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LONG TERM STABILITY OF FARMER TYPE IONIZATION CHAMBER CALIBRATION COEFFICIENT BELONGING TO LOCAL RADIOTHERAPY CENTRES IN MALAYSIA

(Kestabilan Jangka Panjang Pekali Tentukuran Kebuk Pengionan Jenis Farmer Kepunyaan Pusat Radioterapi di Malaysia)

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Abstract

The accuracy of the ionization chambers' calibration coefficient is one of the factors that would contribute to efficient radiotherapy treatment. The IAEA therefore has recommended that an ionization chamber be calibrated every year, with a condition that the deviations between the previous and new calibration coefficients $N_{D,w}$ should not differ by ±1.5%. It has been identified that Farmer type ionization chambers is the most popular ionization chamber among the radiotherapy centres in Malaysia. For this reason, the purpose of this work is to evaluate the calibration coefficients' long term stability of the Farmer type ionization chambers. A total of 33 Farmer type ionization chambers were studied and the mean μ of the $N_{D,w}$ deviation together with its standard error *SE* were calculated. This $\mu \pm SE$ will be used to measure stability of $N_{D,w}$. Our results showed that most chambers have $\mu \pm SE$ lies within the ±1.5%. It is thus concluded that most of the Farmer type ionization chamber were stable in their $N_{D,w}$ and safe to be used for radiotherapy treatment.

Keywords: Farmer type ionization chambers, radiotherapy centres, calibration coefficients $N_{D,w,}$ stability.

Abstrak

Ketepatan pekali tentukuran kebuk pengionan merupakan salah satu faktor yang menyumbang kepada keberkesanan dalam rawatan radioterapi. Oleh itu IAEA mencadangkan supaya kebuk pengionan ditentukur setiap tahun dengan satu syarat bahawa sisihan antara pekali tentukuran baru dan sebelumnya mestilah tidak lebih daripada ±1.5%. Ianya telah dikenalpasti bahawa kebuk pengionan jenis Farmer merupakan kebuk pengionan paling popular dikalangan pusat radioterapi di Malaysia. Oleh sebab itu, tujuan kajian ini adalah untuk menilai kestabilan jangka panjang kebuk pengionan jenis Farmer. Sebanyak 33 buah kebuk pengionan jenis Farmer telah dikaji dan nilai purata μ untuk sisihan $N_{D,w}$ bersama dengan nilai ketidakpastian piawai *SE* dikira. Nilai $\mu \pm SE$ ini akan digunakan untuk mengukur kestabilan $N_{D,w}$. Keputusan menunjukkan hampir kesemua kebuk pengionan mempunyai nilai $\mu \pm SE$ di dalam julat nilai ±1.5%. Oleh itu dapat disimpulkan bahawa hampir kesemua kebuk pengionan jenis Farmer adalah stabil dalam nilai $N_{D,w}$ dan selamat digunakan untuk rawatan radioterapi.

Kata kunci: Kebuk pengionan jenis Farmer, pusat radioterapi, pekali tentukuran $N_{D,w,}$ kestabilan.

Introduction

Presently in Malaysia, radiotherapy treatment with photon beams can be sought from 24 radiotherapy centres (RC) located at eleven hospitals, ten medical centres and three cancer hospitals. These centres used ionization chambers (IC) for the determination of the dose delivered to the patients. The accuracy of the ionization chambers' calibration coefficient is one of the factors that would contribute to efficient radiotherapy treatment [1]. For the absorbed dose

to water calibration coefficient $N_{D,w}$, it is important that the next value of $N_{D,w}$ lies within the accuracy range of ±1.5% recommended by IAEA [2]. Accurate $N_{D,w}$ can only be obtained if the chambers were calibrated annually by the standard laboratory. For this reason, ICRU [3] and IAEA [4] has recommended an ionization chamber be calibrated every year for the purpose of getting accurate and stable $N_{D,w}$.

In Malaysia the standard laboratory for determining the $N_{D,w}$ is the SSDL Malaysia [5]. Most of the ICs belonging to the radiotherapy centres were calibrated here. Table 1 shows an example of a chamber that has been calibrated eight times (frequency f=8) by the SSDL. To calculate the accuracy $\Delta(\%)$ of $N_{D,w}$, this work used the first value of $N_{D,w}$ as the standard. Note that from this accuracy values, the long term stability of the chamber can be evaluated from mean μ, standard deviation σ_{N-1} and standard error SE for $\Delta(\%)$. It is clear from the table, the long term stability evaluation requires f>2.

