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Research Article

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An Evaluation of the Effectiveness of the Structural Radiation Shielding Barriers of a Radiation Therapy Facility: Cancer Institute of Guyana

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Abstract

This project thoroughly investigates the integrity of the structural radiation shielding barriers of the radiation therapy facility of Cancer Institute of Guyana which houses a Linear Accelerator (LINAC) of 6 MV. The LINAC comprises a retractable beam stopper which renders all barriers of the bunker as secondary. However, the barriers that receive the primary incidence of the beam at the gantry angles 900 and 2700, Walls A and B, have been annotated as primary. In addition, for the other barriers, a phantom was used in making measurements for scatter. The bunker at Cancer Institute has been in existence since 2006. Therefore, the primary aim of this study is to validate the effectiveness of the structural radiation barriers of the radiation therapy facility through measurements and computations of the Instantaneous, Time Averaged and Weekly Dose Rates of the barriers and calculations of the attenuation coefficients using the Tenth value layer of the existing shielding material, concrete. The results gathered serve as a basis for comparative analysis to the Institute's Commissioning Report and the International Standards. The Instantaneous measurements were recorded using the Fluke Biomedical Ionization Chamber.

The results of the project annotate that the radiation shielding barriers at Cancer Institute of Guyana are very effective. The instantaneous dose rates recorded by the ionization chamber of the existing barriers were significantly lower than those calculated. The time averaged and weekly dose rates were very low as well. Scattered radiation measured conformed with the international standard of being less than 0.1% of the primary beam. However, calculations for barrier thicknesses required were higher than the existing barrier thicknesses. This was as a result of the field size parameter of the LINAC being utilized at its maximum. Nevertheless, these verifications of the effectiveness of the radiation shielding barriers were in conformity to the stipulated standards and well below calculated outcomes.

Keywords Radiotherapy; TLD; Ionizing radiation; Dose; (OEP) Occupationally exposed personnel

Introduction

Cancer Institute of Guyana (CIG) is a multi-modality imaging facility that has been operational since 2006. This Institution sits on the coastal belt in the capital city of Georgetown, at the corner of Lamaha and East streets, and to the East-north eastern side of the Georgetown Public Hospital Corporation (~1.16 km from the Atlantic Ocean) [1].

Interiorly, all ionizing radiation modalities are located from the western to southern sides of the building while the non-ionizing departments are housed on the eastern side. The ionizing radiation modalities include computed tomography, mammography and x-ray (on the western side) and radiotherapy (with linear accelerator with an energy of 6 MV for photons and a range of energies for electron beams from 5,7,8,10,12 and 14 MeV) to the southern end of the building. Non-ionizing services offered include ultrasonography, chemotherapy and medical consultancy/gynecology [2].

Seeing that the occupancy factor (T) on the western side of the building housing the ionizing radiation modalities is high (where T=1), primary structural shielding barriers have been incorporated. The purpose of this incorporation is to reduce the amount of unnecessary ionizing radiation exposure to members of the public, patients and occupationally exposed personnel whose annual dose limits are 1 mSv and 20 mSv, respectively [3].

At Cancer Institute of Guyana, the linear accelerator has a retractable beam-stopper or beam-shield that acts as a primary barrier, since the average transmission of the beam-stopper does not exceed 0.1% of the primary beam. Therefore, it is safe to say that the radiation therapy bunker has no primary barriers; all barriers are considered secondary [4].

This project seeks to evaluate the effectiveness of the radiation shielding of the radiation therapy department of the facility by means of weekly and instantaneous dose rate measurements. These will be done with the utilization of an ionization chamber.

In addition, the project also encompasses comparisons of the structural shielding from the time of commissioning of the machinery to present day; in an effort to assess the impacts of these changes (in equipment) on the structural shielding barriers of the facility [5]. Together with that, the researcher aims at assessing the attenuation coefficients of each shielding barrier, via the tenth value layer of the existing shielding material of the barriers (concrete) and making an overall comparison of the results gained from these existing measurements to the international standards governing radiation protection in radiotherapy [6].

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Experimental Materials

In carrying out the research, an ionizing chamber was utilized to measure instantaneous dose rates (2,3,5). This was done as a volumetric measurement (Figure 1).

