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Assessment of the Radiation Fields Induced by TR-24 Cyclotron Beam Losses

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Abstract. In the current work we made an evaluation of the radiation fields induced by the beam losses in the TR-24 cyclotron tank. For this purpose we performed simulations with the Monte Carlo particle transport code FLUKA. Simplified models of the bunker, cyclotron and the source of primary particles are implemented in the models. In this study we have evaluated the distribution of the prompt and residual radiation fields generated by the beam losses.

Keywords: TR-24 cyclotron, Radiation shielding, Monte Carlo simulations, FLUKA

1 Introduction

A new cyclotron facility is under construction at the Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences (INRNE-BAS) [1]. The facility will be based on a TR-24 cyclotron, produced by ACSI / Advanced Cyclotron Systems Inc. We are interested in the production of the PET radioisotope ^{18}F [2–4]. The current preliminary activities are aimed at the assessment and analysis of the radiation protection of the facility. For this purpose we are performing Monte Carlo simulations with the particle transport and interaction code FLUKA [5, 6].

The results in this paper present an evaluation of the radiation fields generated by the beam losses in the cyclotron. We have considered the beam losses during normal and abnormal operation of the accelerator. For the purpose of the study we will assume a conservative beam loss of 0.1%, for the normal cyclotron operation. And a bad vacuum condition inside the cyclotron tank, for the case of abnormal cyclotron operation, which will lead to beam losses of 3%. Regardless of the beam loss mechanisms we have deviated beam particles interacting with the cyclotron components. These interactions lead to the generation of gamma and neutron radiation fields. For the two types of beam losses we have considered two irradiation scenarios to evaluate the distribution of the prompt and the residual radiation fields. Thus, our first task is to evaluate the distribution of prompt neutron and gamma radiation fields during the cyclotron operation - first irradiation scenario. The neutrons activate the bunker walls. The decay of these radioisotopes results in the emission of gamma radiation - residual radiation. Thus, our second task is to evaluate the distribution of these residual gamma-radiation fields after two hours of cyclotron operation - second irradiation scenario.

A simplified bunker geometry, the TR-24 cyclotron and the primary particle source are implemented in our models. The activation of the concrete walls is a well known problem. In this study the bunker walls are completely made of standard concrete with Portland cement. In the current work our focus will be on the short-lived radioisotopes since we are considering just a single 2 hour session for production of ^{18}F. An example of short-lived radioisotope is ^{24}Na and it contributes significantly to the residual radiation. It has a half-life of 15 h and is generated by secondary neutrons reacting with the ^{23}Na in the concrete walls.

2 Description of the Model

The modelling domain considered in our simulations is shown in Figure 1. Since, in the current work we are studying the effects of the losses in the process of beam generation a simplified model of the cyclotron and the bunker were implemented. The external wall thickness of the cyclotron bunker (walls, ceiling, floor) is 2.5 m. The respective inner dimensions are 6.5 m (length), 6 (width) x 3.25 m (height). The material of the bunker walls is set to standard concrete with Portland cement (CPC) [7]. In Figure 2

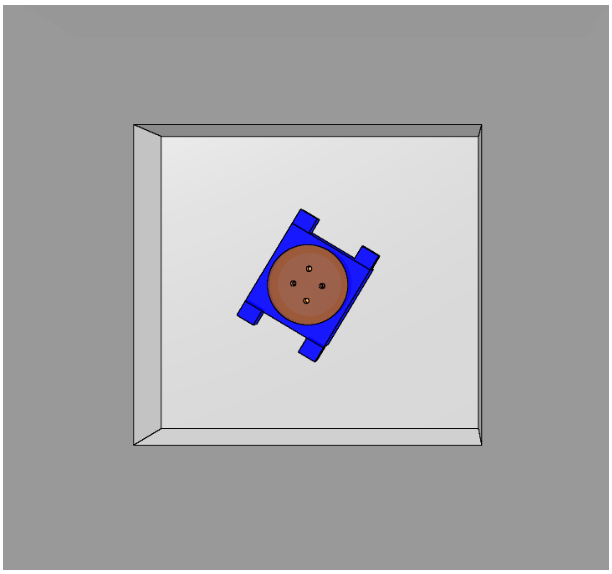

Figure 1. Horizontal view of 3D FLUKA Monte Carlo model of the cyclotron bunker.