Table 1: The accuracy and the long term stability analysis of calibration coefficients of a chamber [1]

Year of calibration	f	$N_{D,w}$(mGy/nC)		$\Delta(\%)$[2]	μ[3]	SE[3][4]	σ_{N-1}[4]
		First	Consequent				
2004	8	57.66 ± 1.44%					
2005			57.57 ± 1.42%	−0.16	–	–	–
2006			57.85 ± 0.94%	0.33	0.09	0.35	0.35
2007			57.73 ± 1.18%	0.12	0.10	0.17	0.25
2008			57.29 ± 1.18%	−0.64	−0.09	0.24	0.42
2009			57.39 ± 1.18%	−0.47	−0.16	0.20	0.40
2010			57.58 ± 1.39%	−0.14	−0.16	0.16	0.36
2012			57.40 ± 1.22%	−0.45	−0.20	0.14	0.35

1) Will be seen in Table 3 that this chamber is Type 2 in NE 2581.
2) $\%\Delta = \frac{N_{D,w} - N_{D,w\ standard}}{N_{D,w\ standard}} \times 100\%$. Note that all $\Delta(\%)$ are within ±1.5%.
3) Note that $\mu \pm SE$ *(all in %)* are within ±1.5%.
4) Method of calculation is described by reference [6].

From year 2004 to 2012 the SSDL Malaysia has calibrated 114 chambers. Table 2 shows the chambers' categories, type, model and the frequency of calibration. It can be seen in the table that the most popular type is Farmer type ionization chambers (48.25 %). For this reason, the purposes of the present work are to get the accuracy and to evaluate the long term stability of the Farmer type ionization chambers.

Table 2: The details of the 114 therapy level ionization chambers belonging to 24 radiotherapy centres in Malaysia calibrated at SSDL Malaysia from year 2004-2012.

Categories	Type	Model	Chamber Number *N*			
			$f < 2$	$f > 2$[1]	Subtotal	%
Cylindrical	Farmer	FC 65-G	8	14	22	19.30
		FC 65-P	0	3	3	2.63
		NE 2571	6	4	6	5.26
		NE2581	3	3	10	8.77
		TW 30001	2	3	5	4.39
		TW 30013	3	6	9	7.89
			22	[illegible]	55[2]	48.25
	Pinpoint	TW 31014	2	1	3	2.63
		TW31016	0	1	1	0.88
			2	2	4	3.51
	Compact	CC01	10	1	11	9.65
		CC13	6	2	8	7.02
			16	3	19	16.67
	Semiflex	TM 31010	2	5	7	6.14
			2	5	7	6.14
	Thimble	A1SL-30-361	3	0	3	2.63
			3	0	3	2.63
Parallel Plate	Roos	PPC05	1	1	2	1.75
		PPC 40	11	5	16	14.04
		TW 34001	2	1	3	2.63
			14	7	21	18.42
	Markus	TW23343	2	1	3	2.63
		TW34045	2	0	2	1.75
			4	1	5	4.39
Total			63	51	114	100.00

1) The present work will focus on this 33 chambers only, as the long term stability evaluation can only be done for f>2, as shown in Table 1.
2) The calibration frequency is given in Table 3.

Materials and Methods

Calibration at SSDL Malaysia

For the calibration purpose of $N_{D,w}$ at SSDL Malaysia, the 1.25 MeV Co-60 beam was obtained from the SSDL Malaysia Eldorado 8(#104) teletherapy machine [7] The standard IAEA substitution method was utilised in determining the chambers' coefficients. The experimental set-up is shown in Figure 1. Reference standard chamber used by SSDL is NE2571 (#1028) with volume 0.6 cm^3. Apparatus and set-up used in this study are as follows: PMMA water phantom size 30 cm × 30 cm × 30 cm, Perspex sheath (used to place the ionization chamber inside the phantom), surface to source distance (SSD) = 100 cm, surface to chamber distance (SCD) = 105 cm (with reference point depth = 5 g/cm^2) and field size (FS) = 10 × 10 cm^2.

