

The Commissioning and Validation of Eclipse™ Treatment Planning System on a Varian VitalBeam™ Medical Linear Accelerator for Photon and Electron Beams

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Abstract

Purpose: Commissioning of a linear accelerator is a process of acquiring a set of data used for patient treatment. This article presents the beam data measurement results from the commissioning of a VitalBeam™ linac.

Materials and Methods: Dosimetric properties for 6,10, and 15 MV photon beams and 6, 9, 12, and 16 MeV electron beams have been performed. Parameters, including Percentage Depth Dose (PDD), depth dose profile, symmetry, flatness, quality index, output factors, and the vital data for Treatment Planning System (TPS) commissioning were measured. The imported data were checked by CIRS phantom accordingly to IAEA TRS-430, TECDOC. Eight different positions of CIRS phantom CT were planned and treated. Finally, the calculated dose at a determined position was compared with measuring data to TPS validation.

Results: After comparing 84 points in a different plan, the 83 points were in agreement with the criteria, and just for one point in 15 MV failed.

Conclusion: Commissioning of dose and field flatness and symmetry are in tolerance intervals given by Varian. This proves that the studied lines meet the specification and can be used in clinical practice with all available electron and photon energies.

Keywords: Radiotherapy; VitalBeam™ Linear Accelerator; Commissioning; Eclipse™ Treatment Planning System.

1. Introduction

Quality Assurance (QA) in Radiotherapy is all procedures that ensure consistency of the medical prescription, and safe fulfillment of that radiotherapy-related prescription. Acceptance tests and commissioning constitute a major part in this QA program for radiotherapy. Various national or international organizations have issued recommendations for standards in radiotherapy; owing to the financial deficit and limited staff confronting lack of commitment to QA by many institutions [1, 2].

The process of linac commissioning for clinical use is covering complete measurements of dosimetry parameters that are necessary to validate the treatment planning systems and treatment technique for patients. Moreover, the accuracy of commissioning data is vitally important due to being reference data for TPS and any error may induce poor radiation outcome [3].

The currently installed linac in Kerman Comprehensive Radiation Oncology Center (KCRC) is Varian Vital Beam™, which is the first of its kind for therapeutic use in Iran.

VitalBeam is a mid-cost high energy linac (Varian Medical System, Palo Alto, CA) that is more progressed than its former models. It contains two types of photon beams flattened filter and flattening filter-free beams, thicker primary collimator for steeper beam fall-off and anti-backscatter filter [4].

Forasmuch as its commissioning data was not obtained in Iran, we provided a summary of the mechanical and dosimetric properties of this new treatment unit and expected notably useful in the future. The objective of this work is the process of commissioning linac for clinical use and its validation. To achieve this aim, Task Group 106 of the Therapy Physics Committee of the American Association of Physicists in Medicine was formed to review the practical aspects as well as the physics of linear accelerator commissioning.

2. Materials and Methods

In this work, the Varian Vital Beam accelerator commissioning was performed and auditing was done for all energy modes. One of the latest generations of the linear accelerator is the Truebeam™ (Varian Medical Systems, Palo Alto, CA), pictured in Figure 1, which was

evaluated in this experimental study at KCRC in Afzalipour Hospital. The VitalBeam™ is a mid-cost linear accelerator model of Truebeam™ manufactured by Varian. This machine has specifications that include a high dose rate, several photon and electron modes, portal vision and equipped with the 120-leaf Multileaf Collimators (MLCs) design consisting of two opposing leaf banks (A&B) with leaves moved along the x-axis. Also, this unit is equipped with the facility of physical and dynamic wedges of standard wedge angles 15, 30, 45, and 60 for its photon mode.



Figure 1. CIRS phantom in the treatment room

2.1. Treatment Planning System

Eclipse™ treatment planning system (Varian Medical Systems, Palo Alto, CA, version 15.5) was used to commission the Anisotropic Analytical Algorithm (AAA) and Electron Monte Carlo (EMC) calculation models for photon and electron beams.

2.2. Measurements

For beam scanning, measurements were made in an MP3 motorized water phantom system, a 3D scanning system controlled by MEPHYSTO software (PTW Company), 3D water scanning system with wireless auto-setup, use of linac acceptance testing, TPS Beam Data Commissioning, Monitor Calibration, and linac QA. Commissioning was performed for photon energies 6, 10, 15MV, and electron energies 6, 9, 12, 16 MeV. The AAPM Task Group (TG) reports number 45 and 106 were carried out as guidelines.

2.3. Absolute Dosimetry

In this study, absorb dose measurements of photon and electron energies, IAEA TRS-398 protocol was used. Absolute dose measurements were carried out using farmer ionization chamber for all photon energies and Roos parallel-plate ionization chamber for all energies of electrons

and detector readings were integrated on Unidos E (PTW, Germany) electrometer. Photon beam data were done in water phantom ($30 \times 40 \times 30 \text{ cm}^3$) at $10 \times 10 \text{ cm}^2$ field size, Source Skin Distance (SSD)=100 cm, and 10 cm depth.

For electron beams, the reference applicator $20 \times 20 \text{ cm}^2$ was set for 16 MeV, and for other energies, $15 \times 15 \text{ cm}^2$ was used (Table 1).

Table 1. References depth (Z_{ref}) used for electron beam absolute dosimetry

Energy (MeV)	Measurement Depth, Z_{ref} (Cm)
6	1.3
10	2
12	2.8
16	3.8

2.4. Relative Dosimetry

PDDs and dose profiles in cross-plane and in-plane direction were acquired for field sizes ranging from 2×2 to $40 \times 40 \text{ cm}^2$ for all photon beams. Field sizes determined by the jaws and MLCs were retracted. Two PTW Semiflex 3D (0.07 cm^3) ionization chambers were used for reference and field detectors where the reference detector was set at the corner of the radiation field.

PDD is defined as the dose at a certain point D_x of the central axis over the maximum dose D_{max} on the central axis multiplied by:

$$PDD = D_x / D_{\text{max}} \cdot 100\%$$

The PDD scanning was performed from 35 to 0 cm depth in an upward direction throughout the phantom to avoid the water turbulence at SSD=100 cm, for 11 different field sizes: 3×3 , 4×4 , 6×6 , 8×8 , 10×10 , 12×12 , 15×15 , 20×20 , 25×25 , 30×30 , and $40 \times 40 \text{ cm}^2$.

