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Testing of a scintillator and fibre optic based radiation sensor

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HIGHLIGHTS

- RadLine® is a small, sleek, real time, beta and gamma radiation detector.
- RadLine® performs long range (>1 km), offering benefits over rival short range detector technologies.
- Our results establish that the lower bound reading is a dose rate of 0.2 mSvhr^{-1}.
- The probe is electrically inactive, can be used underwater, in pipework, and harsh environments.

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ABSTRACT

We describe the optimisation of RadLine®; a small, real time, remotely operated radiation detector, which consists of an inorganic scintillation crystal coupled to a fibre optic cable transporting produced photons to a CCD camera some distance away. RadLine® is tested in a beta and gamma narrow radiation field of 2.4 GBq, from a Caesium-137 (662 KeV) source, at doses rates between 0.125 mSvhr^{-1} and 10 mSvhr^{-1}. Our results establish that the lower limit of the device corresponds to a dose rate of 0.2 mSvhr^{-1}, constrained by the signal to noise ratio of the instrument. We also demonstrate the process of characterising the RadLine® for utilisation underwater due to its partial electrical inactiveness; and to consider how the instrument might perform in aquatic environments and ultimately in a First Generation Magnox Storage Ponds (FGMSP). The RadLine® brings a marked difference to actual underwater radiation monitoring devices such as; HPGe, CZT and GM detectors, which not only incorporate the whole electronics within and are more bulky, only perform over a short range. The RadLine®'s design offers signification value for intermediate (>100 m) and long range detection.

1. Introduction

The National Nuclear Laboratory's (NNL) RadLine® is a small, novel, remotely operated radiation detector which uses a scintillating crystal and fibre optic cable to obtain radiation measurements from difficult to access or large process areas over a wide radiation range (0.01 Svhr^{-1}–8500 Svhr^{-1}). The device is real-time, remotely deployed and initially developed to operate in elevated levels of radiation (the upper radiation limit is estimated at 100,000 Svhr^{-1}); this radiation resistance enables it to be used in highly active waste processing and storage facilities. The main focus of this paper is testing the RadLine in low level radiation environments where the performance during deployment is studied and possible optimisation areas are evaluated such as; crystal orientation within a Caesium-137 field, influence of crystal size (over a range of doses), exposure time, lead shielding and port multiplexing.

The later part of the paper discusses utilising RadLine for real time, in-situ sub-aquatic radiation detection and monitoring for applications such as; the investigation or long-term monitoring of radionuclide levels around sunken nuclear objects/wastes, liquid discharges of radionuclides from nuclear plants and the mapping of large areas to assess the distributions and levels of radionuclides, for example in First Generation Magnox Storage Pond (FGMSP) facilities. The RadLine detector has several advantages over conventional devices such as Geiger-Müller (GM) counters or Cadmium Zinc Telluride (CZT) devices when performing in aquatic environments, and in the case of FGMSPs one that is somewhat complex and confined.

GM and CZT devices perform well over short ranges (<10 m), whereas the RadLine is designed for intermediate (>100 m) to long

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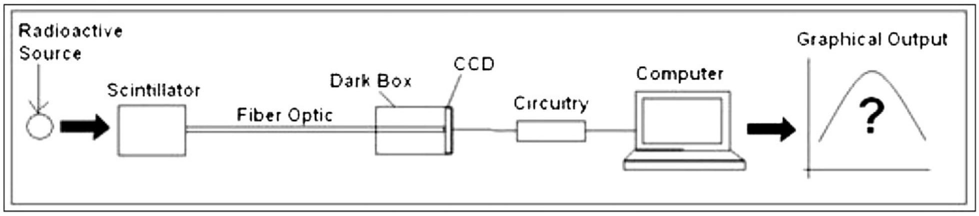

Fig. 1. RadLine™ schematic representation (Holmes, 2008).

range (>1 km) radiation monitoring; the optical fibre can be several kilometres long without significant data transmission losses (Holmes, 2008), and is cased in copper to provide radiation and damage resistance during deployment. Secondly the RadLine's probe (scintillation crystal and its housing) do not require power or any electrical input to function. GM and CZT devices are not designed for submerged water use, and those that are adapted for the purpose it will require an, albeit protected, high voltage supply (500–900 V (Munich, 2012) and 200–400 V (Eurorad, 2013) http://www.eurorad.com/detectors.php respectively) cable to be submerged in the water. The small dimensions of the RadLine; both the probe (the largest size tested here is 4 mm × 4 mm × 40 mm) and the rest of the setup – a CCD and laptop, are compact in comparison to set-ups such as (Povinec, Osvath et al., 1996) and (Thermo Scientific, 2013). The probe's small dimensions and the flexibility of the optical fibre allow it to be deployed into small and difficult to access areas such as pipework, liquid filed or otherwise. The RadLine is safe to use in harsh environments (tested up to a working temperature of 100 °C) with no moving parts, a simple sleek design and it is also inexpensive enough to be made sacrificial.