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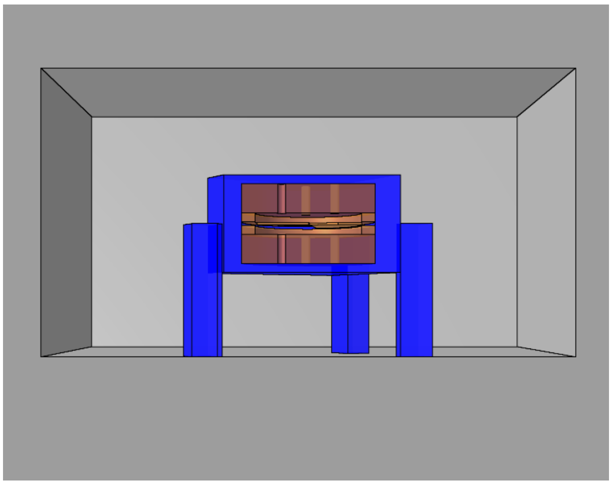

Figure 2. Vertical view of 3D FLUKA Monte Carlo model of the TR-24 cyclotron.

is presented a vertical view/slice of the implemented 3D FLUKA Monte Carlo model of the TR-24 cyclotron. The cyclotron components are set to default FLUKA materials: steel for the main body of the cyclotron and its legs; iron for the yoke; copper for the dees and the coils.

For the purpose of the current study we defined the source of our primary particles as an isotropic proton point source positioned at the centre of the cyclotron tank. We considered two types of beam losses as a fraction of the proton beam: 0.1% conservative beam loss during normal cyclotron operation; 3% beam losses caused by bad vacuum – abnormal cyclotron operation.

Results for the distribution of the gamma and neutron ambient dose equivalent rates (H*(10)) are presented in the current work. FLUKA calculates the fluence (of the gamma and the neutron particles) and uses the fluence-to-dose coefficients provided by the ICRP [8] for the assessment of the dose rates (H*(10)). In order to achieve results with acceptable uncertainty 4×10^9 primary particles were simulated for the two irradiation scenarios.

3 Results and Discussion

3.1 During target irradiation

In Figures 3 and 4 are represented the results for the distribution of the radiation fields generated by beam losses during normal (0.1% beam losses) and abnormal (3% beam losses) cyclotron operation. In the worst case scenario – 3% beam losses (Figure 4) – the dose rates (gamma and neutron radiation fields) outside the bunker are lower than the typical radiation background (0.2–0.4 μSv/h) in Sofia, Bulgaria.

3.2 Evaluation of the residual dose rates after two hours of cyclotron operation

The results from the evaluation of the residual dose rates distribution after 0 h, 2 hours and 1 day of cooling, after 2 hours of cyclotron operation, are presented in Figures 5 and 6. Respectively, for the normal and abnormal cyclotron operation. The residual radiation fields after an irradiation session are generated from the decay of the accumulated radioisotopes in the cyclotron components and the bunker walls.

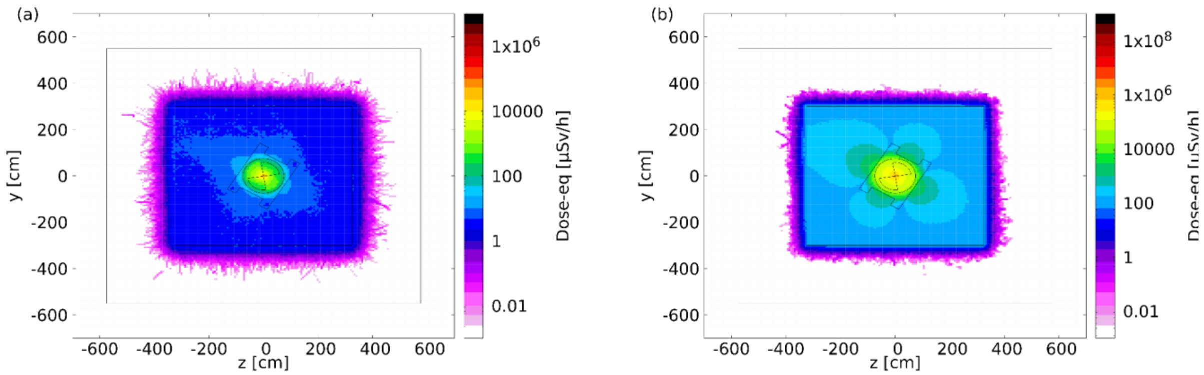

Figure 3. Distribution of gamma (a) and neutron (b) ambient dose equivalent in the case of normal cyclotron operation (beam losses of 0.1%).

