. When P/D ratio was increased, transmutation capability was increased or decreased depend on LLMA isotope respectively. Optimization point was decided at 2.2 of P/D ratio which could be compromised between different tendencies of each LLMA. When neutron leakage was increased by adopting flat core shape, it showed good transmutation performance. Finally, it was confirmed that the more irradiation time of LLMA was extended, the more transmutation performance was improved. However, even though 3 year irradiation with 1 year cycle length were adopted because of high k-effective at BOEC, PEACER core could be achieved a sufficient transmutation capability with 2.0855 of SR.

## Acknowledgement

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Table 1. Change in K-eff, $T_{EX}$ and Fuel Composition Fraction to Cycle Length and Batch

| Total Irradiation Time (yr) | Cycle Length & Batch | Support Ratio | K-effective | Fuel Composition Fraction (U / TRU / Zr) |
|---|---|---|---|---|
| 3 | 3yr x 1Batch | 2.2650 | 1.12175 | 52.9 / 37.1 / 10.0 |
| | 1.5yr x 2Batch | 2.1345 | 1.06056 | 55.0 / 35.0 / 10.0 |
| | 1yr x 3Batch | 2.0855 | 1.03993 | 55.8 / 34.2 / 10.0 |
| 4.5 | 4.5yr x 1Batch | 2.4710 | 1.18915 | 48.7 / 41.3 / 10.0 |
| | 2.25yr x 2Batch | 2.2812 | 1.09275 | 52.1 / 37.9 / 10.0 |
| | 1.5yr x 3Batch | 2.2141 | 1.06147 | 53.3 / 36.7 / 10.0 |
| 6 | 6yr x 1Batch | 2.6559 | 1.25858 | 44.2 / 45.8 / 10.0 |
| | 3yr x 2Batch | 2.4274 | 1.12733 | 48.9 / 41.1 / 10.0 |
| | 2yr x 3Batch | 2.3413 | 1.08426 | 50.5 / 39.5 / 10.0 |