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Long-term stability of beam quality and output of conventional X-ray units

Atsushi Fukuda, Kosuke Matsubara and Tosiaki Miyati

A. Fukuda
Department of Radiology, Shiga Medical Center for Children
5-7-30, Moriyama, Moriyama city, Shiga 524-0022, Japan

A. Fukuda, K. Matsubara and T. Miyati
Division of Health Sciences, Graduate School of Medical Sciences, Kanazawa University
5-11-80 kodatsuno, Kanazawa 920-0942, JAPAN

Corresponding author
Atsushi Fukuda, MSc
Email: ntoki@blue.plala.or.jp TEL: 077-582-6200 FAX: No fax available

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Abstract

Conventional diagnostic X-ray units are used for radiographic imaging in many countries. For obtaining entrance surface doses, a Numerical Dose Determination method has been applied in Japan. Although this technique is effective, it has to account for errors, particularly fluctuations, due to the beam quality and output of X-ray tubes. As a part of our quality control procedures, we recorded the entrance surface air kerma, tube voltage, and half-value layer measurements made for four diagnostic X-ray tubes over a 103-week period. The entrance surface air kerma for one of the four X-ray tubes had increased significantly by 11.4% over one year from its initial setting, whereas the tube voltages and half-value layers did not deviate significantly from their initial values. Medical physicists and radiological technologists should be aware of this fluctuation for diagnostic X-ray tubes and take it into consideration when calculating the entrance surface air kerma.

Keywords

Diagnostic conventional X-ray unit, Long-term stability, Output, Half-value layer, Tube voltage, Entrance surface dose

1. Introduction

The International Commission on Radiological Protection (ICRP) published its report No. 60 which noted a diagnostic reference level (DRL) in 1990 [1]. Subsequently, the ICRP promoted the use of this DRL in its publication No. 73 [2] and requested that the DRL should be used by regional, national, and local bodies. Related to these publications, some approaches to the DRL were reported by several associations [3-5]. The DRL was conventionally defined by the 75th or 80th percentile values after a survey.

There are two ways of evaluating the entrance surface air kerma (ESAK) or the entrance skin dose (ESD), which were acquired during the survey for DRL. The first is to measure the ESAK [3] or ESD [4-5] directly. This is reliable if the dosimeters used are calibrated regularly to national standards. The second is a Numerical Dose Determination (NDD) method that calculates the ESAK or ESD by using the exposure conditions of tube voltage, tube current, total filtration, and field size [6]. Because no dosimeters are available for measuring the ESAK or ESD in many Japanese institutions, the second method is preferred over dosimetry for obtaining the ESAK or ESD [6]. However, the second method needs to take into consideration possible fluctuations in beam quality and output for conventional X-ray tubes.

Conventional diagnostic X-ray units are used for radiographic imaging in many countries. Whereas the radiologic community is interested in ESAK or ESD during medical examinations, long-term stabilities of beam quality and output for conventional X-ray units are not known to medical physicists and radiological technologists who are responsible for quality assurance for conventional diagnostic X-ray units. To the best of our knowledge, there have been no published studies that measured the outputs for conventional X-ray units over a 103-week course.

Thus, in this study, we aimed to provide results for the fluctuations in beam quality and output for four diagnostic X-ray units, and we discuss potential errors involved when the NDD method is used.

2. Methods and materials

We introduced a solid state detector (Xi, Unfors RaySafe, Billdal, Sweden) that was calibrated for diagnostic energy levels in December 2011 [7]. This detector had a backing of 1.0 mm of lead as protection from backscattering photons, and it could concurrently measure the ESAK, tube voltage, and half-value layer (HVL). The sensor contains four diodes which are placed in layers with thin sheets of copper. The changes in x-ray transmission through these filtrations are used for calculation of the tube voltage and HVL. Calibration of this detector was performed periodically for verifying that its sensitivity was consistent. Its accuracy was within 1.5% over the 103-week course.

