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SENSITIVITY TEST ON TEMPERATURE DIFFERENCE FOR MODERATOR TEMPERATURE COEFFICIENT IN A POOL TYPE RESEARCH REACTOR

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ABSTRACT

Moderator temperature coefficient (MTC) is one of the most key parameters to give an inherent safety property of a nuclear reactor. When the reactor is in the under moderation, the temperature rise due to an abrupt accident gives a power decrease resulting from negative reactivity coefficient. Thus, it is very crucial to estimate reactivity coefficient exactly, especially MTC. In this study, a lattice model is tested based on plate type U_3Si_2 fuel assembly with water moderator in a pool type research reactor. In order to estimate MTC more precisely, burnup dependent MTCs on various temperature differences are estimated using a TRITON/NEWT code, which are sub-modules of SCALE6 code system. As depletion proceeds, the MTCs are distributed more negatively in a typical trend. The MTC of an initial state gives a large fluctuation compared with that of irradiated state. And it is also found that even small variation of moderator temperature gives a similar behavior to large temperature difference in the MTC. Moderator-to-fuel ratio effect and dual directional loading effect are also analyzed in this study.

1. Introduction

Korea is considering a new research reactor on the south-east seaside. The reactor will be utilized for medical and industrial purposes such as radioisotope production and neutron transmutation doping, and for research purpose as well. The fuel assembly, we expect, will be a plate type which provides a high power density and is widely used in current research reactors in the world. In this paper, some sensitivity analyses of moderator temperature coefficient will be treated especially for the lattice base calculation using a deterministic code such as TRITON/NEWT, a module of SCALE code system.[1][2] The moderator temperature coefficient (MTC) is roughly defined as the change of the reactor reactivity with respect to change in the moderator temperature. There are additional important reactivity coefficients when designing nuclear reactors newly. It is essential to estimate the sign and magnitude of the various reactivity coefficients because they suggest the consequence of abrupt changes in the nuclear operating parameters. A positive reactivity coefficient shows that a positive change in that parameter will increase reactivity and tend to increase power. On the contrary, a negative value for a reactivity coefficient means that reactivity and power are decreased for a positive change in that parameter. For the inherent safe research reactors, negative temperature coefficients should be guaranteed for all reactor states. Although most abnormal reactor transients are controlled with a sufficiently negative MTC, some cool-down accidents such as loss of coolant accident can be aggravated by the temperature feedback.[3] For this reason, it is very important to determine the temperature coefficients accurately. There are several ways to measure the MTC. The preferred method depends on the type of plant, time in cycle, and plant operation conditions.[4] During the design stage, the accurate estimation of MTC is usually performed by the core depletion analysis. In order to find a fundamental trend, a lattice calculation is carried out in this work. This obtained data for the plate type fuel assembly will be useful as a backup data for the detail design stage of new research reactors.

Some results of temperature difference to obtain accurate MTCs are shown in Section 2. Additionally temperature difference effect for fuel temperature coefficient (FTC) is discussed. Section 3 treats the effect of moderator to fuel (MF) ratio for the MTC. In Section 4, in the case of dual directional loaded fuel assemblies, some gain of MTC is discussed. Finally, the conclusion of this study is provided.

2. Temperature Difference Effects

In order to obtain temperature coefficient, a temperature difference or change should be determined first. The change of average moderator temperature is mostly dependent on cross section libraries and uncertainties of reactivity changes. The objective of this section is to quantify the effect of temperature difference in MTC. In this study, a typical plate type U_3Si_2 fuel assembly is used and its configuration is depicted in Fig. 1. Moderator temperature and fuel temperature are given 40 ^oC and 100 ^oC, respectively. And the changes of moderator temperature are given as between 2 ^oC and 10 ^oC. The total depletion period is 60 days. The used cross section library is ENDF/B-VI, which is adjusted in the SCALE code.

