An attempt to determine the saturation dose for PRESAGETM

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Abstract. This brief work-in-progress outlines two methods that we have attempted for
determining the dose at which the linear relation between optical density of a PRESAGETM
dosimeter and the dose deposited breaks down. Both methods were equally successful in
mapping the linear relation up to an optical density of approximately 6.25 cm−1 (absorbance
2.5), but no saturation was found in this region.

1. Introduction

It is well known that gel dosimeters exhibit saturation effects. In most cases, the “response” to
increasing dose (be it NMR R2, Hounsfield number, ultrasound properties or optical absorption) starts
off as a linear relation and then “rolls off”, with a lower and lower response for additional dose above
a certain threshold. Although different gel formulations have different saturation doses, these generally
lie in the region of tens of Gy. We were keen to know at what dose saturation occurs for PRESAGETM
[1], as this may have a bearing on our ongoing studies of the interaction of this dosimeter with protons.
The results of this study, albeit provisional, are presented here on the basis that other researchers may
find them interesting (and perhaps surprising).

2. Materials and methods

10 cuvettes containing PRESAGETM, of optical path length 4 mm, were supplied by the manufacturer
(Heuris Pharma, Skillman, NJ). These were irradiated using a 6 MV Varian linac at the Royal Surrey
County Hospital. A build-up region was provided by covering the samples with a slab of solid water,
such that Dmax was reached at the surface of the cuvettes, and a bolus was placed around the samples
laterally. The field size was 200 × 200 mm2 and the cuvettes were irradiated together, abutting each
other, to ensure as uniform a dose as possible to the batch. The dose given was fractionated and after
each fraction was given, one cuvette was removed, to yield the following nominal doses in the ten
cuvettes: 40, 60, 80, 100, 120, 140, 160, 180, 240 and 280 Gy.

Each cuvette was measured in two different ways. Firstly, the cuvette was placed in a standard
double-beam spectrophotometer (Camspec, Cambridge, UK) together with an unirradiated cuvette.
Secondly, the cuvette was placed in the beam of the fast laser scanner described in [2]. The standard
acquisition was modified by making the field-of-view (FOV) extremely small, such that the entire
FOV was contained within a single cuvette. This second experiment was performed on the basis that it
might prove possible to extend the range of optical densities measured.
Figure 1: Spectra of PRESAGE™ cuvettes irradiated to increasing doses. Note that, since a double-beam spectrophotometer was used, the baseline spectrum of the compound is subtracted, leaving only the changes that occur with increasing dose.

Figure 2: Absorbance of the PRESAGE™ samples as a function of dose for three different wavelengths (633, 450 and 680 nm). Notice that, although the data at 450 and 680 nm fall within the measureable range of the spectrophotometer for a larger number of cuvettes, the non-linear relation of the peak height with dose would make it much more difficult to determine the saturation threshold.
3. Results and discussion

Figure 1 shows the spectra recorded from the ten cuvettes and the unirradiated sample. It will immediately be obvious that the spectrophotometer records the spectra of the first six samples faithfully, but fails for samples 7–10 in the approximate region 600–680 nm — precisely the region in which we are interested. The upper limit of reliable measurement at 633 nm (the HeNe laser wavelength for which PRESAGE™ was designed) is an absorbance of about 2.6. Since the sample is 4 mm thick, this corresponds to an optical density of the PRESAGE™ of approximately 6.5 cm$^{-1}$, which is exceedingly large.

Initially, it was hoped to use regions of the spectrum slightly away from the 633 nm peak, which do not (optically) saturate the spectrometer in order to measure the (chemical) saturation of the PRESAGE™ samples. However, it will be seen from Figure 2 that the other regions in the absorption spectrum show a strongly non-linear dependence on dose and are thus unsuitable for this purpose.

Figure 3 compares the results of the laser optical CT scanner to those of the spectrophotometer. Once the absorbance of the unirradiated sample and the fixed absorbance of the scanner’s lenses has been taken into account, the two sets of data overlay each other almost perfectly up to 120 Gy (absorbance 1.94). It is no surprise that the error in absorbance increases dramatically above 100 Gy. Standard propagation of errors tells us that the error in log $x$ is proportional to 1/$x$. This means that the size of the error will rise by an order of magnitude with every unit increase in absorbance (all other things being equal).

It should be possible to better adapt the laser scanner for the task of measuring absorbance, on a cuvette sized object, by modifying the position of the sample and photodiode. Some light is currently lost through stray light reflections. Based on the specification of the photoreceiver used, it is anticipated that significantly higher values of absorbance should be measureable.
4. Conclusion
A linear relation was found between dose and optical response between 0 and 150 Gy (absorbance 2.6), the limit of reliable measurement of our spectrophotometer. No detectable saturation effect was observed. The fast laser scanner gave almost identical results to the spectrophotometer in the dose range 0 – 120 Gy (absorbance 0 – 1.94). Further improvements to the measurement capabilities of the latter instrument should be easy to achieve.

References
[1] Adamovics J and Maryanski M, Characterisation of PRESAGE™: a new 3-D radiochromic solid polymer dosimeter for ionising radiation, Rad. Prot. Dosimetry 120(4), 107–112 (2006)
[2] Krstajic, N and Doran S J, Fast laser scanning optical-CT apparatus for 3D radiation dosimetry. Phys. Med. Biol., 52(11) N257-N263 (2007).