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CALCULATION OF DOSE FIELDS AND ENERGY SPECTRA OF SECONDARY RADIATION IN THE EXTRACTION ZONE OF A SYNCHROTRON ACCELERATOR FOR PROTONS WITH ENERGIES UP TO 700 MeV

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Abstract

The possibility of using a multipurpose synchrotron accelerator for studying the processes of interaction of heavy charged particles with various materials is considered. The accelerator provides proton energies up to 700 MeV. At the design stage of the experimental room, it is necessary to evaluate the emerging dose fields. In this case, it is important to evaluate the dose environment, energies and types of secondary radiation that may enter the adjacent rooms.

This paper presents the results of the radiation environment evaluation in the radiation extraction zone of the synchrotron accelerator. Simulation results of secondary radiation energy spectra near the walls, which separate the irradiation zone from adjacent rooms, are presented. Proton energies are equal to 60, 85, 110 and 700 MeV are considered. Simulation was performed by the Monte Carlo method in a program developed using Geant4 libraries.

INTRODUCTION

Dose distribution estimation can be performed in different ways: experiment; simulation; comparison. At experimental rooms development stage estimation of arising dose fields is performed in simulation method. The extraction zone of a synchrotron accelerator which provide proton energies up to 700 MeV for studying the processes of heavy charged particles interaction with matter is considered. Apart from dose field estimation it is necessary to define type and energy of radiation which may enter the adjacent rooms. Against this characteristics can be adjust such parameters as: time spent in adjacent rooms, working hours in additional rooms, biological shielding thickness at the border of two rooms.

Simulation results of dose distribution estimation and energy spectra in experimental room by Monte-Carlo method in Geant4 [1] based software are presented. Primary particles energies are 60, 85, 110 and 700 MeV.

SIMULATION DESCRIPTION

The major mechanisms of proton interaction with the target material are: elastic scattering, excitation and ionization of atoms in the medium and nuclear reactions. Other interaction mechanisms have minor contribution [2, 3]. The package of physical processes "FTFP_BERT" [4] was used. This package includes the functions of the FRITIOF [5] model, the compound-nucleus model and the Bertini intranuclear cascade model [6]. The major nuclear reactions are: (*p*, *MpNn*), where *M* and *N* are integers; (*p, xα*); (*p*, *xd*); (*p*, *xt*); (*p*, γ) [2, 7]. Reactions of type (*p*, *MpNn*) and in a less degree (*p, xα*); (*p*, *xd*); (*p*, *xt*); (*p*, γ) are expected in simulation with protons energy up to 110 MeV. Also arising of muons and different ions is expected in simulation with proton energy equal to 700 MeV.

Simulation geometry is shown in Fig. 1. The air volume 495×600×810 cm is divided to cells 45x45x50 cm. Concrete walls (ρ = 2.3 g/cm^3) 50 cm wide are set around the air volume. At h = 150 cm height from the floor and distance d = 70 cm from the wall iron cylinder with 10 cm diameter and length is located. At 10 cm distance from cylinder the monodirectional proton source with 3 cm diameter is placed (energy distribution - Gaussian).

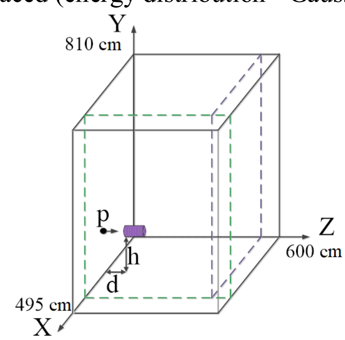

Figure 1: Simulation geometry.

Simulation results were: absorbed dose distribution in volume elements per one primary particle and secondary radiation energy spectra in areas specified by green and purple dotted lines in Fig. 1 (layers of air with 10 cm thickness). Further, coordinate denomination (according to Geant4 geometry): *x* – room width, *y* – height a, *z* – length.

In energy spectra calculation were registered: *p*, γ, *n*, e^- и e^+, μ–mesons, α and other types of secondary radiation ("other"). Width of energy bin for all cases is equal to 100 keV.

