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Validation of MCkeff code using ICSBEP results

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ABSTRACT

Validation of the indigenously developed Monte Carlo program, MCkeff, is carried out by comparing the results of International Criticality Safety Benchmark Evaluation Project (ICSBEP) problems with that of standard legacy code MCNP (general-purpose Monte-Carlo N-particle transport code). Code-to-code criticality validation is essential before the usage of MCkeff to model various kinds of fissile systems. The Evaluated Nuclear Data Files (ENDF/B VII.I in ACE Format) used in MCNP is expended in the present study, thereby avoiding the differences in the results due to cross-section data. Thus, the deviations in the computed results will reflect only the differences arising out of differences in algorithms employed in these codes. Plutonium metal benchmark problems of different geometrical configurations were selected for validation purposes. All problems were simulated using MCkeff with the same inputs as in MCNP validation, and the computed results of keff (neutron multiplication factor) of various systems were compared. The results from MCkeff agree with that of MCNP, and the maximum deviation between them is less than 0.1%. Hence, the code MCkeff can be used to analyze other metal systems problems. Further validation work on the different fissile systems with other physical forms is in progress.

1. Introduction

Uranium and Plutonium are the two fissile materials used in reactors for nuclear power production. The safety of nuclear reactor systems is governed by the neutron multiplication factor or keff of the system. Although many methods are in vogue to estimate the keff of fissile systems, Monte Carlo methods are preferred owing to their ability to take the complex configuration of materials besides easy-to-implement detailed physics models. Therefore, the code MCkeff has been developed to estimate keff, at the Manipal Centre for Natural Sciences, Manipal Academy of Higher Education, Manipal, under the Department of atomic energy, Board of Research in Nuclear Science project [1].

In this work, validation of MCkeff is carried out using plutonium metal benchmark problems in the International Criticality Safety Benchmark Evaluation Project [2] test suite by comparing the results against those computed using standard legacy code MCNP [3]. Both codes use the same neutron cross-section data files from ENDF/B VII.I [4] in ACE (A Compact ENDF) format.

2. Material and methods

MCNP is a well-known general-purpose Monte-Carlo code which has been extensively validated against various criticality problems from the ICSBEP test suite. The available results are used in this work to perform the code-to-code validation of MCkeff with that of MCNP 6.1. As a preliminary work, we have chosen Plutonium metal benchmarks from ICSBEP [2]. The problem inputs have been taken from the MIT-CRPG GitHub repository, which has inputs for all the ICSBEP problems. All the 13 problems chosen are made to complete over 30 million active neutron histories before collecting criticality results. The results generated from MCkeff and available results from MCNP [3] have been compared and are discussed in the next section.

3. Results and discussion

The problem IDs with the descriptions are briefly explained below in Table 1. These problems have Plutonium isotopes with various concentrations reflected by different structural materials. The exact geometry and composition of these problems can be found elsewhere [5]. MCkeff

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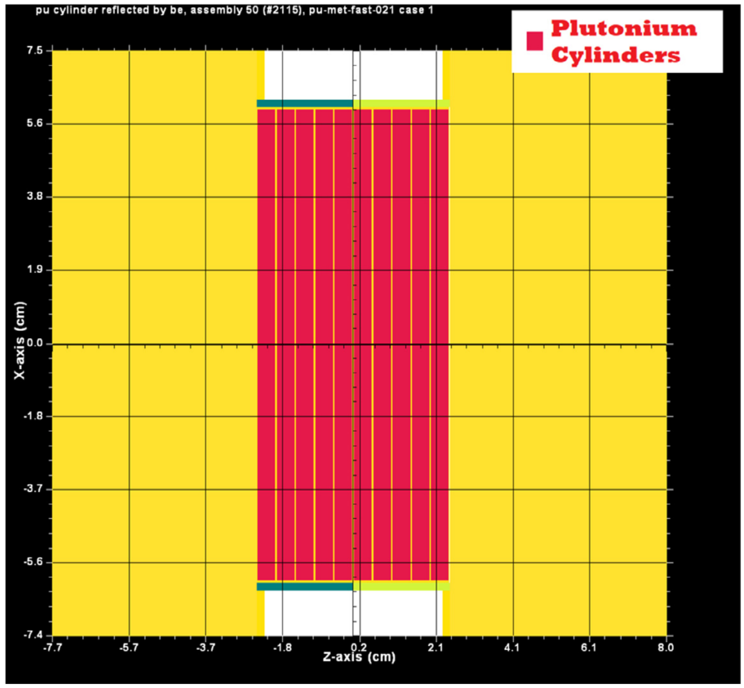

Fig. 1. The geometry of PU-MET-FAST-021 case 1. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

Table 1
Problem ID with description.

