Calibration of ionization chamber survey meter

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Abstract

Radiation measuring devices need to process calibration which lose their sensitivity and the extent of the response and the amount of stability under a changing conditions from time to time and this period depends on the nature and use of field in which used devices. A comparison study was done to a (451P) (ionization chamber survey meter) and this showed the variation of calibration factor in five different years. This study also displayed the concept of radiation instrument calibration and necessity of every year calibration of them.

In this project we used the five years calibration data for ionization chamber survey meter model Inspector (451P) to get that the values of Calibration Factor (CF) and Response (1/CF). The value deviation (Δ%) of CFs for four years of calibration in comparison of CF for the year 2007 are very high and the device under research is not good to use in field and reliable because the ionization chamber is very sensitive to humidity and must calibrate a year or less, or during every two years and must maintain carefully to reduce the discarded effects to the measurements.

Key words

Calibration factor, Ionization Chamber, Deviation.

Article info.

Received: Feb. 2016
Accepted: Mar. 2016
Published: Apr. 2016

معايرة جهاز القياس الإشعاعي (غرفة التأين)

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الخلاصة

تحتاج أجهزة القياس الإشعاعي الى عملية معايرة والتي تفقد حساسيتها ومدى إستجابتها للقياس ومقدار كفائتها في الظروف المتغيرة بين فترة وأخرى وهذه الفترة تعتمد على طبيعة الاستخدام والمجال المستخدمة فيه هذه الأجهزة. حيث تم إجراء دراسة المقارنة هذه لجهاز القياس الإشعاعي (451P)(حجرة التأين) وأظهرت الإختلاف لعامل المعايرة خلال خمس سنوات وكذلك بينت هذه الدراسة مفهوم معايرة جهاز القياس الإشعاعي وضرورة إجرائها. في هذا البحث تم إستخدام قراءات المعايرة لجهاز القياس الإشعاعي (451P)(حجرة التأين) وحصلنا على قيم عامل المعايرة والإستجابة. وإن نسبة الإنحراف (Δ%) عند مقارنة عوامل المعايرة للسنوات الأربعة (2010, 2011, 2012, 2013) مع عامل معايرة السنة (2007) نجدها مرتفعة جدا وبذلك فالجهاز غير موثوق به للعمل والقياس، ذلك بسبب ان كاشف حجرة التأين حساس جدا للرطوبة ويجب معايرته سنويا أو اقل أو خلال كل سنتين والمحافظة عليه للحد من الآثار السلبية المحتملة على القياسات.

Introduction

Radiation instruments used as survey monitors are either gas filled detectors or solid state detectors (e.g. scintillator or semiconductor detectors). A gas filled detector is usually cylindrical in shape, with an outer wall and a central electrode well insulated from each other. The wall is usually made of tissue equivalent material for ionization chamber detectors and of brass or copper for other types of detector [1, 2].

The purposes of calibration are:

- To determine calibration factors and response of x and gamma radiation of ionization chamber survey meters [3].
- To determine of photon energy dependence of radiation survey meters.
- Comparison of calibration factors and response using x and gamma radiation of same model of ionization chamber survey meter with different years [3, 4].
- To ensure that an instrument is working properly and hence will be suitable for its intended monitoring purpose.
- To adjust the instrument calibration, if possible, so that the overall measurement accuracy of the instrument is optimized.

Calibration of survey meters

Calibration is defined as the quantitative determination, under a controlled set of standard conditions, of the indication given by a radiation measuring instrument as a function of the value of the quantity the instrument is intended to measure.

In general, reference instruments do not directly indicate the appropriate dose equivalent quantity for calibrations or type tests. Instead, most frequently reference instruments are used to characterize the reference radiation fields by other measured such as fluence for neutron radiation and air kerma for photon radiation (Fig.1).

