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Survey of Radiation Shielding Design Goals and Workload Based on Radiation Safety Report: Tomotherapy Vault

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The purpose of this study was to perform a survey of the radiation shielding design goals (*P*) and workload (*W*) based on the radiation safety reports concerned with structural shielding design for the IMRT treatment technique in Tomotherapy vaults. The values of the *P* and *W* factors as well as of a verified concrete thickness of the ceiling, bottom, sidewalls (sidewall-1 and sidewall-2), and door have been obtained from radiation safety reports for a total of 16 out of 20 vaults. The recommended and most widely used report for *P* values was the NCRP No. 151 report, which stated that the *P* factor in controlled and uncontrolled areas was 0.1 and 0.02 mSv/week, respectively. The range of the *W* factor was 600~14,720 Gy/week. The absorbed dose delivered per patient was 2~3 Gy. The maximum number of patients treated per day was 10~70. The quality assurance (QA) dose was 100~1,000 Gy/week. Fifteen values of the IMRT factor (*F*) were mostly used but a maximum of 20 values was also used. The concrete thickness for primary structures including the ceiling, bottom, sidewalls, and door was sufficient for radiation shielding. The *P* and *W* factors affect the calculation of the structural shielding design, and several parameters, such as the *absorbed dose*, *patients*, *QA dose*, *days* and *F* factor can be varied according to the type of shielding structure. To ensure the safety of the radiation shielding, it is necessary to use the NCRP No. 151 report for the standard recommendation values.

Keywords: Radiation Shielding, Workload, NCRP-151, Tomotherapy

Introduction

In radiation therapy with high energy, radiation shielding could be considered radiation exposure to members of the public and employees to an acceptable level. In design and installation of structural shielding for megavoltage x-ray radiotherapy facilities, the National Council on Radiation Protection and Measurements' (NCRP) has been refer to recommendation reports. NCRP Report No. 151 (2005) is one of the most suitable documents for structural shielding design and calculation in radiotherapy facilities.[1)]

Increasing frequency of the IMRT techniques affects for radiation shielding. It is important shielding design through verification of radiation shielding calculation in terms of the radiation protection, such as the radiation exposure to pubic and employees when either vault installs or changed situations. The recommend report for the shielding design was mostly used the NCRP No. 151 report that the shielding design goals (P), levels of dose equivalent (H) in controlled and uncontrolled areas was 0.1 and 0.02 mSv/week, respectively.[1)]

Using Tomotherapy vault can be applying the intensity-modulated radiation therapy (IMRT) method with optimization treatment planning and delivery of dose gradient, and as well as the three-dimensional conventional radiotherapy (3D-CRT) by Tomo-Direct modes, which are CRT and static IMRT techniques. Also, Tomotherapy is different in comparison with conventional linear accelerator (LINAC) concerned with radiation delivery type that treatment is usually delivered with 360-degree rotation of the 6-megavolta LINAC gantry.[2,3)] Therefore, the primary beam, though reduced in width and intercepted by a beam-stop opposite the patient, rotates around the patient many times including many more monitor units (MU) than centigrays (cGy) delivered to the iso-center.[1)] It is associated with both magnitude of MU value and barriers thickness concern with the P, primary beam, and secondary beam including leakage- and scatter-radiation. In addition, value of the P factor can be changing either controlled area or uncontrolled area for shielding calculation.

A few of research reported shielding design for Tomotherapyvault.[4-6)] Robinson et al.[5)] reported that primary beam shield is both reduced in width by a factor of almost 10 and increased in thickness by more than a tenth value layer (TVL) in comparison to a conventional accelerator. Baloget et al.[4)] evaluated leakage radiation and shielding considerations, and reported that leakage dose the patient would receive in the course of a treatment concerned with the effect of forward-directed leakage through the beam-collimation system. In general, it is necessary that reevaluation of the shielding structural design for new installation or upgraded existing equipment. Zacariaset et al.[6)] studied shielding design of the new facility at the James Brown Cancer Center.

Assessment of structural shielding is important in terms of radiation protection and operation when uses it. The purpose of this study was to performed survey study for the P and W factor based on radiation safety reports concerned with structural shielding design for IMRT treatment technique by Tomotherapy vault.

