Shielding Design of the Cold Neutron Source for the KIPT Neutron Source Facility

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INTRODUCTION

Argonne National Laboratory (ANL) of the United States and Kharkov Institute of Physics and Technology (KIPT) of Ukraine have cooperated on the development, design, and construction of a neutron source facility [1]. The facility was constructed at Kharkov, Ukraine and its commissioning process is underway. The facility will be utilized for research, producing medical isotopes, and training young nuclear specialists. The neutron source facility is designed including a cryogenically cooled neutron moderator system to provide a cold neutron source (CNS). The low energy neutrons from the cold neutron source will be utilized in scattering experiments, material structure analyses, and other utilizations. Cold neutron guides [2], coated with reflective materials for the low energy neutrons, are used to transport the cold neutron beams to the experimental site. Most of the gamma rays and high-energy neutrons are not affected by the cold neutron guides. These guides are extended several meters outside the main shield of the neutron source facility, and curved guides are used to reduce the gamma rays and high-energy neutron fluxes.

The neutron guides are installed inside a shield structure to insure an acceptable biological dose inside the experimental facility hall. Heavy concrete is the selected shielding material because of its acceptable performance and cost. MCNPX [3] was utilized for the shielding design analysis. In the shielding analysis, the neutron and the gamma doses were calculated separately. The weight windows variance reduction technique was used in the shield design analyses. The goal of the shield design is to keep the total biological dose less than 0.5 mrem/hr outside the shield structure. A series of iterative MCNPX calculations were performed to define the shield geometry and dimensions of the CNS guides.

CALCULATION MODEL AND PROCEDURE

For efficient Monte Carlo calculations, a quarter neutron source facility model was used with reflective boundary conditions utilizing the symmetry of the subcritical assembly of the KIPT neutron source facility. Natural uranium target was used in the analysis because it generates the maximum possible flux and power level. The quarter facility model preserves the sub-criticality as well as the neutron flux level of the facility.

Heavy concrete shielding walls were installed surrounding the neutron guides outside the subcritical assembly shield. Since the neutron and gamma flux values outside the subcritical shield boundary are very low to meet the working dose requirement, a direct analog MCNPX calculation is very time consuming. Variance reduction techniques were employed to deal with this shielding problem including the deep penetrations. Three dimensional mesh-based weight window was utilized [4] to provide a space and energy dependent importance function for the calculations. MCNPX calculations were iterated to determine the weight window, the shield geometry around the neutron guides, and the required shield thickness. The final configuration is shown in Fig.1. In this model, no shield credit is taken for the experimental hardware using the cold neutron source since it will change depending on the experiment. The neutron guides have a curved section with a bending angle of 10°. The thickness of the cold neutron guides is less than 1 cm, which does not affect the shield design.

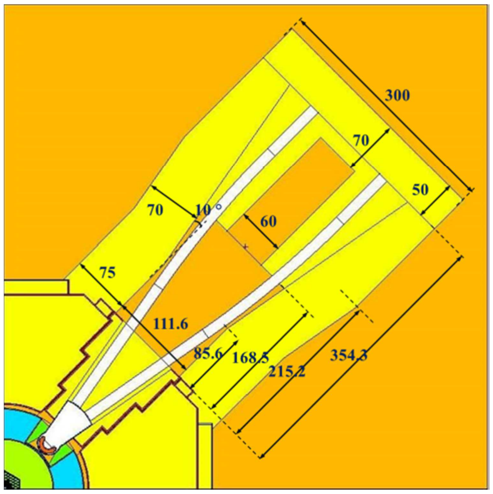

Figure 1. Radial configuration of the CNS guide hall at the core mid-plane

Neutron and gamma doses were calculated separately for this analysis. The gamma dose was obtained through an electron, photon, and neutron coupled transport calculations, which starts with the electron source. While the neutron dose calculation, uses only neutron transport calculations. In this case, the calculation starts from neutron source file, which was generated from previous MCNPX calculation.

The weight windows for neutron and gamma dose calculations were generated separately. The weight windows was first used to optimize the neutron dose tally outside the shield boundaries in two steps. The first step is for the end wall, calculating the neutron dose as a function of the end wall shield thickness. The second step is similar to the first step except it is for the sidewall. The results from the two calculations were combined to define the neutron dose map. These two steps were again performed to define the gamma dose map. An example of the weight windows for gamma dose calculation is shown in Figs. 2 and 3.

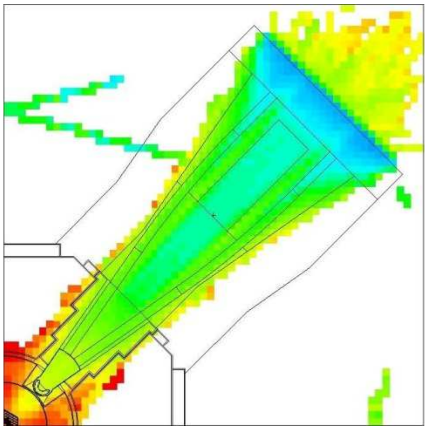

Figure 2. Weight window importance values for the gamma dose outside the end wall.

