DESIGN AND EVALUATION FOR THE SHIELDING SYSTEM OF THE 9 MeV TRAVELLING WAVE LINAC

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Abstract

We use EGS4 code, a general known Monte Carlo computer simulation package, to carry out the simulation analysis of the radiation dose distribution around the head shielding system and inside the accelerator hall of the 9MeV travelling wave linear electron accelerator. The accelerator is used for the large container inspecting system. The comparisons of experience formulae evaluation and practical data are made. The results show that, at the main reference points in the accelerator hall, the dose calculated by EGS4 is well coincided with the results measured. It serves as a good example of flexible application of EGS4.

Key words: Accelerator Shielding Calculation EGS4 Radiation Protection

1 INTRODUCTION

Along with the accelerator being extensively used, the radiation and radiation protection of the accelerator should be known roundly and clearly. With the development of computer technology, Monte Carlo method provides a good analog calculation tool. EGS4 (Electron Gamma Shower Version 4.0) is a computer simulation package using to simulate the transport phenomenon of electron and gamma in medium[1]. Using it, we carry out the simulation analysis of the radiation dose distribution around the head shielding system and inside the hall of the accelerator. The comparisons between the empirical formulae evaluation and the practical data are made. The results show that, at the main reference points in the accelerator hall, the dose calculated by EGS4 is well coincided with the results measured.

2 9MeV TRAVELLING WAVE LINAC AND IT'S SHIELDING REQUIRE

2.1 9MeV Travelling Wave Linac

Electrons are accelerated by Linac, impacts the target and produce bremsstrahlung. X-rays are collimated to be a thin sector. The useful X-ray is only a little part out of the X-rays educed by accelerator, the rest are useless and need to be shielded. The highest energy of the linac that used in the large container inspecting system is 9MeV. The target is tungsten, the thickness is 0.35cm, the electron pulse beam current intensity is 150mA, and the width is 5us, repeat frequency rate is 250Hz. The highest energy of the X-ray is nearly 9MeV and the average energy is 2.55MeV[2]. The dose rate is 30Gy/min at zero degree direction of 1m away.

2.2 Shielding System of the Accelerator Head and Hall

Leak radiant dose rate needs to be under 1‰ of the center of the main X-ray beam, this is one of the requirements of the shielding system. The construction of the shielding system is shown in fig 1. It consists of a series of lead cake. As a result, the leak radiation rate is under 0.4‰[3] at failure-free operation according to the examination made by Beijing epidemic prevention station.

The structure of the accelerator hall is symmetrical. The wall used reinforced concrete, which is 1.5-2m thick. Fig.2 shows the plane figure of the accelerator hall. Shielding system is desired to keep the dose equivalent, which all the staff and public suffer from, as low as possible, when an accelerator is being debugged in the hall.

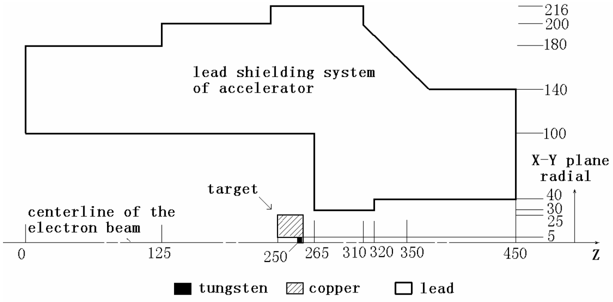

Fig. 1 Shielding system of the accelerator head(mm)

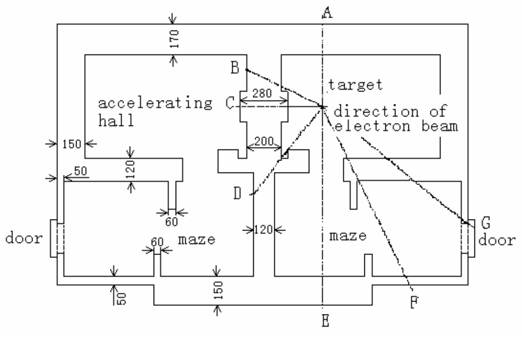

Fig. 2 Plane figure of accelerator hall(cm)