Model: 451B-RYR

Geometry: Perpendicular

Error: <= 10%

Last Calibration Date: 2016/03/24

Barriers

Primary barriers (Walls A and B): Although these barriers are secondary in nature, because of the direct incidence of the beam at angles 90 and 270 degrees, they have been taken as primary barriers throughout the project. Therefore, they have been involved in measurements intended for both primary and secondary barriers. All measurements for these barriers were made without a phantom (Table 1).

Secondary barriers

These are barriers that do not receive the direct incidence of the primary beam of the linear accelerator. Measurements at these barriers were done with a phantom that has the same electron density of a patient in an attempt to estimate the scatter from a patient [7].

Figure 1: Instrument Name: Fluke Biomedical Ionization Chamber.

Measurements

Parameters used in Calculations											
Barrier	Design Dose Limit (P) (mSv/ week)	Distance from Scattering Wall to Point of Interest (m) D2	Distance from Isocenter to Scattering Wall (m)	d (D1+D2) (m)	SAD (m)	Field Area Projected on Wall (cm2)	Workload (W) (µGy/ week)	Use Factor (U)	Occupancy Factor (T)	Scattering Angle	Reflection Coefficient (α)
Dose at Maze Entrance	0.4	0.305	4.2	4.505	1	1600	1.00E+06	1	1	-	-
Wall A'	0.02	0.305	4.2	4.505	1	1600	1.00E+06	0.25	0.125	30	2.77E-03
Wall A"	0.02	0.305	4.2	4.505	1	1600	1.00E+06	0.25	0.125	30	2.77E-03
Wall B'	0.02	0.305	4.2	4.505	1	1600	1.00E+06	0.25	0.125	30	2.77E-03
Wall B"	0.02	0.305	4.2	4.505	1	1600	1.00E+06	0.25	0.125	30	2.77E-03
Wall C	0.02	0.305	4.2	4.505	1	1600	1.00E+06	1	0.125	90	4.26E-04
Wall D	0.4	0.305	4.145	4.45	1	1600	1.00E+06	1	1	90	4.26E-04
Wall E	0.02	0.305	6.26	6.565	1	1600	1.00E+06	1	1	45	1.39E-03

Table 1: Table showing parameters used in calculations (Excerpted from CIG Commissioning Report of 2012).

The formulae and parameters used for each calculation were extracted from the IAEA Safety Report No. 47. The measurements done were:

Barrier required attenuation, This calculation determines how much radiation should be attenuated by the barrier in order to effectively reduce the intensity of the radiation beam and consequently, the barrier thickness required. This was done using the formula, B=Px (d

+SAD)2/WUT, where P is the Design Dose Limit, d is the distance from the source to the point beyond the barrier and the SAD is the source to axis distance. The figures were extracted from the Institute's Commissioning Report of 2012.

Instantaneous Dose Rate (IDR), which is the direct reading of the surveymeter in dose per hour, averaged over one minute [8,9]. The instantaneous measurement was made with the Fluke Biomedical Ionization Chamber. The results were taken as an average of the highest and least reading over the area surveyed. The calculated IDR was also done for comparative analysis with the instantaneous measurements. The formula utilized was: IDR= (DR0 × B)/ (d+SAD) 2, where DR0 is the dose output rate, 150 Gy/h, of the LINAC, B is the Barrier attenuation, d is the distance from the source to the point of measurement and SAD is the Source to Axis Distance, 1 m [10]. The Time Averaged Dose Rate (TADR), which is the barrier attenuated dose equivalent rate averaged over a specified time or period of operation of the linear accelerator. This calculation was done using the formula, R8={IDR x [(WdU)/(8 × DR0)]}, which utilized the IDR measurements and incorporated the Workload (W) and Use Factor (U) of the LINAC. This was done for a period of 8 working hours, with a workload of 20 patients at 2 Gy each [11-14].

Weekly dose rate, this is an accumulated measurement for the purpose of comparison with the daily TADR. This calculation was done for an accumulation of 5 days using the daily TADR for each barrier (DRW=TADR × 5). Tenth value layers and barrier thickness, the Tenth-value layer refers to the thickness that is required to reduce the intensity of a radiation beam by one-tenth its original value. The tenth value layer in this research was calculated using the required barrier attenuation values on the logarithmic scale for each barrier [15].

