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Verification of MCS particle transport calculations using the Sky-shine experiment in the SINBAD benchmark.

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1. Introduction

The MCS code is a three-dimensional continuous energy particle transport calculation program based on the Monte Carlo method[1].The MCS code mainly addresses two major types of problems in nuclear reactor physics: criticality problems and radiation shielding problems. The MCS code verification process is divided into two steps. The first step is to complete this step by comparing with other calculation schemes (calculation/calculation comparison). This step is achieved by comparing with the MCNP code calculation 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. It mainly verifies the MCS code shielding simulation calculation ability for the fixed neutron source. The Sky-shine experiment was selected for verification. The fission source model in the MCS code validation process uses the ENDF/B-VII.1 library, and the fusion source experimental model is calculated using the FENDL3.1 library.

2. Description of experimental model

2.1. Sky-shine RA-reactor

The experimental reactor was carried out on the Ra-reactor belonging to the National Nuclear Center of Kazakhstan. The position of the detector is 1 meter from the ground and 50, 100, 200, 300, 400, 500, 600, 800, 1000m away from the axis. The statistical data of the experiment are neutron flux, neutron dose rate and neutron spectrum. As shown in Figure 1. The main nuclear fuel of the reactor is U235, the moderator material is ZrH2, the main materials of the reflective layer are Beryllium and Graphite, and the shielding materials are concrete and water.

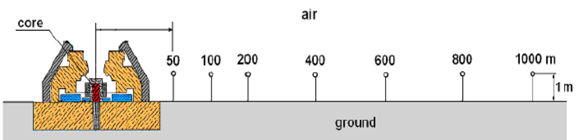

Figure 1. Model figure of Ra-reactor and detector locations.

During the experiment, the measurement system error is related to the accuracy of the instrument calibration. The calibration error does not exceed (3-5)%. The total error of spreading the spectrum with a multi-sphere spectrometer does not exceed (30-50)%. Except for the random error, the total error is determined as the root mean square error by the systematic error and the random error. The measurement error of the activated detector does not exceed 20%. When calculating the neutron flux measured by the activation detector, considering the statistical error and the error related to the inaccurate determination of the cross-section value, the total measurement error does not exceed 30%. The error of measuring fast neutron flux with plastic + ZnS crystal scintillation counter is (15-20)%. The error of thermal neutron flux, fast neutron flux and neutron flux, and fast neutron and neutron flux dose rate measured by MKS-01R instrument is not more than 20%. The reactor was modeled 1:1 during the simulation, but the detector was not modeled. A cylindrical fission source is constructed, the source size is the same as that of the core[2].

2.2. Sky-shine TFTR(Tokamak Fusion Test Reactor)

The experiment was conducted at the Tokamak Fusion Test Reactor in the Princeton Plasma Physics Laboratory. The D-T neutron source is used as the source information. The neutron dose rate was measured.

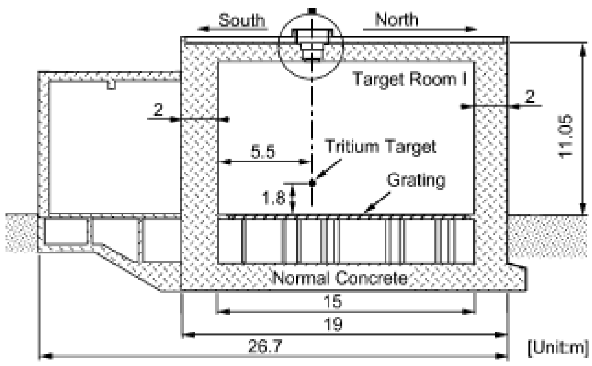

Figure 2. TFTR reactor model figure.

The experimental model is shown in Figure 2. The floor of the target room is an iron grid to reduce neutron scattering from the floor. The tritium target is 1.8m from the ground, 5.5m from the south wall, and 2.75meters from the west wall. The target room has a $0.9\times0.9m^2$ skylight on the roof, which is used for the roof lighting experiment. This port is usually closed with a concrete plug. In the sky-shine experiment, the concrete plug was removed and only a 2mm thick stainless steel plate was used to close the port to maintain the reduced air pressure in the target room. The neutron attenuation of the 2mm stainless steel plate is negligible.

