NRC·CNRC

NRC Publications Archive
Archives des publications du CNRC

Determination of the output of the Elekta Unity MR-linac, installed at the Odette Cancer Centre, using alanine dosimeters traceable to the Canadian primary standard of absorbed dose to water

McEwen, Malcolm; Mansour, Iymad; Muir, Bryan; Moore, Kimberly; Keller, Brian; Sarfehnia, Arman; National Research Council Canada. Metrology Research Centre

For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:

https://doi.org/10.4224/40001925

Report (National Research Council Canada. Metrology Research Centre); no. PIRS-2873, 2019-06-28

NRC Publications Archive Record / Notice des Archives des publications du CNRC :
https://nrc-publications.canada.ca/eng/view/object/?id=ccad8528-c9ea-4e18-bced-2d1e1a4efe3e
https://publications-cnrc.canada.ca/fra/voir/objet/?id=ccad8528-c9ea-4e18-bced-2d1e1a4efe3e

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at
https://nrc-publications.canada.ca/eng/copyright
READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site
https://publications-cnrc.canada.ca/fra/droits
LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research Council Canada | Conseil national de recherches Canada

Canada

Determination of the output of the Elekta Unity MR-linac, installed at the Odette Cancer Centre, using alanine dosimeters traceable to the Canadian primary standard of absorbed dose to water

NRC·CNRC METROLOGY

Malcolm McEwen[1], Iymad Mansour[1], Bryan Muir[1], Kimberley Moore[1]

Brian Keller[2], Arman Sarfehnia[2]

[1]Ionizing Radiation Standards, NRC

[2]Odette Cancer Centre

Report PIRS-2873 June 2019

The provision of this report and results, or the use of any particular equipment described herein does not represent an endorsement by the National Research Council of such equipment for the measurement of ionizing radiation.

© Canadian Crown Copyright 2019
The contents of this report may be reproduced as long as the source is acknowledged

National Research Council Canada | Conseil national de recherches Canada

Canada

Determination of the output of the Elekta Unity MR-linac, installed at the Odette Cancer Centre, using alanine dosimeters traceable to the Canadian primary standard of absorbed dose to water

1. Background

The National Research Council of Canada has, in recent years, been developing a capability for using alanine dosimeters to measure absorbed dose to water at therapy dose levels in Co-60 and MV photon beams (Mansour, 2018). The stated uncertainty in the calibration of a batch of alanine dosimeters irradiated, in a therapy-level Co-60 irradiator, is 0.5 % and the uncertainty in the determination of dose using such dosimeters in a clinical radiation beam is estimated to be 0.6 % for doses in the range 10 Gy to 100 Gy. Other researchers (e.g. Billas *et al*, 2018) have demonstrated the suitability of alanine as a dosimeter for use in magnetic fields, and therefore the NRC capability was applied to the Elekta Unity MR-linac (MRL) installed at the Odette Cancer Centre. The purpose of this investigation was to provide external validation of the dose measured by medical physicists at the centre using standard dosimetry protocols and ionization chambers.

2. Methodology

A calibration curve for a single batch of alanine dosimeters (Harwell batch BQ608) was established through reference Co-60 irradiations in the NRC Gammabeam X200 therapy-level irradiator during the period 14-15 February 2019. Alanine pellets were irradiated in the same geometry as in Zeng *et al* (2004) at the standard reference depth of 5 cm in a water phantom with a field size of 10 cm × 10 cm at the surface of the water phantom. The dose rate, as established by the NRC primary standard water calorimeter, was 0.6263 Gy/min on the reference date of 1-Jan-18. Irradiation times were varied from 0.6 hours to 15 hours to provide doses in the range 20 Gy to 500 Gy. The temperature of the water in the phantom was monitored throughout and this was taken to be the temperature of the alanine pellets for the purpose of applying the known temperature correction (Sharpe *et al*, 2009; Desrosiers *et al*, 2012).

A set of dosimeters from the same batch of alanine pellets was despatched to the Odette Cancer Centre at the end of March 2019. The dosimeters were loaded into POM (Delrin™) holders with the same external dimensions as a Farmer-type ionization chamber (as shown in Figure 1). The holder includes an O-ring so that the pellets are hermetically sealed and the holder can be placed directly in a water phantom. As well as the holders to be irradiated, two holders with pellets, were sent as controls. One holder contained blank pellets and the other contained pellets irradiated to approximately 15 Gy in the NRC Co-60 beam. By including two controls, the effect of the transport process on both un-irradiated and irradiated pellets could be assessed.

