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Preliminary Analysis of Burnup Effect on k-inf for Cr-Coated and SiC Cladding Accident Tolerant Fuel Rods with nTRACER

Kibeom Park*, Jae Uk Seo, Tongkyu Park, Sung-Kyun Zee
FNC Tech., Heungdeok IT Valley, Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, 446-908, Korea
**Corresponding author : kpark1026@fnctech.com*

1. Introduction

Since the Fukushima accident in 2011, there has been an active study on developing accident tolerant fuel (ATF)[1,2]. One of the primary concepts of ATF is to replace traditional cladding made of Zr-based alloy (so-called "Zircaloy") with SiC based materials. Another promising concept is the chromium coated zirconium based alloy cladding ATF (Cr-coated ATF)[3]. The purpose of this study is to preliminarily demonstrate the difference between current nuclear fuel [4] and two ATFs mentioned in the aspects of k-inf in a nuclear fuel assembly depletion calculation by using nTRACER[5].

2. Calculation Conditions

The base assemblies are three representative assembly types depicted as A0, B2, and C3 shown in Fig. 1. In terms of ATF cladding treatment, two approaches are considered: (1) Cr-coated ATFs and (2) SiC-based ATFs.

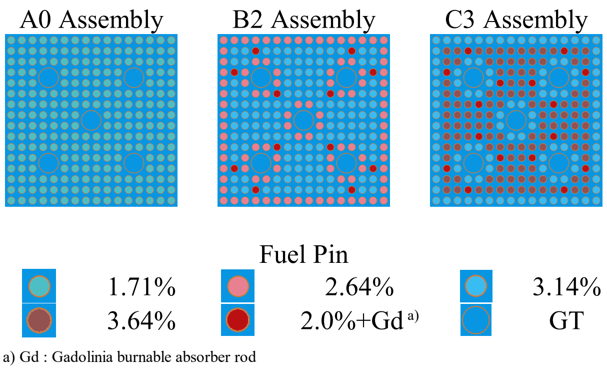

Fig. 1. Base fuel assemblies.

As shown in Fig. 2, Cr-coated fuel rods are manufactured by overlaying thin Cr coating on existing Zircaloy cladding. The thickness of Cr-coat is 20 μm. As a result of the coated material disrupting the neutrons generated in the assembly, it is expected that the neutron generation in the assembly will be reduced. If SiC cladding is utilized as one of the ATF options, as illustrated in Fig. 3, the assembly k-inf is expected to be greater than the original fuels because SiC cladding has lower neutron absorption than Zircaloy cladding.

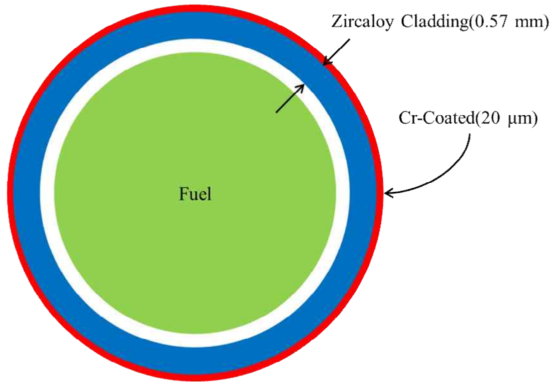

Fig. 2. Schematic of Cr-coated fuel rod.

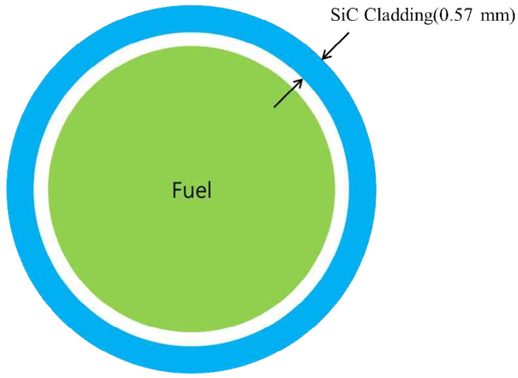

Fig. 3. Schematic of SiC clad fuel rod.

3. Calculation Results

A series of depletion calculations are performed by composing each assembly for each fuel rod. Namely, One reference and two ATFs are considered. Table I shows the time step for depletion calculation. The ray condition for calculating nTRACER is set to 0.05/16/4 (Ray Spacing/Azimuthal Angle/Polar Angle).