DOSE FIELD CALCULATION

The resulting dose field was divided into key sections. The following describes the simulation result for one of these sections (Fig. 2, near the side wall).

Maximum absorbed dose (90-180 cm in height and 0-50 cm in length) is: 60 MeV - 3 158 · 10^{-18} Gy; 85 MeV - 4.934 · 10^{-18} Gy; 110 MeV - 7 284 · 10^{-18} Gy per one primary proton. Minimum values (720-810 cm

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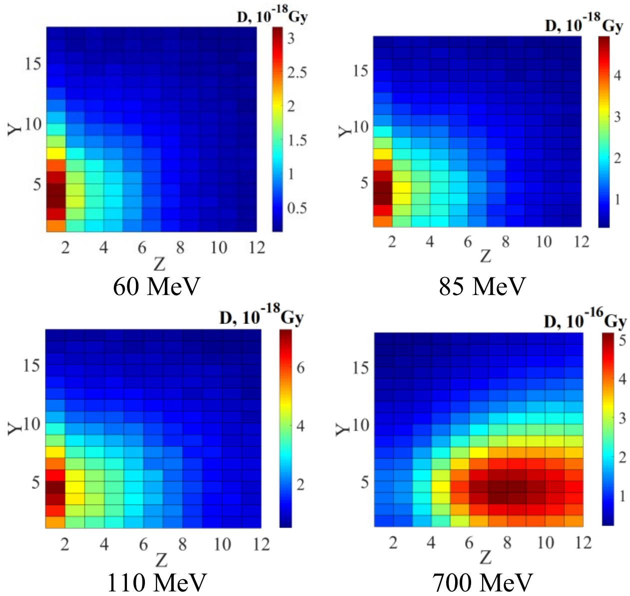

Figure 2: Absorbed dose distribution, $x = 0$.

in height and 500-600 cm in length), respectively: 60 MeV - 0.134 · 10^{-18} Gy; 85 MeV - 0.293 · 10^{-18} Gy; 110 MeV - 0.484 · 10^{-18} Gy per one primary proton. At 700 MeV - maximum value (135-180 cm in height and 300-350 cm in length) 5.172 · 10^{-16} Gy; minimum (765-810 cm in height and 0-50 cm in length) - 0.217 · 10^{-16} Gy per one primary proton. Total absorbed dose per one primary proton: 60 MeV – 116,350·10^{-18} Gy; 85 MeV – 215,461·10^{-18} Gy; 110 MeV – 354,334·10^{-18} Gy; 700 MeV – 423,951·10^{-16} Gy.

1) Absorbed dose maximum values in sections near the floor and ceiling are observed in the region of primary radiation propagation. Absorbed dose maximum value in near the floor section is 25-46 times more than in near the ceiling section. This difference becomes smaller with increasing of primary protons energy. Minimum absorbed dose in near the floor section is 41-77% higher than in near the ceiling section. This difference increase with increasing of primary protons energy. Absorbed dose minimum value in near the floor section is 5 times higher than near the ceiling, when the energy of primary protons is 700 MeV. Minimum values of absorbed dose in near the floor section are located in corners of room. Total absorbed dose in near the floor section is 6-7.5 times higher than near the ceiling, when the energy of the primary protons is 110 MeV; at 700 MeV - 15.4 times higher.

2) Maximum values of absorbed dose in the near front and back walls sections are observed in region of primary radiation propagation. Maximum value is observed in the area where the object is located at when energy of primary protons up to 110 MeV. In the front wall section, maximum and total values are 3 orders of magnitude greater than the same at the rear wall section. At 700 MeV, the propagation of radiation is predominantly forward. Maximum absorbed dose in near the front wall section is 17.5 times less than in near the back wall section.

3) In sections near the side walls at energies up to 110 MeV, maximum value is observed at the level of the source location (90-180 cm in height and 0-50 cm in length); at 700 MeV - in the middle of the room length. Minimum absorbed dose is recorded in cells in the corners of the ceiling near the back wall of the room.

