

## Neutronics Effect to Reactor Core Analysis of Molybdenum Micro-cell Type Accident Tolerance Fuel

Eun Jeong<sup>a</sup>, Yunki Jo<sup>a</sup>, Sooyoung Choi<sup>a</sup>, Hyunsuk Lee<sup>a</sup>, Ho Cheol Shin<sup>b</sup>, Kwangho Lee<sup>b</sup>, Deokjung Lee<sup>a\*</sup>

<sup>a</sup>Department of Nuclear Engineering, Ulsan National Institute of Science and Technology, 50 UNIST-gil, Ulsan 44919, Republic of Korea

<sup>b</sup>Core and Fuel Analysis Group, Korea Hydro and Nuclear Power Central Research Institute (KHNP-CRI), Daejeon, Korea

\*Corresponding author: deokjung@unist.ac.kr

### 1. Introduction

This paper presents neutronics effect to reactor core analysis of Molybdenum (Mo) micro-cell type accident tolerance fuel (ATF). In South Korea, the Korea Atomic Energy Research Institute (KAERI) has suggested and developed microcell UO<sub>2</sub> pellets with some additive materials such as Cr, Mo, and SiO<sub>2</sub>-TiO<sub>2</sub> with coated claddings for an OPR-1000 reactor, which is the Korean standard reactor [1]. Research by KAERI has shown that micro-cell UO<sub>2</sub> pellets improve the retention capability of fission products by forming a metallic film surrounding the UO<sub>2</sub> to connect the micro-cells together, which increases the thermal conductivity of the fuel pellets under normal and accident conditions [2]. The DeCART2D/MASTER two-step code system has analyzed reactor core using Mo micro-cell type fuel. From that previous study, it is noted that the core using Mo micro-cell type has a shorter cycle length as amount of 105 EPFDs than the conventional UO<sub>2</sub> core [3]. Since the cycle length reduction amount cannot be ignored when using the fuel mixed with Mo material, the analysis of the neutronics effect is performed in this paper. The fuel assembly (FA) using Mo material is analyzed by STREAM MOC codes in terms of Mo depletion chain and resonance treatment [4].

### 2. Methods and Results

#### 2.1 Analysis of Mo Cross section

This section focuses on cross sections of Mo materials. As shown in Table I, Mo exists at an approximately uniform ratio for each nuclide.

Table I: Mo nuclide fraction

Nuclide	Fraction (%)	Nuclide	Fraction (%)
<sup>92</sup> Mo	14.53 ± 0.3	<sup>97</sup> Mo	9.60 ± 0.14
<sup>94</sup> Mo	9.15 ± 0.09	<sup>98</sup> Mo	24.39 ± 0.37
<sup>95</sup> Mo	15.84 ± 0.11	<sup>100</sup> Mo	9.82 ± 0.31
<sup>96</sup> Mo	16.67 ± 0.15		

As shown in Fig. 1, <sup>95</sup>Mo has the largest absorption cross section among Mo nuclides. In Fig. 2, the absorption cross section of <sup>95</sup>Mo is compared with that of <sup>238</sup>U and <sup>10</sup>B, which are generally considered as strong absorber in commercial PWRs. As shown in this graph,

the Mo material is influential absorber. Also, it seems that the resonance region overlaps with <sup>238</sup>U, so it is necessary to deal with the effect of resonance interference correctly.

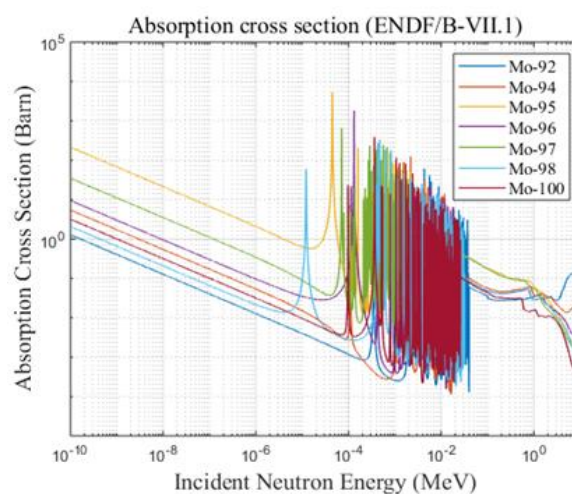


Fig. 1. Mo absorption cross section.

