Title: A COMPARISON OF Cs-137 AND X-RAY SOURCES AS CALIBRATION REFERENCES FOR THERMOLUMINESCENT DOSIMETER CHIPS

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A COMPARISON OF Cs-137 AND X-RAY SOURCES AS CALIBRATION REFERENCES FOR THERMOLUMINESCENT DOSIMETER CHIPS

Abstract

This work is focused on calibrating Thermoluminescent Dosimeters (TLDs) using Cs-137 instead of using x-ray. TLD chips which are used in the Saskatchewan Ministry of Labour Postal Quality Assurance (PQA) program were irradiated using X-Ray machine and an AEA Model 773 Cs-137 Instrument Calibrator at known exposure levels. X-Ray exposures were conducted at several kVp settings and with different beam filtrations in order to identify any confounding factors on the measured response of the TLD chips. After letting the irradiated chips fade for at least 48 hours, the light output of the TLD chips were measured in nanoCoulombs using a Harshaw Model 5500 TLD reader. The response was measured to be 0.1275 ± 0.0049 nC per mR for x-ray exposures and 0.0772 ± 0.0028 nC per mR for the Cs-137 exposures. Neither kVp or beam filtration appeared to have any effect on the chip response. These results show that application of an appropriate correction factor k = 0.6056 ± 0.0057 will allow chips to be calibrated using Cs-137.

1. Introduction

The Radiation Emitting Devices (RED) Act [1] regulates the manufacturer, import, or sale of radiation devices within Canada, however it is up to each Province to regulate the installation, maintenance and use of the equipment. Health Canada's Safety Code 35 [2] provides necessary information to achieve the safe use of diagnostic x-ray machines however, with the exception of federally operated facilities, SC 35 is a guidance document only and it is up to Provincial regulation to provide the necessary enforcement for protection of individuals who may be exposed to radiation emitted by X-ray equipment.

The PQA program is included in Section 16 of the Saskatchewan Radiation Health and Safety Regulations, 2005 [3], and specifies that operators of equipment participate in the program. The test package (medical pack) used in the PQA program consists of a test plate containing eight thermoluminescent dosimeters which are mailed to the hospital or dental clinic in question and an aluminum step wedge and test phantom. The medical pack is placed on top of the test phantom with the aluminum step wedge placed over top. When the pack is radiographed and the TLD chips analyzed, the entrance exposure, and the half value layer of the X-Ray beam can be determined.

Historically calibration of the chips has been done by using an X-Ray combined with a calibrated reference instrument. This process however is tedious and expensive, as it is not always easy to get access to an X-Ray machine for extended periods of time. A solution to this problem is to calibrate these chips using a commercial Cs-137 [4], a naturally occurring radioactive gamma ray source.

X-ray and gamma ray radiations are both ionizing radiations [5], however, to be able to calibrate TLD chips using Cs-137 we need to find a factor which, when multiplied, gives the correct x-ray exposure for a Cs-137 calibrated chip. Additionally, it must be determined how filtration of the x-ray beam may affect this factor. The focus of this work is to measure the appropriate calibration factor to allow for in-house calibrations of the TLD chips using a Cs-137 source.

2. Background

2.1 Cs-137 Calibrator

An AEA Technology, QSA Inc. Model 773 Instrument Calibrator [6] was used in this experiment. It contains a Cs-137 source with a nominal activity of 6.142 GBq. The source is well shielded and equipped with a collimated beam port. It has 3 attenuators with transmission factors of 0.25, 0.10 and 0.10 located at the collimator port to produce a radiation field whose intensity is uniform in any plane perpendicular to the beam axis. Figure 1 shows the beam profile.

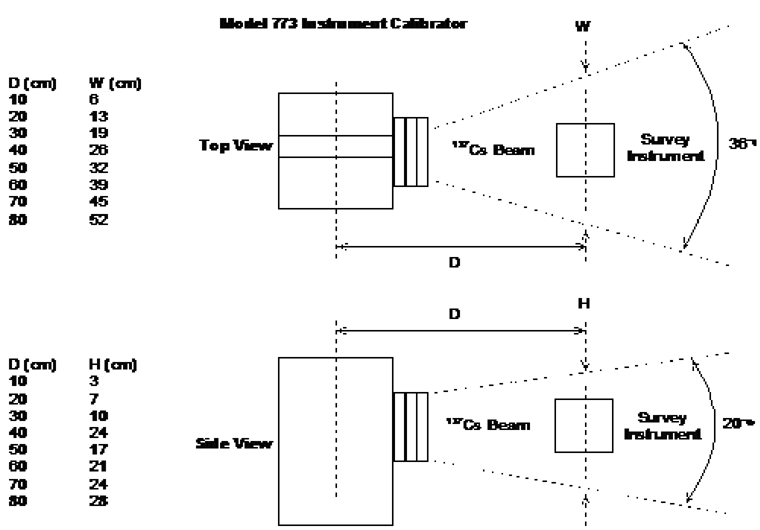

Figure 1 Model 773 Instrument Calibrator beam profile.