As part of our quality control procedures for four conventional X-ray units (RADIOTEX CM, Shimadzu Corporation, Kyoto, Japan), we began in April 2011 to measure the ESAK, tube voltage, and HVL every week under a fixed geometric arrangement. The experimental set-up with this fixed geometry is shown in Fig. 1, and the technical specifications for these units are listed in Table 1.

We used a simple, non-time consuming test to measure fluctuations in these parameters in our busy department. Thus, the solid state detector was placed on the computed radiography (CR) cassette (Imaging Plate Cassette Type C and IP ST-VI, FUJIFILM Holdings Corporation, Tokyo, Japan) on the examination table top or on the floor. The geometric settings used were: focus-CR cassette distance of 100 cm; and field size at the surface of the CR cassette of 25 cm × 30 cm. The beam parameters used were: tube voltage, 70 kV; tube current, 630 mA; and exposure time, 16 ms (10 mAs).

We retrospectively reviewed these measurement records to determine whether any changes in these parameters had occurred over the 103-week course.

3. Results

We retrospectively reviewed our data over the 103-week course and found missing values for 4 weeks, which were for New Year's and the consecutive holidays. Thus, data for 99 weeks were included in this study.

Tables 2 and 3 show the measured tube voltages and HVLs, respectively, over the 103-week course. Voltages for the four tubes fluctuated between −1.9% and 2.7% and were within the Japanese Industrial Standards (JIS) criteria (± 10%) [8]. The HVLs for these four tubes fluctuated between −1.6% and 1.9%.

Figure 2 shows the fluctuations of ESAKs for the four conventional X-ray units as a function of elapsed time. The ESAKs for all tubes increased gradually as a function of elapsed time (range: 6.3%–11.4%). These X-ray tubes were inspected twice by the manufacturers over the 103-week course; between 31 and 32 weeks, and between 92 and 93 weeks. After these inspections, the ESAK with Tube A declined and then increased again as a function of elapsed time. The ESAK with Tube A increased by 11.4% over the 103-week course.

4. Discussion

The American Association of Physicists in Medicine, European Union, and International Atomic Energy Agency accumulated “dosimetric data” to obtain DRLs in their surveys [3-5]. In contrast, in Japan, the DRL was obtained by application of calculated data by use of the NDD method [6].

We verified tube voltages, HVLs, and ESAK values as outputs for four conventional X-ray units. Whereas tube voltages and HVLs for these four X-ray units did not significantly change over the 103-week course, the outputs of these four X-ray units increased gradually as a function of elapsed time. Although the rate of increase was different for Tubes A - D, the mean rate was 8.2%. Because the beam quality of these tubes did not change over the 103-week course, the tube current might have increased gradually, although no definite claim can be made without verification.

Our tests were performed under the same tube conditions (70 kV, 10 mAs) over the 103-week course. The lowest and highest ESAKs were 422.4 μGy with tube D and 562.4 μGy with Tube A, respectively, a difference of 140 μGy (33.1%). These data suggest that (1) the NDD method must take into consideration the fluctuations of X-ray tubes; and (2) the uncertainty with the NDD method should be taken into account when ESAKs are compiled for a survey.

This study had two limitations. First, we verified tube voltages, HVLs, and outputs for four X-ray units and one beam condition provided by one manufacturer. Because many manufacturers provide many types of X-ray units, it is necessary to evaluate fluctuations in tube voltages, HVLs, and outputs for other systems and beam conditions for completeness.

Second, we used a solid state detector to measure the tube voltage and HVL. Although this detector was periodically calibrated based on air kerma, measurement accuracies for tube voltages and HVLs had not been verified after the first calibration (December 14, 2011) made by the manufacturer. Because fluctuations in tube voltage and HVL for the four X-ray units did not change over the 103-week course, we believe that this detector has remained stable.

