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INTERNATIONAL INTERCOMPARISON EXERCISE OF ACTIVE RADON DEVICES AND PASSIVE DETECTORS AT THE FIRST EAST EUROPEAN RADON SYMPOSIUM (FERAS 2012)

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Abstract. During the First East European Radon Symposium (2012), an Intercomparison Exercise of active devices and passive detectors was organized, at two exposure levels. Medium Radon Exposure was made in the laboratory room at low to medium level by an average radon concentration of hundreds of $Bq \cdot m^{-3}$ and involved 12 active devices and 8 groups of passive detectors. High Radon Exposure was performed in a calibration chamber at high level by an average radon concentration of thousands of $Bq \cdot m^{-3}$ and involved 5 active devices and 7 groups of passive detectors. Results of active devices show that mean concentrations of 11 devices from the Medium Exposure and 1 device from High Exposure were inside ± 95% C.I of the means. Results of passive detectors show that the exposure values of 4 groups from the Medium Exposure and 6 groups from the High Exposure were inside ± 20 % admittance level of the reference exposure.

Key words: international inter-comparison, active radon device, passive radon detector, continuous radon monitor, solid state nuclear track detector.

1. INTRODUCTION

Radon is a natural radioactive gas produced in different amounts in rocks and soils, and can reach high concentrations in closed spaces (*i.e.* caves and mines), and also in buildings. Radon and mainly its short-lived decay products are the largest contributors to public radiation dose, thus that the exposure to high radon concentrations leads to an increased risk of lung cancer [1–4]. Widely used methods to measure indoor radon levels in homes are integral methods by passive detectors (*i.e.* track detectors, SSNTD), which determine an annual average indoor radon concentration [5–9]. Measurements of temporal variation of radon concentrations are used by continuous monitoring methods by active devices, used in indoor radon diagnostic and testing radon mitigation techniques [10–16].

Measuring and testing indoor radon levels and residential radiation dose due to natural sources are of high importance to the total effective dose and it is

necessary to ensure that the values provided from measurements and tests are accurate. Testing and calibration of measuring devices for radon and decay products require stable conditions. One of the most common ways to assure the quality of the tests are intercomparisons carried out by approved services or reference laboratories. Intercomparisons are an important tool for measurement services and laboratories in order to detect potential problems and perform rectifications as well as to provide calibrations for the instruments [17–22].

During the First East European Radon Symposium (FERAS 2012) organized in September 2012, in Cluj-Napoca, Romania, an *Intercomparison Exercise of active radon devices and passive detectors* was organized. A total of 13 institutions took part from Bulgaria, Poland, Romania, Serbia, Spain and Sweden, which were universities, research and health institutes (Table 1). Six laboratories submitted active devices, and other nine laboratories used different types of passive radon detectors. The aim of the intercomparison exercise was to test active devices and passive radon detectors at two levels of exposure, **Medium and High**.

Table 1

List of the participated Institute

No	Institution	Country
1	National Center of Radiobiology and Radiation Protection, Sofia	Bulgaria
2	University of Sofia	
3	Central Mining Institute, Katowice	Poland
4	Babes-Bolyai University, Cluj-Napoca	Romania
5	Institute of Public Health, Radiation Hygiene Department, Timisoara	
6	National Institute of Physics and Nuclear Engineering Horia Hulubei, Bucuresti	
7	Sapientia University, Cluj-Napoca	
8	Institute of Physics, Belgrade	Serbia
9	Novi Sad University, Novi Sad	
10	Vinca Institute of Nuclear Sciences, Belgrade	
11	Institute of Physics, Belgrade	
12	University of Cantabria, Santander	Spain
13	Landauer Nordic, Uppsala	Sweden

2. MATERIALS AND METHODS

During the Intercomparison Exercise, two exposures were performed at Medium and High levels of radon gas. Medium Radon Exposure had radon concentration values of hundreds of $Bq \cdot m^{-3}$, involving active and passive detectors as well as active charcoals (Fig. 1). The exposure was performed in the laboratory room, at low to medium radon level, and started on 3th September at 9:00 (AM) and ended on 5th September at 8:00 (PM), thus the total exposure period was 59 hours. For passive detectors, the exposure period was extended until 14th September at 3:00 (PM), thus the extended exposure period was 212 hours. High Radon Exposure had radon concentration values of thousands of $Bq \cdot m^{-3}$, involving passive and active detectors (Fig. 2). The minimum number of the required passive

detectors was five, besides two for background. The exposure was performed in a calibration chamber of 200 L volume, and as Rn source, soil gas pumping was used, from a depth of 80 cm. The exposure started on 3th September at 9:30 (AM) and ended on 5th September at 4:00 (PM), lasting for 54.5 hours.