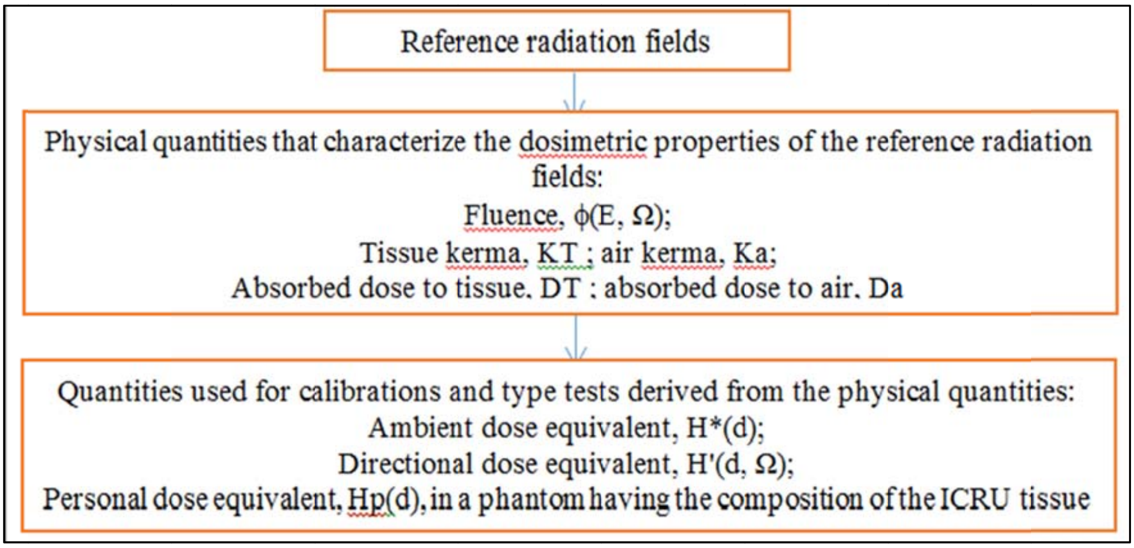

Fig.1: Reference radiation fields, physical quantities that characterize the dosimetric properties of the reference radiation fields, and quantities used for calibrations and type tests.

Protection level area survey meters must be calibrated against a reference instrument that is traceable (directly or indirectly) to a national standards laboratory [4, 5, and 6].

A reference instrument for γ radiation is generally an ionization chamber with a measuring assembly. Reference instruments do not indicate directly the dose equivalent *H* required for calibration of radiation protection monitoring instruments. Rather, they measure basic radiation quantities such as the air kerma in air for photon radiation, and the dose equivalent *H* is then determined by using appropriate conversion coefficients *h*:

$H = hCF_R M_R$ [3]

Where CF_R is the calibration factor (e.g. in terms of air kerma in air or air kerma rate in air) of the reference chamber under reference conditions;

M_R is the reading of the reference instrument corrected for influence quantities.

A reference instrument is calibrated free in air for the range of reference radiation qualities (defined by the International Organization for Standardization (ISO)). The same reference qualities should be used for the calibration of radiation protection monitoring instruments.

Typically, calibration of survey meters in terms of the ambient dose equivalent $H^*(10)$ involves three steps:

- The air kerma in air is measured in a reference field, using a reference standard.
- The values of the conversion coefficient:

$h_{H^*} = [H^*(10)/(K_{air})_{air}]$ [3].

are theoretically available. Using these data for the calibration beam quality, a reference instrument reading can be converted to H*(10).

The survey monitor being calibrated is then placed at the calibration point and its reading M is determined. The calibration factor in terms of the ambient dose equivalent N_{H^*} for the survey monitor is determined from the equation

$CF_{H^*} = H^*(10)/M$ [3].

There are four methods of calibration of survey meter

- Method 1: calibration with a reference instrument without any monitor;
- Method 2: calibration with a reference instrument and with a monitor;
- Method 3: calibration by simultaneous irradiation of reference instrument and instrument under calibration;
- Method 4: calibration in a known radiation field [3, 7, and 8].