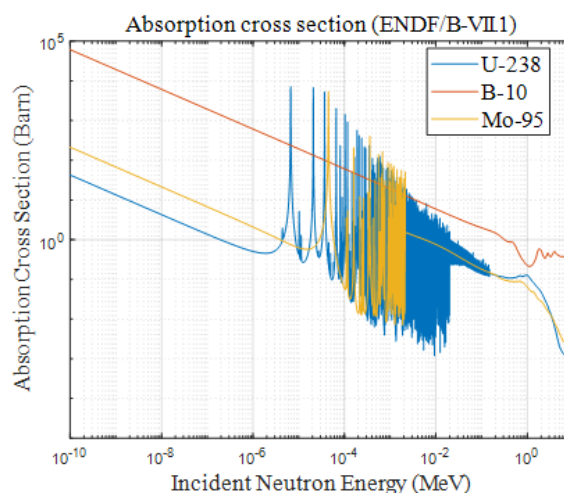


Fig. 2. Comparison of absorption cross section with main absorber in PWR.

## 2.2 Cause Estimation of Mo Micro-cell Fuel Assembly Calculation Difference

Based on the preliminary study of the difference between the conventional UO<sub>2</sub> core and core composed of the FA containing Mo micro-cell type about 105 EFPDs in the calculation of DeCART2D/MASTER code, the necessity of a more intensive and accurate ATF core especially Mo micro-cell type has been founded.

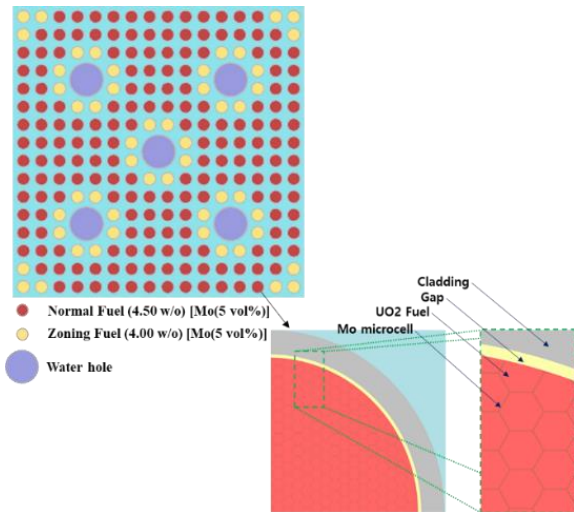


Fig. 3. PLUS7 type fuel assembly with Mo micro-cell fuel pellet.

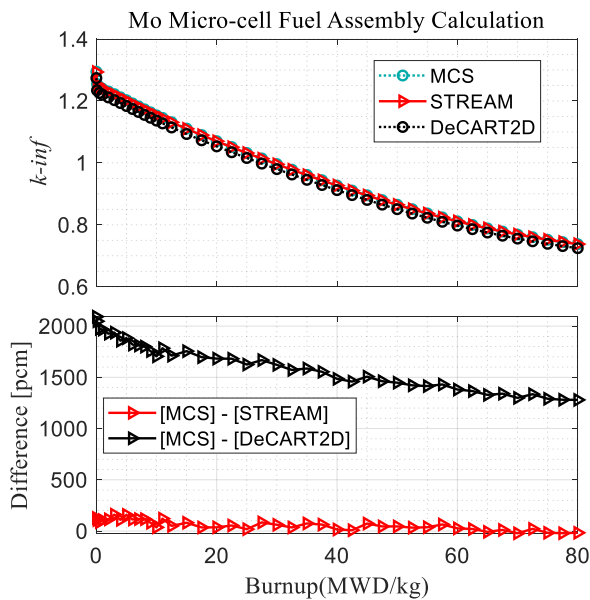


Fig. 4. Verification of Mo micro-cell fuel assembly calculation.

