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Monte Carlo simulation of the responses of gaseous effluent monitors to radioactive isotopes

Mohamed A. Gaheen[a,*], Nader M.A. Mohamed[b]

[a] Department of Nuclear Safety and Radiological Emergencies, NCRRT Center, Egyptian Atomic Energy Authority (EAEA), 11787 Cairo, Egypt
[b] Egypt Second Research Reactor (ETRR-2), 13759 Abou Zabal, Egypt

HIGHLIGHTS

- Monte Carlo simulations facilitate tests and calibration of gaseous effluent monitors.
- MCNP5 accurately simulates responses of the I-131 and Ar-41 detecting units exposed to specific radioactive sources.
- MCNP5 provides a realistic simulation of calibration experiments and measurement configurations.

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ABSTRACT

This paper discusses use of Monte Carlo simulations to facilitate testing and calibration of a gaseous effluent monitor (GEM). MCNP5 was used to simulate responses of the ^{131}I and ^{41}Ar GEM detecting units exposed to specific radioactive sources. The agreement between the MCNP5 predictions and experimental measurements is good enough to validate the MCNP5 model. It has been demonstrated that the Monte Carlo code is a powerful and useful tool to determine accurate detector responses and facilitate the calibration process of this type of the monitors.

1. Introduction

Gas effluent monitors (GEMs) have been designed for use in nuclear and radiological facilities to ensure that the limits of the gaseous effluent (based on dose limits) are not exceeded under normal operation. The monitor is used to detect and identify radioactive components in the gases and provide information necessary to calculate relevant doses. For example, gaseous effluents are monitored for iodine-131 and argon-41 (Kim et al., 2006; Koeth, 2014; Kovar and Dryak, 2008; McLoughlin, 1990; Sion, 1996). Also, GEMs serve to set off alarms and turn on emergency modes of the ventilation system. A GEM system consists of one or more independent detecting units, each of which has inlet/outlet air flow connections to sample air when the system is in operation.

GEMs need to be periodically tested and calibrated to ensure that their detecting units are valid (IAEA, 2006; Welch, 2008). Monte Carlo codes have been used to simulate and calibrate various types and models of radiation detectors (Cinelli et al., 2016; Gallardo et al., 2013; Hansman et al., 2015; Kovar and Dryak, 2008; Ro´denas et al., 2007, 2000; Salgado et al., 2012; Santo et al., 2012). In this paper, we discuss using MCNP5 (LANL, 2003) to simulate detection of iodine-131 and argon-41 by GEMs to facilitate their tests and calibration. Section 2 contains a description of the GEM detecting units with their characteristics (Bourdin, 1995). Nassif and Bourdin (1995) reported procedures for initial calibration of each detecting unit. Section 3 describes the calibration procedures and the relevant sources containing radioactive isotopes.

The Monte Carlo code MCNP5 was used to simulate detection of iodine-131 and argon-41 to determine responses of the detectors when exposed to specific radioactive sources in particular measurement configurations. We considered ^{131}I annular and point sources, an ^{41}Ar volumetric source, and a ^{90}Sr/^{90}Y screw-type source. MCNP5 was used to simulate the specific detector models because data of their initial calibration measurements were available (Nassif, 1996). Calculations with the code facilitate the process of calibration of the detecting units and ultimately reduce the amount of radioactive waste.

2. Detecting units

The iodine detecting unit had a NaI scintillator detector to measure the activity of ^{131}I; an annular charcoal filter consisting of small pieces of carbon was used to collect iodine (in the nCi range of activities) from air. Table 1 lists dimensions and other characteristics of the iodine

* Corresponding author.
E-mail address: magaheen@yahoo.com (M.A. Gaheen).

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Table 1
Dimensions and characteristics of the ^{131}I detecting unit.

Annular charcoal filter (volume 222 cm^3; weight 30 g)	
Outer diameter of the filter	85 mm
Inner diameter of the filter	45 mm
Filter length	48 mm
Detector: 1.5" × 2" NaI BICRON Monoline Scintillator, Model 1.5M2/2	
Diameter of the scintillator	37 mm
Length of the scintillator	50 mm
Diameter of the photomultiplier	50 mm

This iodine source was assembled and calibrated using a CNEA[1]-Argentina standard sample with the activity of 379.5 nCi (Nassif, 1996). From the total measured count rate 41,978 cpm, the calibration constant of the iodine detection unit was found to be 110.6 cpm/nCi.

The argon detecting unit was calibrated with a continuous ^{41}Ar-containing air flow through the inlet and outlet pipes used to sample air during normal operations at the normal flow rate (3 m^3/h). As prescribed in the calibration procedure (Nassif and Bourdin, 1995), the argon unit was first turned on to verify the high voltage, check the detector and measure the background. Then, the unit was turned off, and the inlet/outlet pipes were connected to the air flow containing the ^{41}Ar isotope. The argon unit was turned on again to measure counts per second (cps) with argon source and calculate the calibration constant (or sensitivity) as described above.

