EVALUATION OF A TENTATIVE CONTIGUOUS MESH PARTICLE TRACKING CAPABILITY AND UPDATE OF MCNP6 PERFORMANCE BENCHMARKS WITH MCNP6's UNSTRUCTURED MESH

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1. INTRODUCTION

This document reports on an effort to produce a faster tracking algorithm for MCNP6's [1] Unstructured Mesh (UM) feature when contiguous meshes (CM) are used. Performance results for such work are presented.

Also, this document provides MCNP6 users with an update on the calculational performance of the UM feature. Results from three well documented benchmarks, used in the Verification and Validation (V&V) process for MCNP, are presented in this paper. These include the Big Ten Criticality Benchmark [2], the Godiva simple uranium sphere [2], and the Kobayashi analytical benchmark problem [3]. Relevant, prior V&V work at Los Alamos National Laboratory (LANL) with these benchmarks can be found in References [4 - 6].

2. DISCUSSION

Early requirements for MCNP6's UM feature included the ability to track particles on meshes that contain overlapping elements and/or gaps between elements. Both of these conditions arise for one or more reasons. Some Computer Aided Desing (CAD) / Computer Aided Engineering (CAE) tools permit meshing at the part level in addition to meshing at the assembly level. When parts with curved boundaries are intended to share a surface, but are meshed independently before inclusion in the assembly, common nodes do not exist and there is a propensity for gaps and overlaps to occur. In addition, the non-conformity of the individual finite elements to the true solid model surfaces play a role in producing overlap and gap conditions with these types of surfaces. This results in non-contiguous mesh (NCM) models.

Meshing at the assembly level will produce shared nodes between parts, will not solve the conformality issue, and will eliminate overlaps and gaps in these models. The mesh produced on the assembly results in CM models – one without the aforementioned gaps and overlaps.

Until recently, whether the UM used by MCNP6 was contiguous or not, the same tracking routines were used for both mesh types (contiguous as well as non-contiguous). Therefore, it was unknown what performance penalty existed when a contiguous mesh was used with the routines that accounted for the overlaps and gaps. One objective of the current work was to create separate high-level tracking routines that avoided the overlap and gap tracking machinery before evaluating benchmarks with the standard (existing) and new routines to obtain an understanding of the penalty associated with the gap and overlap treatments.

A second objective of this work was to compare the performance of the existing code, including the proposed contiguous routines, to the performance results obtained from several studies [4,5] completed in the past. Part of this work involves using the contiguous mesh models from Reference [5] in a three way comparison: 1) the code as it existed in the past [5], year 2012; 2) the code as it currently exists, year 2015, with the overlap and gap treatment; and 3) the code as it currently exists, year 2015, with the new top-level contiguous treatment. Another part of this performance assessment work involves evaluating the code under conditions 1) and 2) when the comparison is between contiguous and non-contiguous UM models as was done in Reference [4]. The contiguous UM models from Reference [4] work permit an additional evaluation of the new contiguous tracking routines in a similar fashion as the Reference [5] comparison described above. Similarly, the code can be evaluated under conditions 2) and 3) with the UM equivalent of the Kobayashi benchmarks [6].

All simulations in this work were completed using a serial version of MCNP6. The code was optimized to level 1 with version 12.1.5 of the Intel Fortran Compiler on a Linux cluster. Calculations were performed using an Intel Xeon X5550 CPU at 2.67 GHz on the 64-bit CHAOS operating system.

3. GODIVA BENCHMARK

3.1. Characteristics

The Godiva benchmark consists of a bare sphere of highly enriched uranium (HEU) with a radius of 8.7407 cm. The original purpose of this benchmark from a calculational perspective is to see how well codes, models, and data can predict the expected k_{eff} value of 1. This is represented by the *K-Code* cases below. As with the Reference [5] work, two additional altered versions of the Godiva benchmark were included for performance assessment of the UM tracking routines. The *Void* problem consist of the standard Godiva geometry where all of the materials have been voided out through the use of MCNP's VOID card and the kcode source was replaced with a fixed point source near the origin. This essentially becomes a ray-tracing calculation. The *Gamma* problem replaces the k_{eff} calculation of the K-Code simulations with an isotropic, 6.1 MeV gamma point source positioned at the center of the sphere. Materials remain the same in the *Gamma* cases, but only photons are tracked.

3.2. Results

In order to achieve consistent timing information from the same computing hardware for all problem sets, an archived 2012 build of MCNP6 was used to re-calculate the pertinent cases from Reference [5]. The different benchmark types (*K-Code, Void, Gamma*) were run with CSG and UM geometries using this 2012 build. Then, the same set of calculations were performed with the UM geometries using the standard and contiguous builds with the current (2015) MCNP version. Each set of calculations were completed with 100,000 and 10,000,000 histories, as in Reference [5]. Various results are provided and compared in Tables I to VIII.

Figures 1 to 3 provide a comparison of the Godiva *K-Code, Void,* and *Gamma* simulations for the series of calculations using 10^5 histories; data presented in Tables II to IV. These figures also include the results of the contiguous UM routines. The contiguous feature results in essentially the same performance as the standard build. In Figures 1 to 3, the contiguous and standard results are indistinguishable. This is because of the efficient manner in which the unstructured mesh feature of MCNP handles overlaps and gaps. The checking of gaps and overlaps is designed so as to minimize performance impact. These tables do not extend fully to the finest 0.45 cm mesh seed case because of queue time limitations on the LANL supercomputing clusters.

Table V provides data in an equivalent format as Table I except that the results are for 10^7 particle histories and not 10^5. This table also shows performance improvements relative to 2012, but on first glance the number presented in the two tables are deceiving and bear further explanation.

It is important to note that although calculation time is reduced between the 2015 and 2012 builds, the total runtimes range from approximately the same to moderately improved times. This can be attributed to some reworking of the particle tracking routines that handle unstructured mesh geometries and some UM code reorganization.

One of the largest changes since 2012 deals with the nearest neighbor processing for the elements. In the 2012 build, nearest neighbor lists for an element were constructed dynamically, as-needed during tracking. This was deemed sufficient at the time, but it has since been realized that is makes more sense to include this with the rest of the UM input processing where more efficient parallelization can eventually be implemented; this will benefit the processing of large meshes. In the 2015 build, the construction of the nearest neighbor lists for elements now occurs during the unstructured mesh geometry setup phase. This change allows threads to solely perform particle tracking rather than halting calculations for construction of nearest neighbor lists.

A result of the UM code reorganization is a larger setup time for problems compared to the 2012 build; Figure 7 and Table IX show how setup time is affected as the element count of a problem increases. Mostly, this is a factor of 2 increase. The jitter in the ratios for large seeds is because of the quick processing times for low element counts coupled with the precision with which MCNP outputs the time. The performance ratio for the smaller seed value / larger element counts are more indicative of the effect from nearest neighbor code reorganization.

It is clear from the preceding discussion on the code modifications that the calculation time speedups present in the tables can be misleading for they show the effect of removing the construction of the nearest neighbor lists from "as needed during tracking" status to "generate all during problem setup" status. At this time a truer indication of the speed improvements (attributed to better use of the nearest neighbor lists) for the UM tracking since 2012 is given by the total time speedups. For longer running problems that are more indicative of what users will probably be attempting, the speedups (i.e., see Table V) range from approximately 30 to 40%.

Figures 4 to 6 provide a comparison of the Godiva *K-Code*, *Void*, and *Gamma* simulations where each calculation was performed with 10^7 histories. These figures also include the results of the contiguous UM routine. The data used to generate Figures 4 to 6 is given in Tables VI to VIII. As with the 10^5 history simulations, these tables do not extend fully to the finest 0.45 cm mesh seed case because the calculations could not be finished courtesy of queue time limitations on the LANL supercomputing clusters.

For future use of these performance benchmark problems, it is recommended that the 100,000 history runs be dropped in favor of running only with longer calculational times in order to obtain meaningful run times from the code.

The effect of the MODE card on the K-Code Godiva trials was also investigated with the 2015 build. To this point, calculations only tracked neutrons (mode n). The (n,γ) reactions possible in the Godiva K-Code simulation play a role in total energy deposition; thus, it is important to assess the impact that tracking the photons has on performance. Table X and Figure 8 compare the results of the different MODE card entries on the Godiva K-code simulation performance. What is seen here is basically a constant increase in the run time when the second particle is added to the mode card.

Table I: Godiva mesh results for 10^5 histories: Standard 2015 vs 2012 Results

	Mesh Seed (cm)	Number of Elements	Total Runtime (min) [2015]	Calc. Time (min) [2015]	Total Runtime (min) [2012]	Calc. Time (min) [2012]	Total Time Speedup*	Calc. Time Speedup*
K-Code	0.45	401723	99.04	0.53	110.19	62.16	1.11	117.28
	0.55	320069	63.27	0.51	70.41	40.61	1.11	79.63
	0.65	161971	16.00	0.43	17.84	10.63	1.12	24.72
	0.80	93593	5.62	0.38	6.29	3.84	1.12	10.11
	0.95	59160	2.45	0.33	2.76	1.78	1.13	5.39
	1.00	51336	1.93	0.33	2.21	1.40	1.15	4.24
	1.10	39250	1.25	0.31	1.46	1.02	1.17	3.29
	1.50	16349	0.44	0.25	0.55	0.45	1.25	1.80
	1.70	13305	0.37	0.25	0.47	0.41	1.27	1.64
	2.00	9722	0.31	0.23	0.40	0.35	1.29	1.52
	3.00	3142	0.22	0.19	0.27	0.25	1.23	1.32
	4.00	1375	0.30	0.27	0.23	0.21	0.77	0.78
Void	0.45	401723	101.40	0.72	110.78	61.17	1.09	84.96
	0.55	320069	62.77	0.67	68.42	39.19	1.09	58.49
	0.65	161971	16.74	0.56	17.94	10.60	1.07	18.93
	0.80	93593	5.67	0.47	6.32	3.88	1.11	8.26
	0.95	59160	2.52	0.41	2.80	1.82	1.11	4.44
	1.00	51336	2.00	0.40	2.24	1.50	1.12	3.75
	1.10	39250	1.31	0.38	1.48	1.05	1.13	2.76
	1.50	16349	0.47	0.29	0.54	0.46	1.15	1.59
	1.70	13305	0.39	0.27	0.46	0.40	1.18	1.48
	2.00	9722	0.31	0.24	0.37	0.34	1.19	1.42
	3.00	3142	0.20	0.18	0.23	0.22	1.15	1.22
	4.00	1375	0.15	0.14	0.17	0.16	1.13	1.14
Gamma	0.45	401723	104.08	0.75	52.40	3.85	0.50	5.13
	0.55	320069	63.68	0.71	32.27	3.01	0.51	4.24
	0.65	161971	16.86	0.62	8.88	1.66	0.53	2.68
	0.80	93593	5.82	0.57	3.49	1.06	0.60	1.86
	0.95	59160	2.64	0.52	1.79	0.81	0.68	1.56
	1.00	51336	2.13	0.52	1.50	0.75	0.70	1.44
	1.10	39250	1.45	0.51	1.10	0.66	0.76	1.29
	1.50	16349	0.61	0.43	0.57	0.49	0.93	1.14
	1.70	13305	0.53	0.41	0.52	0.46	0.98	1.12
	2.00	9722	0.45	0.38	0.46	0.42	1.02	1.11
	3.00	3142	0.36	0.33	0.37	0.35	1.03	1.06
	4.00	1375	0.31	0.30	0.33	0.32	1.06	1.07