The micro-cell type FA added 5 vol% Mo as shown in Fig. 3 was calculated by STREAM, DeCART2D and MCS codes. The STREAM and MCS results are calculated by the ENDF/B-VII.1 cross section and

depletion libraries except for Pu-239 nuclide that from JENDL40. As options of the calculations, the doppler-broadening rejection correction (DBRC) is considered and for the depletion calculation, state of equilibrium-xenon is not considered for both codes.

As shown in Fig. 4, the PLUS7 type Mo micro-cell FA calculation results show that the DeCART2D code has about 2000 pcm difference compared to the MCS Monte-Carlo reference code [5]. From this result it was estimated that the reasons of difference are Mo depletion chain treatment and Mo resonance treatment.

In the analysis of existing general commercial PWRs, depletion and resonance treatment of Mo was not focused because Mo is not main material for the general UO<sub>2</sub> fuel PWR analysis. However, for the Mo micro-cell type fuel analysis, it should be more accurate treated. A demonstration of the estimated reasons of the reactivity difference is presented in the next section.

## 2.3 STREAM Mo Neutronics Effect Analysis

First, the effect to reactivity of the Mo resonance treatment is analyzed. Since the STREAM code uses the pin-based pointwise energy slowing-down method (PSM) for the resonance processing, the STREAM code can accurately treat the resonance interference effect of Mo and other materials especially at the absorption cross section. The STREAM code generally performs MOC calculations using 72 multi-group cross sections. In the production of these multi-group cross sections, since the PSM based resonance processing is performed, the pointwise slowing-down equation is solved as each given problem and pointwise energy flux, which is result of the pointwise slowing-down equation calculation, is used for to generate multi-group cross sections. Since this problem dependent resonance treatment, it can be relatively accurately processed as compared with the conventional resonance treatment method. A detailed description of STREAM PSM is given in the reference paper [4].

In Fig. 5, the effect of Mo to reactivity is analyzed compared to the case without such resonance treatment. In case of no PSM treatment, Mo multi-group cross sections are calculated by NJOY code with UO<sub>2</sub> pin cell typical spectrum not from PSM resonance treatment [6]. Therefore, the Mo multi-group cross-sections, especially absorption cross section is over estimated compared to the PSM treatment case. According to the results, reactivity is affected by Mo resonance treatment at BOC as 1200 pcm and 600 pcm at EOC.

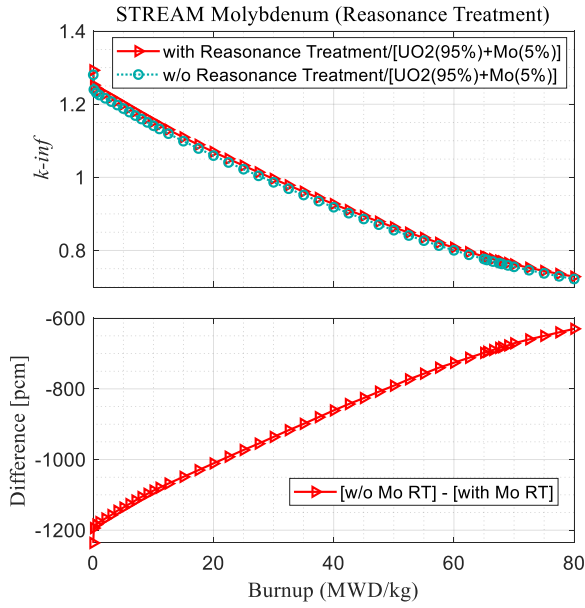


Fig. 5. STREAM Mo resonance treatment result comparison.

