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Compact radioactive aerosol monitoring device for early warning networks

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ABSTRACT

In the frame of the European metrological research project MetroERM, a compact portable aerosol sampling and measurement device was developed at Jožef Stefan Institute. The system incorporates a $CeBr_3$ scintillation detector positioned centrally within a concertinaed filter assembly and an improved high flow rate air pump. It provides continuous on-line low level airborne radioactive particulate monitoring for field station use via 3 G network communications. The calibration of the device was performed at National Physical Laboratory (NPL) with filters, spiked with a certified mixed nuclide solution. Additionally first tests were performed in an environment with an elevated radon concentration.

1. Introduction

In a radiological emergency, early and reliable knowledge of radioactivity concentrations in the air, the assessment of contamination levels in the environment and the dose rate levels in urban areas are of key importance for organizing of efficient countermeasures for protection of the general public from the dangers arising from direct external radiation and from intake of radioactivity by ingestion or inhalation of contaminated food or air. Therefore in 2014, a 3-year EMRP joint research project (JRP) “Metrology for radiological early warning networks in Europe” (MetroERM) was launched, with the aim to improve, optimize and harmonize the metrological foundation of measurements of ambient dose equivalent rate, radioactivity concentrations in air and ground contamination levels in real time.

A primary aim of MetroERM is to improve the capacity of the early warning networks by the development of new methods and systems for rapid and precise measurement of radioactivity-in-air at low concentrations. In this way the global early warning data would be efficiently supplemented with accurate information on airborne radionuclide content including nuclide-specific information. New in-situ spectroscopy systems for airborne radioactive particulate monitoring have been developed on the basis of comprehensive investigations of detector features and of spectral evaluation and deconvolution methods for new and improved measurement systems based on spectrometric detectors like HPGe, CdZnTe, $LaBr_3$:Ce, $CeBr_3$ and Cs(Tl)I (Bell et al., 2016). These systems provide real time information of radioactive aerosol concentration levels and will become the core instrumentation of the next generation of environmental radiation monitoring networks in Europe.

A survey of existing commercial real-time air gamma monitors discloses the specific gap in the niche of truly portable air samplers with real-time gamma spectroscopy. A literature review was completed and the specifications are listed as inclusively as could be determined from the product brochures online. The Ram-31 family by MicroStep-MIS (MicroStep-MIS, 2016) come in the form of a 300 kg wheeled rack cabinet with air flows of 2 m^3/h to 6 m^3/h and a magazine of 31 circular (Ø47 mm) cellulose filters, and are available with a NaI(Tl), CsI(Tl) or a HPGe detector for real-time analysis. Other manufacturers choose to be less specific in their publicly available specifications. The Saphymo range of Bertin Instruments (Bertin Instruments, 2016) includes the SA2XX in a fixed installation cabinet with a $LaBr_3$ detector but stay short of specifying further details within the online resources. Thermo Scientific™ offers a FHT 59 N1 Nuclide-Specific Aerosol Monitor (Thermo Fisher Scientific, 2016), a fixed cabinet installation with a continuous nuclide-specific monitor of aerosol-bound gamma activity in air, airflow of 10 m^3/h, a stepping filter system and an HPGe detector. Another commercially available unit, the MASS system by HI-Q Inc. (HI-Q, 2016), is capable of 12 m^3/h airflow and can be supplied with a gamma real-time monitor. For completeness, we also mention here three detector-less air particulate samplers by VF a.s. (VF, 2016)

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because of their higher air flow rates, compared to the above real-time systems, namely the two mobile systems VOPV-10 (an air sampler with up to 20 m^3/h airflow) and VOPV-12 (with a 20–160 m^3/h airflow), along with the stationary VOPV-7 (600–900 m^3/h).

At Jožef Stefan Institute (JSI) a novel portable aerosol sampling device was developed which incorporates a $CeBr_3$ scintillation detector positioned centrally within a concertinaed filter assembly and an improved high flow rate air pump. The system provides continuous on-line low level airborne radioactive particulate monitoring for field station use via 3 G network communications.

2. Description of the compact radioactive aerosol monitoring device

The compact radioactive aerosol particulate monitoring device consists of a high flow air pump, an innovative concertinaed filter cartridge and a 1 in. $CeBr_3$ scintillation detector, which is positioned within the filter cartridge. The pump provides a stable flow rate up to 200 m^3/h and the detector has a FWHM energy resolution of ~4% at 662 keV. The detector output is processed by a Digital Signal Processing unit (DSP unit) developed in-house at JSI. The entire device is assembled into a heavy-duty portable Peli Case 1740 with exterior dimensions of 37 cm (height without cover), length of 114 cm and width of 50 cm. A schematic render of the entire system assembly is shown on Fig. 1. The system has been divided it into three units based on their functionality: air, detection and base unit. These units will be described in the following sections.

2.1. Air unit

The air unit consists of a concertinaed aerosol filter assembly, a flow meter and a high-performance air pump. Concertina aerosol filter (Fig. 1a) has a tubular shape, so that the air flows through the filter and the deposited aerosols on the filter are constantly being measured by the $CeBr_3$ detector which is fitted inside the filter (Fig. 1b). The air flows through a flow meter (Fig. 1c) and exits the system through the air pump (Fig. 1d).

