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Validation of the MCS code using the SINBAD benchmark.

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1. Introduction

The MCS code is a particle transport simulation program developed by UNIST. The MCS code verification process is presented in this paper and divided into two steps. The first step is achieved by comparing with the MCNP code calculation (calculation/calculation comparison) scheme to verify whether the calculation function of MCS and the solution of the physical equations are correct. The second step is achieved by comparing the calculation results with the SINBAD experimental data (calculation/experiment) to determine the accuracy of the MCS code calculation. This paper verifies the accuracy of the MCS code's radiation shielding calculations through experiments in the SINBAD benchmark. The validation process compares MCS1.0 with MCNP6.0 and analyses the using FENDL3.1 cross-section library.

2. Description of experimental model

During this validation process, 5 experiments were selected from the SINBAD benchmark for comparison. All the measurement uncertainties are assumed to be at 2 standard deviations (2σ) since it is not clearly stated in the benchmark documentation. The MCS code uses the weight window (WW) technique to reduce variance during simulation. The WW feature is composed of two steps. In the first step, optimized weights for a given tally detector of the problem is calculated. In the second step, the weights are used to perform population control of the particles through splitting and Russian roulette. The MCNP simulation was performed using the input provided in the benchmark book. The input of MCS is modified according to the input information of MCNP. The simulations are all in fixed source mode, and the total number of particles per experiment run is 500 million.

2.1. NEA-1553/45 and NEA-1553/72 Benchmark

The experimental models of the NEA-1553/45 and NEA-1553/72 benchmarks are basically similar. The shielding dimensions and material composition are given in Table I [1]. The distance between the D-T neutron source and the front surface of the module is 200 mm [2]. Both the detector and the source are distributed on the central axis of the shielding material. Taking the front surface of the shielding material as a reference, the position of the source is 20 cm away from the front surface, and the detectors are distributed inside the shielding material.

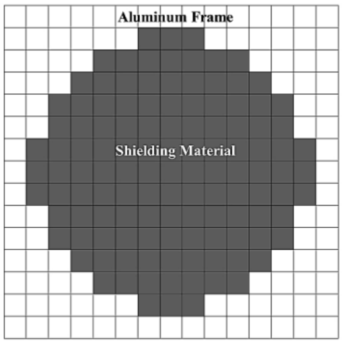


Figure 1. Cu and Graphite model front surface.

Table I. Dimensions of the shielding structure of NEA-1553/45 and NEA-1553/72

Experiment	Shielding Material	Effective Diameters	Thickness
NEA-1553/45	Copper	629 mm	608 mm
NEA-1553/72	Graphite	628 mm	610 mm

2.2. NEA-1553/46, NEA-1553/70 and NEA-1553/47 Benchmark

Fig 2 is the NEA-1553/46 model. The experimental model consists of three components. Q is the position of the D-T neutron source, and D is the position of the detector. The shielding dimensions are given in Table II. [3].

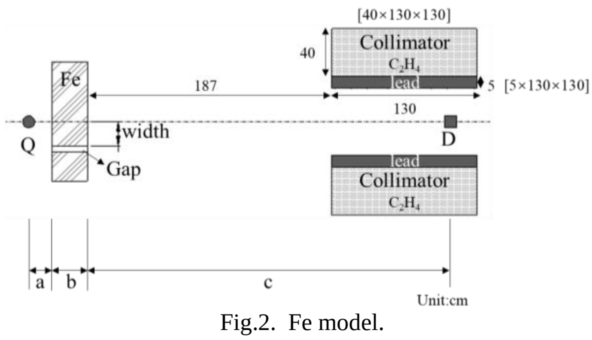


Fig.2. Fe model.

Table II. Dimensions of the shielding structure of NEA-1553/46

Model	Gap [cm]	Width [cm]	a [cm]	b [cm]	c [cm]
A0	0	0	19	30	300
A1	5	10			
A2	5	20			

The components of the NEA-1553/70 and the NEA-1553/47 benchmarks are shown in Fig 3. The shielding dimensions and material compositions are given in Table III. The position of the neutron source is 5.3 cm from the surface of the experimental component. The detectors were arranged at four positions P1, P2, P3, and P4[4,5].

