CPC(HEP & NP), 2011, **35**(7): 675–678 **Chinese Physics C** Vol. 35, No. 7, Jul., 2011

Radiation emission from the “Rhodotron-TT200” cavity

Farshid Tabbakh[1;1)] Mahmud Borhani[2]

[1] Institute of Nuclear Science and Technology, Nuclear Reactors and Accelerators Research School,
North Kargar Av., Tehran, Iran, P.O. Box 1439951113

[2] Science Faculty, Yazd University

Abstract: In this paper, the X-rays emitted from the Rhodotron-TT200 cavity have been studied in depth. We found that the Bremsstrahlung interaction is the only contribution of X-ray generation important to safety. The X-ray dose rate in the Rhodotron vault is calculated for normal conditions based on MCNP4C results. The presented calculation shows good agreement with the experimental measurements, which consequently confirms the reliability of the calculation for use in shielding design and other safety aspects.

Key words: electron beam, rhodotron, beam loss, X-ray dose rate, MCNP code

PACS: 28.41.Te, 29.20.-c, 29.25.Bx **DOI:** 10.1088/1674-1137/35/7/013

1 Introduction

With regard to the radiation protection aspects in nuclear facilities, it is important to analyze the radiation emitted from accelerators from phenomenological points of view. Therefore, this precise study of X-ray dose rate generation in the Rhodotron-TT200 [1, 2] cavity is an approach to this purpose.

“Rhodotron-TT200” produces a 10 MeV electron beam with maximum current of 10 mA using 107 MHz RF in a coaxial cavity with an outer diameter of 208 cm and 9 deflecting magnets to re-inject the electrons into the cavity after each pass. In each pass, electrons obtain 1 MeV energy. Therefore, after 10 passes through the cavity diameter, their energy will reach 10 MeV and will be sent to the irradiation room. During the acceleration process, the particle loss in the slits of the deflecting magnets will cause the production of X-ray photons contributed by “Bremsstrahlung” interaction as the main source and electron-positron annihilation as the smaller source. The X-ray flux and the dose-rate emitted from the deflecting magnets are calculated in normal conditions (no accident) and compared with the experiment in order to evaluate the reliability of the results for shielding calculation and other safety considerations. We will see that the distribution of the lost particles due to system instability cannot be predictable. However, the total value of the beam loss will remain constant. We are going to construct a simulation in order to determine the beam loss values and the corresponding distributions as observed in normal operation. The procedure followed in this paper uses a trial and error method to find an optimized program to simulate the radiationt that is reasonably compatible with the experimental data. Then one can predict the values of particle loss in each magnet and the related parameters precisely.

To determine the contribution of cyclotron radiation, regarding the maximum energy of electrons and bending radius of 17 cm [3] in deflecting magnets, the photon energy emitted from the deflector is in the order of 10^{-3} eV. Hence, there will be no X-ray contribution caused by cyclotron radiation in the “Rhodotron” accelerator. MCNP4C [4] has been used to design the cavity (Fig. 1) and to calculate the X-ray dose rate [5]. The experimental method is discussed in Sec. 2 and the calculation is presented in Sec. 3.

2 Experimental method

The experimental X-ray measurements were performed using a GM counter tube LB 6500 with 20%

Received 29 October 2009, Revised 26 February 2010

1) E-mail: ftabbakh2000@yahoo.com

©2011 Chinese Physical Society and the Institute of High Energy Physics of the Chinese Academy of Sciences and the Institute of Modern Physics of the Chinese Academy of Sciences and IOP Publishing Ltd

accuracy. To omit the X-ray effects emitted from beam line components such as the 270° bending magnet, we shielded those components with lead bricks. Otherwise, we would not be able distinguish between “Rhodotron” and beam line component radiation.