Five types of active devices were intercompared in the present study: RADIM 3A (semiconductor detector, Jiry Plch, Czech Republic), ALPHAGUARD (pulse ionization chamber, Saphymo Gmbh, Germany), RADON SCOUT (semiconductor detector, SARAD Gmbh, Germany), RAD7 (semiconductor detector, Durridge Co, USA) and SUN NUCLEAR (photodyode detector, Sun Nuclear Co, USA). In other ways, five types of passive radon detectors were intercompared: E-PERM (electret detector, Radelec Inc, USA), CR-39 (RADOSYS, Hungary), RADTRACK (Landauer, Norway), activated charcoal and DVD disks. The results obtained by the active devices (*i.e*. the mean concentrations for the given period) were compared with the average mean concentrations of all the devices, and the results obtained by passive detectors (*i.e*. the mean exposures) were compared by the mean exposure obtained by reference radon monitors RADIM 3A (Jiry Plch, Czech Republic) for both, the medium and high radon exposures. These reference radon monitors obtained good results in case of the intercomparison of active radon devices, comparing the obtained results by these with the other participated active devices results (see bellow).

Figs. 1 and 2 – Active radon monitors and passive detectors in the Medium Radon Exposure (left) in the High Radon Exposure (right), by the reference radon monitors RADIM 3A.

3. RESULTS AND DISCUSSIONS

Measurement results are presented in four groups of active devices and passive detectors *versus* Medium and High Radon Exposures. Through evaluations, each active devices and passive detectors had an institutional participant code, from FERAS 1 to FERAS 13. Exposure conditions (*i.e*. climatic parameters in the laboratory room and in the calibration chamber) were measured during the exposures by two reference monitors (RADIM 3A), and were presented in Table 2.

Table 2

Exposure conditions in Medium and High Radon Exposure

Parameter	Medium Radon Exposure (by Ref. 1)			High Radon Exposure (by Ref. 2)		
	Mean ±SD	Min	Max	Mean ±SD	Min	Max
p [hPa]	979.2 ± 1.5	975.5	983.1	979.0 ± 1.3	976.7	982.9
T [°C]	22.1 ± 0.2	21.5	22.6	22.4 ± 0.2	21.7	23.0
RH [%]	55.5 ± 0.6	54.3	57.0	65.3 ± 3.9	54.8	72.4

Group A and Group B contains active devices in MEDIUM and HIGH Radon Exposures, where measurement results of all the devices are shown in Fig. 3 and Fig. 4, and the mean values of the radon concentrations of each data series (C_m) are presented in Table 3. Group C and Group D contains passive detectors in MEDIUM and HIGH Radon Exposures, where the mean values of the measured exposures (E_m) of different groups are presented in Table 4, comparing by the reference exposures (E_{ref}) measured by the reference monitors (RADIM 3A).