For evaluating flatness and symmetry, in-plane and cross-plane profiles were obtained in a water phantom at SSD of 100 cm for five different depths (d_{max} , 5, 10, 20, and 30 cm). Flatness specification is the maximum variation of the integrated dose between the minimum and the maximum points within the central 80% field width of the radial (In-plane) and transversal (Cross-plane) major axes at SSD 100 cm:

$$F = 100 \times (D_{\text{max}} - D_{\text{min}}) / (D_{\text{max}} + D_{\text{min}})$$

Symmetry specification is the maximum variation of the integrated dose between any two corresponding points equidistant from the beam centerline within the central 80% field width of the radial (in-plane) and transversal (cross-plane) major axes at SSD 100 cm.

TG-51 recommendations were used as a guideline (i.e., R_{50} , a quantity calculated for 50 % of the maximum ionization value of the depth ionization curve) for electron data acquisition. Electron applicators, in size: 6×6 , 6×10 , 10×10 , 15×15 , 20×20 , and 25×25 , were installed to limit the radiation field, but more importantly to collimate the beam. PDD, cross-plane and in-plane profiles and output factors were performed for all electron energies and measured with Semiflex 3D.

The depths of ionization at 90%, 80%, and 50% of the maximum beam intensity were determined. The depth dose curves were performed at scanning depth of 30 cm at SSD=100 cm and R_{100} , R_{50} , R_{90} , R_{80} attained.

2.4.1. Beam Quality

An energy parameter value for comparison photon beams was acquired by using Tissue-Phantom Ratio ($TPR_{20,10}$) ratios. According to, IAEA TRS-398, $TPR_{20,10}$ is defined as a beam quality index. The TPR values were determined from the measured PDD data using an empirical approximation relation:

$$TPR_{20,10} = 1.2661 PDD_{20,10} - 0.0595$$

where $PDD_{20,10}$ is the ratio of percent depth doses at 20 cm and 10 cm depths. We measured the TPR from PDD with depth as a function of field sizes from $1 \times 1 \text{ cm}^2$ up to $40 \times 40 \text{ cm}^2$ and depth (from 0 mm to 35 cm).

2.4.2. Output Factors

The ratio of the absorbed dose in water in any field size to the absorbed dose in the reference field at the same depth is expressed as Output Factor (OF). For OF measurements a farmer ion chamber was applied for field sizes ranging from $2 \times 2 \text{ cm}^2$ to the larger field size $40 \times 40 \text{ cm}^2$, at SSD=100cm and 10 cm depth.

2.5. Eclipse Beam Configuration

After beam data acquisition, the data was imported into EclipseTM and configure the AAA algorithm. To commission TPS, the IAEA has published Technical Reports Series No. 430 that provides a large number of tests and procedures to be considered by the TPS users

[5]. Beam configuration is designed for the entry of measured dosimetric beam data. Measured beam data can be imported to beam configuration manually. Beam configuration supports configuring multiple calculation models and energies of different modalities and provides integration with the database that contains the treatment machine definitions.

2.6. Audit Operation

The audit was conducted in our department. For auditing, a commercially available semi-anthropomorphic CIRS Thorax CIRS Thorax Phantom (CIRS Inc., Norfolk, VA, USA) has been used. The phantom is elliptical in shape and illustrates an average human torso in proportion, density, and two-dimensional structure. It has a body made

of plastic water, lung, and bone sections with holes to hold interchangeable rod inserts in order to point dose measurement in various positions [6, 7].

For auditing 5 mm CT slices of the CIRS phantom were acquired. CT images of the phantom in the DICOM format have been transferred to the TPS. A set of clinical cases requiring various beam arrangements according to IAEA suggestion was prepared on TPSs [7]. The phantom was irradiated following the treatment plans and dose measurements of 84 points were done by 0.6cc farmer ionization chamber. The differences between the measured and calculated doses were reported (Table 2). Figure 2 shows the position of measurement points in CIRS thorax phantom and beam geometry, in addition, sample dose distribution of eight test cases.

Table 2. Audit data for case four at point 10

		6 MV			10 MV			15 MV			Agreement Criteria (%)
		Cal. Dose (Gy)	Meas. Dose (Gy)	Dev. (%)	Cal. Dose (Gy)	Meas. Dose (Gy)	Dev. (%)	Cal. Dose (Gy)	Meas. Dose (Gy)	Dev. (%)	
Four Field Box	F₁	1.442	1.470	-1.4	1.525	1.583	-2.8	1.559	1.620	-3.0	3
	F₂	0.138	0.147	-0.5	0.118	0.131	-0.7	0.111	0.124	-0.7	4
	F₃	2.840	2.846	-0.3	2.693	2.753	-3	2.650	2.735	-4.2*	3
	F₄	0.139	0.101	-0.6	0.118	0.135	-0.8	0.110	0.128	-0.9	4
SUM		4.559	4.614	-0.7	4.454	4.602	-1.8	4.430	4.607	-2.2	3

*Failure

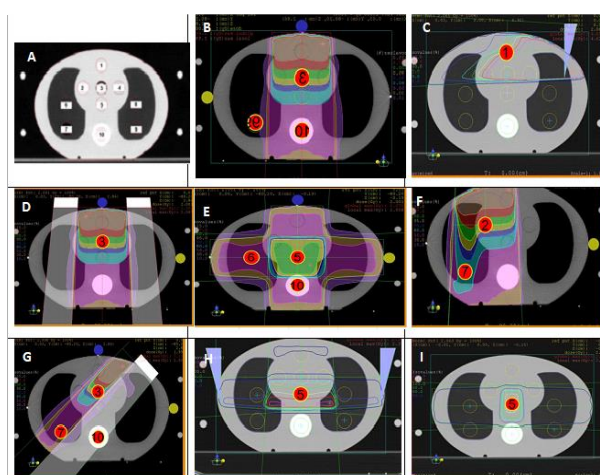


Figure 2. Measurement points and sample dose distribution of eight test cases. A: CIRS phantom with measurement points. B: Standard SSD plan, 10x10 cm², measurement points 3,9,10. C: Source Axis Distance (SAD) plan with isocentric at point 1, field size 9x15 cm², wedge 45, measurement point 1. D: SAD plan, field size 14x14 cm² (blocked down to 10x10cm²) measurement point 3. E: four field box plan, measurement points 5,6,10. F: to test customized blocking plan, measurement points 2, 7. G: 1-shaped field with oblique incidence plan, measurement points 3,7,10. H: asymmetrical fields and wedge plan. I: non-coplanar field plan

3. Results

Photon beam energy is specified in terms of a parameter that indicates the quality of the beam which is specified by the $TPR_{20,10}$ the ratio of the absorbed doses at depths of 20 cm and 10 cm in a water phantom in reference condition. Table 3 lists the values of $TPR_{20,10}$ at different nominal energies of X-ray beams generated by medical linac.

