Performance Evaluation of an Electrometer for Quality Control and Dosimetry in Radiation Therapy

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The performance of an electrometer directly affects on the accuracy and precision in radiation dosimetry. This study is to list of the quality control for maintaining performance and to perform evaluation tests of an electrometer. Performance tests selected include proper polarizing voltages, warm-up and equalization time, leakages, long-term stability, linearity, and effect of ambient conditions. An electrometer connected with a rigid stem ionization chamber was evaluated with a Strontium-90 check device. Bias voltage was measured directly on the input socket. Equalization time is the time required for reaching threshold of charged state after the power is on or the bias voltage is changed. Pre- and post-signal leakages are defined as the accumulation of signal with no exposure and after exposure, respectively. Over three months period, the electrometer's long-term stability was measured by comparison of the temperature-pressure corrected readings. Linearity was expressed as the deviation of readings from multiple short exposures from one continuous exposure. Effect of ambient conditions was expressed as the zero drift of the electrometer over 17-34^{0}C temperature ranges. For two nominal values, 300 and 500 volts, measured voltages were lower by 2.5 and 5.8%, respectively. The warm-up time, 20 minutes, was longer than the lamp time by 9 minutes and the equalization time was less than 1 minute. Without exposure, the zero-drift was 0.002 scale-unit in 15 minutes and the leakage after 10 minutes exposure was minimal. The IQ-4 was stable over 99.4% for three-month periods. Deviation from the linearity was 0.9% for measurement scale, 0.000-9.991. Over 17-34^{0}C temperature range, the zero-drift was minimal, less than 0.2%. For a clinically-used electrometer, a list for the basic performance evaluations is proposed. By running this program, the measurement error using an electrometer can be reduced and in turn the improvement in accuracy and precision of radiation dosimetry can be achieved.

Key Words: Radiation therapy, Performance, Electrometer, Ionization chamber, Quality control

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INTRODUCTION

The performance of an electrometer along with ionization chambers directly affects on the accuracy and precision of output calibration and radiation dosimetry. Desired characteristics of an electrometer used in a dosimetry system include and are not limited to 1) fast warm up (5-10 min) and equalization time after significantly changing voltage, ≤1 min, 2) pre- and post-signal zero drift should be negligible within one minute after zeroing the electrometer, 3) sensitivity should not be a function of ambient conditions, time and scale position, 4) consistency between ranges and functions, and 5) ability to change bias voltage, both magnitude and polarity, and to accept external bias.[1-3] Most clinically used electrometers, however, do not satisfy the criteria above and therefore it is highly recommended that their performances for routine use in radiation dosimetry including output calibration and field measurements are to be evaluated. Even though the performance of an electrometer can be evaluated well with ionization chamber connected, this study mainly focuses on the performance test of the electrometer itself and there was an effort to exclude tests which are strongly related to ionization chambers' performance. For the performance study of ionization chambers, another study was planned and has been done.

The purpose of this study is to show a list of quality assurance tests to keep the performance of an electrometer and to do performance tests of a clinically used electrometer. Here includes proper polarizing voltages, warm-up time and equalization time after high bias voltage, zero drift from the background current, leakage, long-term stability, linearity, and effect of ambient conditions. This study can be used to assist users in maintaining their instrumentation and in making accurate dosimetric measurements.

MATERIALS AND METHODS

Gamma-ray source for chamber exposure was Strontium-90 (0.9 mCi) loaded in the check device (Type 23261) with a hole in which a 0.3 cm^3 rigid stem chamber (M23332, PTW) could be fitted.

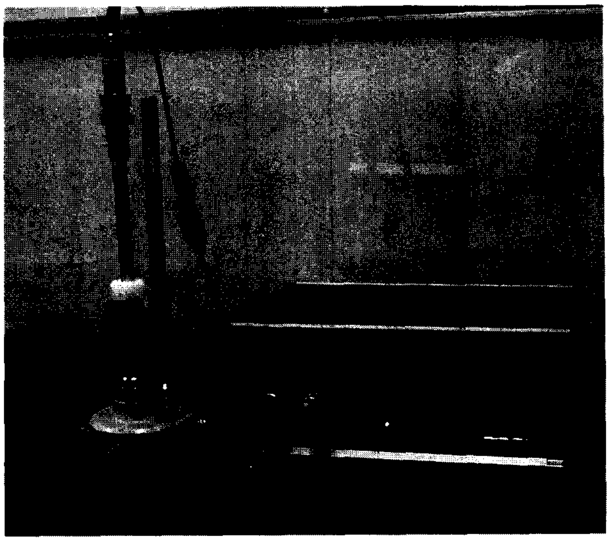


Fig. 1 Basic measurement setup. The check device with a rigid stem chamber and a thermometer is connected to the IQ-4 electrometer

The exposure rate in 10 cm distance from the source was less than 0.1 mR/h. The electrometer used in the study was an IQ-4 (PTW, Germany) and the basic measurement setup is shown in the Fig. 1.

