Output Factor Considerations Of 12 and 16 Mev Electron Beams At Non - Standard Extended Target To Surface Distance in Blocked Beam Technique

■ **Supoj Ua-apisitwong,** M.Sc. (Medical Physics)
Supranee Supanunt, M.Sc. (Medical Physics)
Thana Jampanil, B.Sc. (Physics)
Radiotherapy and Nuclear Medicine Unit,
Faculty of Medicine, Ramathibodi Hospital,

■ **Wararat Prommoon,** B.Sc.(Radiological Technology)
Radiotherapy, Radiology, Rajavithi Hospital.

Objective:

The electron output determination of non-standard technique, especially for extended target to surface distance (TSD) in blocked beam technique is a complicated procedure. This study was performed to prove whether the effective $TSD_{eff,standard\ cone}$ of standard cone can be properly used in an inverse square law formula in TSD effective method for its cutout output factor determination.

Materials and methods:

The relative output factors (ROFs) of electron output measurements at depth of maximum of 12 and 16 MeV from a Varian Clinac 2100C linear accelerator with standard 10 x 10 cm^2 cone and its 21 cutouts were measured by a cylindrical ionization chamber farmer type 0.6 cc and PTW electrometer in solid water phantom at four source to target distances of 100, 105, 110 and 115 cm. The output factors measured at each cutout and TSD were then compared to the output factor values that were calculated by effective TSD method of the same cutout with effective $TSD_{eff,\ cutout}$ of its own cutout and effective $TSD_{eff,\ standard\ cone}$ of standard cone.

Results:

For output factor consideration, it was found that the magnitude of difference by using $TSD_{eff,cutout}$ of its cutout varied within ±1% for all extended distances and cutouts in both energies. Using $TSD_{eff,standard\ cone}$ of standard cone to calculate the ROF, the magnitude of difference of the two energies increased as the small cutouts and longer TSDs were introduced. The error was up to 7.23% and 8.33% for circular cutout 3 cm in diameter at TSD 115 cm of 12 MeV and 16 MeV, respectively.

Conclusion:

The effective $TSD_{eff,standard\ cone}$ of standard cone can be used to determine the relative output factor in effective TSD method. It shows a very good agreement for all cutouts if a side of cutout shields is larger than electron practical range / 2 and extended TSD is shorter than 110 cm.

INTRODUCTION

Electron beams of energy range 4-22 MeV have been used to treat superficial or boost tumors since 1947. Compared to megavoltage photon beams, the penetration of electron beams is shallower and the surface dose is higher. In tissue, electron depth dose curves or isodose charts show a homogeneity region of relative treatment range dose at 80–90 percent and rapid dose fall off beyond the dose of maximum. The size of the homogeneity region and the rapidity of dose fall off are energy and linear accelerator unit dependent. Normally, an electron treatment field is collimated by standard applicator and incorporated with an insertion or cutout for an irregularly – shaped tumor.

The output of electron beam is dependent on the beam energy, the collimator system designed, any field shaping shields and strongly on size and shape of the treatment field. The measurement of outputs for different beam sizes is an important component of electron beam dosimetry in clinical practice. One of the most popular method for output calibration as absorbed dose at the effective point of measurement with the ionization chamber in water phantom, $D_W(P_{eff})$ is recommended by IAEA Technical Reports Series No. 277[1] and it can be determined by using equation 1.

$$D_W(P_{eff}) = M_u \times N_{D,W} \times S_{w,air} \times P_u \quad \text{.......1}$$

Where M_u is the average ion reading corrected for temperature and pressure, polarity effect and recombination effect, $N_{D,W}$ is the calibration factor, $S_{w,air}$ is the stopping-power ratio water to air at the user beam quality at the point of interest and P_u is the perturbation correction factor.