3 CALCULATE THE RADIATION STANDARD

3.1 Methods of Calculating Shielding Thickness

When the primary X-rays dominate the shielding situation, for a point source of X-rays,

$$\dot{H}_{Id,x} = \frac{\dot{D}_{Io} B_x T}{d^2} \le \dot{H}_M \qquad (1)$$

where, $\dot{H}_{Id,x}$ is the calculated dose-equivalent of that point, Sv min^{-1}; $\dot{H}_M$ is the maximum permissible dose-equivalent or dose-limit rate, Sv min^{-1}; $\dot{D}_{I0}$ is the absorbed-dose index rate at a standard reference distance of 1 meter from the source (the target of the accelerator), Gy m^2 min^{-1}; B_x is the shielding transmission ratio for X-rays, T is the area-occupancy factor, it can equal to 1, 1/4 or 1/16 for different case[4]; d is the distance between X-ray source and reference point, meters. For accelerator, $\dot{D}_{I0}$ calculated as follows:

$$\dot{D}_{I0} = I\delta_a \qquad (2)$$

where, I is the electron beam current intensity of the accelerator, mA; δa is the X-ray emissivity of the accelerator, Gy m^2 mA^{-1} min^{-1}; and B_x calculated as follows:

$$B_x = 10^{-n} \quad , \qquad n = 1 + \frac{x - T_1}{T_e} \qquad (3)$$

Where, T_1 is the first tenth-value layer in the shielding thickness, facing the radiation source, cm; T_e is the subsequent tenth-value layer, approximately constant in value. when reflected X-rays dominate the shielding situtation, the dose-equivalent calculated as follows:

$$\dot{H}_{Id_r,x} = \frac{\dot{D}_{I0}\alpha_x A \; B_{xr} T}{d_i^2 d_R^2} \qquad (4)$$

Where, A is the projective area of the reflecting material illuminated by the incident X-ray beam, m^2; α_x is the reflection coefficient of reflecting material, depending on the incident X-ray energy, reflecting angle, and reflecting material; d_i is the distance between the target and the reflecting material, meters; d_R is the distance between the reflecting material and the reference point, meters. X-rays will be reflected more than one time in the maze. There is a shielding door out of the maze, the dose-equivalent index rate out of the maze is calculated as:

$$\dot{H}_{I,rj} = \frac{\dot{D}_{I0}\alpha_1 A_1 (\alpha_2 A_2)^{j-1} B_{xr} T}{(d_i d_{r1} d_{r2} \cdots d_{rj})^2} \qquad (5)$$

Where, α_1 is the reflection coefficient when X-rays incident on the reflecting material firstly; α_2 is the reflection coefficient for the 0.5-MeV X-rays reflected subsequently; A_1 is the projective area made by the X-rays reflected for the first time; A_2 is the cross-section of the maze; $d_{r1}, d_{r2} \cdots d_{rj}$ are the centerline distances along each maze length; j refers to the jth reflection process.

3.2 Result of Using Emprical Formula

To 9MeV Linac, in empirical formula $\triangle_{1/10}$=37cm[4], α_r is between 0.003 and 0.03[4], and let q equal 1. Supposed that the accelerator works 2000 hours a year and operates 12 minutes per hour, the dose-equivalent at each point (A～G in Fig. 1) is show in Tab.1.

4 THE METHOD AND RESULT FOR ANALOG CALCULATION USING EGS4

4.1 The Method for Analog Aalculation

First, simulate the lead shielding system. Taking centerline of the electron beam as axis Z, the plane that plumbs to axis Z as plane X-Y, and the point that electron beam in this system as origin, we set up a coordinate system as Fig.1.