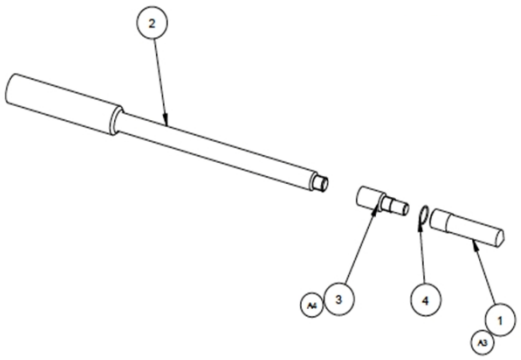

Figure 1. Drawing of holder for alanine pellets. The end capsule can hold six standard alanine pellets (5 mm diameter, ~3 mm thick). A single stem (part 2) is used for multiple holders.

The pellets were irradiated on 9th April 2019 (as reported by Odette staff) and then returned to the NRC for read-out. The pellets remained in their POM holders for the duration of the experiment – from loading at the NRC, through irradiation, to being returned to the NRC for read-out. This meant that any environmental effects (e.g., due to varying humidity) were minimized.

The MRL beam (nominally 7 MV) was calibrated as follows:

Reference chamber	Standard Imaging A19
Phantom	Small MRL water tank filled with distilled water
Gantry	90° (i.e. horizontal beam)
Field size	10 cm × 10 cm
Reference depth	10 cm water equivalent depth
Thimble alignment	Parallel to magnetic field, perpendicular to radiation field
Position verification	MV imaging (AP and lateral)
Protocol used	a) AAPM TG-51: k_Q = 0.9875 b) Malkov and Rogers (2018): k_B = 1.0007
Dose delivered	200 MU (nominally 200 cGy)

The ion chamber readings were corrected for air density (P_{TP}) and the linac calibration was found to be 1 MU = 0.9965 cGy (as reported by Odette staff). After calibration, the alanine irradiations were carried out in both water and solid water phantoms. Rather than deliver a range of doses, all dosimeters were irradiated to the same dose of 15 Gy.

The irradiated alanine pellets were then read out using the NRC EPR spectrometer system (Bruker EMX with Xenon upgrade). There is always a waiting period between irradiation and read-out to allow for radical stabilization (24-48 hours for the NRC read-out protocol). All pellets were readout during the period 16-17 April 2019 and the same read-out protocol was used throughout. The alanine signal was normalized to the mass of each pellet and also corrected to the NRC reference temperature of 21 °C (temperature coefficient used = - 0.14% per °C).

3. Results

3.1 NRC irradiations

The NRC Co-60 alanine calibration is shown in Figure 2. For doses below 800 Gy there is a linear relationship between the alanine intensity and the delivered dose, although an increasing non-linearity is seen at higher dose levels. In addition to normalizing each pellet's EPR signal by its mass, a reference ruby artifact is used to monitor variations in the spectrometer system. The ruby is kept permanently positioned in the EPR cavity of the spectrometer, and the assumption is that any variation in the ruby EPR signal is directly correlated with a change in an alanine pellet signal. Although all doses were below 50 Gy, the entire calibration curve was used as the high dose points robustly constrain the linear fit of the alanine dose response.