For some treatments, if the patient's surface in the area to be treated is not flat and do not permit an electron applicator to be set at the standard treatment distance, such as head and neck lesion that in shoulder region, non standard extended target to surface distances are required. Even though the electron beam is considered well understood, AAPM Task Group No.25 dose not recommend the simple extrapolation of data at standard target to surface distance to be used for extended TSD electron treatments. In these cases, the incident dose for a giving machine setting is reduced on the inverse square law factor by the increased distance. In generally, direct measurement of output factor for every irregularly shaped field cutout is suggested but it is not practical in a busy radiation therapy department. The inverse square law factor for correction the change in doses was used with effective TSD method introduced by Khan et al[2]. In this method, doses are measured at the d_{max} in a phantom as a function of gap, distance between the cone end and phantom surface that extended from nominal TSD_{100}. If the inverse square law is assumed :

$$(Q_0/Q_g) = [(TSD_{eff}+d_{max}+g) / (TSD_{eff}+d_{max})]^2 \quad \text{....2}$$

$$(Q_0/Q_g)^{1/2} = [g / (TSD_{eff} + d_{max})] + 1 \quad \text{...... 3}$$

Where Q_0 and Q_g are the collected ionization with no gap and with gap respectively and TSD_{eff} is the effective target to surface distance. By plotting $(Q_0/Q_g)^{1/2}$ on the y-axis as function of air gap on the x-axis, a straight line is obtained as shown in figure 1:

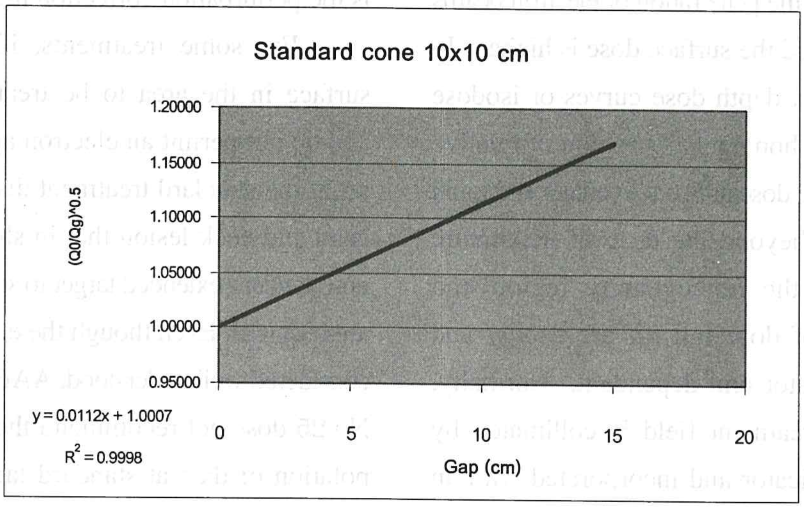

Figure 1. *Determination of effective TSD of standard cone10 x10 cm of electron beam energy 12 MeV, by plotting $(Q_0/Q_g)^{1/2}$ on the y-axis as function of air gap on the x-axis.*

From equation 3, the slope of resulting line is $1/(TSD_{eff} + d_{max})$, thus we can find the TSD_{eff} of each cone as equation 4

$$TSD_{eff} = (1/slope) - d_{max} \quad .....4$$

The effective TSD for each cutout; $TSD_{eff,cutout}$ should be measured and used in an inverse square law formula for calculating the extended dose of its cutout. The dose of each cutout at an extended TSD_{ext}, $D(E,C_{cutout},TSD_{ext})$, is related to the dose at nominal 100 cm TSD_{100} by the following inverse square law relationship :

$$D(E,C_{cutout},TSD_{ext}) = D(E,C_{cutout},TSD_{100}) [(TSD_{eff,cutout} + d_{max} + g) / (TSD_{eff,cutout} + d_{max})]^2 \quad ......5$$

In generally, the effective TSD was measured only for every standard cone; $TSD_{eff,standard\ cone}$ and used in inverse square law formula for calculating the extended dose of every cutout. The dose of each cutout at an extended TSD_{ext}, $D(E,C_{cutout},TSD_{ext})$, is related to the dose at nominal 100 cm TSD_{100} by the following inverse square law relationship :

$$D(E,C_{cutout},TSD_{ext}) = D(E,C_{cutout},TSD_{100}) [(TSD_{eff,standard\ cone} + d_{max} + g) / (TSD_{eff,standard\ cone} + d_{max})]^2 \quad ...... 6$$

In order to prove whether the $TSD_{eff,standard\ cone}$ of standard cone can be used instead the $TSD_{eff,\ cutout}$ in clinical treatments, the comparison of the output factor values that were calculated by the effective TSD method of each cutout with its $TSD_{eff,\ cutout}$ as equation 5 and $TSD_{eff,\ standard\ cone}$ of standard cone as equation 6 with directly measured values were performed. If percent of difference between calculated and measured values as equation 7 are within ± 2%, the calculated output at TSD effective method with $TSD_{eff,standard}$ can be used in routine work to avoid time consuming in direct output measurement procedure.

