Analysis of Beryllium Poisoning Effect on the H-LPRR Core Reactivity

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1. Introduction

In general, the core of research reactors consists of the fuel assemblies, control rods, irradiation holes, moderators, and reflectors. The moderators and/or reflectors are a type of material in a reactor core that works to slow-down the fast neutrons to make them more effective in the fission chain reaction or to minimize the neutron leakage from the fuel by reflecting it. The typically-used materials for moderator and reflector include heavy water, graphite, and beryllium which is one of the lightest metals having unique nuclear properties. Because it has relatively low thermal neutron absorption cross-section (around 10^{-3} barn at 0.625eV), beryllium has been widely used as a reflector in research reactors.

However, beryllium interacted with fast neutrons in the range 0.7–20 MeV undergoes (n,α) and (n,2n) reactions resulting in subsequent formation of the isotopes lithium (Li-6), tritium (H-3) and helium (He-3 and He-4) [1]. Because of their large thermal neutron absorption cross-sections, the buildup of He-3 and Li-6 concentrations results in large negative reactivity which is called as a beryllium poisoning. In this study, the beryllium poisoning is investigated for the Hybrid-Low Power Research Reactor (H-LPRR) [2] where beryllium and graphite are used as a reflector. Using the MCNP6 code [3], the changes of criticality and by-product concentrations (H-3, He-3 and Li-6) are analyzed as a function of reactor operation time.

2. Methods and Materials

2.1 Characteristics of H-LPRR Core

The H-LPRR is an open tank-in-pool type of 50 kW thermal power, which is designed for education and training, producing medical radioisotopes, and applying the Neutron Activation Analysis (NAA). The reactor core is composed of 20 fuel assemblies and reflector blocks with irradiation holes (see **Figure 1**). The fuel assembly includes 3×3 UO_2 fuel rod array distributed on a square lattice, and their basic specifications (e.g., enrichment, radius, material, etc.) are same with ones used in OPR-1000, except for the axial length. The reactor core has two kinds of reflectors of beryllium and graphite which are designed to enable replacement with the fuel assemblies. The beryllium is used as an inner reflector, which is surrounded by an outer reflector of the graphite canned with aluminum. The beryllium and graphite reflectors are located on the grid plate to stand by themselves without any support equipment. The reactivity control is performed by four Control Absorber Rods (CARs) filled with natural B_4C, and the reactor core is cooled by natural convection. There are eight irradiation holes on the edge of the core which is classified into two types: IR (for RI production) and NA (for NAA) holes. In addition, vacant region at the center of the core is partially filled with the reactivity compensator to be made with beryllium, in order to provide additional excess reactivity.

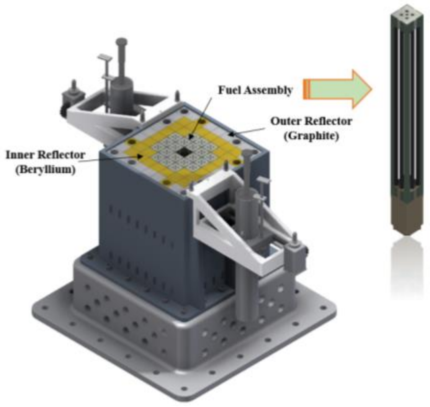


Figure 1. Conceptual Design of H-LPRR

2.2 Nuclear Reaction Between the Fast Neutron and Beryllium

During a reactor operation, beryllium suffers from many nuclear reactions with fission neutrons, and main reaction chain of interest is presented in **Figure 2**. The most significant poisons in the viewpoint of nuclear design are He-3 (σ_a=5,300 barn) and Li-6 (σ_a=940 barn) isotopes, and they are generated during not only the reactor operation but also reactor shutdown. First, He-6 isotope is produced from the nuclear reaction between beryllium and fast neutron, and after a short time ($T_{1/2}$ =0.8 sec), it is decayed to Li-6 isotope. Li-6 isotope interacts with thermal neutron to produce H-3 which suffers β decay ($T_{1/2}$ = 12.35 year) and converts to He-3 which finally interacts with thermal neutron to produce H-3 [4]. High concentrations of these isotopes result in large negative reactivity, neutron flux and power distribution changes in the core. The effect of beryllium poisoning is quantitatively analyzed for the H-LPRR equipped with beryllium and graphite reflectors, and it is estimated from the differences between the criticality calculations with and without beryllium burnup. In these calculations, MCNP6 code is applied to estimate the criticality and by-product concentrations changes, according to the reactor operation time.