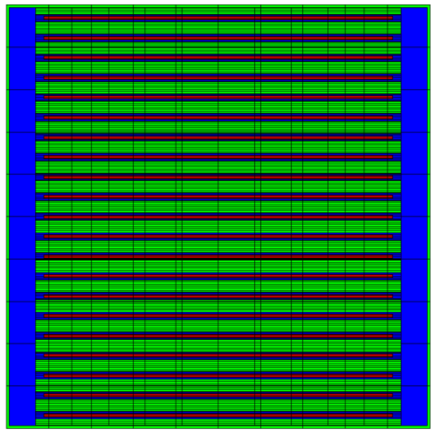

Fig. 1. Configuration of a typical plate type U_3Si_2 fuel assembly.

Fig. 2 shows MTCs for different changes of moderator temperature of 40 ^oC. Fig. 3 also shows the MTC variation as an irradiation day. From the results, it is found that the temperature difference of the average moderator temperature does not provide significant changes in MTC. Fig. 4 shows the MTC behavior for different average moderator temperatures. The more moderator temperature increases, the less MTCs are negative. But there are small fluctuations in MTC when small temperature difference of 2 ^oC is used. Thus, it is recommended at least 5 ^oC of moderator temperature change is required to eliminate such a fluctuation. The temperature dependent MTCs of 10 ^oC are tabulated in Table I.

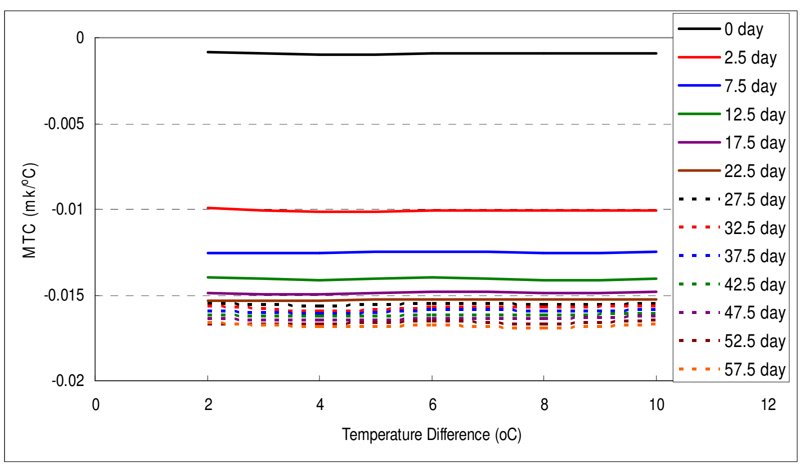

Fig. 2. MTC variation as a function of moderator temperature differences. (Tm = 40 ^oC)

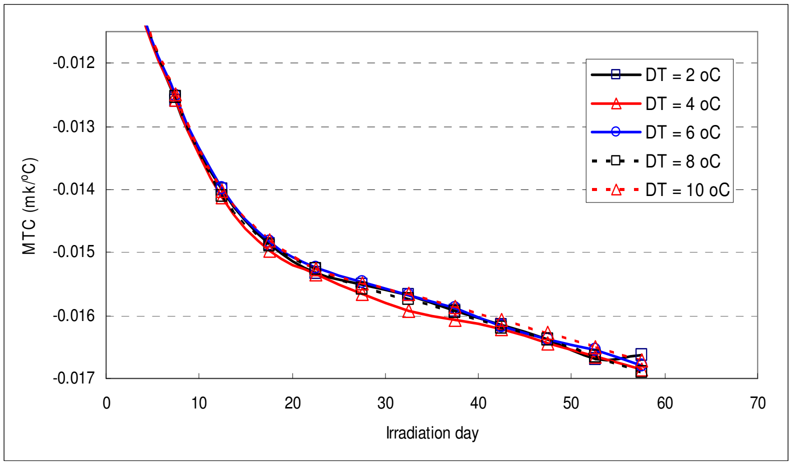

Fig. 3. MTC change for depletion periods. (Tm = 40 ^{o}C)

