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The simulation method based on skeleton animation model and organ-monitoring-points for exposure dose assessment to workers in radioactive environments

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HIGHLIGHTS

- The method was based on skeletal animation and organ-monitoring-points.
- Working postures are considered in the dose assessment process of the method.
- The shape of organs and tissues are considered in uneven radiation fields.
- Virtual reality is used to increase radiation safety and work efficiency.

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ABSTRACT

The objective of this paper is to develop a dose assessment method that takes into account the working postures and the non-uniformity of the radiation fields to ensure the radiation safety of workers in nuclear facilities. To simulate different working postures, the working posture models were developed with skeletal animation technology. And to assess the exposure dose to workers in a non-uniform radiation field, virtual reality technology was used to develop a model of a hypothetical human with organ-monitoring-points distributed in his/her organs and tissues. And then a dose assessment method based on skeletal animation technology and the organ-monitoring-points was developed. Simulation results were compared with that of MCNP, the point model and the organ's minimum bounding box model, and they show that the method is effective in providing dose assessments to workers, taking into consideration the working postures and non-uniformity of radiation environments.

1. Introduction

Excessive nuclear radiation is harmful to human health, and the people working in nuclear facilities face the risk of radiation exposure, especially during the maintenance and decommissioning tasks or when accidents occur. Therefore, thorough assessment and analysis of the amount of dose exposed to the workers are essential, before or during their duties.

Much work has been done in recent years on the method of dose assessment in radioactive environments. Sandia National Laboratories developed the Radiological Environment Modeling System (REMS) to quantify dose to humans by using the IGRIP (Interactive Graphical Robot Instruction Program) and Deneb/ERGO simulation software. However, the process is not flexible enough because it needs to be implemented with fixed working routes under predetermined scenarios (SNL, 1996).

Kim and Park (2004) developed a simulation program based on the virtual environment using VRML and Java Applet to predict exposure dose of workers in a virtual reality environment. The assumption in the study is that the worker is a point with his/her volume ignored, and the worker's movement velocity is constant.

To improve the efficiency of maintenance work and decrease the radiation exposure of maintenance personnel in nuclear power plants, Ohga et al. (2005) developed a calculation and visualization system of the radiation field. The radiation exposure is calculated from the personnel movement data and dose rate distribution by using the dose rates at chest height, discriminating between crouching and standing positions.

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Mól et al. (2009a,b) used a game engine to support dose assessment and optimize the operational routines in nuclear plants. The simulation platform collects dose rate data from radiation monitors installed in a real plant, then researchers assess dose for personnel.

Jeong et al. (2014) developed a method to simulate and assess the exposure dose to workers during decommissioning of nuclear facilities using virtual reality. The dose assessment is accomplished by detecting the amount of collision between the human model and dose distribution which developed as cubes. When a human model is in a radioactive environment, the dose rate can be obtained from values of the latest cube.

Tang et al. (2010) developed a system named radiation virtual simulation for dosimetry (RVIS) to improve the efficiency of maintenance work, and decrease the radiation exposure of maintenance personnel for The Experimental Advanced Superconducting Tokamak, and the coordinates of the sensitive organs are obtained on the basis of the vertical offset of their position from the pelvis. To achieve precise organ-level dose, Li et al. (2013) proposed a voxel-based organs dose assessment method. However, the computation time is expensive. To overcome this problem, Shang et al. (2014a,b) used parallel technology to improve the computation time. Furthermore, Shang et al. (2014a,b) used the minimum bounding box strategy to accurately estimate the dose of organs or tissues. The dose is calculated with the photon flux at the center of organ's minimum bounding box.

The legacy methods of dose assessment are mainly achieved with the standing posture. However, the worker in the actual radioactive environments have different working postures, and different postures expose the sensitive organs and tissues to different radiation levels, and eventually, affect the exposure dose to workers. Furthermore, when the body or organs in the body are treated as a particle, it can obscure the accuracy of dose assessment, especially when the radiation field is strong and non-uniform.