$$\% \text{ Difference} = (ROF_{calculated} - ROF_{measured}) \times 100 / ROF_{measured} \quad \text{...... 7}$$

MATERIALS AND METHODS

Electron beams of 12 and 16 MeV from a Varian Clinac 2100C linear accelerator with the standard 10x10 cm^2 cone and its 21 cutouts that divided by shaped in three groups as 1) three rectangular shaped with short/long side ratio equals to 1:2 , 1:3 and 1:4, 2) eight circular shaped with 3 to 10 cm in diameter and 3) ten irregular shaped were used in this study. The linac secondary collimators provide a fixed jaw 14x14 cm^2 opening that are automatically adjusted for this standard electron cone and energy range. The electron cutouts were simply done by using a low melting point alloy, a 13 mm thick of Lipowitz's metal, attached to the end of the applicator. This is adequate for blocking electron beams up to 20 MeV. The normal radiation geometry is at a target to surface distance of 100 cm with the end of the cone 5 cm away from the surface.

The central axis depth dose curves of standard cone 10 x 10 cm^2 and its all cutouts were made by RFA-300 of Scanditronix with semiconductor detector in water phantom at four source to target distances of 100, 105, 110 and 115 cm in both energies were searched and recorded.

Five readings of each energy, TSD and cutout were measured and normalized at the depth of the maximum dose in solid water phantom with a cylindrical ionization chamber farmer type 0.6 cc and PTW electrometer. The average reading of each giving cutout converted to doses in grays at depth of maximum by using equation 1 in IAEA Protocol from Technical Reports Series No. 277 and finally determined in the term of relative output factor; ROF that defined as the ratio of dose at d_{max} for the cutout field to the dose at d_{max} for the 10x10 cm^2 standard cone.

To determine the effective TSD, the ratio of $(Q_0/Q_g)^{1/2}$ for standard and extended TSD that corrected for polarity effect were plotted as a function of gap of each energy, cone cutout and extended TSD, as shown in figure 1. Then the effective TSD were calculated by equation 4.

The calculated outputs of each cone cutout at extended TSD were divided into two groups. The first group was calculated by using $TSD_{eff,cutout}$ of its cone cutout and the other was calculated by using $TSD_{eff,standard\ cone}$ of standard cone for all extensive distances as shown in equation 5 and 6, respectively. The percentage of difference in ROF for each pairs of calculated and measured values were calculated by using equation 7.

RESULTS

The effective TSDs of various electron treatment fields were measured and calculated for a number of cutout shields used in the clinic. Table 1 shows the smaller of treatment field, the shorter of effective TSD. This is due to the increased-scatter components from the cutout shield effect on the output.

***Table 1** The effective TSD of electron beam energy 12 and 16 MeV of all cones and cutouts.*

	Energy (MeV)	
Cutout #	12	16
10.0 X 10.0	86.29	86.29
7.5 X 10.0	88.74	87.09
5.0 X 10.0	83.96	84.72
2.5 X 10.0	74.52	75.74
Circular 10	83.96	85.50
Circular 9	83.21	84.72
Circular 8	81.75	84.72
Circular 7	83.96	82.47
Circular 6	80.33	81.03
Circular 5	78.30	77.65
Circular 4	73.92	72.19
Circular 3	68.43	66.44
Irregular 9 x 9	86.29	87.09
8.3 x 8.3	85.50	87.91
7.4 x 7.0	84.72	85.50
5.3 x 9.7	83.96	84.72
5.0 x 7.0	81.75	83.21
4.5 x 7.0	81.03	82.47
4.2 x 9.4	79.64	81.03
4.2 x 7.4	78.30	79.64
4.0 x 6.0	77.65	80.33
4.7 x 4.6	77.00	77.65

The relative output factors of measured and calculated values for a number of cutout cone are showed in Table 2 and 3 of electron beam energy 12 MeV and 13 MeV, respectively.

