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Correction for the Effect of Irradiation Temperature on the Response of Alanine Dosimeters in Industrial Electron Beams

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Introduction

Alanine dosimeters irradiated in industrial electron beams require correction for the near adiabatic rise in temperature during irradiation. Many current recommendations suggest correction to the mean irradiation temperature, on the basis that temperature rises linearly with dose during irradiation. However, evidence has been accumulating from a number of sources that suggests correction to the mean irradiation temperature may result in an overestimation of dose.

We present here evidence from studies in calibration laboratories and industrial facilities that indicate the accuracy of alanine dosimetry in industrial electron beams may be improved if the dosimeter is corrected to the maximum, rather than the mean, irradiation temperature.

Temperature correction

Irradiation temperature affects the response of all types of alanine dosimeter, although the magnitude of the effect is dependent on dosimeter formulation. For accurate dosimetry, it is necessary to characterise the effect of irradiation temperature for the dosimeter type and method of measurement and to apply corrections if the dosimeter is irradiated at a temperature different from that used for calibration.

In this work, the dosimeters used were pellets containing ~90% alanine and ~10% paraffin wax, manufactured by Harwell Dosimeters Ltd. The measurements and temperature characterisation were carried out by NPL using ^{60}Co radiation at dose rates of the order of 10 kGy / h. A calibration curve was prepared for the batch of dosimeters by irradiation in ^{60}Co radiation at 25 ºC. Irradiations at a range of temperatures and doses were then used to determine the effect of irradiation temperature on the measured response of the dosimeter (peak-to-peak height) between 25 ºC and 55 ºC. The corrections obtained were linear with temperature for a given dose, but varied with dose. The results are shown in Figure 1, where the temperature coefficient (c) is used to correct measurements to 25 ºC using the equation: $pp(25) = pp(t)[1+c(25-t)]$ where t is the irradiation temperature and pp(t) the measured response.

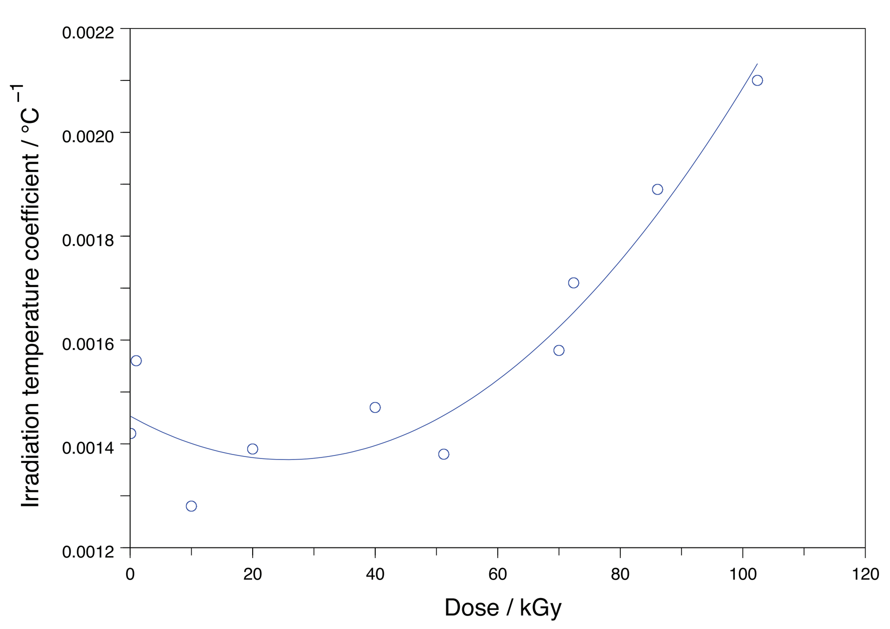

Figure 1. Alanine dosimeter irradiation temperature coefficient as a function of absorbed dose.

Primary Calorimetry

Measurements using a primary calorimeter at an industrial 10 MeV electron beam facility have recently been reported [1]. These enabled the direct calibration of alanine dosimeters under industrial electron beam irradiation conditions. The dose determinations were based on measurement of temperature rise in material (Acrylonitrile butadiene styrene, ABS) of known specific heat and are therefore independent of any other dosimetry standard. Alanine dosimeter pellets were irradiated in an ABS phantom of the same dimensions as the calorimeter core, which was irradiated in close proximity to the calorimeter. Temperature measurements were made both in the phantom and in selected alanine pellets, the latter using a small thermistor embedded in a pellet. Figure 2 shows the temperature both within an alanine pellet and the surrounding ABS phantom immediately after irradiation. It is clear that although the specific heat of the alanine and ABS are different, resulting in slightly different initial temperatures, the pellet equilibrates with the phantom within ~60 s. The phantom temperature can therefore be taken as the alanine pellet temperature in such irradiations.

