Atmospheric radioactivity at meteoLCD: A first intercomparison and analysis of the influence of meteorological parameters

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Abstract

Starting on the 6th May of 2012, an autonomous AGS sensor was operating in tandem with the meteoLCD RS03 sensor in Diekirch, Luxembourg. Both instruments give average results that are practically identical and show similar and same sign correlations with most meteorological parameters. These correlations point to Radon daughters as an additional source of the atmospheric radioactivity. A simple linear model including temperature, pressure and wind velocity gives good results, with modeled dose-rates not more than 10% different from the measured ones.

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1. The equipment and measurements

This study analysis the measurements done by two different gamma-ray sensors installed on the terrace of the meteorological station of the Lycée classique Diekirch (meteoLCD). The coordinates of Diekirch, Luxembourg are: latitude = 49°52' North, longitude = 6°10'**.** The terrace is about 20m above ground-level, at an altitude of 218m asl.

The meteoLCD radioactivity sensor is a RS03 proportional Geiger counter from the Austrian BITT company. This sensor is operating since January 2004; the RS03 model is not manufactured anymore and has been replaced by a similar RS04 model.

The RS03 sends an RS232 data stream which is intercepted by a special nano-computer developed and built by coauthor Claude Baumann. This device extracts the numerical data and transforms it into an analogue voltage which is read by the datalogger. The RS03 sensor operates in the range 10nSv/h to 10 Sv/h and gamma energy levels 60 keV to 3 MeV. This energy range covers the gamma emission levels of the daughters of Radon-222 (Uranium-238 series: 295 (Pb-214) to 3053 keV (Bi-214) **[1]**), the principal contributor to atmospheric radio-activity, as Rn-220 and Rn-219 only have a negligible influence. According to the RS03 manual measurement incertitude is +/- 10%, and temperature dependency +/-3% (this somewhat fuzzy information probably means that incertitude is +/- 10% of the reading, and temperature dependency at most +3% of the reading for usual temperature ranges)

On the 5th of May 2012 the Radiation Protection Division of the Luxembourg Ministry of Health installed an autonomous high-quality AGS sensor manufac-tured by Envinet next to the existing RS03 sensor on the terrace of meteoLCD (cf. Fig.1). The AGS sensor uses three Geiger counters for dose-rate measure-ments, two of them for low dose-rates (< 100 µSv/h). The low-dose counters cover the ranges 10 nSv/h to 10 Sv/h and 38 keV to 1.3 MeV; the same comment on gamma radiation from radon daughters made above clearly also applies to this instrument. Measurement accuracy is given as 15%; the temperature depen-dency is unknown.

Every two hours the AGS stores a dose-rate which is the average of measurements made every minute. The RS03 is scanned by the datalogger every minute, and every half-hour the average is retained by the logger. In this study four consecutive RS03 dose-rates were averaged so that the two time series (AGS and RS03) had the same number of synchronous data. The first data of the day is taken at 01:00 UTC, the last at 23:00 UTC.

Fig.1 Picture of the location of the 2 gamma counters on the terrace of meteoLCD

2. Dose-rate levels from 6 to 31 May 2012

In this report we use two dose-rate measurements starting on the 6th of May 2012 at 01:00 UTC and ending on the 31th of May 2012 at 23:00 UTC. Both series hold 312 readings, there are no missing or bad data.

The averages and standard-deviations of both instruments are extremely close:

Instrument	Average dose–rate [nS/h]	Standard deviation
AGS	82.1	2.4
RS03 (meteoLCD)	83.5	2.3

Both series also show a similar variation pattern over the measurement period (see Fig.2). If the12 daily measurements are averaged, the similarity becomes even more obvious (see Fig.3)

