Long-term study of low energy counting rate with the Large Volume Detector

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Large Volume Detector

Main Features:

- **Active Mass:** M = 1kton
- **840 tanks:** (1.0×1.0×1.5 m^3)
- **2520 pmts:** 15 cm diameter
- **Liquid Scintillator:** $C_n H_{2n+2}$ $\overline{n} = 9.6$, + 1g/l PPO + 0.03 g/l POPOP, $\rho = 0.8$ g/cm^3
- **Thresholds:** $\mathcal{E}_H \simeq$ 4MeV & $\mathcal{E}_L \simeq$ 1MeV

Goal:

The detector is mainly designed to measure low energy $\bar{\nu}_e$ from stellar core collapse.

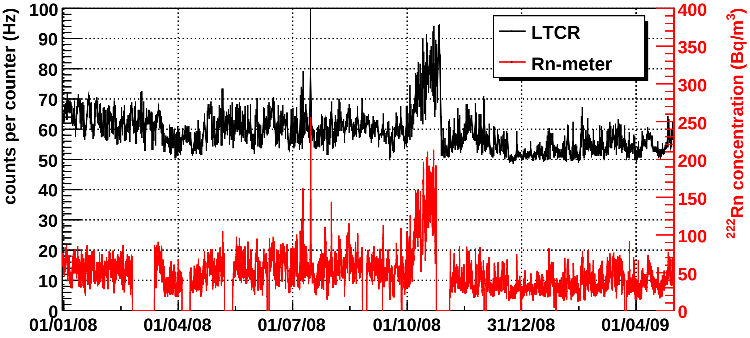
Trigger modes

LVD can operate at 2 different thresholds:

1. The signals of Each PMT are discriminated at two thresholds resulting in two possible levels of coincidence between a counter PMTs: H and L, corresponding to $\mathcal{E}_H \simeq 4$MeV and $\mathcal{E}_L \simeq 1$MeV. The H coincidence, in any counter, represents the **scintillator trigger condition**.
2. The single tank low threshold rate is monitored by a system of 840 scalers. The counting rate of each tank is measured during a time window of 10 s. The read out of this low priority data channel is enabled every 10 minutes by the: **asyncronous monitoring trigger**.
   At energies near $\mathcal{E}_L$ the single tank counting rate is mainly due to:
   - Rock radioactivity
   - Building materials radioactivity
   - Secondary particles generated by muons
   - ^{222}Rn
   - $(\alpha, n)-$reactions

Correlation LTCR – Radonmeter

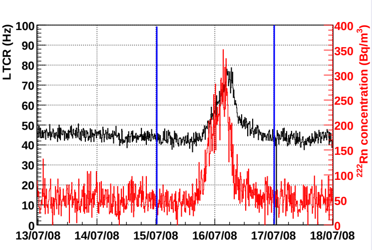
The Low Threshold Counting Rate (**LTCR**) and the radonmeter data are clearly correlated. The last 500 days of data are shown in the picture.

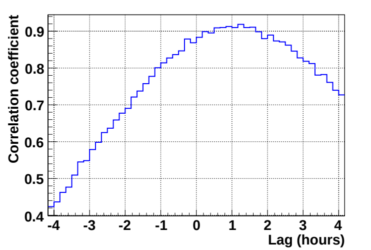


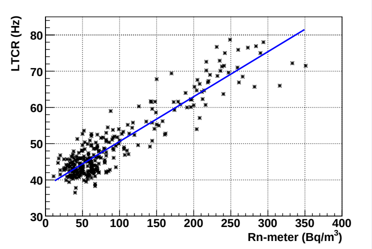
2 questions:

- LVD sensitivity to Rn contamination.
- What are we counting?

Calibration of a single counter



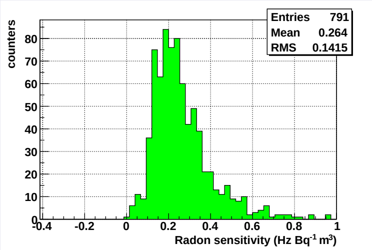


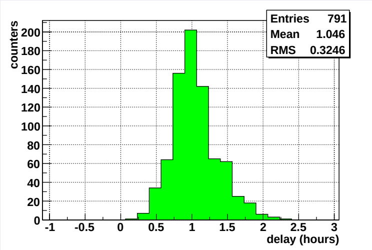


For each counter we determine the time lag at which the maximum of the cross-correlation function occurs, and the sensitivity in terms of radon activity. Sensitivities have been evaluated by fitting the bivariate distribution at the lag corresponding to the maximum correlation.