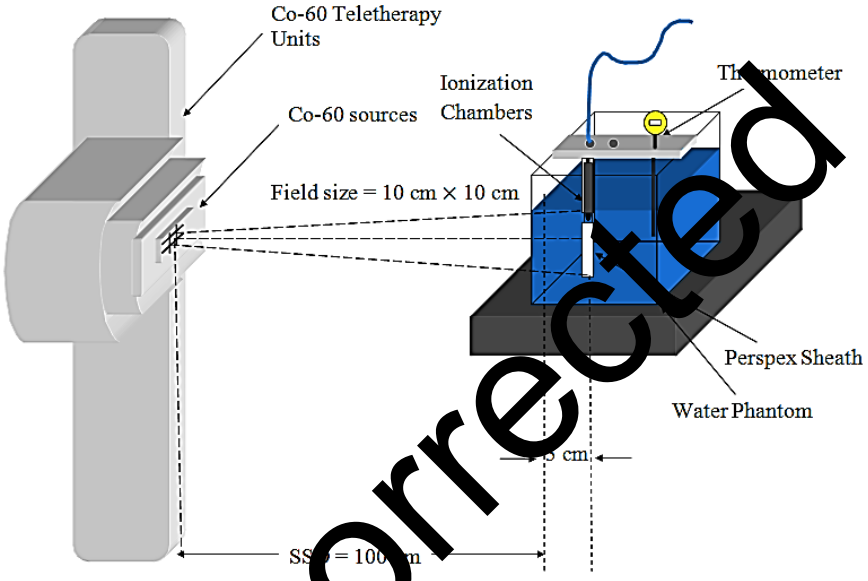

Figure 1: Experimental set-up for the determination of $N_{D,w}$

Long term stability analysis

Table 3 gives the $N_{D,w}$ calibration frequency record for the 33 chambers since 2004. A total of 178 calibration were performed from 2004-2012 while 3 chambers were calibrated 2 times, 8 chambers 7 times, 4 chamber 6 times, 6 chambers 5 times, 8 chamber 4 times and 4 chambers 3 times. For the purpose of confidentiality, only codes are used to represent the RC and the IC respectively. In this work, $\mu \pm SE$ will be used to measure stability of $N_{D,w}$. The $N_{D,w}$ of a chamber is considered stable if $\mu \pm SE$ (at the 95% confidence intervals) are in the range of ±1.5%.

Table 3: $N_{D,w}$ calibration frequency for 55 Farmer type ionization chambers used in this work.

Criteria	Chamber's Model	IC	RC	Year of calibration									Calibration's frequency, f
				2004	2005	2006	2007	2008	2009	2010	2011	2012	
f >2	FC 65-G	1	R1	√		√√		√	√				5
	(N=14)	2	R2	√	√		√	√	√		√	√	7
		3	R3	√	√		√						3
		4	R3		√	√	√	√	√				5
		5	R4	√	√	√	√	√	√	√		√	8
		6	R5	√		√	√	√	√	√		√	7
		7	R5			√		√	√	√	√	√	6