*Taken as the quotient of the 2012 timing divided by the 2015 timing.

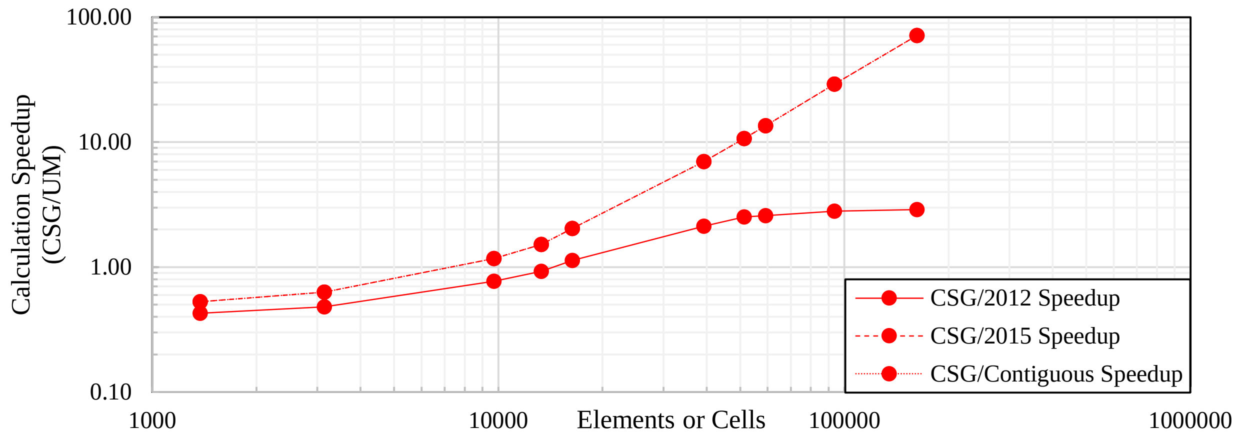


Figure 1: Performance comparison for 10^5 histories of the Godiva *K-Code* problem for the 2015 MCNP6 build, 2012 MCNP6 build, and 2015 MCNP6 build with contiguous mesh routines being used.

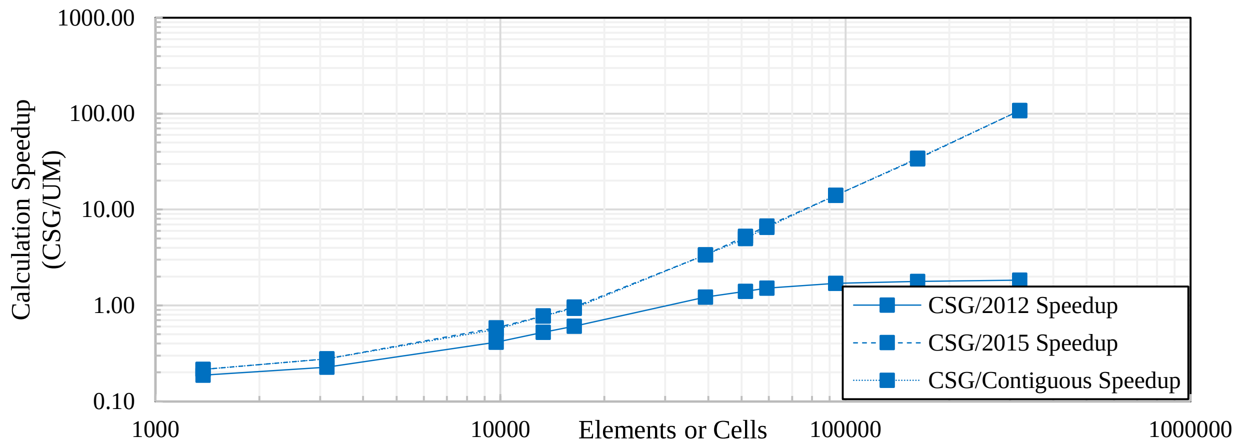


Figure 2: Performance comparison for 10^5 histories of the Godiva *Void* problem for the 2015 MCNP6 build, 2012 MCNP6 build, and 2015 MCNP6 build with contiguous mesh routines being used.

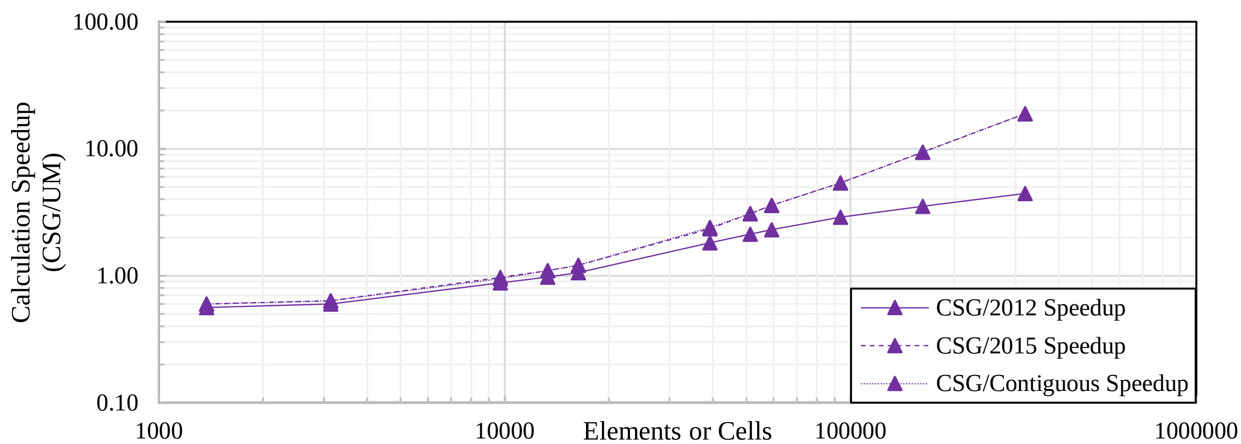


Figure 3: Performance comparison for 10^5 histories of the Godiva *Gamma* source problem for the 2015 MCNP6 build, 2012 MCNP6 build, and 2015 MCNP6 build with contiguous mesh routines being used.

Table II: Godiva mesh results for 10^5 histories: Standard 2015 UM vs 2012 CSG Results

	Mesh Seed (cm)	Number of Elements	Total Runtime (min) [2015]	Calc. Time (min) [2015]	Total Runtime (min) [CSG]	Calc. Time (min) [CSG]	Total Time Speedup*	Calc. Time Speedup*
K-Code	0.65	161971	16.00	0.43	154.97	30.66	9.69	71.30
	0.80	93593	5.62	0.38	52.41	10.78	9.33	28.37
	0.95	59160	2.45	0.33	21.35	4.60	8.71	13.94
	1.00	51336	1.93	0.33	16.17	3.53	8.38	10.70
	1.10	39250	1.25	0.31	9.63	2.17	7.70	7.00
	1.50	16349	0.44	0.25	1.89	0.51	4.30	2.04
	1.70	13305	0.37	0.25	1.31	0.38	3.54	1.52
	2.00	9722	0.31	0.23	0.79	0.27	2.55	1.17
	3.00	3142	0.22	0.19	0.20	0.12	0.91	0.63
	4.00	1375	0.30	0.27	0.13	0.09	0.43	0.33
Void	0.55	320069	62.77	0.67	563.24	72.07	8.97	107.57
	0.65	161971	16.74	0.56	148.03	18.88	8.84	33.71
	0.80	93593	5.67	0.47	50.28	6.59	8.87	14.02
	0.95	59160	2.52	0.41	20.24	2.75	8.03	6.71
	1.00	51336	2.00	0.40	15.31	2.10	7.66	5.25
	1.10	39250	1.31	0.38	9.06	1.28	6.92	3.37
	1.50	16349	0.47	0.29	1.72	0.28	3.66	0.97
	1.70	13305	0.39	0.27	1.19	0.21	3.05	0.78
	2.00	9722	0.31	0.24	0.69	0.14	2.23	0.58
	3.00	3142	0.20	0.18	0.14	0.05	0.70	0.28
	4.00	1375	0.15	0.14	0.07	0.03	0.47	0.21
Gamma	0.55	320069	63.68	0.71	513.31	13.42	8.06	18.90
	0.65	161971	16.86	0.62	132.38	5.84	7.85	9.42
	0.80	93593	5.82	0.57	45.83	3.07	7.87	5.39
	0.95	59160	2.64	0.52	19.21	1.87	7.28	3.60
	1.00	51336	2.13	0.52	14.58	1.60	6.85	3.08
	1.10	39250	1.45	0.51	8.94	1.20	6.17	2.35
	1.50	16349	0.61	0.43	1.93	0.52	3.16	1.21
	1.70	13305	0.53	0.41	1.41	0.45	2.66	1.10
	2.00	9722	0.45	0.38	0.92	0.37	2.04	0.97
	3.00	3142	0.36	0.33	0.31	0.21	0.86	0.64
	4.00	1375	0.31	0.30	0.22	0.18	0.71	0.60

