High sensitivity detectors for measurement of diffusion, emanation and low activity of radon

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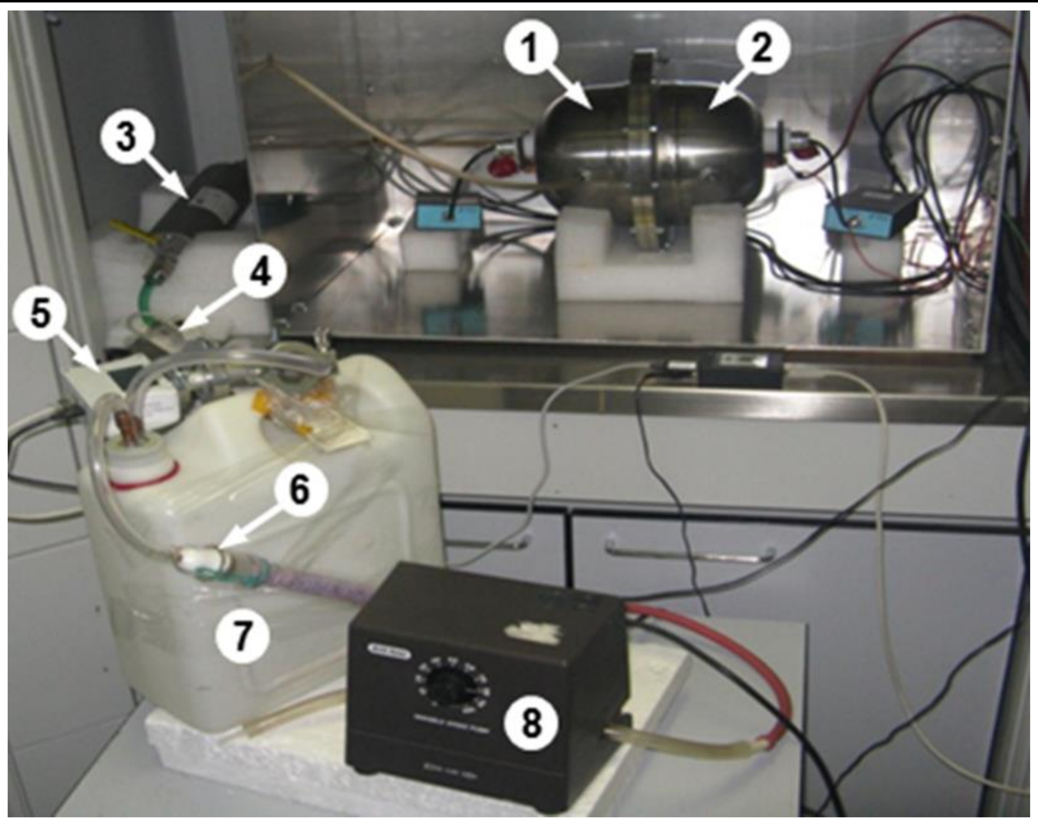
Abstract

Today's underground experiments need ultra-low background conditions. One of the most important source of background is radon. It is necessary to suppress it and also to be able to detect very low radon concentration. In the frame of SuperNEMO collaboration experimental setups for measurement of low radon activity, radon diffusion through shielding foils and radon emanation from construction materials have been constructed in IEAPP CTU in Prague. The application of Timepix device (http://medipix.web.cern.ch/medipix/index.php) in radon detection is briefly discussed.

Radon diffusion apparatus.



Radon apparatus is made of two the stainless steel hemispheres of 2,8 l volume each. In both hemispheres there is Si PIN diode detecting due to electrostatic collection radon progenies (HV=2.5kV). Both hemispheres are divided by testing foil (maximum thickness ~2mm). Left hemisphere contains high radon activity from Ra source, while radon detected in right hemisphere penetrates through shielding foil. Many different foils and glues have been tested and the obtained results are summarized in table below.

