

Comparison between Predicted and Measured X-Ray Output in Some Conventional Radiography Units

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Abstract

This study aims to investigate how accurate are TASMICS and TASMIP models in predicting the X-ray output of some Conventional Radiology X-ray units with high frequency generators. The X-ray output in microgray per milliamperere seconds ($\mu\text{Gy/mAs}$) at 100 cm from the X-ray tube was determined for selected high voltages and taking into account the total filtration. The X-ray output was then measured directly with the multi-purpose detectors (MPD), Raysafe X2. The maximum relative error between measured and predicted values was found to be equal to 20%. The maximum relative error between measured and predicted values obtained demonstrates the difficulty of accurately predicting the X-ray tube output using TASMICS and TASMIP models since they are based on fixed anode angles and different composition of the tungsten anode.

Keywords

X-Ray, Spectra, TASMICS, TASMIP

1. Introduction

Several computational methods are used to characterize X-ray spectra. Boone and Seibert [1] reported on a method for computing X-ray spectra based on the method of interpolating polynomials, called TASMIP, this model computes tungsten anode X-ray spectra in 1 keV energy bins between 30 and 140 kV and provides accurate spectral estimation based on the measurements of Fewell *et al.* [2]. J.H. Hernandez and J.M. Boone [3] later developed a new method named Tungsten Anode Spectral Model using Interpolating Cubic Splines (TASMICS)

that enables the generation of unfiltered X-ray spectra from 20 kV to 640 kV. The TASMICS X-ray spectral model aimed at correcting TASMIP model limitations such as the low energy generation and the fact that this last model was derived from CT X-ray spectra that were already filtered. Siewerdsen *et al.* [4] developed a computational tool for X-ray spectral analysis and imaging system optimization called Spektr that is based on the TASMIP model, this software was improved by J. Punnoose *et al.* [5] to take into account the TASMICS model. TASMICS and TASMIP models are not the only models used to generate X-ray spectra, other models are available like the Poludniowski *et al.* model [6] and the Birch and Marshall's model [7]. In this report a comparison between measured X-ray tube output and model based predicted X-ray tube output was carried out for five conventional X-ray machines with high frequency generators.

In order to establish Diagnostic Reference Levels in conventional radiography, the Entrance Surface Exposure must be reported different radiography examinations. When the radiography unit has a Dose Area product meter, the Entrance Surface Exposure can be easily derived from the Dose Area Product. However, many conventional radiography units in Cameroon do not have a Dose Area Product meter, in this case the Entrance Surface Exposure has to be assessed using the examination parameters recorded by the radiographers.

This work aims to evaluate the accuracy of the assessment of the Entrance Surface Exposure using TASMIP and TASMICS models and the examination parameters used in conventional radiography.

2. Materials and Methods

X-ray spectra were generated with Matlab software using TASMIP and TASMICS models and the output in microgray per milliamperere seconds ($\mu\text{Gy}/\text{mAs}$) at 100 cm from the X-ray tube were determined for each selected high voltage and filtration. The results obtained were compared to those obtained using the Spektr 3.0 software.

Twelve X-ray machines with a high frequency generator were initially considered in this study. The devices selected belong to high-load radiology centers of the republic of Cameroon. Ten standard Quality Control (QC) tests, including voltage accuracy and reproducibility, exposure time accuracy and reproducibility, tube output linearity (time and milliamperere), filtration (half-value layer or HVL), tube output (70 kVp at FSD = 100 cm), tube output reproducibility and beam alignment were performed to assess the devices. Quality Control tests were performed, based on the protocol proposed in Report No. 77 by the Institute of Physics and Engineering in Medicine (IPEM) [8].

The direct measurements were performed, using a calibrated multi-purpose detector (MPD), Raysafe X2. The Raysafe X2 R/F sensor and the associated X2 software was used in this study. The Raysafe X2 R/F sensor enables the measurement of Air Kermas with an uncertainty of 5% in the range 1nGy-9999Gy.

Five X-ray machines that passed all the QC tests were finally selected for the

comparison between predicted and directly measured X-ray outputs.

3. Results

The results of this study are shown in **Table 1** and **Table 2**. The output ratios obtained using the TASMIP model are in the range 0.81 - 1.07 with a mean of 0.90 while the output ratios obtained using the TASMICS model are in the range 0.80 - 1.07 with a mean of 0.91. The two models therefore predict the radiation outputs with the same accuracy.

Figure 1 shows the normal high voltage waveform for an X-ray machine with a high frequency generator that passed all QC tests and **Figure 2** shows the predicted spectra obtained using TASMIP and TASMICS models at 100 kVp and total filtration of 3 mm Al.

Figure 3 shows the output ratios obtained using either TASMICS or TASMIP models.

