



Preliminary Study on Human Dose of X and Γ Flaw Detection Accident Based on FLUKA

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Research Article

Volume 5 Issue 1

Received Date: January 06, 2022

Published Date: January 27, 2022

DOI: 10.23880/ijnmrs-16000145

Abstract

In this work, a Chinese reference human voxel model was established in FLUKA software to simulate the energy deposition, absorbed dose and its spatial distribution. Then the energy deposition, absorbed dose and its spatial distribution were got with different energy photons directly irradiating the human chest under radiation accident in industrial flaw detection. The results showed that organs with high energy deposition were lung, heart, muscle, soft tissue, liver and skin, and the absorbed dose of lung was the highest. The simulation of radiation accident in industrial flaw detection based on the Chinese reference human body model was feasible in FLUKA software. The absorbed dose results of human organs have reference value and significance for the evaluation of similar radiation accidents.

Keywords: Human Voxel Model; FLUKA; Flaw Detection; Energy Deposition; Absorbed Dose

Introduction

X and γ -ray flaw detection technology are widely used in industry field, which can effectively ensure the quality and safety of products and other equipment of active nuclear facilities [1,2]. However, radiation is a double-edged sword, and X, γ -ray flaw detection also cause incidents or accidents from time to time [3-5]. Once the occurrence of a radiation accident, the estimation of human exposure dose was the first problem that doctors must face in the rescue. In order to solve this problem, FLUKA simulation software was employed to study the energy deposition and dose of each organ under the typical conditions assumed that human body were irradiated by X or γ rays. Preliminary research on the dose distribution has been conducted, and the results have important reference significance for the dose assessment of accident-exposed personnel.

Objects and Methods

Mock object

The simulation was based on the Chinese male reference human body model developed by Tsinghua University [6,7]. The phantom, which was 1.76 meters tall and 60 kg in weight, contained 103 tissues or organs. This phantom had been also applied widely in the field of radiation protection [8,9], in order to study on the energy deposition and dose distribution of various tissues and organs of the human body who was irradiated by X-ray, Cs-137 and Co-60 radiation sour.

Calculation Method

In this study, we firstly converted the reference human body model into the voxel structure files that could be

recognized by FLUKA [6,7,10], and then the simulated space structure and human body materials were constructed using the flair program of the FLUKA software [11]. When modeling, circular radiation fields of 200 keV and 300 keV X-ray were set to irradiate the human chest with a radiation field diameter of 10 cm. Besides, the distance between the Cs-137 or Co-60 radiation source and the human body was set to be 1 cm, and the surrounding space was set as an air sphere with a diameter of 1000 m. The number of simulated particles was 1×10^8 .

Quality control

After the Fluka-based model was successfully debugged, 0.10, 0.15, 0.20, 0.30, 0.40, 0.50, 0.60, 0.80, 1.00, 2.00, 4.00, 6.00, and 10.00 MeV X-ray was simulated to isotropically irradiate human body model. The simulation results were compared with that of reported work based on GEANT4 [4] and the deviation was less than 5%.

Results

Dose distribution

The 200 keV X-ray, 300 keV X-ray, Cs-137 and Co-60 radiation sources were respectively simulated to directly irradiate the human body. Then, the spatial distributions of absorbed dose for human body could be got, which were shown in Figure 1 and Figure 2, respectively. When 200 keV and 300 keV X-rays irradiated human chest, the energy deposition was high in the tissues and organs of the chest region. Among them, the absorbed dose of the lung was the highest, and the area in the irradiation field reached the maximum, followed by the heart and liver that were closer to the lungs. When Cs-137 and Co-60 radiation sources were simulated to irradiate the human body at close range, the spatial distribution of the absorbed dose of the human body was generally the same as that of 200 keV and 300 keV X-rays irradiation.

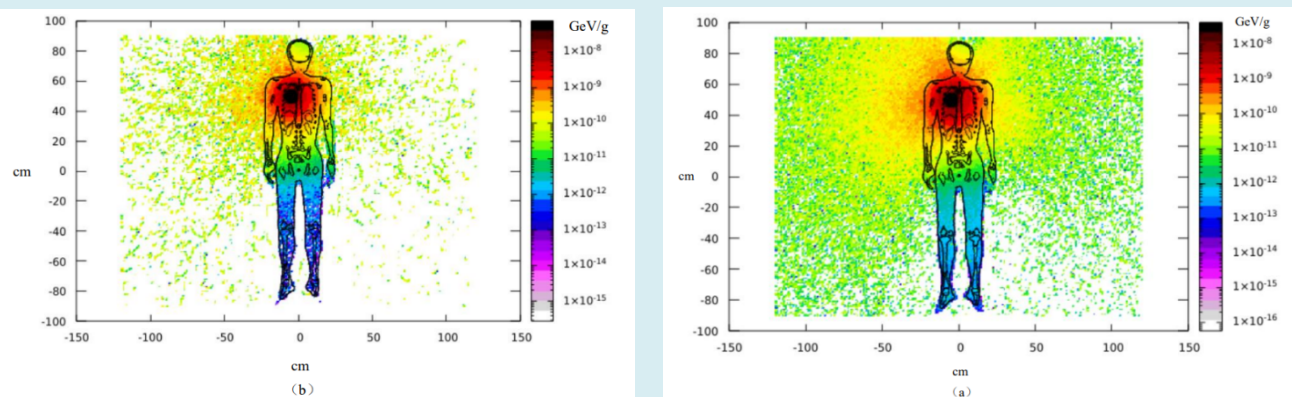


Figure 1: Dose distribution when 200 keV(a) and 300 keV(b) X-ray irradiated human body.