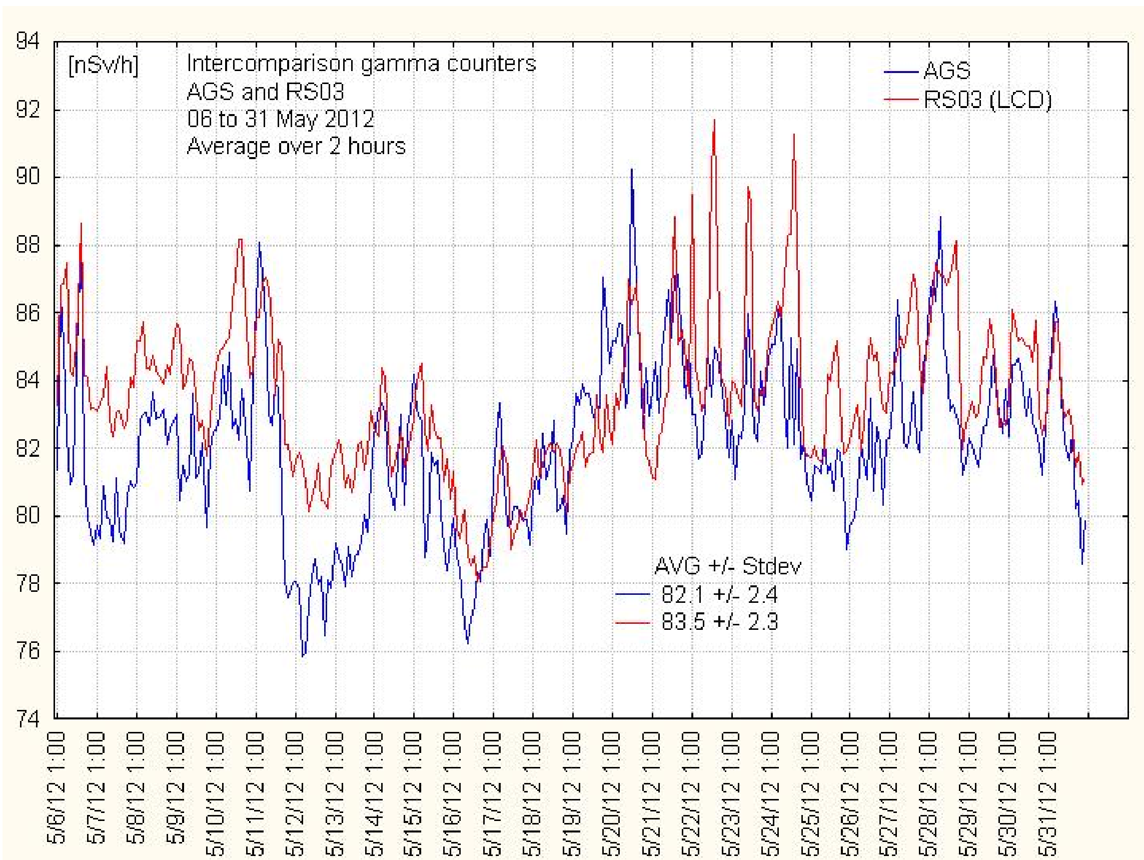

Fig.2 Time series of both dose-rate measurement series (312 data points)

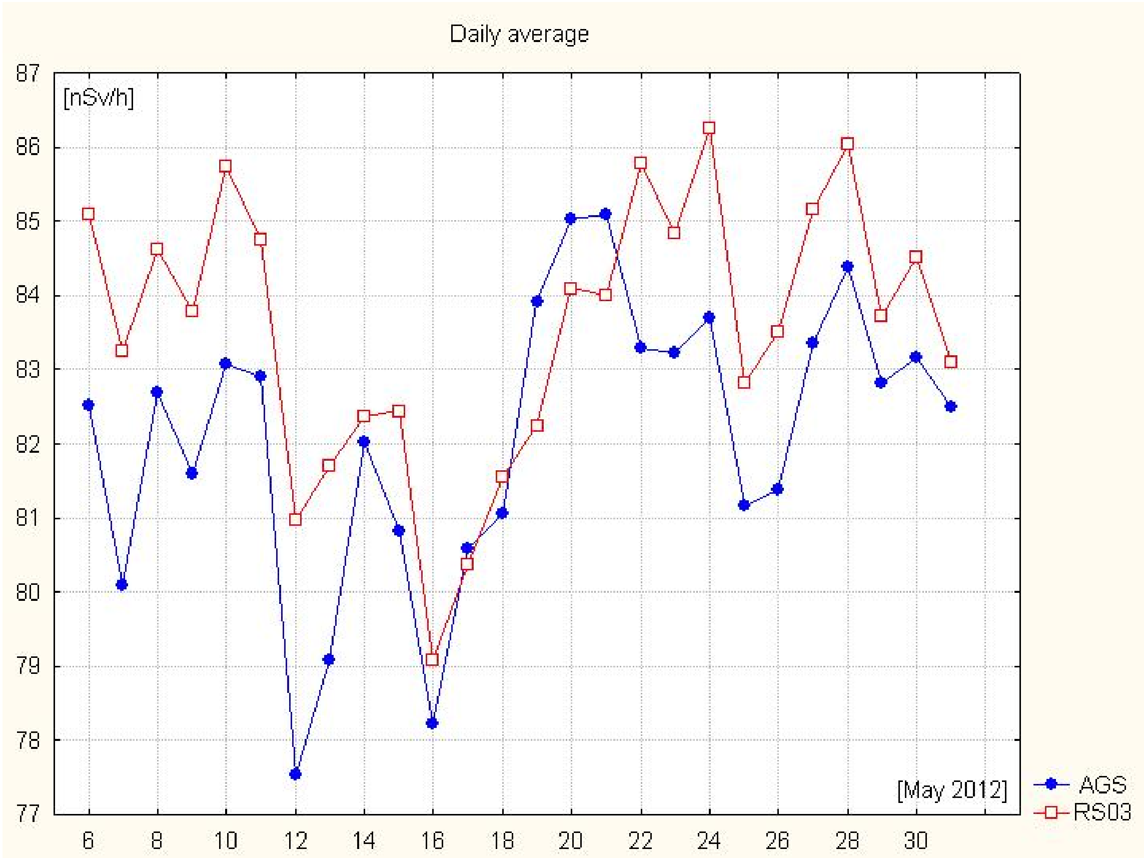

Fig.3 Time series of daily averages.

A first conclusion is that readings from both sensors can be used interchangeably for airborne gamma radiation dose-rate measurements.