Table 3. Values of $TPR_{20,10}$ at different energy

Energy	Max Specification	Actual D_{max} Specification	Actual $TPR_{20,10}$
6	1.6 ± 0.15	1.61	67
10	2.4 ± 0.15	2.5	74
15	2.9 ± 0.15	2.8	76

Figure 3 demonstrates PDD curves for 6 MV beam for various field sizes ranging from 3x3 to 40x40 cm² and measured depth doses for all field sizes with wedge 15 are shown in Figure 4.

Cross plane profiles of different field sizes at the depth of d_{max} are shown in Figure 5.

In Figure 6, 6 MV profiles curves with wedge 15 degrees for five different depths at 10x10 field size are displayed.

6 MV profiles with wedge 15 degrees at 10cm depth for different field sizes are shown in Figure 7.

Output factors of 6, 10, and 15 MV beams are reported in Tables 4, 5, 6.

Moreover, Figures 8-12 represent PDD curves and profiles of 10 and 15 MV photon beams.

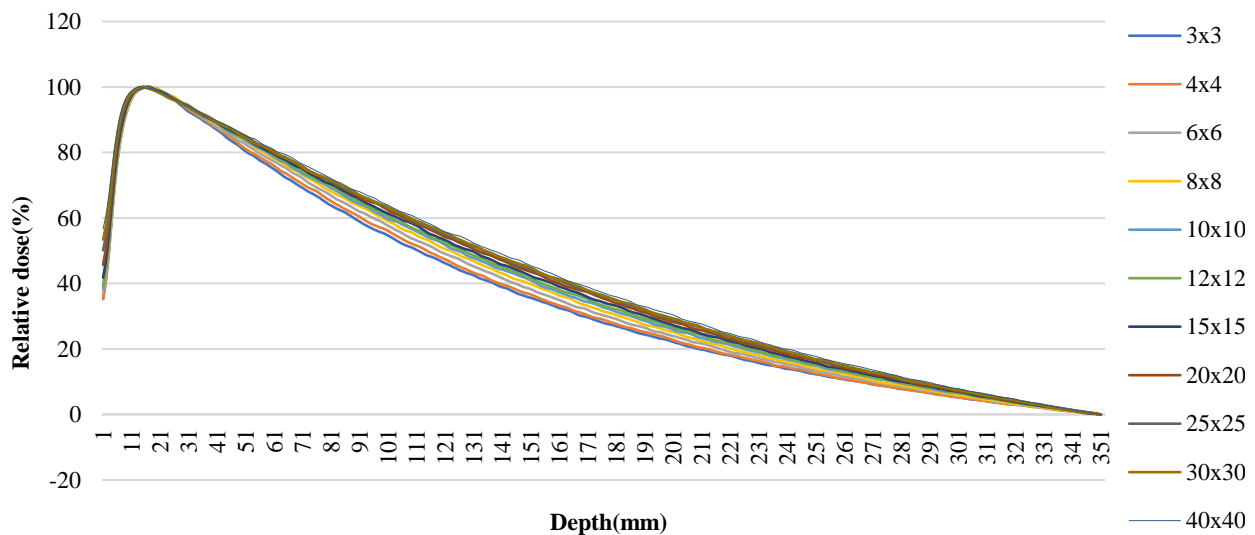


Figure 3. PDD curves for 6 MV

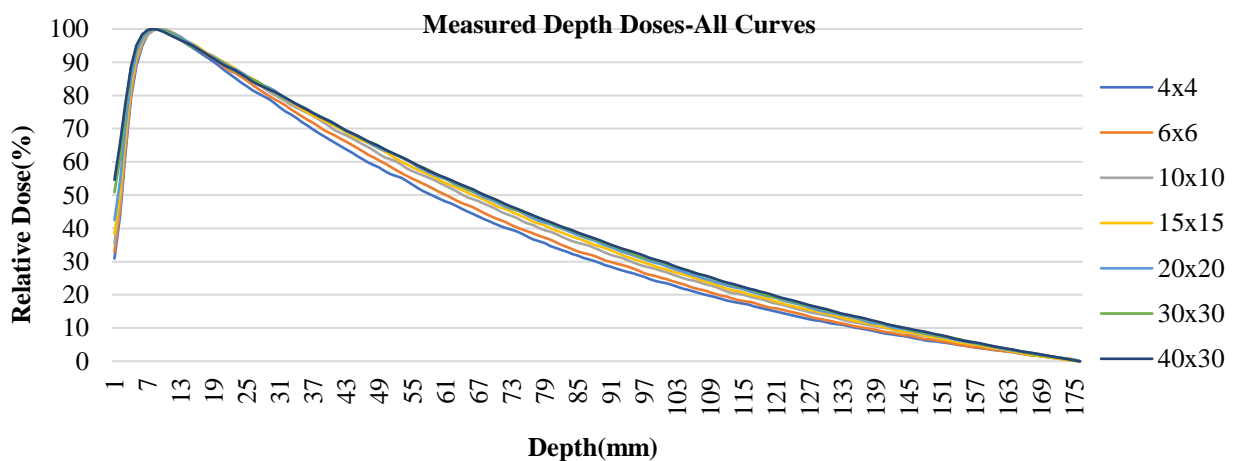


Figure 4. PDD curves for 6 MV with wedge 15

