IL NUOVO CIMENTO **45 C** (2022) 207
DOI 10.1393/ncc/i2022-22207-4

Communications: SIF Congress 2021

Soil samples as a dose sensing element: Preliminary results

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received 4 February 2022

Summary. — In this work, the possibility of exploiting the soil as an X-ray radiation sensor was studied. Different soil samples were irradiated using a 10 MeV X-ray beam, and five different delivered dose values in the 0–35 Gy range. The irradiation effect was correlated, through two electrodes inserted inside the soil, to output voltage (V_{out}) measured by using a specific measurement system. A 4.45% decrease in V_{out} between the non-irradiated and the 35 Gy-irradiated soil samples was found. This evinces a correlation between V_{out}, and the dose absorbed by the soil due to the reduction of bacterial activity which, in turn, suggest that the chemo-electrical transduction propriety of the soil could be exploited to produce low-cost, eco-friendly, mimetic, and natural-based radiation sensors.

1. – Introduction

The natural metabolic processes inside the soil represent, also thanks to the soil redox potential, a natural source of energy. Natural chemo-electrical properties of the bacteria activity [1, 2] can be exploited to realize innovative sensing systems having the following prerogatives: green, non-toxic, ecological, low-cost, and self-generating [3, 4]. In fact, the energy production is the result of biological processes, the enzymatic activity, and the natural metabolic processes of the microorganisms present in the soil [5]. With the aim of going beyond the classic use of soil-based systems used as microbial fuel cells [6], recently, it has been shown that it is possible to use the soil as a sensor to measure physical quantities of interest. A conversion into an output voltage was obtained by inserting electrodes into a soil sample [3, 4] (fig. 1). This voltage depends on the activity

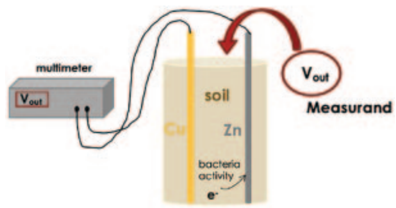

Fig. 1. – Voltage measurements system (not to scale). The Cu and Zn electrodes are inserted in the soil sample and connected to the multimeter.

of microorganisms present in the soil and through an appropriate choice of the system (soil or plant with soil) it is possible to estimate the measurand (*i.e.*, temperature, radiation light), filtering other physical quantities of non-interest or influences such as humidity, chemical and mineralogic compositions, radiation [3, 4]. Several studies have shown the effect of the gamma radiation from ^{60}Co in the microbial activity of the soil [7-9]. In particular, the microorganisms concentration can decrease due to ionizing radiation employed in sterilization procedures [10-12].

In this work, the X-ray source is considered as the measurand, and the correlation between its value and the output voltage (V_{out}) was investigated for the first time in literature in order to consider the possibility to exploit soil samples as green, natural-based, mimetic, low cost, self-generating radiation sensors. A measuring system, capable of measuring (V_{out}) generated by soil samples, was developed, the enzymatic activity of the soil was also evaluated and a preliminary metrological characterization is pursued in order to demonstrate the suitability of the proposed system.

2. – Materials and methods

The soil samples were homogenised by using a ceramic mortar and then, 120 g of soil were placed in six equal and numbered Teflon beaker. The measuring system consisted of two cylindrical electrodes (Cu and Zn), having a 5 mm diameter, connected to a Fluke 45 dual display multimeter. To perform the beakers irradiation, the Computed Tomography (CT) scans of the samples were performed, and the Treatment Planning System (TPS) software was employed to calculate the dose distribution released in the soil samples.

The TPS software is commonly used for clinical radiation therapy purpose and is based on Monte Carlo computation of the dose distribution released in a target (CT scan) taking into account its density and shape. Five different dose distribution plans were produced with the TPS in order to deliver 7.5, 15, 22, 30, and 35 Gy to the five soil samples. One beaker was not subject to irradiation (0 Gy) and was used as reference. A VARIAN TrueBeam LINear ACcelerator (medical LINAC) was employed to generate a 10 MV X-ray beam with a dose rate of 2400 Monitor Unit (MU) per second. The soil samples were placed on the patient bed and, for accurate dose coverage, two opposed fields, $10 \times 10\,\mathrm{cm}^2$ in the x-y direction, were employed (fig. 2). After irradiation, the enzymatic activity of the soil as a function of the absorbed dose was evaluated through the evaluation of the Fluorescin Diacetate Activity (FDA) [13, 14].

3. – Results

Figure 3 on the top left shows the measured V_{out} values with a $\pm 1\sigma$ band, as a function of the absorbed dose. For each sample, the measured V_{out} was normalized to the V_{out} value of the non-irradiated samples ($V_{out-norm}$).

