LEAKAGE RADIATION DOSE ANALYSIS AT ELV-4 BUNKER'S DOOR

Mohd Rizal Md Chulan[1*]; Redzuwan Yahaya[1*]; Abu Bakar Mhd Ghazali[2]

[1]*School of Applied Physics, Faculty of Science and Technology,Universiti Kebangsaan Malaysia,*

[2]*Department of Electronic and Communication, College of Engineering, Universiti Tenaga Nasional.*

**Corresponding author:* rizal@nuclearmalaysia.gov.my; redzuwan@ukm.my

ABSTRACT

Bunker Shielding is most important in the safety of an accelerator and one of the most important aspects of this shielding is the door. The bunker's door have be properly designed to minimize the leakage radiation and shall not exceed the permitted limit of 2.5μSv/hr. In such a bunker, the leakage radiation doses were estimated using the radiation protection concept and the data provided by machine supplier (BINP). The radiation leakage outside the bunker was determined through direct measurement using a survey meter. It was found that there were leakage radiation doses that have exceeded the permitted limit of 2.5μSv/hr at the gap between the bunker's door and the wall, with the highest found to be at the labeled location 10 which were 466.647μSv/hr (from the calculation) and 479.573μSv/hr (from direct measurement). This high leakage radiation dose was due to the lack of significant thickness in the bunker's door of the shielding and the size of the gaps between the door and the wall. Thus modification and improvement to the shielding need to be done in order to protect workers and the public whilst the accelerator is in operation.

ABSTRAK

Perisaian Bunker merupakan aspek keselamatan terpenting dalam suatu pemecut dan salah satu bahagian tersebut yang paling penting adalah pintu. Pintu bunker ini perlu direkabentuk dengan teliti supaya dos sinaran yang melaluinya, dikenali sebagai dos sinaran bocor adalah tidak melebihi had yang ditetapkan iaitu 2.5μSv/j. Dos sinaran bocor telah dianggarkan menggunakan konsep perlindungan sinaran dan juga data yang disediakan oleh pembekal alat (BINP). Sementara, dos sinaran bocor pada luar pintu bunker ini juga telah diperolehi dengan pengukuran terus menggunakan meter tinjau. Daripada analisa melalui pengiraan dan pengukuran terus, didapati terdapat dos sinaran bocor yang melebihi had yang ditetapkan (2.5μSv/j) iaitu pada ruang antara pintu dan dinding bunker dengan dos sinaran bocor tertinggi pada lokasi bertanda 10 iaitu 466.647μSv/j (daripada pengiraan) dan 479.573μSv/j (daripada pengukuran terus). Dos sinaran bocor yang tinggi ini didapati berpunca daripada ketebalan berkesan pintu (perisai) yang tidak mencukupi dan saiz celahan antara pintu dan dinding bunker tersebut. Oleh itu pengubahsuaian dan penambahbaikan kepada perisaian perlu dilakukan bagi melindungi pekerja dan orang awam semasa pemecut sedang beroperasi.

Keywords: Leakage radiation dose, shielding calculation, accelerator bunker, electron accelerator.

INTRODUCTION

ELV-4 is an electron accelerator acquired by Malaysian Nuclear Agency from Budker Institute of Nuclear physics or BINP, Russia. The equipment was acquired for the purpose of radiating cables, thin films and sewage wastewater treatment. It has a maximum power of 50kW with maximum energy of 1MeV and beam currents of 50mA. The electron generated, when interacting with the main metal components will produce x-rays i.e. bremsstrahlung. As such, a shielding construction known as bunker, with a dimension of 5m (width) x 5m (breadth) x 4m (height) was design and constructed in siting the ELV-4 equipment. The leakage radiation dose limit for the bunker was set at 2.5µSv/hr, which is the exposure at the surface of the door on the outside of the bunker. The thickness of the bunker wall was built with Grade 40 reinforced concrete (density > 2.3g/cm^3) as calculated by Abu Bakar Ghazali et al. (2006) with a suggested thickness of 120cm. The same thickness was taken for the door. The problem exist when looking at the door as a whole where there are gaps between the door and the wall of the bunker which could allow radiation to pass through that resulted in leakage radiation dose outside the bunker.