3.1 A0 Assembly

The A0 assembly is made up entirely 1.71 w/o enriched fuel rods and guide tubes without any burnable poison rods. The depletion trend in the absence of burnable poison is confirmed with this assembly showing smooth decrease in assembly k-inf with each depletion step.

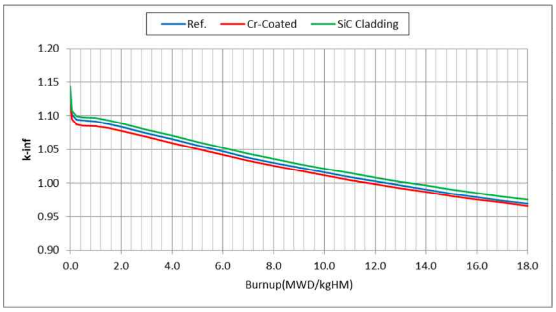

Fig. 4. Assembly depletion results for each ATF [A0].

Table I：Assembly depletion comparison results [A0]

BU[a)]	Ref.	Cr-coated	SiC	Diff. 1[b)]	Diff. 2[c)]
0.0	1.13899	1.13067	1.14367	-646	359
0.05	1.10250	1.09472	1.10718	-645	383
0.25	1.09446	1.08689	1.09916	-636	391
0.5	1.09318	1.08583	1.09793	-619	396
1.0	1.09203	1.08503	1.09690	-591	407
1.5	1.08860	1.08186	1.09355	-572	416
2.0	1.08419	1.07768	1.08921	-557	425
3.0	1.07464	1.06854	1.07980	-531	445
4.0	1.06517	1.05941	1.07043	-510	461
5.0	1.05600	1.05056	1.06136	-490	478
6.0	1.04681	1.04172	1.05230	-467	498
7.0	1.03762	1.03280	1.04325	-450	520
8.0	1.02998	1.02534	1.03565	-439	532
9.0	1.02250	1.01813	1.02827	-420	549
10.0	1.01549	1.01128	1.02128	-410	558
11.0	1.00876	1.00476	1.01461	-395	572
12.0	1.00236	0.99852	1.00823	-384	581
13.0	0.99623	0.99253	1.00214	-374	592
14.0	0.99035	0.98677	0.99629	-366	602
15.0	0.98470	0.98127	0.99065	-355	610
16.0	0.97924	0.97598	0.98529	-341	627
17.0	0.97409	0.97091	0.98010	-336	630
18.0	0.96932	0.96622	0.97534	-331	637

a) Unit of BU : MWD/kgHM
b) Difference between Reference and Cr-coated
c) Difference between Reference and SiC cladding

3.2 B2 Assembly

In the B2 fuel assembly, 2.64 w/o enriched fuel rods are placed at the assembly periphery and around the guide tube pins, and the remaining positions are filled with 3.14 w/o enriched fuel rods and burnable poison rods. Since this assembly has mid-range enrichment and burnable poisons, the assembly k-inf shows different tendency than the A0 assembly. The k-inf difference becomes larger at the final depletion step than at the beginning step. At the final burnup step, the tendency is changed reversely. In order to find the cause, it is necessary to additionally look at XS for each energy region of other materials.

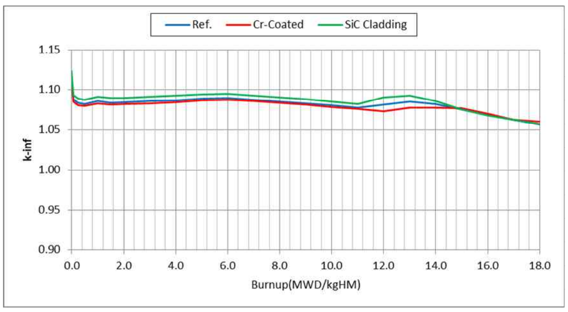

Fig. 5. Assembly depletion results for each ATF [B2].