***Table 2.1** The output factor of 12 MeV of rectangular cutout normalized by standard cone 10x10 cm^2*

Cutout	TSD (cm)											
	100			105			110			115		
	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}
10.0x10.0	1.00000	1.00000	1.00000	0.89525	0.89675	0.89675	0.80578	0.80871	0.80871	0.73374	0.73302	0.73302
7.5x10.0	1.00533	1.00533	1.00533	0.90254	0.90410	0.90154	0.81327	0.81742	0.81302	0.74448	0.74264	0.73693
5.0x10.0	0.99060	0.99060	0.99060	0.88880	0.88580	0.88833	0.79765	0.79680	0.80111	0.72175	0.72056	0.72614
2.5x10.0	0.80073	0.80073	0.80073	0.70466	0.70663	0.71806	0.63155	0.62820	0.64756	0.56130	0.56214	0.58696

***Table 2.2** The output factor of 12 MeV of circular cutout normalized by standard cone 10x10 cm^2*

Cutout	TSD (cm)											
	100			105			110			115		
	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}
Circular 10	1.01422	1.01422	1.01422	0.91130	0.90693	0.90951	0.81947	0.81580	0.82021	0.73800	0.73775	0.74345
Circular 9	1.02369	1.02369	1.02369	0.91898	0.91453	0.91800	0.82405	0.82194	0.82787	0.74327	0.74273	0.75039
Circular 8	1.01925	1.01925	1.01925	0.91283	0.90884	0.91402	0.81900	0.81545	0.82428	0.73487	0.73575	0.74714
Circular 7	1.00320	1.00320	1.00320	0.90342	0.89707	0.89963	0.81002	0.80693	0.81130	0.73018	0.72973	0.73303
Circular 6	0.99068	0.99068	0.99068	0.88475	0.88170	0.88840	0.79141	0.78976	0.80118	0.71081	0.71149	0.72620
Circular 5	0.97214	0.97214	0.97214	0.86404	0.86276	0.87177	0.77462	0.77085	0.78618	0.69131	0.69288	0.71261
Circular 4	0.91448	0.91448	0.91448	0.81313	0.80626	0.82007	0.72270	0.71617	0.73955	0.63860	0.64038	0.67034
Circular 3	0.85170	0.85170	0.85170	0.75139	0.74391	0.76377	0.65969	0.65536	0.68878	0.58223	0.58172	0.62432

***Table 2.3** The output factor of 12 MeV of irregular shaped cutout normalized by standard cone 10x10 cm^2*

Cutout	TSD (cm)											
	100			105			110			115		
	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}
Irregular 9x9	1.00077	1.00770	1.00770	0.90062	0.89744	0.89744	0.81207	0.80933	0.80933	0.73420	0.73358	0.73358
8.3 x 8.3	1.00560	1.00560	1.00560	0.90498	0.90092	0.90178	0.81449	0.81177	0.81324	0.73588	0.73523	0.73713
7.4 x 7.0	0.99952	0.99952	0.99952	0.89721	0.89463	0.89633	0.80981	0.80542	0.80833	0.72894	0.72892	0.73268
5.3 x 9.7	0.99677	0.99677	0.99677	0.89359	0.89132	0.89386	0.80342	0.80176	0.80610	0.72457	0.72505	0.73066
5.0 x 7.0	0.99024	0.99024	0.99024	0.88486	0.88298	0.88800	0.79448	0.79224	0.80082	0.71443	0.71480	0.72587
4.5 x 7.0	0.97685	0.97685	0.97685	0.87053	0.87021	0.87600	0.78276	0.78013	0.78999	0.70277	0.70335	0.71606
4.2 x 9.4	0.98453	0.98453	0.98453	0.87316	0.87540	0.88288	0.78406	0.78346	0.79620	0.70362	0.70528	0.72169
4.2 x 7.4	0.98244	0.98244	0.98244	0.87377	0.87190	0.88101	0.78071	0.77902	0.79451	0.70079	0.70022	0.72016
4.0 x 6.0	0.96086	0.96086	0.96086	0.85728	0.85194	0.86166	0.76420	0.76055	0.77706	0.68252	0.68311	0.70434
4.7 x 4.6	0.96505	0.96505	0.96505	0.85903	0.85485	0.86541	0.76496	0.76251	0.78045	0.68466	0.68436	0.70741

