An attachable alpha spectrometer for research, fast retrospective dosimetry, and measurement of low-level surface contamination+

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A B S T R A C T
Large-area, expensive silicon surface barrier detectors are combined with an inexpensive sound card (analog to digital converter) and modified open source software. Hence, an overall economic and user-friendly open air alpha spectrometer is obtained. Very high sensitivity is demonstrated by fast retrospective dosimetry with Po-210 implanted in mirror or window glass. Likewise trace amounts of thoron in open air are detected by collection on high voltage Cu plates or triboelectrically charged polystyrene Philion-Plates.

1. Introduction

Most naturally occurring radioactive materials contain alpha emitters. They are widespread in air, water and solids, and often of economic importance. Strict radiation protection regulations, as well as scientific curiosity and teaching with experiments call for a mobile and handy instrument with high sensitivity, resolution, and versatility to measure low-level radioactivity. Due to their inherently low background, alpha spectrometric detectors are often preferable to other detectors.

An improvement in handiness for a variety of laboratory and field applications was achieved, as compared with previous own (Pohl and von Philipsborn, 1996; von Philipsborn and Just, 2005), and other instruments (Samuelson et al., 2001; Pöllänen et al., 2013; Pöllänen et al., 2015).

2. Materials and Methods

A miniaturized, but very sensitive alpha spectrometer (Fig. 1, 2) for measurements in air was developed by combining a silicon surface barrier detector, a computer soundcard as analog to digital converter and modified open source software for signal processing.

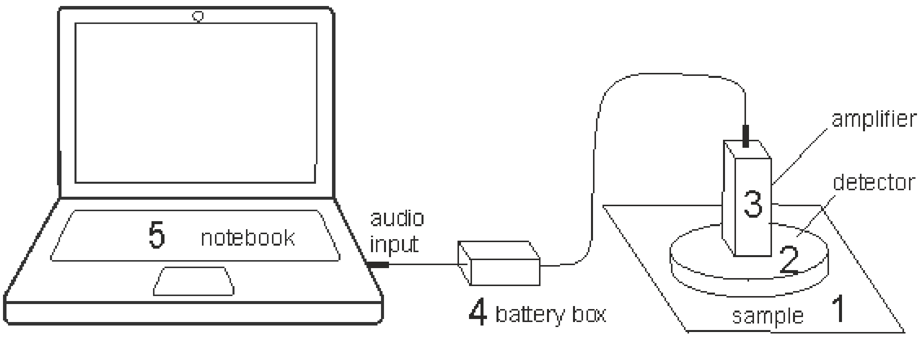

Fig. 1. Scheme of the spectrometer. The silicon alpha detector (2) is placed on top of the sample (1). A homebuilt pulse amplifier (3) is directly attached to the detector. A battery (4) supplies the amplifier. Pulses are fed into the audio input of the computer (5) running the pulse height analyzer software.

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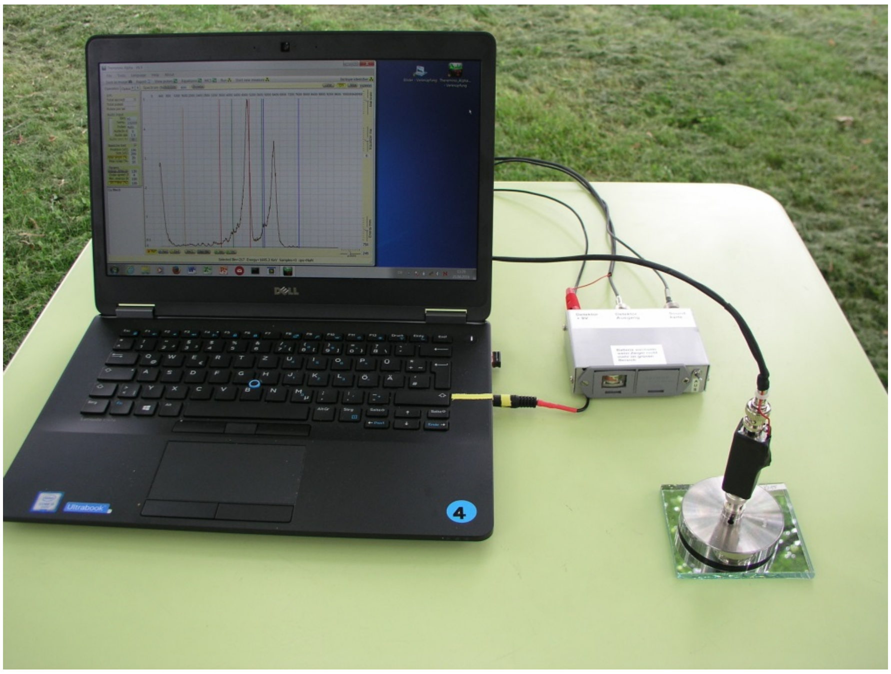

Fig. 2. Photo of the complete spectrometer. The detector (2) is a Canberra CAM-2000-AB.