Materials and Methods

1. Shielding design goals and workload

We collected radiation safety reports from twelve institutions, and analyzed value of P and W for a Tomotherapy vault. The units for W are Gy/week and conversion to a workload W_2 at a distance d_2 different than 1 m would be $W_2=W\,(1\text{ m})^2/(d_2)^2$.[1)] The calculation method for conventional weekly W used by using:

$$Workload\,(W) = (Absorbed\ dose \times Patients \times Days \times F\ \ factor) + QA \quad (1)$$

Where the *absorbed dose* is absorbed dose delivered per patient (Gy/fraction). *Patients* is maximum number of patients (or fields) treated per day. *Days* are operation days per week (day/week), which is mostly used 5. F factor is IMRT factor. The *quality assurance* (QA) is dose for the test and dosimetry procedure (Gy/week).

2. Verification shielding structural

We additionally verified the barrier thickness of a few of areas through the radiation safety reports. Four areas (ceiling, bottom, two sidewalls (1 and 2), and door) were determined according to the design map for each institution, and were reevaluated a difference (%) of barrier thickness in comparison with recommend and current thickness based on the radiation safety reports.

Results

1. Radiation safety report

We performed survey of reports to obtain data for shielding information in Tomotherapy facilities. A total of twelve institutions including number of sixteen Tomotherapy vaults were evaluated for the structural shielding calculation such as the shielding design goals, workload and optimum barrier thickness in the ceiling, bottom, sidewalls (1 and 2), and door based on the radiation safety reports for each facility.

2. Radiation shielding design goals

Table 1 shows a radiation shielding design goals (mSv/week) for control and controlled and uncontrolled areas, as well as recommendations and technical information. Vault 6 and 9 were not confirmed recommendations. A total of five vaults were to be applied the NCRP No. 151 report. Three vaults were to be applied the NCRP No. 49 and 51 report.[7,8] Another six vaults (No. 1, 2, 4, 7, 8, and 15) were to be applied the technical information by the Ministry of Education (ME) in the South Korea.

3. Workload

Table 2 shows the value of workload for sixteen vaults. The range of *W* factor was 600~14,720 Gy/week. The absorbed dose delivered per patient was 2~3 Gy. The average of maximum number of patients treated per day was 33, and range was 10~70. The average of QA or dosimetry dose was 420 Gy/week, and range was 100~1,000 Gy/week with excluding vault No 2. Lastly, The *F* factor was mostly used 15 values and maximum was 20 values (no data in Table).

Table 1. Recommendations of the radiation shielding design goals with reference.

No.	Radiation shielding design goals (mSv/week)		Recommendation
	Controlled areas	Uncontrolled areas	
1	0.4	0.02	ME
2	0.4	0.02	ME
3	0.4	0.1	NCRP No. 49 and 51
4	0.4	0.02	ME
5	0.4	0.1	NCRP No. 49 and 51
6	0.4	0.02	-
7	0.4	0.1	ME
8	0.4	0.02	ME
9	0.3	0.1	-
10	0.4	0.1	NCRP No. 49 and 51
11	0.1	0.02	NCRP No. 151
12	0.1	0.02	NCRP No. 151
13	0.1	0.02	NCRP No. 151
14	0.1	0.02	NCRP No. 151
15	0.4	0.02	ME
16	0.1	0.02	NCRP No. 151

ME: Ministry of Education, NCRP: National Council on Radiation Protection and Measurements.

4. Verification shielding structural

The concrete thickness for primary structures including the ceiling, bottom, sidewalls (1 and 2), and door was satisfactory for radiation shielding in this study. For a difference (%) of the ceiling, maximum (minimum) value was 67.2% (0.4%), and five vaults were excluded evaluation for the primary beam. In bottom, maximum

Table 2. Workload values with determined parameters for sixteen Tomotherapy vaults.

No.	Absorbed dose (Gy)	Patient (No.)	QA dose (Gy/week)	Days	Workload (Gy/week)
1	2.5	70	720	5	14,720
2	2.2	50	0	5	880
3	3	60	100	5	1,000
4	2	20	500	5	3,500
5	2	10	200	5	600
6	2.5	20	1,000	5	6,000
7	3	20	500	5	5,000
8	2	30	500	5	3,500
9	2.5	20	250	5	10,000
10	3	20	500	5	5,000
11	3	40	500	5	9,500
12	3	40	500	5	9,500
13	3	40	500	5	9,500
14	3	40	500	5	9,500
15	2.5	20	250	5	10,000
16	3	20	200	5	4,700

Absorbed dose: Absorbed dose delivered per patient (or field), Patients: Maximum number of patients treated per day, Days: Operation days per week (day/week).