In this project calibrations are performed either by the substitution method (Method 4, comparing the response of the instrument to be calibrated with that of a reference standard instrument) or simultaneous method (Method 3, both instrument to be calibrated and reference standard instrument are placed in the radiation beam at the same time and irradiated together). These methods are normally used when the radiation survey meters are calibrated for exposure to x-ray beams. Calibration is performed in a known radiation field when the survey meters are calibrated against gamma, beta and neutron beams. For a radiation field in which the dose equivalent quantity *H* of the field at the point of test is known, the calibration factor of an instrument CF is obtained by

$CF = H / M$

where *CF* is the calibration factor of the instrument under calibration (under reference conditions); M is the measured value of the instrument under calibration, corrected for reference conditions, i.e. multiplication by appropriate correction factors (e.g. differences in air density);

H is the conventional true value of the dose equivalent quantity to be measured.

Materials

Reference photon radiation selected from ISO Standard 4037-1 is used for calibration of radiation survey instruments and for the determination of their energy response. Standardization of ^{137}Cs, ^{60}Co, and ^{241}Am gamma sources (protection level) at various distances using reference standard dosimeters are performed once a year with an accuracy of better than ± 2%.

Calibration with beta radiation is performed using beta secondary standard sources whose absorbed dose rates at particular distances for each $^{90}Sr/^{90}Y$, ^{85}Kr and ^{147}Pm sources have been determined by the Physikalisch-Technische Bundesanstalt (PTB), the national standard laboratory of

Germany or by using PTW extrapolation ionization chamber.

In this work the following materials and instrument were used:

1. Pressurized ionization chamber survey meter model 451P-DE-SI-RYR.
2. Radiation sources.

a. Ceasium-137 (740GBq) and Cobalt-60 (37GBq) sources from Gamma Calibrator model OB 85.

b. Ceasium-137 (7.4MBq – 7.4GBq) and Cobalt-60 (3.7MBq – 370MBq) sources from Panoramic Gamma Irradiator model OB 34.

c. X-ray sources (Universal Bipolar Constant Potential X-ray Systems MG 325).

3. Working standard ionization chamber model PTW 32002 (1,000 cc).
4. Calibration bench. 5. CCTV. 6. Laser alignment. 7. Telescope. 8. PTW-Unidos electrometer. 9. Digital thermometer. 10. Barometer. 11. Hygrometer. 12. Area monitor. 13. Personal computer.

Methods

1. Calibration using Cs-137 gamma radiation

Calibration of the survey meter should be carried out on at least one point e.g. 50% of the full scale on each measuring range of the survey meter or in each decade for a survey meter with a logarithmic scale or with digital indication.

The conventional true value of exposure rate or dose rate at the point of test for survey meter are determined by using secondary standard ionization chamber.

The steps in the calibration procedures are:

➢ Set the survey meter at appropriate exposure rate/dose rate range.

➢ Place the survey meter in the calibrated source beam at appropriate distance from the sources. Ensure the survey meter is in the middle of the beam.

➢ Expose the survey meter with radiation sources.

➢ Record the meter reading displayed on the survey meter at least five times within a regular interval of time e.g. 10 seconds.

➢ Calculate the average reading value and standard deviation.

➢ Calculate the calibration factors.

➢ Repeat these procedures for other exposure rate or dose rate range.

2. Calibration using Co-60 gamma source

The calibration should be carried out in the 50% of the full scale at one Measuring range. Repeat same procedures that followed with Cs-137 [3, 4].

3. Calibration using X- ray machine (60 kV – 250 kV)

The calibration should be carried out in the 50% of the full scale at one measuring range.

➢ Set the survey meter at low exposure rate/dose rate range.

➢ Place the survey meter in the calibrated source beam at appropriate distance from the sources. The calibrated x-ray beam is determined by using working standard ionization chamber model PTW 32002, which has been calibrated against secondary standard ionization chamber. The survey meter and the ionization chamber must be the same distance from the X-ray source. First the working standard ionization chamber is used to determine the exposure rate or dose rate and then the reading of survey meter is determined.