*Taken as the quotient of the CSG timing divided by the 2015 UM timing

Table III: Godiva mesh results for 10^5 histories: Contiguous 2015 UM vs 2012 CSG Results

	Mesh Seed (cm)	Number of Elements	Total Runtime (min) [2015]	Calc. Time (min) [2015]	Total Runtime (min) [CSG]	Calc. Time (min) [CSG]	Total Time Speedup*	Calc. Time Speedup*
K-Code	0.65	161971	16.12	0.43	154.97	30.66	9.61	71.30
	0.80	93593	5.69	0.37	52.41	10.78	9.21	29.14
	0.95	59160	2.46	0.34	21.35	4.60	8.68	13.53
	1.00	51336	1.93	0.33	16.17	3.53	8.38	10.70
	1.10	39250	1.25	0.31	9.63	2.17	7.70	7.00
	1.50	16349	0.44	0.25	1.89	0.51	4.30	2.04
	1.70	13305	0.37	0.25	1.31	0.38	3.54	1.52
	2.00	9722	0.31	0.23	0.79	0.27	2.55	1.17
	3.00	3142	0.21	0.19	0.20	0.12	0.95	0.63
	4.00	1375	0.19	0.17	0.13	0.09	0.68	0.53
Void	0.55	320069	63.36	0.67	563.24	72.07	8.89	107.57
	0.65	161971	16.22	0.55	148.03	18.88	9.13	34.33
	0.80	93593	5.77	0.47	50.28	6.59	8.71	14.02
	0.95	59160	2.52	0.42	20.24	2.75	8.03	6.55
	1.00	51336	2.01	0.42	15.31	2.10	7.62	5.00
	1.10	39250	1.31	0.38	9.06	1.28	6.92	3.37
	1.50	16349	0.47	0.3	1.72	0.28	3.66	0.93
	1.70	13305	0.39	0.27	1.19	0.21	3.05	0.78
	2.00	9722	0.31	0.25	0.69	0.14	2.23	0.56
	3.00	3142	0.2	0.18	0.14	0.05	0.70	0.28
	4.00	1375	0.15	0.14	0.07	0.03	0.47	0.21
Gamma	0.55	320069	62.37	0.71	513.31	13.42	8.23	18.90
	0.65	161971	16.68	0.62	132.38	5.84	7.94	9.42
	0.80	93593	5.87	0.57	45.83	3.07	7.81	5.39
	0.95	59160	2.63	0.52	19.21	1.87	7.30	3.60
	1.00	51336	2.12	0.52	14.58	1.60	6.88	3.08
	1.10	39250	1.44	0.5	8.94	1.20	6.21	2.40
	1.50	16349	0.61	0.43	1.93	0.52	3.16	1.21
	1.70	13305	0.53	0.41	1.41	0.45	2.66	1.10
	2.00	9722	0.46	0.39	0.92	0.37	2.00	0.95
	3.00	3142	0.36	0.33	0.31	0.21	0.86	0.64
	4.00	1375	0.32	0.3	0.22	0.18	0.69	0.60

*Taken as the quotient of the CSG timing divided by the 2015 UM timing

Table IV: Godiva mesh results for 10^5 histories: 2012 UM vs 2012 CSG Results

	Mesh Seed (cm)	Number of Elements	Total Runtime (min) [2012]	Calc. Time (min) [2012]	Total Runtime (min) [CSG]	Calc. Time (min) [CSG]	Total Time Speedup*	Calc. Time Speedup*
K-Code	0.65	161971	17.84	10.63	154.97	30.66	8.69	2.88
	0.80	93593	6.29	3.84	52.41	10.78	8.33	2.81
	0.95	59160	2.76	1.78	21.35	4.60	7.74	2.58
	1.00	51336	2.21	1.40	16.17	3.53	7.32	2.52
	1.10	39250	1.46	1.02	9.63	2.17	6.60	2.13
	1.50	16349	0.55	0.45	1.89	0.51	3.44	1.13
	1.70	13305	0.47	0.41	1.31	0.38	2.79	0.93
	2.00	9722	0.40	0.35	0.79	0.27	1.98	0.77
	3.00	3142	0.27	0.25	0.20	0.12	0.74	0.48
	4.00	1375	0.23	0.21	0.13	0.09	0.57	0.43
Void	0.55	320069	68.42	39.19	563.24	72.07	8.23	1.84
	0.65	161971	17.94	10.60	148.03	18.88	8.25	1.78
	0.80	93593	6.32	3.88	50.28	6.59	7.96	1.70
	0.95	59160	2.80	1.82	20.24	2.75	7.23	1.51
	1.00	51336	2.24	1.50	15.31	2.10	6.83	1.40
	1.10	39250	1.48	1.05	9.06	1.28	6.12	1.22
	1.50	16349	0.54	0.46	1.72	0.28	3.19	0.61
	1.70	13305	0.46	0.40	1.19	0.21	2.59	0.53
	2.00	9722	0.37	0.34	0.69	0.14	1.86	0.41
	3.00	3142	0.23	0.22	0.14	0.05	0.61	0.23
	4.00	1375	0.17	0.16	0.07	0.03	0.41	0.19
Gamma	0.55	320069	32.27	3.01	513.31	13.42	15.91	4.46
	0.65	161971	8.88	1.66	132.38	5.84	14.91	3.52
	0.80	93593	3.49	1.06	45.83	3.07	13.13	2.90
	0.95	59160	1.79	0.81	19.21	1.87	10.73	2.31
	1.00	51336	1.50	0.75	14.58	1.60	9.72	2.13
	1.10	39250	1.10	0.66	8.94	1.20	8.13	1.82
	1.50	16349	0.57	0.49	1.93	0.52	3.39	1.06
	1.70	13305	0.52	0.46	1.41	0.45	2.71	0.98
	2.00	9722	0.46	0.42	0.92	0.37	2.00	0.88
	3.00	3142	0.37	0.35	0.31	0.21	0.84	0.60
	4.00	1375	0.33	0.32	0.22	0.18	0.67	0.56

*Taken as the quotient of the CSG timing divided by the 2012 UM timing

Table V: Godiva mesh results for 10^7 histories: Standard 2015 UM vs 2012 UM Results

	Mesh Seed (cm)	Number of Elements	Total Runtime (min) [2015]	Calc. Time (min) [2015]	Total Runtime (min) [2012]	Calc. Time (min) [2012]	Total Time Speedup*	Calc. Time Speedup*
K-Code	0.45	401723	181.99	81.93	190.36	141.87	1.05	1.73
	0.55	320069	112.52	50.59	144.32	115.23	1.28	2.28
	0.65	161971	58.72	42.63	81.08	73.70	1.38	1.73
	0.80	93593	42.11	36.88	59.71	57.26	1.42	1.55
	0.95	59160	35.01	32.88	49.37	48.37	1.41	1.47
	1.00	51336	33.83	32.21	46.75	45.99	1.38	1.43
	1.10	39250	31.12	30.16	43.75	43.29	1.41	1.44
	1.50	16349	25.49	25.29	34.66	34.55	1.36	1.37
	1.70	13305	24.46	24.32	33.25	33.17	1.36	1.36
	2.00	9722	23.24	23.15	31.09	31.04	1.34	1.34
	3.00	3142	19.19	19.16	24.72	24.68	1.29	1.29
	4.00	1375	16.96	16.93	21.78	21.75	1.28	1.28
Void	0.45	401723	171.84	72.58	200.44	152.20	1.17	2.10
	0.55	320069	128.73	67.17	153.62	124.20	1.19	1.85
	0.65	161971	71.39	55.64	88.27	80.92	1.24	1.45
	0.80	93593	52.60	47.29	65.16	62.72	1.24	1.33
	0.95	59160	43.41	41.31	53.76	52.78	1.24	1.28
	1.00	51336	41.89	40.29	51.66	50.91	1.23	1.26
	1.10	39250	37.98	37.04	46.56	46.12	1.23	1.25
	1.50	16349	29.47	29.30	35.38	35.29	1.20	1.20
	1.70	13305	27.22	27.10	32.85	32.79	1.21	1.21
	2.00	9722	24.33	24.26	29.79	29.75	1.22	1.23
	3.00	3142	18.37	18.35	21.44	21.43	1.17	1.17
	4.00	1375	14.04	14.03	16.42	16.41	1.17	1.17
Gamma	0.45	401723	175.22	74.52	186.40	137.81	1.06	1.85
	0.55	320069	134.35	70.62	137.81	141.25	1.05	1.58
	0.65	161971	78.47	62.39	82.65	75.43	1.05	1.21
	0.80	93593	61.46	56.21	64.36	61.92	1.05	1.10
	0.95	59160	54.79	52.67	57.03	56.05	1.04	1.06
	1.00	51336	52.91	51.30	55.76	55.02	1.05	1.07
	1.10	39250	49.75	48.80	52.70	52.26	1.06	1.07
	1.50	16349	42.71	42.54	45.20	45.11	1.06	1.06
	1.70	13305	40.46	40.33	42.52	42.45	1.05	1.05
	2.00	9722	38.06	37.99	40.21	40.17	1.06	1.06
	3.00	3142	33.33	33.31	34.07	34.05	1.02	1.02
	4.00	1375	29.57	29.55	30.80	30.78	1.04	1.04

