A PRELIMINARY STUDY OF A POTENTIAL FROND-END FAST REACTOR FUEL CYCLE FED BY A PEBBLE BED REACTOR'S SPENT FUEL

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ABSTRACT

A preliminary study result on searching a potential option to solve the high rate of spent fuel volume collection is provided. This study investigated the spent fuel produced by Indonesian pebble-bed reactor concept, the PeLUIt-40. The study indicated that the spent fuel inventory has potential inventories to be fed to a fast reactor system that may require a good quality of plutonium. A higher initial heavy metal loading on the PeLUIt-40 suggests more useful fedable spent fuel's actinides for the fast reactor system. This study was completed based on fuel cycle and nonproliferation perspectives.

1. INTRODUCTION

Indonesia has been attempting to develop a high-temperature pebble-bed reactor. The reactor concept is based on the HTR-10 reactor concept with an initial power's rating of 10 MWth reactor. However, an uprating of up to 40 MWth is expected to gain its economical benefits, with a codename PeLUIt-40. To simplify the required national licensing, the power is expected to be limited to a 30 MWth power level expected to provide a maximum output of 10 MWe. The reactor is intended to be deployed as a small modular reactor (SMR) deployable in remote areas with limited grids, which is a typical characteristic of an archipelago.

The reactor is designed to deploy uranium dioxide fuel enriched to 17wt% of U-235. A 5 grams of heavy metal is contained in about 7 to 8 thousands of TRISO microspheres loaded in a pebble weighing a total of about 200 grams. The pebble size is about 6 cm in diameter. This fuel design with a concept of containing graphite as moderator in the same pebble sphere results in a low power density For PeLUIt-40 with 10 MWt, the mean power density is about 2 $MW.m^{-3}$ which is about 30 times smaller than of NuScale's light water PWR. A study found that the spent fuel of a pebble bed reactor is about seven times larger than the one produced by a light water SMR [2]. At 40MWth and a burnup level of 80 GWd/MTU, the PeLUIt-40 is expected to produce a volume of spent fuel about 7.46 m^3 per year [3].

The larger volume of spent fuel produced by the PeLUIt-40 may introduce a requirement on a sufficient space to store all the used fuel, especially if a significant number of the reactor is intended to be deployed in Indonesia. Moreover, getting sufficient spaces for storing high level radioactive waste materials in the archipelago might be an issue itself. Hence, a reprocessing to retrieve the actinides for reusing, to compact the high-level radioactive wastes, and to reuse the graphite may be solutions to storage issues. The retrieved actinides may be fed to other reactor systems such as the fast reactor since a pebble reactor produces a quite high quality of plutonium in terms of its fissile inventories [1]. While a fast reactor system can also get benefits from the use of plutonium in its fuel system, the fuse of the fast reactor to the PeLUIt-40's fuel cycle may utilize the retrieved actinides in minimizing the overall risk of proliferation.

This work is intended as a preliminary study on a concept of feeding the spent fuel from the irradiated pebbles deployed to the PeLUIt-40 reactor to a fast reactor to solve the significant volume of spent fuel produced by the reactor due to its low power density. This work aims at some isotopic compositions, specifically of U-235 and plutoniums, of the PeLUIt's40 spent fuel pebbles. This work assumes that all the actinides in interest are not separated nor enriched prior to the feeding to the fast reactor system. However, this preliminary work does not cover the modeling or simulation of the fast reactor system yet.

2. METHODOLOGY

To predict the isotopic compositions of the spent fuel of PeLUIt-40, an infinite lattice modeling and simulation of pebble fuel's lattice containing 2 fuel pebbles was deployed (ref. Figure 1). The pebbles were packed in a body-centered cubic (BCC) configuration with a packing fraction of 61%, with the rest of the volume filled by helium as the working fluid. Each pebble contains heavy metal enriched to 17wt% of U-235 spreaded inside about 7,223 TRISO microspheres. The complete pebble lattice modeling parameters, which were also deployed for this study, can be found in a previous study result [1][3]

This work varies the amounts of heavy metal contained in the pebble and the burnup level to see the quality of the actinides deployable for the fast reactor's fuel. This fuel lattice's power is proportional to the one delivered by about 27,000 pebbles in PeLUIt-40's core. Hence, a full core of PeLUIt-40 may contain about 120 kg of initial heavy metal, equals to 20.4 kg of U-235. This implies that one core of PeLUIt-40 has less than one significant quantity (SQ) of LEU. The model was deployed in a Monte Carlo simulation using OpenMC ran for the fuel depletion simulations using ENDF B.VII-1 nuclear data with a maximum 50 pcm as the standard deviation for the calculated infinite neutron multiplication factor.

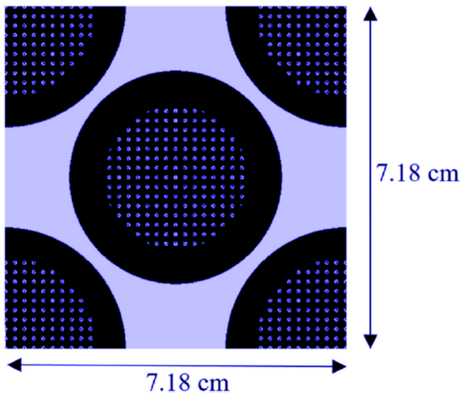

FIG. 1. Body-Centered Cubic (BCC) lattice of fuel pebbles modeled in OpenMC [3].