SECONDARY RADIATION ENERGY SPECTRA

Figure 3 shows the energy spectra of secondary radiation in the layers $z = z_{\max}$ and $x = x_{\max}$. Thickness of the layers is 10 cm, the energy of primary protons (E_{pr}) is 60 MeV.

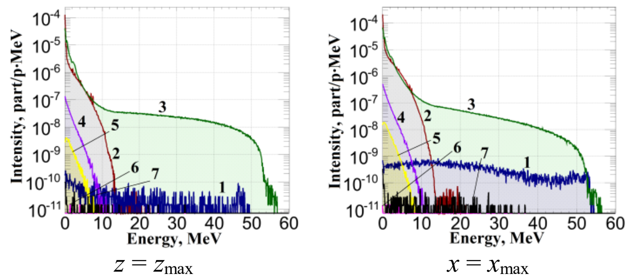

Figure 3: Secondary radiation energy spectra, E_{pr} = 60 MeV (1 – p, 2 – γ, 3 – n, 4 – e^-, 5 – e^+, 6 – α; 7 – "other").

Table 1 shows the average energies of secondary radiation in the air near the back and side walls of the room, depending on the primary protons energy; *ot* - other types of secondary radiation.

Table 1: Secondary Radiation Average Energies, E_{pr} up to 110 MeV

	E, MeV					
	$z = z_{\max}$			$x = x_{\max}$		
	60	85	110	60	85	110
p	14,541	17,607	22,047	20,066	21,475	23,186
γ	0,518	0,573	0,620	0,812	0,819	0,831
n	1,090	1,766	2,662	1,136	1,457	1,790
e^-	1,160	1,189	1,219	1,140	1,150	1,162
e^+	1,571	1,605	1,646	1,479	1,509	1,551
α	5,880	4,349	6,630	3,125	4,603	4,686
ot	3,895	8,188	13,944	7,282	9,379	12,398

Until nuclear interactions begin to prevail over other processes in the interaction of primary protons with matter, the total energy spectra differ slightly. Increasing of average α energy with increasing of primary particles energy is not observed in Table 1 because of its insignificant amount in total energy spectra (from 8,3 · 10^{-6} to 3,87 · 10^{-5} %).

Figure 4 shows the energy spectra of secondary radiation in the layers $z = z_{\max}$ and $x = x_{\max}$. Thickness of the layers is 10 cm, energy of primary protons is 700 MeV. Table 2 shows the average energies of secondary radiation in the air near the back wall at the primary proton energy equal 700 MeV; *ot* - other types of secondary radiation.

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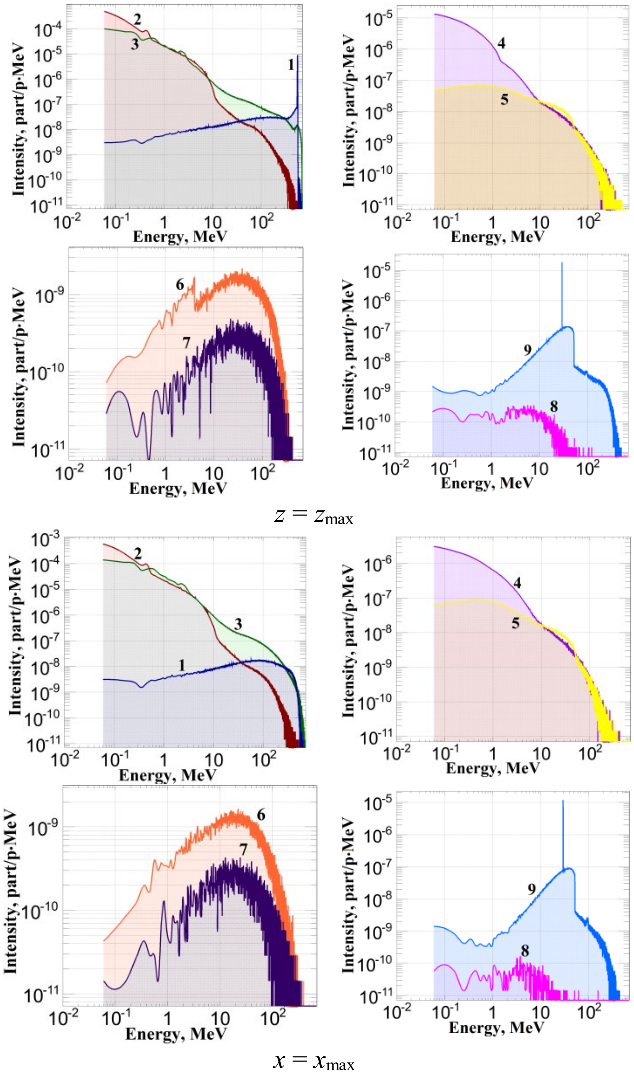

