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A simple voxel-based assessment and visualization of dose to human for radiation protection using virtual simulation

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A R T I C L E I N F O

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A B S T R A C T

In this paper, virtual simulation was taken as an auxiliary tool for radiation protection, dose assessment. So radiation protection using virtual reality was taken as a research subject. A simple voxel modeling for virtual human was proposed. Based on the voxel model, dose assessment and visualization methods for virtual human in radiation environment were proposed. The parallel technology contributed to dose assessment in real-time. Based on dose assessment and visualization methods, a radiation protection method using virtual simulation was developed for the preparation of working in radiation environment. These validation tests demonstrate these methods make it possible to plan for the exposure dose to workers in radiation environment using virtual simulation.

1. Introduction

The decommissioning activities of nuclear facilities are under high radioactivity (IAEA, 2014), so it is necessary that before decommissioning activities of nuclear facilities, the radiation exposure dose of workers has to be assessed and the radiation protection measures have to be taken under the principle of ALARA (as low as reasonably achievable).

Much work has been done recent years on exposure dose assessment method for human in virtual radiation scene in radiation environment. For example, path-planning method took POint Model (POM) to assess the potential exposure dose in radiation field (Liu et al., 2015). POM takes dosimeter sensor as a point at the navel of virtual human and the received dose rate is interpolated value of neighbor dose rates, but calculation accuracy is bad.

Korea Atomic Energy Research Institute designed a dose assessment method based on game engine (Jeong et al., 2014). It is denoted as COllider Model (COM) in this paper. The virtual human is taken as a capsule collider and cubes of dose rate are distributed in virtual scene. The received dose is assessed based on collision detection in game engine, but it ignores the radiation sensitivity of organs and tissues.

Chinese Institute of Nuclear Energy Safety Technology developed the voxel-based organs dose assessment method to achieve precise organ-level dose assessment compared with traditional methods (Li et al., 2013), but millions of voxels cause long calculation time.

The U.S. Department of Energy developed the Radiological Environment Modeling System (REMS) which was also capable of computing an effective dose equivalent by summing doses at certain sensor locations and applying appropriate weighting factors (SNL, 1996). In this paper, this method is denoted as BAsedline method (BAM) in which the sensors are taken as points decorated in virtual human to detect dose rates.

In addition, mathematical phantom was proposed by Oak Ridge National Laboratory in America (Eckerman et al., 1996), in which the human body is simplified as the assembly of several geometries (Snyder et al., 1978). It is used for dose assessment has advantages of a little internal memory, great efficiency and so on.

Different from above-mentioned research results, this paper is intended to design an exposure dose assessment method which has a high precision based on radiation sensitivity of organs and tissues and real-time computing speed, and then address dose visualization for virtual human. In addition, a primary application of dose assessment and visualization for radiation protection is designed to plan worker's exposure dose.

The rest of this paper is organized as follows: Section 2 briefly describes the representation of radiation risk in virtual environment. Section 3 focuses on a simple voxel-based dose assessment method, including virtual human modeling, dose assessment methods and dose visualization for virtual human. Section 4 briefly introduces the application of dose assessment and visualization for radiation protection. Section 5 describes the test and results. Section 6 presents the summary and conclusion.

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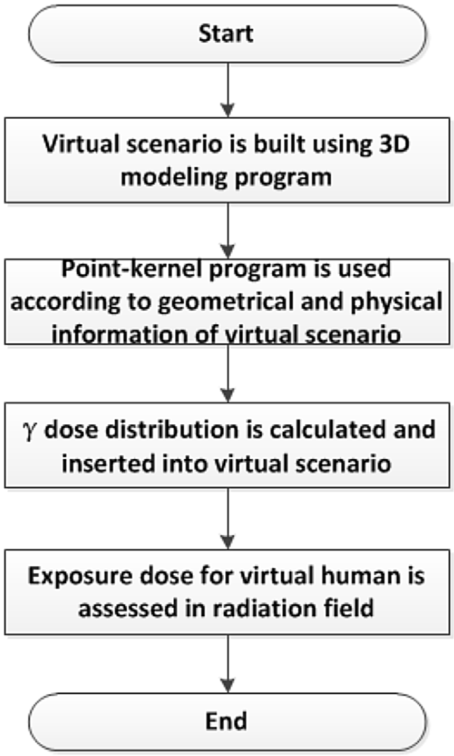

Fig. 1. Application flow of dose calculation for virtual simulation.

