Development of Hybrid Gamma-ray Spectrometry Methods for Enhancing the Capacity of Environmental Radiological Monitoring Around Nuclear Power Plants

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ABSTRACT

In situ gamma spectrometry allows complete characterization of gamma radiation fields at a given location through accurate and sensitive determination of the concentration of radionuclide activity in the soil. When compared with methods that include sample collection and subsequent laboratory analysis, the in situ method enables better soil representativeness, direct and accurate determination of areas of interest (hotspots), higher speed of measurements and reduced monitoring costs. All this makes it a very important complementary or alternative method to laboratory measurements, and unavoidable in case of accidents. The primary goal of this work is to present concepts behind a development and implementation of hybrid gamma spectrometry method for radiological monitoring of the environment of nuclear power plants. The hybrid method would integrate an innovative approach in determining areas of interest with the newly developed method for in situ gamma spectrometric measurements. This would increase the speed of radiological survey, which is critical for rapid decision-making, and in turn would enable the implementation of surveillance of a larger area. For the purpose of determining areas of interest, a hardware-software system for rapid radiological mapping will be developed, applicable in the future for installation in unmanned aerial vehicles, based on dosimetry detectors for measuring ambient dose equivalent, GPS receiver and compact central computer. The maximum area mapping speed will be correlated with the detector sensitivity and its response time. Field measurements will be carried out at least two research sites where in situ and laboratory gamma spectrometric measurements will be performed. Radiological measurements will be accompanied by the measurement of meteorological parameters that will enable the development of a correction pilot algorithm for specific meteorological and other physical environmental conditions of nuclear power plants.

Keywords: *Gamma Spectroscopy, Dosimetry, Environmental Monitoring, Radiation Detectors*

1 INTRODUCTION

Radiological monitoring and complete characterization of radionuclides in the environment are part of mandatory and regular measurements in and near nuclear power plants. In situ gamma spectrometry enables complete characterization of gamma radiation fields at a given location through accurate and sensitive determination of the concentration of radionuclide activity in the environment. In comparison with methods involving sample collection and subsequent laboratory analysis, the in situ method allows for better soil representativeness [1], direct and accurate determination of areas of interest (hotspots) [2], higher speed of measurements and reduced monitoring costs. All this makes it a very important complementary or alternative method to laboratory measurements, and unavoidable in case of accidents.

Some of the biggest challenges in in situ gamma spectrometry relate to measurement uncertainty [3], difficulties caused by lower in situ detector efficiencies compared to laboratory detectors, and optimization and streamlining of methods. The main causes of measurement uncertainty are the absence of standard in situ calibration samples, changing meteorological conditions and the depth distribution of radionuclides.

The primary goal of this paper is to present a development and implementation of hybrid gamma spectrometry method for more efficient radiological monitoring of the environment of nuclear power plants which is a main objective of the scientific research project "Development and implementation of hybrid gamma-ray spectrometry methods for enhancing the capacity of environmental radiological monitoring around nuclear power plants" financed by Krško Nuclear Power Plant and Institute for Medical Research and Occupational Health.

Methods that employ one HPGe and at least one faster detector more efficient detector exist, e.g. Car-borne gamma-ray spectrometry presented by Hassan et al. [4]. Hybrid gamma spectrometry method presented in this article is a further development of such methods that incorporate HPGe spectrometry, but measurement points are determined by the algorithm from preceding ambient dose equivalent measurement with optimized scanning speed and GPS (Global Positioning System) telemetry. This would increase the speed of radiological surveillance, which is critical for rapid decision-making, and in turn would enable the implementation of surveillance of a larger area or increase measurement capacity.

2 METHODOLOGY

When employing High Purity Germanium (HPGe) detectors during in situ measurements, it takes considerable amount of time (order of magnitude 1 hour) for obtaining a measurement at each point. Underlying reason is that HPGe detectors have low efficiency and thus require longer acquisition. Slow measurement process further decreases area that can be efficiently monitored e. g. in vicinity of nuclear power plant.

We are proposing development of a new Fast Radiological Area Scanner (FRAS) for identifying gamma spectroscopy points of interests. It is based on dosimetry detectors that would overcome some deficiencies produced by low efficiency of HPGe detector. Such system will enable scanning the area of interest in order to produce radiation heatmap. System diagram is showed on Fig 1.