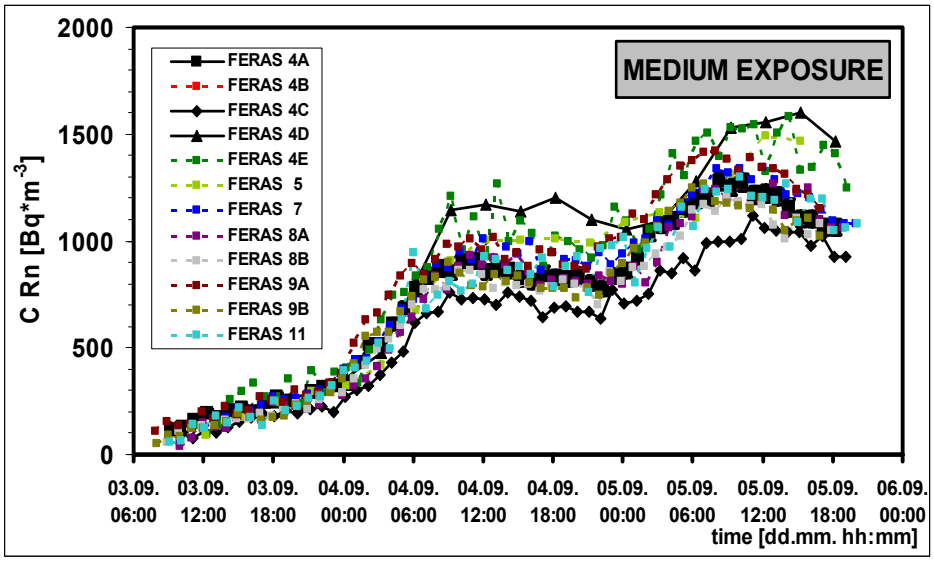

Fig. 3 – Results of the continuous radon concentration measurements by active devices during the Medium Radon Exposure.

In case of the continuous active device measurements, the obtained results from the data series were the mean radon concentrations ($C_m \pm \mathrm{SE}$ [Bq·m^{-3}]) for each device, where SE is the standard error of the mean (*i.e.* ± 95%C.I. or the 2σ) defined by the: $\mathrm{SE} = 1.96 \cdot \mathrm{SD} / \sqrt{n}$. Here, SD is the standard deviation of the mean,

and n is the number of the data in a series (Table 3). To assessment the results of the active devices, the mean concentrations (C_m[Bq·m^{-3}]) were compared by an average value obtained from all the means (AverC_m[Bq·m^{-3}]), by the following relation: R_{dev} = C_m/AverC_m. Also, the reason of the comparison is that the uncertainty ER = SE/AverC_m of the ratio R_{dev} should intersect by the reference ratio R_{dev} = 1 (Fig. 5 and Fig. 6).

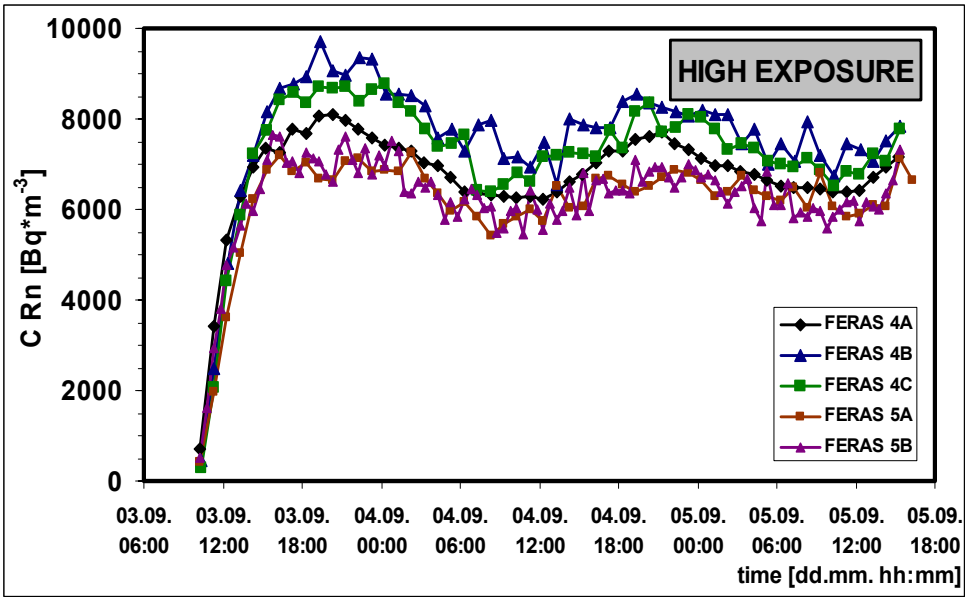

Fig. 4 – Results of the continuous radon concentration measurements by active devices during the High Radon Exposure.