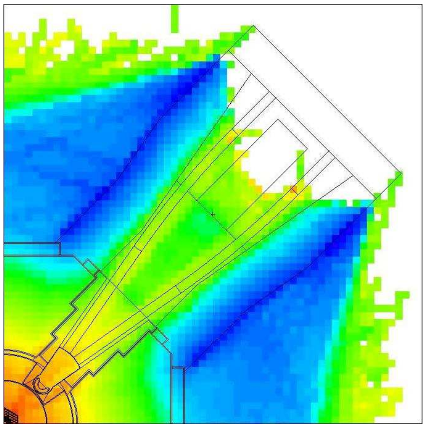

Figure 3. Weight windows importance values for gamma dose outside the sidewall.

BIOLOGICAL DOSE RESULTS

Using the procedure described in the previous section, the neutron and the gamma biological dose maps for the CNS guide hall were calculated, as shown in Figs. 4 and 5. The total (neutron and gamma) dose map is shown in Fig.6. The external boundaries of heavy concrete shield are shown in these three maps. Figures 4 and 5 are not the direct results from MCNPX, but each was obtained by merging two separate set of MCNPX results using different weight windows. For the gamma biological shield, two dose results were calculated separately using the weight windows shown in Figs.2 and 3 respectively, and these two results were merged together. In this way, the gamma biological dose map has small statistical errors along the whole shield boundary (end wall and sidewall) and the combined gamma biological dose map is shown in Fig. 4. The same procedure was used to get the neutron biological dose map shown in Fig. 5. The total biological dose map is shown in Fig. 6 and it is obtained by adding the two maps shown in Figs. 4 and 5.

Based on the results shown in Fig. 6, the 0.5 mrem/hr contour line is inside the external shield boundary, which satisfies the design requirements. The maximum statistical error in the biological dose results at the shield boundary is less than 10 %.

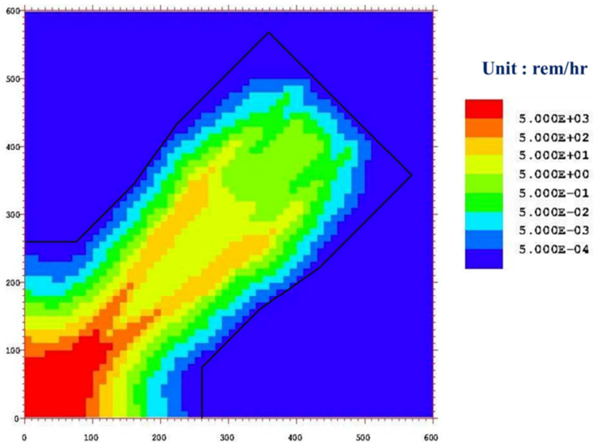

Figure 4. The gamma biological dose map at the mid-plane of the CNS guide hall

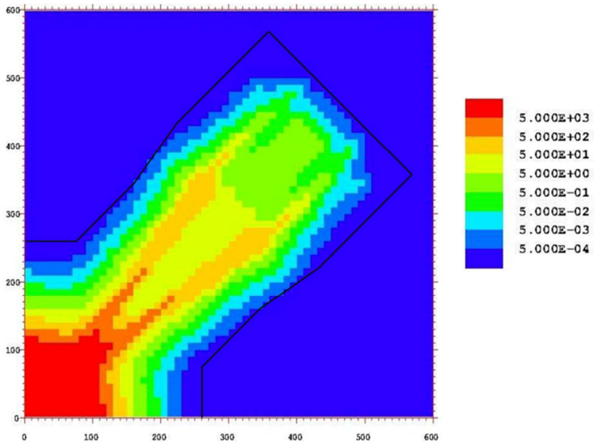

Figure 5. The neutron biological dose map at the mid-plane of the CNS guide hall

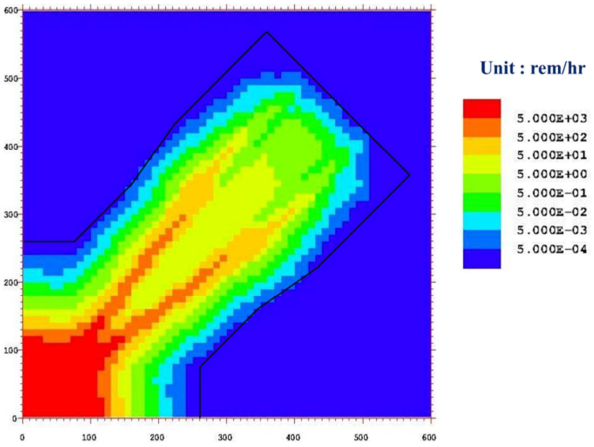

Figure 6. The total biological dose map at the mid-plane of the CNS guide hall

CONCLUSIONS AND SUMMARY

The shielding design and analysis of the CNS hall of the KIPT neutron source facility was carried out successfully. The Monte Carlo computer code MCNPX was used for performing the analysis. The neutron and gamma biological dose were calculated separately, and the weight windows variance reduction technique was utilized in these calculations. After a series of iterative MCNPX calculations, the shield geometry and dimensions of the CNS guide hall shield were determined, and the total biological dose outside the shield boundary is less than the 0.5 mrem/hr design guideline.

ACKNOWLEDGMENTS

This work is supported by the U.S. Department of Energy, National Nuclear Security Administration, Office of Material Management and Minimization (M3).

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