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Depletion and Decay Analyses of a KJRR Fission Moly Target

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1. Introduction

^{99}Mo is a parent radioisotope of ^{99m}Tc that is one of the most widely used medical diagnostic agents. Further growth in demand of ^{99}Mo has been predicted [1]. ^{99}Mo is mostly produced from the fission of ^{235}U in a research reactor to obtain a higher specific activity [2]. However, ^{99}Mo used in Korea depends entirely on imports. To ensure a stable supply via domestic production of ^{99}Mo, the KIJANG research reactor (KJRR) project is going on. The KJRR core has been designed with the aim of ^{99}Mo production over 2,000 curies per week using six target assemblies consisting of eight plate-type targets. The low-enriched uranium (LEU) of UAlx-Al with ^{235}U enrichment of 19.75 w/o is used as a target material.

In this paper the ^{99}Mo production of a KJRR fission moly (FM) target was evaluated. Depletion and decay calculations were performed by the ORIGEN-S [3] code with problem-dependent cross-section library generated by using TRITON [3], and the results were compared with those of the TRITON, McCARD [4], and HELIOS [5] calculations.

2. Methods and Results

2.1 KJRR & FM Target Assembly

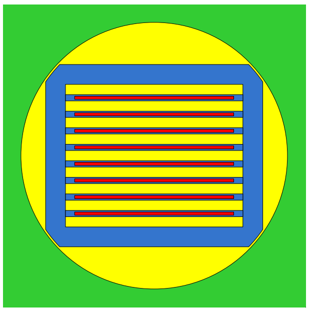

Fig. 1. KJRR FM target assembly cross-sectional view.

The KJRR has been developed at KAERI for the radioisotope (RI) production and neutron transmutation doping (NTD). The KJRR core is composed of 22 plate-type fuel assemblies. Each fuel assembly consists of 21 fuel plates with a high-density, low-enriched U-Mo fuel meat of 19.75 w/o. Also, the core is designed to produce ^{99}Mo using 6 plate-type FM target assemblies at power operation. As shown in Fig. 1, each FM target assembly consists of 8 plates with a 19.75 w/o enriched UAlx-Al target, which is composed of 71.35 w/o uranium and 28.65 w/o aluminum and has a density of 3.645 g/cc.

2.2 Analysis Method

Our analysis procedure is as follows:

1) Obtain the fission power of each FM target through a 3-dimensional KJRR core calculation using the MCNP code,

2) Generate the problem-dependent cross-section library to be used the ORIGEN-S calculation from a 2-dimensional FM target assembly depletion calculation with the reflecting boundary condition using the TRITON code,

3) Preform the ORIGEN-S depletion and decay calculations with the fission power obtained from the procedure 1 and the problem-dependent cross-section library generated in the procedure 2.

In this study it is assumed that the average fission power of a target assembly is 80 kW. By using the calculated power density, the ^{99}Mo production was assessed with four different codes capable of depletion and decay analyses such as ORIGEN-S, TRITON, McCARD, and HELIOS. Fig. 2 shows various code models for a KJRR FM target assembly. All calculations were performed with the condition of 7-day irradiation and 8-day decay from end-of-irradiation (EOI).

(a) TRITON (b) McCARD (c) HELIOS

Fig. 2. The code models for a KJRR FM target assembly.

According to our analysis procedure, the ORIGEN-S calculations were conducted with problem-dependent cross-section library. This library was generated by the TRITON code with a 238-group library based on the ENDF/B-VII R0. TRITON, one of the control modules included in SCALE, supports a 2-dimensional transport and depletion calculation using NEWT and ORIGEN-S. So, the TRITON standalone calculations were carried out to compare the TRITON/ORIGEN-S calculations.

In order to verify the TRITON/ORIGEN-S results, the reference McCARD calculations were run with 10,000 particles per cycle and 100 active cycles after 25 inactive cycles, and full predictor-corrector option. Continuous cross-sections were processed from the

ENDF/B-VII R0 library. For comparison, the HELIOS calculations were done with a coupling order of k=2 and a 47-group library based on the ENDF/B-VI R0.