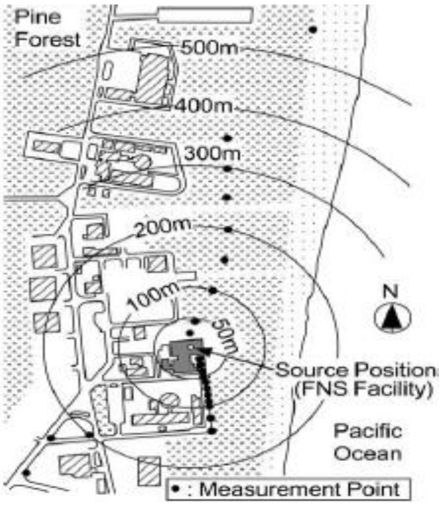

Figure 3. TFTR experimental detector location figure.

The position of the detector in the experiment is shown in Fig. 3, which is 4m above the ground. The laboratory is on flat land, only 150m from the Pacific Ocean. The north and east sides are surrounded by pine forests, about 10m high. The neutron dose rate was measured at 20-550m in the northern pine forest, the neutron dose rate was measured at 20-140m on the southern highway, and the neutron dose rate was measured at 200, 230, and 300m in the southwest. At all the measuring points shown in Figure 3, the neutron dose rate was measured with spherical rem-counters Fuji Electric NSN10002[3]. The model and measurement field adopt a simplified cylindrical geometric model with a diameter of 4000m and a height of 2000m. Assuming that the ground is concrete, the density is $2.3g/cm^3$. The other buildings and pine trees are not modeled..

3. Calculation results

3.1. Sky-shine RA-reactor

Figure 4 shows the statistical results of the neutron flux. It can be seen that the calculation results of MCNP code and MCS code are consistent, but when the energy is less than 0.414eV, there is a large error between the calculation results of thermal neutrons and the experimental results of the benchmark. The calculated result is 2.5-3 times higher than the experimental result. The reason for this error is that the characteristic function of the lithium fluoride scintillation spectrometer response is ignored when the thermal neutron result is counted during the experiment[2]. The results in Figure 5 show the neutron dose rate statistics. The MCS code and MCNP code results are consistent with the Benchmark experimental results, and although there is a certain error at 1000 m, the errors are within 3σ when compared with the experimental results. Figure 6 shows the statistical results of the neutron energy spectrum. When the energy is below 2MeV, the calculated results are basically consistent with the experimental results. However, as the position of the detector keeps getting farther, the error of the calculation result is increasing, and the error of the simulation calculation can be reduced by increasing the calculation time and history.

3.2. Sky-shine TFTR(Tokamak Fusion Test Reactor)

Figure 7 shows the statistical results of the neutron dose rate. It is obvious that the statistical results of MCS code and MCNP code are in good agreement. However, compared with the experimental results, there is a certain error in the position closest to the reactor. The reason for the error is that the experimental model established by the simulation is an axisymmetric cylindrical structure, and the source is located at the center of 5 meters high; but in the actual model, although the source is also at 5 meters high, it does not in the center position, it is biased to one side, so there is a certain deviation. However, the simulated calculation results are basically consistent with the experimental results, and the errors are within 3σ.

4. Conclusion

In this paper, the computational capability of the MCS code neutron-photon coupled transport simulation is verified by the sky-shine benchmark experiment of the SINBAD shielding benchmark. The two experimental models are one for fission source reactor experiment and one for fusion source test reactor experiment; the calculation results show good overall agreement with the experimental results, although there are some errors. Further validation calculations will be performed using the FNS benchmark model to verify the effects on the MCS code neutron-photon coupled transport simulation calculations for different shielding materials and different thicknesses in the fixed source mode.

REFERENCES

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[2] Mikhail E. Netecha, *et al*, "Experimental Study of Reactor Radiation Scattering in the Atmosphere," Research Development Institute of Power Eng., no. 517-96, 1998.