Due to the intrinsic instability of the system and also to maximize the accuracy of the results, the dose rate corresponding to each magnet was measured over three different days. The average values are taken as the standard values for comparison with the simulation results. The average beam loss current obtained from the system indicators is as much as 229 μA with an error of 5%, which is in good agreement with the values discussed in Refs. [6, 7]. The other parameter that should be included in the accuracy measurement is beam stability. According to the system specification, the accuracy of the beam is considered to be as much as 5%. The head of the detector was placed 25 cm from the magnets with the same distances from each slit. The detector position and the distance to the magnet L are shown in Fig. 1. Since the accuracy of the detector position can be ignored, the total accuracy corresponding to the experimental measurements will be as large as 30%. The obtained experimental data are shown and compared with the calculation results in Figs. 3 and 4.

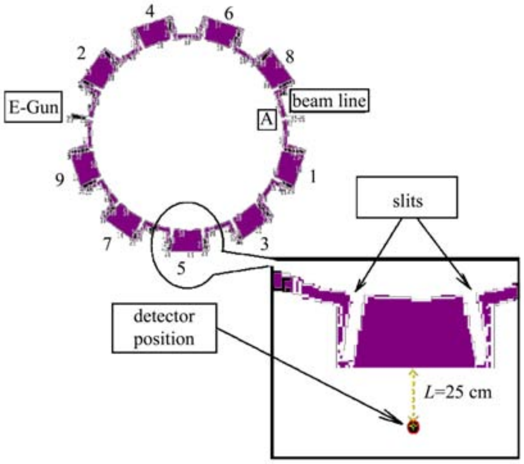

Fig. 1. Horizontal cross section of the cavity, designed by MCNP. Point “A” represents the beginning of the 10 MeV beam line.

3 Calculation and results

Due to the continuous beam injection and the space charge effects [6, 7], during the acceleration process, an unwanted fraction of electrons will be lost in the cavity and deflector slits. These particles will hit the cavity body at the beam exit in particular or in the entrance slits of the deflectors and generate X-rays via Bremsstrahlung. Therefore, the dose rate value of the photons will be very important to safety. To obtain comparable results to the experimental values, the average value of beam loss (229 μA) is considered as the radiation source in the simulation. In addition, calculations are performed for the point corresponding to the detector position, as explained in the experimental method in the previous section.

The MCNP4C results have errors of less than 5%, using tally F5. The “SDEF” card is defined for 19 source positions (18 sources representing 9 magnets slits and one representing the slits of the outgoing 10 MeV beam line). The probability of the distribution is considered as equal as first and then, finally, these probabilities are optimized in order to give the same conditions as in experiment.

According to the MCNP output data for predicting the photons’ average energy, by dividing the weighted energy created (6.0415×10^{-01} MeV) by the total weight of photons produced (6.6673×10^{-01}), one can conclude that the X-ray average energy in the vault is near 0.9 MeV.

Figure 2 shows the MCNP results assuming that the particle losses in the magnets are distributed equally. In this figure the total photon flux emitted from each magnet over 5 different distances is presented. In those magnets with a lower number, the electrons with lower energy interact and produce photons. However, increasing the beam energy will increase the number of Bremsstrahlung interactions. Consequently, as illustrated by this figure, increasing the number of magnets will increase the represented photon flux. In addition, the values representing Mag. 1 and Mag. 8 are higher than the expected values, which refer to the effects caused by the 10 MeV out-going slit at the start of the beam tube (Point “A” in Fig. 1). Since most of the photons are emitted upwards or backwards along the beam direction, decreasing the distance to Magnet No. 1 and No. 8 will decrease the photon contribution emitted from point “A”. Therefore, the line represented by L=10 cm is smoother than the other lines.