2.2 Measuring Exposure with TLD Reader

A Harshaw Model 5500 TLD reader, was used for measurement of the TLD chips. As TLD chips are heated, the light output is analysed using a photomultiplier tube. The PM tube provides an output current which is directly proportional to the chips radiation exposure. Exposure measured from TLD charge is calculated using Equation 1

$$Exposure = \frac{ECC*Charge}{RCF} \tag{1}$$

Where ECC is the Element Correction Coefficient [7] for an individual chip, and the RCF is the Reader Calibration Factor which converts the measured light output to a desired exposure unit, and the charge is the integrated current measured by the PMT.

Not all TLDs have same response. To correct for variation in chip response and to correlate it to the population response, the ECC is determined using Equation 2

$$ECC_j = \frac{<Q>}{Q_j} \tag{2}$$

Where <Q> is the average charge of a set of TLD chips, Q_j is the integrated current measured for a TLD.

The RCF is calculated using Equation 3

$$RCF = \frac{<Q>}{E} \tag{3}$$

Where <Q> is the average integrated current measured for a set, E is the radiation exposure delivered to that set.

3. Method

Medical and dental packs are holders of TLD chips (Figure 2). A medical pack can hold up to 8 TLD chips and a dental pack can hold up to 2 TLD chips. In this experiment, 18 medical packs and 12 dental packs were grouped into 8 sets for x-ray exposure and 3 sets for Cs-137 exposure. While exposing medical packs, phantom slabs were used to simulate human body scattering. Phantom slabs were not used for dental packs as this is not the practice observed in the field. X-ray exposures were conducted at several levels with varying filtration parameters for each set. Cs-137 exposures were conducted at 21.2 cm from the calibrator, and packs were exposed to 3 different exposure levels. Figure 3 shows a medical pack attached to phantom slab during Cs-137 exposure.

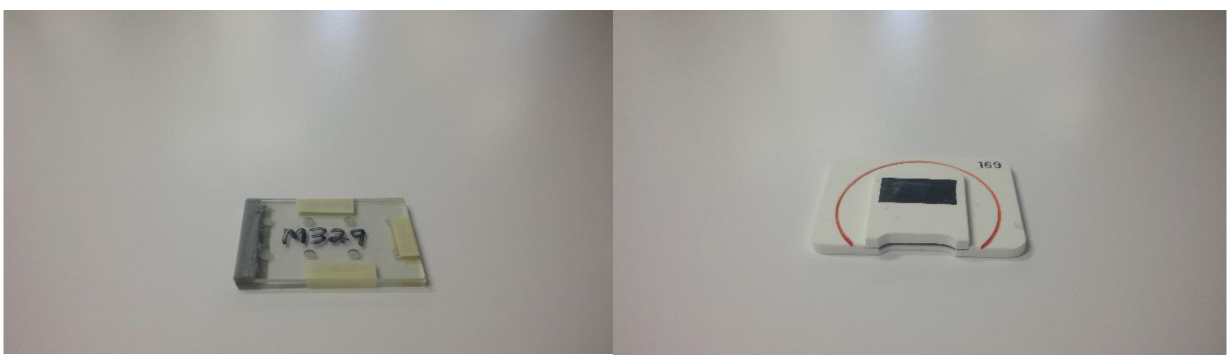

Figure 2 Medical pack (left) and dental pack (right).

Figure 3 Set up of Cs-137 exposure

After exposure, TLD chips from medical and dental packs were set aside for at least 2 days in a dark environment to allow the chips to relax. During analysis, TLD chips were first preheated in an oven for 30 minutes at 100 °C to remove low level noise from the chips. They, were then cooled for 10 minutes before they were analysed using the HARSHAW 5500 TLD Reader. After analysis, chips were annealed by heating in an annealing oven for at least one hour at 450 °C. After annealing, they were transferred to a fridge and cooled for at least one hour at 5 °C.

4. Results

The PMT in the TLD reader measures the light output from the TLD chip in units of integrated current (charge). The charge contained in the TLD chips were measured for different levels of x-ray and Cs-137 exposure. Using the measured charge, exposure levels and average charge for each set, element correction coefficients (ECC) for each chip and a reader calibration factor (RCF) could be determined. For each set of x-ray and Cs-137 exposures ECC and RCF's were computed using Equation 2 and 3 respectively and is shown in table 1 and table 2. Figure 4 shows the distribution of ECC computed from both x-ray and Cs-137 exposures.