This paper discussed the leakage radiation dose values, where radiation passed through the gaps between the door and the wall of the bunker at the labeled location as shown as Figure 1. The leakage radiation dose outside the bunker was estimated using the method shown by Abu Bakar et al. (2006). These calculated results were then compared to the measurement results using Ludlum Model 3 with Probe Model 44-9(G.M).

METHODOLOGY

Theoretical Aspects

The bremsstrahlung radiation is produced when an electron beam impinges on the metal target (iron) as shown in Figure 4. The bremsstrahlung radiation will move from the target to the entire space and to the bunker's wall. The intensity of the absorbed dose in the air for the angle **θ** and the distance **R**, **P(R,θ)** can be calculated by the following the equation:

$$\mathbf{P(R,\theta) = P_0(\theta) \ / \ R^2} \quad (1)$$

where **P(R,θ)** is the effective dose intensity at the current point, unit of rad.m^2.min^{-1}; $\mathbf{P_0(\theta)}$ is the absorbed dose intensity in air at a distance of 1 m from the beam of energy 1.0 MeV and beam current 50 mA and is stopped by the **Fe** target with angle distributions of bremsstrahlung, unit of Gy m^2/h; and with **R** the distance from target to current point, in unit of m.

The radiation on the wall will penetrate or will be scattered. The penetrated radiation after the shielding can be calculated using the equation:

$$\mathbf{P_{shield} = P(R,\theta) \ e^{-\mu t}} \quad (2)$$

where $\mathbf{P_{shield}}$ is the dose intensity at the current point after shielding (which decreases through shielding), in unit of Gy/h; **P(R,θ)** is the dose intensity at the current point without shielding, in unit of Gy/h; **µ** is attenuation coefficient that depends on the electron energy and material (atomic number) used, in unit of m^{-1} and t is the thickness of shielding.

For the scattered radiation, the dose intensity of the scattered radiation can also be calculated using the following equation:

$$\mathbf{P_s = (J_\theta \ x \ P(R,\theta) \ x \ S \ x \ cos \ \Omega) \ / \ (R')^2} \quad (3)$$

where $\mathbf{P_s}$ is the dose intensity of the scattered radiation at the current point, in unit of Gy/h; $\mathbf{\Omega}$ is the angle between direction of falling radiation ray and normal to the scattered surface; **S** is the square of the aligned spot on the scattered surface, in unit of m^2; $\mathbf{P(R,\theta)}$ is the average dose intensity of the aligned spot on the scattered surface, in unit of Gy/h; $\mathbf{J_\theta}$ is the coefficient of differential dose 'albedo' (usually 10^{-2}) and **R'** is the distance from aligned spot on scattered surface to the current point, in unit of m. All the calculation consideration is referred to in Figure 4.

Gaps considered

According to NCRP (1977), the leakage radiation can occur at the gap between the door and the wall of the bunker. The leakage radiation may come from direct or scattered radiation. In this study, the leakage radiation dose monitoring focuses on the surface of the gaps between the door and the wall of the bunker e.g upper gap, P1 (Figure 2), end gap, P2 (Figure 3) and side gap, P3 (Figure 3)

At the upper gap, there are three reference points labeled with 1, 2 and 3. For the end gap, there are three reference points labeled 6, 7 and 8. At the side gap there are three reference points labeled 9, 10, 11 and 12. While the reference points labeled 4 and 5 are at the surface of the bunker's door as reference thickness where the thickness is equal to bunker's wall thickness. For the lower gap, there are three reference points labeled 13, 14 and 15.

Direct measurement using survey meter

Radiation was measured using the Geiger Muller (GM) detector, survey meter, calibrated using radiation source of Cs-137 which has the energy of 0.662 MeV. This energy is almost equal to the bremsstrahlung energy, produced from electron energy of 1 MeV impinging on the target material of iron, which is 0.667 MeV. The measurement was done at the surface of the locations where the dose calculations for the leakage radiation were made.

Some considerations were taken to simplify the calculations such as the radiation source is the point source in a straight line, while the shield material is treated as homogeneous and the leakage radiation dose limit is referred to the clean area in accordance of the Act 304 (1984).