➢ Expose the working ionization chamber with 60 kV X-ray with appropriate current (mA). Determine the exposure rate or dose rate.

➢ Expose the survey meter with 60 kV X-ray.

➢ Record the meter reading displayed on the survey meter at least five times within a regular interval of time e.g. 10 seconds.

- Calculate the average reading value and standard deviation.
- Calculate the calibration factors.
- Repeat these procedures for other radiation qualities i.e. 100 kV, 150 kV, 200 kV and 250 kV [3, 4].

Results and discussion

1. Linearity Test using ^{137}Cs

Linearity test must be performed previously before calibrate the ionization chamber survey meter, Linearity test is performed using gamma source ^{137}Cs given at Table 1 and is shown in Fig. 2.

Table 1: Linearity test using ^{137}Cs.

	Range	Range correction factor						
		2007	**2010**	**2011**	**2012**	**2013**	**Up border**	**Low border**
1.	0-5 µSv/h	0.93	1.056	0.934	0.96	0.78	1.2	0.8
2.	0-50 µSv/h	0.957	0.943	0.945	0.943	0.887	1.2	0.8
3.	0-500 µSv/h	0.954	0.995	1.002	1.006	0.973	1.2	0.8
4.	0-5 mSv/h	1	1	1	1	1	1.2	0.8
5.	0-50 mSv/h	0.984	1.025	1.025	1.042	0.957	1.2	0.8

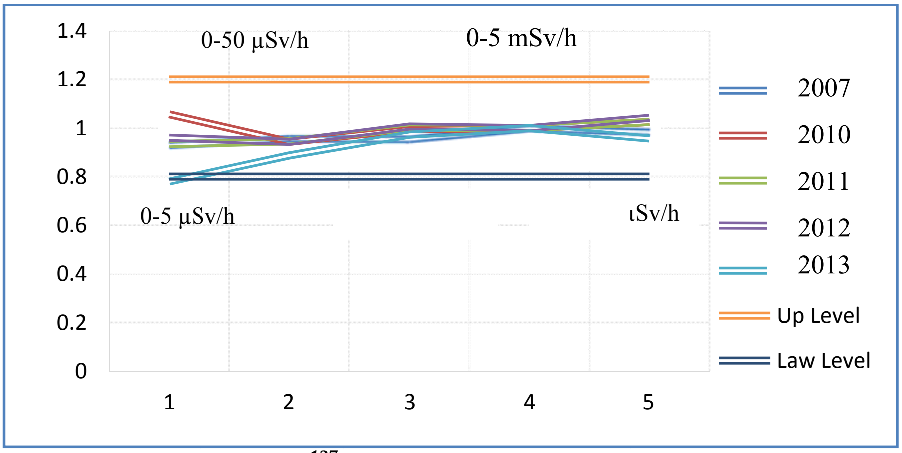

Fig.2: Linearity comparison, using ^{137}Cs of ionisation chamber survey meter model 451P, for 5 different years.

To get true value of measurement using survey meter which has many scales besides using calibration factor also have to be corrected using range correction factor. This Fig.2 show about linearity of the ionisation chamber survey meter at 5 ranges, whereas linearity of survey meter acceptable when its deviation about ± 20 %. From the graph, there is one of range correction factor (linearity) which has value less than 0.8, so it is out of acceptable range.

2. Calculate of the calibration factor and response

Tables 2-6 shows the calculate calibration factors and response in 5 different years as shown in Fig. 3 and 4.

Table 2: Calibration factors and response of 451P survey meter in 2007.

