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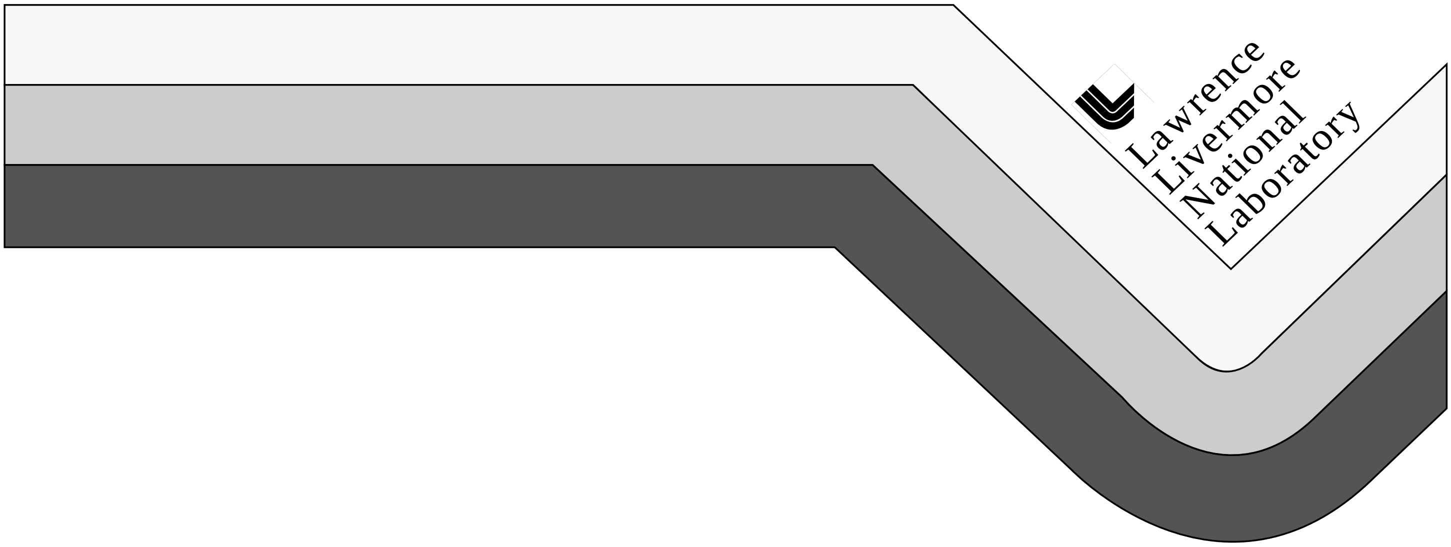

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EPR dosimetry of whole deciduous tooth using a constant rotation goniometer and background subtraction with a dentine standard.

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We report here a rapid method of electron paramagnetic resonance (EPR) dosimetry of dental enamel which will allow screening of whole deciduous teeth of children following a nuclear accident. The technique requires virtually no sample preparation and is capable of measuring doses of less than 100 mGy. Teeth may be scanned for threshold dose levels without the need for added calibration doses and those of particular interest may be more accurately examined using the additive dose method. The success of the technique lies in the elimination of anisotropic effects by rotation of the sample during measurement together with subtraction of spectra from the empty cavity and a standard "background" tooth. normalization using in-cavity mn++ standards is also employed.

EPR spectroscopy is being used to measure radiation doses to the enamel and dentine of teeth of individuals exposed during the Chernobyl nuclear reactor accident. Teeth have been collected by dentists from exposed individuals during routine extractions, and used to document eligibility for government compensation as well as for epidemiological studies into the health effects of ionizing radiation. Although EPR measurements on teeth from mature individuals provide information on doses received they can only be obtained at random from the population. This limitation, together with the time consuming process of sample preparation and analysis, has made EPR dosimetry of teeth an unlikely candidate for screening of a population shortly following a nuclear accident.