Barrier transmission when primary beam strikes a wall and scatter from patient. This calculation was done to verify if the barriers conform to the International Standards stipulated in the IAEA's safety report Series No. 47 relating to scatter radiation; "the radiation scattered by a patient or phantom is usually less than 0.1% of the incident radiation per 0.1 m^2 area irradiated". This was done using the formulae, Bw=Pd2wd2r/αAWUT and BP=Pd2 scad 2 sec/αWT (F/400), for wall and patient respectively; where α is the scatter fraction for the walls and reflection co-efficient for patient; F is the field size. Consequently, the percentage scatter was derived by dividing the scatter from the wall and patient and then dividing that value by the dose output rate of the LINAC before multiplying by 100 [16]. The IDR measurements were taken at a distance 30 cm beyond the barriers with the field size of the linear accelerator at its maximum, 40 cm × 40 cm (Figure 2).

Results with analysis

From the measurements made and calculations done, all results present findings that annotate the effectiveness of the structural shielding barriers of the radiation therapy facility based on recommended standards by the NCRP Report 151.

The required barrier attenuation

Calculations showed that the barriers that required the highest attenuation were walls A and B together with their complements. The reason being these walls received the direct incidence of the photon beam [17].

Wall E, on the other requires the least as a result of its distance from the source and its addition shield from Wall D (Figure 3).

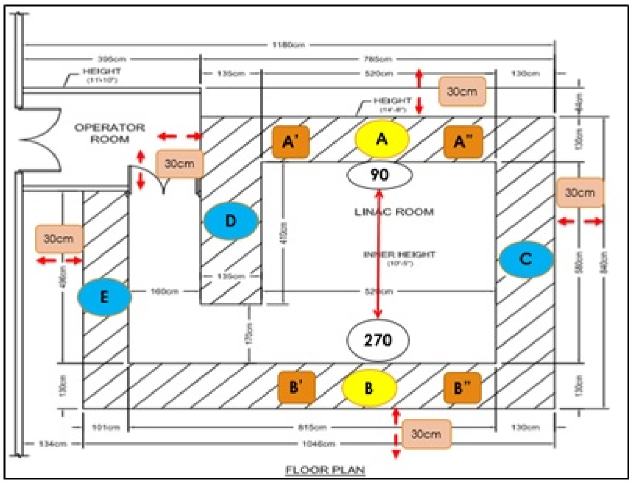

Figure 2: Figure showing floor plan of radiation therapy bunker with barriers and points of measurements.

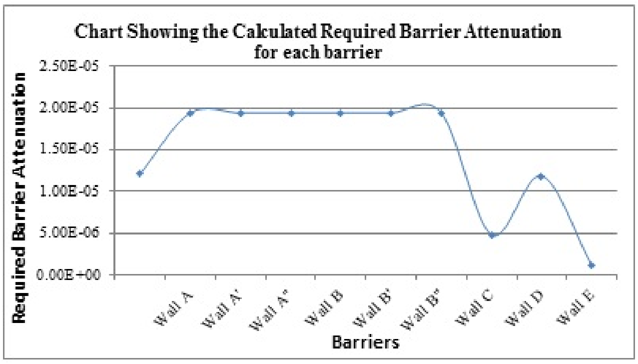

Figure 3: Chart showing required barrier attenuation for each barrier.

Instantaneous dose rates

From the comparison of the measured Instantaneous dose rate with the calculated Instantaneous Dose rates, it was observed that the direct dose rate measurements were significantly below the expected or calculated readings.

The elevated measurements at Walls A and B are due to the direct incidence of the beam. All other barrier measurements were done with the use of a water phantom. This annotates that the barriers are effective in their ability to attenuate the radiation emitted [18-20].

From the results gathered, it was observed that the highest readings were obtained at the Maze Entrance and at Wall D at 2 Sv/h each while the Barriers A through C displayed consistent results of 0.8 Sv/h and Wall E, with the least, 0.1 Sv/h. The consistency in results for Walls A through C could be attributed to the equidistance from the radiation source (Figure 4).