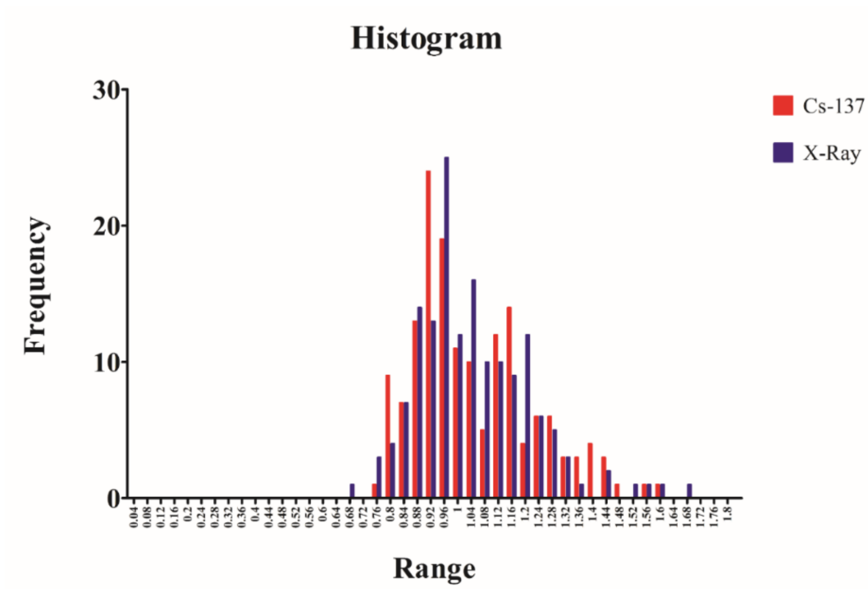

Figure 4 ECC Distribution, x-axis shows the range of ECC. The distribution is centered around ECC value of 1.

It can be noted that the ECC distribution is approximately Gaussian and has similar shape for both x-ray and Cs-137 exposures.

Table 5b: Cs-137 Measurement results

Exposure	error	Filtration	Average charge 137-Cs (nC)	± Error in Average Charge	RCF (nC/mR)	± Error in RCF (nC/mR)

					(nC)			
Exposure (mR)	**Error (mR)**	**Set #**	**Filtration**	**Kvp**	**Average Charge x-ray (nC)**	**± Error in Average Charge (nC)**	**RCF (nC/mR)**	**± Error in RCF (nC/mR)**
293.067	0.173	1	0 mm Al	75.000	32.906	2.329	0.112	0.020
92.987	0.173	2	1 mm Al + 0.1 mm Cu	80.000	13.166	1.106	0.142	0.030
232.967	0.173	3	0 mm Al	85.000	31.793	1.432	0.136	0.015
108.767	0.173	4	1 mm Al + 0.1 mm Cu	85.000	12.056	0.990	0.111	0.017
149.433	0.173	5	2 mm Al	85.000	21.034	1.040	0.141	0.017
163.500	0.173	6	0 mm Al	90.000	24.242	1.135	0.148	0.017
65.440	0.173	7	None	70.000	10.060	1.136	0.154	0.031
257.833	0.173	8	None	70.000	32.613	2.366	0.126	0.016

Table 5a: X-Ray Measurement results

Figure 5 illustrates the average charge measured from the chip as a function of radiation exposure for x-ray and Cs-137 treatments. From Equation 3, the slope of these lines are the RCF. Figure 6 shows the effect of filtration and kVp