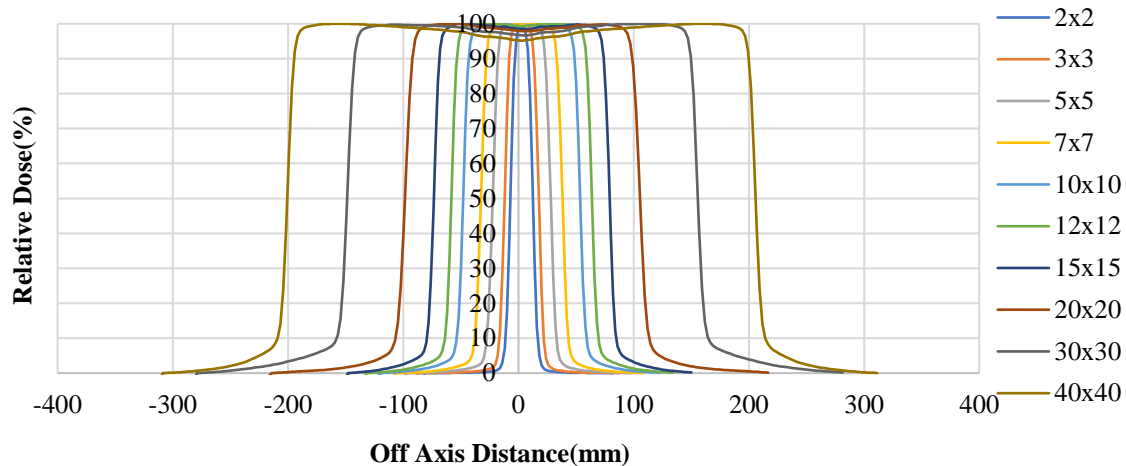


Figure 5. Profiles and off-axis ratios for 6 MV at d_{max}

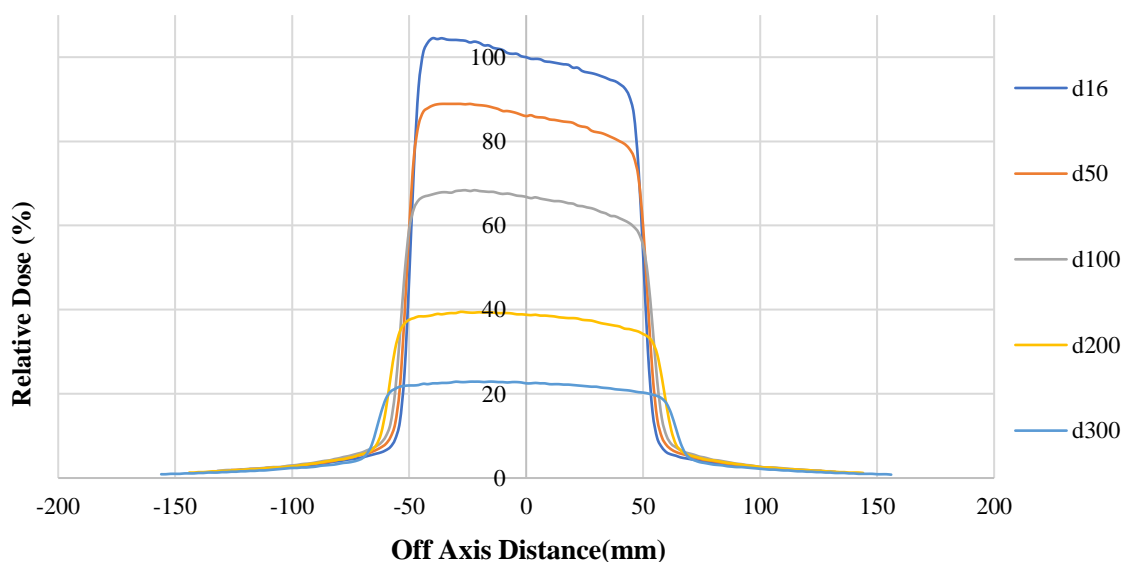


Figure 6. Profile 6MV with W15 at $10 \times 10 \text{ cm}^2$

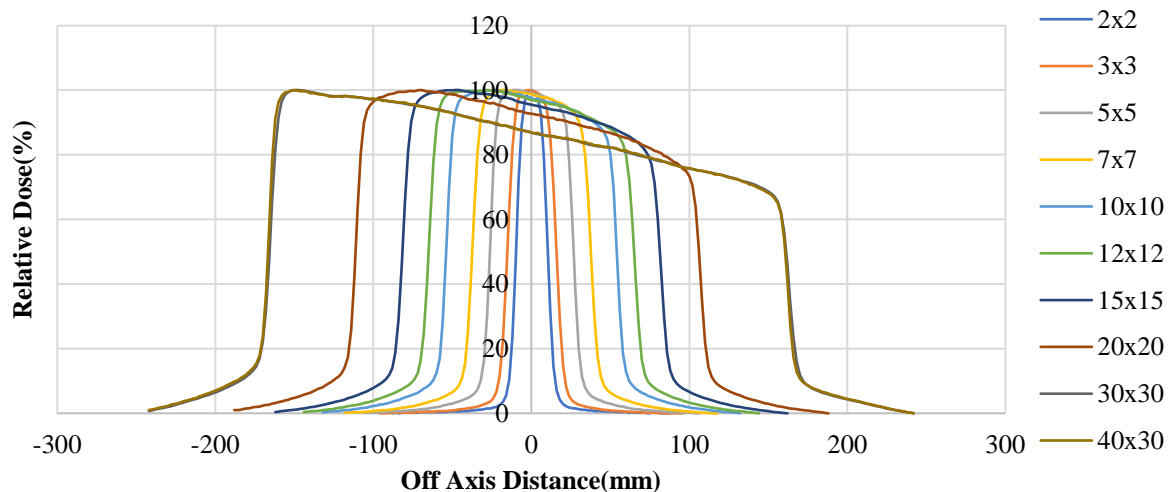


Figure 7. 6MV Profile W15 at 10cm for different field sizes

Table 4. Vital beam Output factors for 6 MV

X*Y mm²	10	20	30	50	70	100	150	200	300	400
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.791	0.809	0.826	0.834	0.841	0.846	0.849	0.851	0.853
30	0.000	0.809	0.834	0.859	0.872	0.884	0.892	0.895	0.898	0.900
50	0.000	0.826	0.859	0.898	0.916	0.934	0.947	0.955	0.959	0.961
70	0.000	0.834	0.872	0.916	0.947	0.969	0.987	0.997	1.003	1.006
100	0.000	0.841	0.884	0.934	0.969	1.000	1.024	1.035	1.047	1.051
150	0.000	0.846	0.892	0.947	0.987	1.024	1.062	1.079	1.093	1.099
200	0.000	0.849	0.895	0.955	0.997	1.035	1.079	1.101	1.123	1.128
300	0.000	0.851	0.898	0.959	1.003	1.047	1.093	1.123	1.138	1.160
400	0.000	0.853	0.900	0.961	1.006	1.051	1.099	1.128	1.160	1.175