*Taken as the quotient of the 2012 timing divided by the 2015 timing

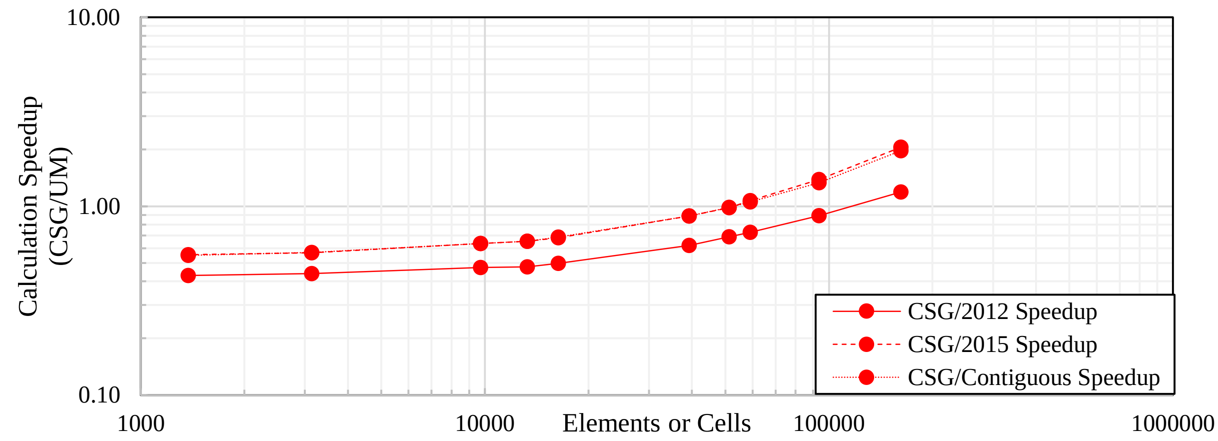


Figure 4: Performance comparison for 10^7 histories of the Godiva *K-Code* problem for the 2015 MCNP6 build, 2012 MCNP6 build, and 2015 MCNP6 build with contiguous mesh routines being used.

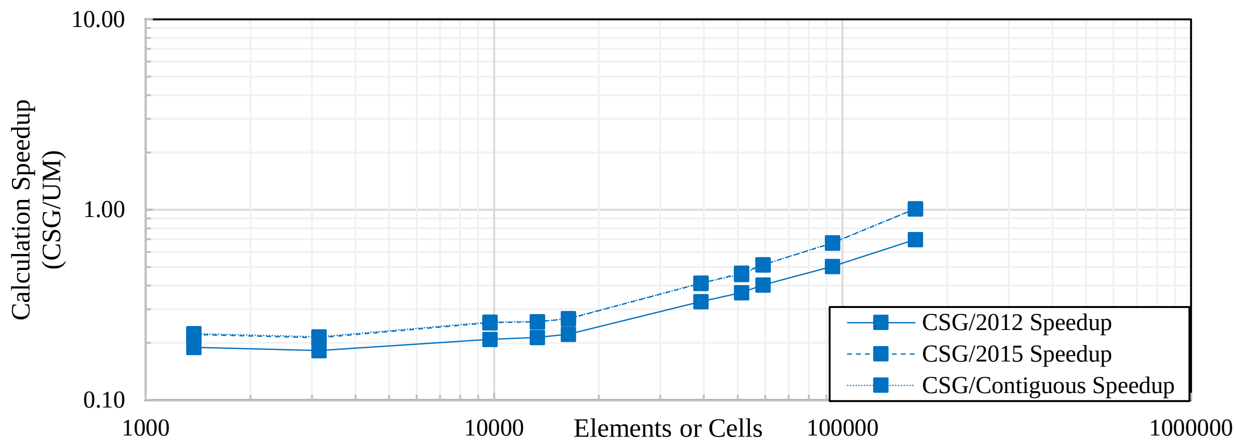


Figure 5: Performance comparison for 10^7 histories of the Godiva *Void* problem for the 2015 MCNP6 build, 2012 MCNP6 build, and 2015 MCNP6 build with contiguous mesh routines being used.

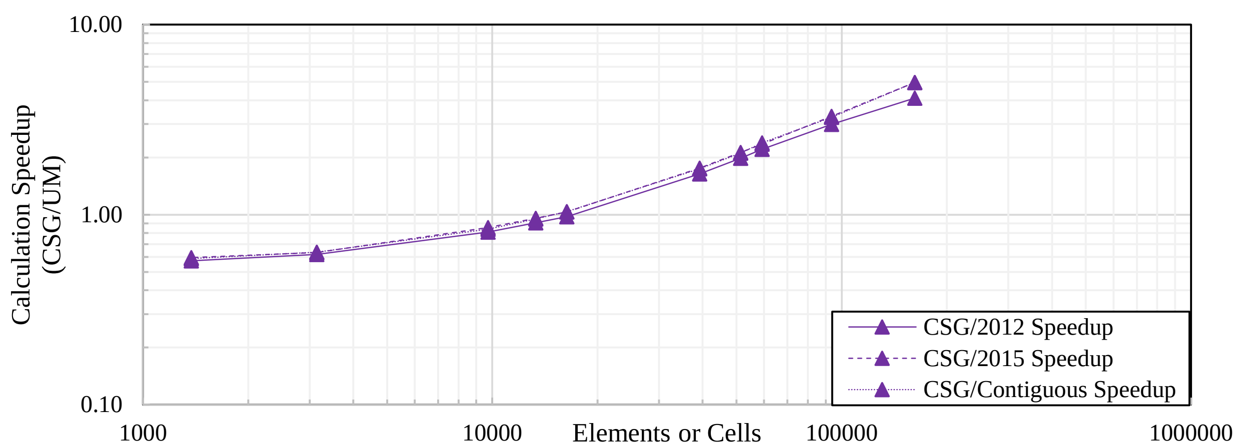


Figure 6*:* Performance comparison for 10^7 histories of the Godiva *Gamma* source problem for the 2015 MCNP6 build, 2012 MCNP6 build, and 2015 MCNP6 build with contiguous mesh routines being used.

Table VI: Godiva mesh results for 10^7 histories: Standard 2015 UM vs 2012 CSG Results

	Mesh Seed (cm)	Number of Elements	Total Runtime (min) [2015]	Calc. Time (min) [2015]	Total Runtime (min) [CSG]	Calc. Time (min) [CSG]	Total Time Speedup*	Calc. Time Speedup*
K-Code	0.65	161971	58.72	42.63	213.98	87.56	3.64	2.05
	0.80	93593	42.11	36.88	94.79	51.07	2.25	1.38
	0.95	59160	35.01	32.88	53.06	35.16	1.52	1.07
	1.00	51336	33.83	32.21	45.23	31.71	1.34	0.98
	1.10	39250	31.12	30.16	34.90	26.82	1.12	0.89
	1.50	16349	25.49	25.29	18.89	17.25	0.74	0.68
	1.70	13305	24.46	24.32	17.03	15.87	0.70	0.65
	2.00	9722	23.24	23.15	15.39	14.70	0.66	0.63
	3.00	3142	19.19	19.16	11.02	10.87	0.57	0.57
	4.00	1375	16.96	16.93	9.43	9.36	0.56	0.55
Void	0.65	161971	71.39	55.64	186.08	56.33	2.61	1.01
	0.80	93593	52.60	47.29	74.96	31.62	1.43	0.67
	0.95	59160	43.41	41.31	38.79	21.23	0.89	0.51
	1.00	51336	41.89	40.29	31.98	18.70	0.76	0.46
	1.10	39250	37.98	37.04	22.97	15.19	0.60	0.41
	1.50	16349	29.47	29.30	9.26	7.81	0.31	0.27
	1.70	13305	27.22	27.10	7.97	6.99	0.29	0.26
	2.00	9722	24.33	24.26	6.75	6.19	0.28	0.26
	3.00	3142	18.37	18.35	3.99	3.90	0.22	0.21
	4.00	1375	14.04	14.03	3.14	3.10	0.22	0.22
Gamma	0.65	161971	78.47	62.39	438.07	310.14	5.58	4.97
	0.80	93593	61.46	56.21	227.75	185.04	3.71	3.29
	0.95	59160	54.79	52.67	140.84	123.62	2.57	2.35
	1.00	51336	52.91	51.30	121.97	108.95	2.31	2.12
	1.10	39250	49.75	48.80	93.31	85.65	1.88	1.76
	1.50	16349	42.71	42.54	45.46	44.03	1.06	1.04
	1.70	13305	40.46	40.33	39.52	38.55	0.98	0.96
	2.00	9722	38.06	37.99	33.09	32.54	0.87	0.86
	3.00	3142	33.33	33.31	21.17	21.08	0.64	0.63
	4.00	1375	29.57	29.55	17.64	17.60	0.60	0.60

*Taken as the quotient of the CSG timing divided by the 2015 UM timing

Table VII: Godiva mesh results for 10^7 histories: Contiguous 2015 UM vs 2012 CSG Results