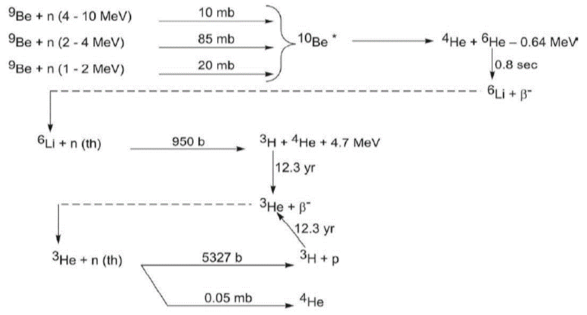
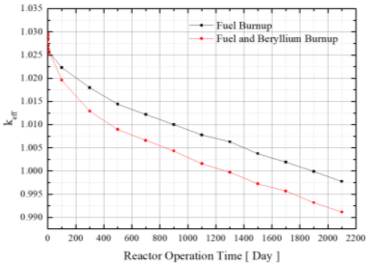


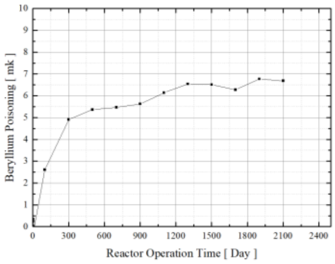
Figure 2. Beryllium (n,α) Reaction

3. Results and Discussions

Figure 3 shows beryllium poisoning effect on H-LPRR core reactivity as a function of reactor operation time. As shown in figure, the criticality considering beryllium poisoning is relatively lower than the other case, and its effect is gradually increased following the operation time. The maximum beryllium poisoning effect on core reactivity approaches about 7 mk at the end of reactor lifetime, and H-LPRR operable period is also decreased from ~1850 day to ~1250 day with consideration of full power operation in the whole day. **Figure 4** shows the concentration change of main isotopes as a function of operation time. Li-6 isotope is rapidly converged compared to others, whereas H-3 and He-3 isotopes are continually increased with the operation time. From these results, it is confirmed that the effect of beryllium poisoning influences on core reactivity for long period, which should be considered in the process of nuclear design.



(a) Criticality



(b) Beryllium Poisoning

Figure 3. Criticality and Beryllium Poisoning Changes

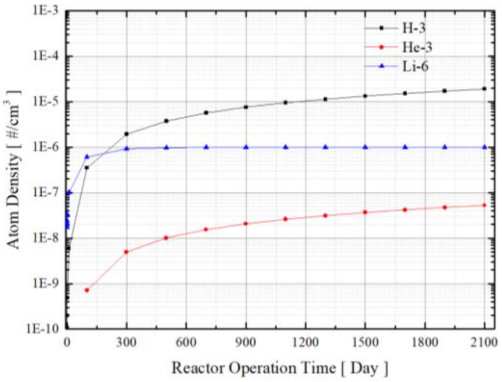


Figure 4. By-product Concentrations with the Time

4. Conclusion

Using the MCNP6 code, the effect of beryllium poisoning on core reactivity is analyzed for the H-LPRR, and the concentration change of main isotopes is investigated as a function of reactor operation time. As a result, core reactivity is maximally decreased by about 7mk for the end of reactor lifetime, and reactor operable period is also decreased from ~1850 day to ~1250 day in full power operation day. Since the most significant poisons in nuclear design point of view are gradually increased with reactor operation time, the effect of beryllium poisoning should be considered as an important negative reactivity parameter in a design of research reactor.

ACKNOWLEDGEMENTS

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