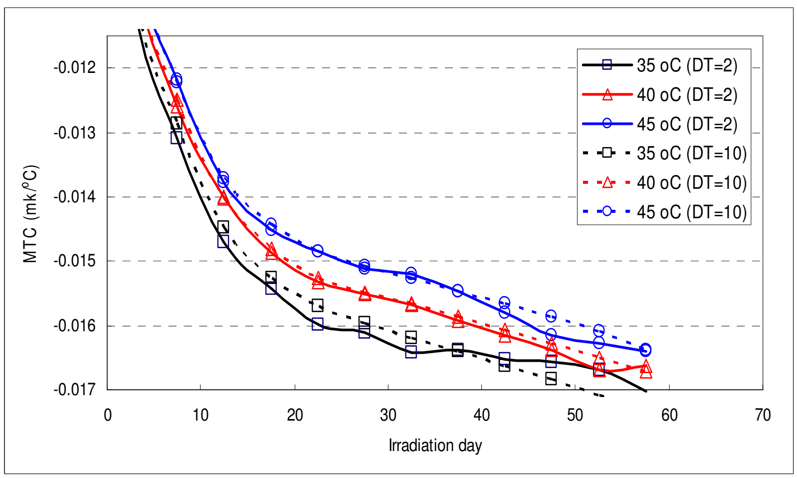

Fig. 4. MTC change for various moderator temperatures.

Table I. MTC for irradiation days of a typical U_3Si_2 plate fuel assembly.

day	Average MTC (mk/ ^oC)		
	35 ^oC	40 ^oC	45 ^oC
0	-0.00075	-0.00089	-0.00104
2.5	-0.01041	-0.01005	-0.00976
7.5	-0.01290	-0.01254	-0.01214
12.5	-0.01452	-0.01404	-0.01368
17.5	-0.01531	-0.01488	-0.01440
22.5	-0.01576	-0.01529	-0.01481
27.5	-0.01600	-0.01554	-0.01504
32.5	-0.01624	-0.01574	-0.01522
37.5	-0.01640	-0.01594	-0.01545
42.5	-0.01660	-0.01616	-0.01566
47.5	-0.01681	-0.01638	-0.01587
52.5	-0.01702	-0.01661	-0.01610
57.5	-0.01727	-0.01678	-0.01635

Additionally, fuel temperature coefficients (FTCs) are analyzed for different temperature changes in this study. Fig. 5 depicts the results of FTC for different fuel temperatures when the changes of fuel temperatures are 10 ^oC and 30 ^oC. A slight difference is found as depletion proceeds from the results, so at least 30 ^oC of temperature difference is recommended.

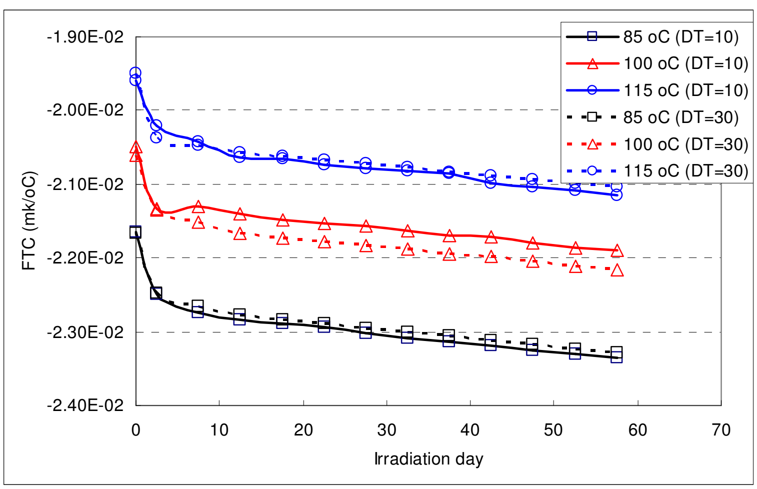

Fig. 5. FTC change for various fuel temperatures.