3. Influence of temperature, air pressure and wind velocity. Comparison with CO_2 and solar heating of the enclosures.

In this section the influences of the 3 main meteorological parameters air temperature T, absolute air pressure P and wind velocity V on dose-rate readings will be analyzed. The last sub-chapters will compare CO_2 and dose-rate variations with wind velocity and look at the possible influence of enclosure heating.

To check for the influence of one parameter, ideally the other two should be maintained constant. Instead of single constant values which would lead to few remaining valid data points, we choose permissible small intervals for T, P and V that are relatively small.

3.1. Correlation table

The table of the Pearson correlation coefficients for all parameters retained in this report (except GlobeT) is shown below (an explanation of the Pearson correlation coefficient can be found here). Red numbers correspond to correlations that are statistically significant at the 95% level. Clearly not all parameters are physically independent: for instance relative humidity RH depends on air temperature and pressure, CO_2 mixing ratios vary with wind etc.
We may assume Temp, Press, Rain and Wind (velocity) as physically more or less independent (GammaLCD is the RS03 instrument).

Marked correlations are significant at p < .05000
N=312 (Casewise deletion of missing data)

Variable	AGSDiekirch	GammaLCD	Temp	Press	RH	Rain	Wind	CO2
AGSDiekirch	1.00	0.66	0.37	-0.48	0.22	0.02	-0.18	0.40
GammaLCD	0.66	1.00	0.53	-0.25	0.04	0.07	-0.05	0.15
Temp	0.37	0.53	1.00	-0.19	-0.57	-0.01	0.37	-0.38
Press	-0.48	-0.25	-0.19	1.00	-0.17	0.03	-0.00	0.09
RH	0.22	0.04	-0.57	-0.17	1.00	0.05	-0.57	0.63
Rain	0.02	0.07	-0.01	0.03	0.05	1.00	-0.03	0.08
Wind	-0.18	-0.05	0.37	-0.00	-0.57	-0.03	1.00	-0.57
CO2	0.40	0.15	-0.38	0.09	0.63	0.08	-0.57	1.00

The table shows that both instruments have significant correlations of the same sign with Temp, Press, Wind (LCD correlation not significant) and CO_2.
The very low and not significant correlation with rainfall is surprising.

3.2. Influence of air temperature

To study the influence of temperature, a subset of samples corresponding to a quasi-constant atmospheric pressure 991 < P < 993 hPa and a quasi-constant wind velocity 0.5 < V < 1.5 m/s will be used. The following table shows the number of valid data points, the slopes of linear regression lines and the coefficient of determination R^2 (a measure for the portion of variation accounted for by the linear regresison model).

Influence of T	points	Linear slope		R^2	
		AGS	LCD	AGS	LCD
All data	312	+ 0.152	+ 0.206	0.137	0.280
991 <P < 993 V all data	52	+ 0.068	+ 0.147	0.029	0.162
991 <P < 993 0.5 < V < 1.5	20	+ 0.229	+ 0.028	0.158	0.007

Clearly the two constraints in the last line leave too few data points for statistical significance. Nevertheless, it should be noted that all slopes are positive, and that the first and second row suggest a higher temperature dependency of the RS03 sensor than of the AGS.

Fig.4 shows both sensor readings in function of temperature under the conditions of the two first lines of the preceding table; “conditional” points are the full markers and the corresponding fit lines are thick lines.

