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Evaluation of General 2D Geometric Transport Code, HELIOS

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Abstract

This paper is devoted to evaluating the accuracy of general 2D geometric transport code, HELIOS, and determining the order of merit in modeling for some important HELIOS input parameters. Benchmark test for 12 critical lattices show that HELIOS predicts criticality accurately within experimental uncertainties, showing only 250 pcm overestimation with a standard deviation of 450 pcm. The sensitivity test suggest that current coupling order, neutron group library, geometrical modeling, and resonance options must be considered carefully to obtain accurate results. Especially, current coupling order and sub-rings in fuel regions turn out to be most critical in HELIOS modeling. For MOX loaded cores, it is additionally necessary to pay attention to the resonance option and the validity of small group neutron library.

I. Introduction

HELIOS[1] is a neutron and gamma transport code for lattice burnup, in general two dimensional geometry. There are two main objectives for developing HELIOS : geometric flexibility and reduction of the computational time. This geometric flexibility requires an accurate and versatile transport method. An obvious choice is collision probability(CP) method. However, long run time has restricted its practical use to small and simple system as done in WIMS or CPM code. That is why the current coupling collision probability(CCCP) method has been adopted in HELIOS. In this method, the system can be partitioned arbitrarily into heterogeneous space elements. These space elements are coupled by interface currents with a discretized angular dependence. Inside the elements, CPs are used.

Because HELIOS code has some special features to solve the transport equations as mentioned above, this paper is devoted to the evaluation of accuracy of HELIOS and the examination of factors to be considered in modeling for HELIOS. Section II and III present benchmark results for many critical lattices and sensitivity tests of various features of HELIOS respectively. By evaluating KOFA and hexagonal assemblies, presented in section IV the order of merit with respect to some important modeling parameters which affect the accuracy.

Finally, conclusion and comment is given in section V.

II. Benchmark Test of HELIOS Verification

To test the accuracy of HELIOS, we calculated the effective multiplication factor(k_{eff}) of 12 critical experiments which include both UO2 and MOX fuels in reactangular and triangular rod array. An ideal calculational model should give k_{eff} = 1.0. Deviations are always present, but should be evaluated on a statistical basis. As shown in table 1 which is the summary of computations, HELIOS overestimates criticality by about 250 pcm with a standard deviation of 410 pcm. This result is in good agreement with experimental data within the experimental uncertainties.

III. Sensitivity Analysis of HELIOS Features

It is important to know the characteristics of HELIOS to use it as a member of nuclear design system. In this section, some specific features of HELIOS were evaluated by sensitivity test. Since many sensitivity tests have been performed and reported by SCANDPOWER[2], the developer of HELIOS, this paper was tried to deal with different but critical subjects, such as the number of groups in neutron library, current coupling order, geometric modeling, and other important options of HELIOS, etc.

Three kinds of neutron libraries are available for HELIOS[3]: 34, 89, and 190 group neutron libraries based on ENDF/B-VI. Since 34 and 89 group libraries are generated from 190 group master neutron library for light water reactors(LWR), one speculates that the accuracy of 34 or 89 group data base would be poor for the reactors having a different spectrum from LWRs. The figure 1 shows the difference of infinite multiplication factors(k_∞) of a lattice loaded with UO_2 and MOX fuel between 34 (or 89) group and 190 group neutron libraries. As shown in figure 1, infinite multiplication factors for MOX cases calculated by 34 and 89 group libraries are 1700 and 560 pcm below at BOC than that of 190 group library. This result suggests that the 34 group library is not appropriate for the analysis of MOX fuels. In contrast with MOX cases, the 34 group library shows very consistent result for UO_2 fuels with the maximum difference of infinite multiplication factor of less than 300 pcm.

The CCCP method is an important feature of HELIOS to reduce run time. Since the interface currents, in CCCP method, are coupled by current coupling order(k) with discretized angular dependence[1], the accuracy and run time depend on the choice of current coupling order. Figure 2, which represents the difference of infinite multiplication factors between current coupling order 2 and others, shows that the infinite multiplication factor is very sensitive to k value.