2.3 Analysis Results

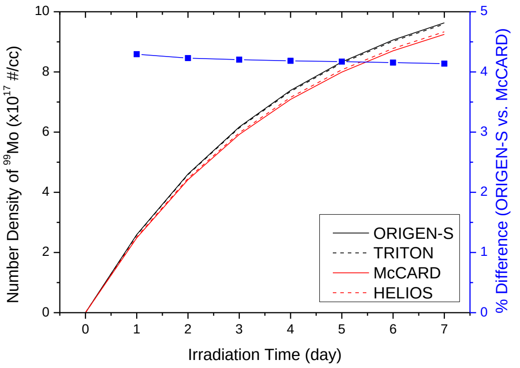

Fig. 3. Comparison of number densities of ^{99}Mo as a function of the irradiation time.

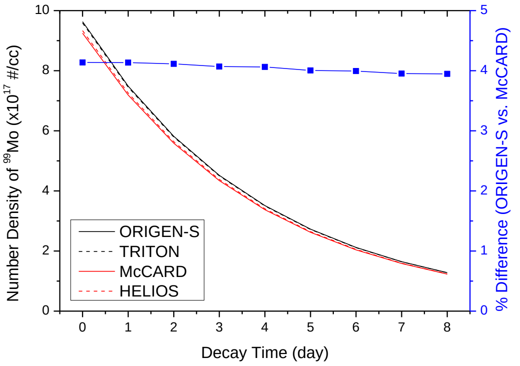

Fig. 4. Comparison of number densities of ^{99}Mo as a function of the decay time.

Fig. 3 and Fig. 4 show a comparison of ^{99}Mo number densities in a target assembly as a function of the irradiation and decay time, respectively. The results of ORIGEN-S are almost same to those of TRITON within a maximum error of 0.5%, but overestimate up to 4.3% compared to those of McCARD. Also, The HELIOS results are very close to the reference solution to within a maximum error of 1.0%. These errors are attributed to the difference of a fission product yield for ^{99}Mo used in each cross-section library. From the above results, a bias factor of 5% was conservatively determined for the KJRR ^{99}Mo production estimation.

Table I shows the ^{99}Mo production of a KJRR FM target assembly calculated by the ORIGEN-S code. The table also shows the results considering a bias factor of 5% and applying a recovery yield of 85% in a chemical separation process for practical evaluation. Therefore, it is expected that a KJRR FM target assembly with the fission power of 80 kW can produce ^{99}Mo of 374 curies.

Table I: ^{99}Mo Production of a KJRR FM Target Assembly

Time (day)	PND ($\times10^{17}$ #/cc)	Activity (Ci)		
		Calculated	w/ Bias	Practical
0	0.000	0	0	
1	2.593	938	891	
2	4.606	1,667	1,584	
3	6.170	2,233	2,121	
4	7.385	2,673	2,539	
5	8.329	3,014	2,863	
6	9.062	3,280	3,116	
7 (EOI)	9.631	3,486	3,312	
8	7.486	2,709	2,574	2,188
9	5.817	2,105	2,000	1,700
10	4.519	1,636	1,554	1,321
11	3.512	1,271	1,207	1,026
12	2.728	988	938	797
13	2.120	767	729	620
14	1.647	596	566	481
15	1.280	463	440	374

* Decay Constant of ^{99}Mo: 2.92×10^{-6} sec^{-1}

3. Conclusions

Depletion and decay analyses using the ORIGEN-S, TRITON, McCARD, and HELIOS codes were carried out to estimate the fission ^{99}Mo production in KJRR. Since the ORIGEN-S results overestimate up to 4.3% compared to the reference McCARD solution, a bias factor of 5% was conservatively applied to the ^{99}Mo production. Also, a recovery yield assumed to 85% was considered for practical evaluation. Therefore, a target assembly with the fission power of 80 kW is able to produce ^{99}Mo of 374 curies per week. In conclusion, it is anticipated that the KJRR can yield ^{99}Mo production over 2,000 curies per week if six target assemblies have 480 kW.

ACKNOWLEDGEMENTS

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