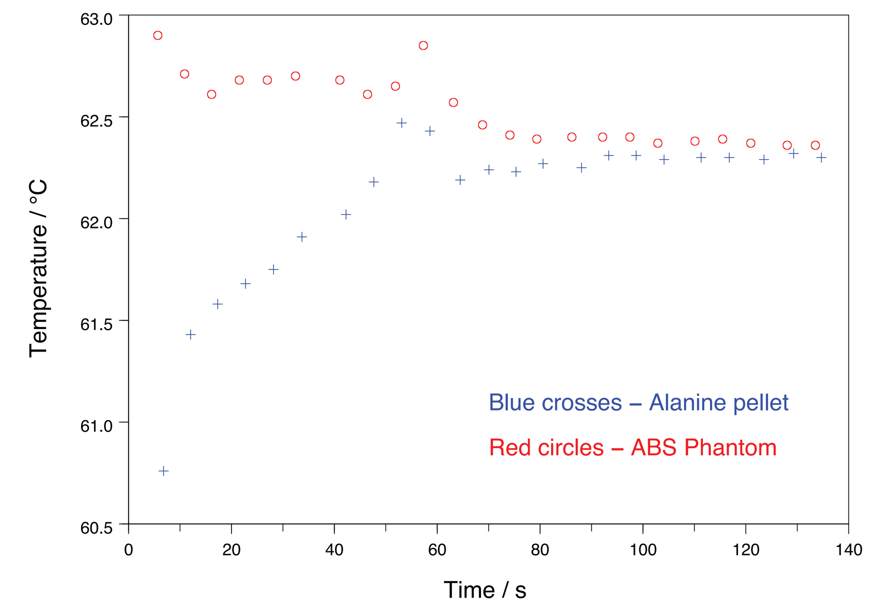

Figure 2. Temperature of alanine pellet and surrounding ABS phantom immediately after irradiation.

The results of direct calibration of alanine dosimeters against the primary calorimeter are shown in Figure 3. The alanine doses have been calculated using both the mean irradiation temperature and the maximum irradiation temperature as the basis of the correction.

It is clear from Figure 3 that alanine dosimeters corrected to the maximum irradiation temperature are in significantly closer agreement to the calorimeter dose than those corrected to the mean irradiation temperature.

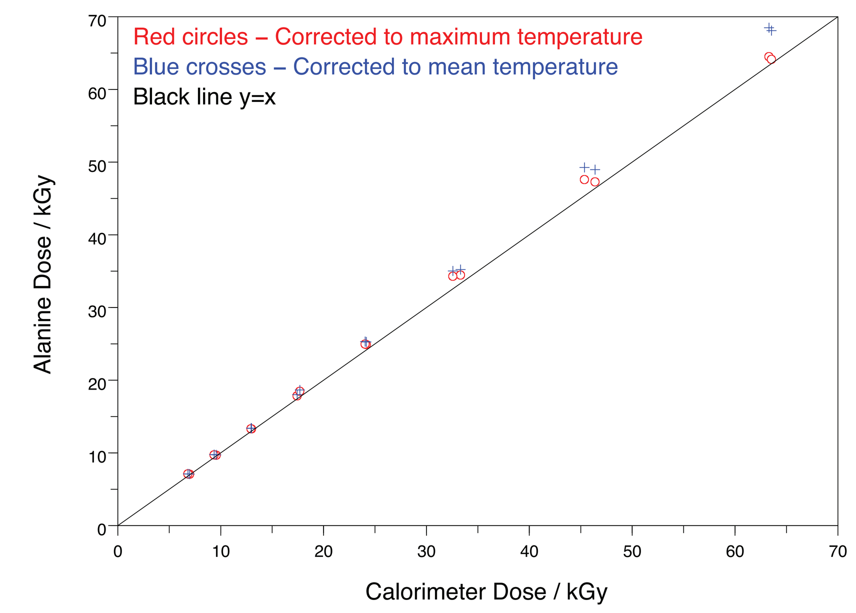

Figure 3. Alanine doses corrected to maximum and mean irradiation temperatures as a function of dose determined by calorimetry.

This is shown clearly in Figure 4, where the ratio of alanine dose to calorimeter dose is plotted against calorimeter dose. The lines shown are first order fits to the data. The relationship between alanine dose corrected to maximum irradiation temperature and calorimeter determined dose is essentially constant over the dose range, whereas the data for alanine corrected to mean irradiation temperature shows a systematic trend.

