A Neutronic Feasibility Study for Deep Burning of Transuranics in LWR Spectrum

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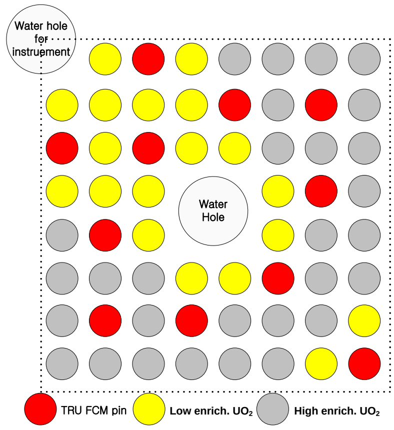
1. Introduction

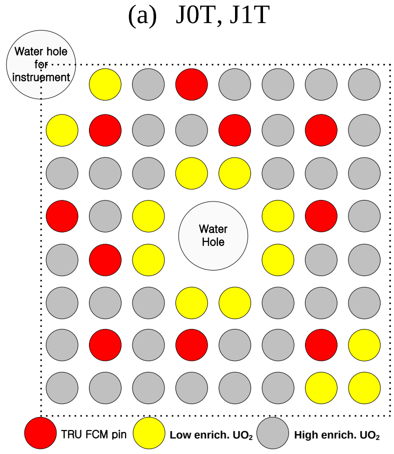
In this paper, a neutronic feasibility study is reported for deep burning of transuranic (TRU) nuclides in the conventional LWR. New fuel assemblies are proposed and they are used in the reload core designs of YGN unit 3 cycle 6 and its following cycles. The new fuel assemblies consist of conventional UO_2 pins and TRU bearing pins. Differently from the previous studies[1] for TRU transmutation in LWRs, our concept uses FCM (Fully Ceramic Micro-encapsulated) fuel pins[2] for TRU burning where TRISO TRU particles are distributed in a SiC matrix. This FCM fuel is characterized by its high thermal conductivity and the excellent irradiation perfornance. Also, our concept does not consider multi-recycling of TRU contained in the FCM fuel pins because the TRISO particle fuel allows for very large fuel utilization (>60% TRU burnup) in a single pass while once recycling of TRU generated in UO_2 pins can be implicitly assumed.

2. Design Methodology

To implement of our deep burn concept, the YGN unit 3 cycle 6 core is selected as a starting reference core. The fresh fuel assemblies to this core are assumed to contain the TRU FCM pins and this reference core consists of 64 fresh assemblies, 49 twice burnt and 64 once burnt fuel assemblies. There are three types (J0T, J1T, J2T) of fresh fuel assemblies in this starting reference core. These fresh assemblies consist of the conventional UO_2 pins and FCM TRU pins. The TRU pins have the same cladding as the UO_2 pins but they consist of FCM fuel, with two types of particles distributed in the SiC matrix : 1) TRU fuel TRISO particles in which a central TRU fuel kernel is surrounded by three external layers and 2) burnable poison (BP) BISO particles in which a central BP kernel (Gd_2O_3) is surrounded by two external layers. These new fresh fuel assemblies are designed to have similar k-inf changes over burnup to the original corresponding fresh fuel assemblies of the original YGN unit 3 cycle 6, which makes it easy to design the reload cores for the following cycles after cycle 6. The other two important targets in designing new fuel assemblies are low pin power peaking factor over burnup and the self recycling capability. The self recycling capability ratio is defined as the ratio of the initial TRU loading to the TRU mass generated in UO_2 pins. In this study, the recycling of the TRU generated in UO_2 pins is not considered but a fixed composition of feed heavy metal composition (0.0014wt% ^{235}U, 0.195wt% ^{238}U, 4.93wt% ^{237}Np, 2.99wt% ^{238}Pu, 58.1wt% ^{239}Pu, 21.97wt% ^{240}Pu, 3.63wt% ^{241}Pu, 6.61wt% ^{242}Pu and 1.55wt% ^{241}Am) in FCM pins is used for all the cycles. The depletion analysis of the new fuel assemblies are done with the DeCART code[3] which uses the 2D MOC transport/1D axial SP_3 nodal method and the subgroup resonance method. The DeCART calculations were done with the HELIOS 47 group cross section library. Fig. 1 shows the configurations of the new fuel assemblies.