4. Discussion

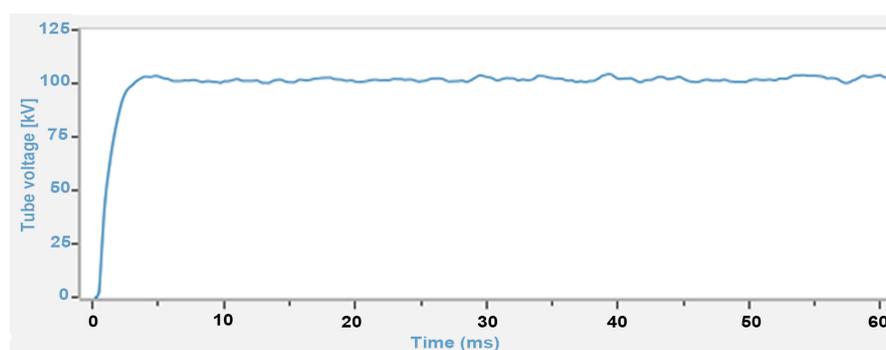
It appears that the maximum relative error between measured and predicted values was found to be equal to 20%. This high uncertainty value cannot be only due to the uncertainty of 5% of the output measured by the multi-purpose detector

Table 1. Predicted and measured X-ray outputs obtained using TASMICS model.

X-ray machine	Total filtration (mm Al)	kVp	Predicted output	Measured output	Output ratios
1	3.2	60	26.00	26.10	0.99
		70	37.16	35.80	1.03
		80	50.37	48.13	1.04
		100	79.47	73.94	1.07
2	4.4	60	18.98	21.70	0.87
		70	28.11	31.04	0.90
		80	38.83	43.75	0.88
		100	64.36	72.95	0.88
3	5.5	60	13.74	16.66	0.82
		70	21.13	25.33	0.83
		80	30.03	35.05	0.85
		100	51.91	59.25	0.87
4	3.5	60	24.30	30.16	0.80
		70	35.01	41.61	0.84
		80	47.31	56.4	0.83
		100	75.96	88.15	0.86
5	3	60	27.87	32.94	0.84
		70	39.54	44.99	0.87
		80	52.81	56.25	0.93
		100	83.29	85.7	0.97

Table 2. Predicted and measured X-ray outputs obtained using and TASMIP model.

X-ray machine	Total filtration (mm Al)	kVp	Predicted output	Measured output	Output ratios
1	3.2	60	26.16	26.10	1.00
		70	37.48	35.80	1.04
		80	49.93	48.13	1.03
		100	79.71	73.94	1.07
2	4.4	60	19.51	21.70	0.89
		70	28.91	31.04	0.93
		80	39.88	43.75	0.91
		100	65.47	72.95	0.89
3	5.5	60	14.36	16.66	0.86
		70	22.07	25.33	0.87
		80	31.31	35.05	0.89
		100	53.42	59.25	0.90
4	3.5	60	24.58	30.16	0.81
		70	35.47	41.61	0.85
		80	47.93	56.40	0.84
		100	76.44	88.15	0.86
5	3	60	27.90	32.94	0.84
		70	39.68	44.99	0.88
		80	53.03	56.25	0.94
		100	83.25	85.70	0.97

**Figure 1.** Normal waveform at a selected 100 kVp high voltage.

(MPD), Raysafe X2 and shows how difficult it is to accurately predict the x ray tube output at 100 cm using TASMICS and TASMIP models.

The discrepancy between predicted and measured X-ray output may be caused by the difference between the anode angle used in the models and the actual anode angle of the X-ray machine. X-ray tubes are manufactured in a range of anode angles but in TASMICS and TASMIP models the anode angle are held constants respectively at 12° and 12.5° .

