Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

A Neutronic Feasibility Study of SMART Core Design Fully Loaded with FCM Fuel

Chungchan Lee*, Kyung-Hoon Lee, Jin Young Cho, Sang-Yoon Park, Sung Quun Zee, Won-Jae Lee
Korea Atomic Energy Research Institute
Daedeok-daero 989-111, Yuseong-gu, Daejeon, 305-353, Republic of Korea
**Corresponding author: cclee@kaeri.re.kr*

1. Introduction

Fully ceramic micro-encapsulated (FCM) fuel is initially developed for the high temperature gas cooled reactor [1]. However for its strong resistance to the fuel failure and fission product release, feasibility has been studied to apply FCM fuel in LWR's [2].

The FCM fuel rod consists of fuel pellets where tri-isotropic (TRISO) particles are highly packed in a dense silicon carbide (SiC) matrix. Since the fissile volume is small in a FCM fuel pellet, high uranium density material, uranium nitride (UN), is encapsulated in a large diameter fuel kernel of 800 µm. Zirconium (Zr) alloy is used for the cladding material with the thin SiC coating to suppress the metal water reaction.

The safety of the small nuclear power plants is more emphasized because of possibly small proposed exclusion area boundaries and of distance to the populated area. In this paper, the applicability of FCM fuel to SMART [3] core is studied. The core of SMART consists of 57 17x17 fuel assemblies with active height of 2m. The fission power is 330 MWth and the cycle length is 3 years with the capacity factor of 0.9.

2. Design and Analysis

In this section fuel assembly and core designs are presented and some basic neutronic parameters are analyzed to find that FCM fuel can be utilized for small IPWR, SMART.

2.1 Design and Analysis Tools

DeCART/MASTER [4,5] code system is used for the FCM loaded SMART core design. The accuracy of DeCART can be found that the k-infinity predictions of the MOC based DeCART and Monte Carlo are not greater than 270 pcm for a FCM loaded fuel assembly in reference [2].

2.2 Fuel Assembly Design

Infinite multiplication factors are investigated for the 17x17 fuel assembly with respect to the pellet diameter. Fig. 1 shows that k infinity decreases for the pellet radius greater than 0.44 cm for 12 w/o U-235 enrichment. This is very important for the FCM fuel loaded core design to ensure negative Moderator Temperature Coefficient (MTC) because carbon in SiC matrix is a good moderator and can cause over-moderation.

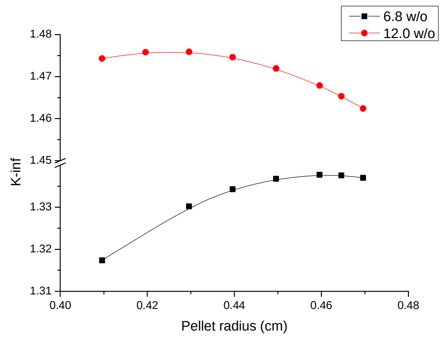

Figure 1. K-inf vs. Pellet Radius

Increased fuel pellet diameter has another apparent advantage in neutronic design view point. The increased pellet diameter means increased fuel volume, and it compensates naturally small uranium mass in TRISO. The large fuel rod diameter also has the benefit in thermal and hydraulics point of view. Large fuel rod surface area decreases heat flux and increased coolant flow velocity, which contributes generally high DNBR or high thermal margin. Therefore, fat fuel pellet (and cladding diameter) is advantageous as far as fuel assembly manufacturing is allowed. Considering this constraint the 17x17 fuel assembly design is chosen for the feasibility study on the SMART core application.

Fig. 2 shows a typical 17x17 fuel assembly modeling for the cross section generation by DeCART. Erbia (Er_2O_3) is used in particle form called bi-isotropic (BISO) particle [6] in every fuel rod if used. Core loading pattern and axial burnable poison zoning design are from SMART standard design.

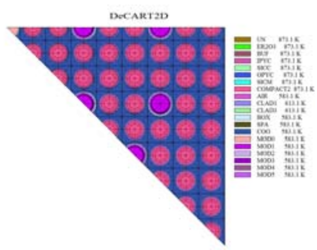

Fig. 2. Assembly Modeling in DeCART

2.3 Core Design and Analysis

Fig. 3 shows the initial and equilibrium core loading patterns in 1/8 core configuration. Batch A uses 8.2 w/o and batch B through F use 16.5 w/o enriched uranium. Equilibrium cycle uses 0.6, 1.2 1.8, 2.4 and 3.0 % erbia BISO for burnable poison at axial zoning, F1, F2, F5 and F6, respectively. The shaded region in the equilibrium cycle are burnt fuels.

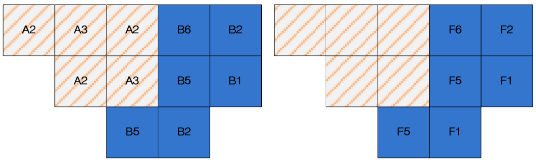

Fig. 3. Initial/equilibrium core loading patterns

Fig. 4 shows typical core parameters, Fq, Fr, critical boron concentrations and axial offset (AO) versus burnup. Critical boron concentration shows that the required cycle length can be obtained with the peaking factors well within the design targets. The axial zoning of Type A fuels in cycle 1 successfully keeps the AO between ± 5%. The relatively high boron concentrations could result in high MTC without erbia burnable poison. But well-chosen erbia BISO can keep them in allowable range, that is, less than 9 pcm/K at hot zero power condition and not positive at hot full power condition as shown in Fig. 5.

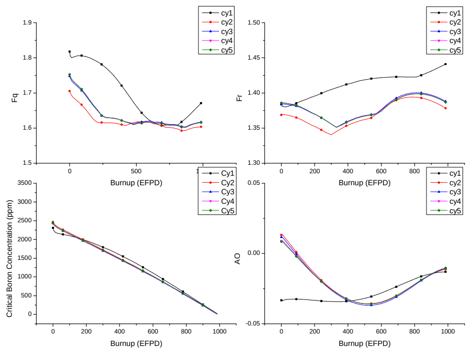

Fig. 4. Typical core parameters

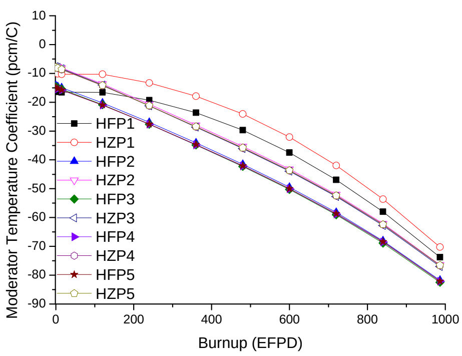

Fig. 5. MTC vs. Burnup

The shutdown margin (SDM) of the initial cycle and equilibrium cycle have been evaluated. The minimum SDM is evaluated 6.12 %Δ ρ from the beginning of cycle 1 and satisfies the requirement.

3. Conclusions

Feasibility study to utilize fully ceramic micro-encapsulated fuel in small LWR such as SMART has been performed. The result shows that accident resistant FCM fuel can be utilized in neutronic design point of view with fat pellet dimension and well-chosen erbia BISO contents to give appropriate cycle length and basic neutronic characteristics. Therefore FCM fuel is worth further study for the small integral reactor such as SMART.

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