Transactions of the Korean Nuclear Society Autumn Meeting Online, Oct 20-22, 2021

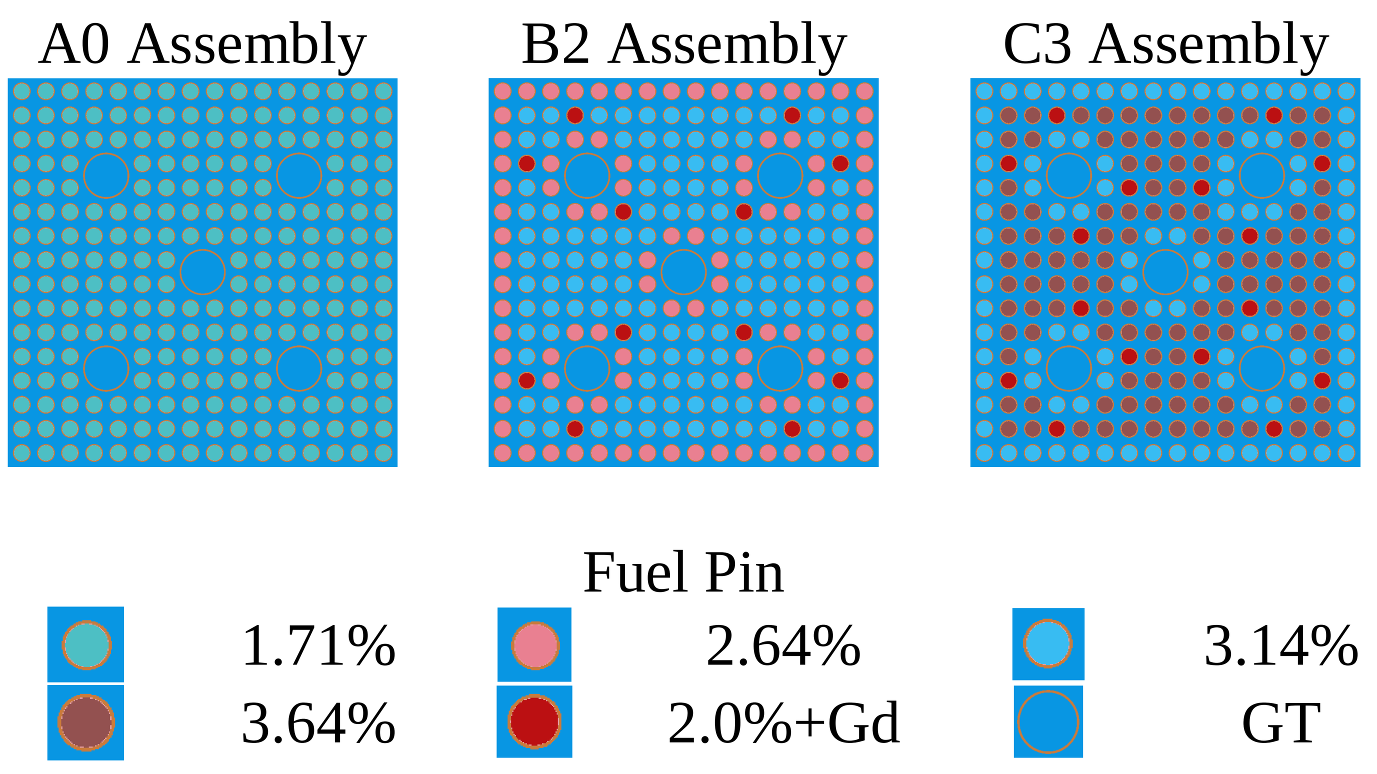
Preliminary Assessment of Neutron Energy Spectrum Hardening in ATF Rods and Assemblies

Kibeom PARK[a*], Jae Uk SEO[a], Tongkyu PARK[a], Kyun S. ZEE[a], Soon-Joon HONG[a]
[a]FNC Tech., Heungdeok IT Valley, Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, 446-908, Korea
*Corresponding author: kpark1026@fnctech.com

Introduction

- Following the accident at the Fukushima Daiichi nuclear power plant, intensive research programs have led to the development of chromium coated zirconium-based alloy cladding accident tolerant fuels (Hereafter, Cr-coated ATFs).
- A series of irradiation test for the Cr-coated Lead Test Rods (LTRs) and Lead Test Assemblies (LTAs) is scheduled in the future.
- In proactive to the future regulatory reviews for the licensing of ATFs, a proper audit code system for the analysis of ATF loaded reactors are required.
- The primary objective of this study is to investigate that the current neutronics analysis methodology and code system are congruous with the ATF loaded cores.
- As a first step of this, the neutron energy spectra of ATF assemblies are generated and compared with base assemblies using OpenMC and nTRACER.