***Table 3.1** The output factor of 16 MeV of rectangular cutout normalized by standard cone 10x10 cm²*

Cutout	TSD (cm)											
	100			105			110			115		
	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}
10.0x10.0	1.00000	1.00000	1.00000	0.89087	0.89675	0.89675	0.80809	0.80871	0.80871	0.73203	0.73302	0.73302
7.5x10.0	1.00431	1.00431	1.00431	0.90394	0.90147	0.90062	0.81540	0.81365	0.81220	0.73854	0.73807	0.73619
5.0x10.0	0.99497	0.99497	0.99497	0.89209	0.89055	0.89225	0.80197	0.80175	0.80465	0.72512	0.72560	0.72934
2.5x10.0	0.86087	0.86087	0.86087	0.76442	0.76114	0.77199	0.68197	0.67778	0.69620	0.60740	0.60741	0.63104

***Table 3.2** The output factor of 16 MeV of circular cutout normalized by standard cone 10x10 cm²*

Cutout	TSD (cm)											
	100			105			110			115		
	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}
Circular 10	1.01358	1.01358	1.01358	0.91296	0.90807	0.90893	0.82457	0.81822	0.81970	0.74072	0.74107	0.74298
Circular 9	1.02119	1.02119	1.02119	0.91971	0.91402	0.91576	0.82920	0.82288	0.82585	0.74382	0.74472	0.74856
Circular 8	1.01657	1.01657	1.01657	0.91349	0.90989	0.91162	0.82449	0.81916	0.82211	0.74004	0.74135	0.74517
Circular 7	1.01253	1.01253	1.01253	0.90544	0.90370	0.90799	0.81611	0.81152	0.81885	0.73110	0.73276	0.73303
Circular 6	1.00166	1.00166	1.00166	0.89257	0.89232	0.89824	0.80340	0.79995	0.81006	0.71997	0.72121	0.73424
Circular 5	0.99728	0.99728	0.99728	0.88454	0.88424	0.89432	0.78987	0.78938	0.80651	0.70935	0.70900	0.73103
Circular 4	0.97890	0.97890	0.97890	0.86425	0.86063	0.87783	0.75938	0.76257	0.79165	0.68150	0.68036	0.71756
Circular 3	0.94045	0.94045	0.94045	0.82216	0.81836	0.84335	0.71868	0.71859	0.76055	0.63639	0.63602	0.68938

***Table 3.3** The output factor of 16 MeV of irregular shaped cutout normalized by standard cone 10x10 cm²*

Cutout	TSD (cm)											
	100			105			110			115		
	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}	Measure	TSD_{cutout}	TSD_{stand}
Irregular 9x9	1.00107	1.00107	1.00107	0.89951	0.89856	0.89772	0.81207	0.81103	0.80958	0.73565	0.73569	0.73381
8.3 x 8.3	1.00340	1.00340	1.00340	0.90356	0.90151	0.89981	0.81595	0.81438	0.81146	0.73882	0.73930	0.73552
7.4 x 7.0	1.00272	1.00272	1.00272	0.90035	0.89834	0.89920	0.81187	0.80945	0.81091	0.73396	0.73313	0.73502
5.3 x 9.7	0.99975	0.99975	0.99975	0.89529	0.89483	0.89653	0.80494	0.80560	0.80851	0.72864	0.72908	0.73284
5.0 x 7.0	0.99481	0.99481	0.99481	0.89303	0.88873	0.89210	0.80203	0.79875	0.80452	0.72214	0.72178	0.72922
4.5 x 7.0	0.98838	0.98838	0.98838	0.88107	0.88215	0.88634	0.79059	0.79217	0.79932	0.71472	0.71528	0.72451
4.2 x 9.4	0.99712	0.99712	0.99712	0.88915	0.88827	0.89417	0.79730	0.79632	0.80638	0.71780	0.71794	0.73092
4.2 x 7.4	1.00121	1.00121	1.00121	0.89129	0.89023	0.89784	0.79688	0.79674	0.80969	0.71658	0.71723	0.73391
4.0 x 6.0	0.98551	0.98551	0.98551	0.87907	0.87674	0.88340	0.78698	0.78532	0.79667	0.70745	0.70749	0.72211
4.7 x 4.6	0.99026	0.99026	0.99026	0.88000	0.87801	0.88802	0.78395	0.78382	0.80084	0.70456	0.70401	0.72589