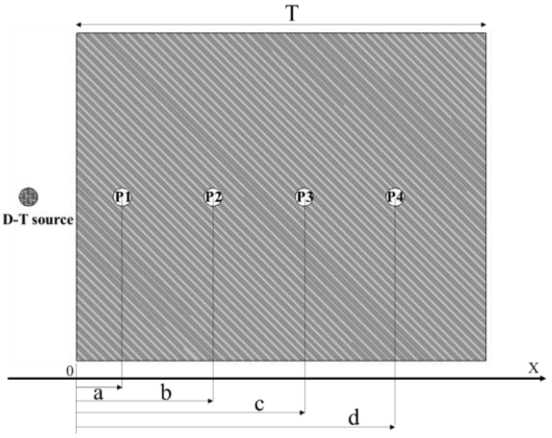


Fig.3. SiC and W model.

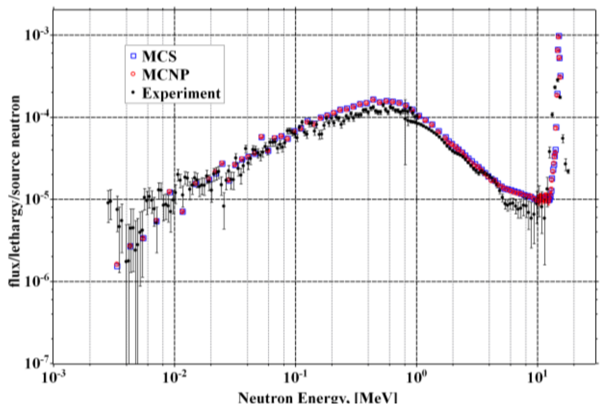
Table III. Dimensions of the shielding structure of NEA-1553/70, NEA-1553/47

Experiment	NEA-1553/70	NEA-1553/47
Shielding Material	SiC	Tungsten
Area [cm^2]	45.7×45.7	47.0×47.0
T [cm]	71.1	49
a [cm]	12.7	5
b [cm]	27.94	15
c [cm]	43.18	25
d [cm]	58.42	35

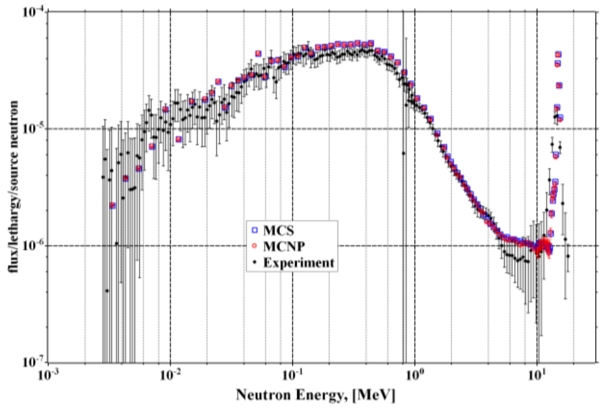
3. Calculation results

Fig. 4 shows the results for NEA-1553/45. The simulation results of the MCS code and the MCNP code agree well for entire energy range and for all distances. Though there is some discrepancy between the simulation results and the experimental data in the energy range 0.1~1.0 MeV at 76m and in the energy range of 1-4 MeV at 532 mm, the simulation results are consistent with the experimental data within their uncertainty level for other cases.

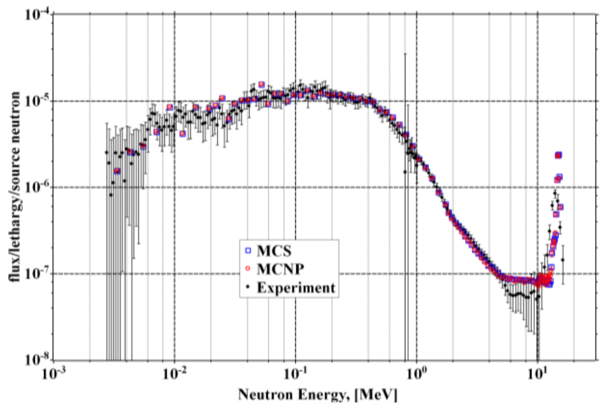
Fig. 5 shows the results for NEA-1553/72. It can be seen from the figure that the simulation calculation results of the MCS code and the MCNP code maintain a high degree of consistency. In the high-energy region where the neutron flux rapidly increases and decreases as the energy increases, the simulation results and the experimental data show a large difference. However, in all other energy domains, simulation results and experimental data are consistent.