Periodic checks of appropriate voltage readings should be a part of any quality assurance program and this is particularly true of battery operated instruments. The polarizing voltage is directly related to the ion collection efficiency and is more important in lower bias voltage range. The polarizing voltage is between the chambers collecting electrode and the entrance wall (thimble or window). There are two positive bias voltage settings possible in the IQ-4 electrometer, 300 and 500 volts. Applied voltages were measured with a multi-tester (YX-360TRD, Sanwa, Japan) from the chamber connector socket.

Warm-up and equalization time was measured after the electrometer is switched on and the voltage is changed, respectively. The IQ-4 has a heated amplifier and the temperature of the amplifier is automatically and continuously controlled. As long as the heating of the amplifier is switched on, the lamp is alight. From the intensity of the light of the lamp, one can see the magnitude of the heating current. The IQ-4 was switched off and was kept located at the same location of measurement for 24 hours. The temperature was 22.9 ^{0}C and the temperature was kept constant within 0.2 ^{0}C over the measurement. The bias potential was 300 volts. A 0.3 cm^3 chamber with the check device is connected to the electrometer. Immediately with switching on the electrometer, the accumulated readings were done up to 26 minutes in 30 s interval.

Equalization time is the time required for reaching threshold of charged state after the polarizing voltage is changed. The bias voltage was set to 300 V. The electrometer is switched on and after the warm-up time, 30 minutes, the bias voltage was switched up to 500 V. The time lapse to reach the threshold of charged state after the polarizing voltage is changed was measured. Reverse was measured.

There are two types in leakage, 1) inability to maintain a reading of zero in the measurement mode in the absence of radiation, and 2) the loss of charge that is accumulating on the capacitive feedback element in the inimkutegration mode.[2,4,5] The first is called the pre-signal leakage or zero-drift phenomenon and is more appropriately termed input offset current, which is commonly referred to as background signal. Without radiation, leakage was expressed as the zero-drift after the equilibrium. Zero-drift after irradiation was the indicator of background current. Background was measured in the integration (coulomb) mode. Sixty minutes after the power switch in on, thermal equilibrium, zero drift of the electrometer at the stable condition without any radiation was checked with a capacitor of 1 nF. Using this capacitor, the scale unit 0.001 per minute corresponds to a leakage current of about 2 × 10^{-14} C. The second called post-signal leakage was measured the loss of signal after the exposure to the chamber is done by the check device. When the exposure was done, the ionization chamber was disconnected from the electrometer to remove the effect from the chamber itself. Even though the typical time for reading after the exposure is less than 1 minute, this measurement was done up to 5 minutes after 10 minutes exposure to the chamber.

A 0.3 cm^3 chamber is introduced into the check device. The check device reading for 2 minutes integrating time is corrected for air density (20 ^{0}C and 760 mmHg). Care is taken that the temperature difference between the room temperature and temperature of the check device is smaller than 0.2 ^{0}C. To meet this requirement, the electrometer and the check device were in the room of measurement for at least 1 hour before the measurement was performed. After 2 minutes exposure reading, the result was corrected with the air density correction factor. This processes were repeated in about one month interval. The comparison of the temperature-pressure-corrected readings was done over three-month periods.

The relationship between display and dose should be examined over the whole measuring range. The rigid stem chamber was exposed in the check device. The scale unit 0.001 corresponds to about 2 × 10^{-14} C with 1 nF capacitor. The electrometer is switched on and after the warm-up time, 30 minutes, the measurement was started. The reading is done in 1 minute interval from 1 to 13 minutes and 5 minute interval from 15 to 25 minutes. Care was taken to reach the maximum reading digit, 9.999, as possible. To get the reading, the function Hold was used. By pressing button Hold the reading on the digital voltmeter was stored without disturbing the measurement. After the reading was done, by pressing button Hold once more, the display was connected with the voltmeter again and the display showed the momentary value. The average of three consecutive measurements for 1 minute

Table 1 Proper Polarizing Voltages. For two possible nominal voltages, the polarizing voltages are measured lower.

Nominal Voltage (V)	Measured Value (V)	Difference (%)
500	471.0	-5.8
300	292.3	-2.6

exposure was obtained. Reading discrepancy of one long exposure from the n times short exposure reading was expressed as a deviation from the linearity.

