A status report on ongoing quality assurance measurements in contemporary radiology

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Abstract

Dosimetric and other Quality Assurance related measurements in contemporary Radiology are inevitable, in order to ensure image-optimization, combined with Patient-safety enhancement. Therefore, we have set-up a program of relevant parameter measurements in Diagnostic Radiology, concerning various types of equipment, installed in Hospitals and other facilities, in the Attica district. In this first phase of the project, the measurements have been focused on following Radiology equipment, mostly after major service or repair. Simple X-ray Radiography systems with Bucky, Fluoroscopy Systems, Analogue Mammography systems (Mo-Rh Anode and Mo-Rh-Al filters), Digital Mammography with solid-state detectors, Dental X-ray equipment and CBCT. Extended High-voltage, Current, Energy spectra, Primary and Scattered Radiation Exposure free-air, Absorbed-dose etc. measurements have been carried out and documented, according to the Manufacturers' and/or Radiation Protection Guidelines and Protocols; a short report of the results of this on-going project is presented in this paper.

Key words: X-Ray Dosimetry, X-Ray Spectrometry, High-voltage measurements, Current measurements.

Introduction

Dosimetry and other Quality Assurance related measurements in contemporary Radiology are inevitable, in order to ensure image-optimization combined with patient-safety enhancement. Therefore, we have set-up a program of relevant parameter measurements in Diagnostic Radiology, concerning various types of equipment, installed in Hospitals and other facilities, in the Attica district. In this first phase of the project, the measurements have been focused on following Radiology equipment, mostly after major service or repair:

- Simple X-ray Radiography systems with Bucky.
- Fluoroscopy Systems.
- Analogue Mammography systems (Mo-Rh Anode and Mo-Rh-Al filters).
- Digital Mammography with solid-state detectors.
- Dental X-ray equipment.
- CBCT.

Extended High-voltage, Current, Energy spectra, Primary and Scattered Radiation Exposure free-air, Absorbed-dose etc. measurements have been carried out and documented, according to the Manufacturers' and/or Radiation Protection Guidelines and Protocols, in the above mentioned X-ray equipment. Table 1 presents the measuring equipment employed during this variety of measurements.

The conventional X-ray examinations still have the largest share of radiological examinations of the population, since they are sufficiently inexpensive and appropriate to answer many diagnostic questions. The technical development towards Digital Radiology has the advantage of virtually unlimited digital storability of the investigations and the easier digital transmission of image-data to other health-care facilities. Solid-state detectors enable comparable diagnostic image quality and a thus, further reduction of patients' Radiation Exposure.

Kilovoltage and current quality assurance measurements

The voltage applied across an X-ray tube determines the intensity and the energy (quality) of X-rays produced during exposure. Peak kilo-voltage (kVp) is the maximum voltage applied across the X-ray tube and governs the maximum energy of X-rays produced. Accurately calibrated and consistent kVp's are important in diagnostic imaging, to control both, optical density and contrast of the x-ray image, as well as, radiation dose to the patient.

The operator's manual should be consulted for limitations and proper operation of the employed meters. Some instruments need a limited range of exposure or exposure rate for proper operation and may require reducing distance for measurements at a low kVp or mA. Others are sensitive to positioning and tilting, with respect to the central ray. Others may require additional correction factors, for use with heavily filtered X-ray tubes or high frequency generators (cf. equipment in Table 1).

It is essential that the user be aware of the potential problems that may be encountered, and sceptical of measurements that vary from expected results. Perhaps the best advice is to note the unusual reading and indicate that further investigation by service personnel appears warranted. The most direct way of measuring kVp is by using a high voltage divider. This invasive test device is connected between the generator and the x-ray tube and provides isolated low level analogue voltage signals, proportional to the kilovoltage applied across the tube. The signal waveforms can be displayed and analyzed on an external oscilloscope or measured by a digital meter. The peak kilovoltage can be visually determined from the voltage waveform displayed on the oscilloscope. These devices are typically intended for calibration and analysis of X-ray generators. Electronic, non-invasive kVp devices provide a measurement based on the change in x-ray transmission through varying thicknesses of filtration.