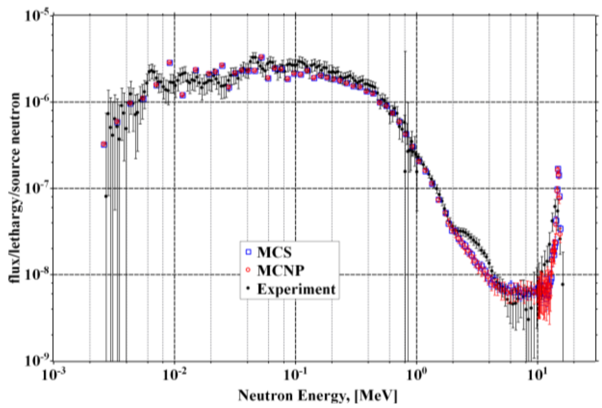
(a) The detector at **76 mm**



(b) The detector at **228 mm**

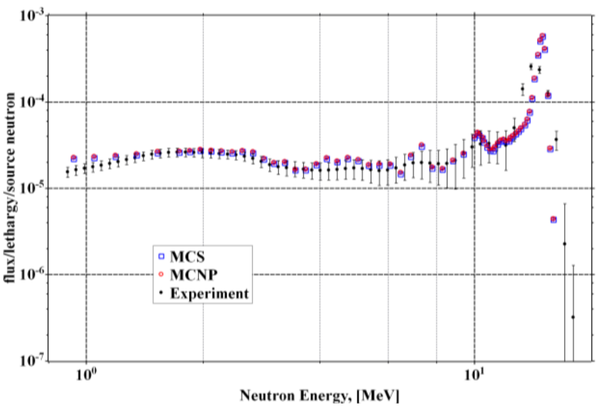


(c) The detector at **380 mm**

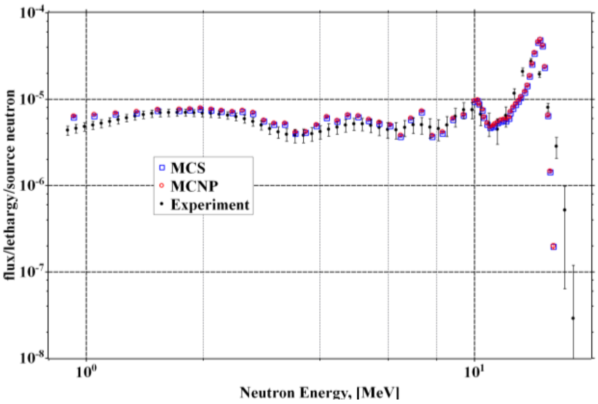


(d) The detector at **532 mm**

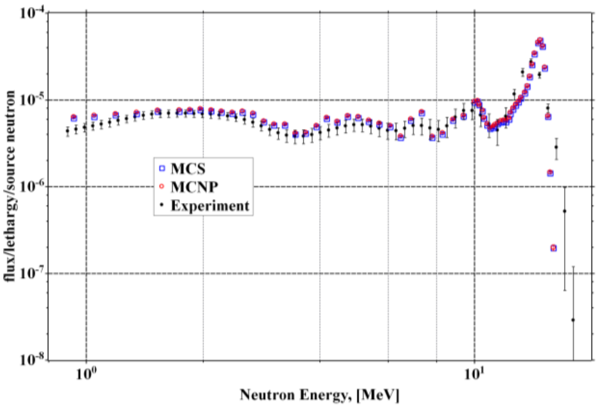
Fig.4. Neutron Spectra of NEA-1553/45 Benchmark