Table 5. Vital beam Output factors for 10 MV

X*Y cm²	10	20	30	50	70	100	150	200	300	400
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.787	0.816	0.832	0.839	0.944	0.848	0.851	0.854	0.854
30	0.000	0.816	0.855	0.877	0.889	0.897	0.904	0.907	0.909	0.910
50	0.000	0.832	0.877	0.915	0.932	0.946	0.955	0.961	0.964	0.967
70	0.000	0.839	0.889	0.932	0.956	0.973	0.987	0.992	0.999	1.000
100	0.000	0.844	0.897	0.946	0.973	1.000	1.019	1.027	1.036	1.038
150	0.000	0.848	0.904	0.955	0.987	1.019	1.050	1.061	1.072	1.076
200	0.000	0.851	0.907	0.961	0.992	1.027	1.061	1.080	1.094	1.101
300	0.000	0.854	0.909	0.964	0.999	1.036	1.072	1.094	1.119	1.125
400	0.000	0.854	0.910	0.967	1.000	1.038	1.076	1.101	1.125	1.135

Table 6. Vital beam Output factors for 15 MV

X*Y cm²	10	20	30	50	70	100	150	200	300	400
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.774	0.808	0.825	0.834	0.837	0.842	0.843	0.846	0.846
30	0.000	0.808	0.854	0.881	0.890	0.900	0.903	0.906	0.908	0.908
50	0.000	0.825	0.881	0.919	0.934	0.946	0.955	0.960	0.961	0.964
70	0.000	0.834	0.890	0.934	0.960	0.974	0.986	0.991	0.997	0.998
100	0.000	0.837	0.900	0.946	0.974	1.000	1.015	1.021	1.028	1.030
150	0.000	0.842	0.903	0.955	0.986	1.015	1.040	1.051	1.060	1.063
200	0.000	0.843	0.906	0.960	0.991	1.021	1.051	1.066	1.079	1.081
300	0.000	0.846	0.908	0.961	0.997	1.028	1.060	1.079	1.097	1.103
400	0.000	0.846	0.908	0.964	0.998	1.030	1.063	1.081	1.103	1.110