5. Conclusions

Fluctuations in tube voltage, HVL, and output for four X-ray units were measured as a part of our quality control procedures. We found that: (1) fluctuations in tube voltage and HVL were stable over the 103-week course; (2) outputs increased as a function of elapsed time (maximum: 11.4%); and (3) even if the same beam conditions (tube voltage, tube current, and exposure time settings: 70 kV, 630 mA, and 16 ms) were applied for measuring the ESAK for four X-ray units, large differences were observed (the lowest and highest ESAKs were 422.4 μGy with Tube D and 562.4 μGy with Tube A).

Medical physicists and radiological technologists should be aware of these fluctuations in output for diagnostic X-ray tubes and should take these into consideration when calculating the entrance surface dose or for determining when periodic inspections should be made by the manufacturers.

Conflict of interest

The authors declare that they had no conflict of interest in this study.

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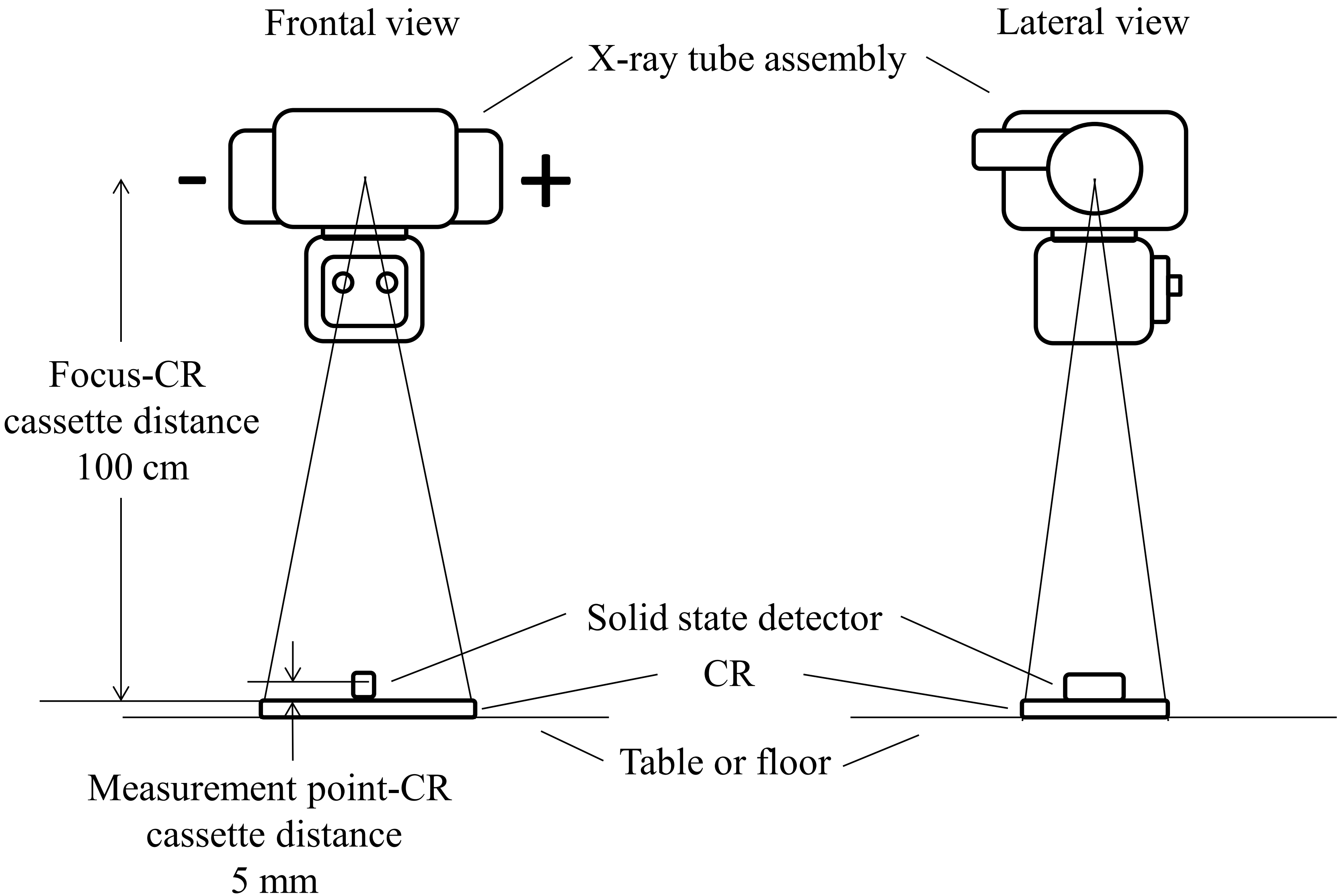
Fig. 1