Table 4 shows the percentage of difference between the calculated and measured values of all cutouts for electron beam energy 12 MeV. By using $TSD_{eff,\ cutout}$ of its cutout in an inverse square law formula for ROF calculation, it was found that the percentage of difference was independent on shape and size of cutouts and TSD. The magnitude of difference varied within ± 1% in the range of +0.51% to -0.90%, for all cutouts. Nearly all the cutouts (126/132) showed the percent of discrepancy less than ± 0.5%. When $TSD_{eff,standard\ cone}$ of standard cone was used to calculate the ROF. The magnitude of deviation rose up to 4.57% in rectangular cutout 2.5x10 cm at TSD 115 cm, 4.41% in circular cutout diameter 3 cm at TSD 110 cm, 3.08%, 4.97% and 7.23% in circular cutouts diameter 5, 4 and 3 cm at TSD 115 cm and 2.57%, 2.76%, 3.20% and 3.32% in irregular cutouts 4.2x9.4, 4.2x7.4, 4.0x6.0 and 4.7x4.6 cm at TSD 115 cm, respectively.

Table 4.1 *The percentage of different between the calculated and measured values of 12 MeV of rectangular cutout.*

rectangular cutout	TSD = 105		TSD = 110		TSD = 115	
Cutout	$TSD_{eff,\ block}$	$TSD_{eff,\ open}$	$TSD_{eff,\ block}$	$TSD_{eff,\ open}$	$TSD_{eff,\ block}$	$TSD_{eff,\ open}$
10.0X10.0	0.17	0.17	0.36	0.36	-0.10	-0.10
7.5X10.0	0.17	-0.11	0.51	-0.03	-0.25	-1.01
5.0X10.0	-0.34	-0.05	-0.11	0.43	-0.16	0.61
2.5X10.0	0.28	1.90	-0.53	2.54	0.15	4.57

Table 4.2 *The percentage of different between the calculated and measured values of 12 MeV of circular cutout.*

circular cutout	TSD = 105		TSD = 110		TSD = 115	
Cutout	$TSD_{eff,\ block}$	$TSD_{eff,\ open}$	$TSD_{eff,\ block}$	$TSD_{eff,\ open}$	$TSD_{eff,\ block}$	$TSD_{eff,\ open}$
Circular10	-0.48	-0.20	-0.45	0.09	-0.03	0.74
Circular9	-0.48	-0.11	-0.26	0.46	-0.07	0.96
Circular8	-0.44	0.13	-0.43	0.64	0.12	1.67
Circular7	-0.70	-0.42	-0.38	0.16	-0.06	0.39
Circular6	-0.34	0.41	-0.21	1.23	0.10	2.16
Circular5	-0.15	0.89	-0.49	1.49	0.23	3.08
Circular4	-0.84	0.85	-0.90	2.33	0.28	4.97
Circular3	-1.00	1.65	-0.66	4.41	-0.09	7.23

***Table 4.3** The percentage of different between the calculated and measured values of 12 MeV of irregular shaped.*

irregular shaped	TSD = 105		TSD = 110		TSD = 115	
Cutout	$TSD_{eff, block}$	$TSD_{eff, open}$	$TSD_{eff, block}$	$TSD_{eff, open}$	$TSD_{eff, block}$	$TSD_{eff, open}$
Irregular9x9	-0.35	-0.35	-0.34	-0.34	-0.08	-0.08
8.3x8.3	-0.45	-0.35	-0.33	-0.15	-0.09	0.17
7.4x7.0	-0.29	-0.10	-0.54	-0.18	0.00	0.51
5.3x9.7	-0.25	0.03	-0.21	0.33	0.07	0.84
5.0x7.0	-0.21	0.36	-0.28	0.80	0.05	1.60
4.5x7.0	-0.04	0.63	-0.34	0.92	0.08	1.89
4.2x9.4	0.26	1.11	-0.08	1.55	0.24	2.57
4.2x7.4	-0.21	0.83	-0.22	1.77	-0.08	2.76
4.0x6.0	-0.62	0.51	-0.48	1.68	0.09	3.20
4.7x4.6	-0.49	0.74	-0.32	2.02	-0.04	3.32

Table 5 shows the percentage of difference between the calculated and measured values of all cutouts for electron energy 16 MeV. Again in electron energy 16 MeV, the results were similar to that of 12 MeV. By using $TSD_{eff,cutout}$, The magnitude of difference varied within ± 1% , range of +0.66% to −0.77% for all cutouts. Almost all the cutouts (125/132) showed the percent of discrepancy less than ± 0.5%.

