Comparative Analysis on Nuclear Fuel Sustainability Aspect of FBR

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Abstract. Recycle program of spent nuclear fuel (SNF) will have some challenges in term of fuel cycle capability and its facilities as well as nuclear non-proliferation concern of special nuclear materials. A different analysis approach as a comparative study have been analyzed based on breeding ratio and heavy metal inventory ratio concepts in fast breeder reactor (FBR) type. Breeding ratio and heavy metal inventory obtain higher than unity which shows breeding gain or surplus inventory of heavy metals are obtained. Breeding ratio indicates the fuel conversion capability from conversion process of fertile materials into fissile material such as fertile materials of U-238, Pu-238, Pu-240 and fissile materials of Pu-239 and Pu-241. Inventory ratio approaches are appropriate to estimate some selected actinide as a mass inventory production such as plutonium inventory ratio which estimate the surplus mass inventory from the ratio of produced plutonium at the net of operation to the initial inventory ratio.

1. Introduction

As one of the important program to improve the reactor fuel utilization capability, fuel breeding program have been investigated in many years. Water cooled reactor technology uses uranium fuel as initial fuel to produce energy with lower fuel conversion ratio similar to high temperature reactor type [1-2]. To improve the fuel conversion capability, some modified reactor designs have been evaluated [3-4]. Recycling fuel program has some challenges to be optimized and harmonized for future nuclear fuel utilization such as a reduction factor of the environmental effects, aspect of nuclear non-proliferation and vie point of nuclear fuel sustainability incuding recycling option of minor actinide (MA) actinides. Some SNF including MA can be recycled and some converted MA into plutonium can be considered to improve the level of nuclear nonproliferation [5-13]. Many purposes to pursue recycling program such as recycling transuranic programs which have been conducted for longer reactor operation purposes and to increase high burning MA level capability and transmutation of transuranium (TRU) in light water reactor (LWR) system and fast breeder reactor (FBR) system[14-
A comparative analysis has been evaluated in the present study which is based on the breeding ratio and heavy metal inventory ratio approaches in fast breeder reactor (FBR) system.

2. Methods
Analysis of LWR fuel composition evaluation for different burnup or irradiation process and cooling time process have been investigated by adopting ORIGEN code [20]. Fast breeder reactor (FBR) core analysis was conducted by adopting a coupling codes of SLAROM, JOINT and CITATION codes based on nuclear data library of JFS-3-J-3.2R and JSFR (Japan Sodium Fast Reactor) as a basic FBR system [21-25]. As mentioned earlier that some composition of spent nuclear fuel (SNF) of LWR will be used as loaded initial fuel of FBR system.

2.1. Breeding Ratio and Heavy Metal Inventory Ratios
Sustainability Aspect of nuclear fuel in the reactors will be analyzed based on nuclear fuel breeding ratio and heavy metal inventory ratio. Fuel breeding analysis will be based on reaction rates of some fissile and fertile materials in the reactor such as uranium and plutonium fuel elements as main actinide. The equation to determine the breeding ratio is shown in Eq. 1.

\[
BR = \frac{\left( \sum_{i=1}^{n} \Sigma_{c,i} \right)}{\left( \sum_{i=1}^{n} \Sigma_{a,i} \right)}
\]  

\[ \Sigma_{c,i} : \text{Macroscopic capture cross-section of fertile material for each } i \text{ isotope} \]

\[ \Sigma_{a,i} : \text{Macroscopic absorption cross-section of fissile materials for each } i \text{ isotope} \]

Heavy metal inventory ratio is used to estimate a mass inventory balance of heavy metals in the reactor such as plutonium and minor actinide (MA). Similar to analysis of plutonium inventory ratio, MA inventory ratio evaluation have been used for future transuranic mass inventory balance of FBR cycle [26]. Heavy metal inventory analysis is used to show the flow of nuclear fuel mass form supply stage up to discharged fuel. The ratio can be used to estimate the mass inventory balance based on the discharged fuel and supply fuel inventories.