Radon diffusion apparatus:
1/2 - Left/right vessel
3 - Radon source
4 - Flow-meter
5 - Sensors of temperature, humidity, and pressure
6 - Air dryer
7 - Air buffer
8 - Air pump, 0.34 l/min

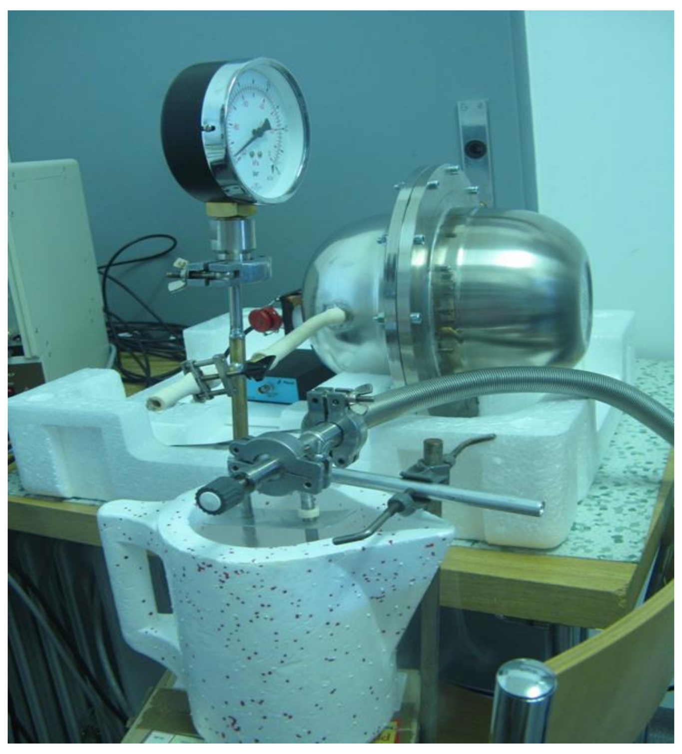
- The device uses the electrostatic collection of charged particles for the detection of Rn decay products
- Left side hemisphere with high Rn activity *[activity Rn 38 kBq/m³ , dry air flow through Rn source 0.34 l/min]*,
- Right side hemisphere with low Rn activity *[background 7±3 events per day]*,
- Lowest Limit of Detection of the device reaches the sensitivity of the radon diffusion *D* at the level ~10^{-18} m^2s^{-1}

Experimental results of radon penetration through materials

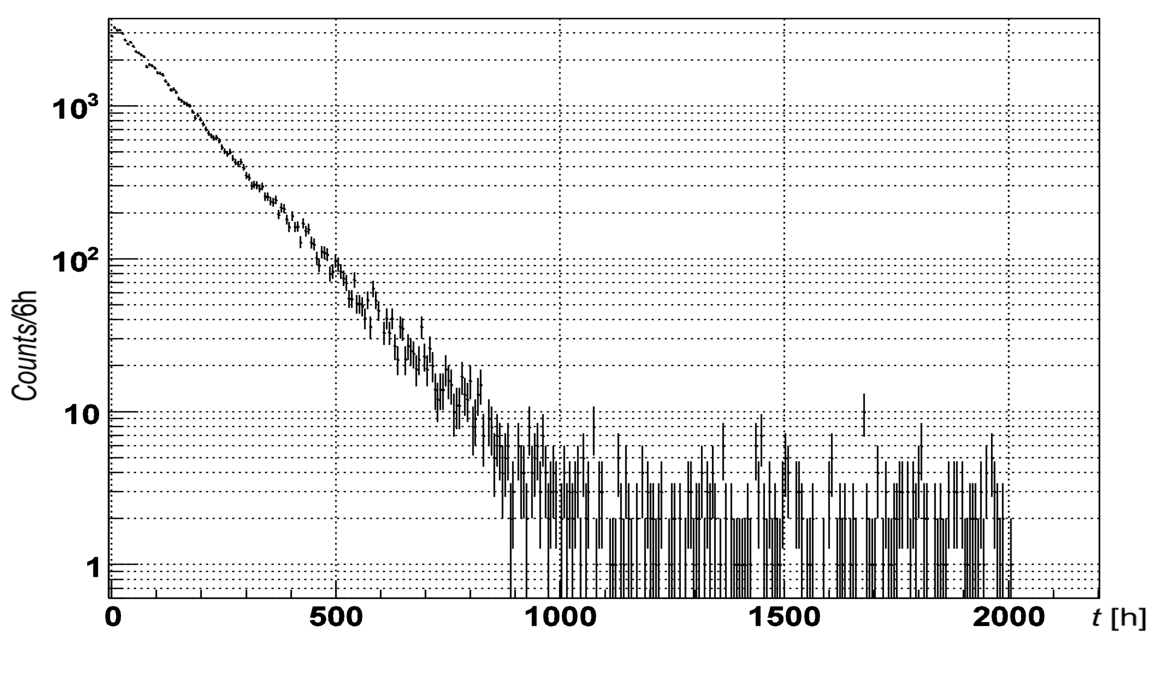
Material	Thickness d [μm]	C_1/C_2	C_1/C_2 normalized to 15 μm	Diff. coefficient D [10^{-12} m^2s^{-1}]	Diff. length L [μm]
HDPE (2 layers)	2×144	3.5	1.1	19	3000
EVOH*	15	4.7	4.7	0.68	570
TROPAC III	102	> 8300	> 600	< 0.0043	< 46
Mylar (2 layers)	2×20	> 9100	> 2300	< 0.0012	< 24