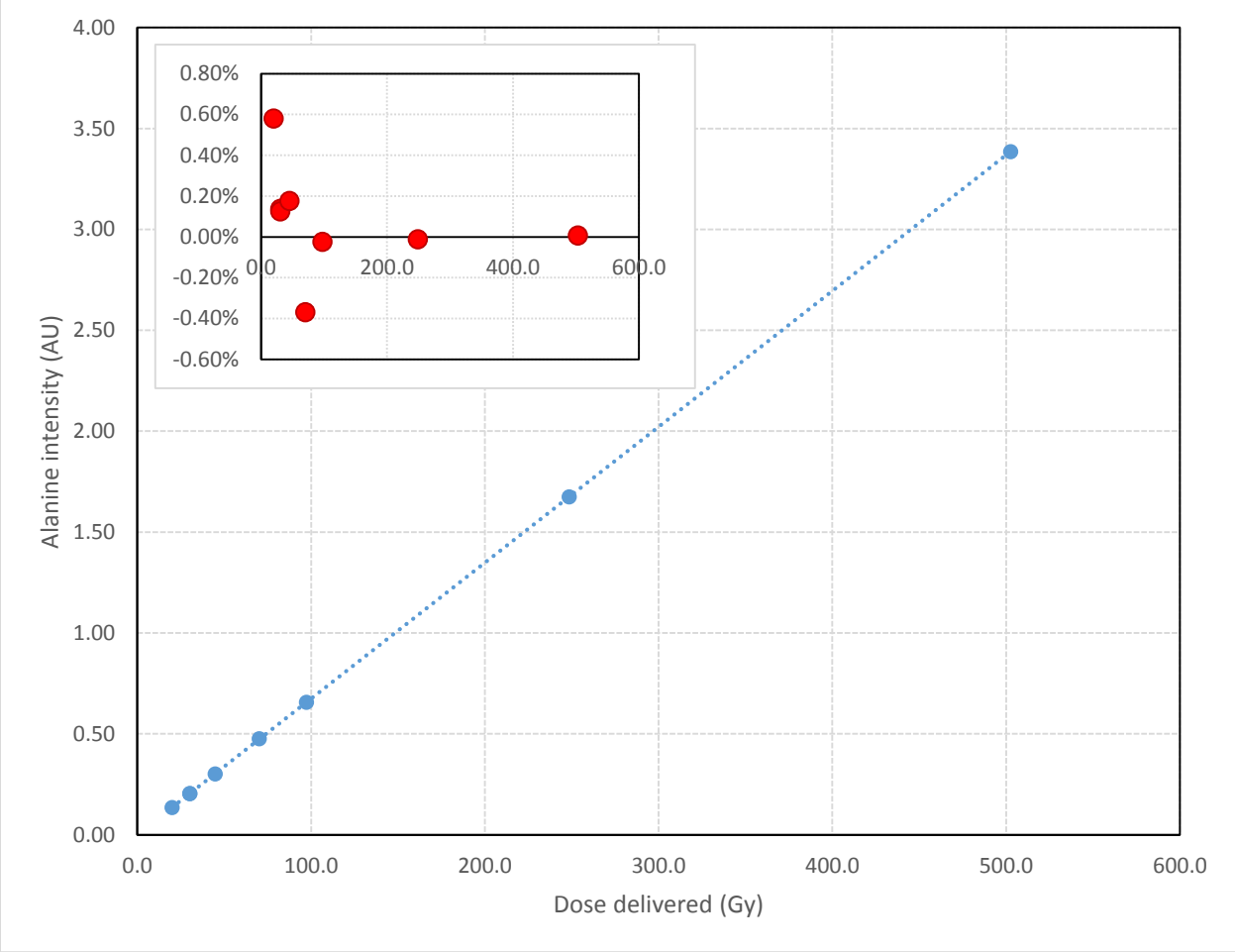

Figure 2. Calibration data for alanine batch, pellets irradiated at NRC. The inset plot shows the relative deviations of the linear fit, which are typically less than 0.2 %. The Type A standard uncertainty of the EPR signal of the five pellets in each irradiation was, on average, around 0.2%.

3.2 Odette MRL irradiations

The data for the Odette irradiations are shown in Table 1.

Table 1 Summary of Odette MRL irradiations 9-Apr-2019

Irradiation label	*Phantom*	D_{stated} (Gy)	M_{read_corr} (Arb units)	Std unc [1]	D_{read} (Gy) [2]	Ratio (D_{read}/D_{stated})
1	Water	15.0	0.10130	0.6 %	15.02	1.0017
2	Water	15.0	0.10162	0.2 %	15.07	1.0048
3	Water	15.0	0.10263	0.5 %	15.22	1.0148
4	Water	15.0	0.10280	0.6 %	15.25	1.0165
5	SW[3]	15.0	0.10141	0.6 %	15.04	1.0027
6	SW	15.0	0.10174	0.7 %	15.09	1.0060
A[4]		15.97	0.10753	0.7 %	15.95	0.9989
C		15.77	0.10575	0.4 %	15.69	0.9948
D		31.54	0.21275	0.5 %	31.57	1.0008

[1] This is the Type A uncertainty only, obtained from the five pellets read from each holder

[2] Based on the Co-60 calibration, corrected for reported energy dependence of alanine and the effect of a 1.5 T magnetic field

[3] The specific type of solid water was Gammex RMI

[4] Letters refer to dosimeters irradiated at NRC in the Co-60 beam. "A" was mailed with the other holders, "C" and "D" were irradiated after the return of the dosimeters from Odette.

The uncertainty of the NRC measurements of the alanine dosimeters irradiated at the Odette are summarized in Table 2. This uncertainty budget is based on that constructed by Mansour (2018) and is significantly less than the standard uncertainty quoted for OSLD and RPLD audit services offered by other organizations.

Table 2. Uncertainty budget for NRC measurements of alanine dosimeters irradiated in the Odette MRL beam in terms of absorbed dose to water

Component of uncertainty	**Standard uncertainty (%)**
Realization of dose (primary standard)	0.4
Signal measurement – calibration	0.2
Temperature @ calibration	0.02
Mass of pellet	0.05
Spectrometer reproducibility	0.25
Calibration fit	0.2
Energy dependence of alanine (Co-60 to 7 MV)	0.2
Magnetic field dependence (0 T to 1.5 T)	0.2
Signal measurement – irradiation	0.6
Temperature @ irradiation†	0.05
Transportation of dosimeters¶	0.1
Combined standard uncertainty	**0.87**

† Temperature at irradiation was supplied by Odette staff, an uncertainty of 0.3 °C is assumed.