Since geometric self-shielding effect can be effectively treated by dividing the whole region of high absorber material into many sub regions, the sensitivity test of geometric modeling was carried out by dividing the fuel and moderator regions into several sub-rings. The more sub-rings we have, as shown in figure 4 and 5, the more accurate the results become. But it is generally enough to divide the fuel region into two sub-rings. The sub-ring modeling is not necessary for all lattices having higher moderation ratio than approximately 1.0.

Other sensitivity tests, such as resonance treatment options, isotopic identification number, *and predictor-corrector method, etc., were performed.* There are nine resonance options(RES) in HELIOS. RES specifies which resonance isotopes act together. The library of HELIOS has 31 resonance isotopes and these isotopes are treated individually by RES 9. RES 4 through 8 treat U^{238} individually with other heavy metal isotopes but RES 1, 2, and 3 do not. In view of the difference of infinite multiplication factors between RES 9 and others, RES 4 or higher value is proper in most cases. The sensitivity test of predictor & corrector(P&C) method suggests that depletion with predictor method only will produce accurate result with a burnup interval of 250 MWD or smaller.

VI. Analysis of Fuel Assembly

Section III shows that the accuracy of HELIOS depends strongly on such factors as current coupling order, geometrical modeling, and the number of neutron groups of library etc. This fact implies that if we use HELIOS to calculate new type of fuel assembly, i.e. hexagonal, MOX fuel, etc., relevant modeling *input parameters which affect the accuracy must* be carefully evaluated. To gain an insight into the proper order of merit, we evaluated a KOFA having 8 gadolinia absorber rods and hexagonal MOX loaded FA. As shown in table 2, and figure 4 and 5, it appears that the current coupling order and geometric modeling should be first determined because they affect the accuracy of reactivity and pin power distributions to the greatest extent. In MOX loaded cases, the effect due to the number of groups in neutron library and the resonance option is not negligible.

V. Conclusion

The criticality calculated by HELIOS for 12 critical lattice experiments is overestimated by only 250 pcm with 450 pcm standard deviation. This result is in good agreement with experimental data, within the experimental uncertainties. From the sensitivity tests and evaluations of rectangular or hexagonal fuel assemblies, it is shown that the accuracy of HELIOS depend strongly on the following factors: current coupling order, geometrical modeling, the number of neutron groups of library, resonance option. Generally the current coupling order and sub-rings in fuel regions must become the first order of merit in developing HELIOS model. For MOX loaded cores, it is additionally necessary to pay attention to the resonance option and the validity of small group neutron library.

VI. References

1. HELIOS Methods, SCANDPOWER (1994).
2. HELIOS verification, SCANDPOWER, T3/41.16.10(1993).
3. Generation and contents of the ENDF/B-VI based HELIOS library hy941a, SCANDPOWER ,TN2/44.70.13(1994)
4. ORION manual, SCANDPOWER (1994).

Table 1. Benchmark Tests for HELIOS Verification

Critical Lattices	k_{eff}	Average	Standard Deviation.	Fuel Type
BAPL 1	1.00076	0.99954	0.00158	UO2
BAPL 2	1.00070			UO2
BAPL 3	0.99717			UO2
TRX 1	0.99611	0.99816	0.00205	U-metal
TRX 2	1.00020			U-metal
B&W 1	0.99936	1.00206	0.00270	UO2
B&W 2	1.00476			MOX
WH 1	1.00852	1.00624	0.00456	UO2
WH 9	1.00122			UO2
WH 15	0.99985			UO2
AEE 1	1.00699			UO2
BNWL 1	1.01461			MOX
Average	1.00251		0.00413	

Table 2. Effect of different modelings on the accuracy of HELIOS

		KOFA with 8 gadolinia rods	MOX loaded Hexagonal FA
Reference k_{∞}		1.12110	1.33758
Factors	number of groups of library	- 200 pcm	- 350 pcm
	sub-rings in fuel regions	- 400 pcm	- 250 pcm
	Resonance option	+ 30 pcm	+ 360 pcm
	current coupling order	+ 500 pcm	+ 50 pcm

Reference case = 89 groups neutron library, 3 or more sub-rings in fuel, resonance option (RES) = 9, current coupling order(k) = 2.