\[
IR_m = \frac{\left( \sum_{i=1}^{n} MI_{\text{isotope } m(i),\text{disc}} \right)}{\left( \sum_{i=1}^{n} MI_{\text{isotope } m(i),\text{sup}} \right)}
\]

\[ IR_m : \text{Mass Inventory Ratio of } m\text{-element} \]

\[ MI_{\text{isotope } m(i),\text{disc}} : \text{Mass Inventory of isotope } i \text{ of } m\text{-element at discharged fuel} \]

\[ MI_{\text{isotope } m(i),\text{sup}} : \text{Mass Inventory of isotope } i \text{ of } m\text{-element at supply fuel} \]

3. Results and Discussion
Some obtained results will be shown and discussed in this section including breeding ratio, and heavy metal inventory ratio during reactor operation. Fuel breeding ratio was studied to evaluate fuel conversion capability based on nuclear reaction aspect and to estimate some addition breeding gain. Spent nuclear fuels of LWR will be analyzed as initial fuels of FBR system based on LWR fuel
burnup level of 50 GWd/t and cooling time process of 30 years. Plutonium composition of SNF LWR has even mass composition of plutonium such as Pu-238 and Pu-240 are about 30% and some odd mass plutonium are about 60% from total plutonium.

Figure 1 Transuranium Inventory Ratio of MOX fuel FBR.

Figure 2 Fuel Conversion Ratio (Breeding Ratio) and Plutonium Inventory Ratio
3.1. Breeding and Heavy Metal Inventory Ratios

Obtained transuranium inventory ratio profile during reactor and fuel breeding ratio as well as plutonium inventory ratio are shown in Figures 1 and 2. Transuranium inventory ratio obtains more than unity during reactor operation as well as breeding ratio and plutonium inventory ratio. The results show that breeding gain level and heavy metal inventory gain of nuclear fuel can be estimated. The differences value of breeding gain and inventory gain are estimated because of the difference approach of achieving breeding gain. Heavy metal inventory ratio is only assuming the contribution of individual element or mixed element such as plutonium and transuranium element. Fuel breeding ratio uses main contribution materials such as uranium and plutonium as fertile and fissile materials.

![Heavy Metal Inventory Ratio](image1)

**Figure 3** Heavy Metal Inventory of Plutonium and Minor actinide (MA).

![Heavy Metal Inventory Ratio](image2)

**Figure 4** Heavy Metal Inventory Ratio of Transuranium (TRU) and Uranium

3.2. Transuranium Inventory Ratio

Heavy metal inventory ratios of FBR system for different reactor operation time are shown in Figures 3 and 4. All heavy metal element inventory ratio obtain higher than unity except uranium element which obtains less than unity. Uranium element inventory are less during reactor operation in comparing to the initial inventory ratio. It can be estimated that uranium element are reduced because of the fission reaction of U-235 and conversion process of U-238 into Pu-239 and so on. This is the
reason why uranium inventory becomes less. On the other hand, transuranium element such as plutonium and minor actinide (MA) as well as transuranium element which is based on a mixed composition of plutonium and MA are always more than unity. More production of transuranium elements are estimated during reactor operation in comparing to the initial composition. In equilibrium condition, plutonium element and transuranium element achieve higher inventory ratio than beginning of cycle (BOC) and minor actinide obtain less for equilibrium condition. This condition of MA can be estimated that during reactor operation, some Mas are converted into plutonium and it produced more plutonium by increasing the reactor operation and at the same time a reduction composition of MA is occur.

4. Conclusions
Breeding ratio and heavy metal inventory ratio approaches have been analyzed based on spent nuclear fuel of LWR as initial loaded fuel in fast breeder reactor (FBR) system. Transuranium and inventory ratio and fuel breeding ratio obtain more than unity during reactor operation. Breeding gain level and heavy metal inventory gain of nuclear fuel can be estimated. The differences value of breeding gain and inventory gain are estimated because of the difference approach of achieving breeding gain. All heavy metal element inventory ratio obtain higher than unity except uranium element which obtains less than unity because of the fission reaction of U-235 and fuel conversion process of U-238 into Pu-239 which causes uranium inventory becomes less. More production of transuranium elements are estimated during reactor operation in comparing to the initial composition. In equilibrium condition, plutonium element and transuranium element achieve higher inventory ratio than beginning of cycle (BOC) and minor actinide obtain less for equilibrium condition because of some MAs are converted into plutonium that makes a reduction composition of MA.

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