Environmental control systems for defining the activity size distribution of radioactive aerosols - a case study

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Abstract. The 1ACFM cascade impactor and the High Volume cascade impactors are the instruments that mainly used to define the activity size distribution of radioactive aerosols in the environmental air. The impactors are instruments designed to collect and separate particulate matter according to its aerodynamic size, determining the penetration of particles in the human lung, as well as the transport and diffusion of particles in the ambient air. An example of the activity size distribution of the natural radionuclide tracer ^{7}Be is given, as this determined by a 20cfm cascade impactor.

Keywords: radioactive aerosols, impactor, AMAD, environmental radioactivity

1 Introduction

The aerodynamic diameter of particles is a critical parameter in characterization of suspension aerosols, while the aerodynamic size distribution defines the manner in which the particles are deposited in the lung during inhalation.

The impactors are instruments designed to collect and separate particulate matter according to its aerodynamic size, which is the most important size in particle work because it determines the penetration of particles in the human lung, as well as the transport and diffusion of particles in the ambient air. These samplers were calibrated so that all particles collected, regardless of physical size, shape, or density, are sized aerodynamically and can be directly related to human lung deposition.

In this study two cascade impactors are presented. Finally, the activity size distribution of the natural radionuclide tracer ^{7}Be in different inhalable fractions (<0.39 μm, 0.30-0.69 μm, 0.69-1.3 μm, 1.3-2.1 μm, 2.1-4.2 μm , 4.2-10.2 μm and >10.2 μm) is given as this obtained by measurements with a 20cfm cascade impactor in the region of the city of Thessaloniki, Greece.

2 Instrumentation

Measurements on aerodynamic sizes of atmospheric aerosols and associated radionuclides are mainly carried out with Anderson 1-ACFM eight-stage cascade impactors as well as with 20 cfm (six-stage) high-volume cascade impactors (HVI).

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The 1-ACFM eight stage cascade impactor (Fig. 1), is operating at a flow rate of 28 l min^{-1} (1 ft^3 min^{-1}). The stages had effective cutoff diameters (ECDs) of 0.4, 0.7, 1.1, 2.1, 3.3, 4.7, 5.8 and 9.0 μm.

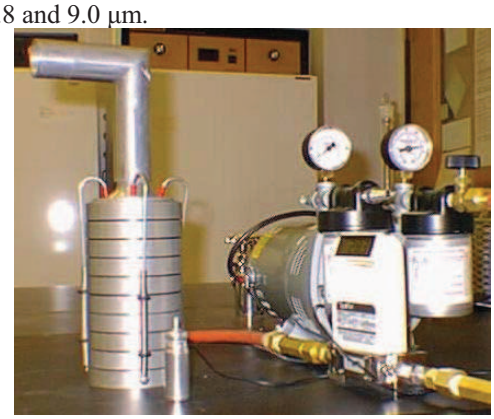

Fig. 1. The set-up of 1ACFM eight-stage Andersen Cascade Impactor

Each impactor stage contains multiple precision drilled orifices. Each stage has a removable glass petri dish with a metal cover. By subsequently making the orifice diameter smaller on each stage of the Cascade Impactor, the particles are increased in velocity and the aerodynamic separation of particles over a large range can be determined. (Fig. 2) Successively smaller particles are inertially impacted onto the collection surfaces (http://www.labautomate.net/, http://www.globalspec.com/FeaturedProducts/Detail/ThermoScientificAirQualityInstruments/The_Original_Andersen_Cascade_Impactors/123307/0).

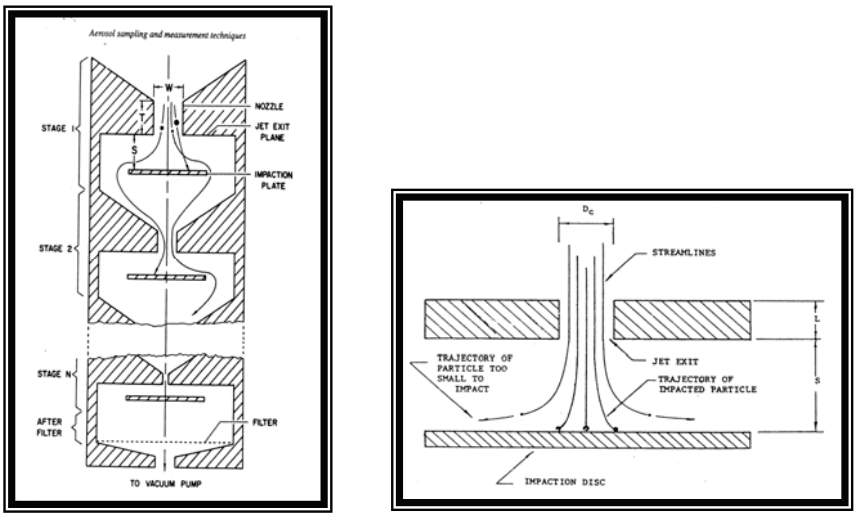

Fig. 2. By subsequently making the orifice diameter smaller on each Stage of the Cascade Impactor, the particles are increased in velocity and the aerodynamic separation of particles over a large range can be determined. Successively smaller particles are inertially impacted

The High Volume Cascade Impactors HVI, are multi-stage cascade impactors which attach to any standard high volume air sampler and fractionate particles into as many as six size ranges (www.staplex.com, http://www.westechinstruments.com /prodlist.asp? productCategory=Ambient Air Samplers).

