University of Adelaide

Doctoral Thesis

# Beryllium oxide (BeO) ceramic fibre-coupled luminescence dosimetry

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and Prof Eva Bezak

*A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy*

*in the*

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# Declaration of Authorship

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# *Publications Contained Within Thesis*

## Published

P1. Alexandre M. C. Santos, Mohammad Mohammadi and Shahraam Afshar V., Optimal light collection from diffuse sources: application to optical fibre-coupled luminescence dosimetry, *OPTICS EXPRESS*, 22 (4), 2014.

P2. Alexandre M. Caraça Santos, Mohammad Mohammadi, Johan Asp, Tanya M. Monro and Shahraam Afshar V., Characterisation of a real-time fibre-coupled beryllium oxide (BeO) luminescence dosimeter in X-ray beams, *Radiation Measurements* 53-54, 2013.

P3. Alexandre M. Caraça Santos, Mohammad Mohammadi and Shahraam Afshar V., Investigation of a fibre-coupled beryllium oxide (BeO) ceramic luminescence dosimetry system, *Radiation Measurements* 52-58, 2014.

P4. Alexandre M. Caraça Santos, Mohammad Mohammadi and Shahraam Afshar V., Energy dependency of a water-equivalent fibre-coupled beryllium oxide (BeO) dosimetry system, *Radiation Measurements* 1-6, 2015.

P5. Alexandre M. C. Santos, Mohammad Mohammadi and Shahraam Afshar V., Evaluation of a real-time beryllium oxide (BeO) ceramic fibre-coupled luminescence dosimetry system for dose verification of high dose rate brachytherapy, *Medical Physics* 42 (11), 2015.

These publications are included within this thesis. When referred to in the text the reference number is prefixed by a ‘P’. For example, the first publication in this list is referred to as [P1].

# *Grants and Scholarships*

- Co-recipient of a small-grant ($10K value) for the construction of a Beyllium oxide (BeO) ceramic fibre-coupled luminescence dosimeter.
- ACPSEM EPSM 2011 Scholarship.

# *Conference Presentations*

- Santos A., Mohammadi M., Asp J., Afshar S., *Beryllium Oxide (BeO) Fibre Optic Dosimeter*, EPSM-ABEC, 2011, Darwin, Australia.
- Santos A., Mohammadi M., Afshar S., *Light Collection Simulations in BeO Fibre Optic Dosimetry*, EPSM-ABEC, 2011, Darwin, Australia.
- Santos A., Mohammadi M., Afshar S., *Optimal Light Collection in BeO Fiber Optic Dosimetry*, CLEO Pacific Rim, 2011, Sydney, Australia.
- Santos A., Mohammadi M., Afshar S., *Fibre optic dosimetry with beryllium oxide (BeO) ceramics*, Radiation, 2012, Sydney, Australia.
- Santos A., Mohammadi M., Afshar S., *Characterisation of an RL/OSL beryllium oxide (BeO) ceramic fibre-coupled luminescence dosimeter in 6MV x-ray beams*, EPSM-ABEC, 2012, Gold Coast, Australia.
- Santos A., Mohammadi M., Afshar S., *A real-time beryllium oxide (BeO) ceramic fibre-coupled luminescence dosimetry system for high dose rate brachytherapy dosimetry*, Australasian Brachytherapy Group Conference, 2014, Adelaide, Australia.
- Santos A., Mohammadi M., Afshar S., *A beryllium oxide (BeO) fibre-coupled luminescence dosimeter for high dose rate brachytherapy*, AAPM Annual Meeting, 2014, Austin, Texas, USA
- Santos A., Mohammadi M., Afshar S., *A near water equivalent beryllium oxide ceramic dosimetry system for high dose rate brachytherapy*, Australasian Brachytherapy Group Conference, 2015, Sydney, New South Wales, Australia

## Other Presentations

- Santos A., Mohammadi M., Afshar S., *The optimal light collection in Fiber Optic Dosimetry, The 2010 student paper night*, ACPSEM - Student Night, 2010, Adelaide, Australia
- Santos A., Mohammadi M., Afshar S., *Beryllium Oxide (BeO) Fibre Optic Dosimetry – a versatile in-vivo dosimeter*, ACPSEM - Student Night, 2011, Adelaide, Australia [Second Prize]

- Santos A., Mohammadi M., Afshar S., *A beryllium oxide (BeO) fibre-coupled luminescence dosimeter for high dose rate brachytherapy*, ACPSEM - Student Night, 2014, Adelaide, Australia [First Prize]
- Santos A., Mohammadi M., Afshar S., *A beryllium oxide (BeO) fibre-coupled luminescence dosimeter for high dose rate brachytherapy*, ARPS - Gerald Laurence Student Award, 2014, Adelaide, Australia [Second Prize]

*"Se não receio o erro, é porque estou sempre disposto a corrigi-lo."*
*"If I don't fear the error, it simply is because I'm always willing to amend it."*

Bento de Jesus Caraça

# *Abstract*

Brachytherapy treatments are becoming more complex and generally high doses per fractions are prescribed. Therefore there is a need for a real-time dosimeter which is able to accurately verify the dose delivered to a patient during treatment. Beryllium oxide (BeO) ceramics are a near water-equivalent material capable of radioluminescence (RL) and optically stimulated luminescence (OSL). A low energy dependence is expected from BeO ceramics since it has an effective atomic number similar to water. In this thesis the feasibility of using BeO ceramic as the probe for a fibre-coupled luminescence dosimetry system is demonstrated.

In order to maximise the sensitivity of the fibre-coupled luminescence dosimetry system, the light collection from the probe material into the optical fibre was simulated. Since BeO ceramics are self optically attenuating, a range of probe designs were investigated including: a reflective wall surrounding the BeO ceramic and the potential use of another optically transparent layer to provide a less attenuating optical path into the optical fibre. A model was developed using ray tracing through the BeO ceramic until reaching the optical fibre. It was found that for a 1 mm diameter BeO ceramic probe coupled directly to an optical fibre, that there is no increase in light collection beyond 1 mm length of BeO ceramic.

An RL/OSL reader system was developed which could be connected to an optical fibre with a 1 mm diameter, 1 mm long BeO ceramic coupled to the fibres tip. The dosimetry system was capable of real-time dose rate measurements by reading the RL signal, and post exposure accumulated dose measurements by stimulating and integrating the OSL. The dosimetry system was characterised with high energy 6 MV and 18 MV x-ray beams, an $^{192}$Ir source, and a range of superficial x-ray beam energies.

The OSL dose response was shown to be supralinear to doses greater than 10 Gy, and independent to dose rate. The RL is shown to be linear to dose rates from 100 cGy/min to 600 cGy/min, and that the integral of the RL responded linearly to doses from 30 cGy to 15 Gy. The RL from BeO ceramics was observed to be insensitive to the accumulated dose, making dose rate measurements easily obtained. Energy dependency measurements showed that there is a different energy response for the OSL and RL signals. The RL shows little energy dependency for x-ray energies above a superficial 50 kVp beam, while the OSL response differs from the RL response for x-ray energies above a superficial 150 kVp beam.

Finally the system was evaluated for use in high dose rate (HDR) brachytherapy applications. The reproducibility, energy dependence, angular dependence and probe temperature dependence were evaluated for an $^{192}$Ir HDR source. An overall uncertainty of 7.9% and 10.1% for the RL and OSL, respectively, was estimated.

This work has shown that BeO ceramics have the potential to be a very useful material for dosimetry in radiotherapy. Especially for dosimetry in brachytherapy where its low energy dependency may be of use.

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*To my family and my fiance.*