Secondly, the effect of reactivity depending on whether the depletion chain of Mo material is processed correctly is analyzed. As shown in Fig. 6, it is confirmed that reactivity is not influenced as large amount by whether the depletion chain is processed correctly. A detailed analysis is given below.

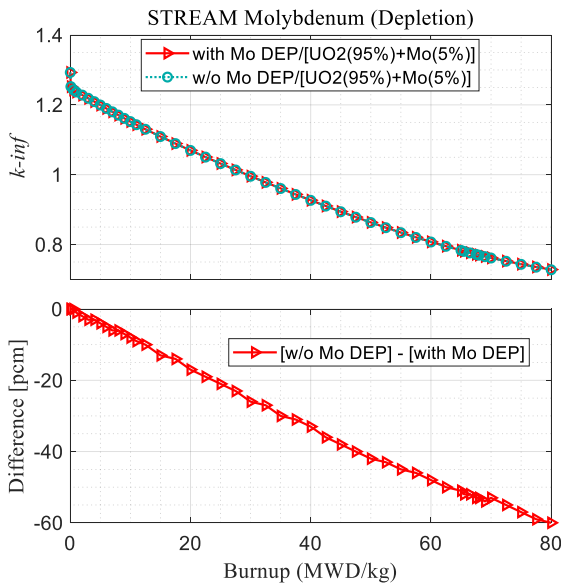


Fig. 6. STREAM Mo depletion result comparison as depletion option.

In Fig. 7, the number of Mo isotope changes were compared according to the depletion option. In this comparison, the summation of  $^{92}\text{Mo}$ ,  $^{94}\text{Mo}$ ,  $^{95}\text{Mo}$ ,  $^{96}\text{Mo}$ ,  $^{97}\text{Mo}$ ,  $^{98}\text{Mo}$ , and  $^{100}\text{Mo}$  amounts are compared. From this comparison, the depletion chain treatment was confirmed to have no significant effect because

maximum difference is 0.4% relative error at the EOC. The reason for this analysis is shown in Fig. 8 more detailly.

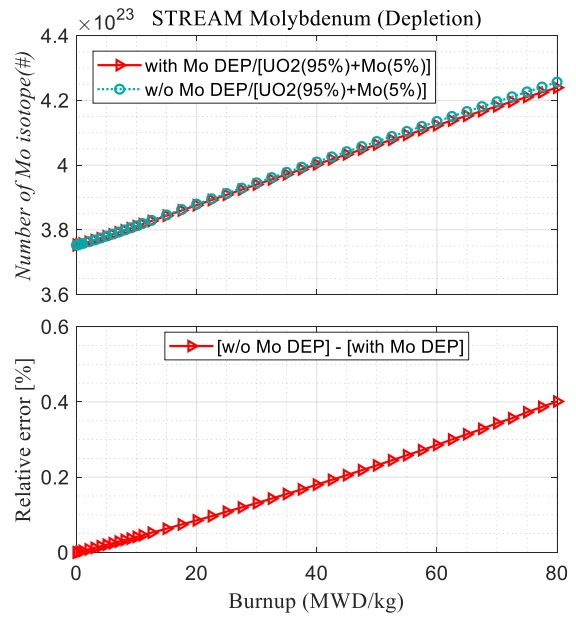


Fig. 7. STREAM number of Mo isotope comparison as depletion option.

Among the isotopes of Mo,  $^{95}\text{Mo}$  and  $^{96}\text{Mo}$  have great amount change as depletion. The change behavior of the two isotopes differs according to the option, but when the total amounts are compared, it has offset effect.

