MOCUM Verification with a Heterogeneous MOX Whole Core C5G7 Benchmark Problem

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INTRODUCTION

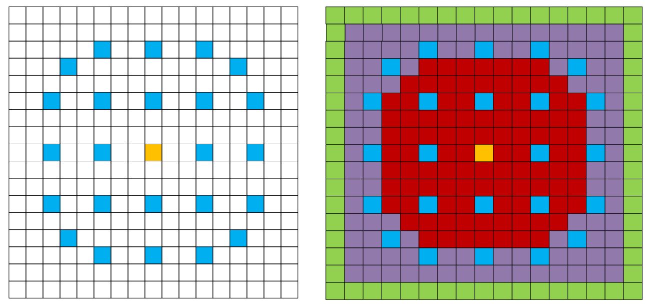
Recent advancements in computer technology has allowed for the possibility to solve complex reactor problems without homogenization, but the present benchmark problems are all limited to small scale with few fuel assemblies and homogeneity at the core level. Therefore, to verify the capabilities of the advanced neutronics codes, heterogeneous full core model shall be developed.

Recently several whole-core benchmark problems such as BEAVRS [1] and VERA [2] are developed with measured data to which computational codes can be compared. With a particular research interest on the MOX fuel, this study develops a two-dimensional (2-D) whole core MOX neutronics benchmark based on the C5G7 benchmark concept [3]. The developed MOX core benchmark will then be used to verify the accuracy of the MOCUM code, which is developed using the method of characteristic (MOC) as the flux solver with an advanced geometry processor designed for arbitrary core geometries [4-6]. MOCUM results will be compared against MCNP5 [7] results as the reference solutions.

BENCHMARK SPECIFICATION

The design of the MOX whole core benchmark problem is adopted from Ref. [8] based on the C5G7 assembly map. Each pin cell in the assemblies has identical dimension. The inner circular region (radius: 0.54cm) is filled with different fuel or structure materials, and the rest region of the square pin cell is filled with the moderator (water).

As shown in Fig. 1, the assembly is a 17×17 square lattice of pin cells, with 24 control rods (for the controlled assemblies) or 24 guide tubes (for the uncontrolled assemblies) and a central fission chamber. The pitches of the pin and assembly are 1.26 cm and 21.42 cm, respectively.



(a) (b)

Fig 1: Assembly configuration. (a) UO_2 assembly; (b) MOX assembly. Green: 4.3% MOX fuel; Violet: 7.0% MOX fuel; Red: 8.7% MOX fuel; Blue: Control rod; Orange: Fission chamber. [3]

Fig. 2 illustrates the core configuration. The reactor core contains 15×15 controlled and uncontrolled fuel assemblies. There are 48 uncontrolled UO_2 assemblies, 21 Controlled UO_2 assemblies, 28 uncontrolled MOX assemblies and 24 controlled MOX assemblies. Eight (8) different materials are used in setting up the problem (UO_2 fuel, 4.3% MOX fuel, 7.0% MOX fuel, 8.7% MOX fuel, guide tube, control rod, fission chamber and water).

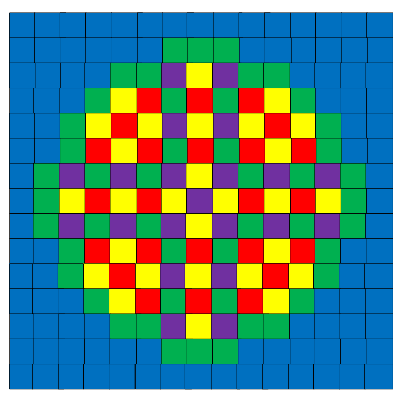


Fig 2: MOX whole core configuration (yellow: controlled MOX assembly; purple: controlled UO_2 assembly; red uncontrolled MOX assembly; green: uncontrolled UO_2 assembly). [8]

Table I: MOCUM calculation parameters

Number of fuel assemblies in one fourth core	37
Number of meshes in one fourth core	1648581
Average mesh size	$0.0157cm^2$
Number of Energy Groups	7
Number of threads for parallel computing	48
Number of Materials	8
Number of Azimuthal angles	48
Number of polar angles	3
Ray Density	$100cm^{-1}$
Convergence Criterion	10^{-8}

The one fourth core of the benchmark problem is solved by the MOCUM code and the calculation parameters are summarized in Table I. MOCUM uses Boolean operation to define the annular structures and automatically construct the nested arrays (pin and assembly arrays).

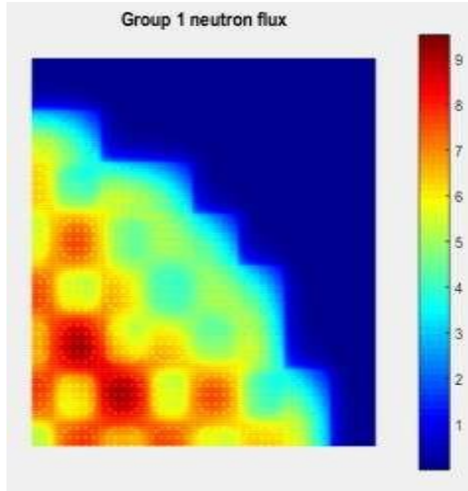
RESULTS AND DISCUSSION

The k_{eff} of the benchmark calculated from MOCUM is 1.12593 with runtime about 8.7 hours. The reference k_{eff} provided in Ref. 6 was calculated by MCNP5. The reference k_{eff} value for the benchmark problem is 1.12623 ± 0.00002. Thus the relative error between the MOCUM result and the reference result is negligible (< 0.03%). After MOCUM calculation, the assembly power and pin power profiles are available. The normalized assembly powers are presented in Table II. Due to the overwhelming number of the fuel pins, their values are not presented in this abstract. Currently, the reference value of the power and flux profiles are not available for comparison. We are working on the MCNP6 model development and the calculation to provide the reference power distribution.