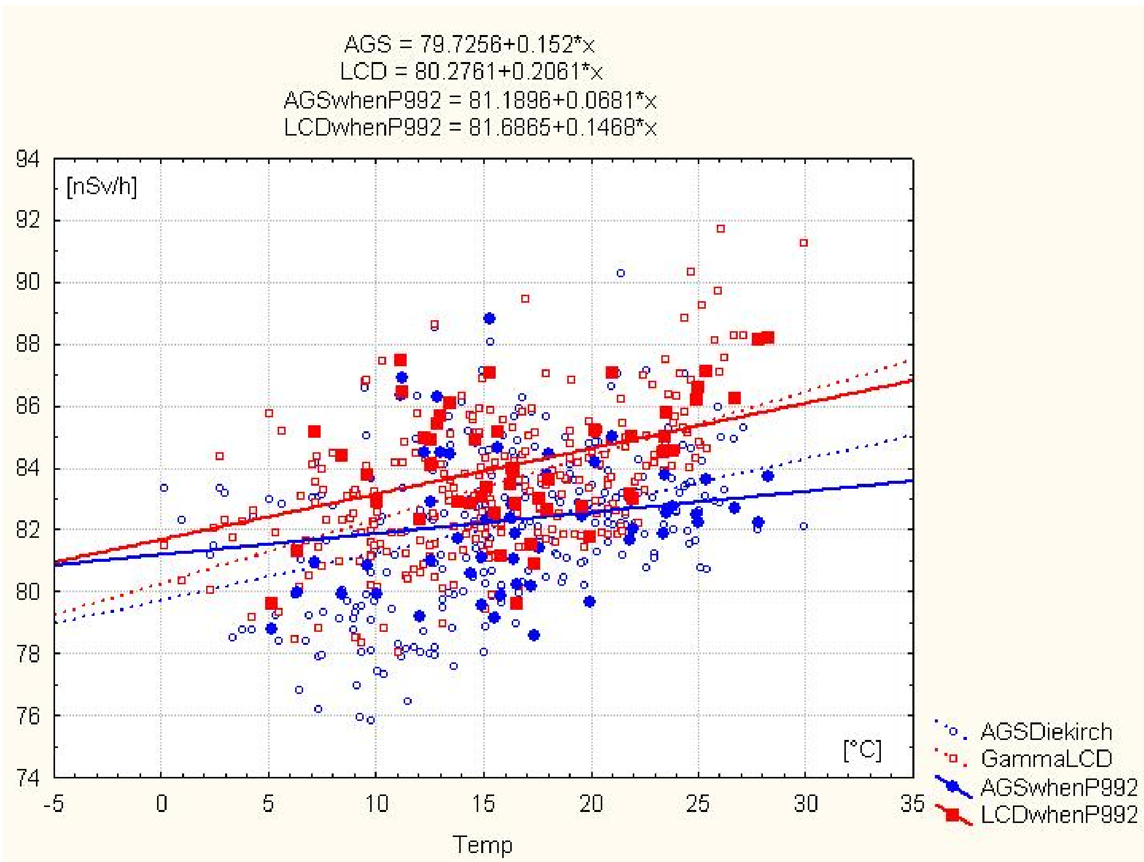

Fig. 4 Dose-rate readings of both sensors are positively correlated to air temperature.

Fig.4 suggests that at least for the RS03 readings, the influence of temperature might not be linear but possible quadratic or exponential. The next table gives the different R^2 parameter for each model (all data and $991 < P < 993$ with no constraint on wind speed V):

R^2 **for different models**	Linear y = a+b*Temp	Quadratic y = a + b*Temp + c*Temp^2	Exponential y = a + b*exp(c*Temp)
LCDwhenP992	0.16	0.23	0.29
AGSwhenP992	0.03	0.05	0.10
LCD	0.28	0.33	0.36
AGS	0.14	0.14	0.00

The exponential model seems best in explaining the variation of dose-rate with temperature for the LCD sensor for both situations (restricted pressure data only or no constraints), a conclusion that is valid for the AGS only in the first case. A future analysis incorporating data with much higher air temperatures than the maximum of 30°C of this report might validate this provisional conclusion.

3.3. Influence of air pressure.

As in the preceding sub-chapter, we will impose restrictions on two parameters. Let us take a nearly constant temperature range as 19 < T < 21°C and keep the same restriction on wind velocity V as above.

Influence of P	points	Linear slope		R^2	
		AGS	LCD	AGS	LCD
All data	312	- 0.166	- 0.081	0.228	0.060
19 < T < 21 V all data	30	- 0.120	- 0.080	0.274	0.173
19 < T < 21 0.5 < V < 1.5	9	- 0.078	- 0.026	0.212	0.047

All situations have the same negative correlation; Fig. 5 shows the dose-readings as a function of air pressure under the conditions of the first two lines:

