FLUKA SIMULATIONS FOR RADIATION PROTECTION AT 3 DIFFERENT FACILITIES

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Abstract

FLUKA Monte Carlo Code is a transport code widely used in radiation protection studies. The code was developed in 1962 by Johannes Ranft and the name stands for FLUktuierende Kaskade (Fluctuating Cascade). The code was developede for high-energy physics and it can track 60 different particles from 1keV to thousands of TeV. It can be applied to accelerator design, shielding design, dosimetry, space radiation and hadron therapy. For particle therapy, FLUKA uses various physical models, all implemented in the PEANUT (Pre-Equilibrium Approach to Nuclear Thermalization) framework. For this study, the aim was to optimize the beam line system and the external shielding in order to ensure radiation safety for patients and workers. The investigation was made for three different facilities : the Clatterbridge Cancer Centre, the Christie Hospital and the OpenMeD facility at CERN. We calculated the secondary dose distributed to the patient, in case of Clatterbridge Cancer Centre, and to the workers in case of the Christie Hospital and OpenMeD, and to investigate whether the shielding methods meet the existing radiation protection requirements and that the doses to the staff are kept As Low As Reasonably Achievable (ALARA).

INTRODUCTION

The main concern in hadron therapy is the production of the secondary radiation, because the unwanted dose delivered to the patients or workers (in case of OpenMed) can induce a secondary cancer. The secondary radiation is produced by the interaction of heavy particles with the beam line components and is strongly dependent on the material in the beam path and on the design of the line. The dose deposited by secondary radiation is not negligible, even if the dose is low, the neutrons can induce secondary cancers due to the fact that they have a high RBE. [1, 2]

Therefore, the aim of this research is to estimate the secondary neutron dose equivalents and neutron fluence delivered outside the irradiation field to the patients undergoing hadron therapy or to the workers, performing FLUKA Monte Carlo simulations. This work was made for the Clatterbridge Cancer Centre facility in Wirral, United Kindom, the Christie Hospital in Manchester, United Kingdom and the OpenMed facility at CERN.

In the initial stage, the geometry of the facilities was implemented and the analysis of the distribution of secondary particles produces was made. Then, the neutron, photon, electron and positron dose equivalent and the neutron fluence was calculated, in order to understand the influence on the total dose absorbed by the patients or workers.

METHODS

FLUKA Monte Carlo

FLUKA is a Monte Carlo code developed for high-energy physics. The code is written in Fortran and it is used for calculations of particle transport and interactions with matter. It can be applied in cosmic ray physics, neutrino physics, accelerator design, particle design, shielding design, dosimetry, space radiation, hadron therapy, neutronics etc. FLUKA was developed in 1962 by Johanees Ranft, but only in 2003 CERN made a collaboration with INFN to develop, main- tain and distribute FLUKA.The name of FLUKA stands for FLUktuierende Kaskade (Fluctuating Cascade). FLUKA can simulate with high accuracy the interaction and propagation in matter of about 60 different particles from 1 keV to thousands of TeV, neutrinos, muons with different energy, hadrons with energies up to 20 TeV and all the corresponding antiparticles, neutrons down to thermal energy and heavy ions. The program can also transport polarised and optical photons. This code has the capability to import CT scans and to correct the Treatment Planning System (TPS).

For particle therapy, FLUKA is using various physical models, all implemented in the PEANUT (Pre-Equilibrium Approach to Nuclear Thermalization) framework.

FLAIR package was used together with FLUKA. FLAIR stands for FLUKA Advanced InteRface and is an advanced user friendly interface for FLUKA to facilitate the editing of FLUKA input files, execution of the code and visualisation of the final results. [3]

For this set of simulations, the latest version of the code was used, in order to simulate the dose deposited by the protons, neutrons and by all the secondary particles and the ambient dose equivalent of the neutrons, during the hadrontherapy treatment. The parameters for hadrontherapy were activated using the DEFAULTS card, with the PRECISIO option. The PRECISIOn option is used for precision simulations. It includes low energy neutron transport down to thermal ener- gies and fully analogue absorption for low-energy neutrons. The particle transport threshold is set at 100 keV and the heavy fragment transport is activated also.