There is, however, an abundant, readily available source of teeth from a subpopulation which is one of the groups at greatest risk, children 12 years old and younger. Between the ages of 6 and 13 years, children shed deciduous teeth at the rate of one every 3 to 6 months. With knowledge of the dosimetric value of the teeth, they could be saved and documented by parents for measurement of radiation dose. That deciduous teeth were not used as dosimeters following the Chernobyl accident was likely due to immaturity of the technology plus the fact that deciduous teeth contain relatively small amounts of enamel both absolutely and relative to the dentine, making the process of separation both time consuming and difficult (1,2).

Considerable progress has been made recently on reducing the lower limits at which gamma ray exposure in tooth enamel can be detected. A recent intercomparision put the lowest detectable EPR dose to enamel at circa 100 mGy with a 45% accuracy (3). A follow-up intercomparison showed that the accuracy levels could be reduced to within 20% for doses of 175 to 250 mGy (4). The success of this effort was due to employing chemical purification of the samples and use of background subtraction techniques by the Scientific Center for Radiation Medicine (SCRM) of Ukraine (5) and the employment of the differential power method (6) by the University of Utah (Utah) group Subsequent to this, further accuracy has been obtained by the Utah group by employing a constant rotation goniometer and a technique for optimizing the distribution of sample points (7).

Untreated enamel has two major signals located at both g = 2.0045 and $g_\perp = 2.0018$, $g_\parallel = 1.9975$. These are commonly referred to as being the native and the radiation sensitive signals respectively. In addition to these there are a number of other signals attributed to such causes as mechanical trauma (8), heating, etc., as well as a number of transient signals (9) incurred by recent irradiation. In the case of enamel, further complications are caused by the addition of unknown doses due to dental x-rays and, in the case of front teeth, by sensitivity to UV light (10).

The importance of painstaking technique and proper removal of background signals cannot be overemphasized. Fig. 1 shows some of the problems which develop when this is not done. Here we have a dose response of the radiation sensitive signal from a single piece of enamel using a constant rotation goniometer. A residual analysis indicates that each point has a 21 mGy standard deviation. Note the uncertainty about the location of the y-intercept. The sample spectra contained a linear baseline offset with a positive slope which can be attributed to some kind of sample or cavity impurity. In this case the problem was failure to subtract out the native signal located at g = 2.0045, and background signals which are known to be dynamic.

Perhaps the best system for minimizing background signals is that employed by SCRM (5). The technique employed by SCRM uses an in cavity Mn^{++} standard combined with chemical purification of the sample and a system for subtracting out the dynamic background and the native signal. The in cavity Mn^{++} standard is used to correct for changes in frequency (g-factor) and intensity (Q-value). The SCRM technique includes a rigorous system of chemical purification which we did not employ in this study because we were studying whole specimens.

The background subtraction technique requires first obtaining sufficiently pure specimens. Once a pure specimen is obtained, it is annealed to remove transient signals, followed by scanning. The following background corrections are made. First of all, the spectrum of an empty EPR tube is subtracted to remove background noise caused by the tube itself. The EPR tube spectrum is superimposed over that of the sample spectrum by adjusting the positions of the third and fourth Mn^{++} lines. The values of the small regions containing the Mn^{++} lines are set to zero before subtraction so as not to remove them from the sample spectrum. Following this, the spectrum of a native signal standard is subtracted from the sample spectrum. The native signal used for this subtraction must in a manner similar to that of the sample, have its empty cavity spectrum already subtracted out. The height of the native signal in the native signal standard is adjusted until it is the same as that of the native signal in the sample spectrum. Once again, adjustments are made to retain the third and fourth Mn^{++} lines.

Experimental. A healthy deciduous lower incisor was used which had never been irradiated. The entire cutting edge of the tooth had been worn down to the dentine. The sample was untreated except for an initial wiping down with methanol. Dried blood was visible on the root, surface yellowing was present on the exterior enamel surfaces and it had a split at the cutting edge extending 2/3 the length of the tooth. The tooth weighed 102.9 mg. The approximate dimensions of the tooth were 6.8 x 4.2 x 4.1 mm. The thickness of the cutting edge was 1.5 mm. The EPR tube used had a 4.9 mm inner diameter. When scanned, it was placed with the cutting edge down and centered in the cavity. This insured the highest possible enamel to dentine ratio during the scan.