Noticeable features of our spectrometer are:

a) Ion-implanted silicon detectors from Ortec and Canberra with 12 respectively 20 cm^2 round active area, insensitive to light, recessed 2 mm from a 5 mm rim. Good energy resolution is maintained in open air and without a collimator;

b) A tiny homebuilt preamplifier fixed to the detector and to a 120 cm cable with BNC connectors;

c) A notebook with a sound card which processes the detector signal to a spectrum.

The software is based on the open source project Theremino MCA (www.theremino.com/downloads/radioactivity) which is designed for gamma spectrometry. It was modified by the first author to be used for alpha spectrometry. The energy range was adapted and a multichannel scaler (MCS) was added which resembles a three channel window discriminator. The MCS records activity in each spectral window as a function of time with selectable resolution. The vertical lines in the spectrum (Fig. 4) define the spectral windows and can be set by mouse click. Pulses in these channels are registered in a table as well as plotted.

Positively charged airborne radon and thoron decay products are collected with two different methods (Fig. 3):

a) on conducting copper plates (Rutherford 1900, Elster and Geitel 1901), connected to a -14 kV source, well suited for long time (h) collection, the charge being maintained. Use is made of two commercially available high voltage modules.

b) on non-conducting polystyrene plates, charged to -20 kV by forceful rubbing with the sharp edge of a piece of wood (von Philipsborn and Hoffmann 1995), so-called Philion-Plates, well suited for short time (min) collection, the plate being neutralized by the collected ions.

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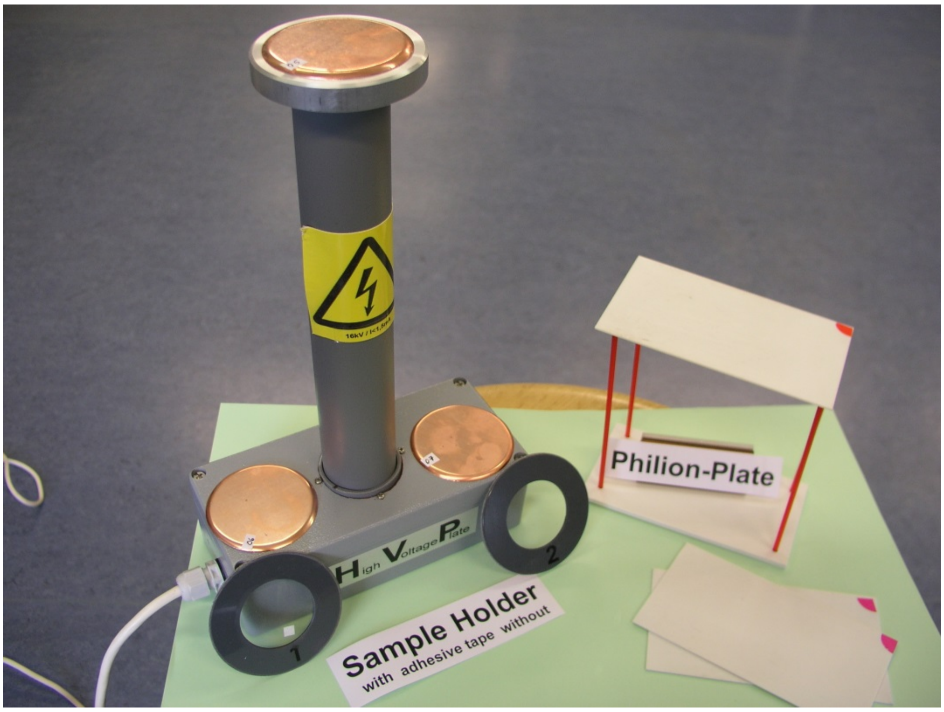

Fig. 3. Two instruments to collect airborne positively charged radon and thoron decay products. Left: Electrostatic sampler. The base contains a mains driven -14 kV high voltage generator which connects to a 6 cm diameter copper plate on top of an insulating tower 30 cm above the surface on which the base is standing. Right: Philion-Plate, polysterene, simply charged to -20 kV by forceful rubbing for 60 s with the sharp edge of a piece of wood.