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The Clatterbridge Cancer Centre

The Clatterbridge Cancer Centre is the first and only proton therapy facility within UK. In 1984 a 62 MeV cyclotron was installed for trials of radio-resistant tumours with fast neutrons. The machine was called Douglas Cyclotron after a benefactor who helped fund the equipment. Because the 62 MeV proton beam was suitable for proton therapy, having a maximum clinical range of 31 mm in water, which is good enough to treat uveal melanomas, choroidal haemangiomas, iris melanomas and conjuctival melanomas, a room equipped with an ocular beam line was built. The first patients were treated in 1989 and since then, the facility has treated more that 2000 patients. [4, 5]

The results of the FLUKA simulations were calculated for a 60 MeV proton beam. The maximum energy value was set at 60 MeV because this is the maximum energy provided by the Douglas Cyclotron. A water phantom of 15 cm long (from 184 cm to 199 cm) was used in order to simulate the patient tissues. The water phantom was placed at 7 cm from the collimator for an acceptable lateral beam spread. The nozzle is 7 cm long and has 34 mm internal diameter. A brass collimator was used to colimate the beam. The collimator aperture size was set at 1 cm. The total distance between the source and the patient is 180 cm. The simulations were performed using an un-modulated beam. The number of particles to be run was set to ten million.

Next results show the neutron and photons dose equivalent in the water phantom. In FLUKA, the results of the ambient dose equivalent are given in pSv/s, therefore, the normalization factor 3600×10^{-6} was used in order to obtain the results in µ*Sv*/*h*. For a 60 MeV incident proton beam, the proton dose equivalent value is 0.008 µ*Sv*/*h*/*primary*, the neutron dose equivalent value is 8×10^{-6} µ*Sv*/*h*/*primary* and the photon dose equivalent is 3×10^{-7} µ*Sv*/*h*/*primary*. The results show that the dose delivered in the tumour and in the eye is mainly due to the proton beam. As the beam is completely stopped in the tumour, only secondary particles (neutrons, photons) will deliver a dose to the regions outside the target (see Figure 1). The maximum value of the dose is found just behind the eye, in the optic nerve.

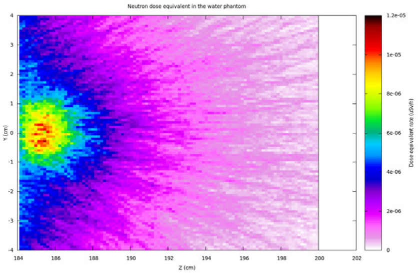

Figure 1: Neutron dose equivalent in the water phantom.

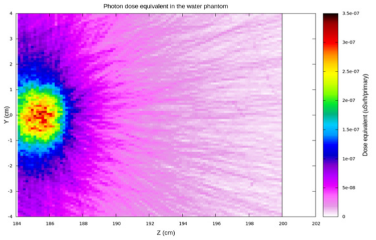

Figure 2: Photon dose equivalent in the water phantom.

The Christie Hospital

The Christie Proton Therapy Centre is a new facility under construction, designed to deliver proton beams with energy up to 250 MeV. The beams will be extracted from the cyclotron and delivered to three treatment rooms and one research room. The treatment rooms will be equipped with a 360° rotating gantry and the research room with two fixed beam lines for reseach purposes.

Radioprotection studies have been performed in order to ensure that the radiation doses are below limits. The studies have been made only for the research room. In order to study the worst-case scenario for shielding requirements a proton beam with a energy of 250 MeV was used. The intensity is presumed to be 0.44 nA. This corresponds to $2.75 * 10^{9}$ protons per second. The beam line is assumed to be at 150 cm above the floor. For the prompt ambient dose rate, the beam is simulated to pass through a 10 metres long Aluminum beam tube with a tickness of 2 mm. Inside the beam tube there is assumed to be vacuum. After passing the beam tube, the beam is impinging a graphite phantom (10x10x25 cm). The ambient dose equivalent is given in terms of μSv/h, normalized with respect to the beam intensity.

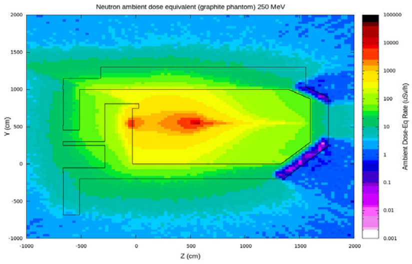

Figure 3: Neutron dose equivalent in the research room at 250 MeV.

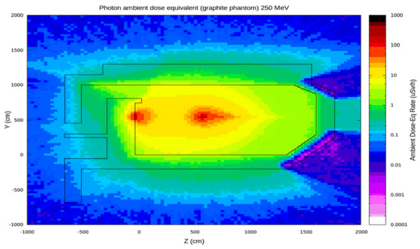

Figure 4: Photon dose equivalent in the research room at 250 MeV.