The specimen used for obtaining the native signal standard was a carved dentine cylinder obtained by removing the enamel cap from a wisdom tooth using a low speed diamond saw. It weighed 211.5 mg and had two cavities in one side which were part of the pulp cavity. It was approximately 3.9 x 10.7 mm and was scanned in an EPR tube with an inner diameter of 4 mm. Its bottom was rounded to fit snugly against the bottom of the EPR tube. Because of the low sensitivity of dentine compared to enamel and assuming that it had received a minimal exposure to dental x-rays, it was deemed to have a radiation sensitive signal sufficiently close to zero to be used as a native signal standard (Fig. 2).

A Bruker ESP300E x-band spectrometer was used (Bruker Instruments, Billerica, MA). Instrument parameters were 25 mW power, 10 mT scan width, 0.5 mT modulation amplitude, 10^5 receiver gain, 82 ms conversion time, 60 sweeps per spectra and a frequency of approximately 9.7 GHz. Irradiations were done with a U.S. Nuclear ^{60}Co source (Burbank, CA 91500). The rotation rate was 0.012/m.

The deciduous tooth and the native signal standard were annealed at 95°C, the deciduous tooth for 1 to 2 hours and the dentine for 30 min subsequent to each irradiation. The dentine and the deciduous tooth were not scanned after annealing until their weights had risen to within 1% of their equilibrium values.

Once all the background signals have been eliminated, the following procedure was used to obtain the peak-to-peak values of the radiation sensitive signals. The resulting curves were first smoothed using the 25 point third order polynomial filter in the standard software package of the Bruker ESP300E. The value of 25 points was found empirically to be the maximum value that would not distort the radiation sensitive signal of enamel at 100 Gy exposure. Measurements were then made at $g = 2.0034$ (peak maxima) and 2.0007 (peak minima) of the perpendicular component of the radiation sensitive signal.

Results. The dose response for the deciduous tooth is shown in Fig. 3. Note that the 100 mGy dose can be readily distinguished from the 0 mGy dose. The maximum dose expected from background should be no more than a few tens of mGys. The large value obtained here of 98 ± 15 mGy can probably be attributed to U.V. light due to the sample being a front tooth.

Discussion. Retrospective EPR dosimetry can now be done on whole or partial pieces of bone and teeth with a large reduction in sample preparation time. It is theoretically possible to extend such studies to shells, calcites, etc. The accuracy with which this can be achieved is now so high that measurements of bone and dentine can be made at levels previously attainable only by enamel, while the accuracy for enamel has been improved by an order of magnitude.

One important result of this study is that it is now possible to routinely screen deciduous teeth from children. Deciduous teeth are so small and have such a thin layer of enamel, that it is difficult to separate them into enamel and dentine fractions.

From standpoint of epidemiology of the population of young people following a nuclear mishap, the availability of deciduous teeth represents an important source of dosimetry data since they are continuously being shed on a routine basis. Further, many of the affected children will be shedding multiple teeth and in some instances will be generating new teeth. These new teeth will date from after the nuclear mishaps and can then also eventually be examined as built in controls following shedding.

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Figure Captions

Fig. 1. Dose response curve of a single enamel piece. It weighed 147 mg and was cut from an enamel cap whose dentine had been removed by grinding with a dental drill. The instrument parameters were the same as for the deciduous tooth except 3.5 mT scan width, 2.56 ms conversion time and ~1,000 sweeps per spectra.

Fig. 2. Dose response curve of the radiation sensitive signal for the dentine cylinder used as a native signal standard. A lower sensitivity is demonstrated relative to the whole tooth because of the zero enamel content. Note the close approximation to zero of the y-intercept. Residual analysis placed individual errors at 0.2 Gy, while the residual errors for pure enamel had previously been found to be 0.1-0.2 Gy for enamel (4). Slope = 27.3e3 ± 2e3. y-intercept = 2.3e3 ± 4.1e3.

