

CALCULATION OF EFFECTIVE NEUTRON MULTIPLICATION FACTOR FOR SOME MINOR ACTINIDES IN A BOILING WATER REACTOR

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ABSTRACT

In this study, using the Monte Carlo method fission reacting a boiling water reactor (BWR) was designed. The designed BWR system is divided into a square lattice of 8x8 type. Each square lattice is divided into 7x7 type small square lattice. Fuel cell in small square lattice was created from fuel rod, gap, clad zones. AmO₂ and AmF₃ minor actinides at 0.085-0.095% ratio in the fuel rod and Zr-2 in the clad region were used.

In this study, the effect of the minor actinides used on the effective neutron multiplication factor (k_{eff}) was investigated. Three-dimensional analyses were performed by using the Monte Carlo code MCNPX-2.7.0 and ENDF/B-VII.0 evaluated nuclear data library.

Keywords: Boiling Water Reactor, k_{eff}, MCNPX-2.7.0

INTRODUCTION

The boiling water reactor (BWR) used mainly for the production of electrical energy based on pressure is a kind of light water nuclear reactor. All of the nuclear reactors available today are fission reactors, and the spent fuel from these reactors includes uranium (about 95 wt%), plutonium (1 wt%), minor actinides Np, Am and Cm (0.1 wt%) and fission products. These wastes, which may have a high radiotoxicity and a good source of energy remaining from the existing reactors, are stored for future use. However, these wastes should be transformed into stable and short-lived isotopes by nuclear reactions such as fission or neutron capture. Thus, solutions will be produced for both environmental and fuel problems that will occur in the near future (Fridstrom, 2010; Loberg et al., 2010; Loberg, 2010; Zakova and Wallenius 2013).

For this reason, in this study AmO_2 and AmF_3 fuels were used to reduce the amount of minor actinides in the spent fuel remaining from existing reactors. In this study, AmO_2 and AmF_3 fuels were used in the ranges of 0.085-0.095% as fuel rod, Zr-2 were used as clad. In this study, the effect of the minor actinides AmO_2 and AmF_3 on the effective neutron multiplication factor (k_{eff}) was investigated in the designed BWR system. MCNPX-2.7.0 Monte Carlo method and the ENDF/B-VIII.0 nuclear data library was used for three-dimensional numerical calculations in the designed BWR system.

MATERIALS AND METHODS

Geometry Description

The designed BWR system is cylinder, and the radius of the cylinder is 264.08 cm. The total active core height is 365.76 cm. As seen in Figure 1, the reactor core was divided into the square lattice 8x8 type with a constant pitch of 30.48 cm. The core was surrounded with the reflector which graphite. The outboard side of reflector was surrounded by SS316LN ferritic steel with width of 5 cm.





Figure 1. The core design of the designed BWR system.

The every square lattice for the fuel rods was separated to four small square zones with a size of 13.40612 cm. As shown in Figure 2, the every small square zone was divided into the small square lattices 7x7 type with a constant pitch of 1.94084 cm.

It was put fuel pins in cylinder shape into the small square lattices. As shown in Figure 3, the fuel pins were created from the fuel rod, gap and clad. It was made the fuel rod radius 0.60579 cm and the clad radius 0.71501 cm in the fuel pins. It was made the gap with width of 0.01524 cm in between the fuel rod and the clad. In this study, it was filled by 0.085-0.095% AmO₂ and AmF₃ the fuel rod. Zircaloy-2 were used as clad in the designed BWR system.

As seen in Figure 2, the control rods used to ensure reactivity control were placed in cruciform between four small square lattices. The control rods were filled by B_4C in the designed BWR system. The absorber pins were made in cylinder shape into the cruciform. In the cruciform was used Type-304 stainless steel as structural material. H_2O was used as coolant in the designed BWR system.





Figure 2. The square lattice in the core of the designed BWR system.



Figure 3. Pin cell geometry.

Numerical Calculations

Monte Carlo method has been developed for reactor simulation and modeling, many physical problems of deterministic method, three-dimensional complex configurations of materials. MCNPX transport code from Monte Carlo method examines neutron, proton and photonuclear interactions using cross-section libraries from ENDF/B.

In this study, the three-dimensional (3-D) modelling of the reactor core and fuel assembly into the designed BWR system was performed by using the ENDF/B-VIII.0 nuclear data library and MCNPX-2.7.0 Monte Carlo method.

Effective Neutron Multiplication Factor

The effective neutron multiplication factor (k_{eff}) plays an extremely important role in determining nuclear reactor behavior. The criticality factor k_{eff} is effective in determining the contribution of nuclear reactions to neutron multiplication. k_{eff} is defined as the net increase in the number of neutrons from one generation to the next (Equation (1)). $k_{eff}=1$ is the desired critical operating mode of a reactor. If $k_{eff}<1$, the number of neutrons will decrease exponentially. If $k_{eff}>1$, the number of neutrons will increase exponentially, which will be dangerous to operate the reactor (Duderstadt and Hamilton, 1976; Ouahdani et al., 2018).

$$k_{eff} = \frac{(number of neutrons generated in the next generation)}{(number of neutrons generated in a generation)}$$
(1)



RESULTS

In this study, k_{eff} was examined for Zr-2 as clad and AmO₂ and AmF₃ as fuel rod. Figure 4 shows the k_{eff} value for 0.085-0.095% AmO₂ and AmF₃ fuel rod. The effective multiplication constant (k_{eff}) must $k_{eff} \leq 1$ in the designed BWR system to avoid the critical accident. Figure 4 shows that the k_{eff} value increases with the increase in the rates of AmO₂ and AmF₃ fuels. In particular, it seems that a reactor for 0.09-0.095% AmO₂ fuels in Zr-2 clad has reached the desired critical operating mode.



Figure 4. The k_{eff} values for Zr-2 clad, the fuel AmO₂ and AmF₃ in the BWR system.

DISCUSSION and CONCLUSIONS

In this study, a BWR system with 8x8 type square lattice is designed. Each square lattice was divided into small square lattices of 7x7 type, and 0.085-0.095% AmO₂, AmF₃ fuel rods with Zr-2 clad were placed in this small square lattice. In the study; k_{eff} were calculated for AmO₂, AmF₃ fuels and Zr-2 clad. In the designed BWR system, these neutronic calculations were made using the MCNPX-2.7.0 Monte Carlo method and ENDF/B-VIII.0 nuclear data library.

In the study, it was observed that k_{eff} value increased with the increasing rates of AmO₂ and AmF₃ fuels in Zr-2 clad. It was found that k_{eff} calculated with AmO₂ fuel were higher than AmF₃ fuel.

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