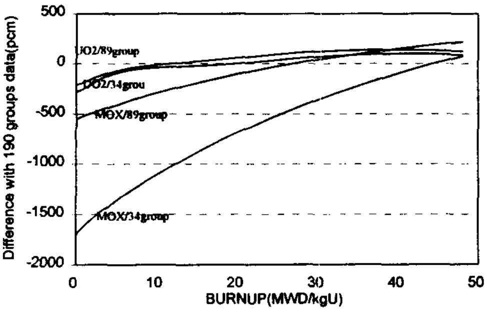


Figure 1. The effect of the number of groups

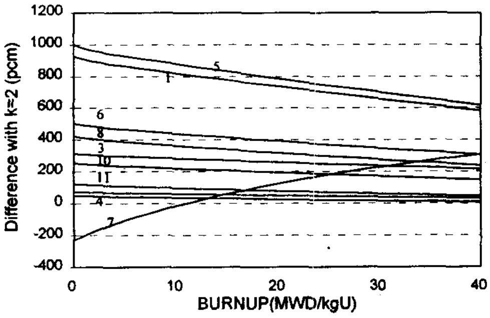


Figure 2. The effect of current coupling order(k)

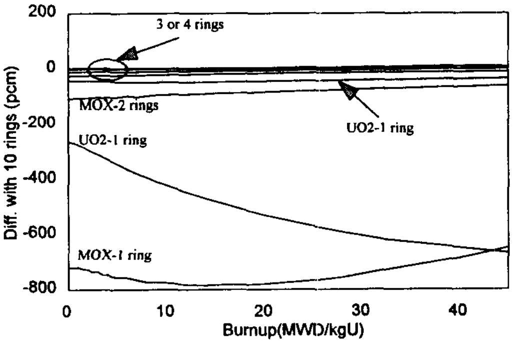


Figure 3. Sub-ring effect in fuel region

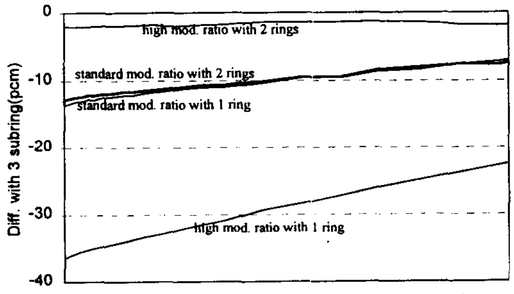
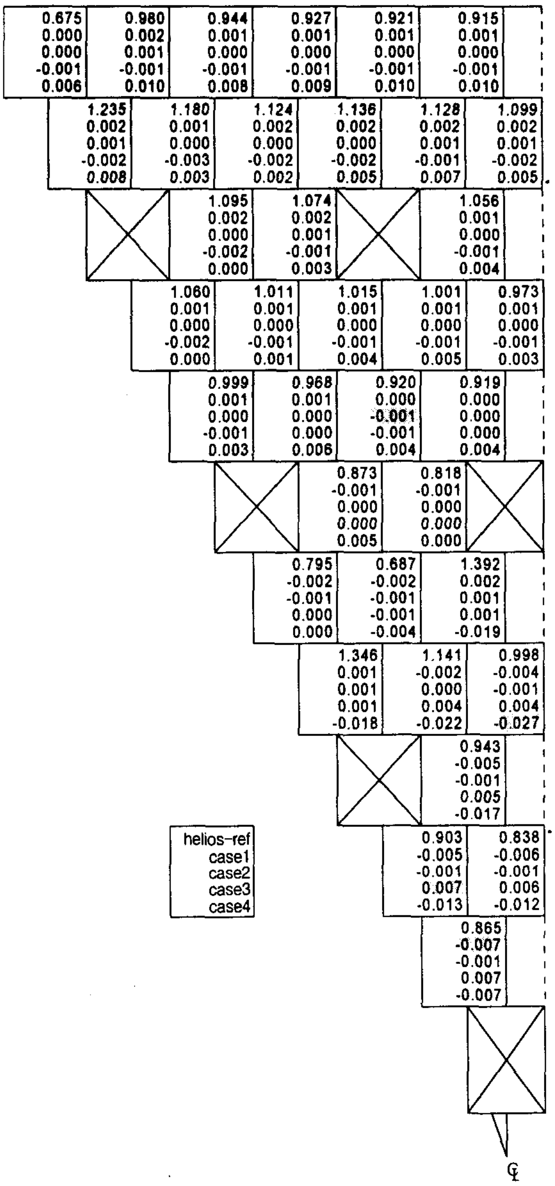


