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Improvements of User-friendly GUI-based Monte Carlo Simulation Code for External Exposure

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1. Introduction

In 2020, the International Commission on Radiological Protection (ICRP) released the adult mesh-type reference computational phantoms (MRCPs) in ICRP *Publication 145* [1]. Following the adult MRCPs, the pediatric MRCPs were also successfully developed and will be released in an upcoming ICRP Publication [2]. The MRCPs define micrometer-scale source and radiosensitive target layers in the alimentary and respiratory tract organs, skin, and urinary bladder, thereby improving the accuracy in dose calculation. In addition, the MRCPs can easily be deformed into other postures or body shapes. Following these advantages of the MRCPs, meanwhile, a high degree of understanding of the MRCPs is required to estimate doses due to their advanced and elaborate structures. Therefore, reconstructing the exposure scenarios and estimating doses using the MRCPs coupled with the Monte Carlo simulation can be challenging for general radiation workers or regulators who lack expertise in the computational phantoms and Monte Carlo codes. For the purpose of easy and accurate dose estimation even by the general radiation workers or regulators, in our previous research, a graphical user interface (GUI)-based Monte Carlo simulation code for external exposure (McSEE) was developed by implementing basic functions [3]. In the present study, through discussions with expert organizations (i.e., ICRP and Korea Institute of Nuclear Safety), the McSEE was updated for (1) practical and user-friendly functions and (2) covering various external exposure situations where the previous code cannot calculate radiation doses. The present study focuses on describing the improvements or updates of the McSEE.

2. Description of McSEE

2.1. Overall design of McSEE

The McSEE, which is a user-friendly GUI-based code, consists of four main panels: phantom panel, shielding panel, source panel, and output panel. The users can set the exposure cases using the former three panels (i.e., phantom, shielding, and source panels). The implemented materials are immediately visualized in the visualization window. For dose calculation, the Geant4 Monte Carlo radiation transport code is implanted in the McSEE [4]. After the calculation, a report containing the detailed information on the exposure case and the resulting dose values are printed out, and the resulting values are displayed in the output panel.

2.2. Phantom panel

The ICRP mesh-type reference phantoms, posture-dependent phantoms, and body-size-dependent phantoms for adults were implemented in the previous version of the McSEE. In the present study, the phantom lists were expanded to include the ICRP mesh-type reference and body-size-dependent pediatric phantoms as well as those with user-defined arbitrary posture phantoms generated from the Mesh Phantom Posture Deformer (MPPD) program to evaluate the doses to the workers and the general public. The clothes and glasses can be added to the phantoms by applying the pre-made wearables [3]. For the MPPD-generated phantoms, however, the wearables cannot be pre-made due to the arbitrary posture. Therefore, a new function was developed to create wearables for these phantoms. The clothes can be generated in their desired shape by selecting regions on the skin surface of the phantom using the mouse and the glasses can be generated by selecting location on the eyes of phantom with a mouse click.

In addition to the phantom lists, unlike the previous version where only one phantom could be implemented for dose calculation, the McSEE was now updated to implement multiple phantoms in one simulation, thereby making it possible to consider the exposure cases involving several workers or the general public. The phantoms can be added as long as the computer memory allows. The users can input the XYZ coordinates of the phantom center and rotation angles for each axis. Although the users can finely adjust the position of the phantom using this function, the users should calculate the coordinates and rotation angles every time the phantom position is changed. For the cases where many phantoms need to be implemented, this process can be very cumbersome. Therefore, an intuitive mouse control UI has been developed for the user convenience. The users can easily translate or rotate phantoms through mouse drag-and-drop; that is, the users can confirm the position of the phantom in real time. When positioning the phantoms, due to the fact that the geometries should not be overlap to be implemented in Monte Carlo codes, a geometry check function was developed to detect and visualize the overlapping regions between the phantoms. Figure 1 shows the pediatric MRCPs and the MPPD-generated phantoms implemented in the visualization window of the McSEE.