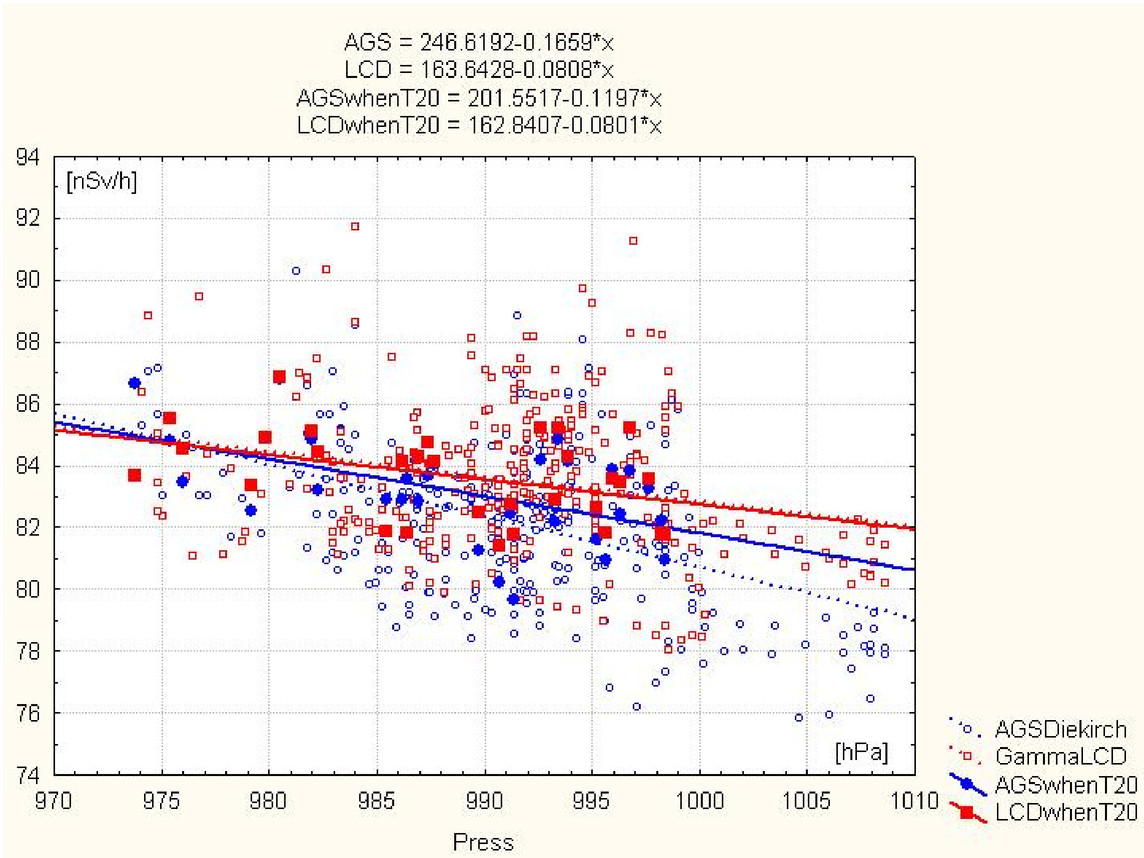

Fig.5 Dose-rate readings of both sensors are negatively correlated to air pressure.

3.4. Influence of wind velocity

The air borne radioactive particles will be more dispersed when wind velocity V is high, whereas their atmospheric concentration increases under conditions of low air movement, especially when the atmospheric layer is trapped in an inversion zone **[2]**

We keep the two restrictions on T and P given above, and analyze the influence of V

Influence of V	points	Linear slope		R^2	
		AGS	LCD	AGS	LCD
All data	312	-0.301	- 0.083	0.034	0.029
19 < T < 21 P all data	30	- 0.535	- 0.368	0.173	0.116
19 < T < 21 991 < P < 993	3				

The dual conditions leave only 3 valid cases, so this situation will be ignored. As expected, the slopes of the regression lines are negative. The second row of the table has highest R^2 and negative slopes of the same magnitude.

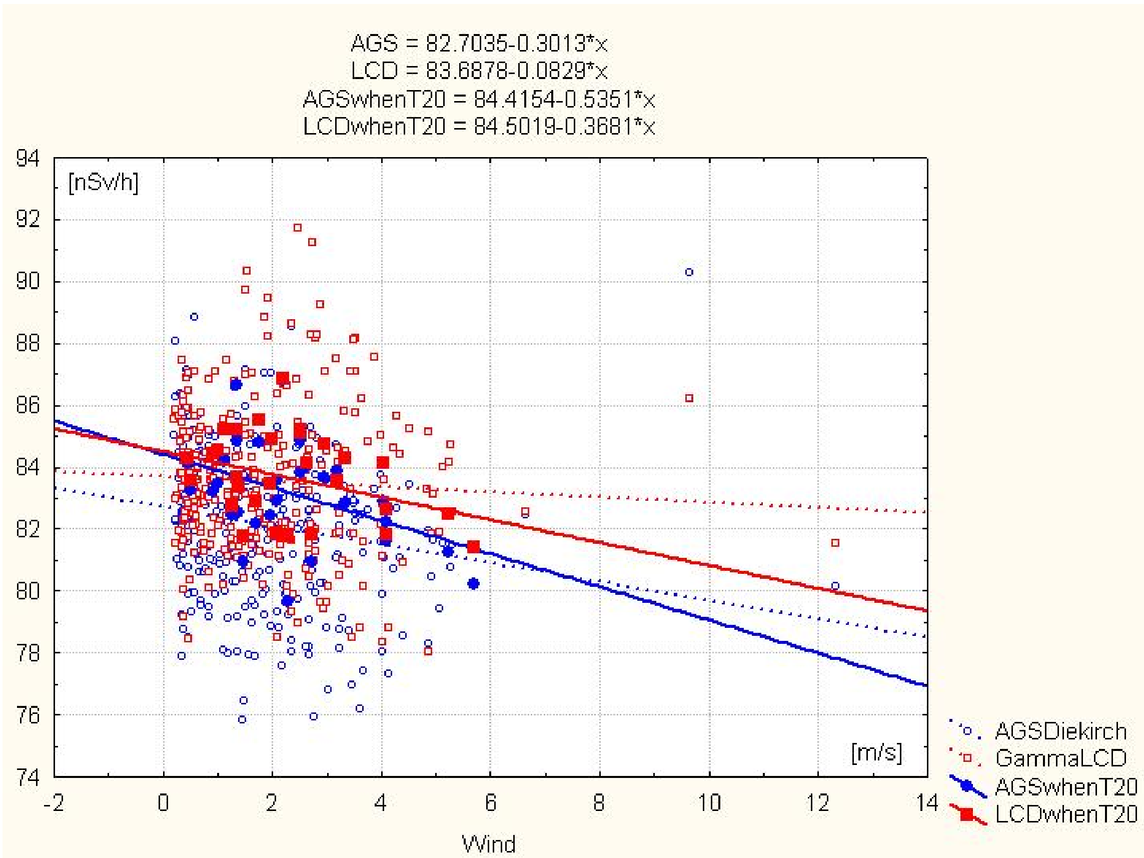

Fig.6 Dose-rate readings of both sensors are negatively correlated to air velocity.

