RADIATION DOSE SIMULATION AND MEASUREMENT PLAN FOR SSRF BEAM LINES BY USING ATOM PHANTOM

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Abstract

Radiation dose assessment in advanced synchrotron radiation facility is challenging due to the complexity and uncertainties of radiation source terms induced by high energy particle accelerator. Shanghai Synchrotron Radiation Facility (SSRF) is the first third-generation synchrotron facility in China, which was completed in 2009. Radiation dose assessment for workers at SSRF Beam lines is highly concerned. This study presents the dose simulation with Monte Carlo method. The dose simulation was performed with a hybrid phantom coupled into MCNPX code. The hybrid phantom was constructed by combining the ATOM phantom and the Voxel-based Chinese Reference female Phantom (VCRP-woman) originally developed by using the high resolution color photographs. The organs absorbed dose calculated for photon and neutron were compared. An Experiment of measuring the organs dose by using the ATOM phantom will be performed in the near future.

INTRODUCTION

In high energy electron accelerator, the gas bremsstrahlung photon and the neutron by means of photonuclear interactions together constitute its complex radiation field. Bremsstrahlung is produced through the inelastic radiative interaction with the residual gas molecules inside the vacuum chambers, energy of these photons extended up to the same as the maximum energy of electron beam. Photons with energy above 5-15MeV, can produce photoneutrons when they collide with slits, pinholes, beam stops, etc [1]. The Shanghai Synchrotron Radiation Facility (SSRF) is a third-generation synchrotron radiation light source which is composed of the linear accelerator, the booster and the storage ring. The energy of electron in the storage ring is 3.5GeV and the average current of electron is up to 300mA in the SSRF, inside the beamline there are mixed radiation fields produced by the gas bremsstrahlung photons and the photoneutrons. The neutron spectra, angular distribution and absorbed dose measurements or calculations have been made at several facilities such as Advanced Photon Source (APS)[2-4], National Synchrotron Radiation Research Center(NSRRC) [5], and Stanford Linear Accelerator Center [6]. In this study, radiation dose distribution at the wiggler beamline BL-13W in SSRF is compared between calculation and measurement. Organ absorbed dose rate induced from photon and neutron are calculated. The FLUKA Monte Carlo code[7-8] is utilized to simulate the spectrum of the gas bremsstrahlung. The energy spectrum of the bremsstrahlung photon is carried out as the source, and a hybrid phantom with 22 organs and identity shape with the ATOM adult female phantom is constructed by using the Monte Carlo-N Particle (MCNP) transport code [9] to calculate radiosensitive organs absorbed dose rate and effective dose for photon and neutron.

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MATERIALS AND METHODS

Simulation Description

The FLUKA program code is a fully integrated particle physics Monte Carlo simulation package. The simulation is started from the primary electrons traveled and interacted with the residual gas molecules in the long straight section, and then the photonuclear reaction is initiating in the target of lead absorber and the slits. The length of the long straight section is 14m. The pressure of the vacuum tube is less than 10^{-9} Torr. The residual gas inside the vacuum tube which is much different from ordinary air is constructed from 48.9% oxygen, 19.5% hydrogen, 18.3% carbon and 13.2% nitrogen in the ratio of atomic mass. The gas pressure used in the simulation is the atmospheric pressure. The results can be inferred by the ratio of the actual storage ring vacuum value and 1atm. Fig.1 illustrates the geometry of BL-13W which is simulated by using FLUKA. Photon and Photoneutron energy spectrum emerged from the slits are calculated.

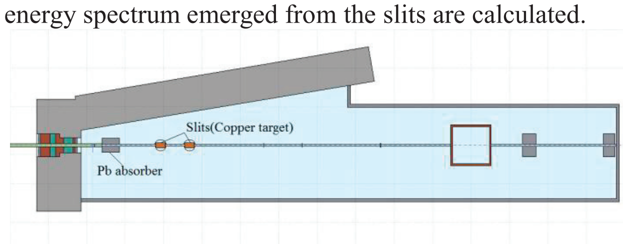

Figure1: Calculation model of the BL13-W.