The 20cfm High Volume six-stage Cascade Impactor (Fig. 3) has ECDs of 0.41, 0.73, 1.4, 2.1, 4.2, and 10.2 μm. The impactor is operated at the flow rate of 20cfm and collection occurred on impaction collection filters.

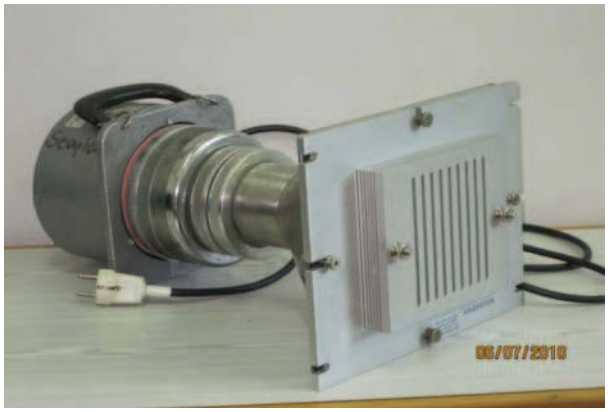

Fig. 3. The set-up of High Volume 20CFM Cascade Impactor (Staplex, Andersen)

Suspended particles enter the high volume air sampler and pass through the parallel slots in the first impactor stage. Those particles larger than the particle cut-off size of the first stage impact on a slotted collection substrate. The air stream passes through the slots of the substrate and accelerates as it flows through the narrower parallel slots of the following impactor stage and eventually most of the particles acquire a sufficient momentum to impact on one of the collection substrates. A back-up filter collects the remaining small particles passing through the last impactor stage. All particles are collected allowing for determination of total particle concentration.

The cascade impactor was designed as a substitute for the human respiratory tract to collect and separate particulate matter according to its aerodynamic size and property (Fig. 4). Stage distribution of collected particle mass will indicate the extent to which the aerosol sampled would have penetrated the human respiratory system. This information is vital to environmentalist, aerosol physicists and industrial hygienists for determining health risk and epidemiological risk.

After sampling is completed, the sampling time is recorded and the collection substrates are removed from the sampling instrument. Each substrate for each cascade stage is counted in detectors for determining the radioactivity for each radionuclide of interest in each stage. Knowing the air sampling flow rate and the sampling time, the mean activity of a radionuclide per unit volume of air can be calculated for each radionuclide of interest, and the percentage radioactivity in each size range can be estimated.

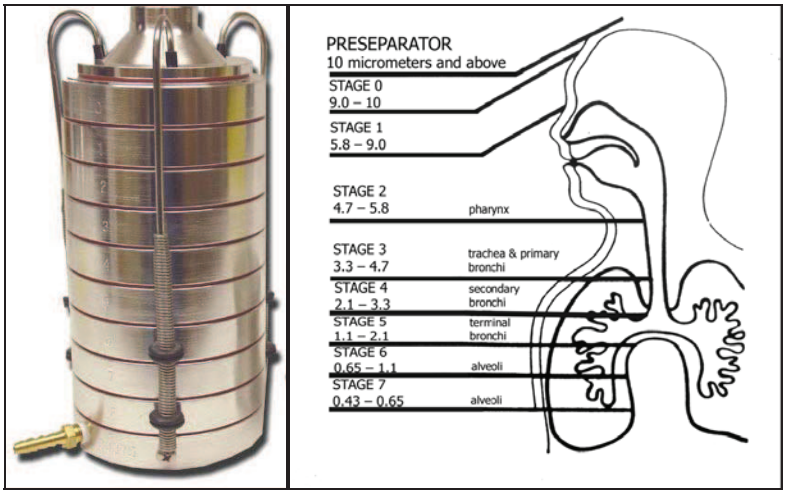

Fig. 4. The Cascade Impactor designed as a substitute for the human respiratory tract to collect and separate particulate matter according to its aerodynamic size and property

3. A case study

Beryllium-7 ($t_{1/2}$ = 53.3 d) is a natural occuring radionuclide with cosmogenic origin with an important fraction of its production taking place in the upper troposphere. Soon after its formation ^{7}Be is attached to atmospheric aerosol particles (Porstendörfer et al., 1991; Papastefanou & Ioannidou, 1995; Paatero and Hatakka, 2000; Eleftheriadis et al., 2007).