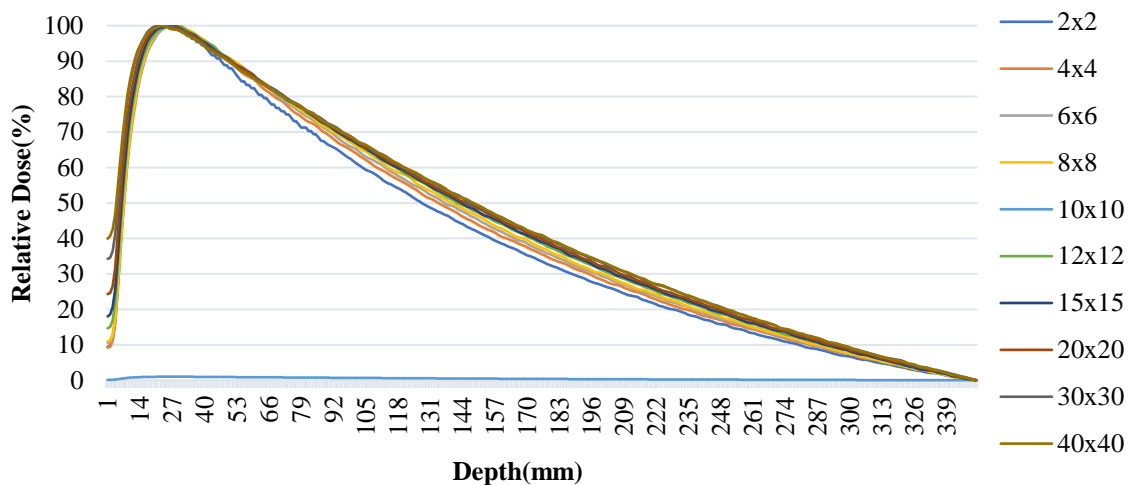


Figure 8. All Measured Depth Doses Curves for 10 MV

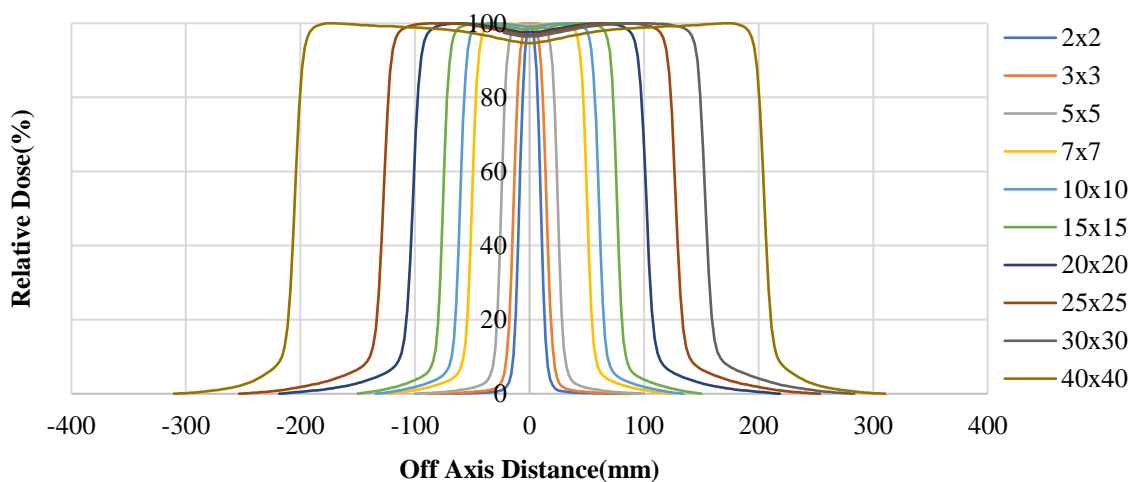


Figure 9. Profiles and off-axis ratios for 10 MV at 10 cm

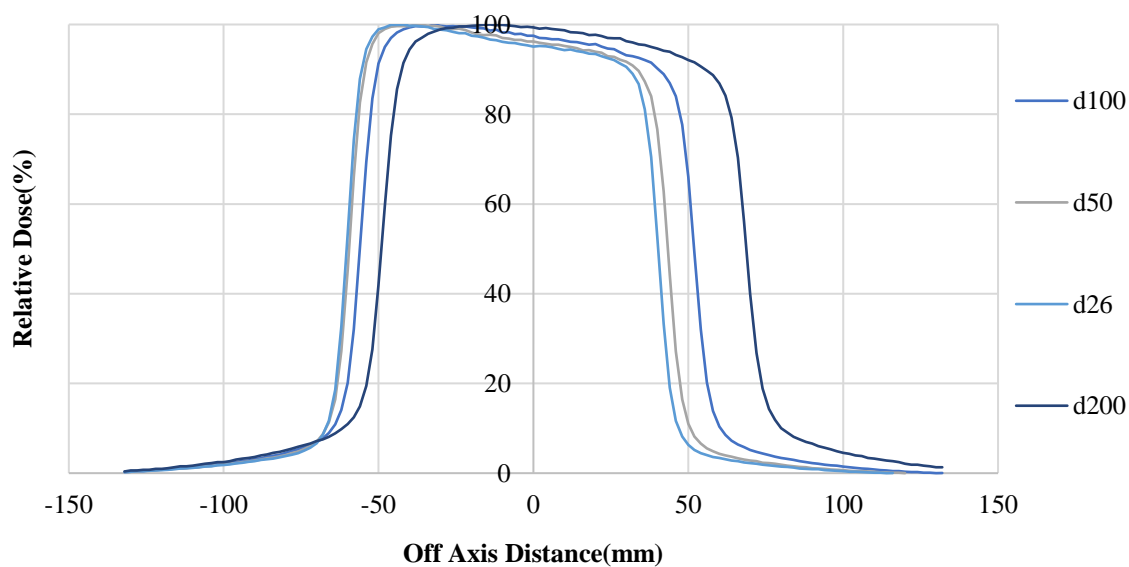


Figure 10. Profile 10MV with W15 at 10×10 cm²

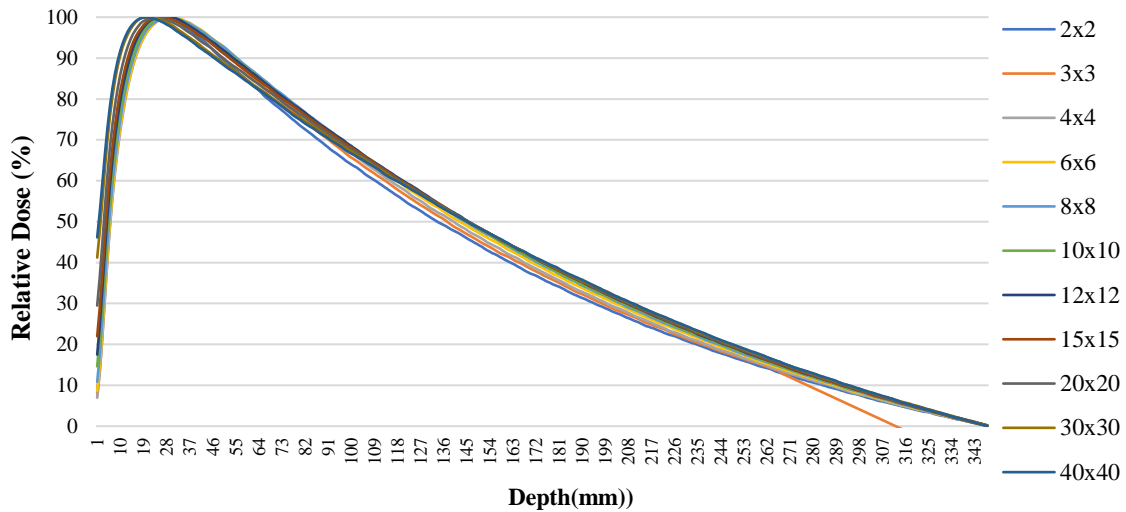


Figure 1. Measured Depth Doses for 15MV

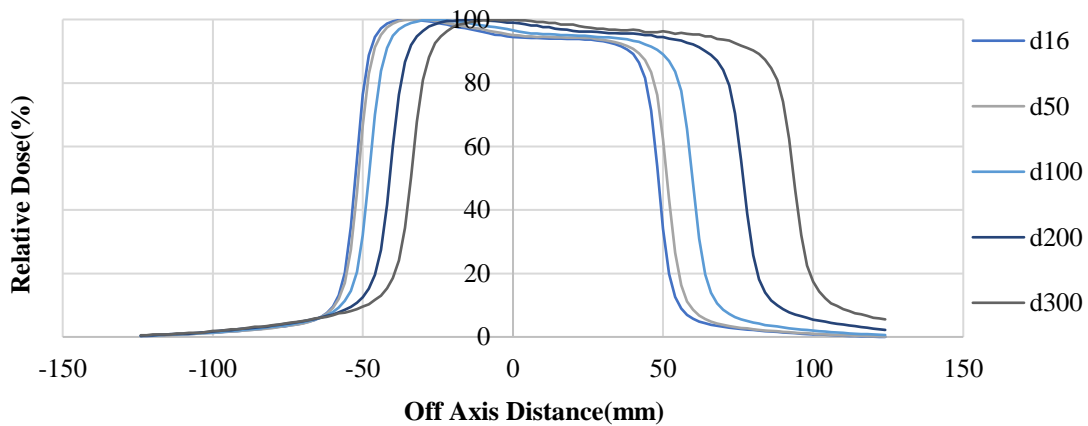


Figure 12. Measured Wedge (15) Profile, at Field size 10× 10 cm²

PDD curves of 6 MeV beam for various applicators, including 6×6, 10×6, 10×10, 15×15, 20×20, and 25×25 cm² are exhibited in Figure 13. The following PDD diagrams are plotted for other energies, Figures 14-16. Open profiles in the air for different energies are shown in Figure 17.

Based on reported data in Table 6, the deviation between calculated and measured dose was in an acceptable level of accuracy and just in case four (four-field box) in 15MV was out of agreement criteria (4.2%).

4. Discussion

This work summarizes the commissioning experiences of vital beam linear accelerators at the Kerman radiotherapy center. Because this machine was the first VitalBeam™ linac in Iran, its commissioning data was not available, so

we expect this work could be significantly useful for most institutions in the future.

