2021 International Nuclear Atlantic Conference - INAC 2021
Virtual meeting, Brazil, November 29 - December 2, 2021

ISBN: 978-65-594-1256-3

On methods for radiometric surveying in radiotherapy bunkers

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1. Introduction

Radiometric surveys in radiotherapy bunkers, have been carried out in the country for many years, both by the same radiotherapy services for verification of shielding as by the regulatory agency for licensing and control purposes. In recent years, the IMRT technique has been gradually incorporated into many services. Therefore, it has been necessary to consider the increased leakage component that has an important impact on the secondary walls. For that, a radiometric survey method has been used that considers an increased "time of beam - on"for the secondary walls. In this work we discuss two methods of doing this: the first considers that this "time of beam - on"affects the sum of the two components, leakage and scattered. In another method it is considered that only the leakage component is affected by this extended "time of beam - on ". We compare the methods and show that for secondary walls with $U = 1$ the first method overestimates dose rates by important percentages and for secondary walls with $U < 1$ it can both overestimate or underestimate the dose rates, depending on the parameters of the project.

2. Methodology

Consider a secondary barrier. The total instantaneous dose-equivalent rate I_T $[\frac{Sv}{h}]$, with the machine operating at the absorbed-dose output rate $\dot{D}_o$, measured $30\,cm$ beyond the secondary barrier, is composed both by leakage $I_L[\frac{Sv}{h}]$ and patient-scattered radiation I_{ps} $[\frac{Sv}{h}]$:

$$I_T = I_L + I_{ps} \qquad (1)$$

It is possible to measure I_T (with phantom) and I_L (without Phantom and with closed collimator)

Then I_{ps} will be given by:

$$I_{ps} = I_T - I_L \qquad (2)$$

Now the total weakly dose-equivalent rate, $R\ [\frac{Sv}{h}]$, for primary-barrier weekly workload $W\ [\frac{Gy}{week}]$, leakage-radiation workload $W_L\ [\frac{Gy}{week}]$ and being the occupation factor T, is

$$R = \left\{ I_L \frac{W_L}{\dot{D}_o} + (I_T - I_L) \frac{W}{\dot{D}_o} \right\} T \tag{3}$$

For the case of a secondary barrier adjacent to a primary barrier, an use factor U in the scattered component, will be used:

$$R = \left\{ I_L \frac{W_L}{\dot{D}_o} + (I_T - I_L) \frac{W\ U}{\dot{D}_o} \right\} T \tag{4}$$

where $\dot{D}_o \equiv$ absorbed-dose output rate at $1\,m$ in $[\frac{Gy}{h}]$

being $\dot{D}_o = \dot{D}_n.60\frac{min}{h}$ where D_n = absorbed-dose output rate at $1\,m$ in $[\frac{Gy}{min}]$.

Each measure will be given by a reading (L (leakage) and L_T (total)) and the Natural Background (L_{BG}), so that the equation (4) can be written as

Method 2 (new)

$$R = \left\{ (L - L_{BG}) \frac{W_L}{\dot{D}_o} + (L_T - L) \frac{W\ U}{\dot{D}_o} \right\} T \tag{5}$$

Note that

$$\frac{W}{\dot{D}_o} = \frac{W}{\dot{D}_n.60\frac{min}{h}} \equiv t_{beam\,on} \ \ in\,[\frac{h}{week}]\ and\ we\ call\ it\ t_{bo} \tag{6}$$

and

$$\frac{W_L}{\dot{D}_o} = \frac{W}{\dot{D}_n.60\frac{min}{h}} \equiv t_{beam\,on-IMRT} \ \ in\,[\frac{h}{week}]\ and\ we\ call\ it\ t_L\ . \tag{7}$$

so we can write

$$R = \{(L - L_{BG})\ t_L + (L_T - L)\ U\ t_{bo}\} T \tag{8}$$

Method 1 (Standard historical method)

Let's call R' to the total weakly dose-equivalent rate measured with this method, which is obtained in general according to:

$$R' = (L_T - L_{BG})\frac{W_L}{\dot{D}_o}\,U\,T \tag{9}$$

or using that

$$\frac{W_L}{\dot{D}_o} = \frac{W}{\dot{D}_n.60\frac{min}{h}} \equiv t_{beam\,on-IMRT}\;\; in\,[\frac{h}{week}]\;and\;we\;call\;it\;t_L\;. \tag{10}$$

$$R' = (L_T - L_{BG})\,U\,T\,t_L \tag{11}$$

or using that:

$$L_T = L + L_T - L \tag{12}$$

$$R' = \{(L - L_{BG})\;U\;t_L + (L_T - L)\;U\;t_L\}\,T \tag{13}$$

In order to compare we write again the two equations (13) and (8) together

$$R = \{(L - L_{BG})\;t_L + (L_T - L)\;U\;t_{bo}\}\,T \qquad "new" \tag{14}$$

$$R' = \{(L - L_{BG})\;U\;t_L + (L_T - L)\;U\;t_L\}\,T \qquad "old" \tag{15}$$

The correct equation is (14) since it is deducted from theory. Then we can notice in equation (15) two problems: the scattered component (the second term) is multiplied by t_L instead of t_{bo} and the leakage component (the first term) is affected by the use factor U even if it is different from 1 (we know that the leakage radiation is always present for any Gantry orientation: U = 1). Then there will be differences in measuring dose rates according to one method or another. To analyze these differences we are going to consider two situations: the first is when the use factor of the secondary wall is the unit $U = 1$ and the second when $U < 1$.

a)Situation $U = 1$.