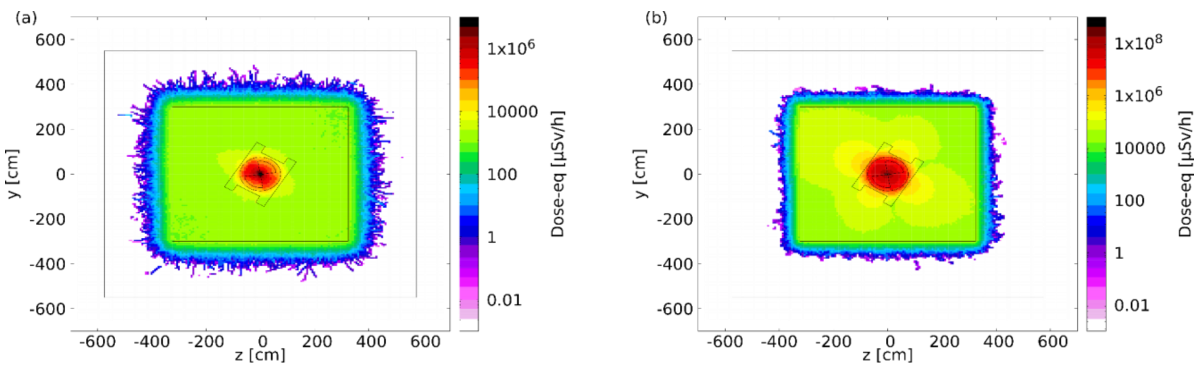

Figure 4. Distribution of the gamma (a) and neutron (b) ambient dose equivalent in the case of beam losses caused by "bad vacuum" 3%.

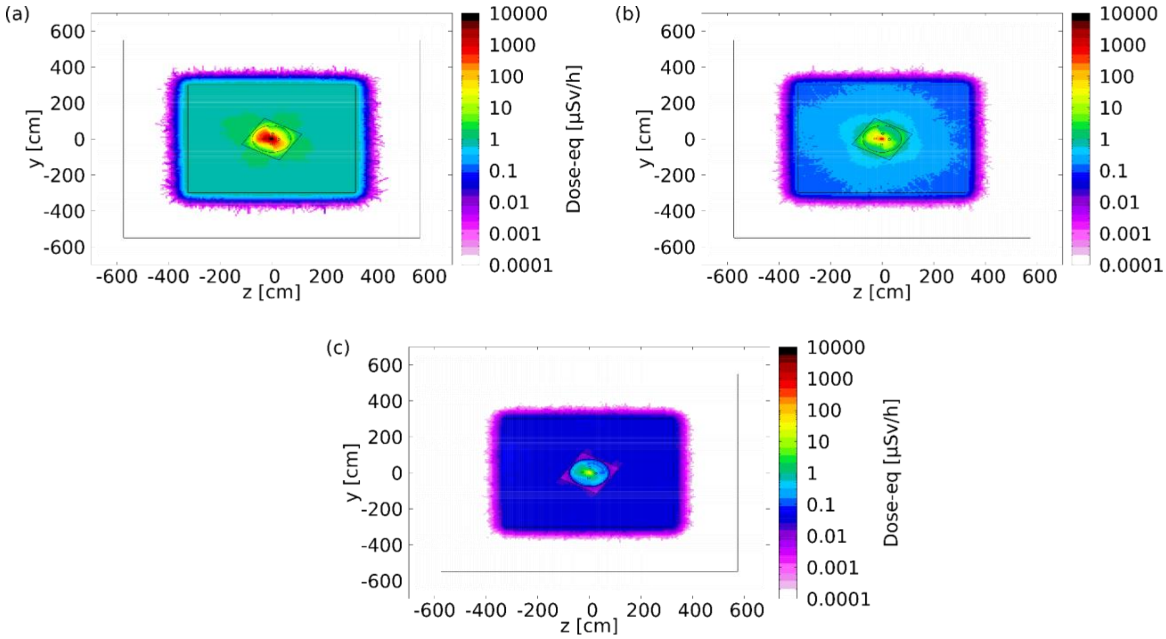

Figure 5. Distribution of the residual gamma dose rates inside the bunker in the case of losses of 0.1% (normal operation – conservative value) for three time intervals after a session for production 6.6929133858 of ^{18}F: 0 h (a); 2 h (b); 1 day (c).