The zero-drift from atmospheric change was examined by changing the ambient condition, here temperature only. Room temperature was changed using a room air conditioner. The obtainable temperature range was 17-34 ^{0}C, which embraces the clinically accessible temperature range. The electrometer reading change in 10 minutes was the indicator of the zero drift and in turn the effect of ambient conditions. Three temperature points, 17, 24, and 34 ^{0}C, were selected for measurement.

RESULTS

For two possible nominal values, 300 and 500 V, measured polarizing potentials between the chambers collecting electrode and the entrance wall (thimble) are 292.3 and 471.0 volts, respectively(Table 1). Polarizing voltages were measured lower by 2.5 and 5.8%, respectively, for low and high bias voltages.

After the IQ-4 is switched on, the indication lamp of the electrometer for reaching threshold lasts 11 minutes at 22.9 ^{0}C. After 20 minutes after the IQ-4 is switched on, the decrease in charge accumulation and therefore the increase in potential is less than 1%(Fig. 2). In the instruction manual, however, it says that for about 15 minutes, the yellow lamp "Th" is alight

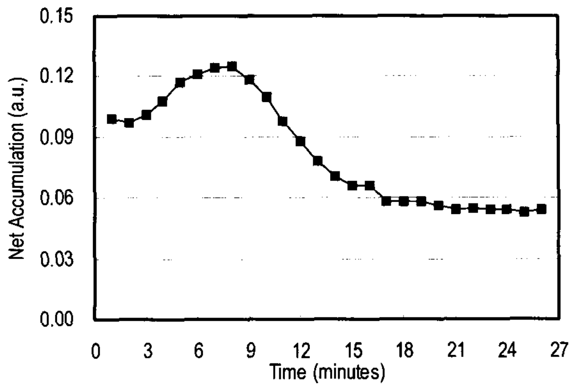


Fig. 2 Warm-up time. After 20 minutes after the IQ-4 is switched on, the increase in potential is found less than 1%.

until the amplifier is in thermal equilibrium.[5]

Measured equalization time after the polarizing voltage of the electrometer from 300 to 500 volts is less than 30 s. Measurement is similar for the other direction, from 500 to 300 volts.

Chamber leakages are shown in the Table 2. Table 2(a) shows the inability to maintain a reading of zero in the measurement mode in the absence of radiation. The pre-signal leakage is measured 0.009 scale unit ten minutes after the power is on. This corresponds 2×10^{-14} C leakage as a capacitor of 1 nF is used for the measurement. Based on the criterion of the electrometer, the display should be between 0.002

Table 2 Long-Term Stability. The IQ-4 is quite stable over 99.6% for three-month periods in different temperature and pressure environments.

	Measurement Condition		
Temperature (^{0}C)	25.0	23.5	26.0
Pressure (mmHg)	766.0	756.5	759.5
$C_{T,P}$	1.009	1.017	1.021
Reading	0.951	0.939	0.943
Corrected Rading	0.960	0.955	0.963

and +0.002 and should not changed by more than 0.001 per minute. After thermal equilibrium is reached, the loss of charge that is accumulating on the capacitive feedback element in the integration mode is found negligible within 0.001 scale unit. The drift is nil after 5 minutes with 10 minutes exposure(Table 2(b)).

Over three-month periods with different ambient conditions, temperature and pressure, the temperature-pressure corrected readings after two minutes exposure in check device are given in the Table 3. Before the air density correction, even though exposure times are same for three different electrometer readings, the variation in meter reading is close to 1%. The measuring results corrected with the air density correction factor show a standard deviation of less than 0.4%. Stability of the IQ-4 was over 99.6% for three-month periods with different temperature and pressure conditions.

Fig. 3 is relationship between display and dose over the whole measuring range, 0.000-9.991.

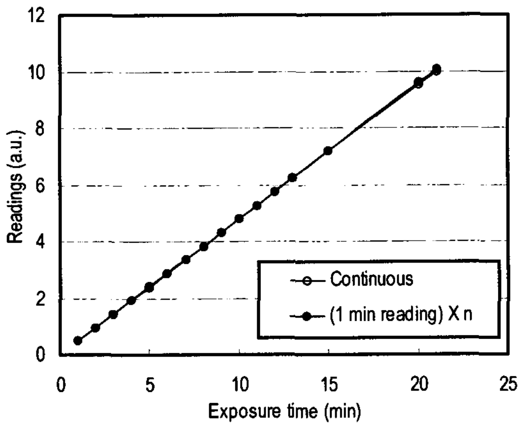
Table 3 Leakages: Pre-signal Leakage(a) and Post-signal Leakage(b). Zero-drift without any irradiation and post-signal leakages after 10 minutes exposure are shown.