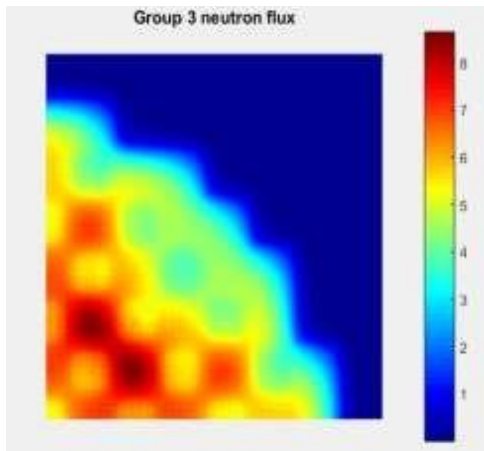
Table II: MOX whole core assembly power profile (upper left entry is the core center).

0.370	1.036	0.877	1.006	0.751	0.857	0.788
1.035	1.819	2.741	1.645	2.254	1.28	1.218
0.876	2.739	1.627	1.647	1.268	1.59	
1.004	1.642	1.646	1.053	1.342	1.188	
0.748	2.249	1.266	1.341	1.194		
0.854	1.277	1.587	1.187			
0.784	1.214					

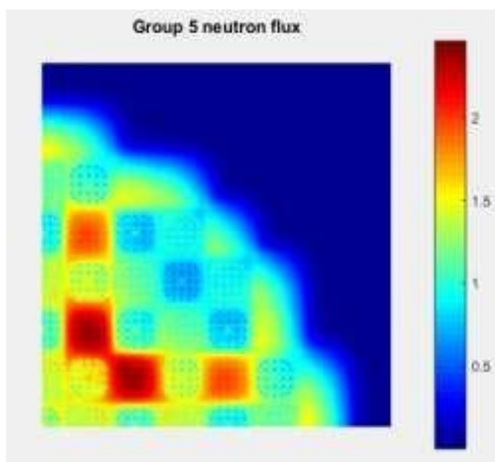
MOCUM flux distribution energy group 1, 3, 5 and 7 are displayed as Fig. 3 (a-d), and the fission reaction rate (power) distribution is displayed as Fig. 4. The X-Y 2D group-wise flux distribution clearly illustrates the spatial behavior of the neutrons at different energy range. The fission reaction rate distribution was used to verify the accurate calculation of the power distribution in MOCUM.



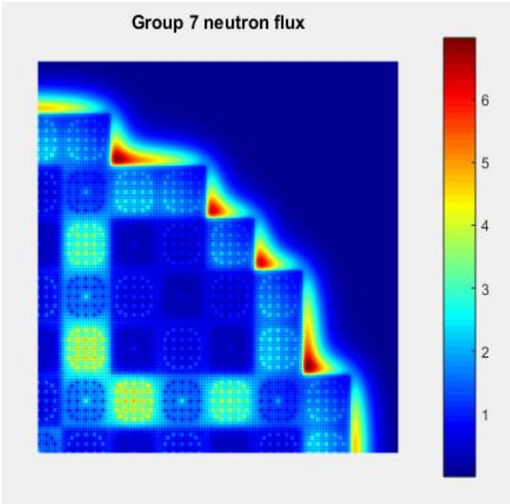
(a)



(b)



(c)



(d)
Fig. 3 MOX whole core flux distribution of energy group 1 3, 5, and 7.

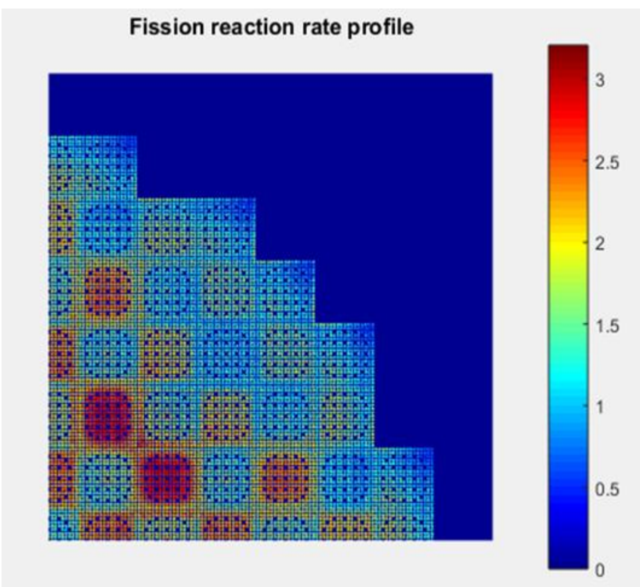


Fig. 4: Fission reaction rate (power) profile.

CONCLUSION

MOCUM k_{eff} of the extended C5G7 reactor shows good agreement with the reference MCNP5 Monte Carlo results [8]. Reference results generated from MCNP6 [9] (in progress) will be compared to provide the reference power distribution, which can be inferred by using the converged fission source number printed the in the universe map table (Table 128) in the standard output of MCNP. [10]

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