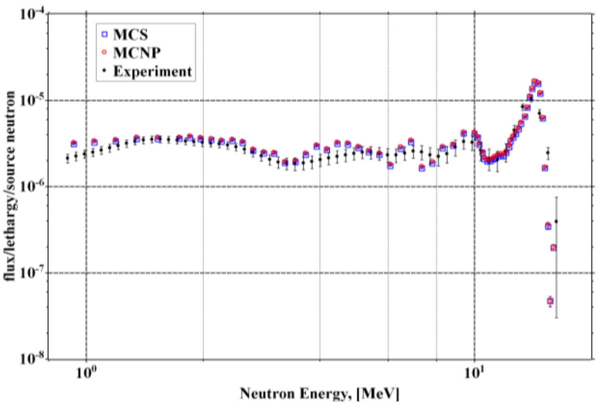
(a) The detector at **317 mm**



(b) The detector at **418 mm**



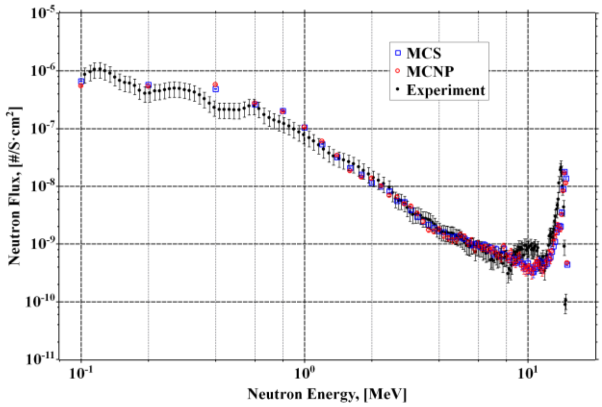
(c) The detector at **520 mm**



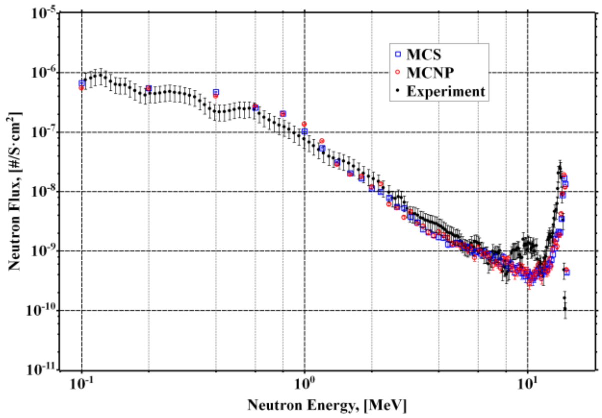
(d) The detector at **621 mm**

Fig.5. Neutron Spectra of NEA-1553/72 Benchmark

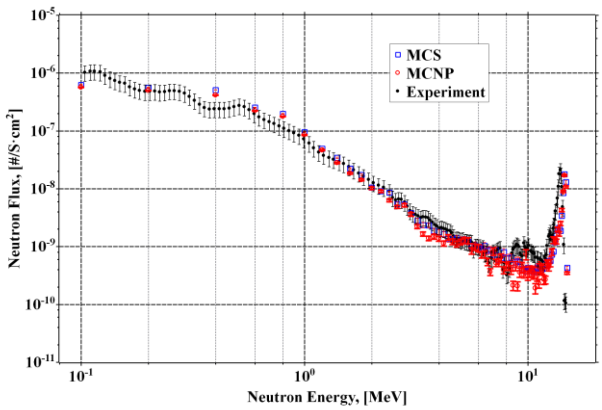
Fig. 6 shows a comparison of the results for the NEA-1553/46 benchmark. The calculated results of the MCS code and the MCNP code are consistent. When the energy is in the range 8-12 MeV, the calculated results are smaller than the experimental results, which is the same information provided by the Benchmark book [5], but the reason is unclear. When the energy is greater than 12 MeV, the simulated results are shifted by 500 keV positively. This error may be caused by the size and shape differences with the actual model due to insufficient data when building the model.