RESULTS AND DISCUSSIONS

From the calculation, it was found that the leakage radiation dose at the reference points 1, 2 and 3 were more than the permitted value of 2.5µSv/hr. These high radiation dose calculation values were attributed to the scattered radiation. These values were found to be close to the measurement values. The high radiation dose is probably due to the insufficient thickness of the shielding especially at the bunker door. In reference to Figure 2, the significant thickness of shielding at that points are only 37.5 cm when compared to the suggested value of 120 cm by Abu Bakar Mhd Ghazali (2009). In reference to Figure 3, the bunker's door design is a sliding and plug type. But according to NCRP (1977), there are two types of recommended bunker's door. First, the sliding type where the door and the wall of the bunker should overlapped each other where the distance of the overlap, **r** should be at least ten times the size of the gap, **d** between the door and the wall of the bunker (Figure 5A) and the movement of the door should be parallel to the bunker's wall. Secondly, the plug type where the bunker's door is design with the step as well as a ladder (Figure 5B) and the door movement perpendicular to the wall where the total significant shielding $[(\mathbf{t1 + t2}), (\mathbf{t3 + t4})\ \mathbf{dan}\ \mathbf{t5}]$ should be less than the recommended value. When we analysed the ELV-4 bunker's door, it was found that the door does not follow the recommended design which may probably resulted in the high leakage radiation dose at the points 1, 2 and 3.

Table 1 Absorbed dose intensity, $\mathbf{P_0(\theta)}$ versus $\boldsymbol{\theta}$

$\boldsymbol{\theta^o}$	0	10	20	30	40	50	60	70	80	90
$\mathbf{P_0(\theta)}$	1740	1530	1266	954	864	690	582	450	342	135
$\boldsymbol{\theta^o}$	100	110	120	130	140	150	160	170	180	
$\mathbf{P_0(\theta)}$	195	250	290	290	290	234	210	210	185	

The different values between the calculation and the direct measurement for the reference points 1, 2 and 3 were probably caused by the size of the upper gap, **d** (Figure 2). The gap size of the conceptual drawing from A Bakar Ghazali (2009) is 25 mm width, but the real gap size at those points is 30 mm to 40 mm. This is due to the unequal concrete surface thickness of the bunker's wall which would allow more radiation to pass through and resulted in the high radiation at the gap surface.

The leakage radiation dose calculation for the reference points 6, 7 and 8 showed the radiation dose to be higher than the permitted value of 2.5μSv/hr which was attributed to the same arguments as for the points 1, 2 and 3 above.

The differences between the calculated and direct measurement values for the reference points 6, 7 and 8 were due to the different sizes of the end gap used in the calculation when compared to the real gap size. The gap size in the calculation is 25 mm, obtained from conceptual drawing by A Bakar Ghazali (2009) while in the real situation, the door and the wall of the bunker almost touched each other especially for reference point 7. This small gap size will allow less radiation dose to pass through and will results in the leakage radiation dose being lower than the permissible limit.

Table 2 Calculated and Measurement Results

Location	Calculation (μSv/hr)		Direct measurement
	Direct radiation	Scattered radiation	(μSv/hr)
1	0.032	14.297	22.745
2	0.197	18.848	43.042
3	0.373	20.722	61.222
4	0.316	0.007	0.000
5	0.265	0.006	0.000
6	0.345	38.119	17.237
7	0.426	43.685	0.466
8	0.188	42.483	9.097
9	0.003	104.140	102.593
10	0.019	466.647	479.573
11	0.009	1.322	0.446
12	0.012	1.180	4.009
13	0.074	2.446	0.252
14	0.009	0.660	0.272

15	0.001	55.660	26.863

Note: The blue values show leakage radiation doses that were lower than the permitted value of 2.5µSv/hr.

Base on the result of the direct measurements, eventhough the door and the wall of the bunker touched each other, the radiation still occurred at the surface of the gap. This is probably due to the crack in the touched surface that permits the radiation to pass through where the radiation dose was dependent on the size of the crack.

From the calculation, the reference points 9 and 10 have very high radiation dose of about 104.14µSv/hr and 466.647µSv/hr, respectively while the results from direct measurement also show that the points have very high radiation dose which were 102.593µSv/j and 479.573µSv/j respectively. From the observation at point 9, the high dose comes from scattered radiation that occurred in the gap and passes through the 200 mm shield thickness before reaching point 9 (Figure 6A). The results at the point 10, with a high dose, may have been due to the scattered radiation that occurred in the gap and goes out to point 10 without any shielding.