		8	R6					√	√	√			3
		9	R6	√	√√	√							4
		10	R7	√	√	√	√	√	√		√	√	8
		11	R8			√	√	√	√	√	√	√	7
		12	R9				√	√	√	√	√		5
		13	R10						√	√		√	3
		14	R11							√	√	√	3
	FC 65-P	15	R10				√	√		√		√	4
	(*N*=3)	16	R12	√		√		√	√	√	√	√	7
		17	R12	√		√	√	√	√	√		√	7
	NE 2571	18	R8	√	√	√	√	√	√				6
	(*N*=4)	19	R10	√	√	√	√						4
		20	R13	√	√	√	√						4
		21	R14	√		√	√	√	√		√	√	7
	NE 2581	22	R9	√	√	√	√	√	√	√		√	8
	(*N*=3)	23	R15		√	√	√		√				4
		24	R16		√	√	√	√	√	√		√	7
	TW 30001	25	R14	√	√		√	√	√	√		√	7
	(*N*=3)	26	R14			√	√	√	√		√	√	6
		27	R17	√	√	√√							4
	TW 30013	28	R17			√	√	√	√		√		5
	(*N*=6)	29	R18			√	√	√	√			√	5
		30	R18			√	√	√	√	√		√	6
		31	R19				√	√	√		√	√	5
		32	R19						√	√	√	√	4
		33	R20				√	√	√	√		√	4
													178[1]
$f < 2^{(2}$	FC 65-G	34	R7									√	1
	(*N*=8)	35	R11							√		√	2
		36	R12									√	1
		37	R12									√	1
		38	R14									√	1
		39	R21	√									1
		40	R22									√	1
		41	R22									√	1
	NE 2571	42	R5		√								1
	(*N*=6)	43	R6			√		√					2
		44	R[illegible]					√					1
		45	R10	√	√								2
		46	R20	√									1
		47	R[illegible]									√	1
	NE 2581	48	R[illegible]		√√								2
	(*N*=3)	49	R15	√									1
		50	R21						√				1
	TW 30001	51	R5				√						1
	(*N*=2)	52	R20	√	√								2
	TW 30013	53	R1							√	√		2
	(*N*=3)	54	R6									√	1
		55	R23							√		√	2
													29

1) The 145 deviations shown in Figure 2 may be calculated from this frequency, i.e. 178−33 = 145.

2) The 22 chambers (IC34 to IC55) under this category were not discussed in this paper. They are included here for two reasons: to justify the details shown in Table 2 and to be used for future references.

Results and Discussion

Figure 2 shows 145 deviations for the 33 chambers. The $\Delta(\%)$ of $N_{D,w}$ calculated in relation to the first value, are as follows: 2nd calibration (33 deviations) = −2.18 % to 6.55 %; 3rd calibrations (33 deviations) = −2.45 % to 3.41 %;

4^{th} calibrations (29 deviations) = −7.08 % to 1.85 %; 5^{th} calibrations (21 deviations) = −1.75 % to 5.81 %; 6^{th} calibrations (15 deviations) = −2.77 % to 4.77 %; 7^{th} calibrations (11 deviations) = −5.34 % to 6.45 %; 8^{th} calibrations (3 deviations) = − 1.15 % to − 0.45 %.

If we see the *Δ(%)* for the calibration coefficients of 33 cylindrical Farmer-type chambers based on the chamber's model, it was found that, the range of *Δ(%)* for; FC 65-G = − 2.77 % to 2.51 %; FC 65-P = − 1.33 % to 0.37 %; NE 2571= − 7.08 % to 6.55 %; NE 2581 = − 1.34 % to 0.62 %; TW 30001= − 0.46 % to 6.45 %; TW 30013= − 1.99 % to 2.29 %. Overall, clear from Figure 2 that most of these deviations lie within the IAEA tolerance value, ±1.5% except for few chambers which have deviations outside the IAEA acceptable limits which will be discussed later.