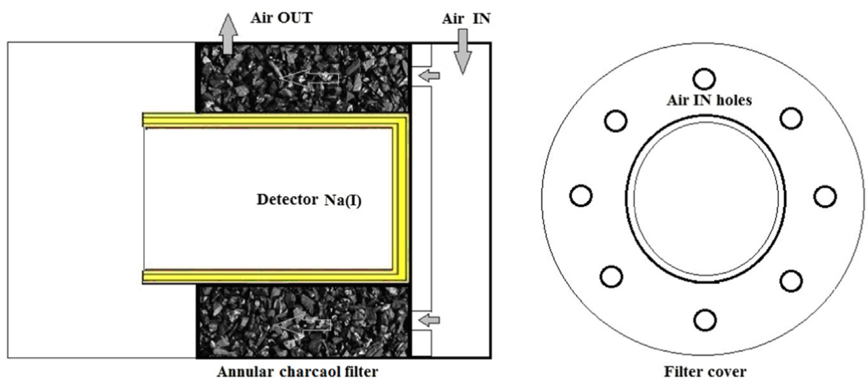

Fig. 1. Measurement configuration of the iodine-131 detecting unit.

Table 2
Dimensions and characteristics of the ^{41}Ar detecting unit.

Measuring chamber with air inlet/outlet connections (air flow 3 m^3/h)	
Diameter of the measuring chamber	89 mm
Length of the measuring chamber	11 mm
Volume of the measuring chamber	491 cm^3
Detector: plastic scintillator NE, Model NE102A	
Diameter of the scintillator	50 mm
Thickness of the scintillator	1 mm
Diameter of the photomultiplier	50 mm

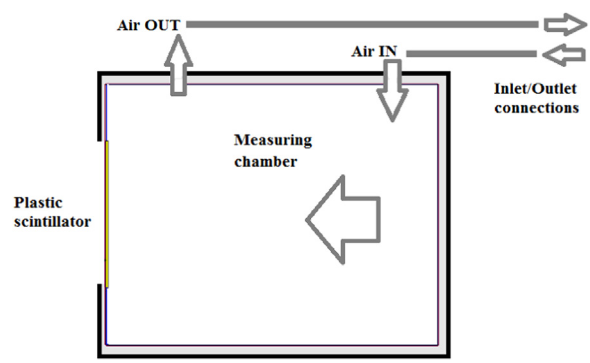

Fig. 2. Measurement configuration of the argon-41 detecting unit.

detecting unit shown in Fig. 1.

The argon detecting unit had a plastic scintillator detector to measure ^{41}Ar and a measuring chamber to measure specific argon activity (Bq/cm^3) in air. Table 2 lists dimensions and other characteristics of the argon detecting unit shown in Fig. 2.

3. GEM calibration procedures

The iodine detecting unit was calibrated with an annular charcoal filter of the dimensions and characteristics identical to those of the one used to collect iodine during operation and impregnated with a solution containing the ^{131}I isotope. As described in the calibration procedure (Nassif and Bourdin, 1995), the iodine unit was first turned on to verify the high voltage, check the detector and measure the initial count rate (background). Then, the unit was turned off, and the clean charcoal filter was replaced with one contaminated with ^{131}I. The iodine unit was then turned on again to measure counts per minute (cpm) with the contaminated filter in place and calculate the calibration constant (or sensitivity) as

$$Cc_i = \frac{CR_i - Icr}{(ACT)_i},$$

where $(ACT)_i$ is the activity of contaminated charcoal filter expressed in nCi, Cc_i is the calibration constant (cpm/nCi), CR_i is the measured count rate (cpm) with the contaminated filter, Icr is the initial count rate with the clean charcoal filter, and the subscript i denotes the iodine unit.

This argon source used for calibration was the air that passed through the core of the reactor (RA-6, Argentina); it had activity of 13.1 Bq/cm^3 (Nassif, 1996). The calibration constant for the argon detecting unit was found to be 76 cps/Bq/cm^3.

Generally, some calibration sources should be used to check the detector performance periodically. The sources used for calibration in this work (^{131}I-contaminated filter and ^{41}Ar source) could not be used later because of the short half-life of ^{131}I (about 8 days) and ^{41}Ar (1.83 h). New sources should be prepared under the same conditions and used in proper radiation protection procedures to avoid contamination or possible leakage of radioactive gases and personnel exposure. Thus, the MCNP5 is used to simulate the detecting units of iodine-131 and argon-41 to facilitate the testing and calibration procedures.

[1] **National Atomic Energy Commission** (Spanish: Comisión Nacional de Energía Atómica, **CNEA**).