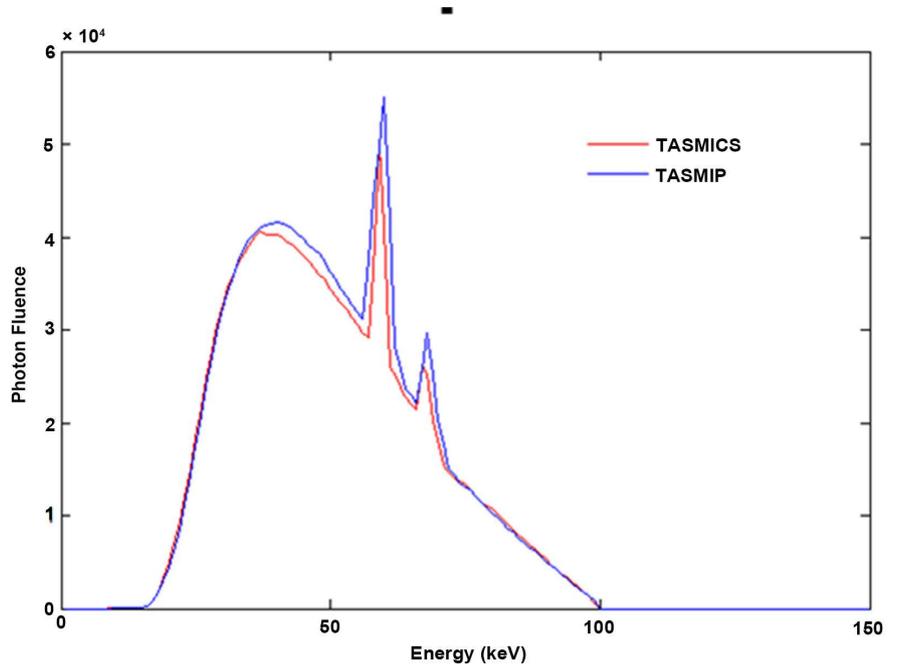


Figure 2. 100 kV spectra using TASMICS and TASMIP models.

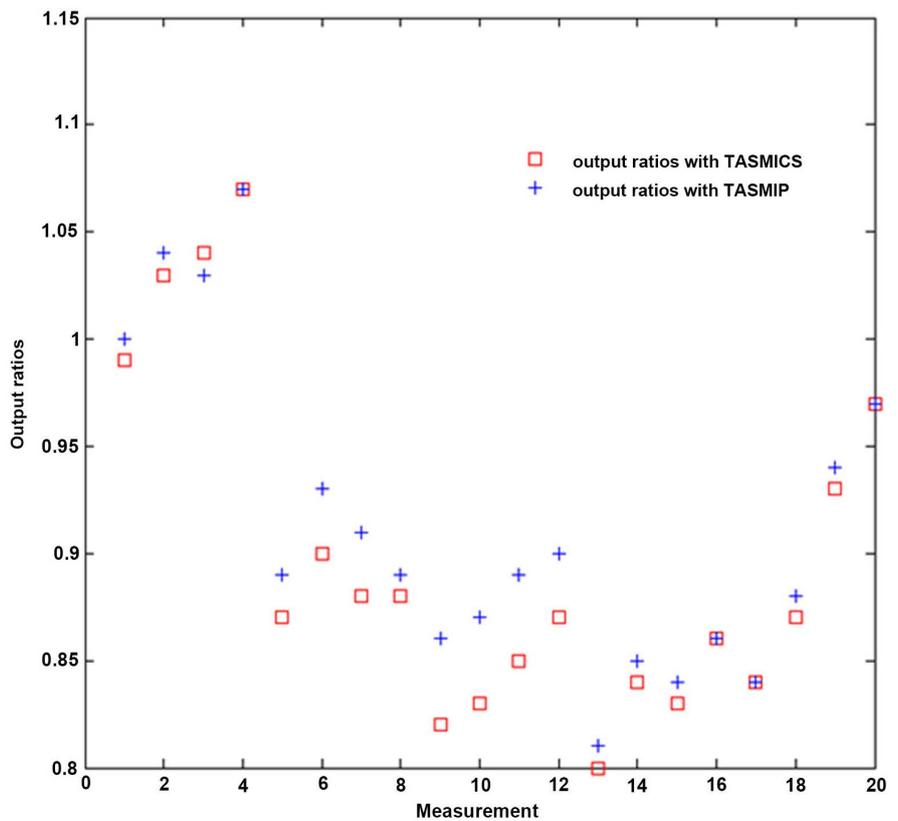


Figure 3. Output ratios obtained using TASMICS or TASMIP model.

We checked the influence of anode angle in the output using the SpekCalc software [6] and we found the results shown in Table 3 below.

Table 3. Effect of anode angle on the X-ray output.

X-ray machine	Total filtration (mm Al)	kVp	Output with 12°	Output with 15°	Difference in %
1	3.2	80	53.51	55.65	3.99
		100	76.00	79.58	4.10
2	4.4	80	39.34	40.64	3.30
		100	58.48	60.78	3.93
3	5.5	80	31.04	31.93	2.86
		100	47.81	49.45	3.43
4	3.5	80	49.24	51.10	3.77
		100	70.80	73.97	4.47
5	3	80	56.72	59.09	4.17
		100	79.87	83.78	4.89

It appears that the increase in anode angle from 12° to 15° can increase the output to about 5%.

5. Conclusion

In Diagnostic Radiology, it is very important to determine the X-ray output after each examination because this value is needed to assess the dose received by the patient. For an X-ray machine that passes all QC tests, it would be very good to use the kVp and the total filtration to predict the X-ray output since the equipment needed to measure entrance air kerma is not always available. The objective of this study was to see if TASMICS or TASMIP models could help to predict the X-ray output accurately. It was found that using one of those two models will lead to an uncertainty of about 20% for kV below or equal to 100. The uncertainty may be reduced if those models took into account the target angle. Using the Speck Calc software we found that if one takes into account the target angle the uncertainty would be reduced by a factor of 5%. The target angle however is not the only parameter that influences the X-ray-output, the composition of the target also has to be taken into account.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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