From the calculation, reference points 11 and 12 leakage radiation doses were lower than permitted limit, while direct measurement showed similar results only for point 11. From the observation, the wall at the location labeled S (Figure 3) has only 47 cm of shielding thickness. This thickness of shielding is 3 cm less than the thickness suggested by A Bakar Ghazali (2009) which is 50 cm. This has been attributed to the high reading (4.01µSv/hr) at point 12.

From the calculation and direct measurement, reference points 4 and 5 showed that the leakage radiation doses were lower than the permissible limit, proving that the thickness of shielding of bunker's door (120 cm) was sufficient to protect from the hazard of bremsstrahlung radiation.

The calculated and direct measurement at reference points 13 and 14 showed that the leakage radiation doses were lower than the permissible limit indicating that the depth of the bunker's door (40.8 cm) to the ground is sufficient to prevent radiation hazard. The calculation also shows that the deeper is the door to the ground level, the thicker (t) is the shielding (Figure 2).

For the last reference point 15, the calculation have shown that the leakage radiation dose was 20 times more than the permissible limit (2.5µSv/hr) which was probably due to the scattered radiation inside the trench that reaches point 15. Direct measurement also shows high reading but was still lower than the calculated result, probably because of the movement mechanism of the bunker's door installed on lower part of the door. The metal equipment itself acts as a shielding for the lower part of the door.

CONCLUSION

As a conclusion, it was found that there were leakage radiation doses that exceeded the permitted value of 2.5µSv/hr at the gaps between door and wall of the bunker with the maximum leakage radiation dose of 466.647µSv/hr from the calculation and 479.573µSv/hr through direct measurement. As such modification and improvement to the shielding should be done at the locations where the leakage radiation doses were higher than the permitted value. Radiation sign should also be placed at the leakage area in order to prevent accidental exposure of the workers to high radiation dose when the electron accelerator is in operation.