Samples, such as glass surfaces implanted with Po-210, are measured horizontally by placing the detector on the surface, or in-situ vertically by approaching or attaching the detector with the preamplifier (fig. 2), held by a clamp on a tripod, to the object to be measured.

Samples, such as deposits or dusts, removable with adhesive tape, are measured with the tape on concentric rings, 1 mm thick, to avoid contamination of the detector, recessed by another 2 mm. The energy shift of alpha particles of 5 to 8 MeV in 3 mm of air is acceptable.

For a certified Am-241 source, 1 kBq, 70 mm diameter, the detectors have efficiencies of 40 respectively 41 %, which is much larger than for scintillation or gas-filled alpha counters. Other artificial alpha emitters have not been measured.

3. Results and Discussion

Fig. 4 is an example for retrospective dosimetry. It shows the spectrum of a glass mirror front surface, exposed for about 20 years to high indoor radon, and studied with the 12 cm^2 Ortec detector, efficiency 40 %, background (Cu) 6 counts per 1000 s in the Po-210 (5.3 MeV) energy range. The average gross yield was 70 ± 3 counts in ten runs of 1000 s each, equivalent to 13 mBq cm^{-2} = 130 Bq m^{-2} of implanted Pb-210/Po-210, equivalent to 5.2 kBq m^{-3} Rn-222. For converting the measured Po-210 Bq m^{-2} to calculated Rn-222 Bq m^{-3} we used the median value k = 42 m^{-1} of Falk et al, 2001. The energy ranges shown in the figure are explained by the insert of fig. 6. Of course, the limit of detection is much lower for longer counting times.

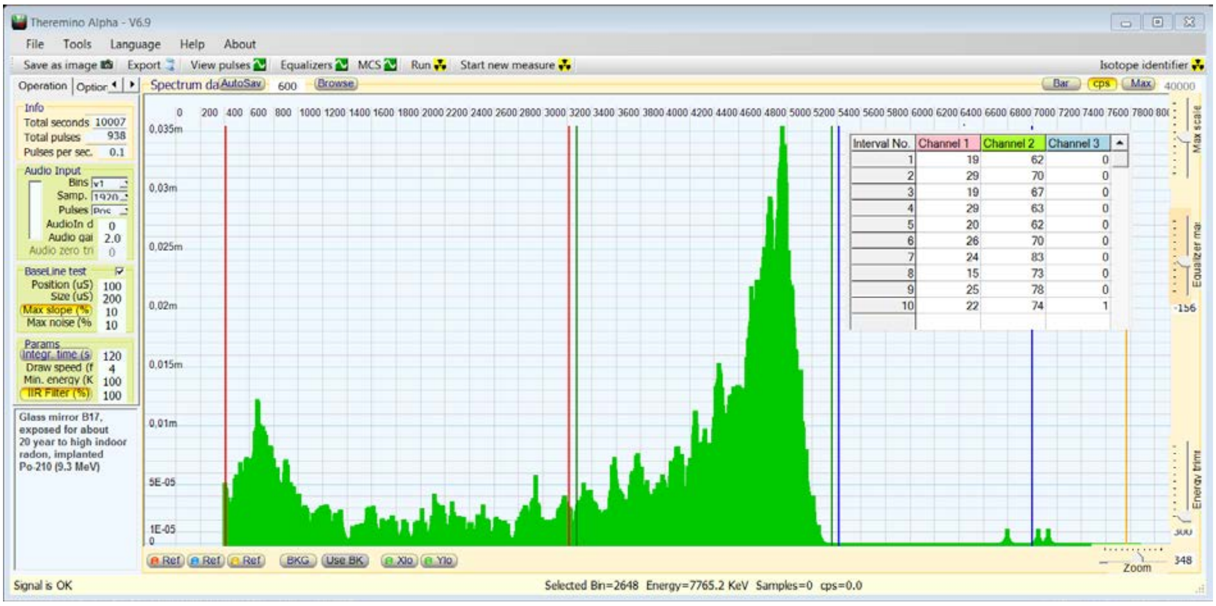

Fig. 4. Spectrum of a glass mirror front surface, exposed for about 20 years to high indoor radon. Ortec detector 12 cm^2, efficiency 40 %, background (Cu) 6 counts per 1000 s. The energy ranges are explained by the insert of fig. 6. Sample with Po-210 (5.3 MeV, misspelled 9.3) yields 70 counts per 1000 s, equivalent to 130 Bq m^{-2} and about 5.2 kBq m^{-3} Rn-222. The pulses on the left are from beta emitters.