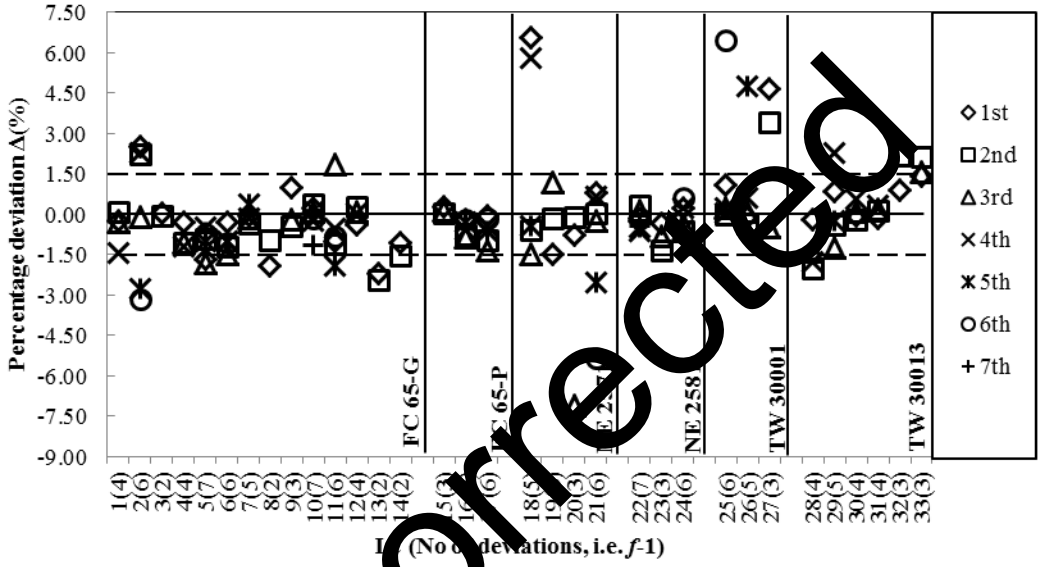

Figure 2: 145 percentage deviations of $N_{D,w}$ for 33 Farmer type chambers. From these deviations, *μ±SE* were calculated as shown in Figure 3. As an example, for IC22, Table 1 shows the values of *μ±SE*, and Figure 3 shows the plot.

Discussion will mainly focus on *μ±SE* in particular. It is interesting to see the chambers with most calibration frequency first. Based on Table 2, there are three chambers with 8 calibration frequency in the period of 9 years (2004-2012) namely IC5, IC10 and IC22. All three chambers give a quite good value of *μ±SE* which are -1.05 ± 0.19, 0.19 ± -0.10 and -0.[illegible] ± 0.[illegible] respectively. The variation of *μ±SE* for the 33 chambers is shown in Figure 3.

It is interesting to check whether *μ±SE* include the value of zero for each chamber. If it does, we conclude that the result is satisfactory and no evidence that a systematic error occurred in the measurements. On the other hand, if it does not, the student's t-test [8] needs to be done as shown in Table 4.

On examining Figure 3, it is obvious that *μ±SE* for 23 chambers do not include the value of zero. This may lean the results towards a systematic error. Thus, a student's-t test is conducted to prove that the results were statistically significance. Upon checking this test (Table 4) it is found 8 out of 23 chamber have evidence that a systematic errors have occurred in the measurement (of calibration coefficients) at 5% significance level. IC5 (which is chambers with most calibration frequency) however also indicated the existence of systematic errors in the $N_{D,w}$ during the long term period of measurements. In terms of chamber's model, 66.67 % from the total amount of FC 65-P chambers give systematic errors. This is then followed with 33.33 % for TW 30013 and 14.29 % for FC 65-P.

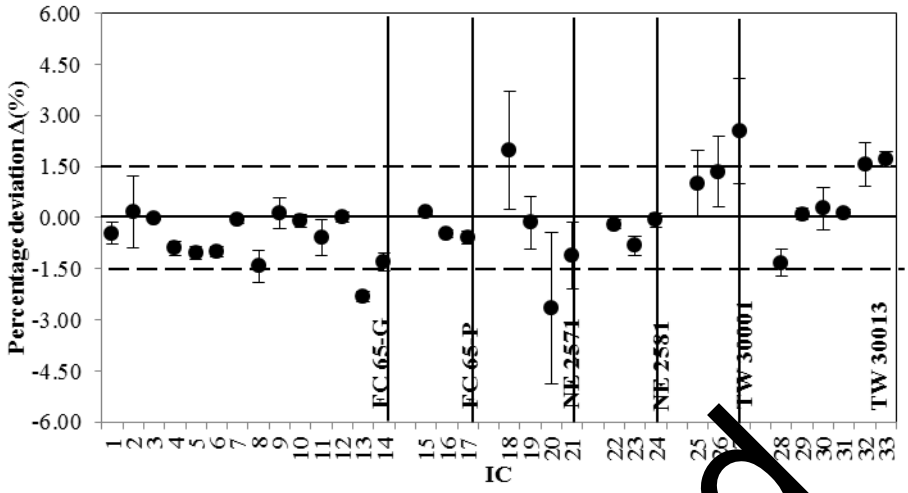

Figure 3: Variation of Δ(%) for μ±SE with chamber number

Table 4: Student's t-test analysis for a selected 23 chambers with μ±SE do not include the value of zero