***Table 5.1** The percentage of different between the calculated and measured values of 16 MeV of rectangular cutout.*

rectangular cutout	TSD = 105		TSD = 110		TSD = 115	
Cutout #	$TSD_{eff, block}$	$TSD_{eff, open}$	$TSD_{eff, block}$	$TSD_{eff, open}$	$TSD_{eff, block}$	$TSD_{eff, open}$
10.0X10.0	0.66	0.66	0.08	0.08	0.13	0.13
7.5X10.0	-0.27	-0.37	-0.21	0.39	-0.06	-0.32
5.0X10.0	-0.17	0.02	-0.03	0.33	0.07	0.58
2.5X10.0	-0.43	0.99	-0.61	2.09	0.00	3.89

Table 5.2 *The percentage of different between the calculated and measured values of 16 MeV of circular cutout.*

circular cutout	TSD = 105		TSD = 110		TSD = 115	
Cutout	$TSD_{eff, block}$	$TSD_{eff, open}$	$TSD_{eff, block}$	$TSD_{eff, open}$	$TSD_{eff, block}$	$TSD_{eff, open}$
Circular10	-0.54	-0.44	-0.77	-0.59	0.05	0.31
Circular9	-0.62	-0.43	-0.76	-0.40	0.12	0.64
Circular8	-0.39	-0.21	-0.65	-0.29	0.18	0.69
Circular7	-0.19	0.28	-0.56	0.34	0.23	0.26
Circular6	-0.03	0.64	-0.43	0.83	0.17	1.98
Circular5	-0.03	1.11	-0.06	2.11	-0.05	3.06
Circular4	-0.42	1.57	0.42	4.25	-0.17	5.29
Circular3	-0.47	2.57	-0.01	5.83	-0.06	8.33

Table 5.3 *The percentage of different between the calculated and measured values of 16 MeV of irregular shaped.*

irregular shaped	TSD = 105		TSD = 110		TSD = 115	
Cutout	$TSD_{eff, block}$	$TSD_{eff, open}$	$TSD_{eff, block}$	$TSD_{eff, open}$	$TSD_{eff, block}$	$TSD_{eff, open}$
Irregular9x9	-0.11	-0.20	-0.13	-0.31	0.01	-0.25
8.3x8.3	-0.23	-0.42	-0.19	-0.55	0.07	-0.45
7.4x7.0	-0.22	-0.13	-0.30	-0.12	-0.11	0.14
5.3x9.7	-0.05	0.14	0.08	0.44	0.06	0.58
5.0x7.0	-0.48	-0.10	-0.41	0.31	-0.05	0.98
4.5x7.0	0.12	0.60	0.20	1.10	0.08	1.37
4.2x9.4	-0.10	0.56	-0.12	1.14	0.02	1.83
4.2x7.4	-0.12	0.74	-0.02	1.61	0.09	2.42
4.0x6.0	-0.26	0.49	-0.21	1.23	0.01	2.07
4.7x4.6	-0.23	0.91	-0.02	2.15	-0.08	3.03

When $TSD_{eff,standard\ cone}$ was used to calculate the ROF, the magnitude of deviation rose up to 3.89% in rectangular cutout 2.5x10 cm at TSD 115 cm, 4.25 and 5.83% in circular cutouts diameter 4 and 3 cm at TSD 110 cm, 3.06%, 5.29% and 8.33% in circular cutouts diameter 5, 4 and 3 cm at TSD 115 cm, and 2.42% and 3.03% in irregular cutouts 4.2x7.4 and 4.7x4.6 cm at TSD 115 cm, respectively.

DISCUSSION

Even though the effective TSD method was widely used in electron dose calculation for extended target to surface distance. The effects of extended TSD on electron output was studied by several investigators [4,7,12,15,16] and showed to be more significantly in higher electron beam energy with small cone cutout. Though the relative output factor calculation for all cutouts by using its $TSD_{eff,cutout}$ showed very good agreement but it is not a practical work for the cancer treatment center in routine work. The $TSD_{eff, standard\ cone}$ of standard cone can be used to calculate the relative output factor calculation in effective TSD method for all cutouts if a side of cutout shield is not smaller than electron practical range / 2 and extended TSD is not longer than 110 cm. However, isodose chart distribution and central axis depth dose curve construction for each cutout should be performed to ensure the coverage and homo geneous distribution in whole volume of the tumor.

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