SN	Problem ID	Description
1	pu-met-fast-001	JEZEBEL-39, metallic plutonium sphere enriched in the ^{239}Pu isotope (95.17%), (4.5 at% ^{240}Pu, 1.02 wt% Ga), without a reflector.
2	pu-met-fast-002	JEZEBEL-40 metallic plutonium sphere enriched in the ^{239}Pu isotope (20.1 at% ^{240}Pu, 1.01 wt% Ga), without a reflector.
3	pu-met-fast-005	metallic plutonium sphere enriched in the ^{239}Pu isotope (94.76%), reflected by tungsten.
4	pu-met-fast-006	FLATTOP-39, metallic plutonium sphere highly enriched in the ^{239}Pu isotope (94.84% wt) reflected by natural uranium.
5	pu-met-fast-008	THOR -Metallic plutonium sphere highly enriched in the ^{239}Pu isotope (94.54% wt), reflected by thorium.
6	pu-met-fast-009	plutonium metallic sphere highly enriched in the ^{239}Pu isotope (94.8% wt), reflected by aluminium.
7	pu-met-fast-010	DELTA-PHASE, metallic plutonium sphere highly enriched in the ^{239}Pu isotope (94.76% wt), reflected by natural uranium.
8	pu-met-fast-011	ALPHA-PHASE, metallic plutonium sphere highly enriched in ^{239}Pu (94.4% wt) reflected by light water.
9	pu-met-fast-018	DELTA-PHASE, metallic plutonium sphere highly enriched in the ^{239}Pu isotope (94.7% wt) reflected by beryllium.
10	pu-met-fast-019	pu-met-fast-019 contains a sphere of plutonium reflected by two hemispherical shells of beryllium. The sphere contains 8.15 at.% 240 Pu.
11	pu-met-fast-020	pu-met-fast-020 contains two hemispheres of plutonium reflected by four hemispherical shells of depleted uranium, and they contain 8.15 at.% 240 Pu.
12	pu-met-fast-021 case 1	pu-met-fast-021-case-1 and pu-met-fast-021-case-2 contain stacked cylinders of plutonium reflected on the top and bottom by beryllium and
13	pu-met-fast-021 case 2	beryllium oxide, respectively, and it contains 4.57 at.% 240 Pu.

has a similar input structure as that of MCNP and has a geometry plotter built in. A sample 2D geometry plot of the problem ID PU-MET-FAST-021 case 1 is shown in Fig. 1. This is a cylindrical system (Plutonium - red color) reflected by an annular cylinder (beryllium - yellow color) with other structural materials.

All the problems listed in Table 1 have been run with both the codes with the input conditions that would provide convergent results.

The results of k_{eff} obtained by the codes are plotted in Fig. 2. The shaded portion (0.999-1.001) of the graph contain the results of the systems which are critical. Few are found to be above the shaded portion, and these are super-critical systems, and some are below the shaded portion, and these systems correspond to sub-critical systems. The difference in the k_{eff} between MCNP and MCkeff for all the problems is less than 0.1%. Relatively large differences in values found in a few cases among the 13 problems are attributed to the convergence algorithms employed in MCkeff, for which the values can be found below in Table 2.

4. Conclusion

The preliminary criticality validation work showed that the program MCkeff gives the results with differences of less than 0.1% of the val-

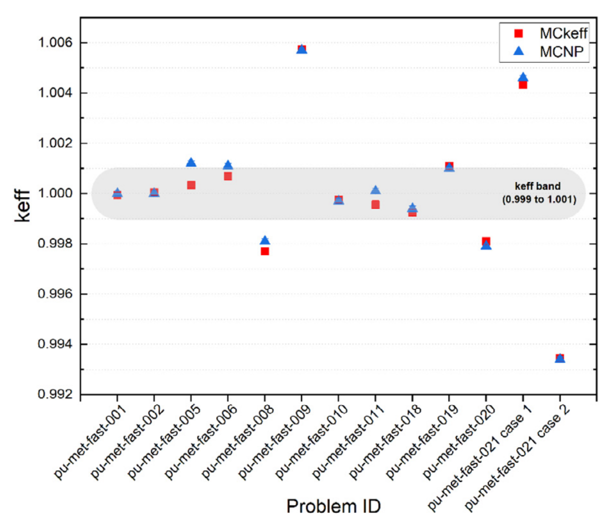

Fig. 2. Comparison of ICSBEP problems k_{eff} results of MCNP with MCkeff.

Table 2
Problems with k_{eff} results from MCkeff and MCNP.

SN	Problem ID	MCkeff	MCNP (Brown et al., 2014)
1	pu-met-fast-005	1.0003 ± 1.30E-04	1.0012 ± 1.00E-04
2	pu-met-fast-006	1.0006 ± 1.40E-04	1.0011 ± 1.00E-04
3	pu-met-fast-008	0.9977 ± 1.30E-04	0.9981 ± 1.00E-04
4	pu-met-fast-011	0.9995 ± 1.60E-04	1.0001 ± 1.00E-04

ues obtained with the standard code MCNP. Therefore, MCkeff can be employed for analyzing other criticality problems as well.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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