EVOH (2 layers)	2×15	> 31000	> 8900	< 0.00035	< 13
EVOH + PE	125	165	20	0.013	254
Silicon	2 800	2.5	1.008	320	12 000
RTV 615	2 100	1.33	1.002	1084	22 747
RTV 116 (in the metal)	3.5	25	1.1	7201	58599
RTV ECOO	2 000	1.5	1.002	1 030	22 200
STYCAST 1264	2 000	> 7268	> 6.9	< 0.43	< 455
PET	1 000	> 41 136	> 35	< 0.076	< 190
PLEXY	1 000	1 617	9.8	0.29	371
Butyl	1 000	2.5	1.02	1180	7 496
Emultex 518 (6 μm)+ PE (11 μm)	17	> 9 985	> 8 261	< 0.00038	<13
WB 50T	50	12.5	4.4	0.74	593
RTV 615 with 60% resin Stycast	1 000	1.3	1.005	521	15 765
Mylar junction	20	110	85	0.030	120
TROPAC junction	102	> 6300	> 500	< 0.0051	< 50
PVC 2mm	2	9	1.1	44	4 600
Derlin sheets	1	47 860	36	0.072	186
Resin UR6 manufacturer KEMICA	2.1	159 000	15	0.19	297
Neoprene	1	15.6	1.2	12.4	2 430
Bovlon film	0.015	4.0	4.0	0.84	633
SBR+Acrylic on stainless steel sheet	2	6 680	47	16	2 760
Emultex 518 on stainless steel sheet	2	>20 900	>126	<5.9	<1 680
NYLON	50	76 500	6 380	0.00047	15
Synthomer 47B40+PE	700+120	739	8.3	0.27	406