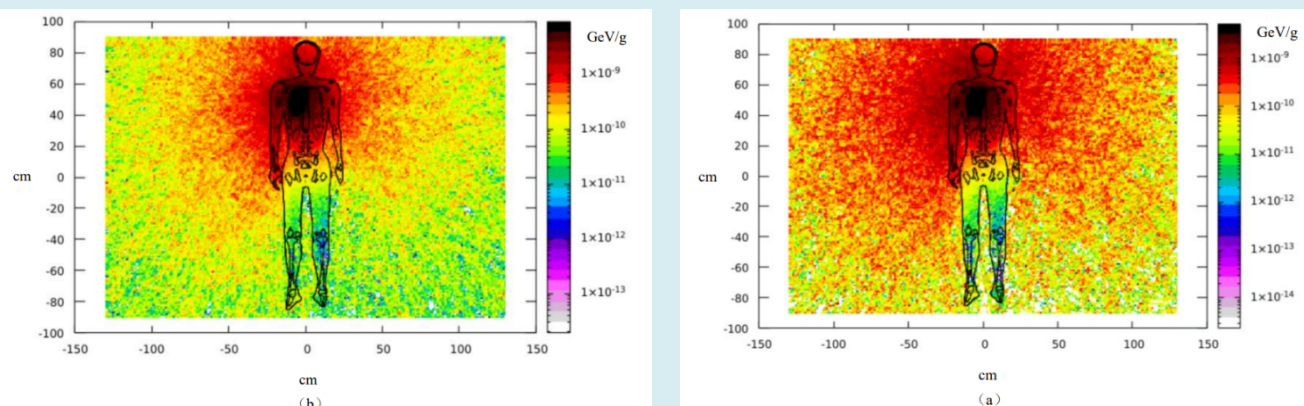


Figure 2: Dose distribution when Cs-137 (a) and Co-60 (b) irradiated human body.

Energy Deposition and Absorbed Dose in Major Organs

The simulated results of energy deposition in 103 tissues and organs of the human body were statistically analyzed. The top 5 organs of energy deposition were lung, heart, muscle,

soft tissue, liver, and skin. The energy deposition of the five organs and the whole body was listed in Table 1, whose unit was GeV/photon. The top 5 organs of energy deposition at each energy point of X ray were the same. The masses of lung, heart, muscle, soft tissue, liver, skin and whole body used in simulation calculation were given in Table 2.

Ray types	Lung	Heart	muscle & soft tissue	Liver	Skin	Whole body
200keV X ray	5.07E-05	5.33E-05	3.75E-05	1.58E-06	1.99E-06	1.07E-04
300keV X ray	8.20E-05	7.79E-06	5.76E-05	2.50E-06	3.08E-06	1.67E-04
Cs-137 γ ray	2.21E-05	5.78E-06	4.65E-05	5.09E-06	3.60E-06	9.66E-04
Co-60 γ ray	3.74E-05	1.01E-05	8.55E-05	9.13E-06	5.37E-06	1.74E-05

Table 1: Simulation results of energy deposition in the body and main organs (GeV/photon).

Organ	Lung	Heart	Muscle and soft tissue	Liver	Skin	Whole body
Mass	1250g	744g	40524g	1460g	2401g	60000g

Table 2: The masses of the whole body and main organs of the human body.

To obtain the absorbed dose of organ in unit of Gy during single photon irradiation, the energy deposition per unit mass of the organ should be obtained firstly, that is, divide the organ energy deposition data in Table 1 by its mass, and then multiply it by $1.602176462 \times 10^{-7}$, the absorbed dose of

each organ could be obtained [10]. The absorbed doses of lung, heart, muscle and soft tissue, liver and skin were shown in Table 3. Among them, the lung had the largest absorbed dose, followed by the heart and liver, while the skin, muscle and soft tissues had the third highest absorbed dose.

Ray types	Lung	Heart	Liver	Muscle & soft tissue	Skin
200keV X ray	6.50E-15	1.12E-15	1.74E-16	1.48E-16	1.33E-16
300keV X ray	1.05E-14	1.68E-15	2.09E-16	2.28E-16	2.05E-16
Cs-137 γ ray	4.79E-15	2.18E-15	1.00E-15	3.38E-16	3.58E-16
Co-60 γ ray	2.72E-15	1.24E-15	5.59E-16	1.84E-16	2.40E-16

Table 3: Absorbed dose of the top 5 organs for energy deposition, Gy/photon.

Discussion

In this article, the authors preliminarily studied energy deposition and absorbed dose in various tissues and organs when the human body was irradiated at close range by the typical energy of X-ray (200 keV and 300 keV X-ray) and γ -ray (Co-60 and Cs-137 radiation sources). Chinese reference human body model based on FLUKA was feasible for simulating the absorbed dose of human body in industrial flaw detection radiation accidents. The obtained basic data could be used to quickly calculate the organ equivalent dose, whole body absorbed dose, and local absorbed doses in areas of interest under the same similar accidents. These calculation results also could provide critical dose data for the treatment of exposed persons.

It should be pointed out that although muscle and soft tissue had higher energy deposits in this study, this was

due to their large mass distribution in the human body. The overall absorbed dose of muscle and soft tissue was low, but the absorbed dose in the irradiation field was still high.

The calculation methods and calculation results used in this work have important reference value and reference significance for the dose calculation of accidental exposure in Co-60 and Cs-137 radiation field. However, the simulation results for X-ray exposure of 200 keV and 300 keV have certain limitations, because the X-ray machines generate X-ray with continuous energy spectrum when working, and only the X-ray with single energy spectrum was used for simulation calculation. Therefore, there may be certain deviations from the actual results, but it can be used for conservative evaluation in accidental exposure.

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