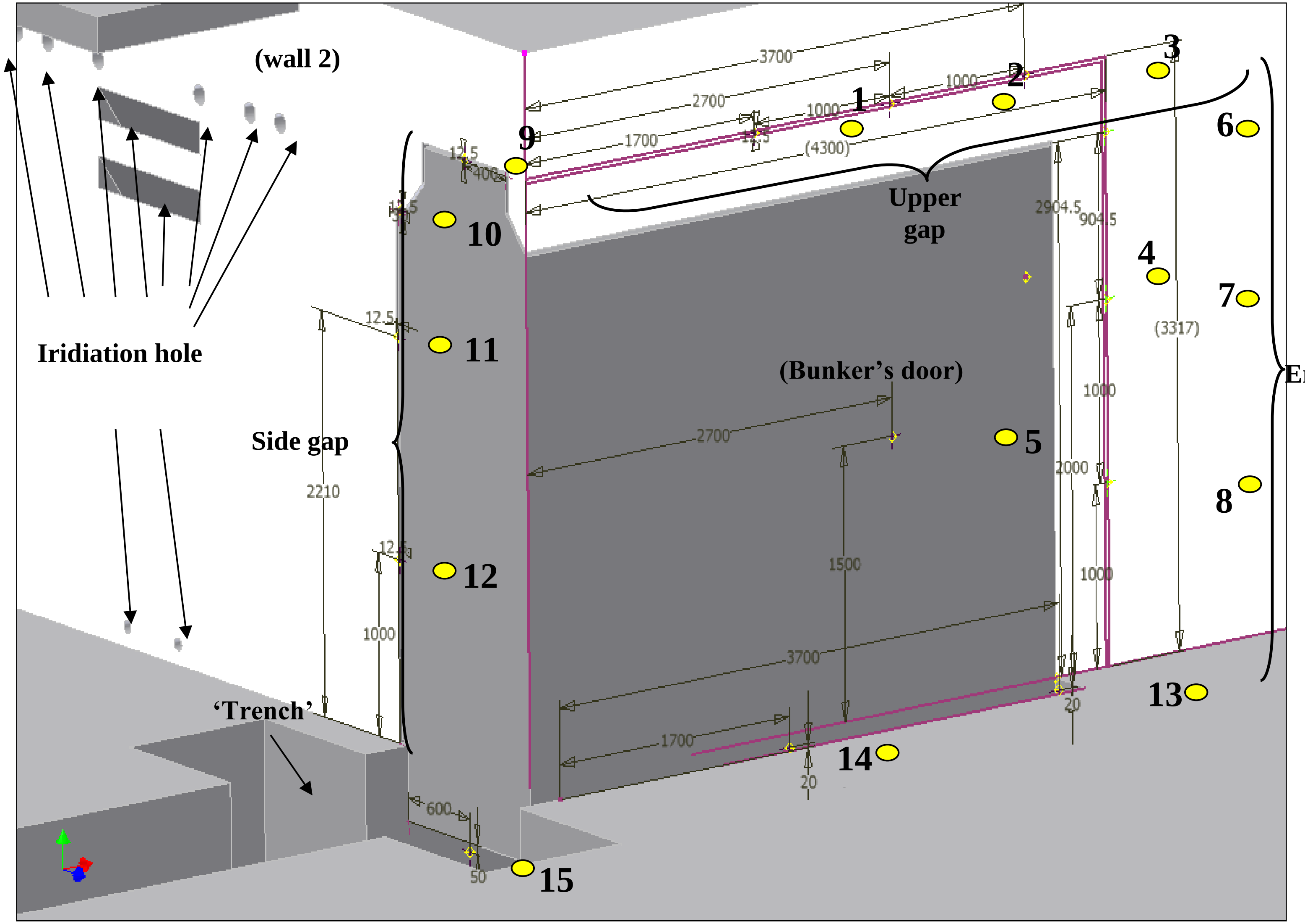


Figure 1.The illustration of the ELV-4 bunker showing the considered locations or reference points (labeled with yellow circle)

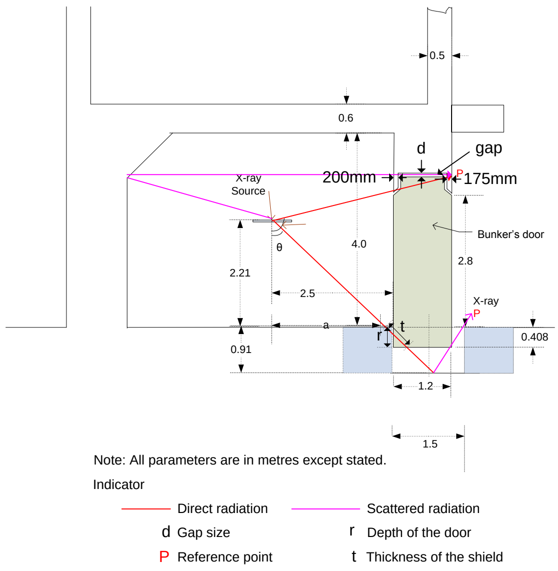


Figure 2 Side view of the bunker show the considered gap (P) for calculation and direct measurement

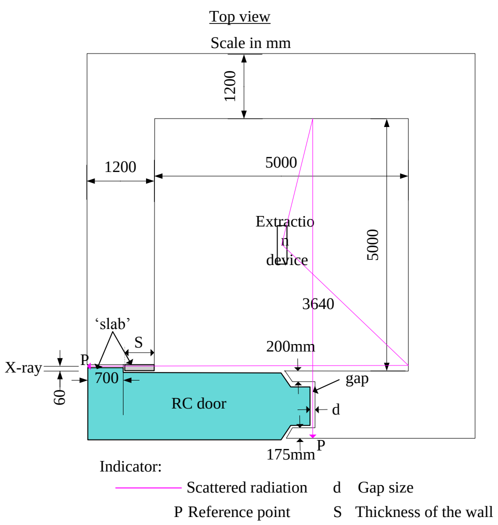


Figure 3 Top view of the bunker shows the considered gaps (P) for calculation and direct measurement.