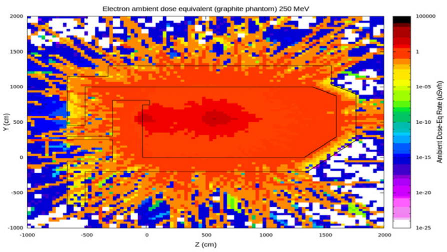

Figure 5: Electron dose equivalent in the research room at 250 MeV.

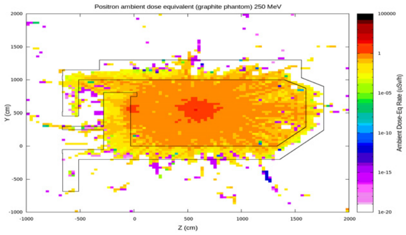

Figure 6: Positron dose equivalent in the research room at 250 MeV.

The OpenMed Facility

The Low Energy Ion Ring is used to receive heavy ions from LINAC3 and to prepare beams for LHC. The new objective is to use Leir for a biomedical research facility: to provide ions from protons up to neon for medical applications (up to 430 MeV). The simulations were made for carbon and oxygen ions at an intensity of 1.9×10^9 ions/cycle. Ions are interacting with the surface of the stainless steel beam tube with the extracting energy. The beam losses were assumed to be 1%, 10% and 20%. The neutron dose equivalent was calculated for carbon and oxygen ions with the maximum energy of 430 MeV at the visitor platform level (6.5 m) for different beam losses. The results are given in μSv/h and are normalized with respect to the beam intensity.

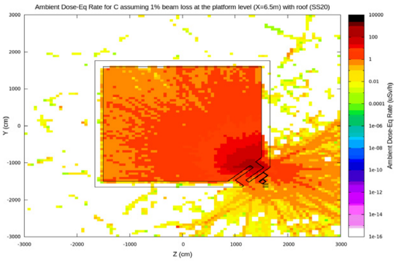

Figure 7: The neutron dose equivalent for C ions with roof.

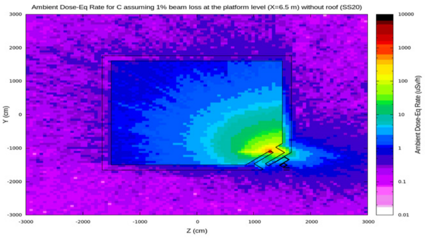

Figure 8: The neutron dose equivalent for C ions without roof.

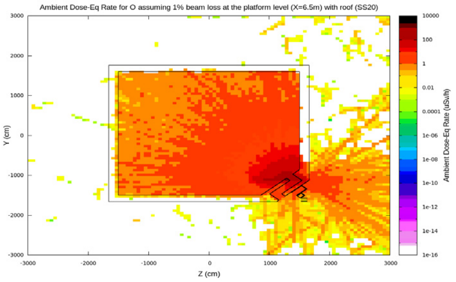

Figure 9: The neutron dose equivalent for O ions with roof.

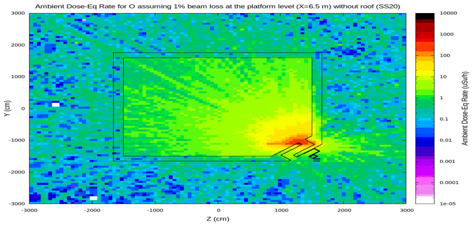

Figure 10: The neutron dose equivalent for O ions without roof.

CONCLUSION

For the Claterbridge Cancer Centre, the maximum contribution of the neutrons was found in the optic nerve, behind the irradiated eye. The neutron dose equivalent ranged between 0.001 μS/h/primary and 0.0015 μS/h/primary. These findings indicate that the secondary neutron dose is relatively low.

For the Christie Hospital the results showed that the secondary dose is increasing with increasing the energy, especially in the direction of the beamline. In the improbable case that the full proton beam (10^9 protons) would be lost in the graphite phantom, the total dose would be < 10 μSv in the accesible areas around the research room. This value can be regarded as sufficiently low.

For the OpenMed facility future work should be done in order to calculate the ambient dose equivalent for different types of ions at different energies in order to decide if the facility needs an additional roof and to ensure that the existing walls are thick enough or additional shielding walls should be placed.

REFERENCES

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[3] FLUKA website: http://www.fluka.org

[4] A. K., “Protontherapy of eye tumours in the UK: A review of treatment at Clatterbridge”,Applied Radiation and Isotopes