Therefore, taking into account different working postures and the non-uniformity of radiation fields, dose assessment method based on skeletal animation and organ-monitoring-points is proposed. To simulate the working environment, task process and assess the radiation exposure to workers, a model of a hypothetical human and his working postures are designed with virtual reality. The method makes it possible for a flexible and reliable real-time simulation and dose assessment for workers, taking into consideration the working posture.

This paper is organized as follows: Section 2 briefly describes the mathematical concepts for dose assessment. Section 3 focuses on the implementation of the proposed method. Section 4 is allotted to describing the simulation experiments. Section 5 analyzes the results of simulation experiments, and Section 6 presents the concluding remarks.

2. Mathematical model for dose assessment

For radiation protection purposes, the International Commission on Radiological Protection (ICRP) developed a set of protection quantities specific to the human body, such as absorbed dose, equivalent dose, effective dose and so on, and provided six irradiation geometries to calculate the conversion coefficients (ICRP, 1996).

The absorbed dose of an organ or tissue can be expressed as air kerma free-in-air (subsequently simplified as 'kerma'), K_a, multiply by relevant organ dose conversion coefficients, C_{D_T}

$$D_T = K_a \cdot C_{D_T} \tag{1}$$

The equivalent dose for an organ or tissue is expressed as follow

$$H_T = \sum_R W_R \cdot D_{T,R} \tag{2}$$

where $D_{T,R}$ is the absorbed dose averaged over the organ or tissue, T, due to radiation, R, and W_R is the radiation weighting factor for radiation, R.

The effective dose is the sum of the weighted equivalent doses in all the organs and tissues of the body, and it is given by the expression:

$$E = \sum_T W_T \cdot H_T \tag{3}$$

where H_T is the equivalent dose in organ or tissue, T, and W_T is the tissue weighting factor for tissue, T.

Meanwhile, the Chines organ dose conversion coefficients (Liu et al., 2009) is used in this paper, and for purposes of conservative dose assessment and simplified calculation, the largest conversion coefficients under different photon energies in six irradiation geometries are applied.

3. Methodology

The structure of the dose assessment method for workers in radioactive environments is as shown in Fig. 1. First, preliminary data is obtained. And then the human models, organ-monitoring-points and skeletal animation models are designed with virtual reality. Finally, a dose assessment method based on skeletal animation technology and organ-monitoring-points is developed.

3.1. The human model and organ-monitoring-points

The human model is designed based on the data from Asian Reference Man (Tanaka et al., 1998), and Fig. 2 presents the modeling process of the human model with organ-monitoring-points. The bones, organs and tissues that are being monitored are shown in Table 1.

The organs and tissues are described with a set of discrete monitoring points that are uniformly distributed in the organs and tissues. Then the doses of organs and tissues can be calculated with the average dose of these organ-monitoring-points. Consequently, considering the characteristics of the organs and tissues (such as shape, deformation, etc.) is convenient and can result in improved computation time, while keeping the accuracy of the dose assessment.

When performing a task in the radioactive environments, the worker has different working postures. To precisely obtain the location of the organ-monitoring-points, they are bound to the skeleton. As a result, the organ-monitoring-points move with the

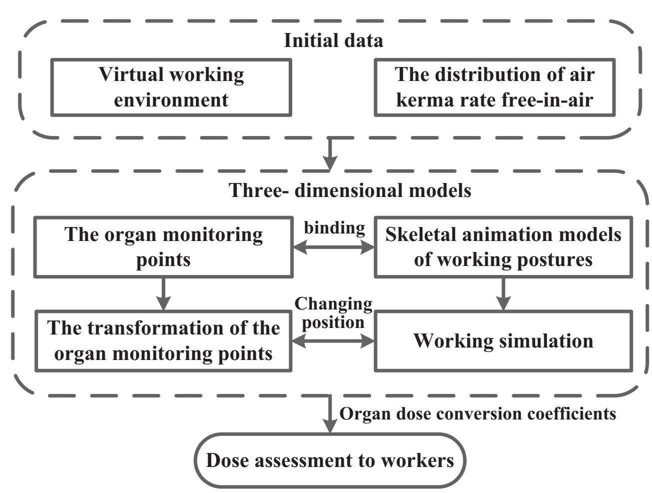

Fig. 1. The structure of the proposed dose assessment method in nuclear facilities.