Table 1. Some of the measuring equipment employed during the performed measurements

PTW "Diavolt" kV meter / timer	"Siemens" High Voltage (HV) Tank Blinder	"Gammex" mA/mAs meter up to 2000 mA up to 3 sec	Precision Multi-meters Portable Oscilloscope "Fluke" 189	"AMPTEK" XR-100 T CdTe X-ray Spectral Analyzer
"Gammex RMI 240" kVp meter / timer	Oscilloscope "Hameg" 2- Channel A/D Autoset	"GE" dosimeter up to 40 kV (mammography up to 20 mGy)	Photo-sensitive plates	"Solidose" RTI Electronics 300/308/400 Dose-meter

These devices are accurate (if properly used) and are widely employed, for routine quality control, due to their ease of use. However, it is important to understand how the meter works and what measurement variables may affect the accuracy of the results. These considerations may vary from one type of meter to another, and from one generator to the next one. The kVp meter basically consists of a pair of matched, closely spaced diodes that are filtered by different thicknesses of material, e.g. copper.

Figure 1. Two indicative measuring systems employed during Quality Assurance measurements.

Set Mode kV	Measured kV	Variation %	Set Mode mAs	Measured mAs	Variation %
40	40,3	0,75	5	5	0,00
50	50,7	1,40	10	9	**-10,00**
60	61,4	2,33	15	14	-6,67
70	71,1	1,57	20	19	-5,00
81	80,0	-1,23	25	24	-4,00
90	92,7	3,00	30	28	-6,67
102	108,7	6,57	35	33	-5,71
109	115,4	5,87	40	38	-5,00
113	119,9	6,11	50	47	-6,00
117	121,3	3,68	60	57	-5,00
125	130,1	4,08	70	63	**-10,00**

Table 2. Excerpt of the measurements on a SIEMENS POLIDOROS 712 50kW (Leukada G.H.)

The ratio of the signals from the filtered diodes will depend on the energies of the x-ray beam (which are determined by the tube voltage). This ratio is electronically compared against an appropriate calibration "look-up" table to obtain the kVp.

Most non-invasive instruments do not measure true peak voltage, but rather a value that is integrated over exposure time and the ratio of the signals. This value is the effective kV (kV_{ef}) and it is lower than the actual kVp. Knowing the amount of ripple in the waveform, the instrument can correct this value to provide an effective kVp (kVp_{eff}).

Some instruments will automatically select the appropriate waveform calibration (e.g., single vs. three-phase), while others require the user to turn a knob to the appropriate setting.

Set Mode kV	Measured kV	Variation %	Set Mode mAs	Measured mAs	Variation %
40	38,5	-3,75	50	55	**10,00%**
50	48,9	-2,20	100	101	1,00%
60	57,4	-4,33	200	209	4,50%
70	66,7	-4,71	300	298	-0,67%
81	78,6	-2,96	400	390	-2,50%
90	87,8	-2,44	500	498	-0,40%
102	100,2	-1,76	1000	1001	0,10%
109	104,5	-4,13	2000	2003	0,15%
113	119,9	6,11	3000	3070	2,33%
117	121,3	3,68			
125	130,1	4,08			

Table 3. Excerpt of the measurements on a G.E. PROTEUS JEDI 50kW (Zakynthos G.H.)

Set Mode kV	Measured kV	Variation %	Measured kV	Variation %	Measured kV	Variation %
40	41,2	3,00	40,7	1,75	41,8	4,50
50	52	4,00	53,5	7,00	54,8	9,60
60	60,4	0,67	62,7	4,50	64,9	8,17
70	71,4	2,00	72,4	3,43	79,0	**12,86**
81	81,3	0,37	87,5	8,02	87,0	7,41
90	92,7	3,00	95,6	6,22	96,0	6,67
102	102,8	0,78	105,8	3,73	107,0	4,90
109	110,4	1,28	110,3	1,19	115,0	5,50
113	114,5	1,33	115,8	2,48	121,0	7,08
117	117,5	0,43	121,2	3,59	127,0	8,55
125	127,6	2,08	129,5	3,60	134,0	7,20

Table 4. Comparison of kV measurements on three Siemens LX50 kW systems (KAT G.H.)

Some times, when using a kVp meter, an abnormality may appear during a measurement, displaying an outlier (unusually high) reading that cannot be reproduced (c.f. Table 3 and Table 4 values printed in bold). This may be due to a voltage spike, which could potentially damage the X-ray tube.

Many dental X-ray machines contain self-rectified X-ray tubes, which should not affect kVp measurements. However, generation in these units tend to have poorly regulated circuits that could allow the kVp to vary significantly during an exposure.