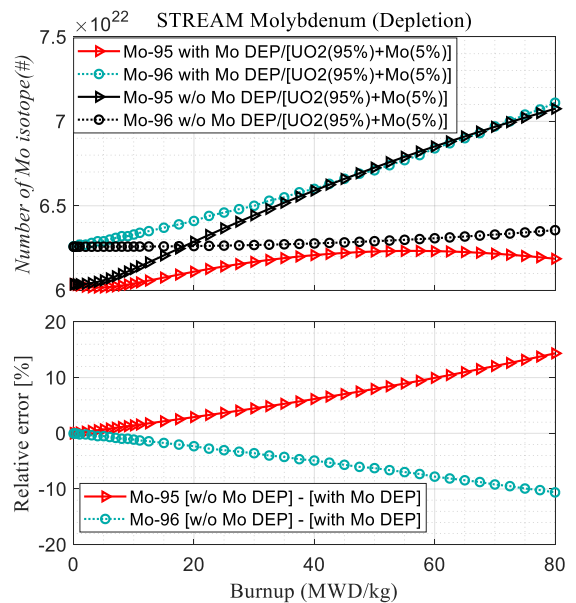


Fig. 8. STREAM number of  $^{95}\text{Mo}$  and  $^{96}\text{Mo}$  isotopes comparison as depletion option.

#### 2.4 Summary of STREAM Mo Neutronics Effect Analysis

In fact, when the Mo resonance processing and the depletion are properly considered in the STREAM code, the influence on the reactivity, i.e., the core cycle length, is analyzed.

First, since the Mo is a strong absorber, the Mo is expected to disappear at the end of the cycle, but the influence of the Mo is persistent until the end of the cycle. These analyses can be confirmed at the Fig. 9 synthetically. The black difference value shows reactivity effect by Mo addition to existing UO<sub>2</sub> fuel assembly. The reactivity changes from 3500 pcm at the BOC to 1200 pcm at the EOC. In the cyan difference value, it is shown that the reactivity reduction effect caused by the reduction of the 5 vol% UO<sub>2</sub> amounts as 1000 pcm at the EOC. When these two effects are combined, the actual Mo 5 vol% addition FA shows a difference between UO<sub>2</sub> FA as 3500 pcm at the BOC and 2300 pcm at the EOC. Respectively. From these detail reactivity effect analyses, since the influence of the Mo material lasts from the BOC to the EOC, accurate resonance treatment and depletion effect processing are considered very important study as neutronics point of view.

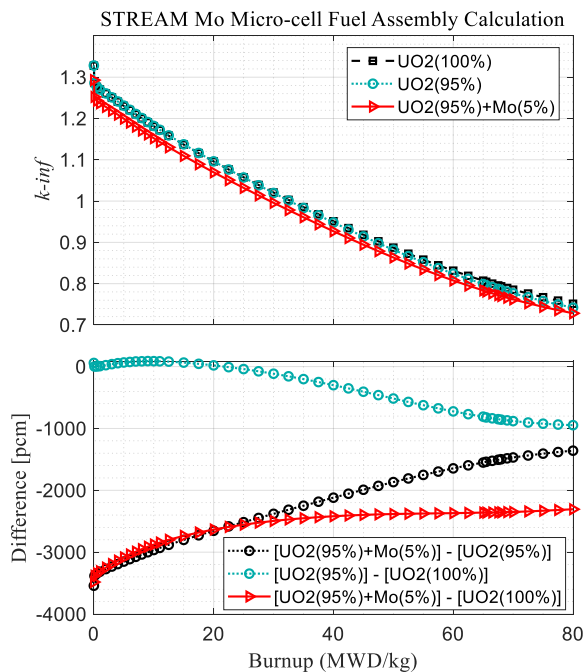


Fig. 9. STREAM Mo neutronics effect analysis.

### 3. Conclusions

In this paper, it was focused on the analysis of neutronics effect of Mo for ATF reactor core. Unlike the conventional UO<sub>2</sub> commercial core, it was confirmed that importance of the accurate Mo resonance treatment and the depletion chain treatment for the Mo micro-cell type ATF core.

As future work, through this precise processing of Mo, it will be performed that the core-based analysis using ATF especially Mo micro-cell type and analyze how it affects cycle length and core design parameters.

### Acknowledgement

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