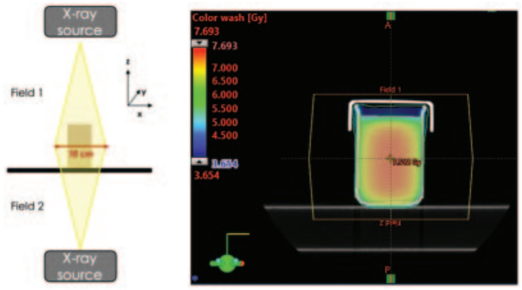

Fig. 2. – Left: X-ray irradiation setup (not to scale). Right: interface of TPS software, the dose distribution is indicated in false colors.

A decreasing trend can be observed in $V_{out-norm}$ as the dose values increase. A third-degree polynomial model was considered to describe the data, and a correlation coefficient of 0.997 was found. Figure 3 on the top right shows the percentage of V_{out} loss ($V_{out-loss}$) as a function of the absorbed dose by the soil sample. A 4.45% increase in $V_{out-loss}$ between the non-irradiated and the 35 Gy-irradiated soil samples was found. Figure 3 on the bottom shows that the radiation doses do not affect the FDA activity, therefore it is possible to attribute the increase in $V_{out-loss}$ to bacterial mortality. If quantity $V_{out-norm}$

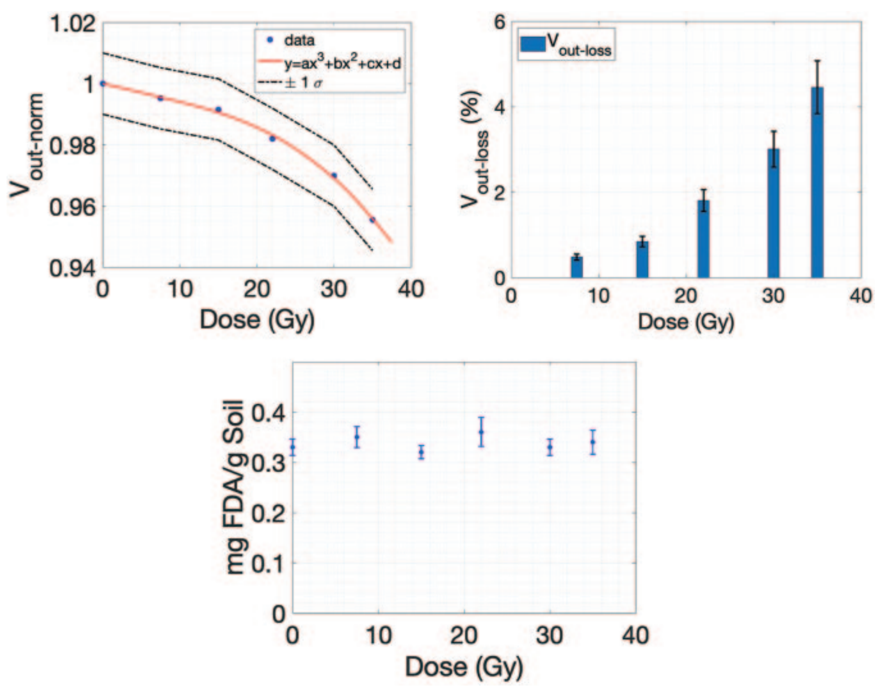

Fig. 3. – Top left: $V_{out-norm}$ as a function of the absorbed dose (blue dots), with the relative $\pm 1\sigma$ band (black dashed line), and the results of the third-degree polynomial regression (red line). Top right: percentage of $V_{out-loss}$ as a function of the absorbed dose. Bottom: FDA activities expressed as mg FDA per g of soil, as a function of the absorbed dose.

were linked to the surviving fraction of bacteria, and $V_{out-loss}$ were connected to the bacteria mortality, it would be possible to state that bacteria concentration decreases as the absorbed dose increases.

4. – Conclusions

In this work, the possibility of exploiting the chemo-electrical transduction property of the soil, for the development of X-ray radiation dose sensor, was evaluated. The obtained results suggest that the observed decrease of bacteria activity could be correlated to the increased radiation dose in the soil samples. Thanks to the correlation between bacteria activity and the electrical voltage generated through the metabolic processes of the soil, it was possible to measure doses (Gy), in the range of 0–35 Gy, for environmental radiation monitoring purposes. Dose values from 7.5 to 35 Gy with ∼5–7 Gy steps, were explored. The study is proceeding with an exhaustive metrological characterization of the performance of the proposed sensor. A new set of irradiations will be performed with dose values within the range 0–7.5 Gy with smaller steps, in order to estimate the minimum quantity of radiation that can be measured. Soils with different mineralogical-petrographic compositions will also be considered and characterized.

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The authors are grateful to the Medical Physics Department of the Humanitas Istituto Clinico Catanese for the support with the irradiation equipment. The research activity was partially funded by DELIAS (Development and application of innovative materials and processes for the diagnosis and restoration of cultural heritage).

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