Fuel Assemblies Geometry & Calculation Condtition



- Base Fuel Assemblies (APR1400)

- **Calculation Condition**

Effects of the Cr Coating thickness on the 47 group neutron energy spectrum and the assembly multiplication factor(AMF) were evaluated by OpenMC and nTRACER.

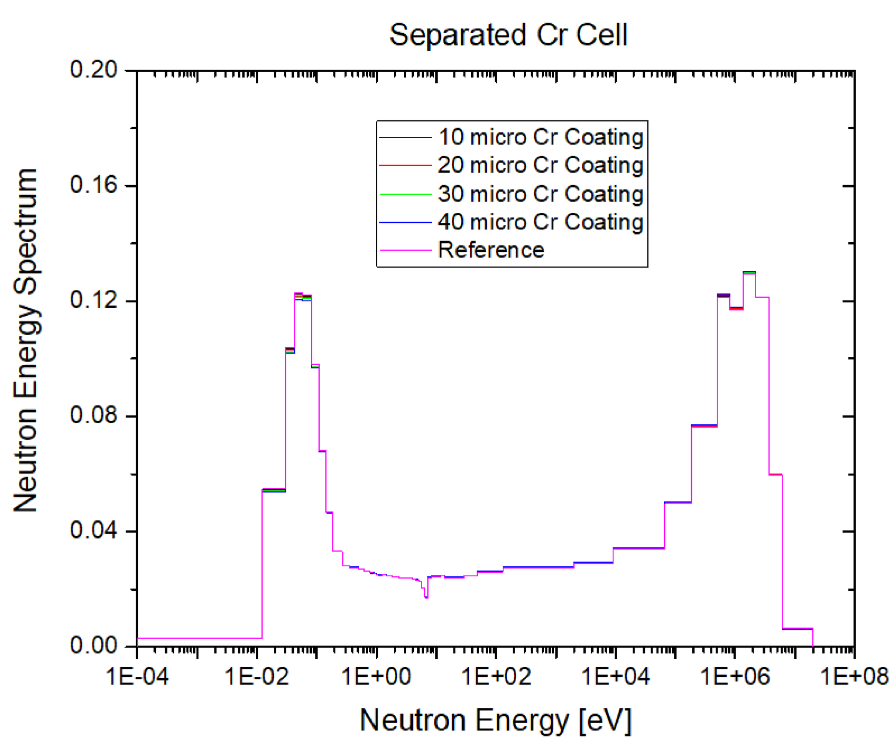
- OpenMC

OpenMC is a Monte Carlo neutron and photon transport simulation code. It is capable of performing k-eigenvalue on models built using a constructive solid geometry. For the calculation, the OpenMC model is set up as follows;
# of particles = 100,000, # of inactive cycles = 50, # of active cycles = 200