Quality assurance is required for safe and accurate delivery of prescription dose and therefore effective outcomes. Any inaccuracy at different steps of radiation-therapy-induced patient mistreatment and cure reducing [8]. Commissioning is performed for QA enhancement, finding any error or limitation in the dose calculation algorithm and reducing down uncertainties. In addition, clinical use can only begin when the physicist in charge of commissioning satisfied the completion of all aspects that the equipment and any necessary data are safe to use on patients [9].

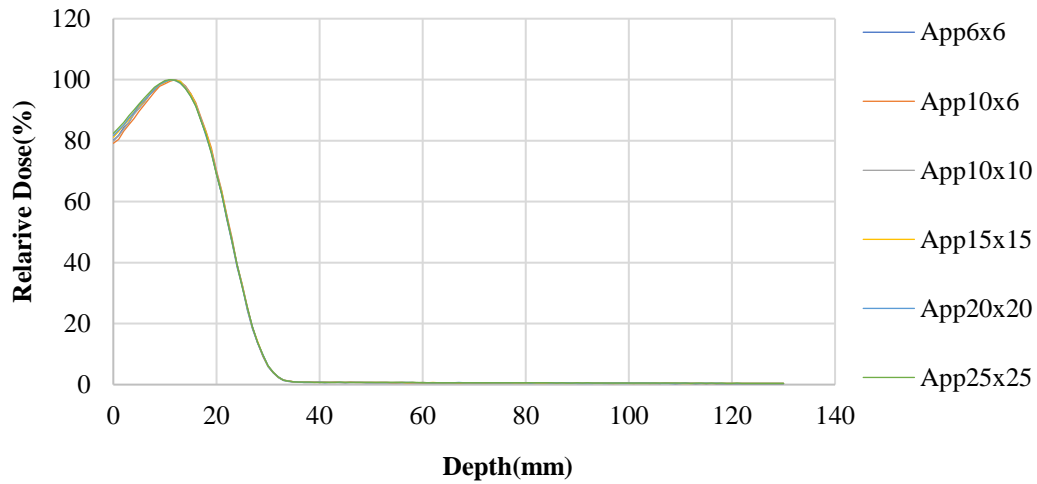


Figure 13. Measured Depth Doses for electron beam for 6 MeV

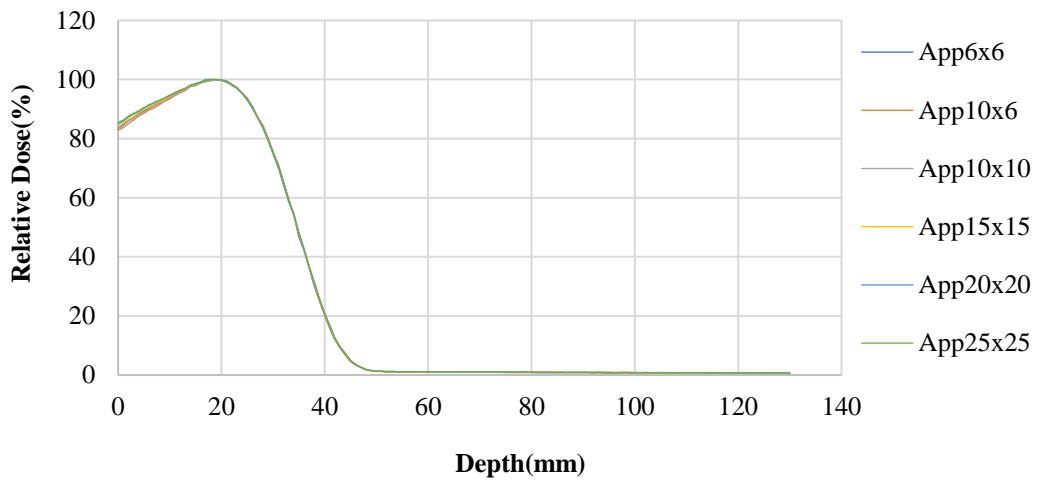


Figure 14. Measured Depth Doses for electron beam for 9 MeV

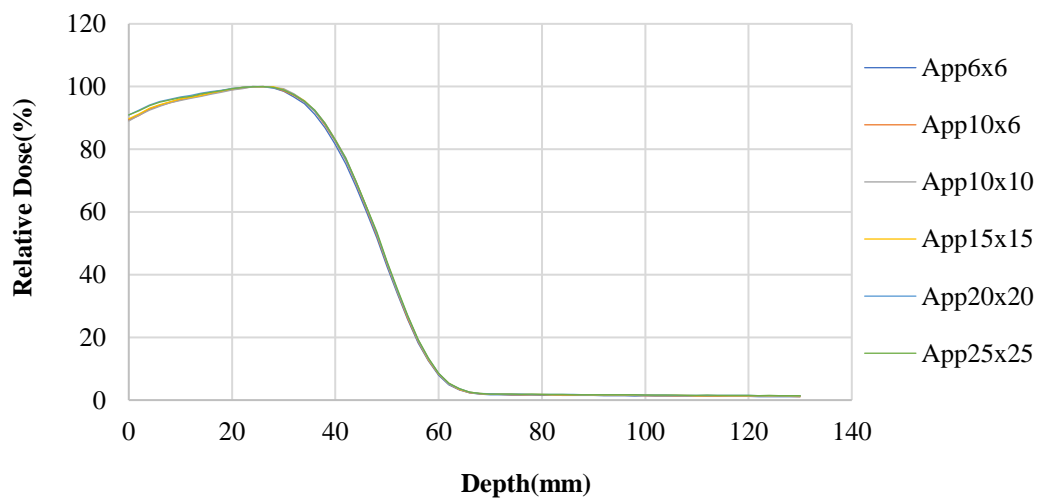


Figure 15. Measured Depth Doses for electron beam for 12 MeV

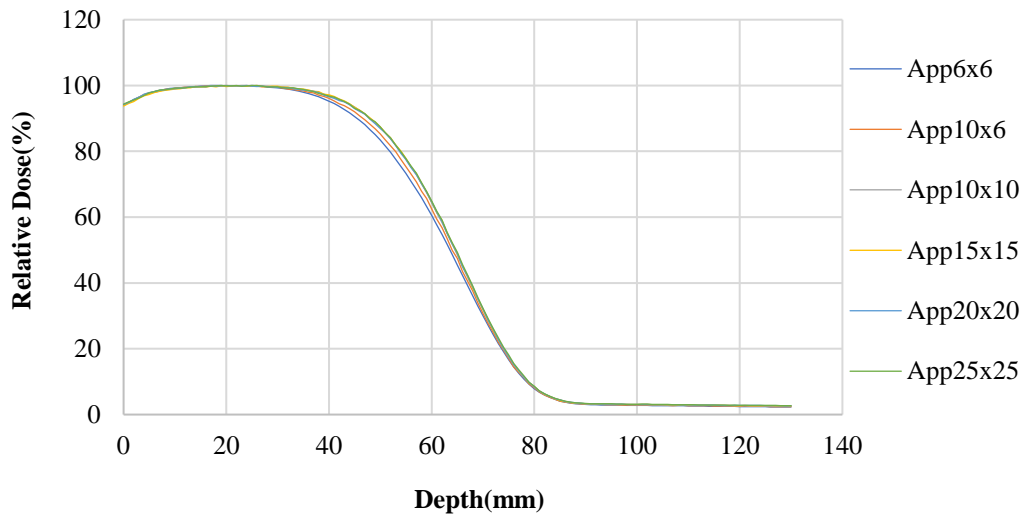


Figure 16. Measured Depth Doses for electron beam for 16 MeV

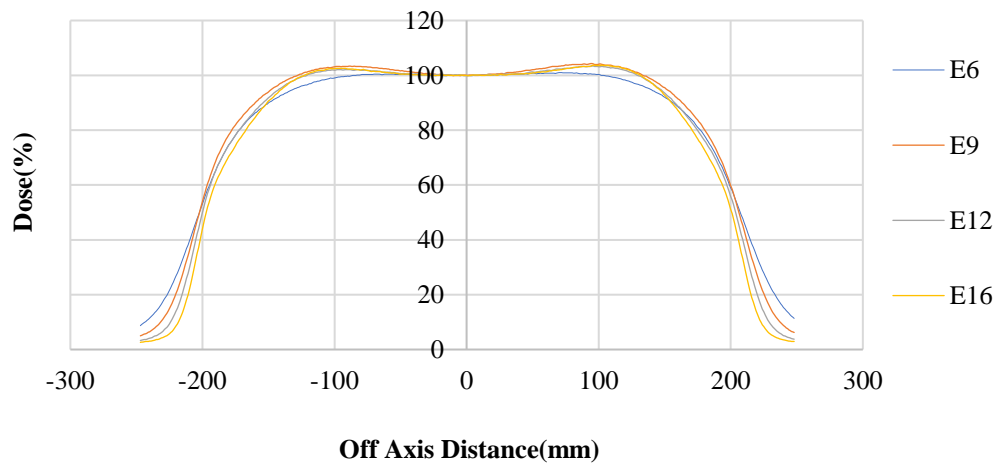


Figure 17. Measured Open Beam Profile in Air for all electron beams

The testing of the accelerator machine has been classified into two types: electrical and mechanical tests. Electrical tests involve testing of all interlocks and emergency cutoff switches. In addition, mechanical tests involve the movement of the couch, collimator rotation, gantry rotation, Optical Distance Indicator (ODI), and verification of Isocenter [10].

We experienced no major challenges or disagreements between the measured data and the data provided by the vendor. Owing to the fact that an appropriate energy index is the one easily achievable and determined uniquely, IAEA TRS-398 recommended energy index of photon beams $TPR_{20,10}$ which is calculated from $PDD_{20,10}$ thus accuracy in relative dosimetry is vitally important [11, 12]. Measurement of TPR between the acceptance results and data measured

in commissioning showed the variability of less than 1% and variability within 1mm for the D_{max} (Table1).

J. Anhrbacek *et al.* also investigated dosimetric characteristics of Varian's TrueBeam machine and obtained $TPR_{20,10}$ for 6, 10 MV photon beams equal to 0.667, 0.738, and d_{max} : 1.43, 2.23 cm, respectively which were in congruence with our results [13]. Interesting to mention that T. Knoos *et al.* studied Eclipse™ TPS and AAA algorithm found out $TPR_{20,10}$: 0.647, 0.734 for 6, 15MV beams, respectively, were compatible with our results [14].