3.5. Comparison with CO_2

CO_2 mixing ratios vary strongly with wind velocity, as shown in **[3]**. High velocities mix up the boundary layer and may lower CO_2 concentrations at Diekirch to levels comparable with the global background. The plot of CO_2 versus velocity has a typical "boomerang" profile. As shown in figure 7, this is not the case for dose rates: for clarity only the RS03 readings and the CO_2 mixing ratio measured at meteoLCD are given:

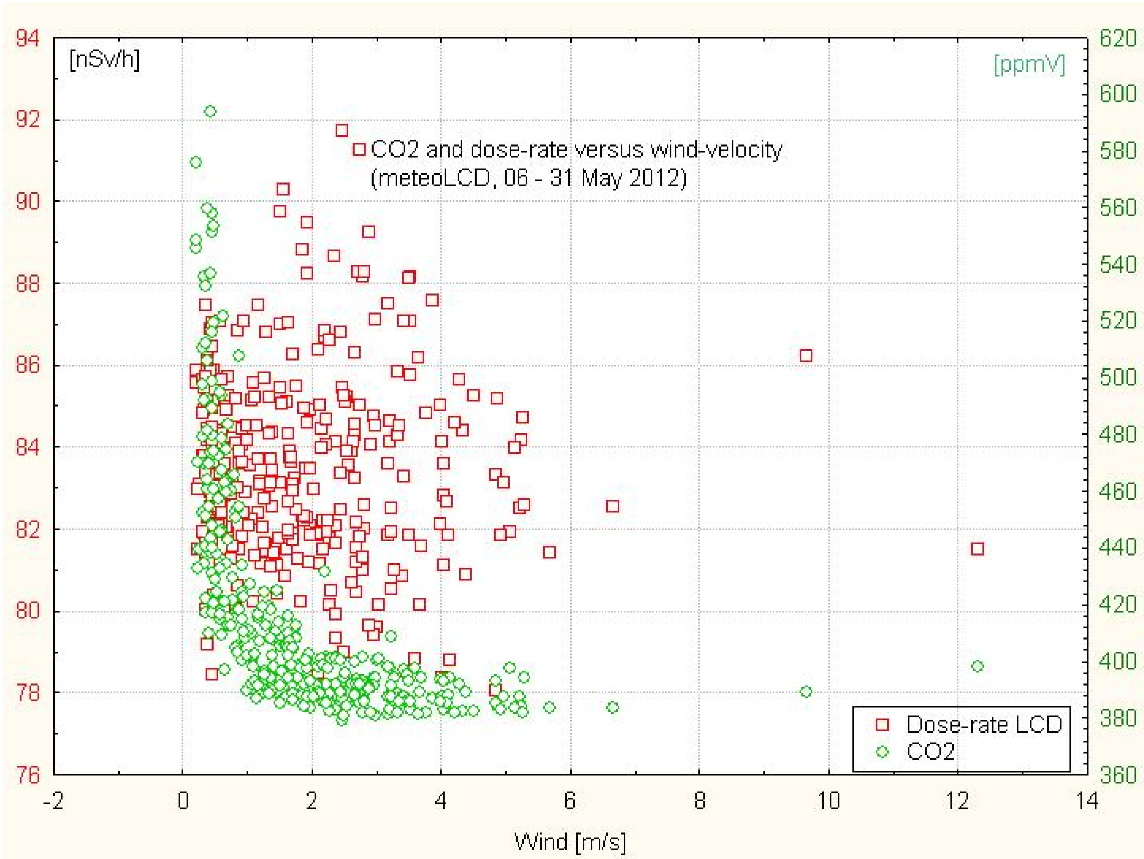

Fig.7 Both CO_2 mixing ratios and gamma dose-rates diminish with higher wind velocities. The effect on dose-rate is less clear than that on CO_2.

Diurnal CO_2 concentrations are maximal during the thermal inversion situations that exist usually during the night and the morning hours. Let us compare the situation for a couple of days which show marked CO_2 peaks. During the 6 days from the 26 to 31 May, four days show maximum CO_2 levels greater than 500 ppmV. These CO_2 peaks happen around 07:00 UTC. The six CO_2 maxima always correspond to a dose-rate spike with one exception for the LCD readings on the 27th May. Close inspection shows a second diurnal peak in the dose-rates, located near the time where CO_2 levels are lowest and air temperature highest (around 15:00 UTC)

Fig.8. gives the explanation: For the LCD series a part of the second diurnal spike seems to be caused by the temperature dependency of the instruments (and/or increased radon exhalation). The observed increase for the RS03 sensor is about 3 nSv/h, close to the 3% temperature dependency given in the technical documentation. The influence of air temperature on the AGS might be marginally lower during these 6 days, about 2 nSv/h by inspection. This fraction of 2/3 is close to that of the correlation values 0.37/0.53 = 0.70) found in the correlation table