The constant difference of 3% between the alanine corrected to maximum irradiation temperature and the calorimeter derived dose is well within the uncertainties of the two methods (2.4% and 4% *k*=2) respectively.

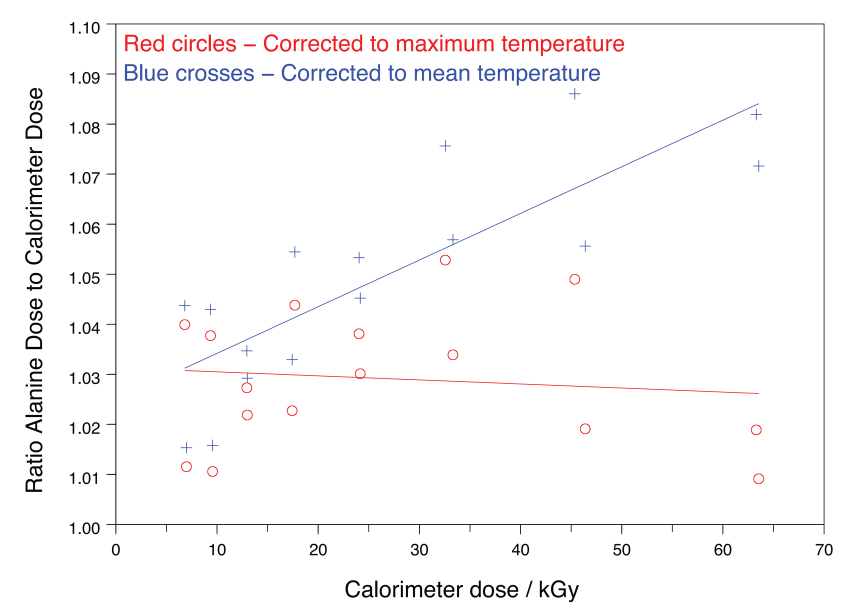

Figure 4. Ratio of alanine dose to calorimeter dose corrected to maximum and mean irradiation temperatures.

Machine output data

The relationship between dose measured by alanine dosimeters and machine output can also be used to demonstrate the validity of the temperature correction. Figure 5 shows plots of alanine dose against machine output, in arbitrary units, for alanine corrected to maximum and mean irradiation temperatures. The accelerator was a 10 MeV IBA Rhodotron with machine parameters controlled to within 1.5%. The alanine was irradiated in polystyrene phantoms and the temperature measured using permanent change "thermo labels" with an uncertainty of ±2 ºC. The alanine entered the irradiator at room temperature and the maximum temperature recorded was 65 ºC. The lines shown are through the origin first order fits and the residuals from the plots are shown in Figure 6.

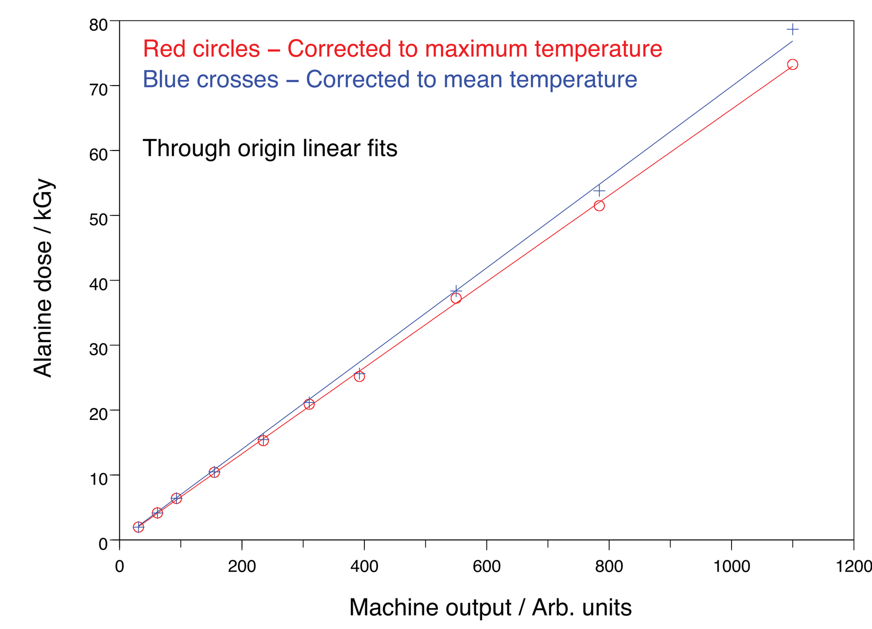

Figure 5. Alanine doses corrected to maximum and mean irradiation temperatures as a function of machine output.