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The elevated Maze Entrance calculation relates to an accumulated dose from scatter. On the other hand, the corresponding Wall D, has a matching result due to its close proximity to the source of the LINAC in relation to the other barriers. This elevated result at Wall D is also reflective of the reading at Wall E, which displayed the lowest TADR. Wall D is situated in such a way that it shields Wall E by almost 66% in area and eliminates approximately 95% of the radiation intended for Wall E. Together with that, it is closer to the LINAC by 160 cm than Wall E (Figure 5).

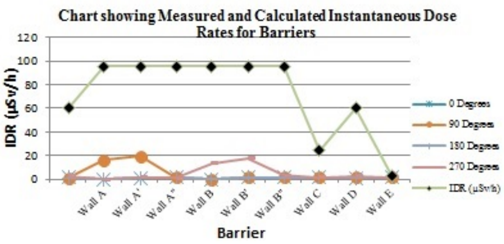

Figure 4: Chart showing comparison of Direct Instantaneous Dose Rate which are Calculated from Instantaneous Dose Rate vs Time Averaged Dose Rate.

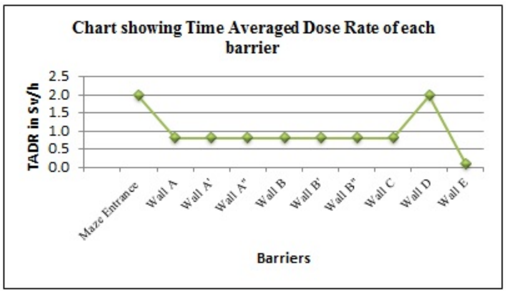

Figure 5: Chart showing calculated Daily TADR.

Weekly dose rate

The Weekly Dose Rate was calculated by multiplying the TADR by 5 working days per week (Figure 6). Hence the reasons for the consistent and elevated results for the respective barrier remain the same as that of the Time Averaged Dose Rate.

Tenth value layer and barrier thickness

From the values obtained through the calculations, it was observed that the Barriers' A, A', A", B, B' and B" were consistent in values while Walls C, D, E and the Maze Entrance displayed higher results of 5.31, 4.93, 5.94 and 4.92 respectively. This is because of the Occupancy factors beyond each of these barriers [21].

Wall D, Maze Entrance and Wall E have an occupancy factor of one since they border the Control Panel, the washroom and adjacent waiting area, respectively.

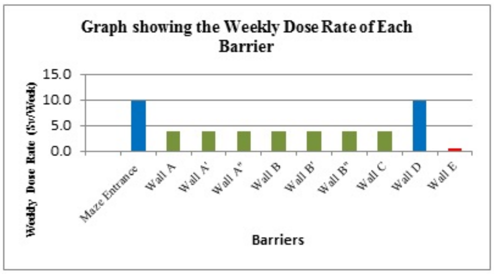

Figure 6: Chart showing Weekly Dose Rate of the Barriers.

From the tenth value layers, calculations for the barrier thickness for each barrier were made via multiplication with the shielding material's (concrete) tenth value layer, 33 (NCRP Report 151, (Figure 7). The calculated results were elevated as compared to the existing values of the facility's barriers, which were quoted from the Institute's Commissioning Report.

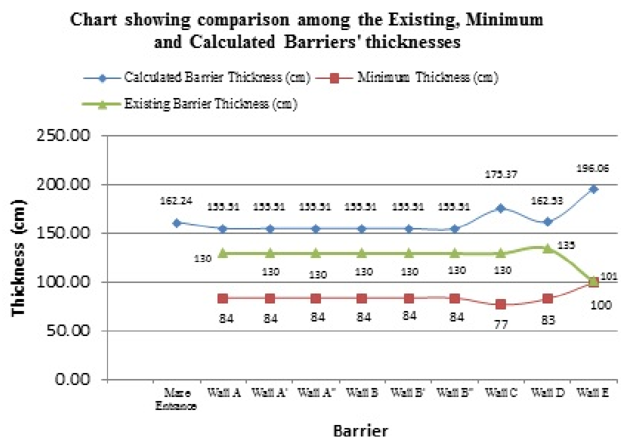

Figure 7: Figure showing comparisons of the minimum, existing and calculated the thicknesses of each barrier.

There was also a correlation in the calculated Barrier thicknesses for the Maze Entrance and Wall D. These form two borders of the Control panel as well as the Maze.