Fig 5 shows a contamination, the spectrum of Bi-212 and Po-212 from the inside surface of a closed box with a thoriated gas mantle.

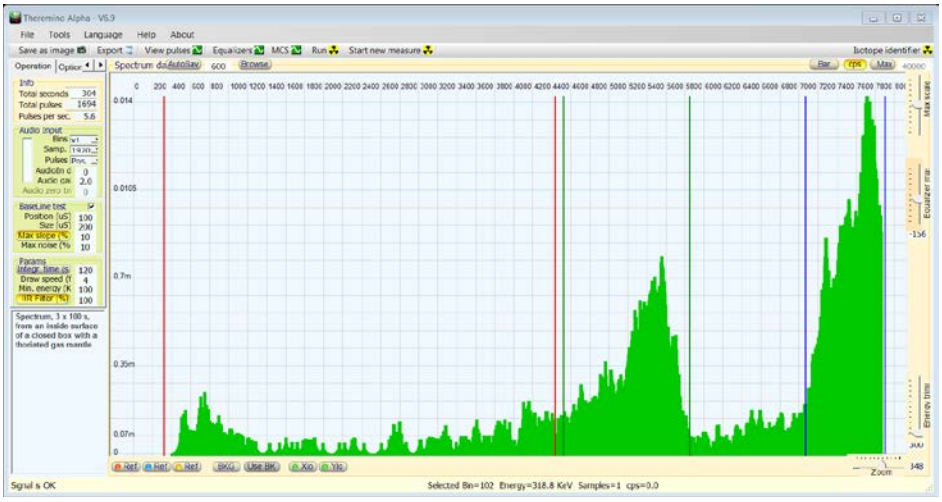

Fig. 5. Bi-212 (6.0 MeV) and Po-212 (8.7 MeV) from an inside surface of a box, closed for several days, with a thoriated gas mantle, measured 3 x 100 s.

For demonstration purposes, Philion-Plates were exposed for 3 min to indoor air with about 100 Bq m^{-3} radon (spectrum Fig. 6) and to outdoor air of about 10 Bq m^{-3}. The two curves of count rates vs. time (Fig. 7a and b) show for Po-214 significant differences due to the factor of equilibrium q which is high for indoor air and low for outdoor air, and shown by the ratio of Po-214 to Po-218 after 3 min sampling and 3 min measurement. q = activities of Rn decay products to activity of Rn gas. $0<q\leq1$.

Trace amount of Bi-212 and Po-212 can be detected even in outdoor air by collecting on copper plates for 1 to 3 h and measuring immediately and after 12 h. In the Rn-222 decay scheme, the intermediate beta-emitters Pb-214 and Bi-214 between the first alpha emitter Po-218 and the later Po-214 have half-lives of 27 and 20 min. In the Rn-220 decay scheme Pb-212 and Bi-212 between Po-216 and Bi-212 and Po-212 have half-lives of 10 and 1 h. Hence, only Rn-220 alpha emitting decay products are left and are well detectable with a second measurement 12 h later.

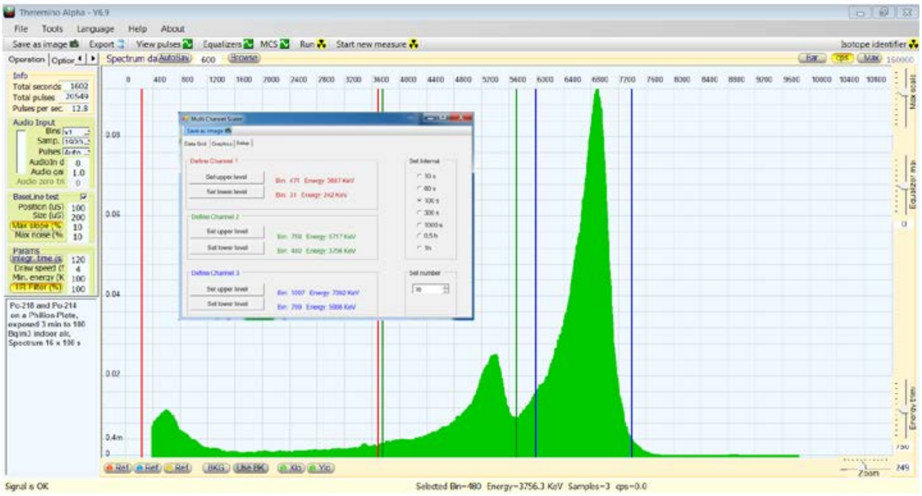

Fig. 6. Energy spectrum of Po-218 (6.0 MeV) and Po-214 (7.7 MeV), collected on a Philion-Plate, exposed for 3 min to indoor air with about 100 Bq m^{-3} Rn-222 and measured for 16 x 100 s. The vertical lines in red, green and blue define the spectral windows and can be set by mouse click. See also Fig. 7a.