The data clearly show significantly better linear correlation between alanine dose and machine output when the alanine is corrected to the maximum irradiation temperature.

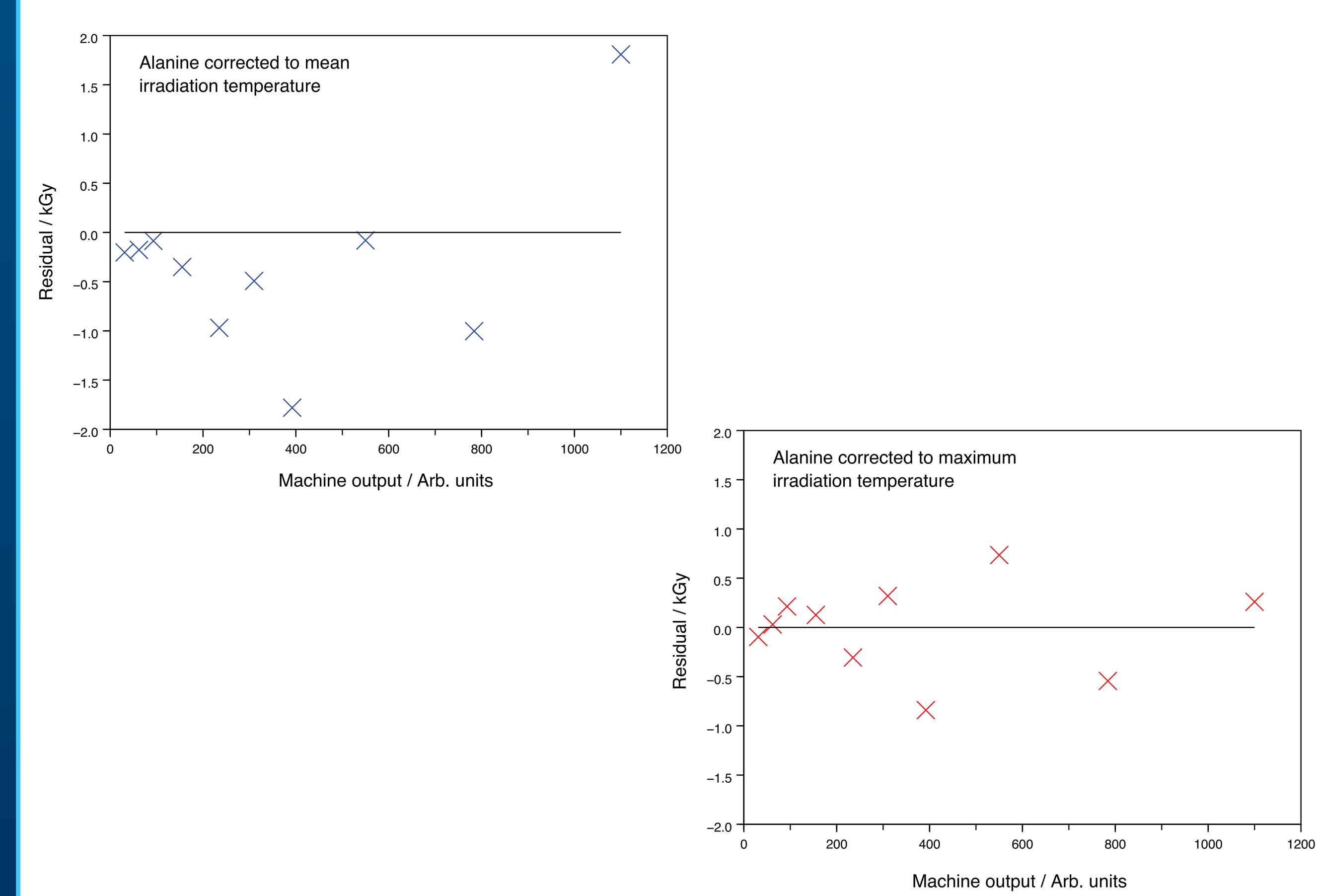

Figure 6. Residual plots of through origin first order regression fits of alanine dose as a function of machine output.

Conclusion

For industrial electron beam irradiations, data from both primary calorimetric methods and machine output measurements indicate a significantly better correlation with alanine dosimetry if the alanine is corrected to maximum irradiation temperature, rather than mean irradiation temperature. It is therefore recommended that correction to maximum irradiation temperature is used for such measurements.

National Measurement System

References

[1] Galer S.,Bailey M., Sephton J. P. and Sharpe P. H. G., "A Primary Calorimeter for Dosimetry at Industrial Electron Beam Facilities", Presented at IMRP 2011

Acknowledgements

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