3. Moderator-to-Fuel (MF) Ratio Effect

It is well known that moderator-to-fuel (MF) ratio affects the effective multiplication factor (k-eff), especially on thermal utilization factor and the resonance escape probability.[5] There is an optimal point of the MF ratio for the effective multiplication factor. That is, when increasing the MF ratio, the effective multiplication factor (k-eff) increases below the optimal point, because the thermal utilization factor increases in this region. Above this point, an increase in MF ratio decrease in k-eff due to the dominance of increased resonance escape probability. Therefore, nuclear reactors are usually designed in the undermoderation condition. To identify the typical plate type of U_3Si_2 fuel assembly, an MF ratio is slightly increased from 5.0 to 5.4 by changing the geometrical configuration. Figs. 6 and 7 show the k-eff for two different MF ratios and the MTC changes, respectively. From the figures, it is found that a slight increase in MF ratio increase in k-eff and decrease in MTC, simultaneously, which means that the fuel lies undermoderation state.

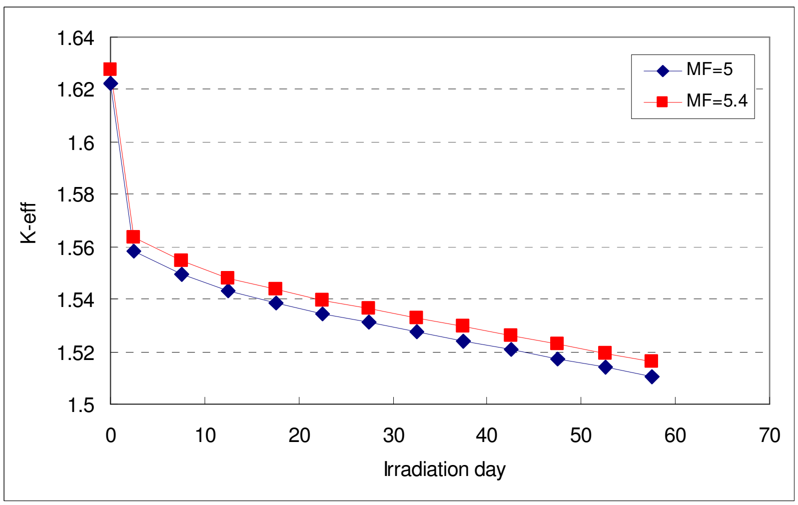

Fig. 6. Effective multiplication factor change for different MF ratios.

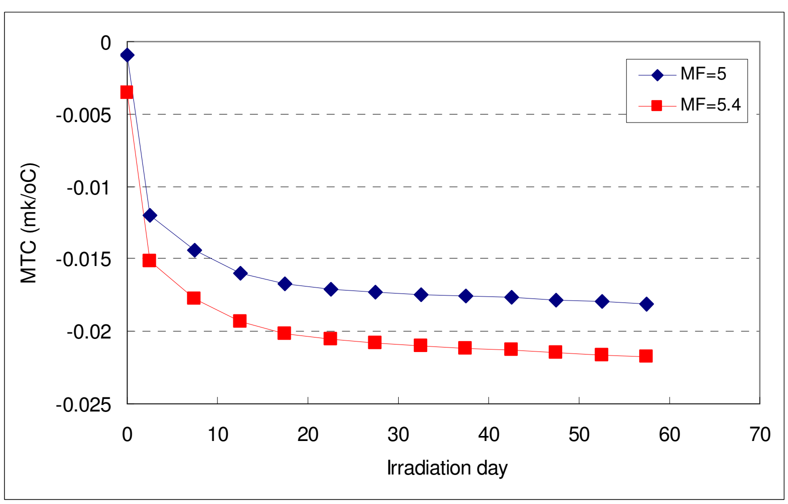

Fig. 7. MTC change for different MF ratios.