In case of the passive detectors, the obtained results were the determined mean exposures ($E_m \pm$ SD [kBq·h·m^{-3}]) for each detector groups, where SD is the standard deviation from the mean exposure (Table 4). To assess the results, the mean exposures (E_m) were compared by the reference exposures (E_{ref} [kBq·h·m^{-3}]) measured by the reference radon monitors (RADIM 3A) for the given periods, by the following relation: $R_{det} = E_m/E_{ref}$. The reference exposures were determined from the reference mean radon concentrations ($C_{m,ref}$[Bq·m^{-3}]), by the relation: $E_{ref} = C_{m,ref}*t$, where t[hours] is the exposures duration. Also, the reason of the comparison of the passive detectors, is that the ratio R_{det} of each detector groups should be inside of an admittance level of ± 20 % of the reference ratio R_{det} = 1 [16, 17] (Fig. 7 and Fig. 8).

Table 3

List of the active devices from the Medium and High Radon Exposures and the mean values of the measured radon concentrations

Code	Device	$C_m \pm$ SE [Bq·m^{-3}]
MEDIUM Radon Exposure		
FERAS 4A	**RADIM 3A (075) – Ref.1**	**741.3 ± 94.5**
FERAS 4B	ALPHA GUARD (2011)	770.0 ± 94.0
FERAS 4C	RAD7 (2716)	617.8 ± 82.0
FERAS 4D	RSC445	985.3 ± 211.6
FERAS 4E	RSC453	916.9 ± 116.2
FERAS 5	RSC196	817.3 ± 203.5
FERAS 7	ALPHA GUARD (1493)	798.8 ± 99.6
FERAS 8A	RAD7 (2039)	723.6 ± 98.7
FERAS 8B	RAD7 (2170)	683.7 ± 91.7
FERAS 9A	RAD7 (1021)	812.7 ± 109.6
FERAS 9B	RAD7 (2732)	695.1 ± 97.4
FERAS 11	SUN NUCLEAR (1029)	743.8 ± 97.3
Average [Bq·m^{-3}]		**775.5 ± 36.3**
HIGH Radon Exposure		
FERAS 4A	**RADIM 3A (087) – Ref.2**	**6765.8 ± 297.2**
FERAS 4B	RSC446	7620.6 ± 393.7
FERAS 4C	RSC454	7235.7 ± 385.7
FERAS 5A	RSC150	6181.7 ± 303.4
FERAS 5B	RSC269 PRO	6269.6 ± 287.5
Average [Bq·m^{-3}]		**6803.5 ± 152.7**

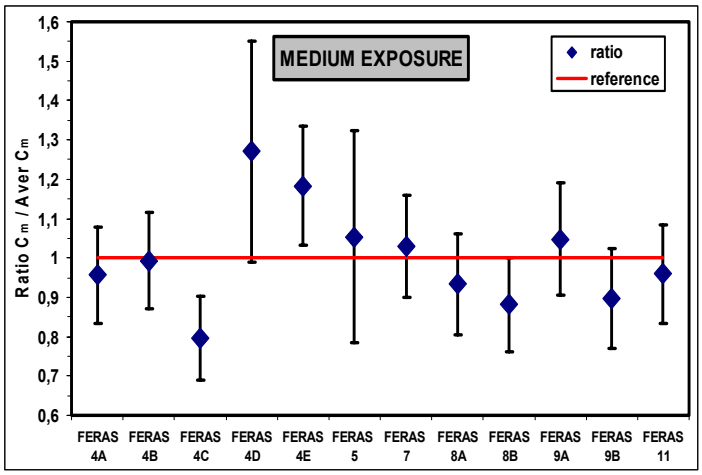

Fig. 5 – Distribution of the relative ratios ($R_{dev} \pm$ ER) of the active devices comparison measurement from the Medium Radon Exposure (dots are the relative ratio values by the corresponding 95% C.I. error bars, and the continuous line is the value of the relative reference, $R_{dev} = 1$).

Table 4

List of the passive detectors from the Medium and High Radon Exposures,
and the determined exposure values by the reference exposures