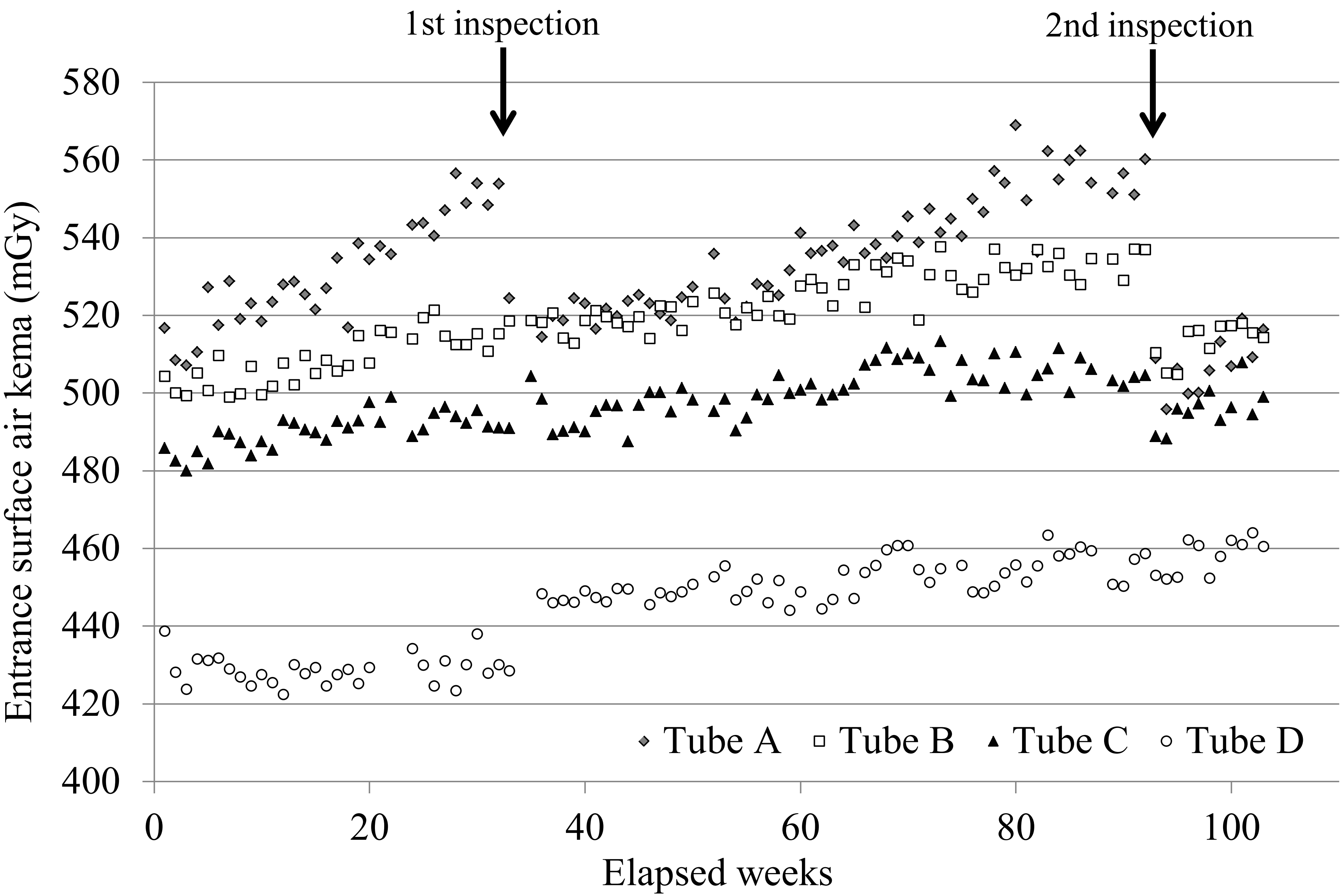
Frontal and lateral views of our experimental arrangement. Tube voltage, HVL, and ESAK were measured. A CR cassette was placed on the examination tabletop or on the floor for a set field (25 cm × 30 cm). Because the focus-CR cassette distance was 100 cm, the focus-detector measurement point distance was 99.5 cm.