R.Q	C mA	E KeV	CF.S mSv/nC	Readings E.C nC/min	Readings S.R mSv/y	Readings SM.R mSv/y	CF	R (1/CF)	HVL mm	(T),(P),(H)
N-60	2.88	47	0.0281	2.320	3.955	2.5	1.582	0.6321	0.24	T :21.76 °C P :1003.6 mbar H :66.36 % Ktp :1.016
	Additional filter : 4.0 mm Al + 0.62 mm Cu									
N-100	8.75	84	0.0279	1.930	3.282	2.5	1.313	0.7616	1.14	
	Additional filter : 4.0 mm Al + 5.04 mm Cu									
N-150	0.94	121	0.0283	1.857	3.198	2.5	1.279	0.7818	2.42	
	Additional filter : 4.0 mm Al + 2.5 mm Sn									
N-200	1.80	171	0.0284	1.796	3.114	2.5	1.246	0.8052	4.16	
	Additional filter : 4.0 mm Al + 2 mm Cu + 3 mm Sn + 1 mm Pb									
N-250	1.93	218	0.0290	1.809	3.193	2.5	1.277	0.7831	5.38	
	Additional filter : 4.0 mm Al + 2 mm Sn + 3 mm Pb									
Cs-137	-	662	-	-	2.5	1.822	1.372	0.7288	-	T :21.3 °C P :997.8 mbar H :51.63 %
Co-60	-	1250	-	-	2.5	1.822	1.372	0.7288	-	T :21.3 °C P :997.8 mbar H :51.63 %

Table 3: Calibration factors and response of 451P survey meter in 2010.

R.Q	C mA	E KeV	CF.S mSv/nC	Readings E.C nC/min	Readings S.R mSv/y	Readings SM.R mSv/y	CF	R (1/CF)	HVL mm	(T),(P),(H)
N-60	3.05	47	0.0281	2.472	4.248	2.5	1.699	0.5886	0.24	T :21.76 °C P :1003.6 mbar H :66.36 % Ktp :1.016
	Additional filter : 4.0 mm Al + 0.62 mm Cu									
N-100	9.30	84	0.0281	2.039	3.510	2.5	1.404	0.7122	1.08	
	Additional filter : 4.0 mm Al + 5.04 mm Cu									
N-150	0.94	121	0.0284	1.916	3.424	2.5	1.370	0.7299	2.46	
	Additional filter : 4.0 mm Al + 2.5 mm Sn									
N-200	1.60	171	0.0286	1.916	3.356	2.5	1.342	0.7451	4.07	
	Additional filter : 4.0 mm Al + 2 mm Cu + 3 mm Sn + 1 mm Pb									
N-250	1.95	218	0.0288	1.9196	3.386	2.5	1.344	0.7440	5.32	
	Additional filter : 4.0 mm Al + 2 mm Sn + 3 mm Pb									
Cs-137	-	662	-	-	2.5	1.471	1.372	0.6798	-	T :21.3 °C P :997.8 mbar H :51.63 %
Co-60	-	1250	-	-	2.5	1.400	1.372	0.7143	-	T :21.3 °C P :997.8 mbar H :51.63 %

Table 4: Calibration factors and response of 451P survey meter in 2011.

R.Q	C mA	E KeV	CF.S mSv/nC	Readings E.C nC/min	Readings S.R mSv/y	Readings SM.R mSv/y	CF	R (1/CF)	HVL mm	(T),(P),(H)
N-60	4.78	47	0.0281	2.610	4.501	2.5	1.801	0.5552	0.24	T :22.5 °C P :99.9 mbar H :48 % Ktp :1.023
	Additional filter : 4.0 mm Al + 0.62 mm Cu									
N-100	14.6	84	0.0281	2.190	3.774	2.5	1.510	0.662	1.08	
	Additional filter : 4.0 mm Al + 5.04 mm Cu									
N-150	1.59	121	0.0285	2.0608	3.603	2.5	1.441	0.6993	2.46	
	Additional filter : 4.0 mm Al + 2.5 mm Sn									
N-200	2.51	171	0.0286	2.0489	3.359	2.5	1.340	0.6944	4.07	
	Additional filter : 4.0 mm Al + 2 mm Cu + 3 mm Sn + 1 mm Pb									
N-250	2.92	218	0.0289	2.0164	3.576	2.5	1.431	0.6988	5.32	
	Additional filter : 4.0 mm Al + 2 mm Sn + 3 mm Pb									
Cs-137	-	662	-	-	2.5	1.636	1.528	0.6544	-	T :21.5 °C P :996 mbar H :69.2 %
Co-60	-	1250	-	-	2.5	1.752	1.427	0.7007	-	T :23 °C P :998 mbar H :50.5 %

Table 5: Calibration factors and response of 451P survey meter in 2012.