Chamber's Model	IC	*f*	μ±SE	T value[1]	T-test[2]	T test < |μ|[3]	Systematic Error
FC 65-G	1	5	−0.46±0.33	2.776	0.916	N	N
	4	5	−0.90±0.21	2.776	2.569	Y	Y
	5	8	−1.05±0.19	2.365	0.455	Y	Y
	7	6	−0.07±0.12	2.571	0.308	N	N
	9	4	0.13±0.45	3.182	1.424	N	N
	10	8	−0.10±0.19	2.365	0.458	N	N
	13	3	−2.32±0.13	4.303	0.581	Y	Y
	14	3	−1.00±0.25	4.303	1.082	Y	Y
FC 65-P	15	4	0.13±0.06	3.182	0.199	N	N
	16	7	0.48±0.12	2.447	0.291	Y	Y
	17	7	−0.30±0.20	2.447	0.485	Y	Y
NE 2571	19	4	−0.15±0.78	3.182	2.471	N	N
	20	4	−2.65±2.22	3.182	7.069	N	N
	21	7	−1.10±0.98	2.447	2.393	N	N
NE 2581	22	8	−0.20±0.13	2.365	0.310	N	N
	23	4	−0.83±0.29	3.182	0.921	N	N
TW 30001	25	7	1.01±0.95	2.447	2.332	N	N
	26	6	1.34±1.03	2.571	2.658	N	N
	27	4	2.54±1.55	3.182	4.921	N	N
TW 300013	28	5	−1.33±0.40	2.776	1.111	Y	Y
	30	5	0.26±0.61	2.776	1.692	N	N
	32	4	1.56±0.65	3.182	2.054	N	N
	33	4	1.71±0.21	3.182	0.680	Y	Y

1) from Student's t table [9,10].
2) T test = T value × SE.
3) Y = Yes, N = No.

In Figure 3, it is also can be seen that few chamber (i.e. IC2, IC18, IC19, IC20, IC21, IC25, IC26 and IC27) gives a large value of *SE*. If now we look back again at Figure 2 for these particular chambers, we can see that there is a deviation values which are significantly different from the groups of deviations.

It is also obvious that 5 chambers (i.e. IC13, IC18, IC20, IC27 and IC33) have μ values outside the IAEA tolerance value, ±1.5%. However $\mu \pm SE$ value for these chambers still lies within the IAEA action value, ±3.0%.

Conclusion

As a conclusion, almost all 33 Farmer type ionization chamber have a stable $N_{D,w}$ calibration coefficients despite 8 chambers that shown a systematic error in their measurements. It is also concluded that all these chambers is safe to be used for radiotherapy treatment.

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References

1. Czap, L., Matcheko, G., Andreo, P. 1995. Intercomparison of ionization chamber calibration factors in the IAEA/WHO network of SSDLs. SSDL Newsletter 34:17-25.
2. IAEA. 2000a. *Technical Report Series No. 398: Absorbed Dose Determination in External Beam Radiotherapy.* Vienna: International Atomic Agency.
3. ICRU. 1976. *Determination of Absorbed Dose in a Patient Irradiated by beams of X or Gamma Rays in Radiotherapy Procedures, Rep 24*. Bethesda: International Commissioning Radiation Unit.
4. IAEA 2000b. *Safety Report Series No. 17: Lesson learned from accidental exposures in radiotherapy*. Vienna: International Atomic Agency.
5. Kadni, T. 2004. Calibration of Radiation Instruments Used in Radiation Protection and Radiotherapy in Malaysia. *Australian Physical and Engineering Sciences in Medicine.* 27(2): 79.
6. Samat, S.B. and Evans, C.J. 1992. Statistics and Nuclear Counting – Theory, Problems and Solutions. Serdang: Universiti Putra Malaysia Press.
7. Samat, S.B., Evans, C.J., Kadni, T. & Dorah, M.A. 2000. Accurate measurement of exposure rate from a Co^{60} teletherapy sources: deviations from the inverse square law.
8. Bland, M. 1987. *An Introduction to Medical Statistics*. Oxford: Oxford University Press.
9. Lind, D.A., Marchal, W.G. & Wathen, S.A. 2008. *Basic Statistics for Business and Economics*. Ed. ke-6. New York: McGraw Hill.
10. Spiegel, M.R. and Stephens, L.J. 2011. *Statistics*. 4th ed. United States: McGraw Hill.