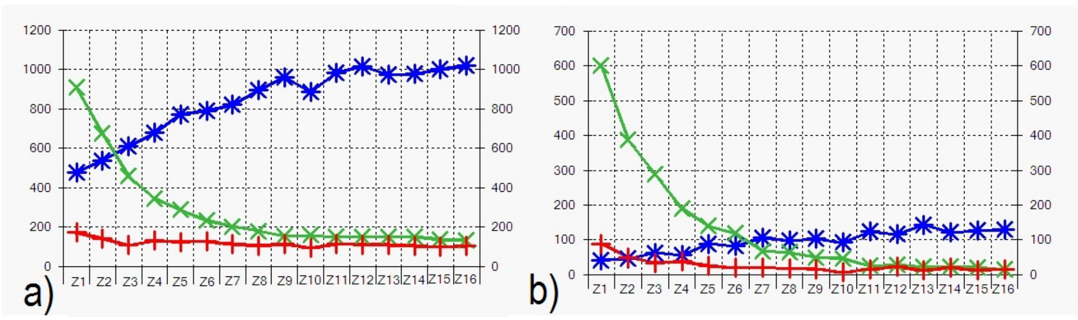

Fig. 7. Count rates vs time (16 x 100 s) for Po-218 (green) and Po-214 (blue), collected as in Fig 4 from indoor air (a) and from outdoor air (b). Note the significant difference of the blue curves (Po-214), due to the factor of equilibrium which is high for indoor air and low for outdoor air.

Other specimens measured so far are: Po-216 on a thorium oxide coated germanium mirror used for infrared optics; inside surfaces of boxes or glass show-cases used for storing or exhibiting radioactive minerals; red granite from Finland emanating thoron; flat surfaces of radioactive ceramics; and glass fiber filters (von Philipsborn, 1997) dried after filtration of fresh rain water (up to 100 Bq L^{-1}, tap water (down to 2 Bq L^{-1}, and spa water (up to 2000 Bq L^{-1}) all with Po-218 und Po-214.

4. Conclusions

Our alpha spectrometer and samplers are an improvement to previous instruments and are less expensive, more sensitive and more versatile for research, screening, field work and teaching than alpha spectrometers and samplers described in the literature for laboratory, in-situ or handheld applications, or commercially available.

Acknowledgements

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References

Elster, J., Geitel, H., 1901. Über eine fernere Analogie in dem elektrischen Verhalten der natürlichen und der durch Becquerelstrahlen abnorm leitend gemachten Luft. Physikalische Zeitschrift 2, 590-593.

Falk, R. et al., 2001. Experience from retrospective radon exposure estimations for individuals in a radon epidemiological study using solid-state nuclear track detector. The Science of the Total Environment 272, 61-66.

http://www.theremino.com/en/downloads/radioactivity.

Pöllänen, R., et al., 2013. In-situ alpha spectrometry from air filters at ambient air pressure. Radiation Measurements 53-54, 65-70.

Pöllänen, R., et al., 2015. Novel equipment for in situ alpha spectrometry with good energy resolution. Health Physics 109, 601-605.

Pohl, M., von Philipsborn, H. 1996. Recent progress in sampling and measurement of radon and thoron decay products. IRPA 9 Proceedings vol 2, 160-162.

Rutherford, E., 1900. Radioactivity produced in substances by the action of thorium compounds. Philosophical Magazine ser.5, xlix, 161-192.

Samuelsson, C. et al., 2001. Alpha particle emission from reference glass surfaces implanted with ^{210}Po. The Science of the Total Environment 272, 175-179.

von Philipsborn, H., Hoffmann, C., 1995. Messung von Radonfolgeprodukten: ein einfaches Verfahren. Strahlenschutzpraxis Heft 4, 56-58.

von Philipsborn, H., 1997. Efficient adsorption of waterborne short-lived radon decay products by glass fiber filters. Health Physics 72, 277-281.

von Philipsborn, H., Just, G., 2005. Fast retrospective determination of radon exposure with a sensitive alpha scintillation probe. J. Radiol. Prot. 25, 299-303