Also, the preheat cycle for some dental X-ray tubes, may generate sufficient X-rays flow, to trigger the electronic kVp measurement, resulting in erroneous results. Accordingly, a single digital readout from a non-invasive kVp meter could be misleading.

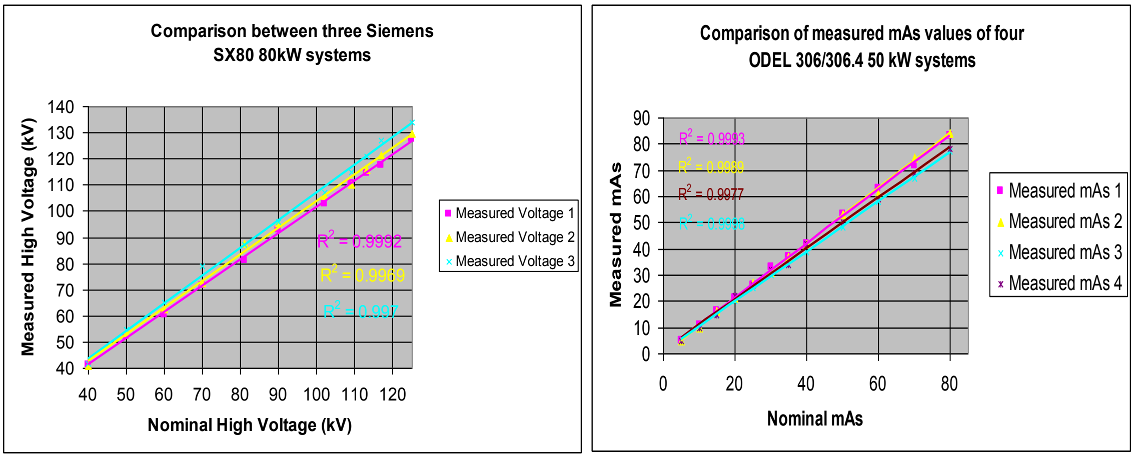

Figure 2. Left: Comparison of kV measurements on three Siemens LX50 50kW systems (KAT G.H.) Right: Comparison of mAs measurements on 4 ODEL 306/306.4 50kW systems (G.H.P. "Tzaneion")

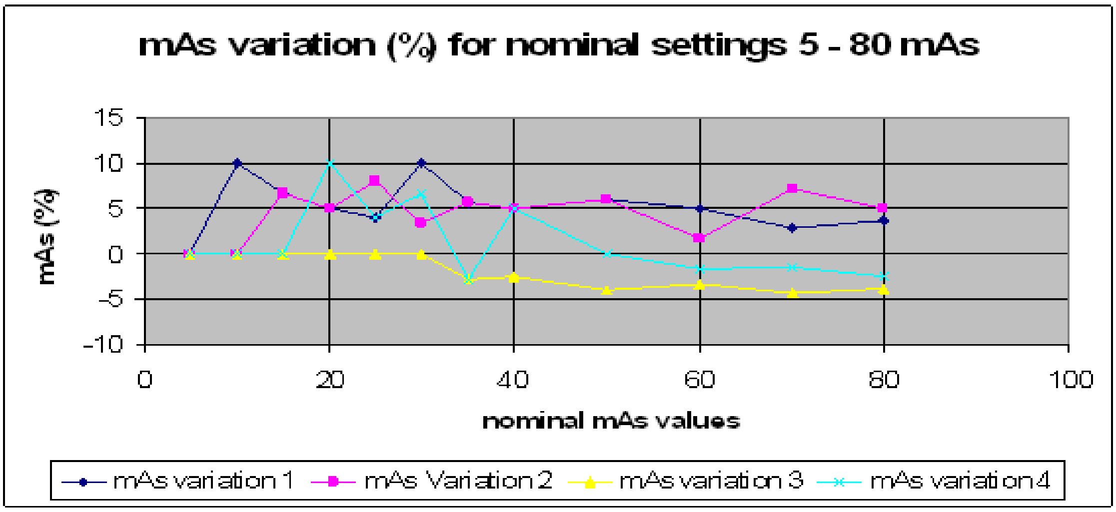

Figure 3. Comparison of mAs variation (%) on 4 ODEL 306/306.4 50kW systems (G.H.P. "Tzaneion").

Unless the X-ray output waveform is displayed and viewed, the total kVp picture is not seen. Measuring fluoroscopic kVp is challenging, due to the time necessary for the exposure to stabilize. Also, the low mA causes high voltage cable capacitance, which distorts the waveform, resulting in erroneous measurements.