	Mesh Seed (cm)	Number of Elements	Total Runtime (min) [2015]	Calc. Time (min) [2015]	Total Runtime (min) [CSG]	Calc. Time (min) [CSG]	Total Time Speedup*	Calc. Time Speedup*
K-Code	0.65	161971	60.71	44.52	213.98	87.56	3.52	1.97
	0.80	93593	43.62	38.30	94.79	51.07	2.17	1.33
	0.95	59160	35.50	33.37	53.06	35.16	1.49	1.05
	1.00	51336	33.72	32.10	45.23	31.71	1.34	0.99
	1.10	39250	31.16	30.20	34.9	26.82	1.12	0.89
	1.50	16349	25.31	25.11	18.89	17.25	0.75	0.69
	1.70	13305	24.44	24.30	17.03	15.87	0.70	0.65
	2.00	9722	23.23	23.15	15.39	14.70	0.66	0.63
	3.00	3142	19.14	19.10	11.02	10.87	0.58	0.57
	4.00	1375	17.03	17.00	9.43	9.36	0.55	0.55
Void	0.65	161971	71.51	55.61	186.08	56.33	2.60	1.01
	0.80	93593	52.49	47.19	74.96	31.62	1.43	0.67
	0.95	59160	43.46	41.35	38.79	21.23	0.89	0.51
	1.00	51336	42.5	40.9	31.98	18.70	0.75	0.46
	1.10	39250	37.78	36.84	22.97	15.19	0.61	0.41
	1.50	16349	29.34	29.17	9.26	7.81	0.32	0.27
	1.70	13305	27.25	27.13	7.97	6.99	0.29	0.26
	2.00	9722	24.18	24.11	6.75	6.19	0.28	0.26
	3.00	3142	18.15	18.13	3.99	3.90	0.22	0.22
	4.00	1375	13.88	13.87	3.14	3.10	0.23	0.22
Gamma	0.65	161971	78.72	62.51	438.07	310.14	5.56	4.96
	0.80	93593	62.15	56.84	227.75	185.04	3.66	3.26
	0.95	59160	53.84	51.73	140.84	123.62	2.62	2.39
	1.00	51336	53.22	51.62	121.97	108.95	2.29	2.11
	1.10	39250	50.07	49.13	93.31	85.65	1.86	1.74
	1.50	16349	42.53	42.36	45.46	44.03	1.07	1.04
	1.70	13305	40.64	40.51	39.52	38.55	0.97	0.95
	2.00	9722	38.88	38.81	33.09	32.54	0.85	0.84
	3.00	3142	33.18	33.16	21.17	21.08	0.64	0.64
	4.00	1375	29.92	29.90	17.64	17.60	0.59	0.59

*Taken as the quotient of the CSG timing divided by the 2015 UM timing

Table VIII: Godiva mesh results for 10^7 histories: Standard 2012 UM vs 2012 CSG Results

	Mesh Seed (cm)	Number of Elements	Total Runtime (min) [2012]	Calc. Time (min) [2012]	Total Runtime (min) [CSG]	Calc. Time (min) [CSG]	Total Time Speedup*	Calc. Time Speedup*
K-Code	0.65	161971	81.08	73.7	213.98	87.56	2.64	1.19
	0.80	93593	59.71	57.26	94.79	51.07	1.59	0.89
	0.95	59160	49.37	48.37	53.06	35.16	1.07	0.73
	1.00	51336	46.75	45.99	45.23	31.71	0.97	0.69
	1.10	39250	43.75	43.29	34.9	26.82	0.80	0.62
	1.50	16349	34.66	34.55	18.89	17.25	0.55	0.50
	1.70	13305	33.25	33.17	17.03	15.87	0.51	0.48
	2.00	9722	31.09	31.04	15.39	14.70	0.50	0.47
	3.00	3142	24.72	24.68	11.02	10.87	0.45	0.44
	4.00	1375	21.78	21.75	9.43	9.36	0.43	0.43
Void	0.65	161971	88.27	80.92	186.08	56.33	2.11	0.70
	0.80	93593	65.16	62.72	74.96	31.62	1.15	0.50
	0.95	59160	53.76	52.78	38.79	21.23	0.72	0.40
	1.00	51336	51.66	50.91	31.98	18.70	0.62	0.37
	1.10	39250	46.56	46.12	22.97	15.19	0.49	0.33
	1.50	16349	35.38	35.29	9.26	7.81	0.26	0.22
	1.70	13305	32.85	32.79	7.97	6.99	0.24	0.21
	2.00	9722	29.79	29.75	6.75	6.19	0.23	0.21
	3.00	3142	21.44	21.43	3.99	3.90	0.19	0.18
	4.00	1375	16.42	16.41	3.14	3.10	0.19	0.19
Gamma	0.65	161971	82.65	75.43	438.07	310.14	5.30	4.11
	0.80	93593	64.36	61.92	227.75	185.04	3.54	2.99
	0.95	59160	57.03	56.05	140.84	123.62	2.47	2.21
	1.00	51336	55.76	55.02	121.97	108.95	2.19	1.98
	1.10	39250	52.70	52.26	93.31	85.65	1.77	1.64
	1.50	16349	45.20	45.11	45.46	44.03	1.01	0.98
	1.70	13305	42.52	42.45	39.52	38.55	0.93	0.91
	2.00	9722	40.21	40.17	33.09	32.54	0.82	0.81
	3.00	3142	34.07	34.05	21.17	21.08	0.62	0.62
	4.00	1375	30.80	30.78	17.64	17.60	0.57	0.57

*Taken as the quotient of the 2012 CSG timing divided by the 2012 UM timing

Table IIX: Comparison of Setup Time for 2015 and 2012 Standard UM MCNP Godiva Trial with 10^7 histories

	Mesh Seed (cm)	Number of Elements	Setup Time (min) [2015]	Setup Time (min) [2012]	Performance Ratio*
K-Code	0.45	401723	100.06	48.49	2.06
	0.55	320069	61.93	29.09	2.13
	0.65	161971	16.09	7.38	2.18
	0.80	93593	5.23	2.45	2.13
	0.95	59160	2.13	1.00	2.13
	1.00	51336	1.62	0.76	2.13
	1.10	39250	0.96	0.46	2.09
	1.50	16349	0.20	0.11	1.82
	1.70	13305	0.14	0.08	1.75
	2.00	9722	0.09	0.05	1.80
	3.00	3142	0.03	0.04	0.75
	4.00	1375	0.03	0.03	1.00
Void	0.45	401723	99.26	48.24	2.06
	0.55	320069	61.56	29.42	2.09
	0.65	161971	15.75	7.35	2.14
	0.80	93593	5.31	2.44	2.18
	0.95	59160	2.10	0.98	2.14
	1.00	51336	1.60	0.75	2.13
	1.10	39250	0.94	0.44	2.14
	1.50	16349	0.17	0.09	1.89
	1.70	13305	0.12	0.06	2.00
	2.00	9722	0.07	0.04	1.75
	3.00	3142	0.02	0.01	2.00
	4.00	1375	0.01	0.01	1.00
Gamma	0.45	401723	100.70	48.59	2.07
	0.55	320069	63.73	29.53	2.16
	0.65	161971	16.08	7.22	2.23
	0.80	93593	5.25	2.44	2.15
	0.95	59160	2.12	0.98	2.16
	1.00	51336	1.61	0.74	2.18
	1.10	39250	0.95	0.44	2.16
	1.50	16349	0.17	0.09	1.89
	1.70	13305	0.13	0.07	1.86
	2.00	9722	0.07	0.04	1.75
	3.00	3142	0.02	0.02	1.00
	4.00	1375	0.02	0.02	1.00

*Taken as the quotient of the 2015 UM timing divided by the 2012 UM timing

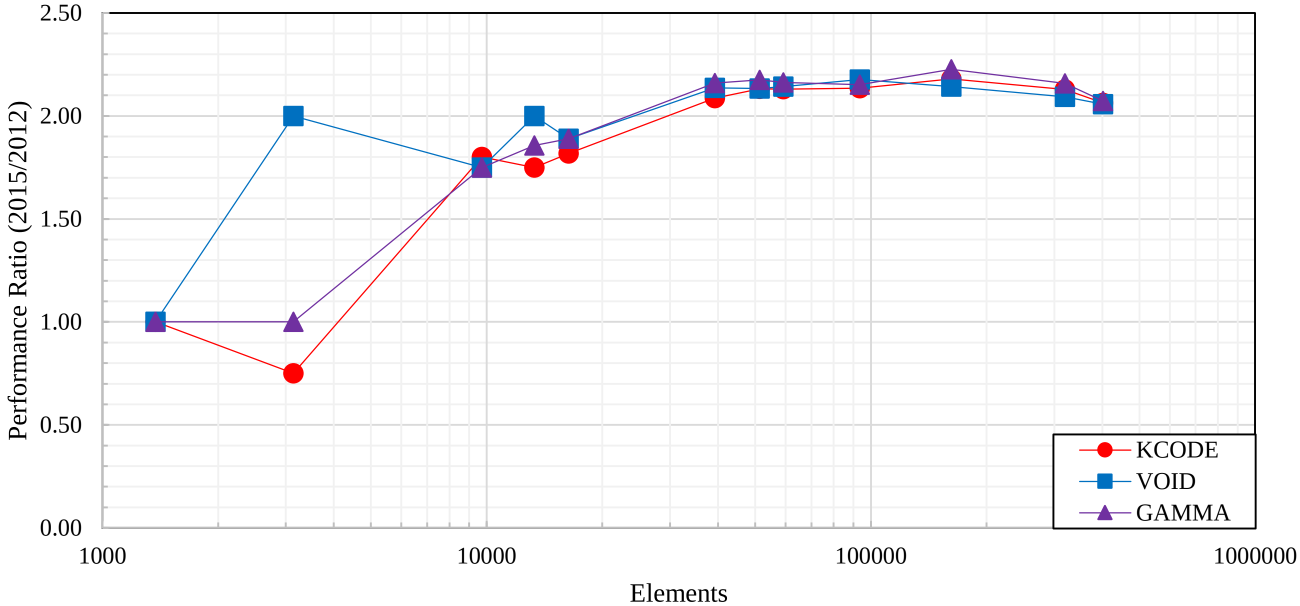


Figure 7: Setup Time Performance Ratio vs. Element Count for 10^7 history Godiva simulation

Table X: MODE Card Performance Impact on Standard 2015 MCNP6 Build Godiva K-Code Simulation with 10^7 Histories

	Mesh Seed (cm)	Number of Elements	Total Runtime (min) [mode n]	Calculation Time (min) [mode n]	Total Runtime (min) [mode n p]	Calculation Time (min) [mode n p]
	0.45	401723	154.50	52.96	186.16	82.07
	0.55	320069	112.52	50.59	136.37	74.72
	0.65	161971	58.72	42.63	82.09	66.29
	0.80	93593	42.11	36.88	66.48	61.12
	0.95	59160	35.01	32.88	56.54	54.40
K-Code	1.00	51336	33.83	32.21	55.74	54.12
	1.10	39250	31.12	30.16	53.27	52.29
	1.50	16349	25.49	25.29	45.83	45.62
	1.70	13305	24.46	24.32	45.15	45.00
	2.00	9722	23.24	23.15	43.61	43.51
	3.00	3142	19.19	19.16	38.66	38.62
	4.00	1375	16.96	16.93	36.66	36.62