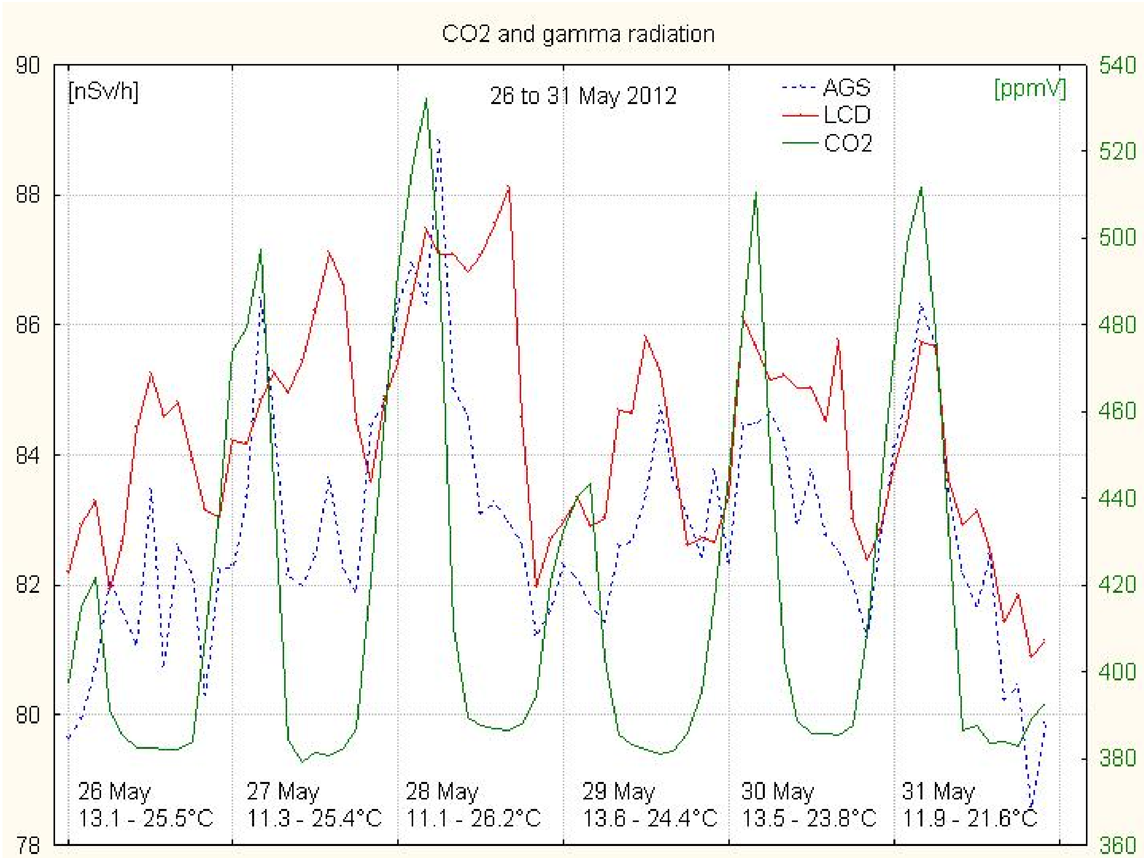

Fig.8 Two diurnal dose-rate peaks.
Date and daily min-max temperatures at the bottom of the figure..

3.6. Solar heating of the enclosures

The positive correlations between the dose-rates and temperature could be the result of a genuinely increased radon exhalation, sensitivity to the heating of the enclosures or both. MeteoLCD has a WBGT (wet bulb globe temperature) sensor to measure the heat stress. The GlobeT parameter in the meteoLCD data files corresponds to the readings of a thermometer located in a black sphere, and so responding quickly to solar heating. Fig.9 shows the dose-rates versus the GlobeT temperature. As expected, the slopes of the regression lines are both positive, but are approx. 50% lower than those found for the dependency on air temperature.

Influence of GlobeT and air temperature	Param.	Linear slope		R^2	
		AGS	LCD	AGS	LCD
All data (312 points)	GlobeT Temp	0.075 0.152	0.119 0.206	0.08 0.14	0.22 0.28