High frequency generators may also cause problems in obtaining accurate kVp measurements. The X-ray pulse rate from the generator, may change with different technique factors and may correspond to the sampling rate of the kVp meter. Therefore, the coincidence of the meter sampling rate versus the X-ray pulse rate, or lack thereof, may cause measurement errors.

Set mAs	Measure mAs	Variation %	Measure mAs	Variation %
5	5	0,00%	5	0,00%
10	10	0,00%	11	10,00 %
15	15	0,00%	17	13,33 %
20	20	0,00%	22	10,00 %
25	25	0,00%	24	-4,00%
30	30	0,00%	29	-3,33%
35	35	0,00%	36	2,86%
40	40	0,00%	43	7,50%
50	51	2,00%	52	4,00%
60	63	5,00%	64	6,67%
70	72	2,86%	75	7,14%
80	81	1,25%	87	8,75%

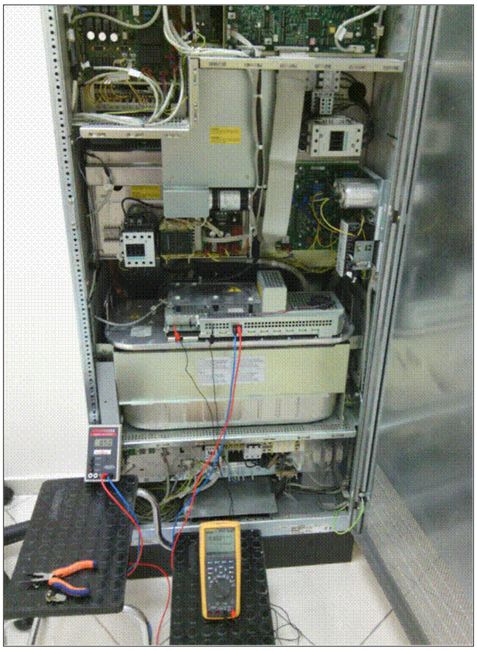

Table 5. Left: Comparison of mAs variation (%) between two CGR: MPH 80kW systems (G.H. Agia Olga) Right: An indicative experimental set-up.

Dosimetry and spectrometry quality assurance measurements

Cadmium telluride (CdTe) detectors belong to a new "family" of semiconductor crystals employed in photon spectroscopy (as GaAs and HgI_2) [1-4]. These detectors are constituted of elements with high atomic number (Cd: 48 and Te: 52), when compared to Germanium (Ge: 32) and Silicon (Si: 14), allowing for a good efficiency for energies of tens of keV, with relatively small crystals (a few cubic millimeters). Many surveys have been published about these detectors [5-11].

As a cryogenic cooling system is not necessary to their operation, the experimental apparatus becomes simpler, allowing measurements out of the laboratory, e.g., under clinical conditions [12]. The main drawbacks of these new detectors are the incomplete collection of charge together with the relatively high probability of escape of fluorescence x-rays, due to the small dimensions. With the advent of new crystal growth techniques and the improvement of electronic signal processing, the resolution these detectors have become closer to the germanium detectors. For the energy of 122 keV (^{57}Co), FWHM of 1.3 keV [7] and 0.9 keV [13] are obtained for CdZnTe and Ge, respectively. The use of Peltier cooler [6] and rise time discrimination circuit (RTD), and the incorporation of electronic processing for reduction of leakage current and noise were also important refinements to this detection system. The hermetic package of the detector has a light tight, vacuum tight 4 mil (100 μm) Beryllium window [6]. All the critical connections between the detector and the preamplifier have been made internally to the XR-100T-CdTe and it is provided complete with BNC connectors and power cable. The XR-100T-CdTe is capable of detecting energies from a few keV to several hundreds of keV.

X-rays & gamma rays interact with CdTe atoms, to create an average of one electron/hole pair for every 4.43 eV of energy lost in the CdTe. Depending on the energy of the incoming radiation, this energy loss is dominated by either the photoelectric effect or Compton scattering. The probability or efficiency of the detector to "stop" the incoming radiation and create electron/hole pairs increases with the thickness of CdTe. In order to facilitate the electron/hole collection process in the CdTe detector, a 400 volt potential is applied. This voltage is too high for operation at room temperature, as it will cause excessive leakage, and eventually a breakdown. Since the detector in the XR-100TCdTe is cooled, the leakage current is reduced considerably, thus permitting the high bias voltage. Electron/hole pairs created by radiation, which interact with the CdTe, near the back contact of the detector, result in fluctuations of charge collection times. These fluctuations are observed as rise time variations of the voltage step, at the output of the charge sensitive preamplifier. As a result, the acquired spectra suffer from increased background counts and degraded energy resolution.