R.Q	C mA	E KeV	CF.S mSv/nC	Readings E.C nC/min	Readings S.R mSv/y	Readings SM.R mSv/y	CF	R (1/CF)	HVL mm	(T),(P),(H)
N-60	4.0	47	0.0281	2.1944	3.763	2.0	1.882	0.5313	0.24	T :22 °C P :1003 mbar H :40 % Ktp :1.017
	Additional filter : 4.0 mm Al + 0.62 mm Cu									
N-100	11.8	84	0.0281	1.7804	3.051	2.0	1.525	0.6557	1.08	
	Additional filter : 4.0 mm Al + 5.04 mm Cu									
N-150	1.30	121	0.0285	1.6864	2.932	2.0	1.466	0.6821	2.46	
	Additional filter : 4.0 mm Al + 2.5 mm Sn									
N-200	2.10	171	0.0286	1.7082	2.983	2.0	1.492	0.6702	4.07	
	Additional filter : 4.0 mm Al + 2 mm Cu + 3 mm Sn + 1 mm Pb									
N-250	2.40	218	0.0289	1.7450	3.077	2.0	1.539	0.6498	5.32	
	Additional filter : 4.0 mm Al + 2 mm Sn + 3 mm Pb									
Cs-137	-	662	-	-	2.5	1.598	1.564	0.6394	-	T :22 °C P :1001 mbar H :45 %
Co-60	-	1250	-	-	2.5	1.752	1.427	0.7007	-	T :21.3 °C P :1003 mbar H :50 %

Table 6: Calibration factors and response of 451P survey meter in 2013.

R.Q	C mA	E KeV	CF.S mSv/nC	Readings E.C nC/min	Readings S.R mSv/y	Readings SM.R mSv/y	CF	R (1/CF)	HVL mm	(T),(P),(H)
N-60	3.40	47	0.0282	1.3614	2.35	2.5	0.941	1.0626	0.24	T :23 °C P :1003 mbar H :57 % Ktp :1.021
	Additional filter : 4.0 mm Al + 0.62 mm Cu									
N-100	9.0	84	0.0283	0.9298	1.61	1.918	0.842	1.1876	1.08	
	Additional filter : 4.0 mm Al + 5.04 mm Cu									
N-150	1.53	121	0.0284	1.3790	2.40	2.5	0.961	1.0406	2.46	
	Additional filter : 4.0 mm Al + 2.5 mm Sn									
N-200	2.55	171	0.0287	1.4538	2.56	2.5	1.023	0.9775	4.07	
	Additional filter : 4.0 mm Al + 2 mm Cu + 3 mm Sn + 1 mm Pb									
N-250	2.90	218	0.0289	1.4244	2.52	2.5	1.008	0.9920	5.32	
	Additional filter : 4.0 mm Al + 2 mm Sn + 3 mm Pb									
Cs-137	-	662	-	-	2.5	2.20	1.136	0.8803	-	T :23 °C P :997 mbar H :74.1 %
Co-60	-	1250	-	-	2.5	2.260	1.106	0.9041	-	T :23 °C P :997 mbar H :74.1 %