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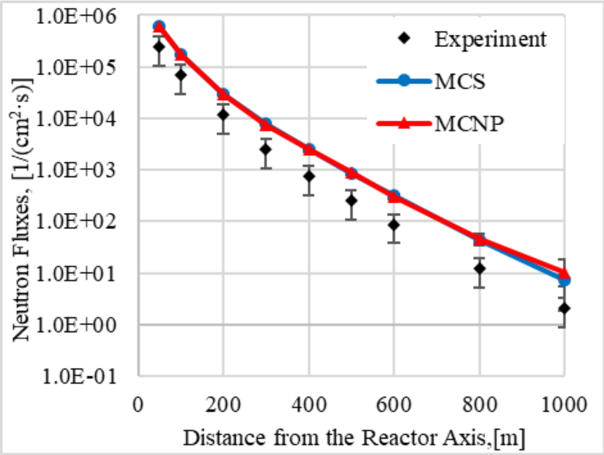
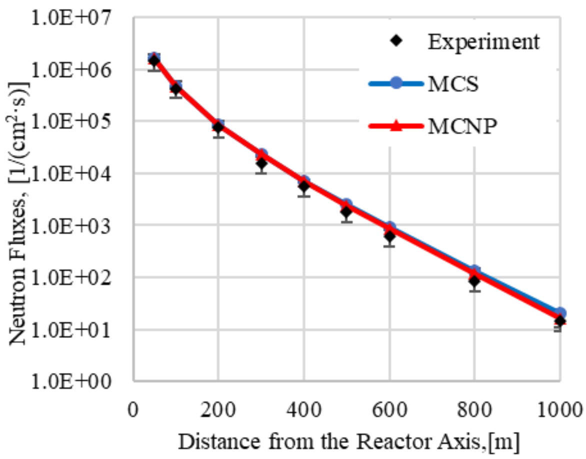


(a) Thermal Neutron Fluxes



(b) Intermediate and Fast Neutron Fluxes

Figure 4. Statistic results of neutron flux in Ra reactor

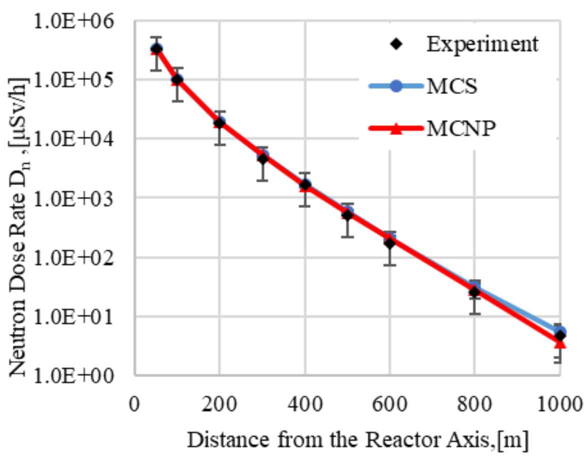
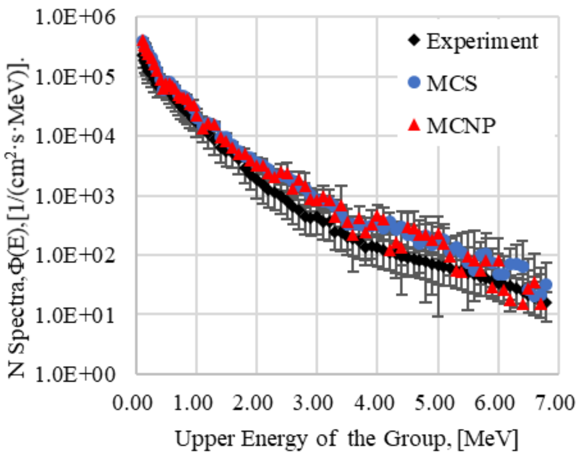
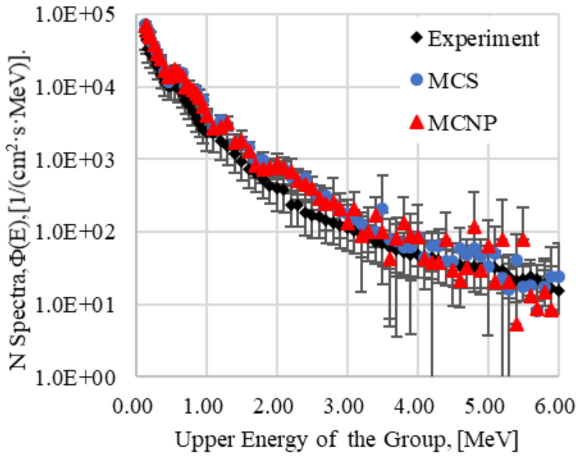


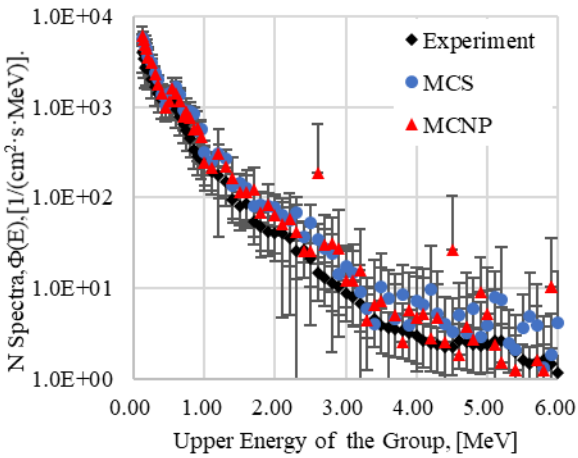
Figure 5. Statistic results of neutron dose rate in Ra reactor