Fig. 2

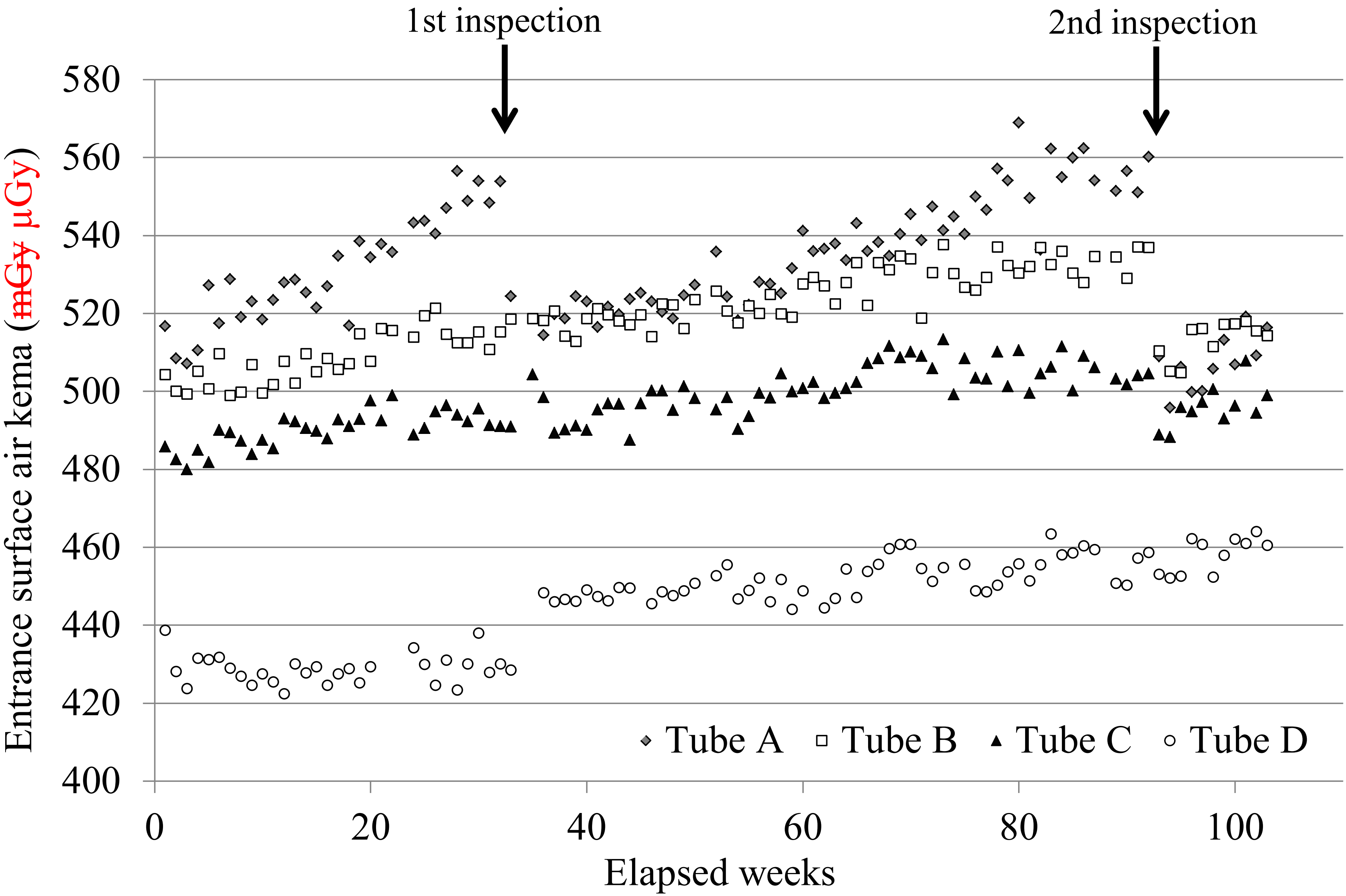
Fluctuations in ESAKs for four X-ray units over the 103-week course. All ESAKs increased as a function of elapsed time. After these X-ray units were inspected twice by the manufacturer, ESAKs with Tube A declined and then soon increased as a function of elapsed time. ESAK with Tube A increased by 11.4% over the 103-week course.