4. Assembly Loading Effect

The plate type of fuel assembly has a direction of each fuel plate. It is normal for a mono directional loading for fuel plate assembly, however it is also considered a dual directional loading to obtain higher power density for high neutron flux or a marginal flow in thermal hydraulic design. The dual directional loading means that different directions of fuel plates are laid in a color set shape. Fig. 8 depicted the dual directional loading configuration. To quantify the effect in MTC and FTC, a simple color set calculation is performed which corresponds to the center part of Fig.8 with all reflective boundary conditions. Table II shows the effective multiplication factor for two cases and there is almost overlapped for normal plate and color set plate. However, there is a slight change in temperature coefficients. Figs. 9 and 10 depict the MTC and FTC variations for two different loading cases. Color-set shaped fuel assembly provides more negative values about from 33 to 52 pcm/^{o}C in MTC and from 12 to 16 pcm/^{o}C in FTC. Thus, the dual directional loading is expected to provide some benefits in terms of reactivity coefficients.

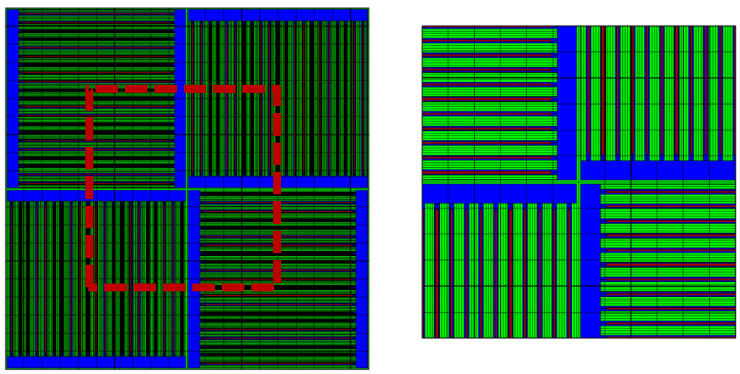

Fig. 8. Configuration of color set plate or dual directional loading plate.

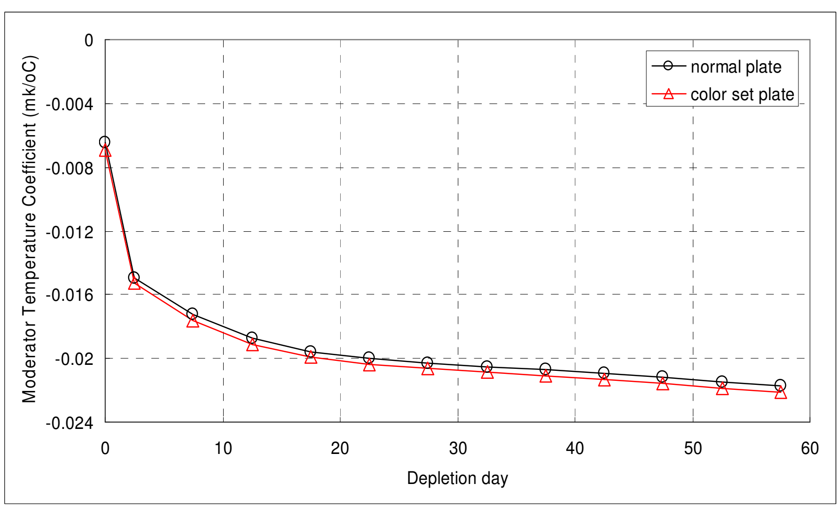

Fig. 9. MTC changes for different loadings of fuel plates.