We have developed a simple Method to determine, under clinical conditions, the diagnostic Dental X-ray equipment emitted spectra, by employing a high-resolution Schottky CdTe detector [6], in order to accurately determine the High Voltage actually applied on the X-ray tube. The Molybdenum 17.5 keV and 19.6 keV characteristic spectral lines from a Mammography System and the 241Am isotope 59.5 keV line have been employed for the Energy Calibration of the system. Dental X-ray equipment of various types and manufacturers has already been tested with the developed method [14], and in this paper are presented the results of the employment of the method in a CBCT system.

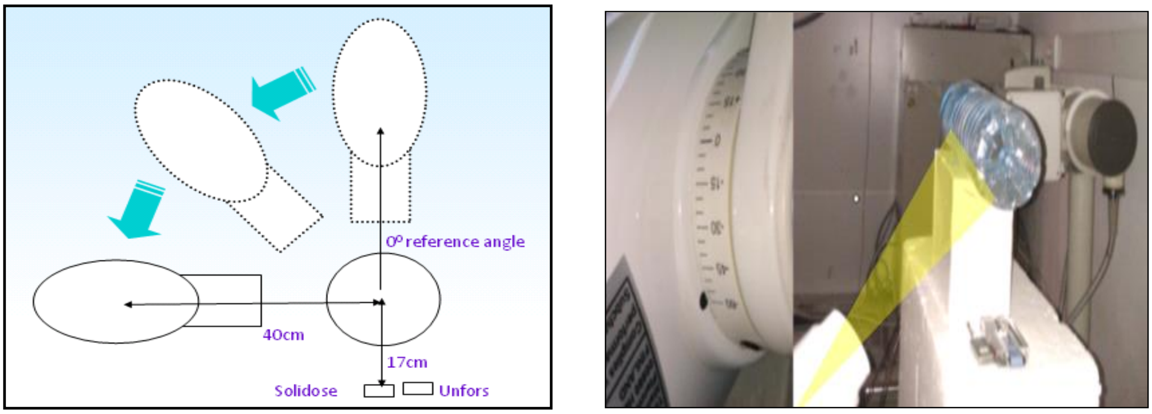

Figure 4.Lay-out and picture of the experimental setup

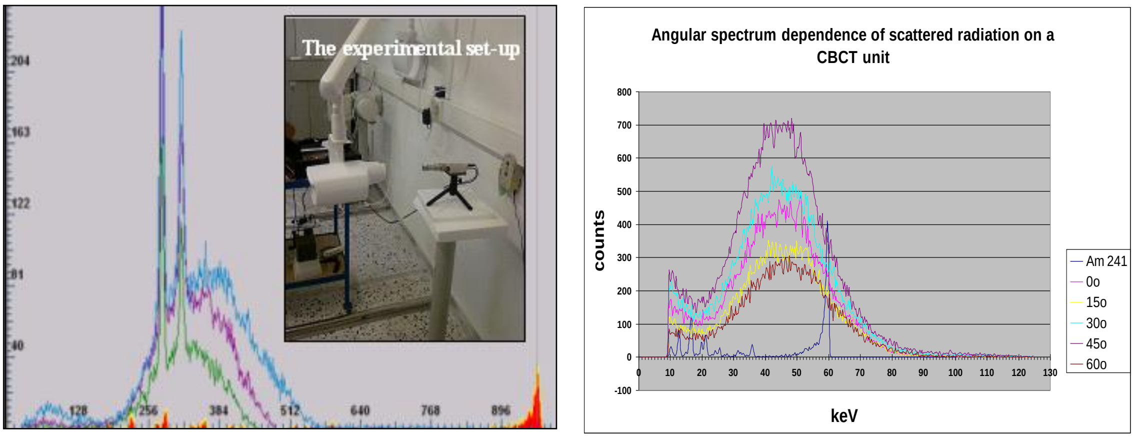

Figure 5. Employment of the Molybdenum 17.5 keV and 19.6 keV characteristic spectral lines from a Mammography System and the 241Am 59.5 keV line (left) and the angular dependence of the spectra of scattered radiation around the CBCT unit