Figure 3 shows both the simulation and experimental values of the dose rate at a distance of 25 cm as the reference point from the magnets. The simulation presented in this figure is performed for the equal distribution of beam loss in all the magnets (called the ideal source), which is equivalent to the line L=25 cm in Fig. 2. Opposite to the ideal source, there is unequal distribution of beam loss in the

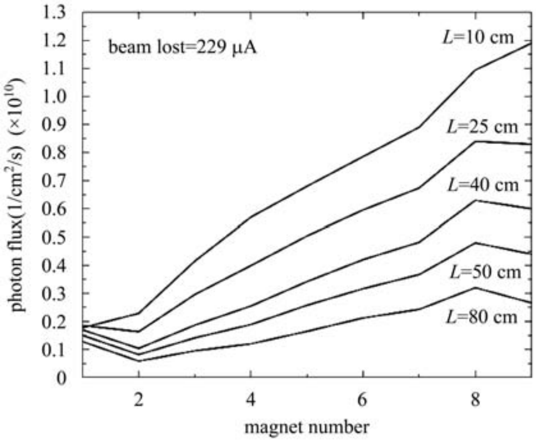

Fig. 2. MCNP results for photon flux with respect to each magnet (X-ray sources) for different distances.

magnets represented by circle symbols showing the experimental values with a total accuracy of 30% discussed in Sec. 2. As illustrated in this figure and due to the reasons mentioned above, reducing the beam loss in Magnets 7 and 9 will cause the measured values to drop to smaller ones than expected. Leaning on pure experimental data cannot give the particle loss value in the magnets except by referring to the calculation results also. The output data, as we mentioned, declare that the average energy belongs to 1 MeV photons. Therefore, from this figure the measured dose rates are 2.25×10^4 mSv/h and 2.2×10^4 mSv/h. Using the flux-to-dose rate conversion factors [5] for 1MeV photons, we estimate that the emitted photon flux from Magnets 7 and 9 as 1.25×10^9 and 1.1×10^9 photon/cm^2/s, respectively, with 30% of accuracy. To confirm this, we have to modify the sources in MCNP to achieve the experimental values and then calculate the related flux as discussed in Fig. 4.

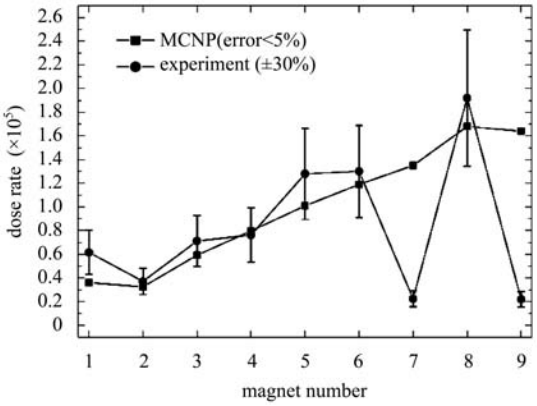

Fig. 3. Experimental measurement (real condition) and calculation results (ideal condition) of dose rate at a distance of 25 cm from the magnets.

Figure 4 shows the dose rate after modifying the probability distribution of the source in the input file. The square and circle symbols represent the MCNP and experimental data, respectively. Such a modification of the source card will lead to obtaining results comparable to the experimental data.

The corresponding flux to Magnets 7 and 9 according to MCNP in this figure is 1.3×10^9 photon/cm^2/s and 8.7×10^8 photon/cm^2/s, respectively, which are close to what is extracted from Fig. 3. In other words, the experimental and modified output data show an agreement of results.

Referring to the total particle loss (229 μA) on the one hand and obtaining the agreeable dose rate when the beam only hits the slits on the other, reconfirms our assumption that there is no considerable loss inside the cavity.

Figure 5 presents the energy distribution of the photons emitted from Magnets No. 1 and No. 9 with

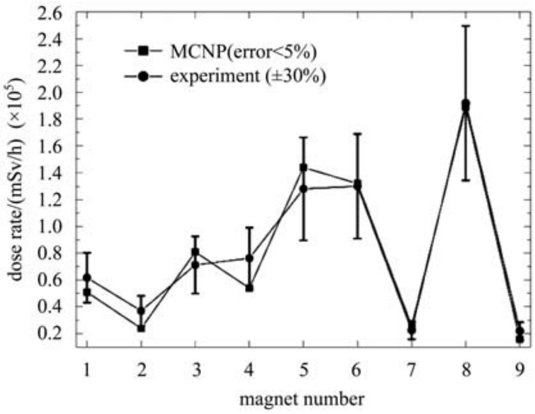

Fig. 4. Experimental measurement (real condition) and calculation results of dose rate after the source modifications at a distance of 25 cm from the magnets.