Tab. 1 The dose rate distribution educed by emprical formula （mSv/a）

points	A	B	C	D	E	F	G
primary X-rays	0.78	0.0425	1.73	0.0080	0.85	0.02	3.3e-4
reflected X-rays	0.064	4.3e-5	9.3e-8	0.12	0.0047	0.68	0.58
reflected from maze	0.0019	5.0e-6	1.1e-8	0.018	3.6e-4	0.27	0.16
total	0.85	0.043	1.73	0.14	0.86	0.97	0.74

Tab. 2 The coordinate position of the XY planes and the radius of the column planes(cm)

Plane number	1	2	3	4	5	6	7	8	9	10	11	12
Position of axis Z	0	12.5	22.5	23.15	25	25.35	25.45	26.5	31	32	35	45
Column plane number	1	2	3	4	5	6	7	8	9			
Radius of column	0.5	2.5	3.0	4.0	10.0	14.0	18.0	20.0	21.6			

Tab. 3 The coordinate position of the planes in dissection of the geometry configuration of the accelerator hall

Plane Y-Z	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
X-axis	0	50	100	200	430	470	530	590	620	770	880	920	960	1080	1120
Plane X-Z	16	17	18	19	20	21	22	23	24	25	26	27	28		
Y-axis	0	100	150	270	450	600	650	720	770	870	970	1120	1290		

Second, simulate the accelerator hall. Taking the horizontal plane as plane X-Y, upright direction as axis Z, we set up a coordinate system as Fig.3.

4.2 The Result of Calculation Using EGS4

The dose-equivalent of all units in Fig.3 can be obtained by EGS4. There are some representative units, which have high dose-equivalent, shown in Tab.4.

5 THE MEASURED RESULT AND THE COMPARISON

5.1 The Measured Result

The dose-equivalent of the points A~G are measured, the results are show in Tab.5.

The measuring instrument is X-γ personal dosimeter (Type ЮПИТЁР) that made in Russia. Measuring range is 0.2～99.99μSv/h, energy response range is 0.05～1.3MeV.

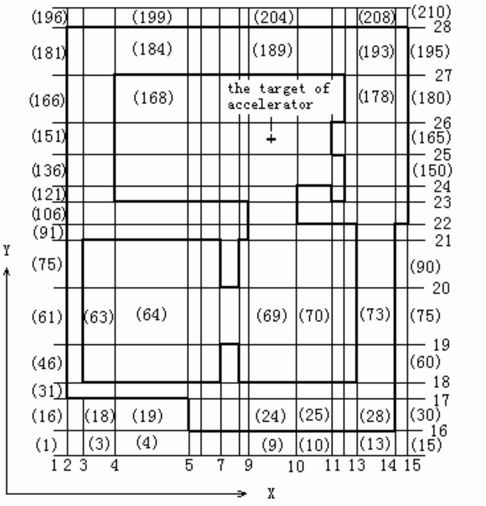

Fig. 3 The dissected geometry configuration of the accelerator hall

Tab. 4 The dose rate distribution at some reference point deduced by EGS4, (uint, mSv/a)

Unit number	3	4(F)	9(E)	10	46(G)	60	61	75	90	106	135	136
Dose-equivalent	0.11	0.33	0.58	0.64	0.02	<0.02	<0.02	<0.02	0.05	0.05	0.04	0.07
Unit number	150	151	165(C)	166	180(B)	181	195	199	202	204(A)	205	208
Dose-equivalent	0.14	<0.02	1.84	0.06	0.09	0.02	<0.02	<0.02	0.17	0.49	0.10	0.02

1) A～G are the same of that in Fig.2 and Tab.1.

Tab. 5 The dose rate distribution measured(mSv/a)

Points that measured	A	B	C	D	E	F	G	Back-ground
Dose rate	0.46	0.06	1.88	0.06	0.70	0.40	0.48	1.40

5.2 Comparison of the Results

Tab. 6 The comparison of the dose rate distribution at the main reference point in the hall(mSv/a)

Reference points	A	B	C	D	E	F	G
Actual measurement data	0.46	0.06	1.88	0.06	0.70	0.40	0.48
Results of using emprical formula	0.85	0.04	1.73	0.14	0.86	0.97	0.74
Results of using EGS4	0.49	0.09	1.84	0.05	0.58	0.33	0.02

At point G, the dose-equivalent obtained by EGS4 is lower than measurement. The reason is that the dose-equivalent of this point mostly caused by the reflected X-rays, but the low energy X-rays (lower than 0.5MV) of the primary X-rays is not included in the physics model in order to reduce calculation quantity. The other reason is that, the door's capability is equal to the 35cm thick concrete, while we use 50cm to calculate for easiness. And the gap between wall and door is a maze, some low energy X-rays leak out from this maze. This is a reason too.

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