3. RESULTS AND DISCUSSIONS

Based on a simulation with a rated power of 10 MWth, each PeLUIt-40's spent fuel pebble with 5 g of initial heavy metal loading was calculated to have a U-235 leftover of 8.31% at a burnup level of 80 GWd/MTU achieved in 294 days. This amount of U-235 is considerably high for a spent fuel. This leftover quantity is about 50% of its initial quantity. Meanwhile the plutonium quantity produced in the spent fuel is about 0.065 g/pebble, which is about 1.25% of its initial heavy metal loading. This implies that, at this configuration, PeLUIt-40 produces only 0.18 SQ of plutonium per year. The plutonium contains 72.9% of Pu-239 and 8.2% of Pu-241 totaling the fissile plutonium of 81.1%. These indicate that the plutonium quality is significantly high to be utilized in a fast reactor system.

Important to note that this calculation was completed through an infinite lattice simulation that assumes no neutron loss allowing a maximum attainable discharged burnup level prediction. At 80 GWd/MTU, the reactor system did not imply subcriticality. The system could go with a higher burnup level. The level of 80 GWd/MTU is not based on the maximum extractable energy from the fuel. Instead, the level represents a safety limit of how long the fuel pebble may reside in the core. All the fuel configurations for the simulation performed for the study could achieve higher burnup levels.

Generally, higher burnup levels at the same rated power decreased the quantity of U-235 leftover giving a better U-235 utilization, while also increasing the total plutonium quantity. Table 1 indicates the quantities of U-235 and plutonium in the spent fuel pebble at different initial heavy metal loading, rated power, and fuel discharged burnup level. Note that the higher burnup level than 80 GWd/MTU in each case is the maximum attainable discharged burnup level for the related case. While the power uprating results positively in a higher volume of spent fuel, it does not result in any significant differences in the quantities of U-235 leftover and plutonium.

Although resulted in a less U-235 utilization, the higher initial heavy metal loading decreases the volume rate of the spent fuels. It also increases the amount of plutonium required to be deployed in the fast reactor system. Increasing the initial heavy metal loading from 5 g to 9 g decreases the volume rate of the spent fuel by about 44%. These suggest that increasing the initial heavy metal loading may provide more plutonium required by the fast reactor system while keeping the volume of the spent fuel of PeLUIt-40 at a lower rate. This can solve the spent fuel pebble storage's issue while also providing a more quantity of high quality plutonium.

TABLE 1. SPENT FUEL QUANTITIES OF PELUIT-40 PREDICTED BY MONTE CARLO SIMULATIONS

Spent fuel inventory	**10 MWt, 5 g HM**		**40 MWt, 5 g HM**		**40 MWt, 9 g HM**		**40 MWt, 13 g HM**	
	80*	**145***	**80***	**145***	**80***	**121***	**80***	**96***
U-235 per initial HM (%)	8.31%	2.99%	8.37%	3.21%	8.80%	5.83%	9.87%	8.83%
Total Pu per initial HM (%)	1.25%	1.50%	1.27%	1.53%	2.05%	2.53%	2.59%	2.94%
Spent fuel volume (m^3/yr)	1.87	1.01	7.46	3.82	4.20	2.71	2.91	2.38
* Fuel burnup with a unit in GWd/MTU								

This promising inventory, however, also introduces an increasing proliferation risk with the increasing initial heavy metal loading. With higher heavy metal loading, less reactor core of PeLUIt is required to produce 1 SQ of U-235 in LEU and plutonium (ref. Table 2). Depending on the inventory required to be inputted to the fast reactor system, the safeguards system must be in PeLUIt-40 reactors, in the reprocessing facility, as well as in the fast reactor system if the indicated number of PeLUIt-40 reactor deployed in a country equals to or exceed the number of PeLUIt-40 core required to collect 1 SQ per year.

TABLE 2. SPECIAL NUCLEAR MATERIAL COLLECTIONS FROM PELUIT-40 REACTOR CORE

Special Nuclear Material	**10 MWt, 5 g HM**		**40 MWt, 5 g HM**		**40 MWt, 9 g HM**		**40 MWt, 13 g HM**	
	1*	**n****	**1***	**n****	**1***	**n****	**1***	**n****
U-235	0.03	34	0.11	9	0.16	7	0.20	5
Pu	0.04	25	0.15	7	0.36	3	0.50	2
* significant quantity (SQ) produced by 1 reactor core per year ** number of reactor core required to collect 1 SQ per year								

4. CONCLUSIONS

This preliminary study indicated that the leftover U-235 and plutonium inventories of the PeLUIt-40 system are potential to feed a fast reactor system due to its about 80% fissile plutonium inventory and significant U-235 quantity. The reprocessing of PeLUIt-40's spent fuel shows a possibility to be a front-end cycle for the fast reactor systems. Fusing the PeLUit-40's fuel cycle to a fast reactor's fuel cycle can be beneficial to solve the high volume collection rate of PeLUIt-40's spent fuel. Deploying higher heavy metal loading to the PeLUIt-40's core may help to reduce the volume but would increase the proliferation risk due to higher leftover U-235 and plutonium inventories. However, these higher inventories might be useful for the fast reactor system By deploying the back-end of PeLUIt-40 as the front-end of a fast reactor, the proliferation risk can be mitigated although requiring a fuel reprocessing stage. With this potency, a future work will be on a modeling and simulation of a fast reactor core using the isotopic compositions fed by PeLUIt-40 to model a complete fused fuel cycle.

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