Figure 4. Sub-ring effect in moderation region



0.675	0.980	0.944	0.927	0.921	0.915
0.000	0.002	0.001	0.001	0.001	0.001
0.000	0.001	0.000	0.000	0.000	0.000
-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
0.006	0.010	0.008	0.009	0.010	0.010

1.235	1.180	1.124	1.136	1.128	1.099
0.002	0.001	0.002	0.002	0.002	0.002
0.001	0.000	0.000	0.000	0.001	0.001
-0.002	-0.003	-0.002	-0.002	-0.001	-0.002
0.008	0.003	0.002	0.005	0.007	0.005

	1.095	1.074		1.056
	0.002	0.002		0.001
	0.000	0.001		0.000
	-0.002	-0.001		-0.001
	0.000	0.003		0.004

1.060	1.011	1.015	1.001	0.973
0.001	0.001	0.001	0.001	0.001
0.000	0.000	0.000	0.000	0.000
-0.002	-0.001	-0.001	-0.001	-0.001
0.000	0.001	0.004	0.005	0.003

0.999	0.968	0.920	0.919
0.001	0.001	0.000	0.000
0.000	0.000	-0.001	0.000
-0.001	0.000	-0.001	0.000
0.003	0.006	0.004	0.004

	0.873	0.818	
	-0.001	-0.001	
	0.000	0.000	
	0.000	0.000	
	0.005	0.000	

0.795	0.687	1.392
-0.002	-0.002	0.002
-0.001	-0.001	0.001
0.000	-0.001	0.001
0.000	-0.004	-0.019

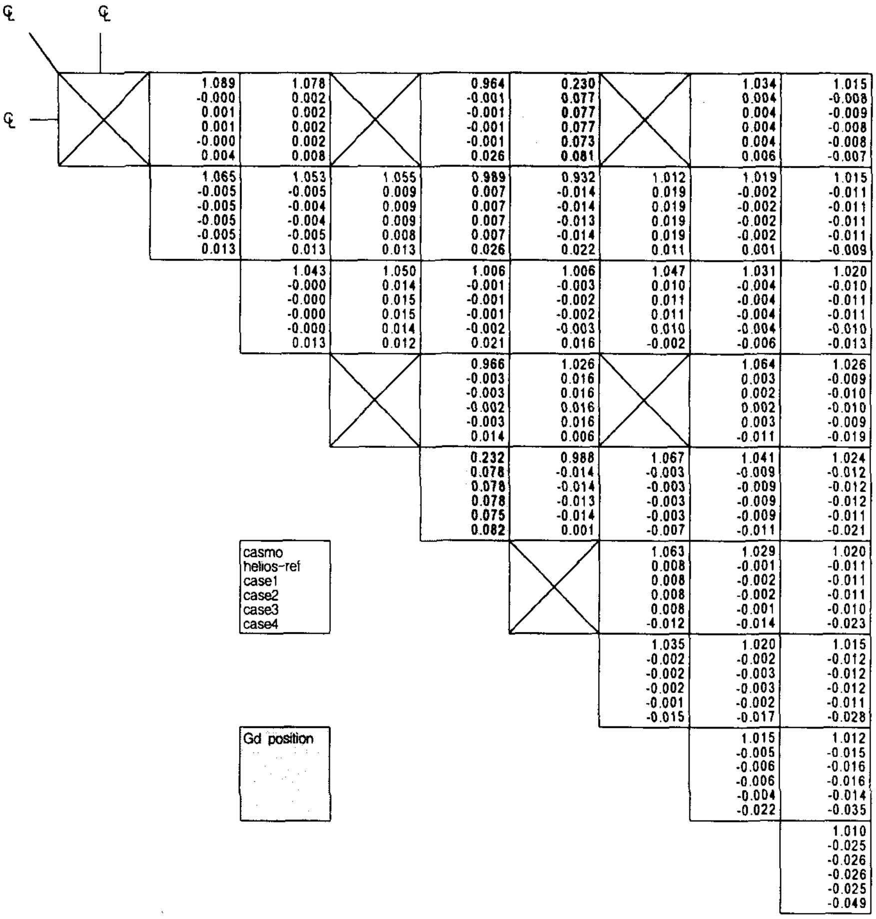
1.346	1.141	0.998
0.001	-0.002	-0.004
0.001	0.000	-0.001
0.001	0.004	0.004
-0.018	-0.022	-0.027