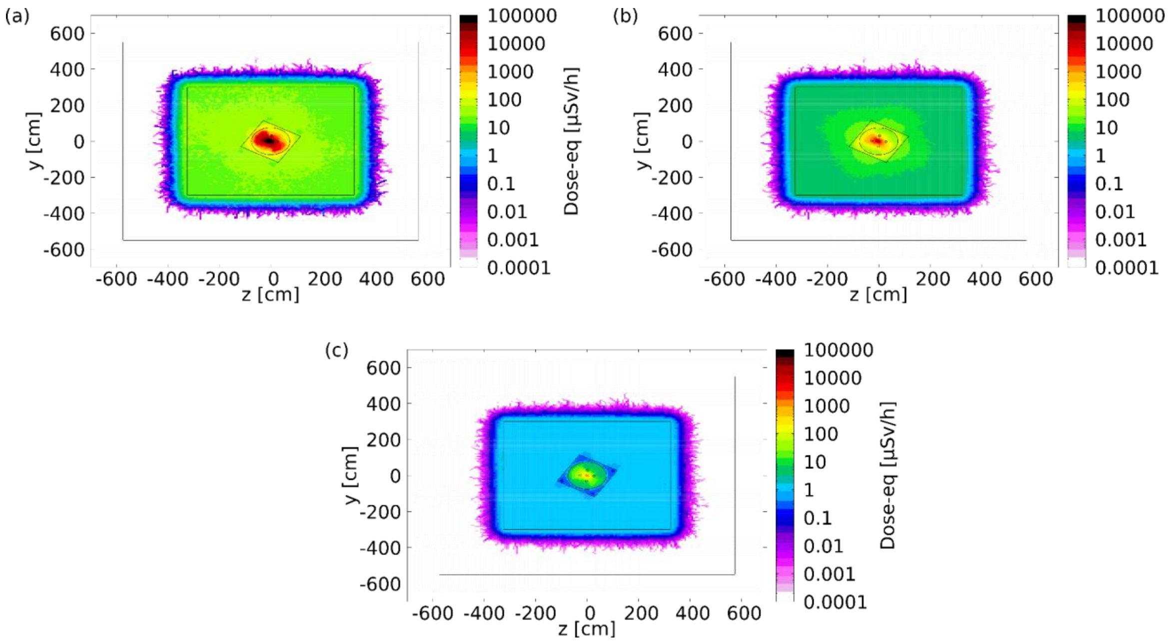

Figure 6. Distribution of the residual gamma dose rates inside the bunker in the case of losses of 3% (abnormal operation – bad vacuum) for three time intervals after a session for production of ^{18}F: 0 h (a); 2 h (b); 1 d (c).

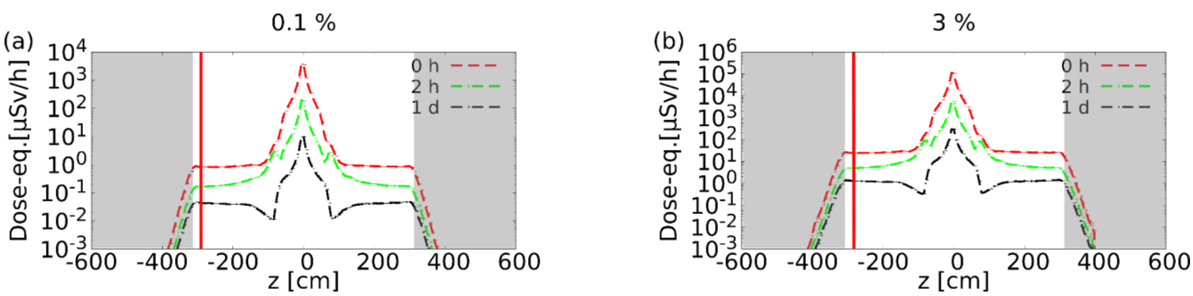

Figure 7. Profiles of the residual gamma ambient dose equivalent rate after 0 h, 2h, 1d of cooling in the case of normal (a) and abnormal (b) cyclotron operation.

The higher beam losses lead to higher dose rates (Figure 6). This is shown by the profiles of the residual gamma ambient dose equivalent rates in Figure 7. The peak is inside the cyclotron and the dose rates decrease towards the walls. In Table 1. are presented the values of the dose rates inside the bunker, in the vicinity of the wall (marked by the intersection points of the vertical red line with the residual dose rate profiles). In the case of abnormal cyclotron operation the dose rates are 26 to 35 times higher. The dose rates after 2h of cooling, or more, are lower than 10 μSv/h which means that the personnel could be allowed to operate inside the bunker.

Table 1. The residual gamma ambient equivalent dose rate in the vicinity of the bunker wall for the three considered cooling times

Cooling time	Beam losses (fraction of 100 μA beam) [μSv/h]	
	0.1%	3%
0 h.	0.9±0.016.6929133858	26.7±0.29
2 h.	0.16±1E-3	4.98±0.05
1 d.	0.04±3E-4	1.4±0.01

4 Conclusions

In the current work we have considered a simplified model of the bunker and the cyclotron. The simulations are conducted for two types of beam losses. Two irradiation scenarios were studied - during cyclotron operation and after a two hour session. During the cyclotron operation the bunker proved to shield effectively the prompt radiation fields. For the two types of beam losses the residual dose rates after two hours of cooling are low and the personnel could be allowed to operate inside the bunker.

Acknowledgements

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