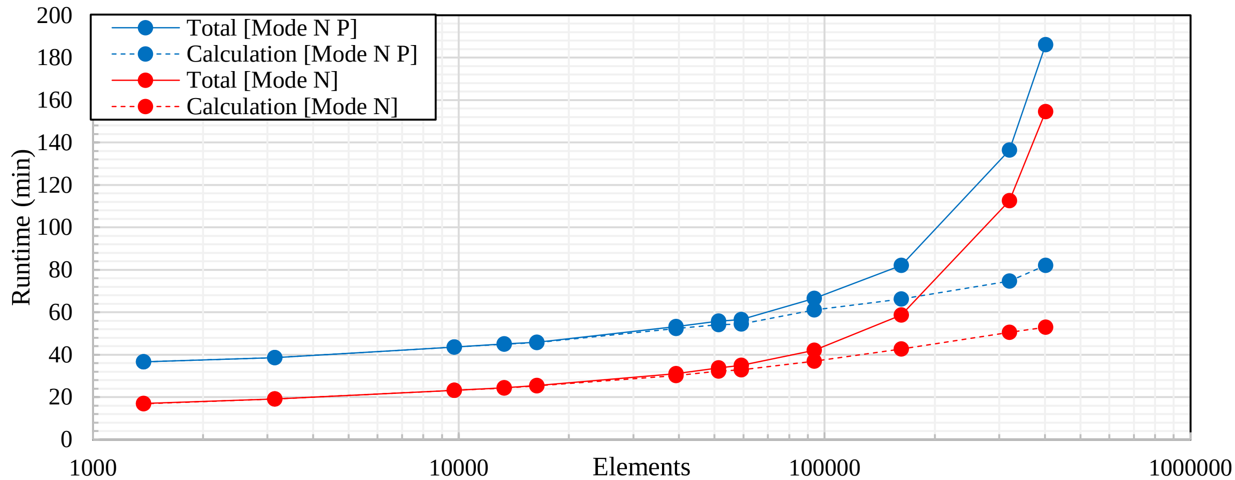


Figure 8: Performance comparison of runtimes using different MODE cards on Godiva K-Code simulation with 10^7 histories.

4. BIG TEN BENCHMARK

4.1. Characteristics

The Big Ten benchmark is composed of a low-enriched uranium cylinder, surrounded by a larger cylinder of depleted uranium. This benchmark represents a fuel pin, but with features and dimensions simplified for easier analysis [2]. For the current work, the Big Ten model was recreated using Abaqus/CAE, a Dassault Systemes product [7]. Both multi-part (NCM) models and merged part (CM) models were created for assessing the UM feature performance, as discussed above. Figures 9 and 10 depict the Big Ten models.

Four mesh seed sizes were used (18 cm, 6 cm, 3 cm, 1 cm maximum edge lengths) to assess the impact of mesh resolution on the performance of the UM feature. For k_{eff} calculations, it is important to have accurate volumes, masses, and geometry of the system under evaluation. Figure 10 depicts the difference between CM and NCM Big Ten models for one mesh seed size. Visually, it is clear which method provides a better representation of the true system. Because of the lack of inter-part gaps and overlaps, CM models better approximate this system than NCM models. This is also true of finer versus coarser mesh sizes.

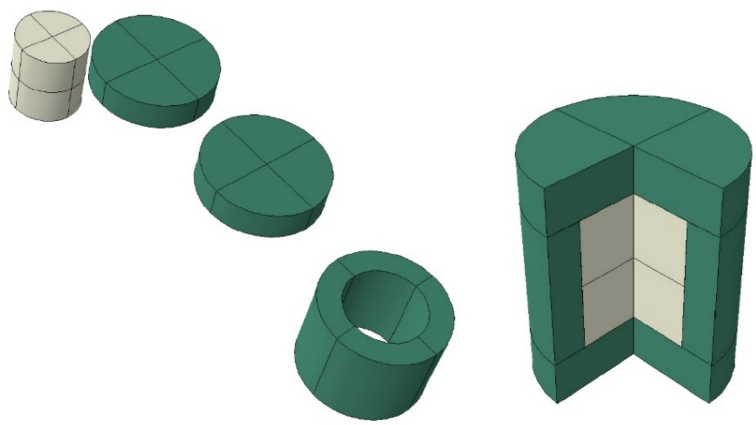


Figure 9: Big Ten model components (left) and full assembly (right). Image taken from [1].

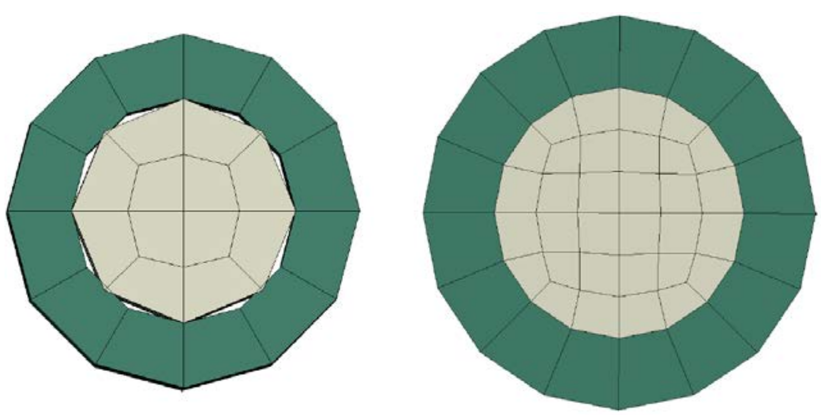


Figure 10: Big Ten multi-part model (left) and merged part model (right). Image taken from [1].

4.2. Results

These results serve as a performance update to Reference [4]; both CM and NCM sets are provided in Table XI.

Table XII shows an approximate factor of 2 speed up overall for the UM feature in MCNP6 since 2012 with the 1st order elements showing better improvement over the 2nd order elements. In general, the improvement with the 2nd order elements is driven by the underlying poorer performance of the 2nd order elements and is attributed to two factors:

1) The 2nd order algorithms are more complicated than 1st order and require more floating point operations to execute, and
2) Not as much time and effort has been spent in tuning these routines; to date, accuracy has been emphasized over speed.

Table XIII presents a comparison of the results from the proposed contiguous tracking routes with the existing, standard UM tracking routines for the CM Big Ten models. Differences between run times and speed up factors are virtually negligible. This demonstrates the efficiency of the existing code in handling CM models and that all gap / overlap adjustments are necessary and provide low performance impact.

The speedup factor, taken as the quotient of the new Big Ten model calculation time over the Reference [4] time is displayed graphically in Figure 11 and Figure 12. The contiguous results were omitted as they are virtually identical to the standard results.

Table I of the Reference [4] work showed a problem for the multi-part (NCM), 2nd-order hex models with respect to calculating the correct k_{eff}. Table XI of this work shows that this is no longer a problem and is attributed to one of many codes fixes since 2012.

Table XI: Comparison of Big Ten CSG and Standard Unstructured Mesh Routine Results

	Element Type	Mesh Seed (cm)	Number of Elements	Fuel Volume % Error	Refl. Volume % Error	k_{eff}	k_{eff} % Error	Total runtime (min)	mcrun runtime (min)
Multi-Part	1st-Order Hex	1	36912	0.024	0.225	0.99337(29)	-0.154	53.73	52.74
		3	4848	0.210	0.277	0.99313(26)	-0.178	37.02	36.98
		6	1944	0.837	0.456	0.99192(29)	-0.300	32.91	32.87
		18	984	9.969	2.330	0.97430(29)	-2.092	29.90	29.87
	1st-Order Tet	1	139526	0.024	0.179	0.99264(30)	-0.227	70.71	63.87
		3	24233	0.210	0.237	0.99257(29)	-0.234	44.45	44.25
		6	10492	0.837	0.409	0.99175(30)	-0.317	38.52	38.46
		18	4993	9.969	2.284	0.97402(30)	-2.121	33.29	33.25
	2nd-Order Hex	1	36912	0.000	-0.001	0.99341(30)	-0.150	963.87	962.29
		3	4848	0.000	-0.001	0.99314(30)	-0.177	527.15	527.05
		6	1944	0.000	0.000	0.99101(29)	-0.392	451.19	451.14
		18	984	0.005	0.007	0.97489(30)	-2.032	429.77	429.73
	2nd-Order Tet	1	139526	0.000	-0.001	0.99313(30)	-0.178	520.60	513.49
		3	24233	0.000	-0.001	0.99286(29)	-0.205	357.99	357.77
		6	10492	0.000	0.000	0.99213(27)	-0.279	297.63	297.56
		18[1]	4993	0.078	0.007				
Merged Part	1st-Order Hex	1	47520	0.032	0.031	0.99511(26)	0.021	39.72	37.58
		3	5840	0.183	0.182	0.99489(28)	-0.001	27.51	27.44
		6	1920	0.642	0.641	0.99415(28)	-0.075	25.21	25.17
		18	480	2.550	2.550	0.99182(27)	-0.310	23.61	23.58
	1st-Order Tet	1	329718	0.034	0.033	0.99488(27)	-0.002	92.47	40.14
		3	42395	0.160	0.160	0.99477(31)	-0.013	29.24	28.36
		6	12038	0.642	0.641	0.99436(31)	-0.054	25.25	25.15
		18	3501	2.550	2.550	0.99187(27)	-0.305	23.20	23.17
	2nd-Order Hex	1	47520	0.000	-0.001	0.99543(31)	0.053	888.51	885.66
		3	5840	0.000	-0.001	0.99542(33)	0.052	502.74	502.64
		6	1920	0.000	0.000	0.99467(31)	-0.023	440.96	440.90
		18	480	0.005	0.007	0.99467(30)	-0.023	428.63	428.60
	2nd-Order Tet	1	329718	0.000	0.000	0.99457(30)	-0.033	519.14	464.61
		3	42395	0.000	0.000	0.99480(33)	-0.010	308.91	307.99
		6	12038	0.000	0.000	0.99454(30)	-0.036	256.66	256.54
		18	3501	0.078	0.005	0.99475(32)	-0.015	234.20	234.16
CSG		-	-	-	-	0.99490(29)	-	-	-