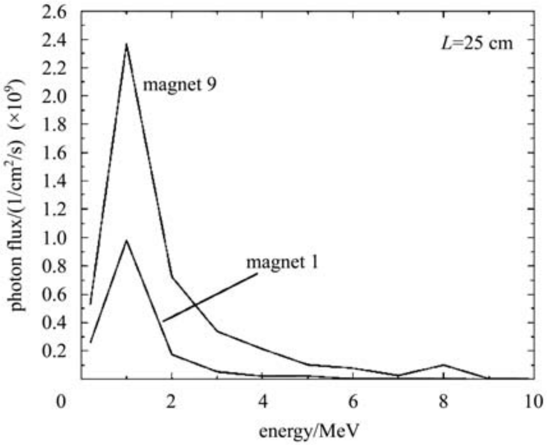

Fig. 5. Energy distribution of photons emitted from the magnets 1 and 9.

a peak at 1 MeV that certifies the value obtained previously. In this figure, although Magnet No. 1, emits photons with a maximum energy of 1 MeV, due to the other sources' affects, one can observe the energy range from a few keV to almost 6 MeV and so is the case with the other magnets. The spectra corresponding to the other magnets will lie between these two lines with the same maximum energy of 1 MeV.

4 Conclusion and discussion

We have calculated the flux and dose rate distribution of an X-ray in a vault caused by particle loss in the cavity (the magnet slits). We understand that there are no other considerable sources contributing to the dose rate in the accelerator, ignoring the photons emitted from the beam line 270° deflecting magnet. Here, we have to emphasize that the nature of this problem is statistical, which means that we cannot ensure that there is no particle loss in the other components of the accelerator body, but the results confirm that the main part of the radiation in safety aspects is what we have calculated and the particle loss in other parts of the cavity can be neglected. Therefore, the particles which may hit the inner cylinder of the cavity will have no contribution to the X-ray emission because the cavity will shield such a small number of photons.

In this paper, the calculations were performed by supposing that all 9 deflecting magnets are well tuned and that the beam loss is distributed between them equally (ideal condition). To achieve a simulation comparable to the experiment, we performed our calculation including the modified fractions of particle loss in each slit (real condition). Now, after obtaining the prediction method using MCNP code, we can attempt to calculate the shielding design and other safety purposes for the "Rhodotron" accelerator, which is under development.

References

1 Pattier J. A New Type of RF Electron Accelerator: The Rhodotron. Nucl. Instrum. Methods. Phys. Res., 1989, B40/41: 943–945

2 Umiastovski K et al. Rhodotron: an Accelerator for Industrial Irradiation. In: Proc. 2nd European Conf. on Accelerator in Applied Res. and Tech. Frankfurt, Germany. 1991

3 Tabbakh F. Chinese Physics C. 2009, **33**(10): 1–4

4 OAK Ridge National Laboratory. Monte Carlo N-Particle Transport Code System (MCNP4C). Los Alamos National Laboratory, 2000

5 ANSI/ANS-6.1.1. Neutron and Gamma Fluence-to-Dose Factors. American Nuclear Society, 1991

6 Gal O, Bassaler J M. Numerical and Experimental Results on the Beam Dynamic in the Rhodotron Accelerator. In: EPAC1992. 819–821

7 Jongen Y, Abs M, Defrise D et al. First Beam Test Results of the 10 MeV, 100 kW Rhodotron. In: EPAC1994. 527–529