Radon emanation apparatus

- setup is based on diffusion apparatus, volume 6 litres
- HV=2.5kV
- long term measurement of background (to estimate minimal level of radon emanation which can be achieved) was finished
- Background = 7.0 ± 0.6 counts/day

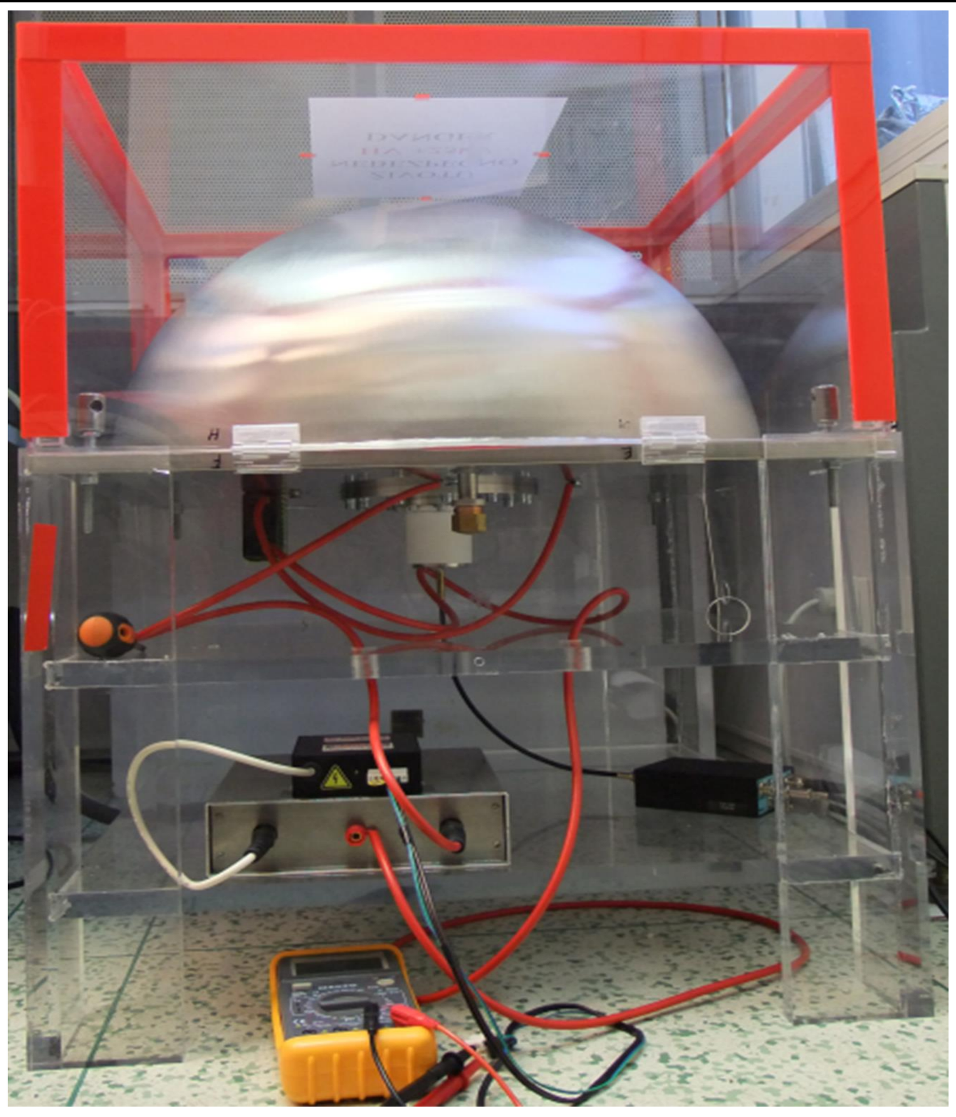


Measurement of background in emanation apparatus



High sensitivity detector for measurement of low activity of radon

The Rn volume activity of 1 mBq/m³ corresponds to 86 radon decays per day in 1 m³ of air. To reach activities at the level of 1 mBq/m³ and below, there are two crucial challenges:
-high sensitivity of collection;
-low background in the measurement.
The different shapes of the detector (e.g. cylindrical, hemispheric), different positions of the Si PIN diode, adjustable HV as well as different materials (wire net, stainless steel) have been provided by benchmark tests to reach highest efficiency of measurement (~ 30%). Two prototypes were already produced (50 l prototype, 400 l prototype). Measurement of radon detection efficiency for 50 l prototype was finished Up to now, we reached 30% efficiency for 12 kV of used high voltage. The detection limit of the apparatus is influenced by the level of background. The background measurement with the first detector prototype was performed. The final result of the background is 11±1 events/day in the region of our interest (6.2–7.8MeV peak of ^{214}Po).
Measurement of sensitivity and background for 400 l prototype is running.



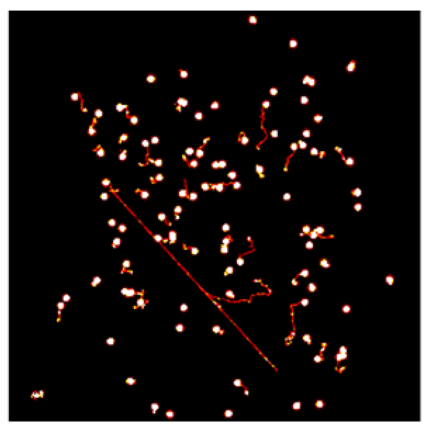
The setup used for the measurement of the detection efficiency of the first prototype is show here. The air from the laboratory goes through the air-dryer. The dry air (with the relative humidity at the level of 3%) is pumped (with the speed of 0.5 l/min) through the hemispheric detector. The air coming from the detector chamber is then measured in the detector of humidity, temperature and pressure. At the end of the detection chain, the radon concentration in the air measured by the AlphaGUARD (commercial device for activities over 2 Bq/m³).

High voltage [kV]	Rn activity* [Bq/m³]	Number of ^{214}Po events [h^{-1}]	Temperature [°C]	Relative humidity [%]	Air flow [l/min]	Rn detection efficiency [%]
6.0	45	1 045	22	25.0	-----	13.1
6.0	33	1 424	27	3.2	0.5	24.0
7.5	16	742	28	3.2	0.5	25.8
7.5	25	1 160	20	3.2	0.5	25.8
9.0	24	1 144	20	3.0	0.5	26.5
12.0	28	1 494	19	3.0	0.5	30.0