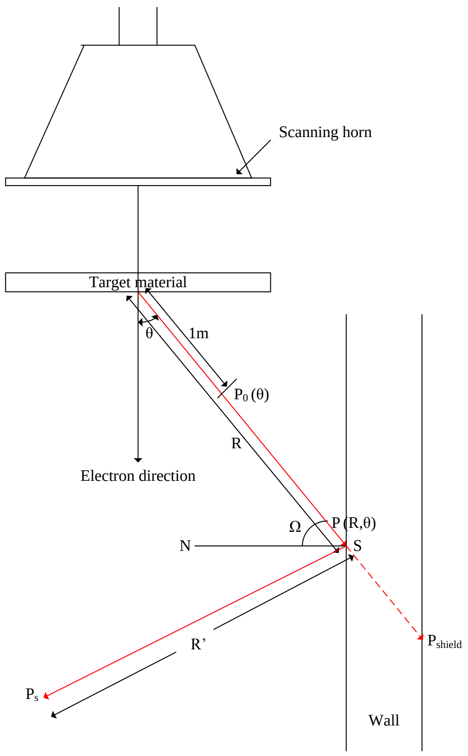


Figure 4 Definition of P(R,θ), P_{shield} and P_s

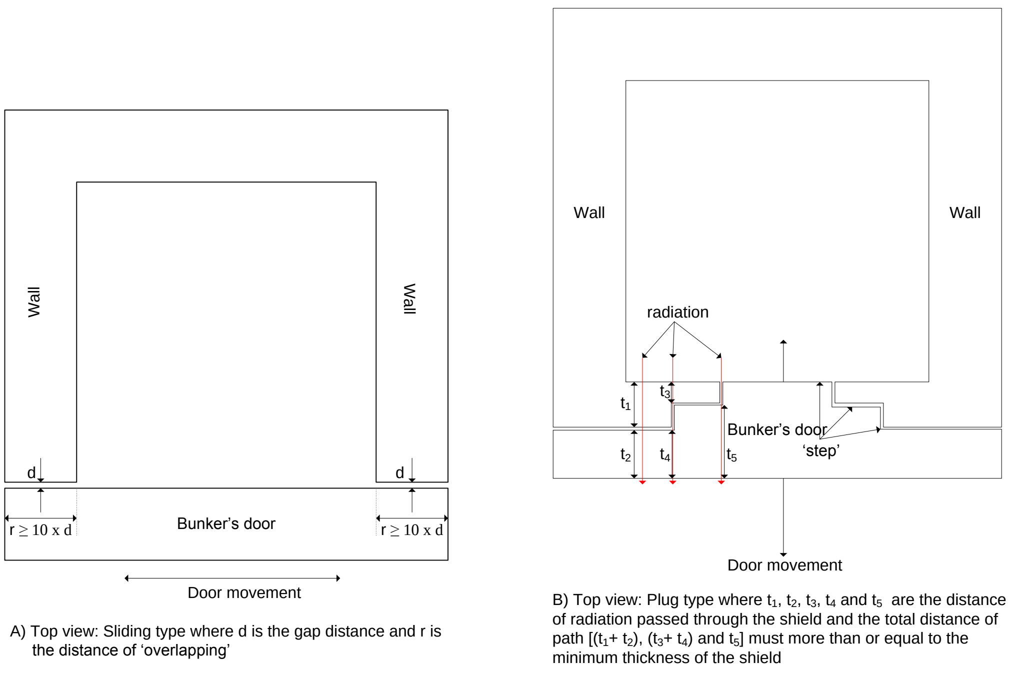
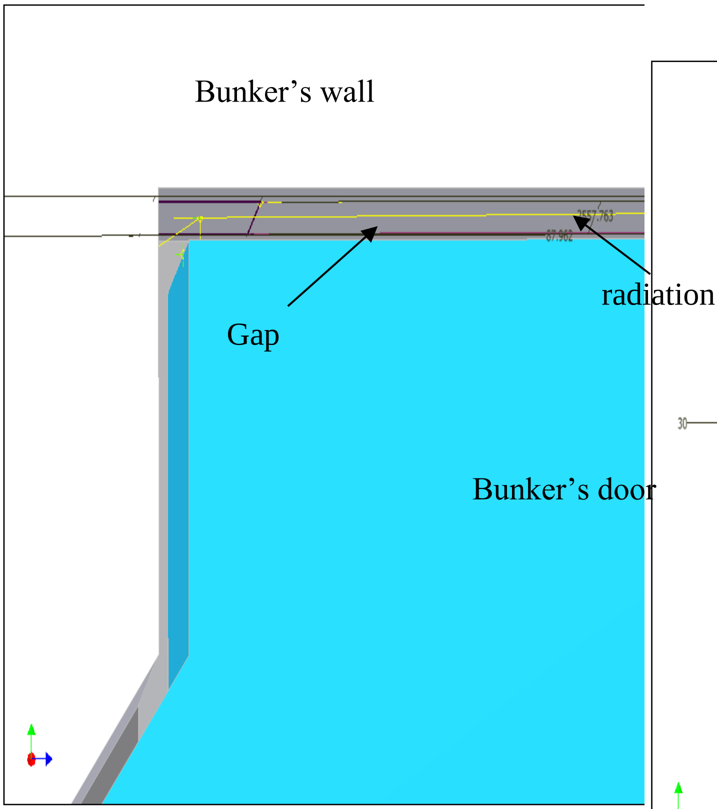
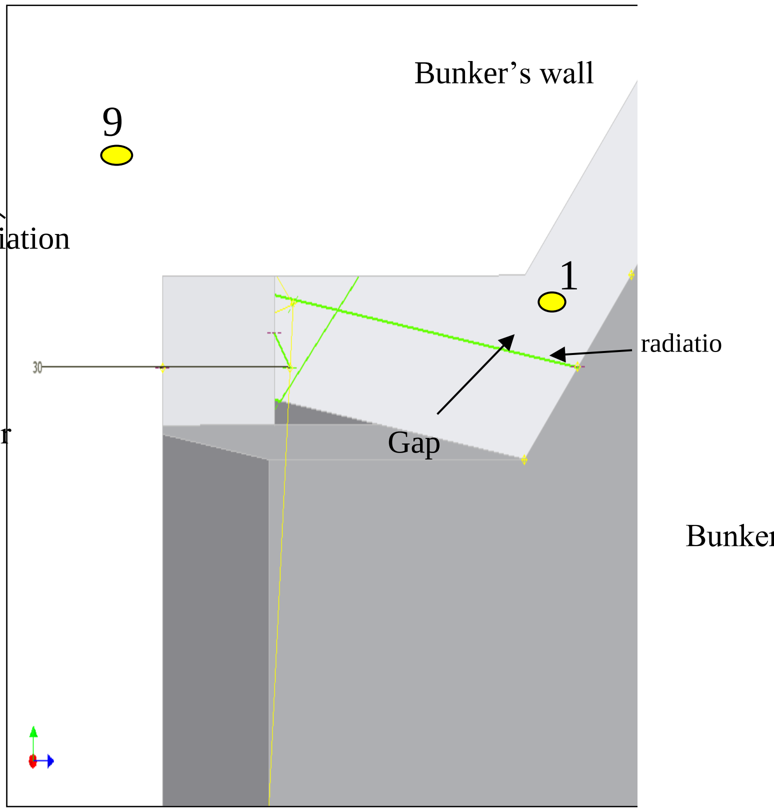