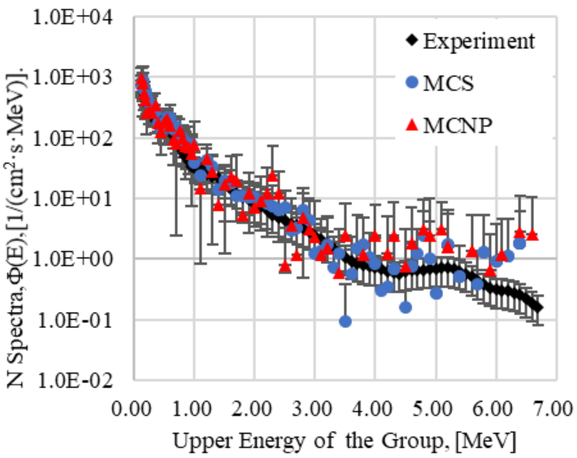
(a) 100m from the RA Reactor



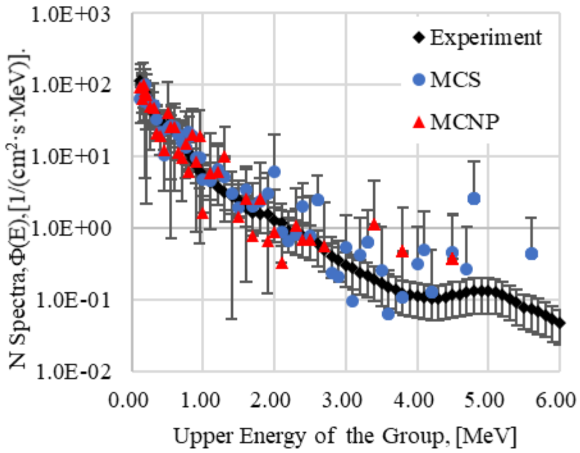
(b) At 200m from the RA Reactor



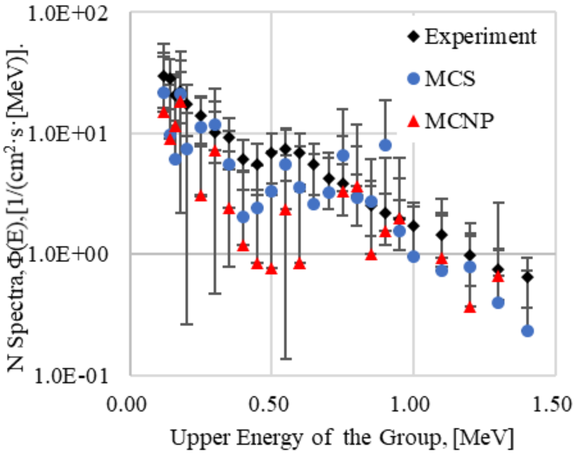
(c) At 400m from the RA Reactor



(d) At 600m from the RA Reactor



(e) At 800m from the RA Reactor



(f) At 1000m from the RA Reactor

Figure 6. Differential Neutron Spectra phi(E) of RA Reactor

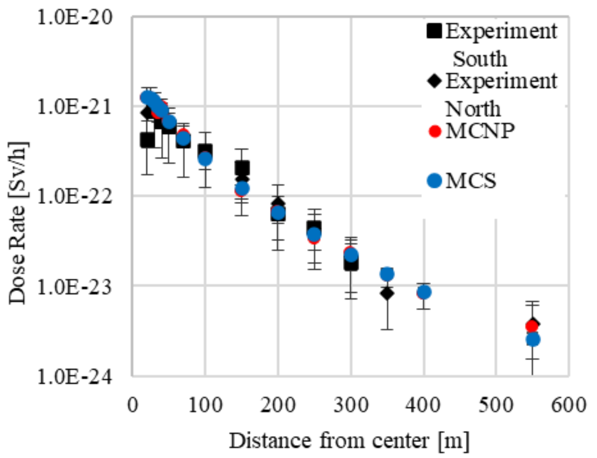


Figure 7. Statistical Results of Neutron Dose Rate in Tokamak Model