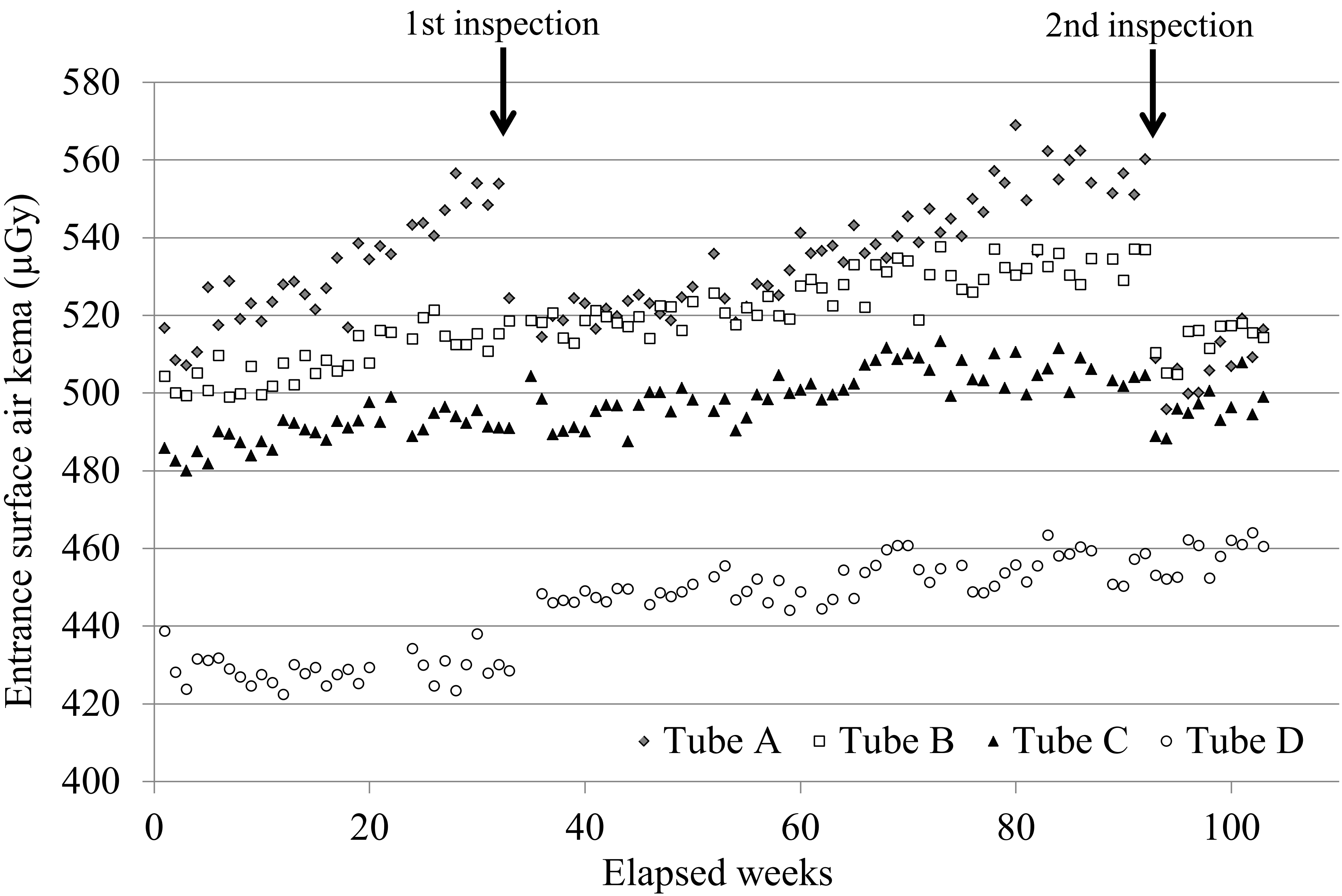


Frontal view
Lateral view
X-ray tube assembly
-
+
Focus-CR
cassette distance
100 cm
Solid state detector
CR
Table or floor
Measurement point-CR
cassette distance
5 mm



1st inspection
2nd inspection
Entrance surface air kema (mGy)
580
560
540
520
500
480
460
440
420
400
0
20
40
60
80
100
Elapsed weeks
Tube A
Tube B
Tube C
Tube D


1st inspection
2nd inspection
Entrance surface air kema (mGy μGy)
580
560
540
520
500
480
460
440
420
400
0
20
40
60
80
100
Elapsed weeks
Tube A
Tube B
Tube C
Tube D



1st inspection
2nd inspection
580
560
540
520
500
480
460
440
420
400
Entrance surface air kema (μGy)
Tube A
Tube B
Tube C
Tube D
0
20
40
60
80
100
Elapsed weeks

TABLE 1 Technical information on Shimadzu RADIOTEX CM conventional X-ray units

Number of X-ray tube assemblies	3	1
X-ray tube model	0.6/1.2P33DK	0.6/1.2P38DE
Focus (mm)	0.6 / 1.2	0.6 / 1.2