2. RadLine® detector

2.1. Overview of RadLine

RadLine uses a zinc tungstate ($ZnW0_4$) scintillating crystal that produces scintillation light in response to beta and gamma radiation, this is connected to a fibre optic cable which transmits the light to a CCD (charge-coupled device) camera, shown schematically in Fig. 1. The camera determines photon flux and converts this to a voltage – read and processed by software which predicts the resultant dose (Holmes, 2008). A plate with ports for fibre optic cables is mounted over the CCD in order to divide it into sections. This permits more than one fibre optic cable to be connected, with the software configurable for multiple ports and multiple cameras in order to solve activity-distance ambiguity and to monitor larger process areas.

Patents filed at the United States Patent office by Hurst, Gilhen et al. (1984), Suter, Poret et al. (1991), Thevenin (1997) and Fernandez, Brichard et al. (2008) on the use of fibre optics for radiation detectors highlight the active, on-going research work in this field. Fernandez has successfully calibrated a CsI (TI) crystal scintillator mounted at the end of a 10 m long fibre optic in the range 0.3–3000 mGyhr^{-1} for in situ gamma monitoring during the operation and maintenance of the future ITER thermonuclear fusion reactor. The difference between this device and the RadLine is Fernandez's device uses a PMT instead of a CCD, and has been developed to be active in a much narrower radiation range.

2.2. Scintillation crystal

Fig. 2 depicts the RadLine aluminium head (A) containing the scintillation crystal (B). The crystal in the schematic has the dimensions 2 mm × 2 mm × 40 mm, with two further sizes tested for device optimisation; a smaller one with dimensions of 1 mm × 1 mm × 40 mm and a larger one which measured 4 mm × 4 mm × 40 mm. Within this work these three crystal sizes are abbreviated to 1 mm, 2 mm and 4 mm respectively. The crystals are encased in a thin aluminium sheath for radiation resistance (blocking beta particles), protection during deployment and to improve the collection of scintillated light. The scintillation crystal zinc tungstate ($ZnWO_4$) was chosen for this application as it possesses the optimum wavelength for fibre optic transmission (between 470 and 540 nm, ideally nearer the red region for intermediate to long range detection), does not suffer from afterglow and has a density of high enough to attenuate radiation. Properties of zinc tungstate include; a decay constant of 20.0 μs, density of 7.62 g.cm^{-3}, an emission spectral range of between 310 nm and 500 nm, with a peak scintillation wavelength of 490 nm whilst producing 9500 photons per MeV (HilgerCrystals, 1999).

2.3. Optical fibre

The scintillation crystal is coupled to an optical fibre which is copper encased to provide radiation and damage resistance during deployment. The fibres are able to operate in high temperatures, have improved hermeticity properties and have higher strength than polymer coated fibres. (Oxford Electronics, 2008) quotes that the coating allows use up to 700 °C, this compares well with gold-

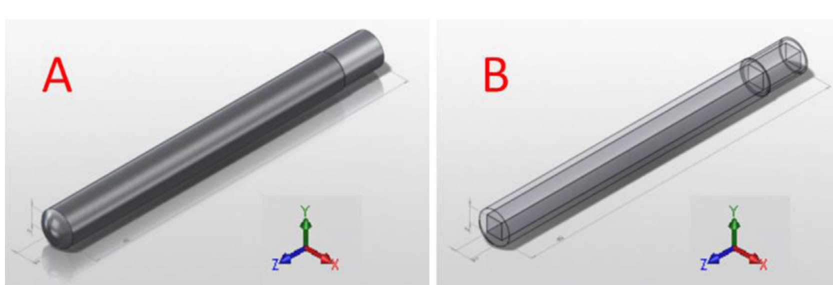

Fig. 2. RadLine™ aluminium head (A) and skeletal view with scintillation crystal inside (B).