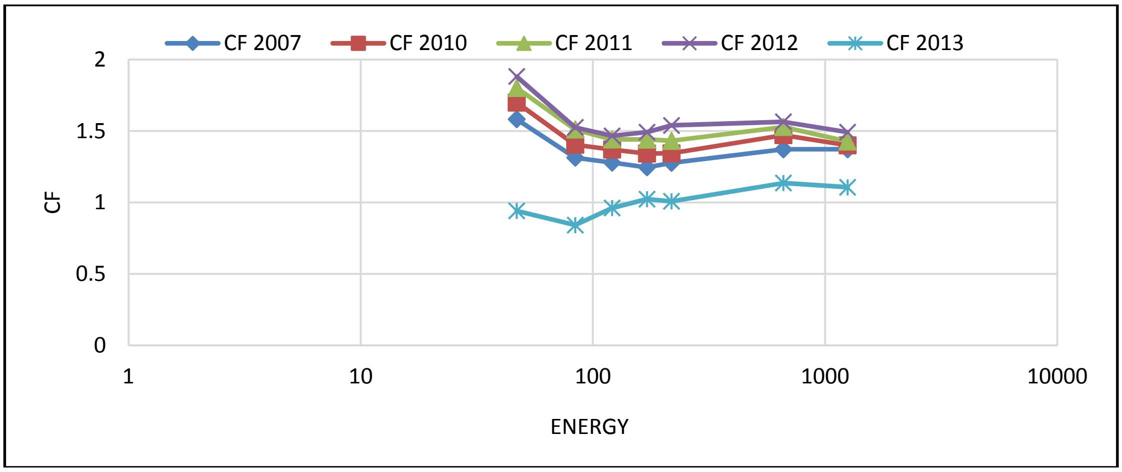

Fig.3: Calibration factors of 451P survey meter in 5 different years.

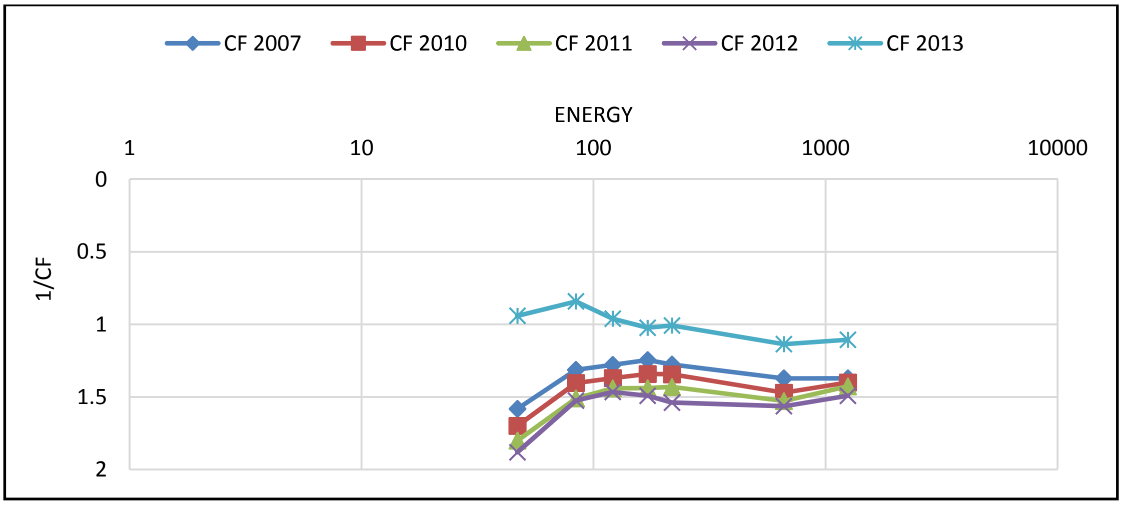

Fig.4: Response of 451P survey meter in 5 different years.

Comparison of calibration factors between year 2007 and other year is shown in Table 7. As can be seen CFs are changing from year to other year.

Percentage deviation:

$$\Delta\% = \frac{CF(year) - CF(2007)}{CF(2007)} \times 100$$

Table 7: Comparison of CFs between year 2007 and other years.