From Eqs. (14) and (15), making $U = 1$, we have

$$R' - R = (L_T - L)\;(t_L - t_{bo})\;T \tag{16}$$

Since on the Right Side of this equation each factor is positive, we have $R' - R$ is always positive

$$R' - R = (L_T - L)\ (t_L - t_{bo})\ T > 0 \tag{17}$$

This already is an indication that the old method, in this situation, super-estimates the doses.

Let's calculate the relative excess $\frac{R'-R}{R}$. From Eqs. (16) and (14) we obtain:

$$\frac{R' - R}{R} = \frac{t_L - t_{bo}}{\frac{L-L_{BG}}{L_T-L}\, t_L + t_{bo}}\,. \tag{18}$$

b)Situation $U < 1$.

From Eqs. (14) and (15) we obtain

$$R' - R = \{(L - L_f)\,(U - 1)\,t_L\ +\ (L_T - L)\,U\,(t_L - t_{bo})\} \tag{19}$$

Investigating the sign of $R' - R$ found two cases:

Case b1)

$$R' - R \geq 0 \Longleftrightarrow \tag{20}$$

$$\frac{L_T - L}{L - L_f} \geq \frac{1 - U}{U} \cdot \frac{t_L}{t_L - t_{bo}} \tag{21}$$

or

$$\frac{Scattered}{Leakage - BG} \geq \frac{1 - U}{U} \cdot \frac{t_L}{t_L - t_{bo}} \tag{22}$$

Case b2)

$$R' - R < 0 \Longleftrightarrow \tag{23}$$

$$\frac{L_T - L}{L - L_f} < \frac{1 - U}{U} \cdot \frac{t_L}{t_L - t_{bo}} \tag{24}$$

or

$$\frac{Scattered}{Leakage - BG} < \frac{1-U}{U} \cdot \frac{t_L}{t_L - t_{bo}} \tag{25}$$

Eq. (21) or (22) gives the conditions for $R' - R \geq 0$ i.e. R' super-estimate doses. Eq. (24) or (25) gives the conditions for $R' - R < 0$ i.e. R' under-estimate doses.

For the relative difference we obtain:

$$\frac{R' - R}{R} = \frac{(U-1)t_L + \frac{L_T - L}{L - L_{BG}} U (t_L - t_{bo})}{t_L + \frac{L_T - L}{L - L_{BG}} U t_{bo}} . \tag{26}$$

Our methodology is to particularize the situations and cases found, for concrete examples with real values of parameters and verify them experimentally.

Situation a) U=1

a1) For an AL of 6 MV with primary workload $W = 1000\frac{Gy}{week}$ and secondary IMRT leakage load $W_L = 1625\frac{Gy}{week}$ and in a nominal absorbed-dose output rate $\dot{D}_o = 210\frac{Gy}{h}$ we have:

$$t_{bo} = \frac{1000\frac{Gy}{week}}{210\frac{Gy}{h}} \cong 4,76\frac{h}{week} \tag{27}$$

$$t_L = \frac{1625\frac{Gy}{week}}{210\frac{Gy}{h}} \cong 7,74\frac{h}{week} \tag{28}$$

Measures with Ionization chamber Ludlum 9DP serial number 25018216, we obtained for secondary wall Roof with $T = \frac{1}{40}$:

$L_T = 17,2\frac{\mu Sv}{h}$

$L = 1,4\frac{\mu Sv}{h}$

$L_{BG} = 1,4\frac{\mu Sv}{h}$

Then from Eqs. (16) and (18) we have

$$R' - R = (17,2\frac{\mu Sv}{h} - 1,4\frac{\mu Sv}{h})(7,74\frac{h}{week} - 4,76\frac{h}{week})\frac{1}{40} = 1,178\frac{\mu Sv}{week} \tag{29}$$

$$\frac{R' - R}{R} = \frac{t_L - t_{bo}}{\frac{L - L_f}{L_T - L} t_L + t_{bo}} = \frac{7,74\frac{h}{week} - 4,76\frac{h}{week}}{\frac{1,4\frac{\mu Sv}{h} - 1,4\frac{\mu Sv}{h}}{17,2\frac{\mu Sv}{h} - 1,4\frac{\mu Sv}{h}} 7,74\frac{h}{week} + 4,76\frac{h}{week}} \cong 0,63 \tag{30}$$