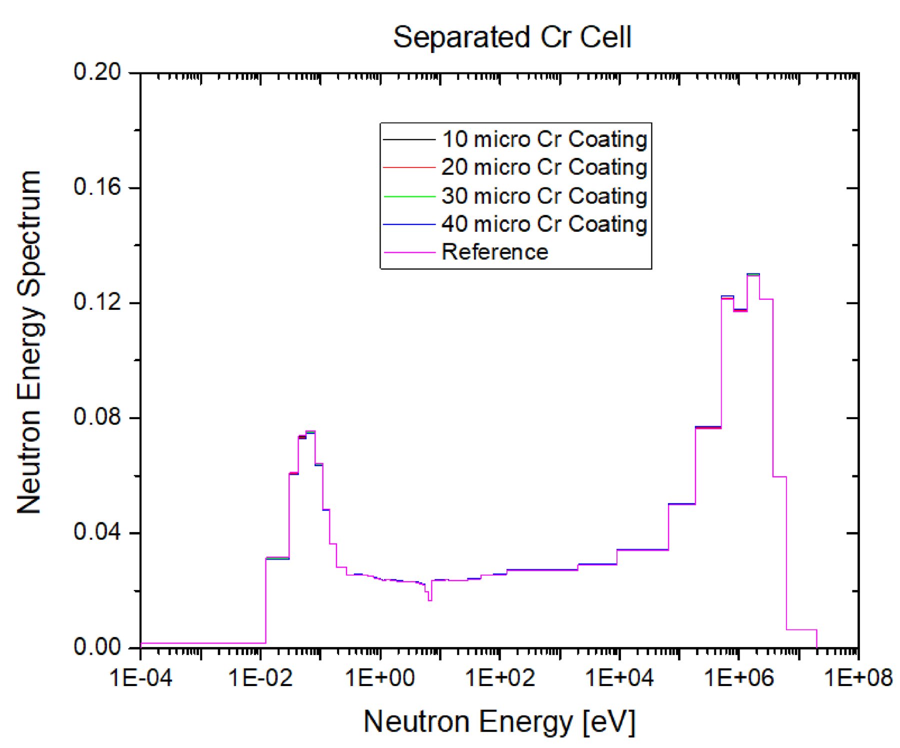
- nTRACER

nTRACER is a 3-D direct whole core transport calculation code, which can calculate the AMF and power distribution without generating group constants. nTRACER deals with explicitly heterogeneous reactor core geometries including fuel pellets and claddings on the base of fine energy groups with spatial homogenization for each region. MOC ray conditions are set up as follows;
Ray spacing = 0.05cm, # of Azimuthal rays = 16, # of polar ray angles = 4

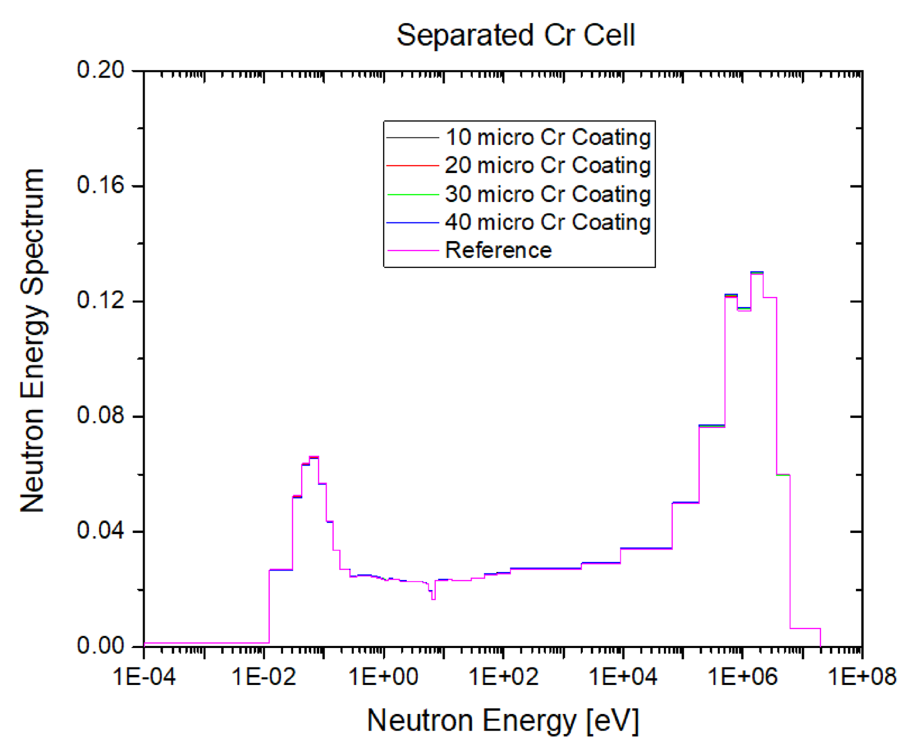
Analysis Results and Conclusion



- Neutron Energy Spectrum [A0 Assembly]