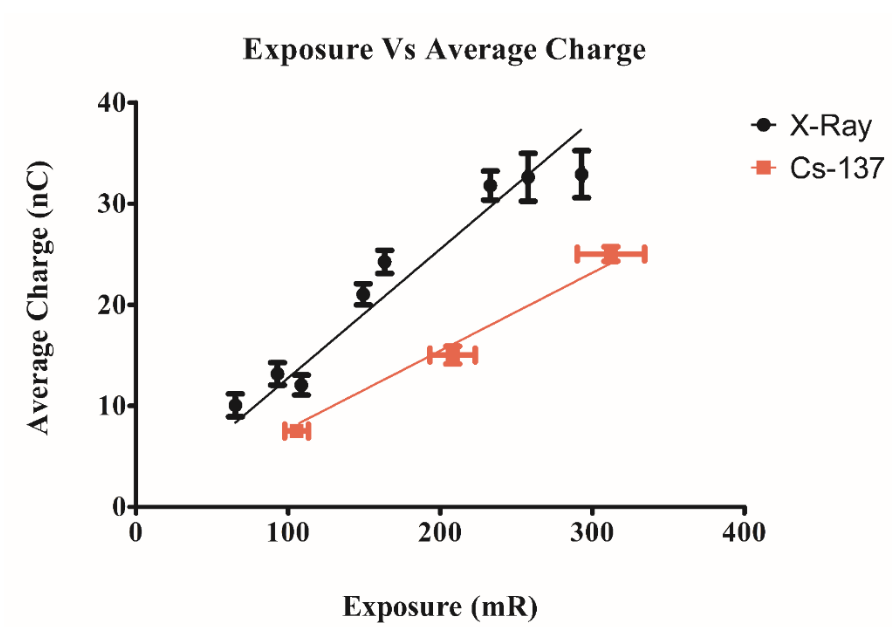

Figure 5 Exposure Vs Average charge

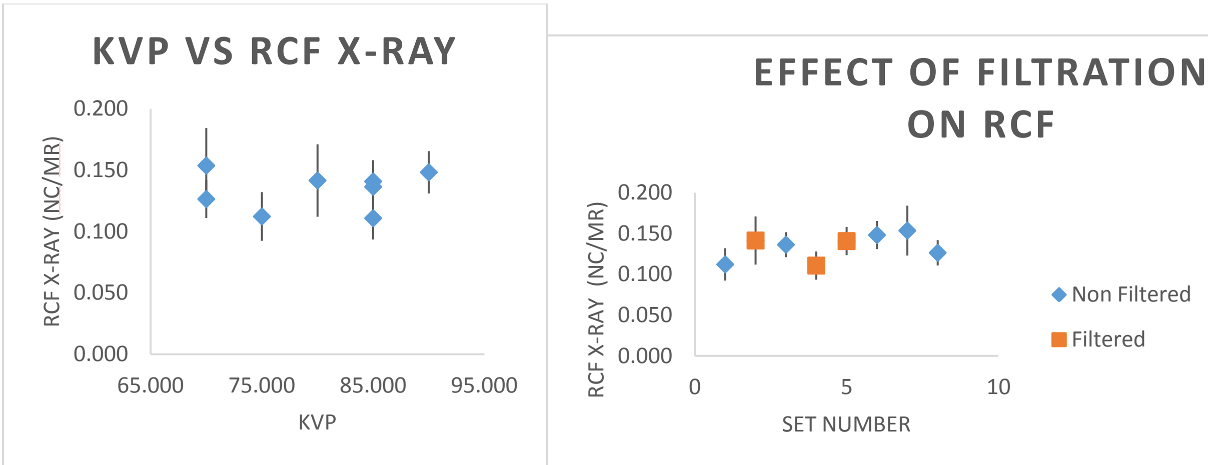

Figure 6 Effect on RCF with Filtration and KVp

The TLD chip response was measured to be 0.1275 ± 0.0049 nC/mR for x-ray exposures, and 0.0772 ± 0.0028 nC/mR for Cs-137 exposures.

K = $\frac{RCF_{Cs-137}}{RCF_{X-Ray}}$ = 0.6056 ± 0.0057, is the correction factor relating TLD response for for x-ray exposed chip given it is calibrated for Cs-137 source. Neither kVp nor beam filtration appeared to have any effect on the chip response

5. Conclusion

A comparison of TLD chip response for x-ray and Cs-137 exposures was conducted. A calibration factor relating Cs-137 exposure to x-ray exposure was calculated to be K = 0.6056 ± 0.0057. It was found that x-ray machine settings like kVp, or beam filtration does not affect the calibration factor K. Given a TLD chip calibrated using Cs-137 and exposed to an x-ray source, we can now multiply the obtained result from a TLD reader by K to get its equivalent x-ray exposure. Chips calibrated using Cs-137 source can now be used in the Saskatchewan PQA program to monitor X-Ray machines within the province.

6. Reference

[1] Radiation Emitting Devices Act, in, Canada.

[2] Safety Code 35: Safety Procedures for the Installation, Use and Control of X-ray Equipment in Large Medical Radiological Facilities, in, Ca.

[3] R-1.1 Reg 2 - The Radiation Health and Safety Regulations, 2005, in, Queen's Printer, Regina, SK.

[4] https://www.nndc.bnl.gov/, in.

[5] H. Cember, T. Johnson, Introduction to Health Physics: Fourth Edition, McGraw-Hill Education, 2008.

[6] Operating Manual Model 773 Instrument Calibrator in.

[7] A. Savva, Personnel TLD monitors, their calibration and response, in: Department of Physics, University of Surrey, Surrey, 2010, pp. 60.