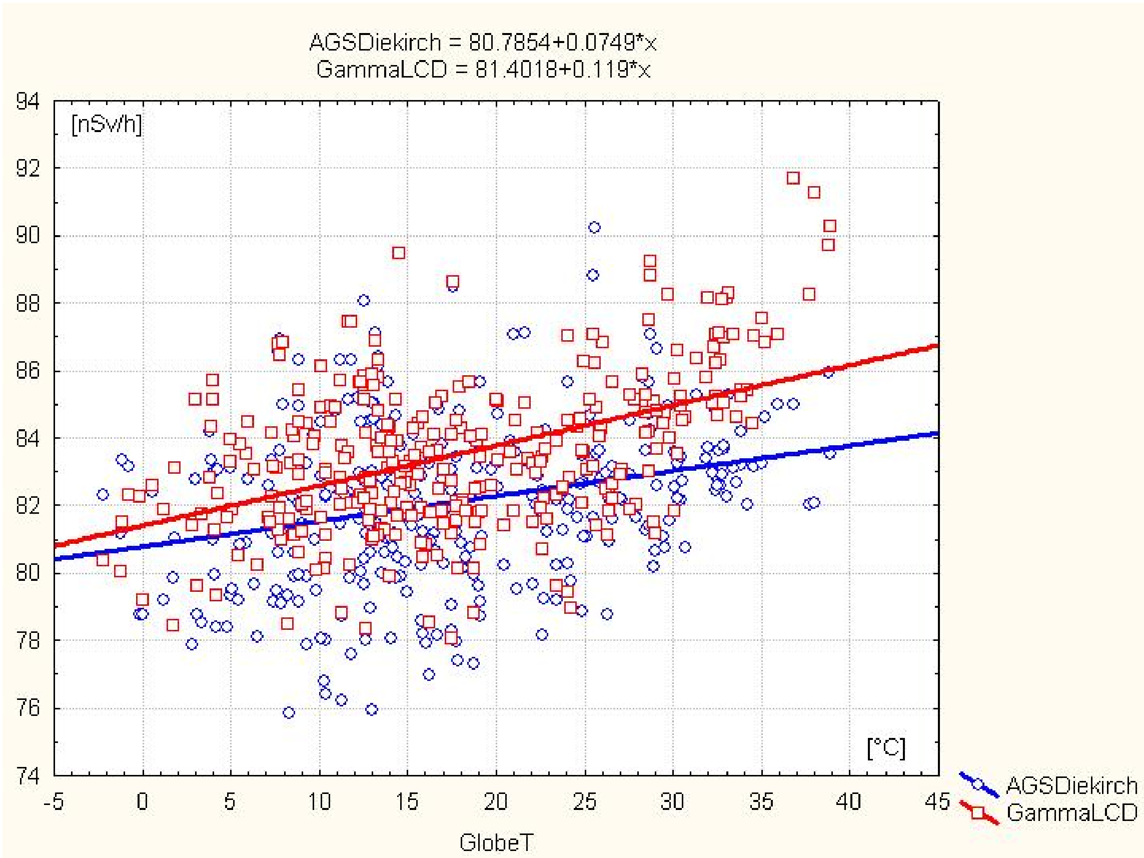

Fig. 9 Dose-rates versus the Globe Temperature

The AGS and RS03 enclosures are painted in grey - beige resp. in a reflective grey. The lower slope magnitudes in Fig.9 compared to that of Fig.4 lead to the conclusion that enclosure temperature is not the only cause of higher readings. Neverless the almost double value of the RS03 regression slope compared to the AGS can be taken as a sign of a greater susceptility to case temperature. A future analysis including very hot summer days may help to clarify this situation.

4. Is radon the major contributor to measured dose-rate?

The signs of the correlation between gamma-ray dose-rates, temperature, pressure and wind-velocity are identical to those known to exist with atmospheric radon concentration.

We can conclude that radon exhalation is a certain contributor to the measured air-borne gamma-ray dose-rate. Whereas the almost constant background is caused by the surrounding radionuclides and cosmic rays, the wiggles around that background seem to reflect both the impact of radon daughters and the temperature dependency of the sensors. As the sensors are mounted 20m above ground level, radon derived radioactivity could be much less important at the measurement site than at ground level.

5. A simple linear model

Following Occam's razor, we will test an extremely simple linear model expressing the dose-rate as a linear function of the 3 meteorological parameters T, P and V.

Gamma dose-rate = a + b*T +c*P +d*V

Using the Statistica software package we find the following results:

Linear model	AGS	LCD (RS03)
All parameters significant at the 95% level?	yes	yes
R^2 of the model	0.41	0.37
Range of residuals = difference between observation and model	-3.7 … +10.1 [nSv/h]	- 3.7 …. + 5.7 [nSv/h]
a	217.96	123.71
b	0.17	0.24
c	-0.14	-0.04
d	-0.56	-0.44

Rounding the constant parameter, one has:

AGS = 218 + 0.17*T - 0.14*P - 0.56*V
LCD = 124 + 0.24*T - 0.04*P - 0.44*V

Applying this ultra-simple model allows to predict gamma dose-rates that are not more than approx. 10% different from the measured ones!

6. Conclusion

This first analysis shows that the BITT RS03 gamma counter gives results that are very close to those of the much more expensive AGS instrument. The time series of both sensors change in a common way, and correlations with meteo-rological parameters are of the same sign, and mostly of the same magnitude.
These correlations point to radon daughters being a noticeable contributor to the measured gamma radiation. The variation of the readings with temperature also suggests a temperature dependency of both instruments, the RS03 sensor being more temperature dependent than the AGS.

A very simple linear model allows predicting dose-rates from the meteorological parameters Temperature, Pressure and wind Velocity with an incertitude of about 10%.

Hopefully both sensors will continue to operate in tandem during a longer period (including summer months), which could put these preliminary findings on more solid feet.

7. References

[1] Gamma-Ray spectrum catalogue; 4th edition, September 1998; Dr. R. G. Helmer; Idaho National Engineering & Environmental Laboratory

[2] NCRP: Measurement of Radon Daughters in Air. NCRP report #97, 1988.

[3] F. Massen, G.-E. Beck: Accurate Estimation of CO_2 Background Level from Near-Ground Measurements at Non-Mixed Environments. Climate Change Management, 2011, part 4 (editor W. Leal). Springer. (link1) (full text)

History:

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