- Neutron Energy Spectrum [B2 Assembly]



- Neutron Energy Spectrum [C3 Assembly]

Cr [μm]	Separated Cr Cell		
	k_∞	stdv	diff.
Ref.	1.23055	0.00020	N/A
10	1.22510	0.00021	-0.00545
20	1.22029	0.00020	-0.01026
30	1.21566	0.00020	-0.01489
40	1.21087	0.00019	-0.01968

Cr [μm]	Separated Cr Cell	
	k_∞	diff.
Ref.	1.23362	N/A
10	1.22850	-0.00512
20	1.22411	-0.00951
30	1.21938	-0.01424
40	1.21467	-0.01895

- AMF; Top: OpenMC, Bottom: nTRACER [A0 Assembly]

Cr [μm]	Separated Cr Cell		
	k_{eff}	stdv	diff.
Ref.	1.21337	0.00021	N/A
10	1.20983	0.00020	-0.00354
20	1.20656	0.00020	-0.00681
30	1.20330	0.00021	-0.01007
40	1.19960	0.00020	-0.01377

Cr [μm]	Separated Cr Cell	
	k_∞	diff.
Ref.	1.21463	N/A
10	1.21138	-0.00325
20	1.20814	-0.00649
30	1.20490	-0.00973
40	1.20167	-0.01296

- AMF; Top: OpenMC, Bottom: nTRACER [B2 Assembly]

Cr [μm]	Separated Cr Cell		
	k_∞	stdv	diff.
Ref.	1.20909	0.00021	N/A
10	1.20676	0.00020	-0.00233
20	1.20410	0.00024	-0.00499
30	1.20074	0.00019	-0.00835
40	1.19785	0.00021	-0.01124

Cr [μm]	Separated Cr Cell	
	k_∞	diff.
Ref.	1.21139	N/A
10	1.20848	-0.00291
20	1.20558	-0.00581
30	1.20267	-0.00872
40	1.19977	-0.01162

- AMF; Top: OpenMC, Bottom: nTRACER [C3 Assembly]

1.113	1.045	0.983	0.920	0.992	1.039	1.053	1.056	1.056	1.053	1.039	0.992	0.920	0.983	1.044	1.113
1.045	1.087	1.002	0.130	1.052	1.115	1.111	1.106	1.106	1.111	1.115	1.052	0.130	1.002	1.087	1.044
0.983	1.002	1.093	1.086	1.151	1.174	1.084	1.059	1.059	1.084	1.175	1.151	1.086	1.093	1.002	0.983
0.920	0.130	1.086			1.144	1.014	1.003	1.003	1.015	1.146			1.086	0.130	0.920
0.992	1.052	1.151			1.082	0.130	0.938	0.939	0.130	1.087			1.151	1.052	0.992
1.039	1.115	1.175	1.144	1.082	1.093	1.005	1.069	1.070	1.011	0.984	1.087	1.146	1.175	1.115	1.039
1.053	1.111	1.084	1.015	0.130	1.005	1.161	1.192	1.192	1.164	1.011	0.130	1.015	1.084	1.111	1.052
1.056	1.106	1.059	1.003	0.938	1.069	1.191			1.192	1.070	0.939	1.003	1.059	1.106	1.056
1.056	1.106	1.059	1.003	0.938	1.069	1.191			1.192	1.069	0.938	1.003	1.059	1.106	1.056
1.053	1.111	1.084	1.015	0.130	1.005	1.160	1.191	1.191	1.160	1.005	0.130	1.014	1.084	1.111	1.053
1.039	1.115	1.175	1.144	1.082	1.093	1.005	1.069	1.069	1.005	1.093	1.082	1.144	1.174	1.115	1.039
0.992	1.052	1.151			1.082	0.130	0.938	0.938	0.130	1.082			1.151	1.052	0.992
0.921	0.130	1.087			1.144	1.015	1.003	1.003	1.014	1.144			1.086	0.130	0.920
0.983	1.003	1.093	1.087	1.151	1.175	1.084	1.059	1.059	1.084	1.175	1.151	1.086	1.093	1.002	0.983
1.045	1.087	1.003	0.130	1.052	1.115	1.111	1.106	1.106	1.111	1.115	1.052	0.130	1.002	1.087	1.045
1.113	1.045	0.983	0.921	0.992	1.039	1.053	1.056	1.056	1.053	1.039	0.992	0.920	0.983	1.045	1.113

