Motivation
In the case of a nuclear disaster such as an explosion or meltdown medical triage should include estimation of how much radiation the patient has absorbed. Unfortunately current methods for estimating this are invasive and painful. With radiation deaths in the wake of such events often numbering in the tens of thousands, a cheap and portable method that can detect a person’s radiation exposure would be invaluable. When a tooth is irradiated, radicals are formed in the enamel layer that can be detected by electron spin resonance (ESR).

Background
ESR, sometimes denoted as electron paramagnetic spin resonance - (EPR) spectroscopy is used in many fields of science for a variety of paramagnetic(1) samples, i.e. samples that contain one or more unpaired electrons in their valence shell otherwise called radicals.

ESR takes advantage of the magnetic resonance phenomenon. When a paramagnetic sample is introduced into a magnetic field, you can measure it using microwave radiation (9GHz - 100GHz) in the sample’s magnetic resonance frequency: the frequency at which the radicals vibrate. This is like pushing a swing at the perfect time to amplify its movement or causing it to break a glass.

The relaxation mechanism for $T_1$ is defined as spin-lattice relaxation where energy dissipates from the spins into the environment whilst $T_2$ is defined as spin-spin relaxation where energy dissipates from the spins to other spins. Figs 1+2.

Objective
The objective of the project is to explore the use of advanced ESR techniques in order to measure irradiated paramagnetic samples in specific dosages.

Methods
Teeth preparation - Teeth were irradiated by Cobalt 60 and Cesium 137 sources with doses from 1 to 1000 greys. Subsequently teeth were etched using acid while heated and sonicated for 200 minutes in order to achieve isolated enamel layer. Because only this layer contains the radicals.

A Constant wave spectrometer (CW) was used to determine the correlation between spin density and the radiation dose and source.

In order to identify the number of spins present in our tooth samples, the teeth were measured by themselves and then together with a quartz reference with a known number of spins. The weight of the samples was also measured in order to calculate their spin density. Fig3.

Pulsed ESR - The relaxation time of $T_2$ was measured as a function of radiation dose in order to characterise the relationship between the dose and the resulting $T_2$.

In order to compare the results, $T_2$ was also measured to determine which method would best allow us to calculate the radiation level in an unknown sample.

In the equations below to gain the $T_1$ and $T_2$ relaxation times:

$M = M_0(1 - 2e^{-\frac{T_1}{T_2}})$

Results

Spin density vs Dosage

Fig 4. $T_2$ and Spin density vs radiation dosage results. Each bar represents a different tooth with the colors representing different radiation sources.

Discussion and Conclusions
Spin density increase with dose, enamel show different energy response to Cs$^{137}$ and Co$^{60}$. $T_2$ increase with the dose in both radiation sources. This is contradicting the basic theory. Fig 4.

$T_1$ distribution show that the enamel layer contains different contributions for the spin environment. Fig 5.

However, more analysis is needed to understand these phenomena.

Our project shows the complexity of dose response in teeth enamel and the use of advanced ESR techniques of $T_1$ and $T_2$ give us a different aspect of the irradiated teeth samples.

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