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OSL/FO remote dosimetry for radiological investigations in hard-to-access zones

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ABSTRACT

Radiological investigations in the context of Decommissioning and Dismantling (D&D) of nuclear installations are still challenging in hard-to-access zones. OSL/FO (Optically Stimulated Luminescence/Fiber Optics) remote dosimetry is a cost-effective solution in the constrained budget framework of D&D. Within the INSPECT Project, a newly-designed OSL/FO readout device and innovative multichannel probes have been designed and successfully field-tested at CEA/Marcoule, CEA/Cadarache and ORANO/La Hague in France. The monitoring of dose rate profiles improves localization accuracy and speeds up investigations. We report current device performance and future improvements.

PACS Keywords: *Optically Stimulated Luminescence (OSL), Fiber Optics, Remote Dosimetry, Decommissioning and Dismantling (D&D).*

1 INTRODUCTION

Decommissioning and Dismantling (D&D) require the use of innovative dismantling techniques such as remote handling, robotics and remote dosimetry (RD), the latter being an essential tool to set up a cost-effective dismantling scenario and predict the impact of decontamination procedures in terms of worker exposition.

Radiological investigations are performed during pre-dismantling stage and cleanup phase to assess for the real radiological state of the installation [1]. In open spaces (either indoor or outdoor), conventional point detectors (CdZnTe (CZT), Geiger-Mueller (GM), scintillators) are used on account of their performance [2]. Gamma cameras also help localize hot spots [3]. The 3D dose rate (DR) distribution is eventually retrieved from both radiological and topological data using for instance the SLAM (Simultaneous Localization and Mapping) technique.

However, long-range RD in hard-to-access zones or hidden parts (e.g. tanks, reactors, storage ponds etc.) is still challenging. Radiological investigations from the outside is tricky and conveys large uncertainties. Therefore, RD from the inside allows for more accurate results than from the outside due to attenuation from concrete and metal walls. In

hidden parts, a 3D dose rate distribution is estimated as well by inverse calculation with the help of Monte-Carlo codes. Two main issues arise: miniaturization and topographic reconstruction, currently addressed by CEA and ORANO within the European Project CLEANDEM (<https://cordis.europa.eu/project/id/945335>).

2 OSL/FO REMOTE DOSIMETRY

Readers are referred to publications of the same team to review basics of OSL [4]. OSL/FO is a fiber-coupled OSL dosimetry providing online remote measurements (the readout unit is placed out of radiological zone). Contrarily to active dosimeters, OSL/FO probes do not require local electronics to operate (no high voltage, no temperature regulation, no electromagnetic (EM) shielding). Main advantages are EM and Cerenkov immunity, long-range remote operation, high miniaturization (sensor head $\varnothing = 6$ mm to 8 mm), high mechanical and radiation resistance and wide range in DR detection (6 decades from 30 μ Gy/h up to 10 Gy/h). OSL/FO probes are waterproof and easy to decontaminate.

Miniature dosimetric-grade sapphire crystals are used as detectors (Landauer Co.). Owing to the high sensitivity of sapphire, a very small detection volume may be used (~ 0.1 mm³). Finally, the very low fading of sapphire at usual temperatures ($< 1\%$ per decade in time) allows to adjust the exposure time from several minutes up to months if necessary, in view of detecting low DRs (μ Sv/h).

3 THE INSPECT PROJECT

The INSPECT Project was granted by the French government through the PIA initiative (“Investing for the future” program, operated by Andra, French organization in charge of radioactive waste management), in collaboration with the ANR (French National Research Agency).

INSPECT was managed by the CEA List and started 11/2016 for 54 months. It involved ORANO (nuclear operator) and the industrial partner SDS. INSPECT aimed at developing and test two multichannel OSL/FO readout units, a human-machine interface and OSL/FO probes for the monitoring of dose rate profiles, according to specifications given by operators (CEA and ORANO).

3.1 INSPECT OSL/FO readout unit + probes

The INSPECT readout unit is assembled within a 19-inch 3U enclosure (Fig. 1 top) that includes an optical box (enclosing a laser, a photomultiplier and associated electronics), a 16-channel optical switch and dedicated electronics based on a Raspberry Compute module 3+.