Code	Detector (pieces)	$E_m \pm$ SD [kBq·h·m^{-3}]	$E_{ref} \pm$ SE [kBq·h·m^{-3}]
MEDIUM Radon Exposure			
FERAS 1A	E-PERM (5 pcs)	32.6 ± 0.8	31.0 ± 4.6
FERAS 9	activated charcoal (2 pcs)	45.8 ± 1.6	43.0 ± 5.5
FERAS 10	activated charcoal (2 pcs)	61.4 ± 0.4	
FERAS 1B	CR-39 (5 pcs)	389.0 ± 18.0	307.0 ± 11.4
FERAS 4	CR-39 (5 pcs)	372.6 ± 36.5	
FERAS 3A	CR-39 (5 pcs)	435.2 ± 22.5	
FERAS 3B	CR-39 old type (5 pcs)	352.0 ± 16.5	
FERAS 6	CR-39 (5 pcs)	280.3 ± 19.6	
HIGH Radon Exposure			
FERAS 1	CR-39 (5 pcs)	378.6 ± 18.2	368.7 ± 16.2
FERAS 2	DVD disks (5 pcs)	332.4 ± 87.2	
FERAS 3A	CR-39 (5 pcs)	440.1 ± 41.2	
FERAS 3B	CR-39 old type (5 pcs)	367.6 ± 8.3	
FERAS 4	CR-39 (8 pcs)	960.6 ± 125.3	997.6 ± 34.1
FERAS 12	CR-39 (4 pcs)	639.9 ± 78.5	
FERAS 13	RADTRAK 2 (4 pcs)	851.3 ± 24.9	

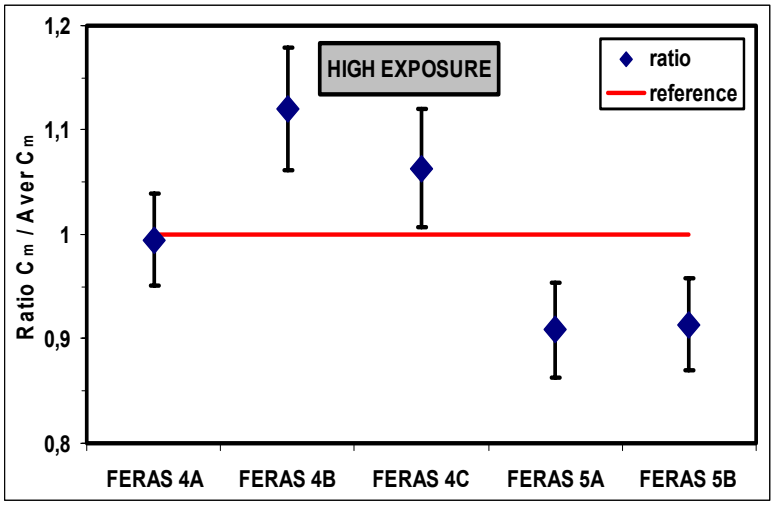

Fig. 6 – Distribution of the relative ratios ($R_{dev} \pm$ ER) of the active devices comparison measurement from the High Radon Exposure (dots are the relative ratio values by the corresponding 95% C.I. error bars, and the continuous line is the value of the relative reference, $R_{dev} = 1$).

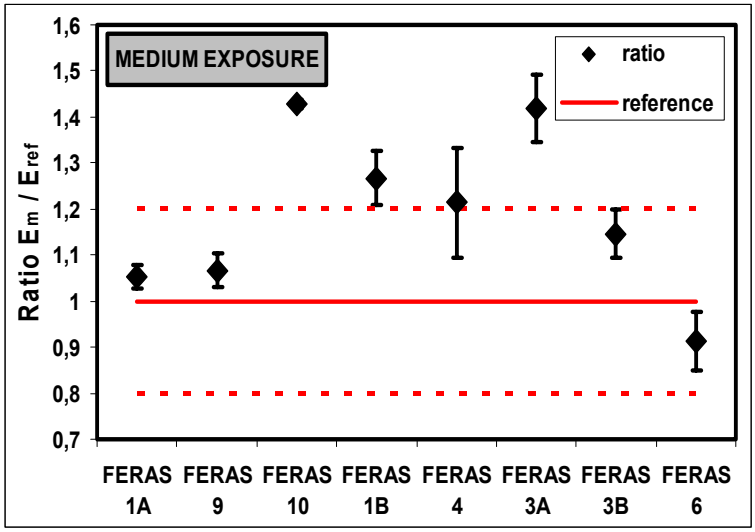

Fig. 7 – Distribution of the relative ratios (R_{det}) of the passive detectors comparison measurements *versus* a reference monitor from the Medium Radon Exposure (dots are the relative ratio values by the corresponding SD error bars, and the continuous and dashed lines are the value of the relative reference, R_{det} = 1 by the corresponding 20 % admittance level).