Our purpose is to define the aerodynamic size distributions of naturally occurring radioactive aerosols of ^{7}Be in the region of the city of Thessaloniki, Greece in the temperate zones (40°N).

3.1 Aerosol Collection Procedure

Aerosol samplings were carried out in the open air by using a 20cfm high volume 6-stage cascade impactor with a regulated air flow rate of about 0.57 m^3 min^{-1} (20 cfm) and Efficient Cutoff Diameters of 0.39, 0.69, 1.4, 2.1, 4.2 and 10.2 μm.

The length of each collection period was 24 h and the collected air volume was about 800m^3. Glass fiber filters were used as impaction substrates. After the collection procedure the filters were measured for ^{7}Be activity (Eγ=477 keV) using a high resolution (1.9 keV at 1.33 MeV), with 42% relative efficiency, low-background HPGe detector (Fig.5). Activity Median Aerodynamic Diameters (AMAD) were derived by calculating the percentage distribution in each size fraction and plotting the cumulative frequency distribution on log probability paper.

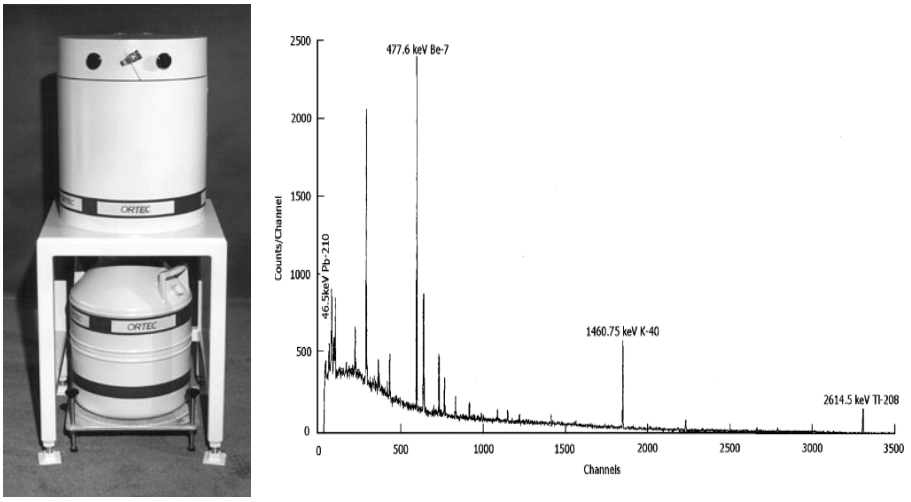

Fig. 5. A typical Ge detector for gamma-radioactivity and a gamma spectra, where the peaks of some radionuclides are defined

3.2 Experimental Results

The activity median aerodynamic diameter (AMAD) of ^{7}Be aerosols ranged from 0.58 μm to 1.22 μm (avg 0.80 μm) (Table 1). More than 80% of the ^{7}Be activity was found to be associated with particles smaller than 1.3 μm (Fig. 6). Finally, the age of aerosol particles was defined in the order of week.

The local meteorological conditions seems to affect the activity size distribution of ^{7}Be, while increased relative humidity during the sampling period results in incresed AMAD values (Ioannidou, 2011).

4. Conclusions

The 20cfm Cascade Impactor has been proved the ideal impactor for characterizing the activity size distribution ^{7}Be aerosols in a daily measurements. The estimation of the AMAD values of ^{7}Be aerosols allow us to detrmine the AMAD value of any tropospheric aerosol of the same origin, and calculate the total residence time of tropospheric aerososl in the order of a week.

Table 1. Experimental Data for ^{7}Be aerosols (Ioannidou, 2011)

Start of sampling	^{7}Be AMAD (μm)	σ_s
17-Jun-09	0.74	2.54
07-Sep-09	0.91	3.63
22-Sep-09	0.58	1.86
13-Oct-09	0.62	2.23
16-Oct-09	1.22	2.85
20-Oct-09	0.75	2.41
13-Jan-10	0.83	2.21

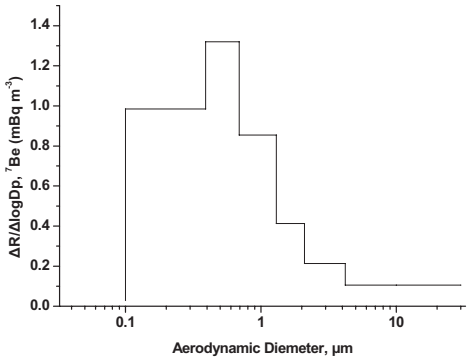

Fig. 6. Activity size distribution of ^{7}Be aerosols

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