(a) **A0** Model

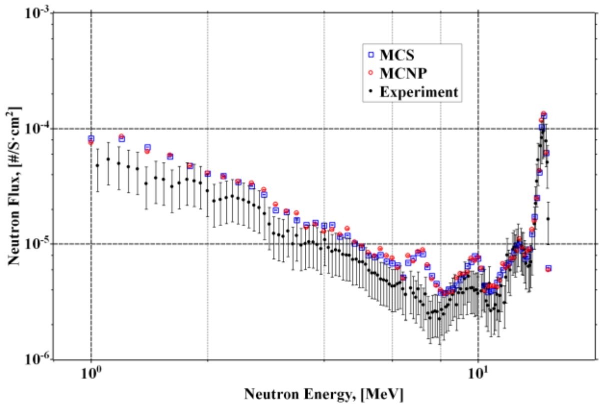


(b) **A1** Model

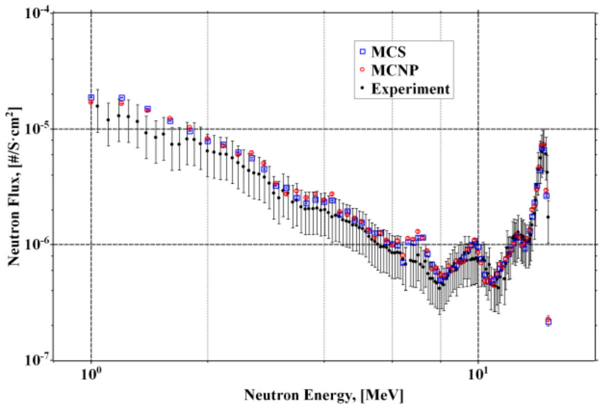


(c) **A2** Model

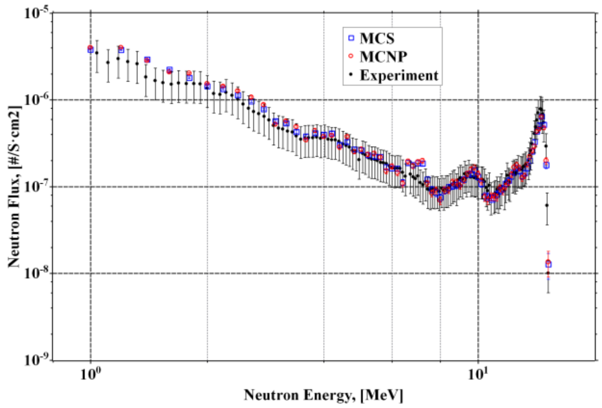
Fig.6. Neutron Flux of NEA-1553/46 Benchmark