2. Representation of radiation risk in virtual environment

Radiation data in virtual scenario and simulation is used to provide data support for dose assessment and visualization. Four radiation visualizations were designed using Unity engine, which are basis of the following dose assessment methods.

2.1. Application of dose calculation for virtual simulation

According to virtual scenario, radiation data is calculated by any transport code calculations such as Monte Carlo (X5 Monte Carlo Team, 2003), point-kernel integral method (Prokhorets et al., 2007) and discrete ordinates method (Azmy, 1996). In this paper, gamma dose rate distribution in virtual scenario is calculated by point-kernel program.

The application flow of dose calculation for virtual simulation is shown in Fig. 1. Firstly, 3D models of nuclear facilities are built using 3D modeling software and virtual scenario is decorated using Unity. Secondly, data of radiation distribution is calculated and radiation data is stored into database for reusing. Thirdly, radiation data from database is inserted into virtual scenario for dose visualization and exposure dose assessment for virtual human. The functions of dose assessment and dose visualization in the simulation program were developed using C# language based on Unity.

2.2. Radiation risk in virtual environment

Radiation visualization contributes to understand and watch the dose distribution in special environment, which helps users to plan work under the principle of ALARA. To convenient to use radiation data in virtual scenario, dose rate distribution is equidistant and uniform in 3D space.

To directly perceive radiation risk through the senses and fast reflect the high and low radiation place, figure and graph are combined to present the radiation data to environment and human in virtual scenario. According to the existing radiation visualization methods, none of the techniques should be considered fundamentally flawed for radiation visualization purposes limitations of each technique. So several dose visualization methods were designed, such as dose mesh, dose volume and dose point for environment, dose voxel and value for human.

Dose mesh is used to graphically display the dose distribution at a given height using a mesh with different colors according to dose rates, but it lacks of a vertical dimensionality. Different from the representation of dose cubes in reference (Jeong et al., 2014), dose volumes have their own dose rates and independent colors. Dose points are used to display the dose distribution in 3D space using points with different colors. Fig. 2 presents the interpretation of the references to color in above three radiation visualizations. Fig. 3 presents a synthetical example of above three radiation risk visualization to environment.

To represent radiation risk for human, voxel-based dose assessment and visualization for virtual human were introduced in the following paper.

3. Voxel-based dose assessment and visualization for virtual human

A simple voxel modeling of virtual human body, two kinds of dose assessment methods and dose visualization are described in this section.

3.1. A simple voxel modeling for virtual human

In radiation protection, radiotherapy and radiation processing, human phantom is designed to simulate measure and calculate the absorbed dose distribution of human from external radiation source. To give human qualities to virtual human in virtual simulation, a simple virtual bottle human was designed according to BOttle MAnnikin ABsorber (BOMAB). Based on virtual bottles human, voxel model of virtual human is built to estimate exposure dose and visualize dose distribution in human body.

The BOMAB was developed by Bush in 1949, which consists of 10 polyethylene bottles, either cylinders or elliptical cylinders, that

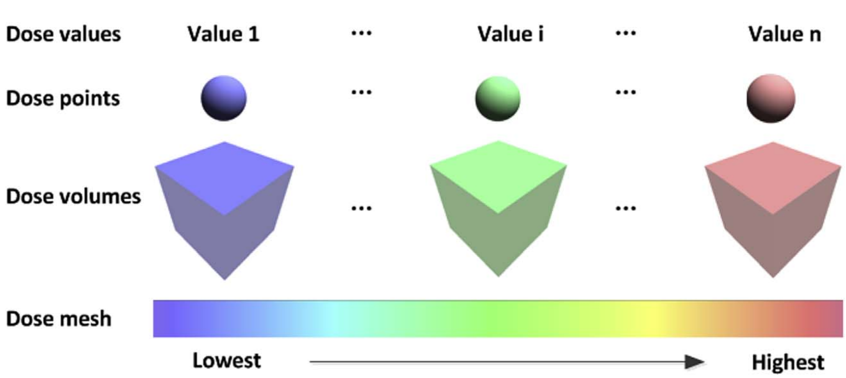

Fig. 2. The interpretation of the references to color in three radiation visualizations. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)