Permanent filtration	1.5 mm Al at 70 kV	1.5 mm Al at 70 kV
Target angle (deg)	16	12
Tube voltage available (kV)	40 – 150	40 – 150
Tube current available (mA)	100 – 630	100 – 630
Collimator model	R-30H	R-30H
Filtration	1.0 mm Al Eq	1.0 mm Al Eq

TABLE 2 Tube voltages (kVp) measured for Shimadzu RADIOTEX CM conventional X-ray units

Tube	A	B	C	D
X-ray tube model	0.6/1.2P33DK	0.6/1.2P33DK	0.6/1.2P33DK	0.6/1.2P38DE
Minimum	69.6	68.8	68.7	70.3
1st quartile	70.0	69.1	69.3	70.7
Median	70.2	69.3	69.4	70.9
Mean	70.3	69.3	69.5	70.9
3rd quartile	70.5	69.5	69.7	71.1
Maximum	70.9	70.2	70.3	71.9

TABLE 3 HVL (mm Al) measured for Shimadzu RADIOTEX CM conventional X-ray units

Tube number	A	B	C	D
X-ray tube model	0.6/1.2P33DK	0.6/1.2P33DK	0.6/1.2P33DK	0.6/1.2P38DE
Minimum	2.3	2.2	2.2	2.5
1st quartile	2.4	2.2	2.3	2.6
Median	2.4	2.2	2.3	2.6
Mean	2.4	2.2	2.3	2.6
3rd quartile	2.4	2.2	2.3	2.6
Maximum	2.4	2.3	2.3	2.6