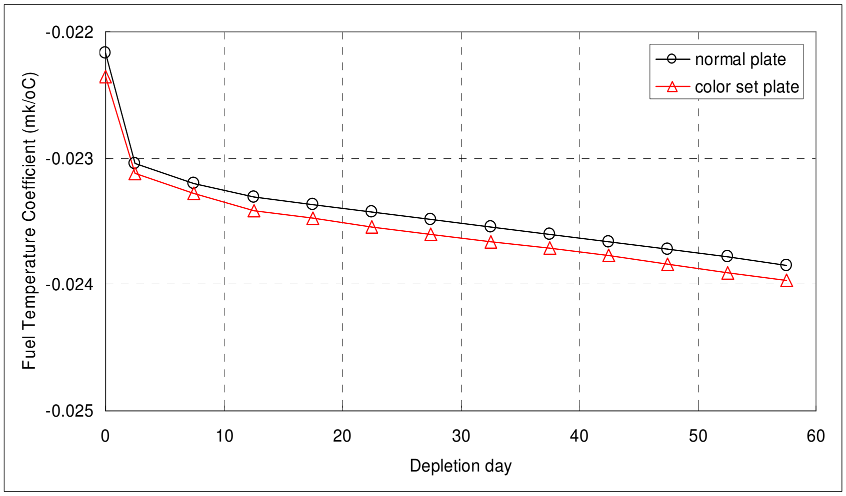

Fig. 10. FTC changes for different loadings of fuel plates.

5. Conclusions

In order to investigate the reactivity behavior of the plate type fuel assembly which is loaded in a pool type research reactor, some sensitivity tests of temperature coefficients have been carried out by using a two-dimensional depletion tool. From the analyses, several valuable findings are obtained. First, the temperature coefficient of the reactivity does not strongly dependent changes in temperature. However, a small change in temperature is not recommended and proper temperature change should be given considering trends of reactivities and uncertainties of cross sections. Second, the lattice characteristics of the normal plate type fuel assembly shows undermoderated reactor condition from the results of a small deviation of moderator to fuel ratio. It goes without saying that the moderator temperature coefficients of reactivities are negative in the undermoderation reactor condition. Finally, a dual directional loading of the plate type fuel assembly gives some credits in the temperature coefficient. Thus, it is a good way to load fuel assemblies in a color set type not only for a marginal thermal hydraulic design but also for a safe reactor design.

There are several remaining works to be done for the design of a new research reactor. A three dimensional full core analysis should be followed including reactivity coefficient, power coefficient, and xenon worth analyses. Furthermore, it is strongly recommended to consider more precise method such as the Monte Carlo technology so as to obtain very accurate and realistic reactor design parameters.

Table II. FTC changes for different loadings of fuel plates.

day	Normal Plate			Color Set Plate		
	FTC (mk/^{o}C)	MTC (mk/^{o}C)	k-eff	FTC (mk/^{o}C)	MTC (mk/^{o}C)	k-eff
0	-0.02217	-0.00644	1.62206	-0.02235	-0.00696	1.62233
2.5	-0.02304	-0.01492	1.55840	-0.02312	-0.01529	1.55863
7.5	-0.02320	-0.01724	1.54937	-0.02328	-0.01761	1.54959
12.5	-0.02330	-0.01876	1.54302	-0.02342	-0.01910	1.54324
17.5	-0.02337	-0.01956	1.53838	-0.02348	-0.01989	1.53858
22.5	-0.02343	-0.02001	1.53454	-0.02354	-0.02035	1.53474
27.5	-0.02349	-0.02030	1.53102	-0.02360	-0.02065	1.53121
32.5	-0.02355	-0.02052	1.52760	-0.02366	-0.02087	1.52778
37.5	-0.02360	-0.02071	1.52420	-0.02372	-0.02110	1.52438
42.5	-0.02366	-0.02097	1.52078	-0.02377	-0.02134	1.52096
47.5	-0.02372	-0.02120	1.51735	-0.02384	-0.02156	1.51751
52.5	-0.02378	-0.02148	1.51388	-0.02391	-0.02188	1.51403
57.5	-0.02384	-0.02174	1.51038	-0.02397	-0.02214	1.51053

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