Fig. 3. Dose response for deciduous tooth taken using a constant rotation goniometer and analyzed with the modified SCRM method. There are two superimposed points where the line crosses the y-axis. The lowest point at zero appears to be an

outlier. Slope = 167.7e3±8.2e3, y-intercept = 16.4e3±2.4e3. The dose estimate (x-intercept) is 98±15mGy. Residual analysis showed the standard deviation of each measurement was 35 mGy.

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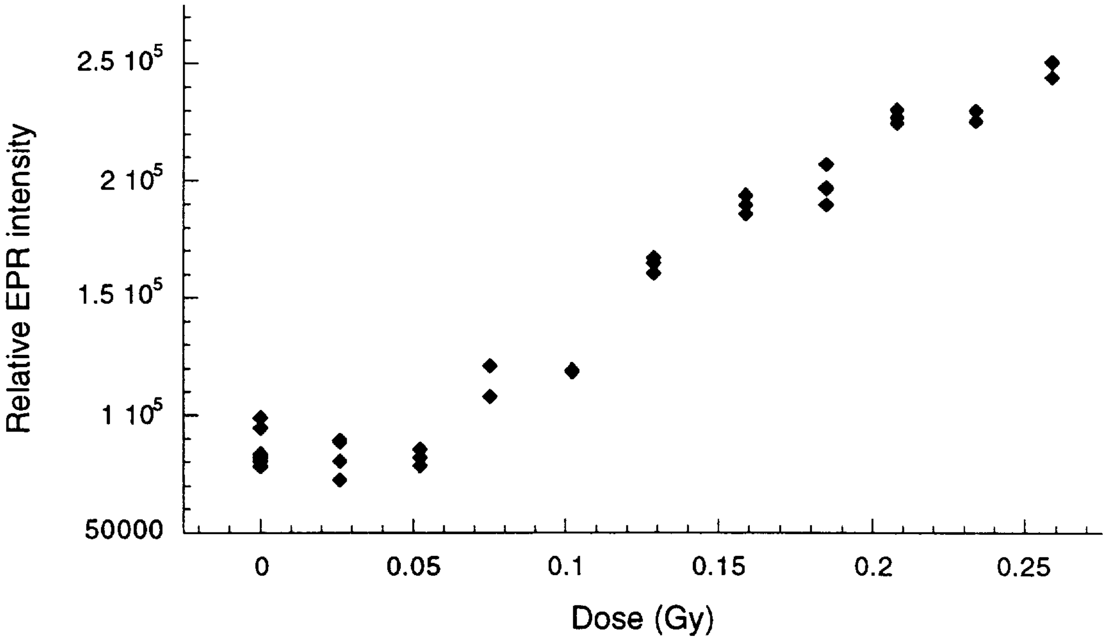

Figure 1 - Haskell et al. Deciduous tooth paper.