1 Run is currently incomplete.

Table XII: Comparison of 2015 Standard MCNP6 Big Ten results to Burke Results [1]

	Element Type	Mesh Seed (cm)	Number of Elements	Total runtime (min) 2015 Standard	Total runtime (min) Burke [1]	Speedup Factor
Multi Part	1st-Order Hex	1	47520	53.73	139.00	2.59
		3	5840	37.02	82.79	2.24
		6	1920	32.91	68.35	2.08
		18	480	29.90	59.52	1.99
	1st-Order Tet	1	329718	70.71	178.07	2.52
		3	42395	44.45	107.34	2.41
		6	12038	38.52	84.67	2.20
		18	3501	33.29	68.35	2.05
	2nd-Order Hex	1	47520	963.87	1057.20	1.10
		3	5840	527.15	586.99	1.11
		6	1920	451.19	549.78	1.22
		18	480	429.77	698.45	1.63
	2nd-Order Tet	1	329718	520.60	916.91	1.76
		3	42395	357.99	606.54	1.69
		6	12038	297.63	474.02	1.59
		18[1]	3501		450.69	
Merged Part	1st-Order Hex	1	47520	39.72	120.89	3.04
		3	5840	27.51	71.22	2.59
		6	1920	25.21	61.69	2.45
		18	480	23.61	55.95	2.37
	1st-Order Tet	1	329718	92.47	243.32	2.63
		3	42395	29.24	83.98	2.87
		6	12038	25.25	67.09	2.66
		18	3501	23.20	57.50	2.48
	2nd-Order Hex	1	47520	888.51	837.71	0.94
		3	5840	502.74	436.88	0.87
		6	1920	440.96	392.89	0.89
		18	480	428.63	424.63	0.99
	2nd-Order Tet	1	329718	519.14	978.93	1.89
		3	42395	308.91	562.02	1.82
		6	12038	256.66	440.71	1.72
		18	3501	234.20	387.98	1.66

1 Run is currently incomplete.

Table XIII: Comparison of Contiguous Unstructured Mesh Results to Burke Results [1]

	Element Type	Mesh Seed (cm)	Number of Elements	Total runtime (min) 2015 Contiguous	Total runtime (min) Burke [1]	Speedup Factor
Merged Part (Standard)	1st-Order Hex	1	47520	39.72	120.89	3.04
		3	5840	27.51	71.22	2.59
		6	1920	25.21	61.69	2.45
		18	480	23.61	55.95	2.37
	1st-Order Tet	1	329718	92.47	243.32	2.63
		3	42395	29.24	83.98	2.87
		6	12038	25.25	67.09	2.66
		18	3501	23.20	57.50	2.48
	2nd-Order Hex	1	47520	888.51	837.71	0.94
		3	5840	502.74	436.88	0.87
		6	1920	440.96	392.89	0.89
		18	480	428.63	424.63	0.99
	2nd-Order Tet	1	329718	519.14	978.93	1.89
		3	42395	308.91	562.02	1.82
		6	12038	256.66	440.71	1.72
		18	3501	234.20	387.98	1.66
Merged Part (Contiguous)	1st-Order Hex	1	47520	39.33	120.89	3.07
		3	5840	27.39	71.22	2.60
		6	1920	25.01	61.69	2.47
		18	480	23.47	55.95	2.38
	1st-Order Tet	1	329718	92.94	243.32	2.62
		3	42395	29.33	83.98	2.86
		6	12038	25.4	67.09	2.64
		18	3501	23.45	57.50	2.45
	2nd-Order Hex	1	47520	887.84	837.71	0.94
		3	5840	502.02	436.88	0.87
		6	1920	440.61	392.89	0.89
		18	480	426.45	424.63	1.00
	2nd-Order Tet	1	329718	510.13	978.93	1.92
		3	42395	308.47	562.02	1.82
		6	12038	255.08	440.71	1.73
		18	3501	235.49	387.98	1.65

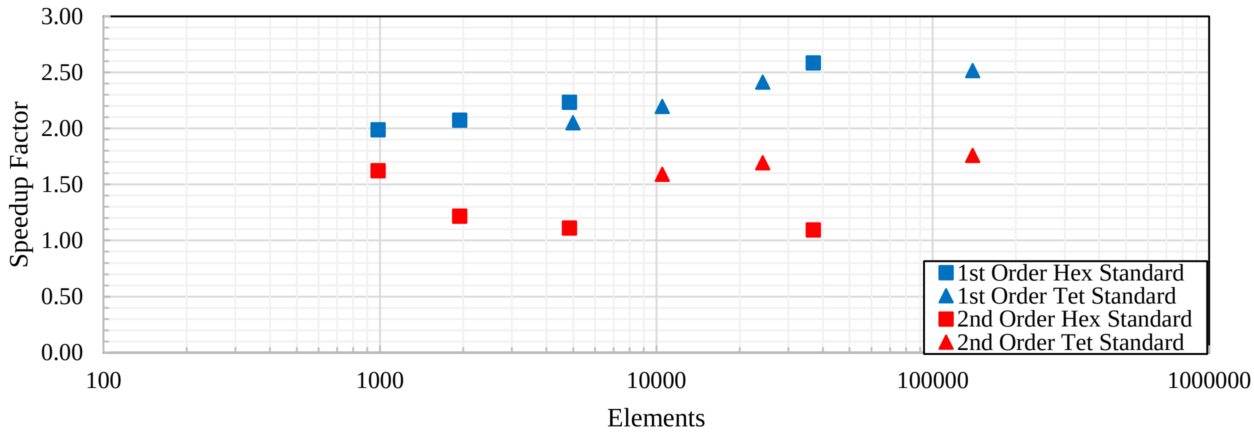


Figure 11: Big Ten NCM Speedup Factors

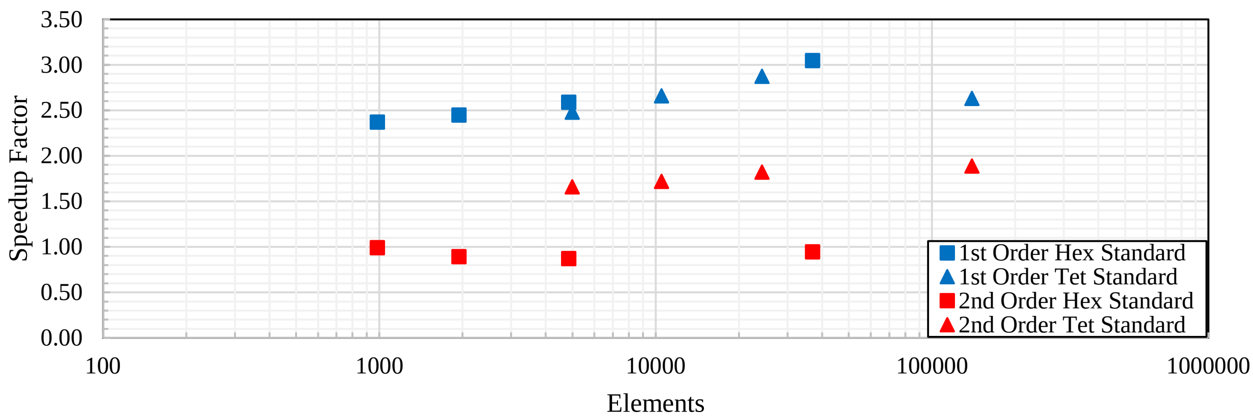


Figure 12: Big Ten CM Speedup Factors

5. KOBAYASHI BENCHMARK

5.1. Characteristics

The Kobayashi Benchmark consists of a series of problems, all of them containing simple source, void, and reflector regions. The source region in the problems emits neutrons from a volume source through the UM volume source methodology [8]. Including this test provides coverage of another source type in this report, as well as a geometry with an interior void region. In addition, these problems require the use of point detectors which test the UM tracking routines in a different way since the point detector tracking is separate from the normal particle tracking. These problems were originally conceived to test the performance of discrete ordinate radiation transport codes [3]. Figures 13 to 16 display the setup of each problem in the Kobayashi set.

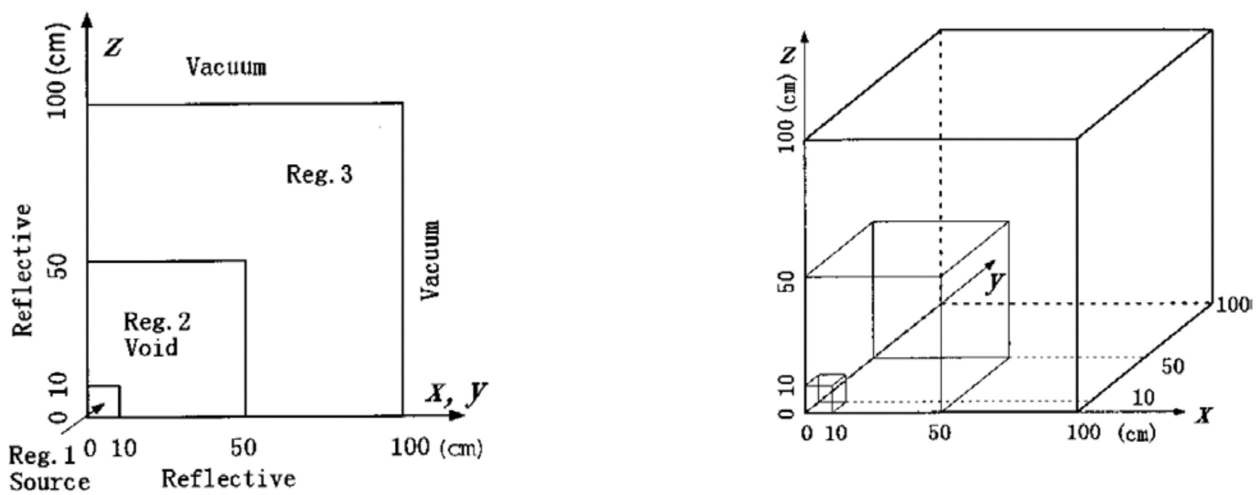
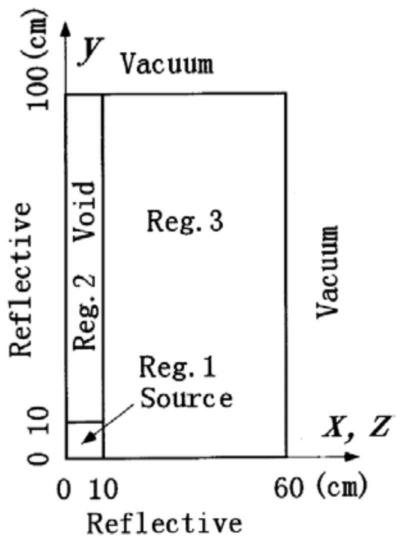