(a)

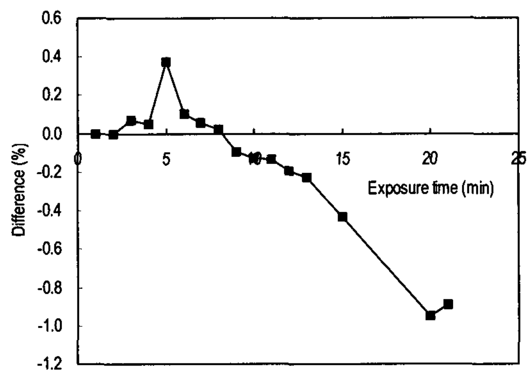
Time (minutes)	Reading (scale unit)
1	0.000
2	0.001
3	0.002
4	0.003
5	0.005
6	0.006
7	0.006
⋮	⋮
10	0.009

(b)

Time (minutes)	Reading (scale unit)
0.5	0.000
1	0.000
2	0.000
3	0.000
⋮	⋮
5	0.000



(a)



(b)

Fig. 3 Relationship between display and dose over the measuring range, 0.000-9.991. The plot of readings (arbitrary unit) against the exposure time for two cases, reading from Continuous Exposure (●) and Multiple of one minute exposure reading (○)(a). Discrepancy that the formal is less than the latter is found when the exposure time is large enough to reach the end of the measuring range(b).

Fig. 3(a) is the plot of Reading (arbitrary unit) against the Exposure time for two cases, Reading from Continuous Exposure (●) and Multiple of one minute exposure reading (○). That the former is less than the latter is found when the exposure time is large enough to reach the end of the measuring range. In the Fig. 3(b), the relationship between display and dose is within ±0.5% constant in the range from 0 to 15 minutes exposures, which corresponds to 0.000 to 7.169

Table 4 Effect of Ambient Conditions. The standard deviation of the zero-drift from the temperature change from 17 to 34 ^{0}C is minimal.

Temperature (^{0}C)	17	24	34
Drift in 10 minutes	0.009	0.008	0.008

digits and within ±0.9% thereafter.

The effect of the ambient conditions, especially temperature change, can affect the zero drift of the electrometer(Table 4). Over the obtainable temperature range, 17-34 ^{0}C, which embraces the clinically achievable temperature range, the standard deviation of the zero-drift was minimal, less than ±0.05%.

DISCUSSION

This study has been done for a clinically used electrometer of authors Radiation Oncology Department and the tests are mainly focused on one electrometer model, IQ-4. As many other electrometers have additional functions, some more factors have to be added in the performance tests. IQ-4 does not have the capability of changing polarity, negative bias voltage, as the additional voltage supply unit KS 4 is not equipped.[5] Most of electrometers have both polarities. When the output calibration is done, however, there is a factor to be considered from the bias voltage polarity, polarity effect. This has to be done if an electrometer has both polarities.

Collection efficiency is related to the incompleteness in collecting charges in the cavity volume due to ion recombination, which requires the use of a correction factor. The effect depends on the geometry of the chamber, the applied collection voltage, and the rate of charge production by the radiation.[6] For continuous radiation (gamma ray beams) the effect is reported very small.[7] Even though there is 5.8% difference in polarizing voltage for nominal voltage of 500 V, there is no doubt of resulting nil change in collection efficiency

Table 5 Pre-signal Leakage after the Off-set Adjustment. The standard deviation of the zero-drift from the temperature change from 17 to 34 ^{0}C is minimal.

Time (minute)	1	···	5	···	10	···	15
Reading (scale unit)	0.000	···	0.000	···	0.001	···	0.002

The pre-signal leakage tested was measured 0.009 scale unit(Table 2(a)). The leakage is outranged the values given in the Instruction Manual, saying that the display should be between -0.002 and +0.002 and should not changed by more than 0.001 per minute. The off-set current was adjusted by turning the screw U0, which gives less pre-signal leakage(Table 5). The pre-signal leakage was only 0.002 scale unit after the adjustment is done, which meets the acceptance test criteria. Humidity is another factor causing zero drift and has to be tested. Often excessive zero drift and capacitor leakage are caused by humidity, so these problems occur more often in the summer months.[8] This change in zero drift from an environment of greater than 60% relative humidity needs considered to be tested. It is strongly recommended to be informed to the manufacturer before the test is started as the electrometer is recommended to be used in lower humidity environment. When the electrometer is planned to be used or stored in higher humidity environment, one should consider keeping it in a ziplock plastic bag, possibly with desiccant.