Hybrid Phantom and Dose Calculation

Anthropomorphic phantoms such as the ATOM[10] phantoms and the RANDO phantoms have designed for many years. The female ATOM phantom represents a 160cm tall and 54kg female. It is composed of 38 sections, 2.5cm thick each. A set of 485 scanned CT images at an interval of 2mm is obtained. The image resolution is 512×512 pixels which then rescaled to 513×257pixels to achieve the same resolution as the VCRP-woman. The image processing of erosion and dilation was utilized to segment the brain, skeleton, lungs, and skin from the set of CT images. The Voxel-based Chinese Reference Female Phantom (VCRP-woman) was previously developed from high resolution cross-sectional color images of a female cadaver (162cm, 54kg). Organs

ISBN 978-3-95450-115-1

mass inside the VCRP-woman were adjusted to the Chinese Reference Female value. It is impossible to calculate the organ dose simply use the ATOM phantom because there are only four organs inside the ATOM phantom [10]. A hybrid female phantom is constructed by combining the ATOM phantom and the VCRP-woman.

With the external shape and 4 organs from the ATOM phantom, 18 other organs from the VCRP-woman, a hybrid female phantom is finally constructed. Fig.2 represents the 3D view of ATOM phantom, VCRP-woman and the hybrid female phantom. The MCNPX radiation transport code with the Evaluated Nuclear Data File (ENDF60) cross-section data is utilized. The organs equivalent dose rate and effective dose rate is calculated using photon and neutron energy spectrum from the FLUKA model. Fig.3 illustrates a sectional view of the simulated BL13W and the position of the hybrid phantom. Repeated structure cards is used to import the hybrid phantom to MCNPX, A cell card that include 513*257*485 (64million) voxels is utilized to construct the geometry of the hybrid phantom, *F6 tally is used to record the energy deposition averaged over a cell. Simulations are implemented on 8 nodes cluster, the MPI parallel protocol is utilized. A total of 10^6 particle histories have transported.

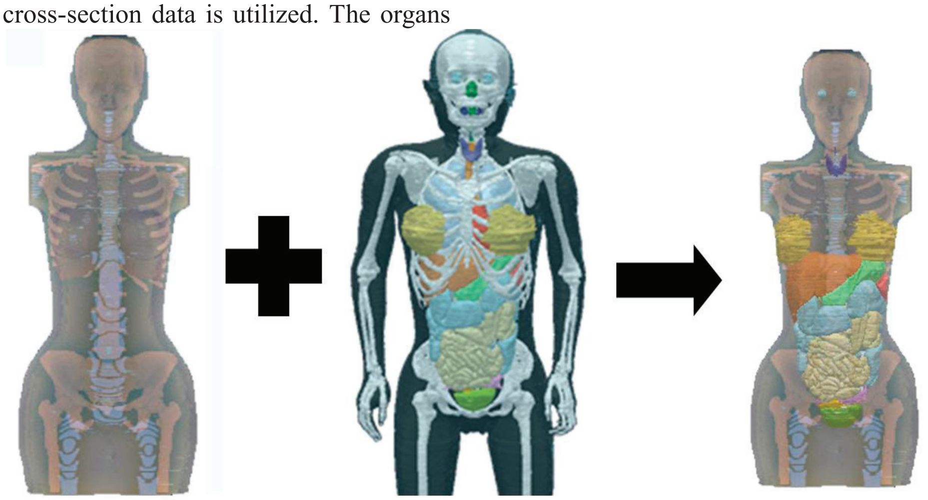

Figure 2: ATOM female phantom, Voxel-based Chinese reference female phantom and Hybrid female phantom.

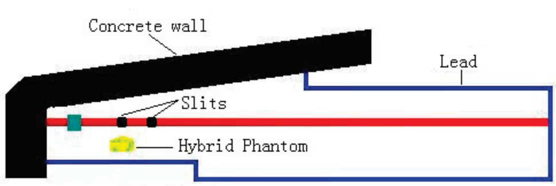

Figure 3: The Sectional view of the beam line BL13W and the position of hybrid voxel female phantom.

Measurement

In this study TLD600 and TLD700 pairs are selected as the dual TLD detector. The TLD600 chips content 95.62% 6Li and 4.38% 7Li, while the TLD700 chips are composed of 99.93% 7Li, the responses to neutron for TLD600 and TLD700 are different due to the cross section of 6Li is 943.2 barns while 7Li is 14.7 barn for thermal neutron [11]. It was assumed that the response to photons in the same irradiated condition is identical. ^{60}Co standard source in Shanghai Institute of Measurement and Testing Technology (SIMT) was utilized to calibrate photon of the dual TLDs. For neutron calibration, the dual TLDs were irradiated in the neutron-gamma field produced by a moderated 241Am-Be source ($3.7\text{x}10^6 s^{-1}$). Calibration factor of TLD600 can be estimated by using the fluence to kerma factors. The neutron dose can be obtain by subtracting the photons contribution from the total readout of the TLD600[12] as the equation shown below.

$$D_n = (Q_6 - Q_7 \times \frac{CF_{7,\gamma}}{CF_{6,\gamma}}) \times CF_{6,n} \qquad (1)$$

where Q6 and Q7 is the collective charges of TLD600 and TLD700. CF7,ɤ, CF6,ɤ is the calibration factors for photon of TLD600 and TLD700. CF6,n is the calibration factor of TLD600 for neutron.