- Power Distribution with 20μm coated [C3 Assembly]

0.037%	0.048%	0.027%	0.016%	0.029%	0.058%	0.072%	0.078%	0.079%	0.072%	0.057%	0.029%	0.016%	0.028%	0.048%	0.037%
0.048%	0.041%	0.002%	-0.719%	-0.008%	0.045%	0.066%	0.075%	0.075%	0.066%	0.045%	-0.008%	-0.720%	0.002%	0.041%	0.048%
0.028%	0.001%	-0.037%	-0.094%	-0.073%	0.004%	0.044%	0.058%	0.059%	0.044%	0.005%	-0.072%	-0.093%	-0.036%	0.002%	0.028%
0.015%	-0.727%	-0.093%			-0.074%	-0.010%	0.024%	0.024%	-0.010%	-0.073%			-0.093%	-0.720%	0.016%
0.029%	-0.008%	-0.071%			-0.097%	-0.731%	0.002%	0.002%	-0.723%	-0.094%			-0.071%	-0.008%	0.029%
0.057%	0.045%	0.005%	-0.075%	-0.098%	-0.045%	-0.022%	-0.012%	-0.013%	-0.020%	-0.029%	-0.094%	-0.074%	0.005%	0.045%	0.057%
0.072%	0.067%	0.043%	-0.012%	-0.723%	-0.023%	-0.009%	-0.061%	-0.060%	-0.008%	-0.019%	-0.723%	-0.011%	0.044%	0.067%	0.072%
0.079%	0.075%	0.058%	0.024%	0.002%	-0.013%	-0.060%			-0.060%	-0.012%	0.002%	0.025%	0.058%	0.075%	0.079%
0.079%	0.075%	0.058%	0.024%	0.001%	-0.013%	-0.060%			-0.060%	-0.013%	0.001%	0.025%	0.059%	0.075%	0.079%
0.072%	0.067%	0.043%	-0.012%	-0.723%	-0.022%	-0.009%	-0.060%	-0.060%	-0.009%	-0.022%	-0.731%	-0.012%	0.044%	0.066%	0.072%
0.058%	0.045%	0.004%	-0.074%	-0.098%	-0.045%	-0.022%	-0.012%	-0.012%	-0.021%	-0.044%	-0.097%	-0.074%	0.005%	0.046%	0.057%
0.028%	-0.008%	-0.072%			-0.097%	-0.723%	0.003%	0.003%	-0.723%	-0.096%			-0.072%	-0.008%	0.029%
0.016%	-0.719%	-0.093%			-0.073%	-0.010%	0.025%	0.025%	-0.011%	-0.073%			-0.093%	-0.719%	0.016%
0.028%	0.001%	-0.036%	-0.094%	-0.072%	0.004%	0.044%	0.058%	0.059%	0.044%	0.004%	-0.073%	-0.093%	-0.036%	0.001%	0.028%
0.048%	0.041%	0.002%	-0.727%	-0.008%	0.045%	0.067%	0.075%	0.075%	0.067%	0.045%	-0.008%	-0.719%	0.002%	0.041%	0.048%
0.037%	0.048%	0.028%	0.015%	0.028%	0.057%	0.072%	0.079%	0.079%	0.073%	0.057%	0.029%	0.016%	0.028%	0.049%	0.037%

- Power Distribution Error between 20μm coated and base Assembly [C3 Assembly]

Summary

- It was confirmed that the current methodology utilized for the analysis of PWR cores loaded with zirconium-based alloy cladding fuels are still valid for the analysis of the Cr-coated ATF loaded cores since the effects on the key neutronics parameters due to the thin chromium coatings are minimal.
- Any thin Cr coating on the existing cladding, however, results in reducing the assembly multiplication factor.
- From the point view of reactor fuel management, this reduction in the assembly multiplication factor can affect the cycle length and subsequently requiring additional study on the reactor core cycle analysis.