Energy	Percentage deviation (Δ%)			
	2010	**2011**	**2012**	**2013**
47	7.39	13.83	18.96	-40.52
84	6.93	15	16.14	-35.87
121	7.11	12.66	14.62	-24.86
171	7.70	15.57	19.74	-17.90
218	5.24	12.06	20.52	-21.06
662	7.21	11.73	13.99	-17.20
1250	2.04	4.01	8.74	-19.39

*The acronyms in Tables (2, 3, 4, 5, and 6) are explained in Table 8.

Table 8: The acronyms in Tables (2, 3, 4, 5, and 6).

	Acronyms	Meaning		Acronyms	Meaning
1.	R.Q	Radiation Quality	8.	CF	Calibration Factor
2.	C mA	Current	9.	R (1/CF)	Response
3.	E KeV	Energy	10.	T	Temperature
4.	E.C nC/min	Electrometer Charge	11.	P	Pressure
5.	S.R mSv/y	Standard Reading	12.	H	Humidity
6.	SM.R mSv/y	Survey Meter Reading			
7.	CF.S mSv/nC	Calibration Factor Standard			

Radiation survey meters are used to measure the presence of any radiation from radioactive sources or radiation generators such as X-ray machine and linear accelerator. The proper calibration of these instruments is to ensure that all meters are working correctly. Annual calibrations are required for all the type of survey meters. But the survey meters use in the radiation facilities with very high activity sources (eg: Co-60 plant), the calibration should be done at once in six months. Portable radiation survey meters must be calibrated at least annually to an accuracy of ±20 percent for the gamma energy of the sources in use. Portable radiation survey meters must be of a type that does not saturate and read zero at high radiation dose rates.

The calibration of ion chamber is mandatory to fulfill the legal requirement and IAEA recommendation to ensure that the measurements are compatible with those made elsewhere, assure constancy to promote customer acceptance. The pressurize ionization chamber was calibrated on 06 Sep 2013, with Co-60, Cs-137 gamma energies and five energies of x rays.

The calibration factors of ionization chamber survey meter are changing from time to time.

For example, the calibration factors of survey meter are deviated from -41% to +21% compare with calibration factor of 2007 (refer Table.7).

The ionization chambers are sensitive, reliable and good energy response to x-ray and gamma radiation. They should be maintained and keep carefully in the dry cabinet if they aren't in use.

The poor maintenance will give high background reading of the survey meter due to leakage current. High humidity can cause the massive variation in CF. The chamber is very sensitive to the humidity which can cause high leakage current of the chamber and that leads to high variation of CF. To reduce the avoidable leakage due to humidity, chamber must be kept inside a dry cabinet or desiccator which might be kept relative humidity always less than 50%.

The insulator of the chamber must be with low surface conductivity to reduce the unwanted component to the signal through leakage as well. The resistance of the insulator must be greater than 1016 Ω. Thus the instrument should be compiled with the insulators as amber, polystyrene, polyethylene, nylon and Teflon.

When Calibrate the survey meters,

- Calibrations are to be conducted in an isolated area of the facility where the background radiation is low.
- The individual conducting the calibration shall wear a dosimetry badge.
- A calibrated survey meter should be used as a referenced standard to ensure that unexpected changes in exposure rates are identified.
- A radioactive sealed point source shall contain a nuclide which emits a strong enough radiation field of similar type and energy that would be seen in labs.
- The survey meter calibration should be considered successful if the exposure rate differs from the calculated rate by less than 20%.
- Records shall be kept of each survey performed, and will include owner of instrument; manufacturer's name, model number and serial number; signature of individual who performed the calibration; date the calibration was performed; and next expected calibration date.
- All records of calibration results should be kept for at least three years or requirement of the organization. Radiation Safety Officer should be informed, if any survey meter calibration is out of date or any new purchase or disposal of survey meters.

The results can be concluded that the ionization chamber or survey meters must calibrate annually and must maintain carefully to reduce the discarded effects to the measurements. The calibration of survey meter should be performed by means of gamma sources such as Cs-137 and Co-60 and x-rays.

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