Table II : Assembly depletion comparison results [B2]

BU[a)]	Ref.	Cr-coated	SiC	Diff. 1[b)]	Diff. 2[c)]
0.0	1.11853	1.11582	1.12394	-217	430
0.05	1.08798	1.08541	1.09335	-218	451
0.25	1.08337	1.08083	1.08873	-217	454
0.5	1.08207	1.07959	1.08746	-212	458
1.0	1.08574	1.08327	1.09118	-210	459
1.5	1.08393	1.08155	1.08942	-203	465
2.0	1.08428	1.08193	1.08980	-200	467
3.0	1.08558	1.08328	1.09111	-196	467
4.0	1.08687	1.08464	1.09235	-189	462
5.0	1.08883	1.08666	1.09414	-183	446
6.0	1.08961	1.08748	1.09483	-180	438
7.0	1.08772	1.08567	1.09288	-174	434
8.0	1.08537	1.08344	1.09048	-164	432
9.0	1.08293	1.08109	1.08793	-157	424
10.0	1.08035	1.07863	1.08519	-148	413
11.0	1.07755	1.07604	1.08222	-130	400
12.0	1.08168	1.07357	1.09031	-698	732
13.0	1.08540	1.07766	1.09247	-662	596
14.0	1.08232	1.07776	1.08615	-391	326
15.0	1.07584	1.07677	1.07580	80	-3
16.0	1.06888	1.07037	1.06832	130	-49
17.0	1.06290	1.06293	1.06287	3	-3
18.0	1.05707	1.06052	1.05795	308	79

a) Unit of BU : MWD/kgHM
b) Difference between Reference and Cr-coated
c) Difference between Reference and SiC cladding

3.3 C3 Assembly

3.14 w/o enriched fuel rods are placed around the assembly periphery and guide tubes in the C3 assembly. The remaining positions are filled with 3.64 w/o enriched fuel rods and burnable poison rods. The high enrichment and strong burnable poison effects can be observed with this assembly. The k-inf increases during the mid-burnup step and then decreases. The Cr-coated and SiC cladding differs from the reference assembly in the same way that other assemblies such as A0 and B2 do.

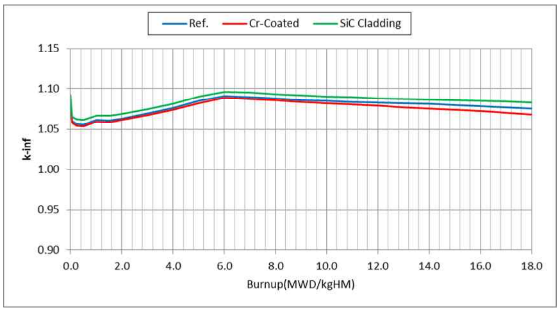

Fig. 6. Assembly depletion results for each ATF [C3].

Table III : Assembly depletion comparison results [C3]

BU[a)]	Ref.	Cr-coated	SiC	Diff. 1[b)]	Diff. 2[c)]
0.0	1.08694	1.08466	1.09247	-193	466
0.05	1.05984	1.05768	1.06533	-193	486
0.25	1.05640	1.05425	1.06188	-193	489
0.5	1.05578	1.05367	1.06128	-190	491
1.0	1.06133	1.05922	1.06686	-188	488
1.5	1.06085	1.05881	1.06642	-182	492
2.0	1.06322	1.06119	1.06883	-180	494
3.0	1.06925	1.06721	1.07490	-179	492
4.0	1.07578	1.07367	1.08138	-183	481

5.0	1.08456	1.08229	1.08992	-193	453
6.0	1.09061	1.08833	1.09599	-192	450
7.0	1.08937	1.08719	1.09482	-184	457
8.0	1.08742	1.08526	1.09289	-183	460
9.0	1.08590	1.08362	1.09133	-194	458
10.0	1.08470	1.08198	1.09009	-232	456
11.0	1.08365	1.08034	1.08897	-283	451
12.0	1.08277	1.07870	1.08806	-348	449
13.0	1.08186	1.07706	1.08720	-412	454
14.0	1.08092	1.07542	1.08634	-473	462
15.0	1.08003	1.07378	1.08548	-539	465
16.0	1.07849	1.07214	1.08462	-549	524
17.0	1.07675	1.07050	1.08376	-542	601
18.0	1.07514	1.06804	1.08247	-618	630

a) Unit of BU : MWD/kgHM
b) Difference between Reference and Cr-coated
c) Difference between Reference and SiC cladding

4. Conclusion

It was determined that the Cr-coated ATF and SiC cladding ATF exhibit a similar tendency between reference assemblies. However, the assembly k-inf values for each depletion step yield contradictory results. In the case of Cr-coated ATF, the coated material disrupts neutron behavior, resulting in a lower k-inf. SiC cladding, on the other hand, has less neutron absorption and increased scattering than Zircaloy, resulting in higher k-inf values. The ATF loaded core calculations are required for future work to confirm the key nuclear parameters of the core as well as the safety factors.

ACKNOWLEDGEMENT

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