OSL/FO probes are shown on Fig. 1 down. They are made of a shock-proof/crush-resistant cable connected with the help of a backshell to a hybrid military connector (MIL-DTL-38999) that hosts an EEPROM as well. The fibers are protected from shock and light inside the steel-armored cable, also covered by a smooth PVC coating. Such coating reduces friction (to ease insertion into long and small tubes) and simplifies decontamination.

Three different OSL/FO probes were designed by the CEA-List: single-channel, 10-channel (50-cm period) and 16-channel (10-cm period). The crystals (0.09 mm^3) are affixed onto fiber extremities using a proprietary procedure. They are connected to the readout unit through a MIL-DTL-38999 hybrid (electrical + FO) connector which also incorporates an EEPROM storing manufacturing and calibration data. These data are automatically available to the user once the cable is connected to the INSPECT device, therefore simplifying the procedure and eliminating mistakes. The electrical connection also acts as safe interlock to switch the laser off in case of unintended disconnection during readout.

The INSPECT readout unit operates in continuous-wave OSL mode. The background signal is subtracted from the raw signal, thus eliminating any unwanted luminescence such as Cerenkov light. The resulting OSL signal is finally integrated and multiplied by a calibration coefficient to provide the absorbed dose. The dose is eventually divided by the exposure time to yield the average dose rate.

OSL probes are read and reset sequentially. The readout time is typically $\sim 40 \text{ s}$ per sensor (~ 11 minutes for a 16-channel probe).

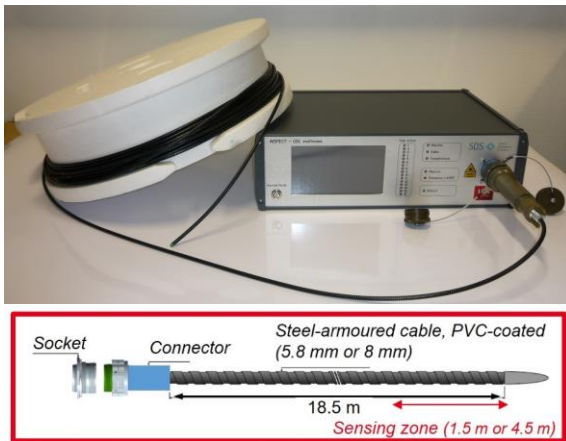


Figure 1: View of the INSPECT readout unit (top), multichannel probe (down)

3.2 INSPECT software

The INSPECT readout device is driven by a web application loaded onto the CM3+ (with additional libraries .NET.IoT and Blazor). It runs under the Raspbian Operating System with .NET core 3.1 (open-source cross-platform framework). The webapp may be operated directly onto the machine (local use) or remotely (Ethernet link).

INSPECT first makes a checklist of onboard devices and gives access to 3 modes: Admin, Measures, History.

Depending on whether the expected dose rate is lower (Low-D) or higher (High-D) than $\sim 10 \text{ mSv/h}$, two operating modes are accessible to the user:

- Hi-D: INSPECT asks for the exposure time, then reset the sensors and enters in sleep mode. It automatically triggers the OSL recording at the end of the exposure time.
- Low-D: INSPECT is turned off (may be re-used). The user disconnects the probe that is left in place for a long time. Once the probe reconnected, the user enters the exposure time and INSPECT records the OSL signal.

4 CALIBRATION AND FIELD TESTS

4.1 Calibration

We performed dose calibrations of four OSL/FO probes at ORANO (La Hague, France) with the help of a panoramic irradiator (Buchler OB20, ^{137}Cs , 16 TBq). The dose rate was 0.84 Gy/h ($\pm 0.01 \text{ Gy/h}$). The dose response was linear in the dose range $[0 - 3 \text{ Gy}]$.

4.2 Field tests

The INSPECT readout device and probes were successfully tested on four D&D sites [5]: G1 (Gas-cooled reactor (GCR)), APM (CEA/Marcoule), Phebus (carousel casemate of the experimental nuclear reactor, CEA/Cadarache) and UP2-400 (cesium filters in UP2 plutonium factory, La Hague). All sites were previously investigated with conventional techniques (GM) except Phebus. OSL probes were inserted through thermocouples guide tubes (APM), projected through an aeration grid (Phebus) or through access holes (G1, UP2-400). We also implemented visual inspection for investigating G1 and APM. Current performances and improvements for the future will be detailed during the conference.

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