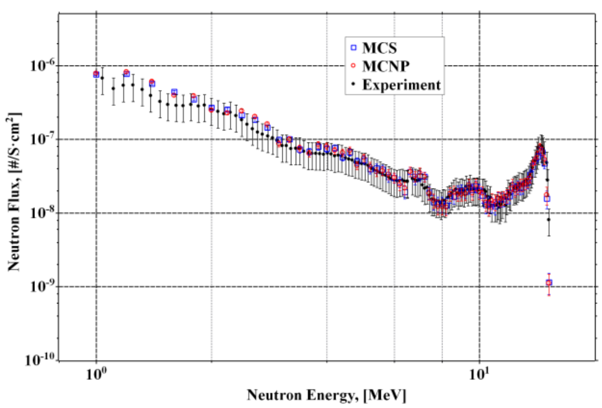
(a) The detector at **P1**



(b) The detector at **P2**

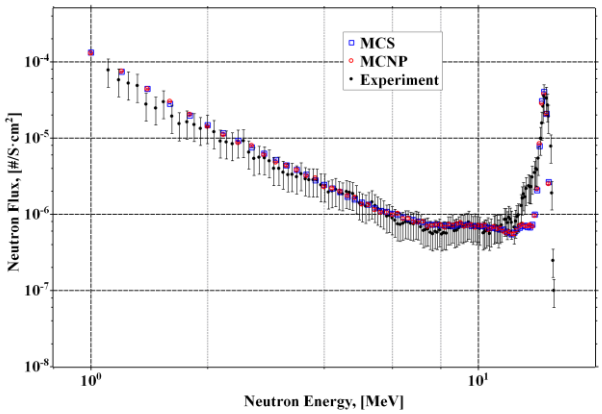


(c) The detector at **P3**

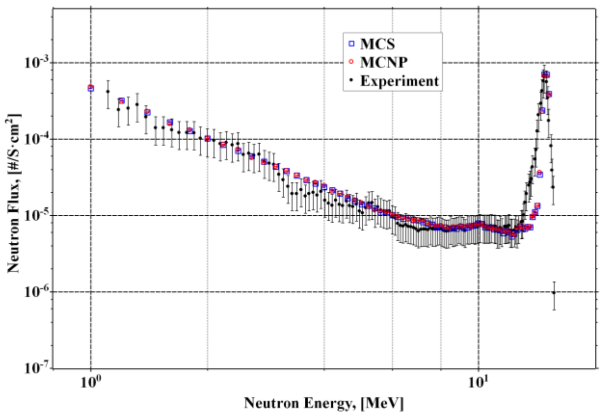


(d) The detector at **P4**

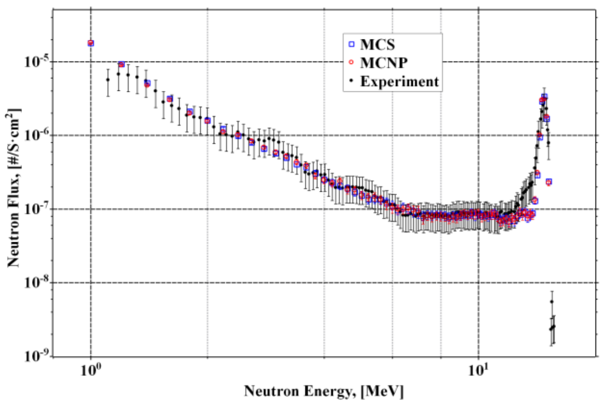
Fig.7. Neutron Spectra of NEA-1553/70 Benchmark



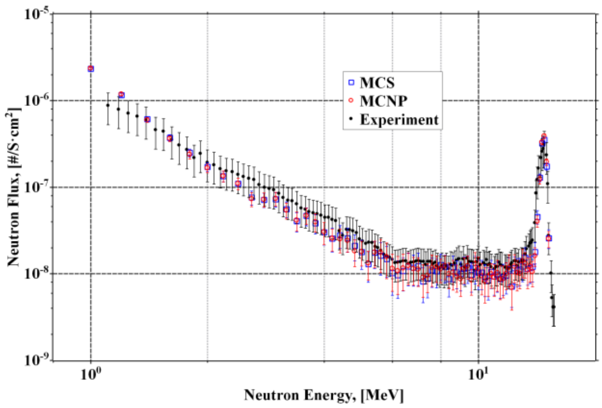
(a) The detector at **P1**



(b) The detector at **P2**



(c) The detector at **P3**



(d) The detector at **P4**

Fig.8. Neutron Spectra of NEA-1553/47 Benchmark

Fig. 7 compares the results for the NEA-1553/70 benchmark. From the results, it can be found that the simulation results of the MCS code are consistent with those of the MCNP code, but when the detector position is at the P1 position (Fig. 7(a)), the simulation result is much larger than the experimental result. The reason for is not clear, but it is the same as the result given in the benchmark document.

Fig. 8 compares the results for the NEA-1553/47 benchmark. Similarly, the simulation results of the MCS code are consistent with those of the MCNP code. The simulation results are within the error bound (2σ) of experimental results except for some energy range around 13-14 MeV. Overall, the simulation results are consistent with the experimental results.

4. Conclusion

In summary, when the simulation environment of the MCS code is consistent with the MCNP code, the computational results maintain a high degree of consistency, indicating that there is no problem with the computational power of the MCS code in solving the shielding problem. When the MCS simulation results are compared with the experimental results, specific errors do exist. However, after excluding unexpected factors in the experiments, the MCS simulation results agree with the experimental results, and the simulation results are within the confidence interval. The results show that the computational accuracy of the MCS code is reliable based on several experimental benchmarks that have been analyzed.

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[5] H. Freiesleben, C. Negoita, K. Seidel, S. Unholzer, U. Fischer, D. Leichtle, M. Angelone, P. Batistoni, M. Pillon, "Measurement and analysis of neutron and gamma-ray flux spectra in Tungsten", Report TUD-IKTP/01-03, Dresden, EFFDOC-857 (2003).