On the other hand, the calculated thickness for Wall E was the highest. This escalation was also recorded for the Minimum thickness required for the aforementioned barrier. However, in the Commissioning Report, the thickness value for this barrier is represented as the lowest.

One possible reason for this could be the occupancy factor which is greater there (T=1), as it relates to neighbouring washrooms, waiting area and hall.

Together with that, one reason for the overall elevated thicknesses of the barriers as compared to the existing thicknesses is the use of maximum intensity and fluence of the beam. In this project, measurements were taken with the field size set at its maximum, 40 cm x 40 cm; however, in any therapy procedure, the beam is collimated precisely to the target site of the patient. Hence, with the utilization of maximum intensity of the beam, the thickness of the barriers would increase accordingly.

In addition, using the parameter at maximum value makes the assumption that the initial intensity of the beam would be the same beyond the barriers, without any interaction with matter. This is a phenomenon that is impossible. Hence, this is another factor that is responsible for the elevated barrier thicknesses.

Barrier transmission when primary beam strikes a wall and scatter from patient

The International Protocol, as per IAEA Safety Report Series No. 47, states that the radiation scattered by a patient or phantom is usually less than 0.1% of the incident radiation per 0.1 m^2 area irradiated. This research did not encompass patient exposures; however an improvised phantom was utilized as a patient.

From the calculations done to find the amount of scatter radiation obtained from the barriers, it was observed that Wall D displayed the highest result of 0.93 μSv and Wall E recorded the least at 0.03 μSv since the majority of the scatter would've already been attenuated by the intercepting Wall D. In addition, this reading for Wall E is only accountable for the scatter transmitted along the 170 cm pathway to the barrier [22].

Walls A', A", B' and B" were consistent in their results, 0.237 μSv.

In terms of the percentage scatter per 0.1 m^2 irradiated on each barrier, none of barriers had an excess of the stipulated protocol of 0.1%.

Patient scatter

From the simulated calculations done for scatter from patient beyond the barrier, it was observed that the percentage scatter obtained for each barrier, with the exception of Wall D, corresponded to the stipulated standard of the IAEA Report No 47, by being below 0.1% of the primary beam.

This elevated result could be as a result of Wall D's close proximity to the source and an additional result from the maze as well. Together with that, this simulation was done using a phantom with the field size at its maximum (1600 cm^2) and this is never done in an actual procedure since the beam is collimated to the target site on the patient.

Recommendations

- Constant Monitoring of Equivalent Dose by Linear Accelerator
- Monitoring the Dose Equivalent ensures that the facility complies with the national and international standards.
- Annual Radiometric Survey to evaluate Structural Integrity of shielding barriers
- Having an annual radiometric survey to evaluate structural engineering aims at assessing the structural integrity of the structural barriers, especially in the event of earthquakes which can compromise the barriers by facilitating leakage radiation beyond the structural barriers
- Regular workshops for all those (in)directly associated with radiation therapy (for regular and unusual situations)

Workshops or any other form of on-going education for those (in)directly associated with the radiation therapy should be done to better equip the team with new developments in the field as well as having a revision of those procedures already established. This aims at having them better informed thus providing the scope to work at one level, hence minimizing accidents.

Conclusions

With this LINAC, which has a retractable beam-stopper, all barriers are considered secondary since the average transmission of the primary beam through the beam-shield does not exceed 0.1%. However, Walls A and B, are, per se, considered primary due to the direct incidence of the beam at gantry angles 900 and 2700, respectively.

In conclusion, all measurements gathered annotate the effectiveness of the radiation shielding barriers. The comparison of the direct Instantaneous Dose rates (IDR) to the calculated instantaneous dose rate of the barriers was significantly different. The Direct Readings obtained from the survey meter 0.3 m beyond each barrier were well below the calculated IDR, which annotates that the barriers are effective.

The Weekly Dose Rate, on the other hand, was calculated using the Time Averaged Dose rate over a period of five working days. These were also low.

The calculated barrier thicknesses, however, surpassed the existing thicknesses as quoted in the Institute's Commissioning Report. The reason for the elevation was the use of the primary beam at maximum intensity.

Lastly, the scattered radiation for each barrier when the radiation beam strikes a wall and from patient conform with the IAEA standard of being less than 0.1% of the 0.1 m^2 area irradiated.

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