Field flatness and symmetry of our study are in tolerance intervals given by TPS QA for all energy were < 2% and < 3%, respectively [15]. Flatness and symmetric values of cross plane profiles in $10 \times 10 \text{ cm}^2$ for 6, 10, and 15 MV beams were, respectively, 0.7, 1.2, 1.00 and 100.3, 100.4,

100,4 in R. Shende *et al.* investigation which were close to our measured data [16].

C.G-Hurst *et al.* attained commissioning data of five TrueBeam™ linacs at three different institutions for different electron energies for 20×20 cone and represented R_{50} for 6, 9, 12 and 16 MeV, respectively: 1.24, 2.03, 2.79 and 2, 91 cm, were inconsistent with our data 1.3, 2, 2.8, 3,8 for the same electron beams [17].

The total output factor is the product of collimator scatter (S_c) and phantom scatters (S_p) factor. The relative output factors were also in excellent agreement between data in acceptance day and commissioning. Beyer *et al.* presented output factors of three TrueBeam™ Linear Accelerators for 6 and 15 MV photon beams. For field sizes: 3×3, 10×10, 20×20 and 40×40 the average output factors are 0.877,1,1.067,1.115 for 6MV and 0.874, 1, 1.049, 1.083, respectively which are in agreement with our data [18].

As is clear in our auditing results indicated comparing 84 points in different plans, the 83 points were within the agreement criteria and just one point in 15 MV failed. Advanced dose calculation algorithms induced a better compromising between calculated and measured dose and Model-based algorithms (including AAA) lead to better accuracy [19, 20]. It is necessary to perform proper tests for finding out the TPS limitations, therefore accuracy in dose calculation algorithm to prevent uncertainties of delivered dose [21]. To commission TPS, the IAEA has published Technical Reports Series No. 430 that provides a large number of tests and procedures to be considered by the TPS users [22].

5. Conclusion

Commissioning of dose and field flatness and symmetry are in tolerance intervals given by Varian. This proves that the studied lines meet the specification and can be used in clinical practice with all available electron and photon energies.

Acknowledgments

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