(a) J0T, J1T



(b) J2T

Fig. 1 Configuration of the new fuel assemblies

As shown in Fig. 1, J0T and J1T have the same configuration but J0T has no BISO particles in FCM pins but J1T has BISO particles in FCM pins. The configurations use enrichment zoning to obtain low pin power peaking factor. J0T and J1T have 44 TRU FCM pins while J2T has 40 FCM pins. J0T, J1T, and J2T have 39%, 40%, and 45% packing fractions of TRISO fuel particles, respectively. J1T and J2T have 1.9% and 3.5% packing fractions of BISO particles, respectively. Table I summarizes the main design parameters and performances of these new fuel assemblies. This table shows that these fuel assemblies have high TRU destruction rate of ~60% over 1200EFPD in FCM pins, low pin power peaking factors, and self recycling capability ratio larger than unity. With the fresh fuel assemblies described above, the reload cores for cycle 6 and for the following cycles are designed. For cycle 6, its loading pattern is slightly changed from the original YGN unit 3 cycle 6 core to optimize cycle length and power peaking factor. All the core analyzes were done with the 3D nodal diffusion code MASTER[4]. The cycle 11 core was determined to be an equilibrium core. Table II shows the cycle lengths, the BOC critical boron concentrations, the axial power offset (AO), and maximum power peaking factors for the reload cores. From this table, it is shown that these reload cores have comparable values of cycle lengths and power peaking factors to the conventional LWRs. The full loading of the new fuel assemblies having FCM pins starts from the cycle 8 reload core. For the equilibrium core (cycle 11), 64 fresh fuel assemblies are charged at BOC while 49 three time burnt fuel assemblies and 15 twice burnt fuel assemblies are discharged at EOC. Table III summarizes the charge/discharge TRU masses for the equilibrium core. This table shows that the TRU destruction rate in FCM pins is ~61.4% and this core has unity self recycling capability ratio. The safety related-reactivity coefficients and the shutdown margins were also evaluated for the equilibrium cycle core but they are not given here. They were shown to be not so deviated from those of the conventional LWRs.

Table I Main design parameters and performances of the new fuel assemblies

Items	J0T	J1T	J2T
Number of FCM pins	44	44	40
Enrichments of UO_2 pins	5.1/4.6	4.9/4.4	4.6/4.15
Packing fractions (%, TRISO/BISO)	39/0	40/1.9	45/3.5
Initial TRU loading (g, 1/8FA, per 1cm active length)	1.425	1.461	1.494
TRU mass produced in UO2 pins (g, 1/8FA, per 1cm active length)	1.401	1.413	1.453
Self recycling capability ratio	1.02	1.03	1.03
TRU destruction rate over 1200EFPD (%, FCM pins)	59.9	59.9	58.2
Maximum pin peaking factors (0/1200EFPD)	1.11/1.15	1.07/1.15	1.11/1.13

Table II Short summary of core performances

Items	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11
Cycle length (EFPD)	479	450	463	457	457	457
CBC (BOC, ppm)	1609	1531	1575	1578	1564	1568
Axial offset (%)						
Max/Min	5.6/-3.0	4.0/-3.3	5.5/-3.3	4.6/-3.1	4.6/-3.1	4.5/-3.0
Maximum Fr	1.47	1.50	1.50	1.50	1.50	1.51
Maximum Fq	1.80	1.77	1.77	1.83	1.83	1.83

Table III TRU mass flow through charge and discharge (equilibrium cycle core)

Charged FA	# of FAs	TRU mass (kg)	Discharged FA	# of FAs	TRU mass (kg, in UO_2 pins)	TRU mass (kg, in FCM pins)
P0 (=J0T)	20	86.85	M0	20	91.33	30.49
P1 (=J1T)	20	89.08	M1	24	107.88	39.29
P2 (=J2T)	24	109.32	M2	5	22.31	93.92
Total	64	**285.24(A)**	N2	15	63.51	30.82
			Total	64	**285.03(C)**	**110.00(B)**
TRU consumption in FCM pins (%,(A-B)/Bx100)		**61.4%**	Self-recycling capability ratio (=A/C)		**1.0**	

3. Summary and Conclusion

A new deep burning concept of TRU in LWR spectrum was explored to show its feasibility. For this purpose, new fuel assemblies having TRU FCM pins were designed and they were used in designing the reload cores for the following cycles from YGN unit 3 cycle 6. From the results of the design study, it is concluded that the reload cores can be designed without severe changes of the safety related parameters and the equilibrium core have unity self recycling capability ratio and TRU destruction rate of 61%.

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