Figure 13: X-Z or Y-Z plane of Problem 1 (left), 3D sketch of Problem 1, shield with square void (right). Image taken from [5]



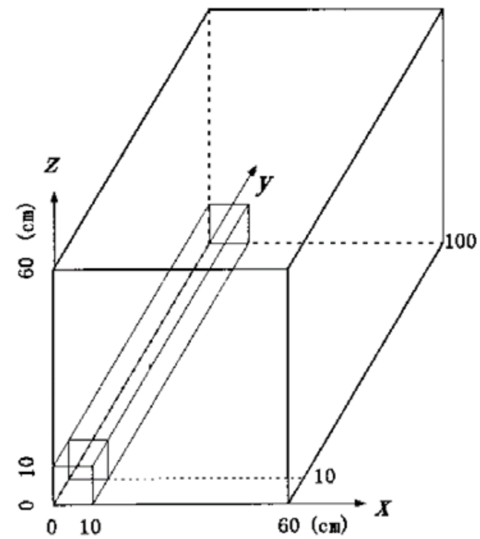
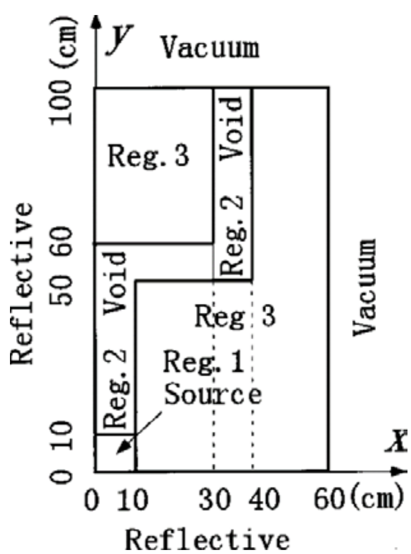


Figure 14: X-Y or Y-Z plane of Problem 2 (left), 3D sketch of Problem 2, shield with void duct (right) Image taken from [5].



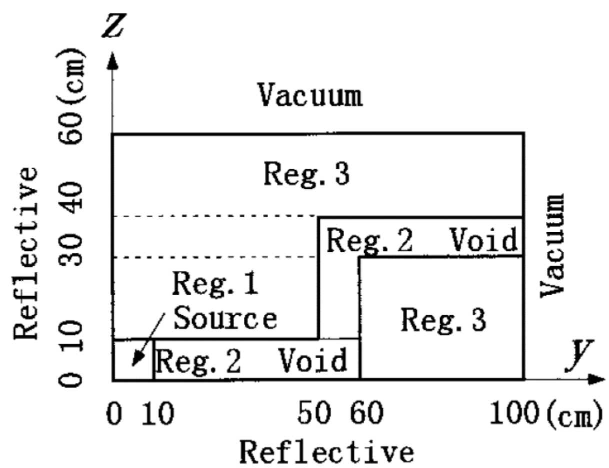
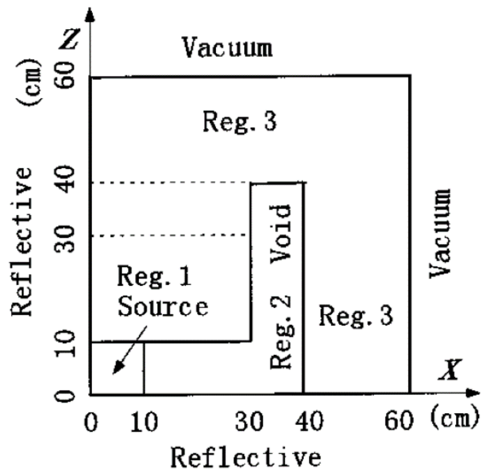


Figure 15: X-Y plane of Problem 3 (left), Y-Z plane of Problem 3 (right). Image taken from [5].



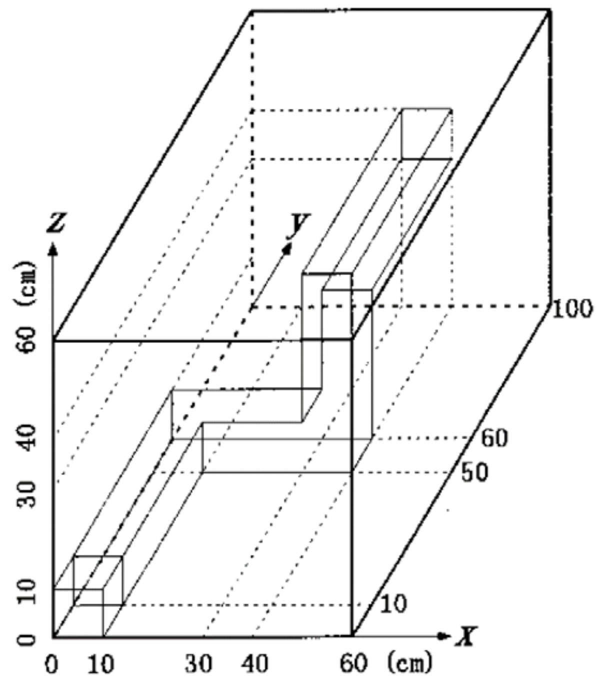


Figure 16: X-Z plane of Problem 3 (left), 3D sketch of Problem 3, shield with dogleg void duct (right). Image taken from [5].

5.2. Results

For each problem in the Kobayashi test suite, first and second order versions of the geometry were constructed with both hexahedral and tetrahedral elements. Results of the trials for the purely absorbing cases are presented in Table XIV where the same performance is seen for the standard and contiguous trials.

Table XIV: Comparison of Kobayashi Simulation using 2015 MCNP6 Build with Standard and Contiguous UM Tracking Routines.

	Element Type	Number of Elements	Total Runtime (min) [Stand.][1]	Calc. Time (min) [Stand.]	Total Runtime (min) [Cont.][2]	Calc. Time (min) [Cont.]	Total Speedup Factor*	Calculation Speedup Factor*
P 1	1st Order Hex	1728	11.33	11.31	11.34	11.32	1.00	1.00
	2nd Order Hex	1728	325.12	325.08	321.92	321.88	1.01	1.01
	1st Order Tet	17430	21.34	21.14	21.40	21.20	1.00	1.00
	2nd Order Tet	17430	574.94	574.71	572.43	572.21	1.00	1.00
P 2	1st Order Hex	768	4.84	4.83	4.81	4.80	1.01	1.01
	2nd Order Hex	768	115.08	115.06	114.64	114.63	1.00	1.00
	1st Order Tet	6668	9.51	9.47	9.52	9.48	1.00	1.00
	2nd Order Tet	6668	217.66	217.62	216.44	216.39	1.01	1.01
P 3	1st Order Hex	2880	9.20	9.18	9.19	9.17	1.00	1.00
	2nd Order Hex	2880	218.25	218.20	217.73	217.63	1.00	1.00
	1st Order Tet	30791	20.04	19.42	20.02	19.40	1.00	1.00
	2nd Order Tet	30791	452.87	452.21	451.75	451.09	1.00	1.00

*Taken as the quotient of the 2015 standard UM timing divided by the 2015 contiguous UM timing.
1 Existing, standard UM tracking.
2 Proposed, contiguous UM tracking.

6. CONCLUSIONS

This report documents the performance progress that has been made in the development of MCNP6's UM capability. Various benchmark problems that have various source types and geometric configurations have been studied, and fair comparisons made to the 2012 MCNP6 build. The experimental contiguous mesh particle tracking capability has been evaluated as part of this work.

At the current time, the contiguous ability does not see a significant enough performance increase relative to the standard UM particle tracking routines to warrant inclusion in the next MCNP6 release. Further examination and refinement of the appropriate particle tracking routines must be completed before implementation is fully accepted or rejected. The contiguous ability currently affects a very small portion of the UM source code, namely segments that handle gaps and overlaps. There may be performance gains that can be realized for contiguous meshes by changing how particle tracking is handled for UM on a more fundamental level. Implementing changes for contiguous meshes in lower-level code of the particle tracking routines would be a fairly significant undertaking and may warrant future investigation.

In general, the behavior documented in this paper suggests the benefits of UM versus CSG become noticeable with as little as ~16,000 elements/cells while in some cases aren't seen until ~90,000 elements/cells are used in the mesh. This is entirely dependent on the type of calculation being performed, as well as the complexity of the problem geometry. In particular, the Godiva benchmark in Section 3 illustrates this observation. As presented in Reference [5], as the mesh is refined further, the speedup factor of the latest MCNP6 build relative to the CSG increases.

The results of the Big Ten trials in Section 4.2 demonstrate the improvements in performance that have been made since the publication of [4] with the 2012 MCNP6 build. First order mesh elements with the merged part model showed the greatest improvement compared to the older performance data. The latest MCNP6 build contains many changes compared to the tracking routines used in the 2012 build. These include a more sophisticated method of selecting the intersecting face of an element, as well as construction of nearest neighbor lists for elements during problem setup.

Overall, the run times with the UM capability have improved since the 2012 version of MCNP6.

7. REFERENCES

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