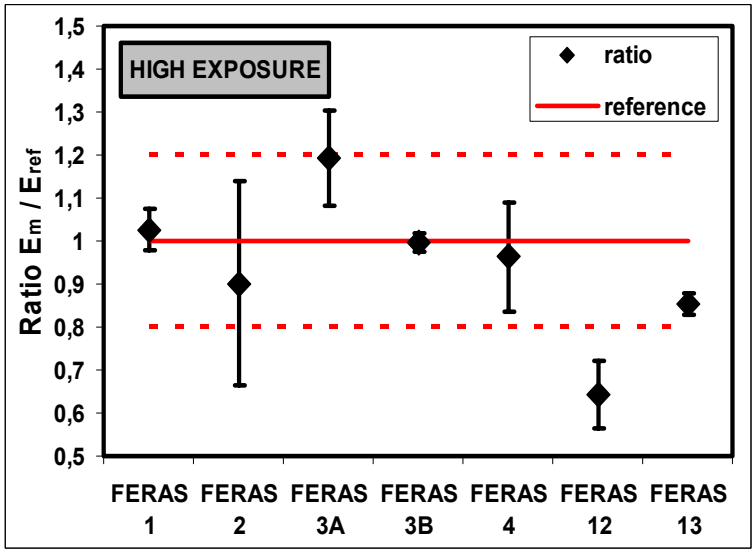

Fig. 8 – Distribution of the relative ratios (R_{det}) of the passive detectors comparison measurement *versus* a reference monitor from the High Radon Exposure (dots are the relative ratio values by the corresponding SD error bars, and the continuous and dashed lines are the value of the relative reference, R_{det} = 1 by the corresponding 20 % admittance level).

Following the intercomparison measurements of the active devices, the range of the ratios (R_{dev}) is from 0.80 to 1.27 in case of the 12 devices from the Medium Exposure, from which two devices had uncertainty of the ratio (ER) higher than the others (± 27 % for FERAS 4D and ± 28 % for FERAS 5). This was caused by the shorter data series (*i.e.* higher integration time). In case of the FERAS 4C, the ratio of 0.80 ± 0.11 do not intersect the reference ratio $R_{dev} = 1$. In High Exposure, the range of the ratios (R_{dev}) is from 0.91 to 1.12 in case of the 5 devices, from which the ratio of four devices do not intersect the reference ratio $R_{dev} = 1$ (1.12 ± 0.06 for FERAS 4B; 1.06 ± 0.06 for FERAS 4C; 0.91 ± 0.05 for FERAS 5A; and 0.91 ± 0.04 for FERAS 5B). As for the passive detectors intercomparison, the range of the ratio (R_{det}) is from 0.91 to 1.43 in case of the 8 groups from the Medium Exposure, from which the ratio of four detector groups had outside from the ± 20 % admittance level of the reference ratio $R_{det} = 1$ (1.43 ± 0.01 for FERAS 10; 1.27 ± 0.06 for FERAS 1B; 1.21 ± 0.12 for FERAS 4 and 1.42 ± 0.07 for FERAS 3A). In High Exposure, the range of the ratio is from 0.64 to 1.19 in case of the 7 groups, from which only one group had the ratio outside from the ± 20 % admittance level of the reference ratio $R_{det} = 1$ (0.64 ± 0.08 for FERAS 12).

4. CONCLUSIONS

During the Intercomparison Exercise of the active radon devices and passive detectors (organized in the frame of the First European Radon Symposium, FERAS 2012) were performed radon exposure measurements at two levels, medium and high. In total 13 institutions participated from Bulgaria, Poland, Romania, Serbia, Spain and Sweden. Results of the active devices measurements show that in case of 11 devices (from 12 total) from Medium Radon Exposure, and of only 1 device (from 5 total) from High Radon Exposure, the mean concentrations relative to the average value of all the means were inside in an uncertainty of ± 2 σ (*i.e.* 95% CI). Results of passive devices show that the exposure values of 4 groups (from 8 total) in Medium Radon Exposure and of 6 groups (from 7 total) in High Radon Exposure were inside the ± 20 % admittance level of the reference exposures, measured by reference radon monitors.

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