¶ Takes into account possible signal variation (e.g. due environmental effects or free radical recombination)

4. Discussion

The three control irradiations give agreement between the measured and stated doses, within the Type A uncertainties and therefore no correction to D_{read} for the dosimeters irradiated in the MRL beam is required.

The standard uncertainty on a set of pellets from one holder is larger than previously seen with internal testing at the NRC (both Co-60 and linac beams) but since there is no significant difference between pellets that were transported and those that never left the NRC, there would not appear to be any effect due to transport or use at the Odette.

Using a Co-60 calibration for the alanine (zero magnetic field) means that two corrections are required, one for the relative energy response of alanine and one for the effect of the 1.5 T magnetic field. The former has been investigated by many authors and is summarized well by Anton *et al* (2013). For a photon energy in the range 6-8 MV, a correction factor of 1.005 is appropriate (i.e., the apparent dose determined from a Co-60 calibration should be multiplied by 1.005). The magnetic field correction has been investigated by Billas *et al* (2018) and data from that publication was analyzed to give a correction factor for a 1.5 T field of 0.994 (i.e., the apparent dose determined from a Co-60 calibration should be multiplied by 0.994). There is therefore a fortuitous cancellation of these two factors.

The results in Table 1 can be combined to give a mean values for measurements in both water and solid water in Table 3.

Table 3. Summary of alanine irradiations

Phantom	Mean dose (Gy)	Std dev[1]	D_{read}/D_{stated}
Water	15.14	0.7 %	1.0094
Solid Water	15.06	0.3 %	1.0043

[1] The standard deviation of the distribution of mean dose values should be consistent with the standard uncertainty on the dose measurement for a single irradiation for the data to be considered as a single set.

There is an apparent difference of 0.5 % between measurements in water and in solid water, but it is not possible to conclude that this is statistically significant, given the Type A uncertainties. Combining the uncertainty budget in Table 2 with the data given in the TG-51 Appendix (McEwen *et al*, 2014) and removing the common component of the Canadian primary standard of absorbed dose to water, then it is clear that the level of agreement between stated and measured doses is within the overall k=1 uncertainty. Other than the common primary standard, the two dose measurement methods use different reference data and rely on significantly different physical bases for the raw measurement and read-out. This independence does result in an overall larger standard uncertainty (due to an increased number of factors involved compared to a comparison of ion chamber measurements) but it also provides increased confidence in the end-to-end process.

References

Anton M, Kapsch R-P, Krauss A, von Voigts-Rhetz P, Zink K and McEwen M, "Difference in the relative response of the alanine dosimeter to megavoltage x-ray and electron beams", *Phys. Med. Biol.* **58**, 3259 (2013)

Billas I, Bouchard H, Gouldstone C, DuaneS, "PO-0875 The suitability of alanine as a reference class detector for MRI-linac dosimetry", ESTRO37 S461 (2018)

Desrosiers M F, Forney A M, and Puhl J M, "A Comparison of Harwell & FWT Alanine Temperature Coefficients from 25 °C to 80 °C", *NIST J. of Res.,* 117 143-153 (2012).

Malkov V and Rogers D W O, "Monte Carlo study of ionization chamber magnetic field correction factors as a function of angle and beam quality", *Med. Phys.* **45** 908-925 (2018)

Mansour I, "Development of mailed dosimetric audit for external beam radiotherapy in Canadian cancer centers using alanine dosimeters", MSc Thesis, Ottawa: Carleton University (2018)

McEwen M, DeWerd L, Ibbott G, Followill D, Rogers D W O, Seltzer S, Seuntjens J, "Addendum to the AAPM's TG-51 Protocol for Clinical Reference Dosimetry of High-Energy Photon Beams" *Med. Phys.* **41**, 041501 (2014)

Sharpe P H G, Miller A, Sephton J P, Gouldstone C A, Bailey M, Helt-Hansen J, "The effect of irradiation temperatures between ambient and 80 °C on the response of alanine dosimeters", *Rad. Phys. Chem.* **78** 473–475 (2009)

Zeng G G, McEwen M R, Rogers D W O and Klassen N V, "An experimental and Monte Carlo investigation of the energy dependence of alanine/EPR dosimetry: I. Clinical x-ray beams", *Phys. Med. Biol.* **49** 257-270 (2004)