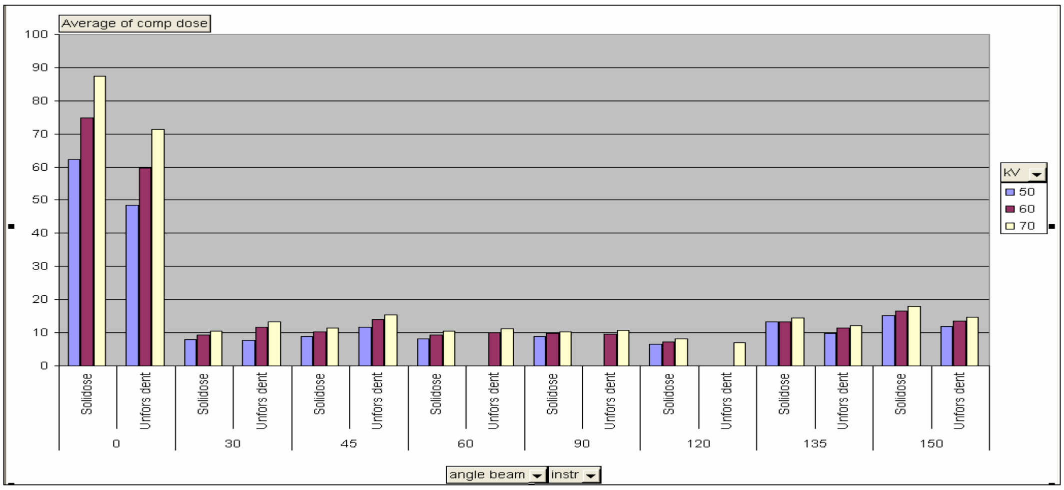

Figure 6. Dose distribution around dental X-ray equipment caused by scattered radiation and measured by employing Solidose and Unfors-dose detectors.

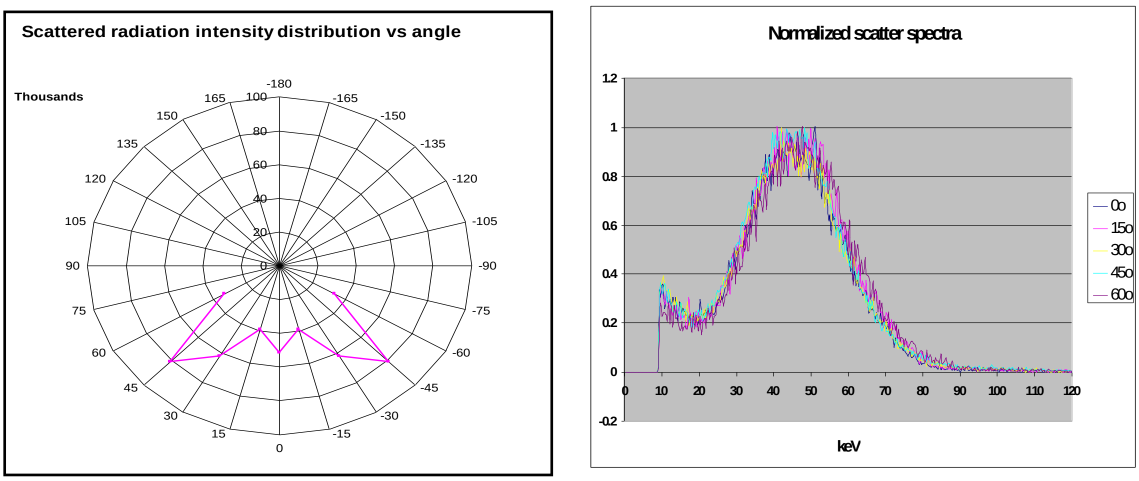

Figure 7. Angular dependence of the scattered radiation Intensity and the corresponding normalized spectra for angles of 0o to 60o from rotation axis

Conclusion

Extended High-voltage, Current, Energy spectra, Primary and Scattered Radiation Exposure free-air, Absorbed-dose etc. measurements, have been carried out and documented. The measurements have been carried out according to the Manufacturers' and/or Radiation Protection Guidelines and Protocols, in the above mentioned X-ray equipment. The need for such systematic measurements in contemporary Radiology is rather obvious.

Acknowledgement

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