Figure 4: Secondary radiation energy spectra, E_{pr} = 700 MeV (1 – p, 2 – γ, 3 – n, 4 – e^-, 5 – e^+, 6 – μ^+, 7 – μ^-, 8 – α, 9 – "other").

In the layer near the back wall of the room, the main contributions to the total energy spectrum are made by protons (19.24%), gammas (40.58%) and neutrons (36.35%). In near the side wall layer, the main contributions are made by gammas (47.99%) and neutrons (49.14%).

Table 2: Secondary Radiation Average Energies, E_{pr} = 700 MeV

	$z = z_{max}$	$x = x_{max}$
p	511,284	182,114
γ	1,693	1,247
n	25,869	8,724
e^-	2,626	4,487
e^+	24,539	19,626
μ^+	86,112	56,755
μ^-	84,836	57,189
α	11,036	8,032
ot	41,838	36,592

CONCLUSION

With proton energies up to 110 MeV, the maximum dose load occurs along the propagation region of the primary radiation, mainly in the lower part of the room. The minimum absorbed dose in near the floor section is recorded in the corners.

Front and back walls of the room. At proton energies up to 110 MeV, the highest absorbed dose is observed in the area of the irradiated object. At 700 MeV, the maximum dose load occurs near the back wall of the room.

Side walls of the room. At energies of primary protons up to 110 MeV, the maximum absorbed dose is observed at the level of the radiation source projection. At 700 MeV, maximum absorbed dose is observed in coordinates corresponding to the projection of the middle of the room; minimum value is for the corners under the ceiling of the room near the back wall.

When the primary particles energy is up to 110 MeV, it is necessary to provide radiation protection primarily from n and γ. Their contributions to the total energy spectra: from 39.6 to 42.9% for γ, from 55.8 to 60.2% for n. At 700 MeV, secondary protons begin to make an additional contribution (near the back wall of the room).

REFERENCES

[1] Geant4, `https://geant4.web.cern.ch/node/1`

[2] A.P. Chernyaev, A.V. Belousov, E.N. Lykova, "Interaction of ionizing radiation with matter: a tutorial", Moscow: Phys. fac., Moscow State University, 2019. ISBN 978-5-6042768-5-3

[3] V.A. Egorova, M.E. Zhukovskiy, S.V. Podolyako, I.A. Tarakanov, "Mathematical model of the interaction between protons and matter", Preprints of the Institute of applied Mathematics M.V. Keldysh, № 138, 2017. doi:10.20948/prepr-2017-138.

[4] Geant4 Physics List Guide. Release 10.7, `https://geant4-userdoc.web.cern.ch/UsersGuides/PhysicsListGuide/html/index.html`

[5] B. Nilsson-Almqvist and Stenlund. *E. Comp. Phys. Comm.* 1987, № 43, p. 387.

[6] M.P. Guthrie, R.G. Alsmiller and H.W. Bertini, *Nucl. Instr. Meth*, № 66, p. 29, 1968.

[7] I.V. Racobolskaya, "Nuclear Physics: a tutorial", Under ed. of Petukhov, Moscow University press, 1971.