Table 3. Radiation shielding design goals according to recommendation reports in the controlled and uncontrolled areas.

Recommendation	Controlled areas (mSv/week)	Uncontrolled areas (mSv/week)
ICRP 60	0.4	0.02
AEL	1.0 (20 mSv/year)	0.1 (1 mSv/week)
ME	0.4	0.02
NCRP 49 (<10 MV)	0.4	0.1
NCRP 51 (>10 MV)	0.4	0.1
NCRP 151	0.1	0.02

ICRP: International Committee for Radioactivity Prevention, AEL: Atomic Energy Law (Thirteenth, 2014-34), ME: Ministry of Education, NCRP: National Council on Radiation Protection and Measurements.

(minimum) value was 88.0% (3.6%), and eleven vaults were excluded evaluation for the primary beam including the structure-foundation (six vaults). In sidewall-1, maximum (minimum) value was 78.3% (7.8%), and four vaults were excluded evaluation for the primary beam. In sidewall-2, maximum (minimum) value was 114.3% (9.4%), and six vaults were excluded evaluation for the primary beam. Lastly, maximum (minimum) value for a difference (%) of lead barrier thickness in the door was 18.6% (0.0%), and three vaults were excluded evaluation for the primary beam.

Discussion

We performed survey study for the structural shielding design (*P*) and workload (*W*) and installed a sixteen Tomotherapy vaults based on survey analysisthe radiation safety report. Our study was considered two categories in terms of parameters to determine the applied recommendation for shielding design goals and workload value and. We also verified concrete thickness for the ceiling, bottom, sidewalls (1 and 2), and door, which was conservatively evaluated for radiation shielding.

Table 3 shows value of the radiation shielding design goals for controlled and uncontrolled areas according to recommendation. For controlled areas, *P* factor of NCRP No. 151 recommendation is more conservative than No. 49 (or 51) and ME, as well as in uncontrolled areas. Several recommendations has different *P* factor. Determination of *P* factor must be considering before shielding in terms of the primary and secondary barrier thickness.

The *W* factor has changed according to each institution due to different location of vault, shielding structures, interest areas (controlled or uncontrolled), and estimated of treated patients before shielding. In *W* factor, variable factors are the *absorbed dose*, *patients*, *F* factor, and *QA* excluding *days*. Consequentially, it is unlikely to be able to discuss for magnitude of the *W* factor. However, we have described some important points in this study. It is no consistency of recording in the radiation safety report. We have assuming due to different company for shielding evaluation before installation. There is no problem for radiation shielding in terms of installation in each institution. And, it is discordance of applied *W* factor in barrier calculation for the primary and secondary beam. In vault No. 9 and 15, *W* factor applied in actual calculation for the barrier was 10,000 Gy/week, which was recommended value by Equipment Company. This value is very conservative. Here, calculated value of the *W* factor for both vaults was 4,000 Gy/week. Lastly, it is no consistency of *F* factor. Most vaults were used 15. There is no problem for shielding. However, we need to consider for reference value of *F* factor, which is value of 16, based on the radiation safety report installed vault in recent. This value is based on by Balog et al.,[4] which calculated by using follow formula: *MF*×*leaves*×*slicd width*. Here, an *MF* is the modulated factor as the maximum leaf open time divided by the average leaf open time. Average *MF* is 2.0. A *leaves* is average number of MLC leaves that open during treatment, which is 16 of the 64 leaves in typically. A slice width is size of primary beam for treatment, which is 2.5 cm (typical) versus 5.0 cm (maximum). Consequently, *F* factor of 16 is reasonable assumption for typical facility.[9]

In addition, Tomotherapy has beam stopper, which a primary-beam block consisting of 13-cm thick lead slabs on the ring gantry opposite the source supplies this.[4] Therefore, some institution did not evaluate radiation shielding for primary-beam (vaults: 7, 8, 9, 10 and 15). We need to check it more closely and will analyze this issue, shielding evaluation for the primary and secondary beam, in the future.

Conclusion

The *P* and *W* factor affects calculation of the structural shielding design, and can be varied several parameters, such as the *absorbed dose*, *patients*, *QA dose*, *days* and *F* factor according to type of shielding structure. To ensure safety of the radiation shielding, it is necessary to use NCRP No. 151 report as the standard recommendations.

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Conflicts of Interest

The authors have nothing to disclose.

Availability of Data and Materials

All relevant data are within the paper and its Supporting Information files.

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