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Development of a radiochemical sensor, Part 2: Application to liquid effluents

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Abstract

Monitoring programmes to evaluate the impact of nuclear activities on the environment require an increasing number of analytical determinations. In such a scenario, the development of a sensor could be especially helpful to increase the limited analytical capabilities of laboratories. The present study continues an initial feasibility project and focuses on the evaluation of the capabilities of a radiochemical sensor for liquid effluents applicable to real samples. This sensor is capable of sending information about the specific activity and volume of a contamination episode to a remote position, on-line and continuously. The sensor is made of plastic scintillator beads and includes two receptors, one for alpha and beta particles and the other for gamma radiations. Contamination pulses of ^{90}Sr/^{90}Y, ^{134}Cs and ^{240}Pu of different volumes and activity levels included in a continuous stream were quantified. Relative errors obtained for both magnitudes are, in the majority of the cases, less than 10%. Lower limits for these quantifications are 5 ml and around 1 Bq/ml. These thresholds could be improved in new designs adapted to specific problems.

Keywords: Radiochemical sensor; Plastic scintillator; Optical fibres; Liquid effluents; Remote; Radioactive waste

1. Introduction

The relationship between environmental protection and nuclear activities uses environmental monitoring programmes as an informative tool. These programmes include the activity determination of many radionuclides in the different natural compartments of the earth [1–3].

Few efforts have been made to develop sensors as an alternative to the classical analytical approach [4–6], and well established portable detection systems such as Geiger–Muller counters yield limited information of alpha and beta activity and are not compatible with direct measurements in liquid samples. The present article continues a previous study devoted to determining the feasibility of a radioactive sensor prototype for liquid effluents [7,8] (patent in process). Based on the results of that study, the objective here is to design and evaluate the capability of an evolution of the initial proposal, which will be applicable to real samples.

The main changes with regard to the first version are related, in the receptor, to the absence of size restrictions and the use of long optical fibres. In the transductor, the changes are related to the incorporation of a periphery gamma detector that can also be used as active shielding.

The transductor is based on the architecture of a conventional liquid scintillation detector with logarithmic amplification.

2. Experimental

2.1. Reagents and solutions

All regents used were of reagent or analytical grade. The active stock solutions used for the preparation of calibration and test solutions were:

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1. $^{90}Sr/^{90}Y$ calibrant of $6.22 \times 10^4 \pm 9.32 \times 10^2$ disintegration per minute per gram (dpm/g) in 0.1 M HCl from Amersham International.
2. ^{134}Cs calibrant of $86.04 \times 10^7 \pm 4.30 \times 10^6$ dpm/g in 0.1 M CsCl and 0.1 M HCl from Amersham international.
3. ^{240}Pu calibrant of $8.16 \times 10^4 \pm 1.22 \times 10^3$ dpm/g in 2 M nitric acid from Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT).

All the active solutions were prepared by diluting a weighed amount of standard solution in a weighed amount of the specific medium previously prepared with inactive distilled water.

2.2. Apparatus

A peristaltic pump Gilson Miniplus 3 with eight channels was used to pump solutions into the sensor. The tubing used was PVC purple–purple pump tubes 2.06 mm i.d. and 50 cm long.

A 1414 liquid scintillation detector (EGG&Wallac) with logarithmic amplification and a 1024-channel analyser was used. The detector was modified by EGG&Wallac to allow top entry of the bundles of optical fibres from the top. A reflective conical metallic piece, located in the measurement chamber, was used to reflect the transmitted light from the end of the fibres to the photomultipliers.

SenCont software was designed to control the 1414 detector and manage the files generated. This software enables acquisition time control with high accuracy and extreme reduction of detector dead time.

2.3. Sensor description

The sensor is composed of two parts, the receptor and the transductor, connected by optical fibres (patent in process). The receptor is made of plastic scintillator, and it is there that the signal related to the concentration of the radionuclides in the liquid effluent is produced. The transductor is composed of electronic units that convert the optical signals into electrical pulses and classifies them according to their origin, shape and energy. The spectrum obtained is finally stored for further data treatment. SenCont software commands the transductor and thus the entire measurement process.

The receptor structure is shown in Fig. 1. It is composed of two concentric cylinders surrounded by a plastic shield. The internal cylinder is the alpha–beta receptor, whereas the external cylinder is the gamma receptor.

The alpha–beta receptor is made of BC-408 plastic scintillator and it is externally coated, except for one of the sides, first by a light reflective layer and secondly by a black light-tight layer. The uncoated side is coupled to a pipe of light made of BC-408 plastic scintillator, which is also externally covered by a reflective and a light-tight layer except at its end. The pipe of light is coupled to a bundle of optical fibres prepared to conduct photons by total internal reflection. The alpha–beta cylinder is totally filled up with BC-400 plastic scintillator beads 250–500 μm in diameter. This chamber is connected to the exterior by two stainless steel tubes (“in” and “out”) located on the same side as the fibres. These tubes cross the plastic scintillator wall of the cylinder, the pipe of light and the plastic shield. One of the tubes starts at the top of the chamber and the other at the bottom.

The gamma receptor is also made of BC-408 plastic scintillator and completely surrounds the alpha–beta receptor (Fig. 1). As in the alpha–beta receptor, the walls are coated by a reflective and by a light-tight layer. One of the sides of the cylinder is not coated and is coupled to a plastic pipe of light, again, externally coated. The end of the pipe is connected to an optical fibre bundle.

Each bundle of optical fibres, the alpha–beta and the gamma, is randomly divided into two sub-bundles before they reach the transductor.

A modified commercial liquid scintillation detector 1414 EGG&Wallac is used as transductor. Transduction begins with the pair of phomultiplier tubes (PMT), which are connected to a coincidence system to reduce electronic background. Each sub-bundle, from the alpha–beta or the gamma bundle, is positioned in front of one PMT. The pair of sub-bundles is changed depending on the receptor studied. The signal obtained by the PMT is amplified, converted to digital, analysed and stored in the computer. The transductor is controlled by SenCont software.

2.4. Sensor operation

The analysed effluent enters into the alpha–beta receptor by the “in” tube, fills the free space of the chamber and, once the chamber is completely full, leaves it by the “out” tube.

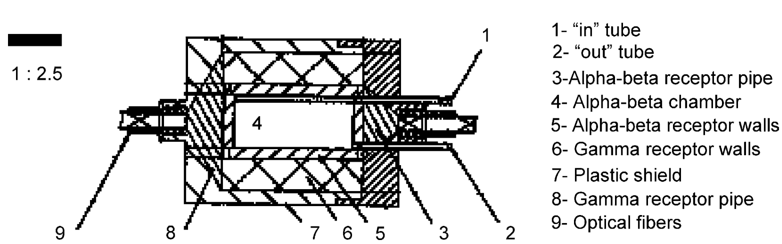

Fig. 1. Structure of the receptor.