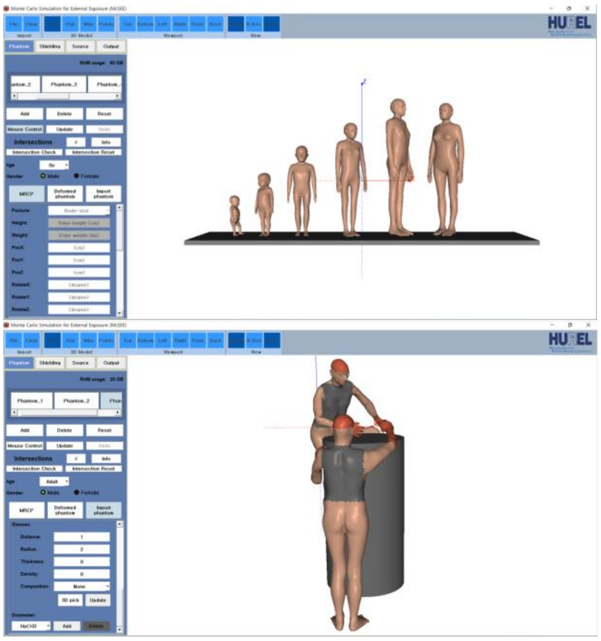

Figure 1. McSEE phantom panel showing six pediatric MRCPs (upper) and two MPPD-generated phantoms with wearables and glasses (lower).

2.3. Shielding panel

The previous version of the McSEE allows the users to define the external shielding objects in the form of box, sphere, and cylinder by specifying their size, position, and rotation. In this case, the inside of the shielding objects is fully filled with user-defined materials. Therefore, the users should make several shielding objects to make a hollow shielding object, e.g., walls in a room, tubes, or shells. In the present study, therefore, the external shielding object implementation function was updated to include the wall thickness of shielding object. To see the inner side of the shielding objects (e.g., inside of the walls), set transparency function was newly developed.

2.4. Source panel

In the previous version of the McSEE, four source types were implemented: broad beam, external point, hot particle on the body/clothes, and floor disk. In the present study, phase-space file source was added to cover very complex source which cannot be defined using aforementioned source types. Two types of phase-space file can be used in the McSEE: (1) the International Atomic Energy Agency (IAEA) phase-space file and (2) user-made phase-space file. First, the IAEA has created a public database of phase-space files from linear accelerators used for external radiotherapy [5]. Users can import this IAEA phase-space file database into the McSEE to define the complicated accelerator sources. Second, users can score the particle information at the surface of the geometry covering the phantoms and generate phase-space file using general Monte Carlo codes. For this case, the generated phase-space file should be written in order of particle type, position, direction, energy, and statistical weight. When the phase-space file is read, the position of the source particles is visualized in the visualization window of the McSEE (Figure 2). Using the phase-space source as well as pre-developed multiple points source, we believe almost all source geometries can be defined in the McSEE.

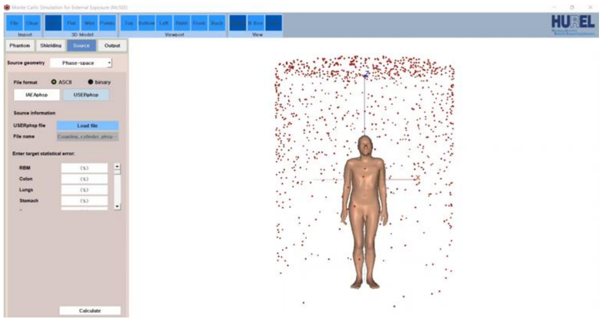

Figure 2. McSEE source panel showing user-made phase-space source using a coupling cylinder.

3. Conclusion

In the present study, the practical and user-friendly functions were developed and implanted in the GUI-based Monte Carlo simulation code for external exposure (McSEE). Using the updated version of the McSEE, even general radiation workers or regulators, who lack knowledge in computational phantoms and Monte Carlo codes, are expected to easily define most of the external exposure scenarios by implementing the multiple phantoms with wearables, external shielding objects, and various source geometries, thereby accurately estimating doses to the workers and the general public. In addition, after development and validation, the McSEE will be used by the ICRP Task Group 112 for calculating the dose coefficients for the representative emergency exposure situations and be distributed through an upcoming ICRP Publication of the Task Group 112 as a reference software tool for calculating doses for various emergency external exposure situations.

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