	0.943
	-0.005
	-0.001
	0.005
	-0.017

0.903	0.838
-0.005	-0.006
-0.001	-0.001
0.007	0.006
-0.013	-0.012

0.865
-0.007
-0.001
0.007
-0.007

Figure 5. Power distribution in hexagonal FA
ref = 89group library, RES=9, k=2
4 subrings in fuel
case1 = same ref. without 34 group
case2 = same ref. without 1 subring
case3 = same ref. without RES=1
case4 = same ref. without k=1



	1.089 -0.000 0.001 0.001 -0.000 0.004	1.078 0.002 0.002 0.002 0.002 0.008		0.964 -0.001 -0.001 -0.001 -0.001 0.026	0.230 0.077 0.077 0.077 0.073 0.081		1.034 0.004 0.004 0.004 0.004 0.006	1.015 -0.008 -0.009 -0.008 -0.008 -0.007
	1.065 -0.005 -0.005 -0.005 -0.005 0.013	1.053 -0.005 -0.004 -0.004 -0.005 0.013	1.055 0.009 0.009 0.009 0.008 0.013	0.989 0.007 0.007 0.007 0.007 0.026	0.932 -0.014 -0.014 -0.013 -0.014 0.022	1.012 0.019 0.019 0.019 0.019 0.011	1.019 -0.002 -0.002 -0.002 -0.002 0.001	1.015 -0.011 -0.011 -0.011 -0.011 -0.009
		1.043 -0.000 -0.000 -0.000 -0.000 0.013	1.050 0.014 0.015 0.015 0.014 0.012	1.006 -0.001 -0.001 -0.001 -0.002 0.021	1.006 -0.003 -0.002 -0.002 -0.003 0.016	1.047 0.010 0.011 0.011 0.010 -0.002	1.031 -0.004 -0.004 -0.004 -0.004 -0.006	1.020 -0.010 -0.011 -0.011 -0.010 -0.013
				0.966 -0.003 -0.003 -0.002 -0.003 0.014	1.026 0.016 0.016 0.016 0.016 0.006		1.064 0.003 0.002 0.002 0.003 -0.011	1.026 -0.009 -0.010 -0.010 -0.009 -0.019
				0.232 0.078 0.078 0.078 0.075 0.082	0.988 -0.014 -0.014 -0.013 -0.014 0.001	1.067 -0.003 -0.003 -0.003 -0.003 -0.007	1.041 -0.009 -0.009 -0.009 -0.009 -0.011	1.024 -0.012 -0.012 -0.012 -0.011 -0.021
						1.063 0.008 0.008 0.008 0.008 -0.012	1.029 -0.001 -0.002 -0.002 -0.001 -0.014	1.020 -0.011 -0.011 -0.011 -0.010 -0.023
						1.035 -0.002 -0.002 -0.002 -0.001 -0.015	1.020 -0.002 -0.003 -0.003 -0.002 -0.017	1.015 -0.012 -0.012 -0.012 -0.011 -0.028
							1.015 -0.005 -0.006 -0.006 -0.004 -0.022	1.012 -0.015 -0.016 -0.016 -0.014 -0.035
								1.010 -0.025 -0.026 -0.026 -0.025 -0.049

Figure 6. Power distribution in KOFA
ref = 89group library, RES=9, k=2, 4 subrings in fuel
case1 = same ref. without 34 group
case2 = same ref. without 1 subring
case3 = same ref. without RES=1
case4 = same ref. without k=1