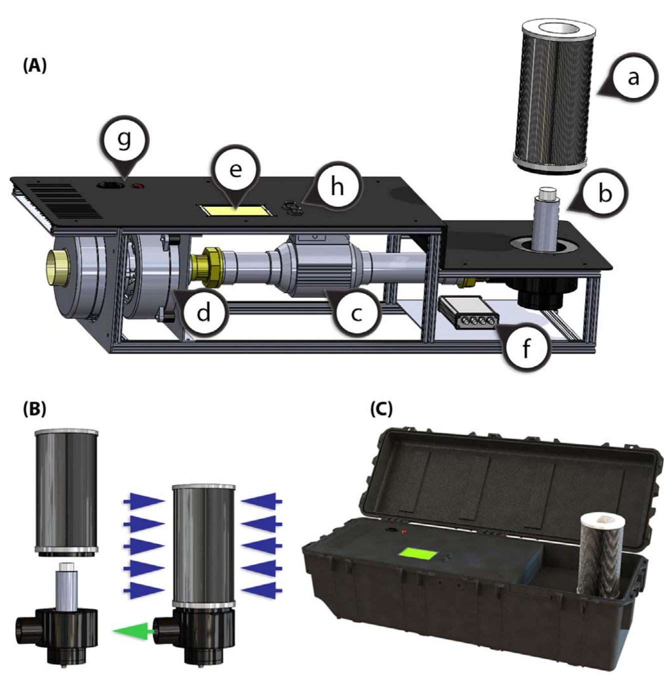

Fig. 1. Air pump system assembly (A): a) concertina aerosol filter, b) $CeBr_3$ detector with integrated bias voltage supply, c) flow meter, d) air pump motor and turbine (brushless blower), e) microcontroller unit with TFT touch screen and I/O controls, f) preamplifier and digital pulse processing unit, g) 230 V AC power IEC connector and ON/OFF switch with LED indicator and h) 2 USB connectors for firmware upgrades and serial communication with a PC. Scheme (B) illustrates the filter assembly, multiple arrows indicate entry of air through the filter and the single arrow shows airflow output into the flow meter. Scheme (C) presents a top view of the entire system in a rugged Peli Case.

Table 1
Energy resolution and intrinsic radioactivity specification for investigated scintillation detectors.

Detector	Resolution – FWHM @662 keV [%]	Intrinsic activity
CsI:Tl	< 7%	no
$CeBr_3$	< 4%	very low with careful selection of raw material (e.g. without ^{227}Ac contamination)
$LaBr_3$:Ce	< 3%	yes

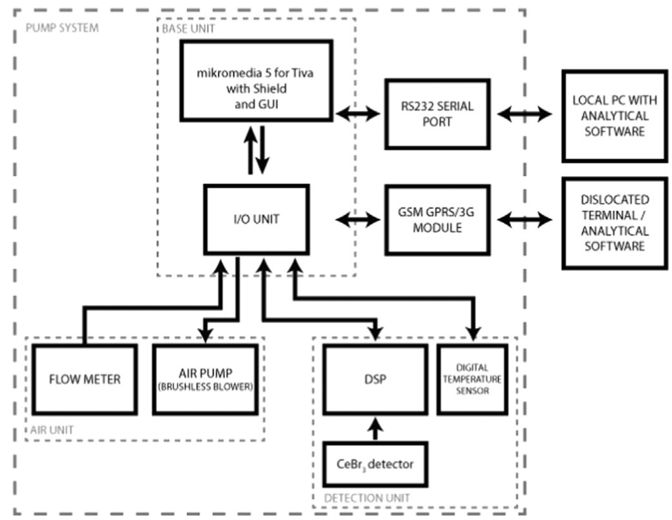

Fig. 2. Communication scheme between airflow, detection and base units.

Filter cartridge consists of a metallic housing where 0.87 m^2 of fiberglass H13 class filter paper folded in an accordion form is placed. At air-flow rates used, the collection efficiency for particles with sizes above 0.3 μm is 99.99%, according to manufacturer.

The air output from the assembly continues through a Testo 6444 flow meter, mounted to the filter assembly. The flow meter records volume flow according to the calorimetric principle, keeping the measurement results independent of the process pressure and does not cause a permanent pressure drop. While the glass-coated ceramic thermal sensor offers a high level of robustness and fast response times, the integrated inflow and outflow pipes ensure optimum accuracy. The flow meter encodes real time data on the instant and integrated total air flow into a digital pulse stream, suitable for readout by the microcontroller unit.

The air pump can operate at up to 1.8 kW power and is designed for high flow applications. It features a continuous speed control input, allowing for an electronic adjustment of speed in real time.

2.2. Detection unit

The sensitivity of the system was boosted by a careful selection of the radiation detector. Since the device should be portable, special care was taken in choosing a suitable size for the detector that still fits in the concertina aerosol filter without significant impact on the airflow rate, to keep within the required specifications. Due to their best cost/benefit ratio we decided to use a scintillation detector. Two fairly new scintillation materials, lanthanum bromide ($LaBr_3$:Ce) and cerium bromide ($CeBr_3$) were considered alongside the classic, cesium iodide (CsI: Tl). Since the design is to serve as an early warning system, it needs to be as sensitive as possible for low activities, therefore a low inherent background is required. On this basis, the main decision