Radiation Gel Dosimetry Using an Earth Field NMR Relaxometer

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The increase of relaxation rate with increasing radiation dose is a well-known effect for certain polymer gels. Using magnetic resonance imaging techniques, it is possible to use this effect to obtain 3D dose distributions [1]. However, quantitative measurements of the dose are still difficult. Since MRI equipment is optimised for spatial resolution, the precision and reproducibility of relaxation rate measurements are restricted and do not allow multi-exponential analysis of the signal.

The NMR device applied in this study measures the free induction decay (FID) in the Earth's magnetic field ($\nu_L \approx 2$ kHz) with high precision (S/N ≈ 100, improved by signal accumulation). The homogeneity of the Earth's magnetic field in the laboratory is improved by shims. Natural and anthropogenic disturbances of the signal are almost completely eliminated by active and passive shielding. The temperature of the sample is kept constant (+/- 2°C) during the measurement by thermostatized airflow. The sample volume of 25 ml provides a high signal to noise ratio and minimises the influence of dose gradients at sample and sample holder interfaces, but is still small enough to minimise the effect of dose inhomogeneity in a carefully chosen irradiation geometry. The transversal relaxation rates are directly derived from the digitized FID signal (no spin-echo technique is needed) with a time resolution of 250 µs. Due to the high S/N ratio, the high reproducibility and the large amount of data points, a multiexponential analysis is possible which leads to a more precise description of the gel system.

Fig. 1 The Earth Field NMR device with shims, shielding and air-cooling.

A first experiment was performed with a normoxic polymer gel based on methacrylic acid (nMAG: 8% gelatin, 6% methacrylic acid, 2mM THP [2]). The samples were irradiated with opposing fields of ^{60}Co gamma rays. A massive Perspex sample holder was surrounded by dose build-up material to obtain constant dose throughout the sample volume. Temperature was kept constant to +/- 2°C during storage, irradiation and measurement. The transverse magnetization decays of the gels showed a, previously undiscovered, bi-exponential behaviour. The relaxation rates of the fast component increase linearly with dose. The slow component appears to be dose independent. The R_2-dose sensitivity is about 8 s^{-1} per Gy. Literature values for the same gel in high field applications indicate a much lower sensitivity of 2 s^{-1} per Gy [2].

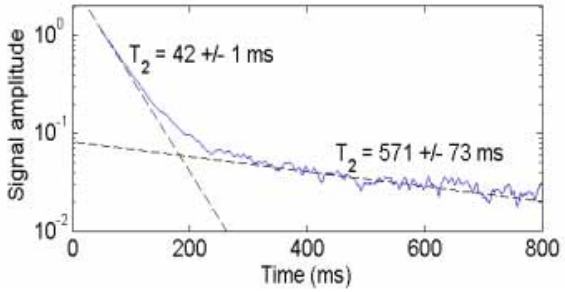

Fig. 2: Free Induction Decay signal (20 accumulations) of nMAG after radiation with a dose of 3 Gy. The bi-exponential decay is clearly visible. Both components are indicated by the dashed lines.

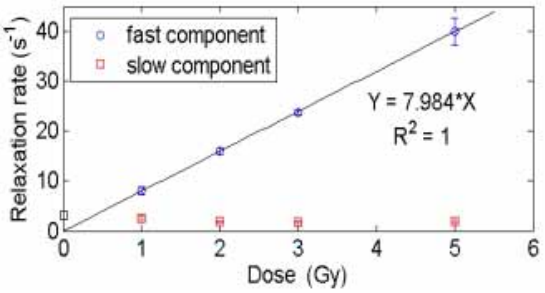

Fig. 3: Dependence of the relaxation rates on dose after multi-exponential analysis. The fast component is perfectly linear with dose.

The results appear promising in the view of exploring the effects governing gel relaxation rates. Further experiments will continue investigating multiexponentiality and the influence of temperature, time and gel composition. The overall goal is to get closer to absolute dose determination using NMR gel relaxometry.

[1] Maryanski *et al.*, Phys. Med. Biol. 39 (1994) 1437-1455
[2] DeDeene *et al.*, Phys. Med. Biol. 51 (2006) 653-673