Innovative X-Ray Dosimeter Devices: Point and 2-D Detection

Dose verification and validation for high energy photon radiotherapy

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Motivation

In radiotherapy, the x-ray dose is concentrated on the tumour, with a low x-ray dose to the surrounding healthy tissues. This involves small beams and high dose gradients which are very difficult to measure and quantify [1,2].

Currently, x-ray doses are measured using air-filled ionisation chambers. However, because they use air as the sensitive medium, these chambers are large. Of the available alternatives, each has its own limitations [3].

We have developed two dosimeter prototypes: one for point measurements of the dose rate and accumulated dose, and one for 2-D dose imaging. One potential application is the verification and validation of radiation treatment plans that use medical linear accelerators.

X-Ray Dosimeter Materials

As the radiation sensor, we use our own patented fluoroperovskite materials doped with fluorescent ions which have a response to radiation close to that of tissue. These materials display optically stimulated luminescence [4-7] which can be used to record the radiation dose both during and post irradiation [7].

Optically stimulated luminescence is a process where x-rays create trapped electrons and holes, which, when optically excited, produce light in proportion to the x-ray dose.

Photograph of one of the transparent polycrystalline fluoroperovskites.

We have developed a method to make transparent polycrystalline samples that can be made significantly faster than bulk single crystals. One of the transparent polycrystalline samples is shown in the picture to the left.

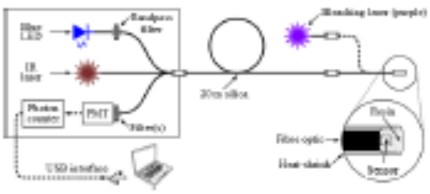
Nanoparticles of these materials have also been made and can also be used as real-time nearly tissue-equivalent dosimeters because the radioluminescence is only weakly dependent on the dose history [8].

Radioluminescence occurs during irradiation when the radiation-generated electrons and holes promptly recombine, resulting in emitted light that is proportional to the dose rate.

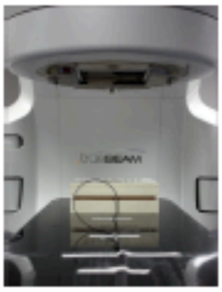
Point Dosimeter

The transparent polycrystalline samples have been used as the radiation sensor in a fibre optic dosimeter prototype that we are developing, where the sensor is only 1 mm³. The current version is shown in the picture to the right, with the concept of operation below.

Photograph of the fibre optic dosimeter prototype.

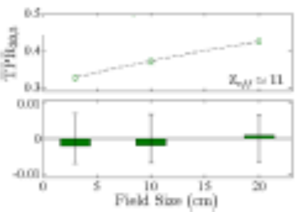


Concept of operation of the fibre optic dosimeter prototype.



The fluoroperovskites are currently being studied at Wellington Hospital using the fibre optic dosimeter prototype and x-rays from a medical linear accelerator operating at 6 MV that is used to treat cancer.

Testing of the fibre optic point dosimeter using a medical linear accelerator.



The graph to the left shows a comparison of the radioluminescence of our sample with the ionisation current from a 0.03 cm³ ionisation chamber, the present standard. We tested various collimations and depths in water (which affect the x-ray energy spectrum). The results suggest that our materials and the ionisation chamber have similar responses to high energy x-rays, which is one of the key requirements for a dosimeter for radiotherapy applications.

Tissue phantom ratio for a 1 mm³ bulk compound on the end of an optical fibre, and compared with an ionisation chamber.

Fast 2-D Dosimeter

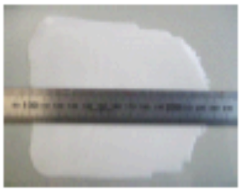
We have started to develop a two-dimensional imaging system with the following aims:

- Tissue equivalent plates
- Spatial resolution better than 0.5 mm²
- Rapid large area readout (e.g. an A4 plate in less than ten minutes)
- Absolute 2D dose (with capacity to extend to 3D)
- Linear dose response
- Re-usable over 1000 times

Our fluoroperovskite materials are powdered and embedded to give a semi-transparent imaging plate of 100-200 μm thickness.

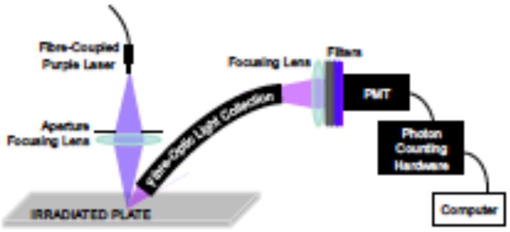
Left: Transparency of the plate indicates 50 μm resolution should be possible.

Right: Imaging plate segment that is roughly 100 mm square.



We have developed a prototype dosimeter which reads a 2-D dose image from an irradiated plate using optically stimulated luminescence. Doses below 1 mGy can be detected.

Concept of operation of the 2-D dosimeter prototype.



The figures below show scattering and x-ray (40 kV) images of an early stage plate. The left-hand image shows variation due to the film itself. The right-hand image shows a step-wise pattern resulting from successive irradiations.

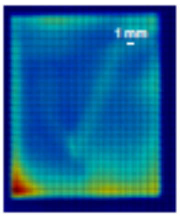
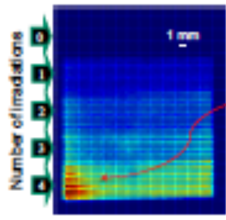


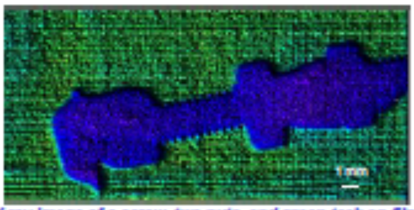
Image of non-irradiated film using scattered light.



Multiple irradiations on the same film with a moveable lead edge.

There is a region of higher fluoroperovskite particle concentration which can be seen (in red) in both images. This means the actual dose can be measured, even with uneven particle dispersion in the imaging plates, by using a correction from the scattering image.

Our first higher resolution image is shown on the right.



X-ray image of a screw, two nuts, and green-tack on film.

Summary

These fluoroperovskite materials have potential as nearly tissue-equivalent radiation dosimeter materials. The radiation dose, from micro-Grays to 100's of Grays, can be measured after irradiation via optically stimulated luminescence, and real-time dose rates can be measured via radioluminescence.

Prototype dosimeters that make use of these materials have been developed for both point measurements of the dose rate and accumulated dose, and also for 2-D dose imaging where the spatial resolution is better than the required spatial resolution of 1 mm².

References

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