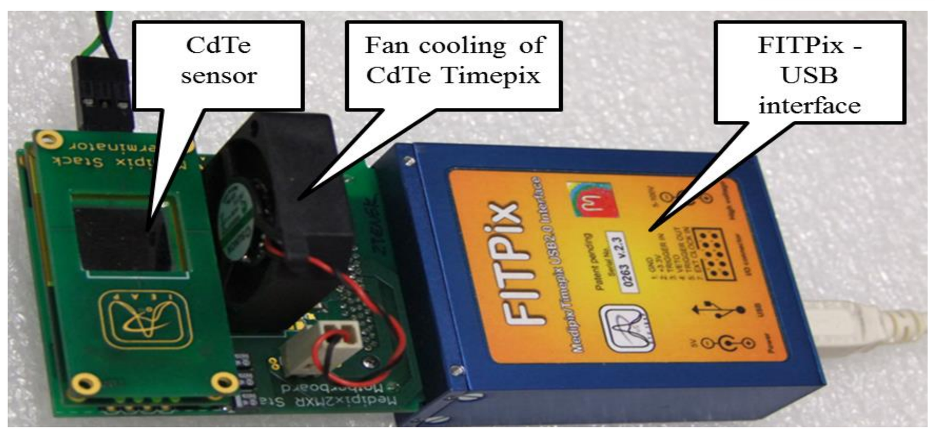
Efficiencies of radon detection measured under different experimental conditions with the first prototype.
**Radon activity was measured by AlphaGUARD used as the reference equipment.*

Measurement of radon activity in air using electrostatic collection to Timepix detector

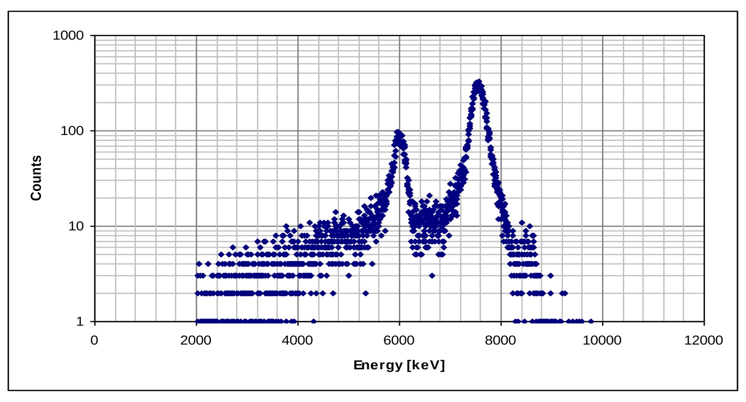
To detect Rn progenies the CdTe Timepix detector was used. The thickness of the CdTe detector was 1000 μm with the pixel pitch of 55 x 55 μm². The first test was dedicated for the measurement of signals provided by the CdTe Timepix detector without the presence of the electrostatic field (collecting only progenies very close to the detector surface or detecting alpha particles from ions sitting on the sensor surface). The purpose of this measurement was to show the feasibility of pixel detector for detection of alphas emitted by Rn progenies.



This picture an example of events corresponding to the energy region above approximately 8 MeV. It is a mixture of events generated by the cosmic rays (muon), thoron progenies (alpha at 8.9 MeV), and successive decay of ^{214}Bi and ^{214}Po (beta decay followed by an alpha decay forming large blob with a tail). This demonstrates the capability of pixel detector to provide a data for deeper analysis and understanding of spectrum measured by the electrostatic collection.



CdTe pixel detector



Energy spectrum detected by the CdTe pixel detector

Conclusion

An apparatus for the measurement of radon diffusion through shielding foils has been constructed. The apparatus is used for routine evaluation of radon shielding capabilities of thin shielding foils or various glues or sealants. The aim is to select an appropriate shielding wrapping to fulfil the needs of the experiment SuperNEMO from the point of view of radon penetration into the tracking detector or into the whole SuperNEMO module.

Two prototypes of high sensitive radon detectors are ready and under final testing. Assuming the background 11 events per day, the first prototype of the detector (50 l) can reach the sensitivity of the radon activity of 11 mBq/m³ for one day measurement. The background measurement with the second prototype (400 l) is still running and will be finished in two months. Tests with higher HV (from 12 to 20 kV) will be performed to increase the sensitivity of the radon detectors. Long-term tests at Modane underground laboratory at the antiradon facility are planned in the near future.

The activities with application of Timepix detector (http://medipix.web.cern.ch/medipix/index.php) in radon detection will also continue. Using unique feature of pixel detector to distinguished different types of particles there is a chance to decrease background signal further.