Warm-up time was measured longer than the time in the users manual of the electrometer, 20 versus 15 minutes. Considering this in the authors department, it is routinely recommended to turn the instrument on at least 20 minutes ahead of use.

The check device is charged with 0.9 mCi Strontium-90 radioisotope, half life time of 28.5 ± 0.8 years. This means that the activity and in turn the reading is reduced by about 0.2% per month.[5)] In the measurement, the corrected reading with the air density correction factor shows a standard deviation of less than ±0.4%, which sits below the 0.6%, reduction in reading from the natural decay of the source. This says the electrometer is stable over 99.6% for three-month periods with different temperature and pressure conditions.

CONCLUSION

For a clinically-used electrometer, a list for the basic performance evaluation is proposed and basic performance tests are performed. Here includes proper voltage levels, warm-up time and equalization time after high voltage, leakage, zero drift from the background current, long-term stability, linearity, and effect of ambient conditions. The methods can be adapted and test procedures can be used as references for performance tests of most of clinically used electrometers. This study can be used to assist users in maintaining their instrumentation and for the improvement of the accuracy and precision of radiation dosimetry.

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방사선 치료의 정도관리 및 선량측정에 이용되는 전리계의 성능평가

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전리계의 성능은 방사선 선량측정의 정확도와 정밀도에 직접적으로 영향을 준다. 본 연구에서는 전리계의 성능을 유지하기 위한 정도관리의 항목들을 제시하고 구체적인 성능검사를 시행하고자 한다. 선정된 성능평가 항목들은 적절한 인가전압, 예열 및 고전압 후의 평형시간, 누설에 의한 상쇄전류, 방사선 측정 전후의 영점이동 (배경전류), 장시간 안정성, 선형성, 외부조건의 영향 등이었다. 전리계에 연결된 자루가 단단한 전리함과 방사선원으로 스트론티움-90이 내장된 검사기가 성능검사용으로 이용되었다. 인가전압의 측정은 전리함의 입력단자에서 직접 측정하였고 평형시간의 측정은 전리계에 전원을 연결한 후와 인가전압을 바꾼 후 검사기에 연결된 전리함의 반응이 안정을 가져오는 시간으로 측정하였다. 누설은 전리계가 안정된 후 방사선을 조사하지 않은 상태에서 전리계의 측정값이 영점에서 이동하는 것으로 나타냈으며 배경전류는 안정된 전리계의 영점을 조정하고 전리계에 연결된 검사기에서 전리함을 10분 조사한 후 영점의 변화로 나타냈다. 장시간의 안정성 3개월에 걸쳐 측정되었으며 이때 검사기의 측정값을 온도-기압에 대한 보정을 한 후 그 값을 비교하였다. 선형성은 전리계에 연결된 전리함을 n번 연속하여 조사하여 그 전체의 측정값과 초기값을 n번 곱한 값을 비교하였다. 외부조건의 영향은 인위적으로 외부온도를 17-34 ^{0}C 로 변화시켜서 환경변화에 의한 전리계의 영점이동으로 나타냈다. 인가전압의 측정에서 명목상의 인가전압 300, 500 V에 대한 측정값은 각각 2.5%와 5.8% 작게 나타났다. 전원을 연결한 후 전리계가 실제로 평형에 도달하는 시간은 20분으로 이는 전리계의 안정성 표시기보다 9분 지연되었으며 인가전압을 바꾼 경우에는 1분 이내에 평형에 도달하였다. 전리계의 누설의 측정에서 영점의 이동은 0.002(스케일)/15분이었고 10분 조사 후 영점의 이동은 발견되지 않았다. 전리계는 3개월 동안 99.4%의 안정성을 유지하였다. 스케일 영역 0.000-9.991 에서 전리계의 선형성에서의 이탈은 0.9% 이었다. 온도 범위 17 - 34 ^{0}C 에서 전리계의 영점이동은 0.2% 이내였다. 본 연구에서는 임상에서 사용하고 있는 전리계에 대한 성능을 평가하는 항목을 제시하고 이를 전리계의 정도관리에 이용하도록 하였다. 이러한 프로그램의 운용을 통하여 전리계에 의한 오차를 줄임으로써 방사선측정에서의 정확도와 정밀도를 향상시킬 수 있을 것으로 사료된다.

중심단어: 방사선 치료, 성능검사, 전리계, 전리함, 정도관리