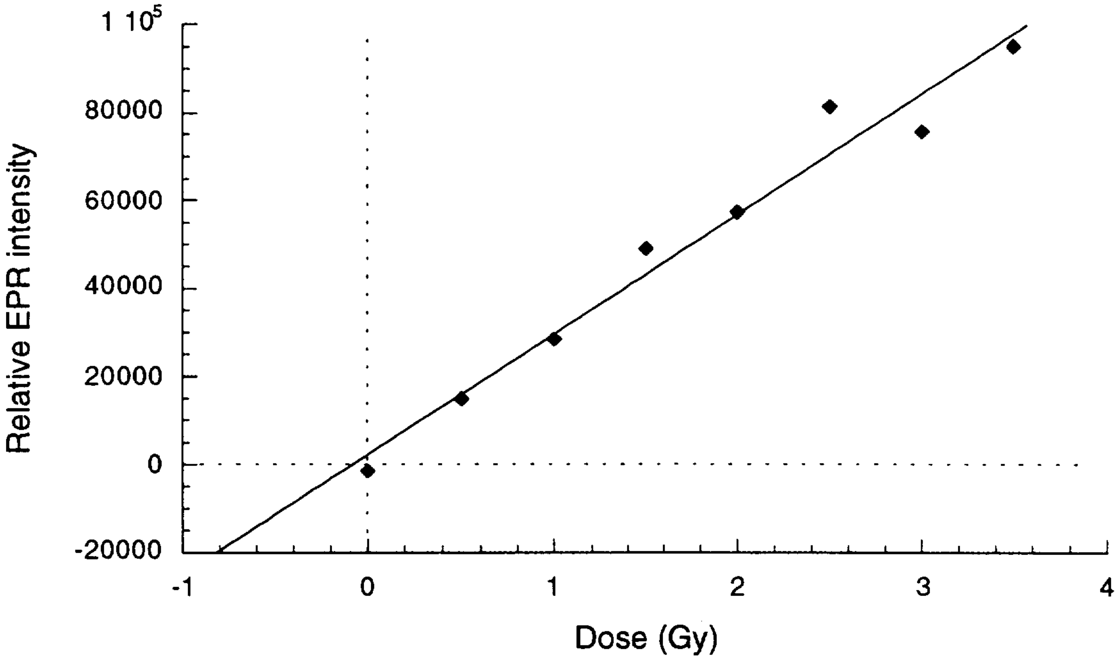

Figure 2 - Haskell et al. Deciduous tooth paper.

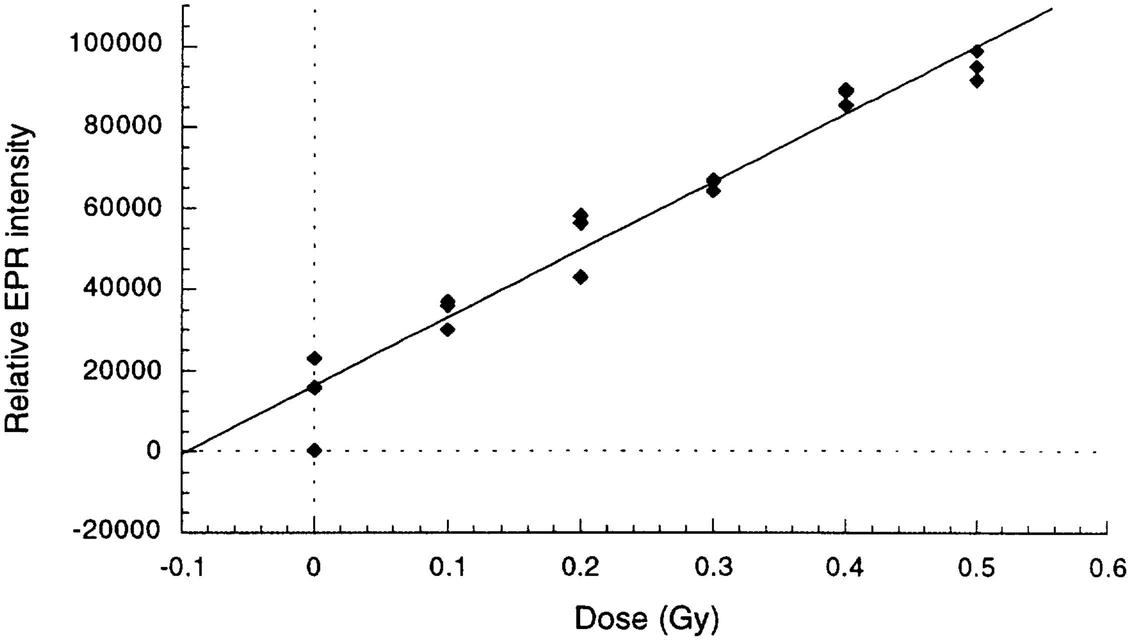

Figure 3 - Haskell et al. Deciduous tooth paper.

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