It means

$$R' \cong 1,63R \tag{31}$$

the old method is giving a 63 % excess for this wall.

a2) For an AL of 10 MV with primary workload $W = 1200\frac{Gy}{week}$ and secondary IMRT leakage load $W_L = 3600\frac{Gy}{week}$ and in a nominal absorbed-dose output rate $\dot{D}_o = 360\frac{Gy}{h}$ we have:

$$t_{bo} = \frac{1200\frac{Gy}{week}}{360\frac{Gy}{h}} = \frac{10}{3}\frac{h}{week} cong\ 3,33\frac{h}{week} \tag{32}$$

$$t_L = \frac{3200\frac{Gy}{week}}{360\frac{Gy}{h}} \cong 10\frac{h}{week} \tag{33}$$

Measures with Ionization chamber Ludlum 9DP serial number 25009347, we obtained for the Door with $T = \frac{1}{8}$:

$L_T = 16,0\frac{\mu Sv}{h}$

$L = 1,4\frac{\mu Sv}{h}$

$L_{BG} = 0,01\frac{\mu Sv}{h}$

Then from Eqs. (16) and (18) we have

$$R' - R = (14,6\frac{\mu Sv}{h} - 1,4\frac{\mu Sv}{h})(10\frac{h}{week} - \frac{10}{3}\frac{h}{week})\frac{1}{8} \cong 12,17\frac{\mu Sv}{week} \tag{34}$$

$$\frac{R' - R}{R} = \frac{t_L - t_{bo}}{\frac{L-L_f}{L_T-L}t_L + t_{bo}} = \frac{10\frac{h}{week} - \frac{10}{3}\frac{h}{week}}{\frac{1,4\frac{\mu Sv}{h} - 0,01\frac{\mu Sv}{h}}{16,0\frac{\mu Sv}{h} - 1,4\frac{\mu Sv}{h}}10\frac{h}{week} + \frac{10}{3}\frac{h}{week}} \cong 1,56 \tag{35}$$

It means

$$R' \cong 2,56R \tag{36}$$

the old method is giving a 156 % excess for the door.

Situation b) U< 1

For an AL of 10 MV with primary workload $W = 1200\frac{Gy}{week}$ and secondary IMRT leakage load $W_L = 3600\frac{Gy}{week}$ and in a nominal absorbed-dose output rate $\dot{D}_o = 360\frac{Gy}{h}$ we have:

Comand, secondary wall, $U = \frac{1}{5}$ for scattered component.

$$\frac{1-U}{U} \cdot \frac{t_L}{t_L - t_{bo}} = \frac{1-\frac{1}{5}}{\frac{1}{5}} \cdot \frac{10}{10-\frac{10}{3}} = 6 \tag{37}$$

$L_T = 6,30\frac{\mu Sv}{h}$

$L = 4,30\frac{\mu Sv}{h}$

$L_{BG} = 1,37\frac{\mu Sv}{h}$

Then:

$$\frac{Scattered}{Leakage - BG} = \frac{L_T - L}{L - L_{BG}} = 0,683 \tag{38}$$

So, because $0,683 < 6$, it is verified that

$$\frac{Scattered}{Leakage - BG} < \frac{1-U}{U} \cdot \frac{t_L}{t_L - t_{bo}} = 6 \tag{39}$$

Then, we are in the case b2) which means $R' - R < 0$ i.e. R' is underestimating doses.

It is obtained

$$\frac{R' - R}{R} = -0,678 \tag{40}$$

so

$$R' = R - 0,678\,R = 0,322\,R \tag{41}$$

The old method underestimates in $\cong$ 68 %

3. Results and Discussion

We can say that, from the theoretical point of view, the old method for measuring secondary walls is not strictly correct. Based on the analysis and the examples we have presented, we may notice that when the old method super-estimates, maybe it can still be used to provide a higher level for dose rates, as long as it does not exceed the limits (legal and project goal). But when the old method underestimates dose, you have to be careful because it is dangerous. One way to work would be the following: situation $U = 1$: the "hot"points obtained with the old method must be verified with the new one. Situation $U < 1$ "'superstimative"' case: the same as the case $U = 1$. Situation $U < 1$ "'underestimative"' case: discard it and use the new method.

Here you show your results in a compact fashion and give a brief discussion.

4. Conclusions

We have compared two methods to perform radiometric surveys in linear accelerator radiotherapy services that use IMRT technique. One, the "old"method, employs an adapted formula of the period prior to IMRT technique and is widely used in all radiotherapy services with AL. The "new"method uses a formula that is deducted from the theory of structural shielding for IMRT. We found that for secondary walls there are differences: if the secondary wall is "pure"($U = 1$) the old method super estimate the doses. If the secondary wall is not "pure"($U < 1$) the old method can both superestimate or underestimate. We have made some measurements that preliminary verify these conclusions.

Acknowledgments

We thank CNEN/CGMI / MCTI-Brazil for technical support and to all the country's radiotherapy services that kindly have allowed us to make some measurements.

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