Figure 5 Two types of the bunker's door (A) and (B) proposed by NCRP (1977)



A) Illustration of location 9



B) Illustration of location 10

Figure 6. The yellow line shows the bremsstrahlung radiation that produced high leakage radiation dose

REFERENCES

Abu Bakar Mhd Ghazali, Mohd Rizal Md Chulan, and Rokiah Mohd Sabri, 2006. *Calculation of Radiation Shielding of lMeV, 50mA ELV-Type Accelerator at Nuclear Malaysia*. Nuclear Malaysia Technical Report. Jun.'06 (MINT/PPP/BPK/lSG/TR'06(I)

A Bakar Ghazali and Mohd Rizal Md Chulan, 2009. *Design of the bunker's door for 1 MeV, 50mA Electron Accelerator Facility*. Nuclear Malaysia Technical Report No. NM/PPT/BST/ADC/TR09(3).

Kartika Juara Sdn. Bhd. 2009. *Key Plan (Shop-drawing) of RC sliding Door, Drawing No. DWG-GA-0(2042)-A-KPLN-00*. Top- Mech Provincial Sdn Bhd on behalf of Kartika Juara Sdn. Bhd. 20 March 2009.

NCRP. 1977. *Radiation Protection Design Guidelines For 0.1-l00MeV Particle Accelerator Facilities*. NCRP Rep. No.5l, March 1, 1977" Washington D.C. National Council on Radiation Protection and Measurement.

ACT 304. 1984. *Warta Kerajaan Malaysia:* Jil.32 No. 5 (3 hb. Mac 1988). *Akta Perlesenan Tenaga Atom 1984:Peraturan-peraturan Perlesenan Tenaga Atom (Standard Keselamatan Asas) 1988.*