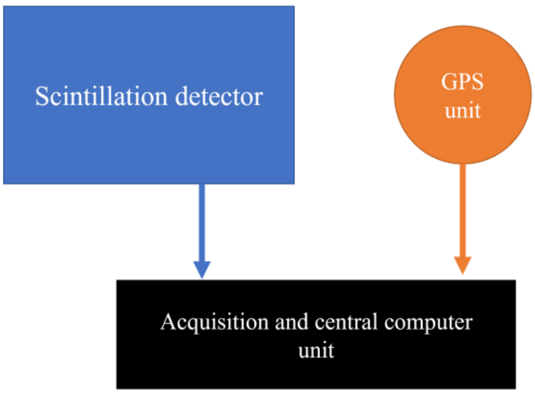

Figure 1: Diagram of the Fast Radiological Area Scanner (FRAS).

We have employed Thermo Fisher Scientific FH40NBR scintillation detector [5] (Fig 2) and GPS module, all of which are connected using RS232 communication protocol to compact central computer unit - Raspberry Pi 4 Model B [6]. Detector and GPS module are sending readings each second to a python acquisition program. An algorithm (in development) will determine optimal number of measurement points to be executed with HPGe detector thus minimizing the use of more expensive and slower detector. Measurement points will always include all hotspots (if present) and depending on the surface area and at least one point in radiologically homogeneous area.

Figure 2: Thermo Fisher Scientific FH40NBR dosimeter

The time response of the measuring device/dosimeter usually depends on the ambient dose equivalent rate, i.e., on the radiological activity of sources such as radionuclides in the soil. For low dose rates comparable to natural background radiation, the response time in the instrument is automatically increased to achieve a statistically significant measurement. In this case, the response time of the instrument can range from a few seconds to a few minutes [7], which is by no means applicable for performing rapid scanning measurements above the ground, e.g. UAV (Unarmed aeral vehicle) or helicopter. Agile mobile robots such as the Boston Dynamics Spot Robot are more suitable for such purposes.

When measuring the ambient dose equivalent, the area of interest is most often scanned with a measuring device / dosimeter worn by an expert or attached to an off-road vehicle / UAV. If the scan speed is too high in terms of movement of the measuring instrument over the area of interest, there may be serious underestimation of the measured values, associating the measurement result with the wrong position point on the surface (inconsistency of GPS coordinates and measurement values) and not finding an area of interest (or a lost source of ionizing radiation). Therefore, special attention should be paid to the time response of the detector and its sensitivity before determining the measurement protocol.

Using data collected by discrete measurements of meteorological and air quality parameters (air temperature, wind speed, relative humidity, air pollution with P10 particles and lower) and radiological monitoring at two or more research sites, the correction algorithm will be derived employing numerical methods. Measurements will be carried out over a period of at least one year to collect data in different meteorological and seasonal conditions.

Upon completion of the required measurements and completion of the development of the necessary software tools, all individual methods will be combined into one comprehensive in situ hybrid gamma spectrometric method with the aim of reducing measurement uncertainty, rapid radiological evaluation and increasing measurement capacity required for possible radiological surveillance.

3 PRELIMINARY RESULTS

Fig 3 shows preliminary results obtained after 20 minutes of measurement using a current version of FRAS system. It is a satellite image of the Institute and its surroundings to which a radiological heatmap generated by FRAS system is superimposed.

Figure 3: Heatmap generated with early version of FRAS system around IMROH building. (Note: Measured values are not representation of total ambient dose equivalent as detector employs proprietary natural background rejection – NBR system.)

In the figure, lower dose rate is represented with smaller diameter circle and colder colour while higher dose rate is represented by larger circle and warmer colour. System demonstrated excellent performance and proved to be verry beneficial for radiological characterization of the area of interest and finding radiological hotspots. GPS data was recorded with a resolution up to 2 m while ambient dose equivalent was measured with resolution up to 1 nSv (resolution varied due to instrument autoranging).

4 DISCUSSION AND CONCLUSION

In-situ gamma spectrometric methods are an active area of research and continue to be a challenge in the scientific and professional community. In scope of this work, we have presented a development of Fast Radiological Area Scanner (FRAS) as a part of a hybrid gamma-ray sspectrometry method. FRAS is based on scintillation dosimeter and GPS module that is intended to be used for fast identification of in situ gamma spectroscopy points of interests or hotspots. Its output is feed to an algorithm in development for determination of points of interest.

Preliminary results suggest that system will make possible to reduce the number of HPGe measurement points up to 50% for the given area of interest and reduction in measurement uncertainty (when compared with measurements without preceding survey).

Reduction of measurement uncertainty and measurement time will enhance the capacity and quality in environmental raudiological monitoring and provide necessary fast tools when rapid decision making is required.

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