Dual TLDs are placed into suitable holes inside ATOM phantom to estimate neutron and photon doses of corresponding organs. The tissue/organs in which the absorbed dose is measured are: eyes, brain, thyroid, heart, thymus, lungs, liver, gall bladder, spleen, oesophagus, stomach, pancreas, kidneys, adrenals, colon, small intestine, ovaries, uterus, urinary bladder, breasts, red bone marrow and skin. A wiggler beam line of X-ray imaging and biomedical application (BL-13W) at SSRF was selected. The phantom will then be irradiated at beamline BL-13W within a fixed time.

RESULTS AND DISCUSSION

The results of photon and neutron absorbed dose rate of 22 radiosensitive organs in the Hybrid phantom is shown in Table1. Organs absorbed dose contributions of neutron are about 2% compared with dose of photon. The maximum neutron/photon dose ratio is 3.0% appears in breast gland, the minimum dose ratio is 1.4% appears in adrenal. The uncertainty of the photon and neutron dose is within 12%. Effective dose is given by equation 2.

$$E = \sum_T \omega_T \sum_R \omega_R D_{T,R} \quad (2)$$

where $\omega_R D_{T,R}$ is the equivalent dose in an organ, and ω_T is the tissue weighting factor. The radiation weighting factor for neutron is set to 20 due to the neutron energy spectra obtained from FLUKA model. The tissue weighting factor [13] for specified organs are shown in Table1. Effective dose for photon and neutron is 0.177μSv/h and 0.068μSv/h respectively.

It should be noted that calculation is carried out by simulate bremsstrahlung photon shooting the target. Synchrotron photon and low energy X ray is not considered. Experiment by using ATOM phantom irradiated on BL13-W is now preparing, and will finish in the near future.

Table1. Photon and Neutron Absorbed Dose of Radiosensitive Organs

Organs	Photon absorbed dose rate (10^{-2}μGy/h)	Neutron absorbed dose rate (10^{-2}μGy/h)	Ratio (Neutron /Photon)	Tissue weighting factor[13]
Adrenal	19.07	0.26	1.4%	0.0133
Brain	12.98	0.22	1.7%	0.01
Breast gland	27.27	0.81	3.0%	0.12
Colon	16.57	0.34	2.0%	0.12
Gall Bladder	18.14	0.34	1.9%	0.0133
Heart	21.46	0.43	2.0%	0.0133
Kidneys	14.13	0.22	1.5%	0.0133
Liver	19.45	0.38	2.0%	0.04
Lungs	18.11	0.34	1.9%	0.12
Oesophagus	16.92	0.35	2.1%	0.04
Ovaries	7.58	0.16	2.1%	0.08
Pancreas	17.53	0.35	2.0%	0.0133
RBM	10.66	0.22	2.1%	0.12
Skin	11.11	0.32	2.8%	0.01
Small intestine	16.34	0.31	1.9%	0.0133
Spleen	13.89	0.22	1.6%	0.0133
Stomach	21.28	0.44	2.1%	0.12
Thymus	22.94	0.60	2.6%	0.0133
Thyroid	26.47	0.71	2.7%	0.04
Urinary bladder	16.64	0.34	2.1%	0.04
Uterus	11.77	0.17	1.5%	0.0133

CONCLUSION

A hybrid phantom with 22 organs and identity shape with the ATOM adult female phantom is constructed by using MCNP code to calculate radiosensitive organs external absorbed dose and effective dose for photon and neutron .TLD 600 and 700 pairs are chosen to distinguish the doses of neutron from photon. They are then putted inside the ATOM phantom. The phantom full of TLDs will be irradiated at a wiggler beam line BL-13W to measure the organ dose of corresponding organs in the future plan. This study will provide a method to accurately assess radiation dose of human body and improve beamline shielding at SSRF.

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