Distribution of the calibration parameters

The distribution of the calibration parameters (angular coefficient of the straight line) and the distribution of the delays obtained for all the counters are shown.





- On average, a variation in Rn activity of 1 Bq/m^3, corresponds to a variation in the single counters low threshold counting rate, of 0.3 ± 0.1 Hz.
- The average delay between a Rn-meter peak and the corresponding peak in the counter rate is: 1 ± 0.3 hours.

^{222}Rn and its decay products

Radium series:

$$^{222}Rn \xrightarrow[3.82d]{\alpha} {}^{218}Po \xrightarrow[3.10min]{\alpha} {}^{214}Pb \xrightarrow[26.8min]{\beta} {}^{214}Bi \xrightarrow[19.9min]{\beta} {}^{214}Po \xrightarrow[164\mu s]{\alpha} {}^{210}Pb$$

- The parent radionuclide A decay according to exponential law producing atoms of type B:

$$A = A_0 e^{-\lambda_A t}$$

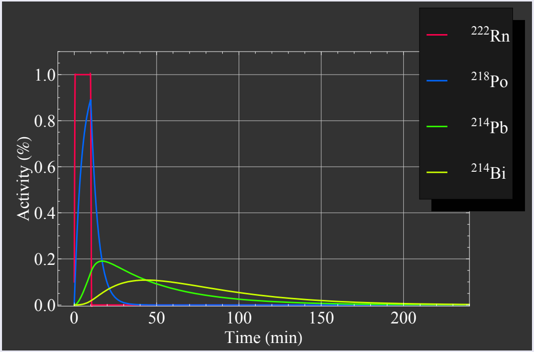
- B change with a rate depending on:
  1. the parent decay
  2. the decay of B itself

$$\frac{dB}{dt} = A\lambda_A - B\lambda_B$$

Decay chain

The more generale case of a n members chain is described by a system of differential equation:

$$\begin{cases} \frac{dA}{dt} = -A\lambda_A \\ \frac{dB}{dt} = A\lambda_A - B\lambda_B \\ \frac{dC}{dt} = B\lambda_B - C\lambda_C \\ \dots \end{cases}$$



The time evolution of the signal has been calculated assuming that a certain quantity of radon (as measured by the Rn-meter) persists in the environment during 10 minutes.

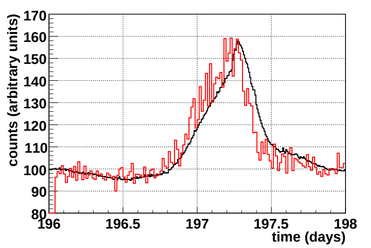
Decay chain

The previously obtained curves can be regarded as pulse response functions of our system to a brief *Rn* injection. Discrete time convolution can be used to determine the output of a sampled data system from its input and pulse response.

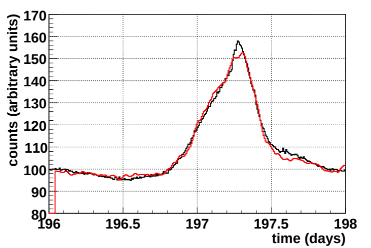
$$y(t) = \sum_{n=0}^{\infty} x(t-n)h(n)$$

Thus, appliyng a convolution between each one of that curves and the radonmeter data series we can convert the activity of the radon in activity of the corresponding product.

Shape

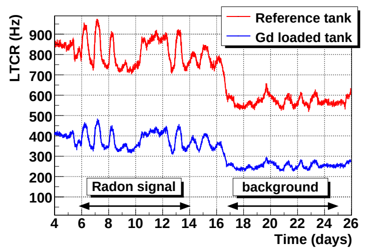


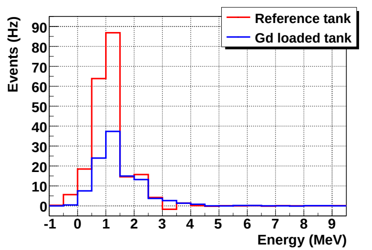
Comparison between radonmeter data (**red line**) and LTCR data (**black line**), during a time period of intense variation in radon concentration due to a scheduled switch off of the ventilation system in the experimental hall.



Now the **red line** represent the activity of ^{214}Bi calculated from the radon-meter data series. A significantly better agreement is achieved, explaining the delay measured, so we can state that:

our counters can measure the Rn concentration because gammas from ^{214}Bi ($E_\gamma = 609KeV$ $I_\gamma = 46.1\%$) are detected.

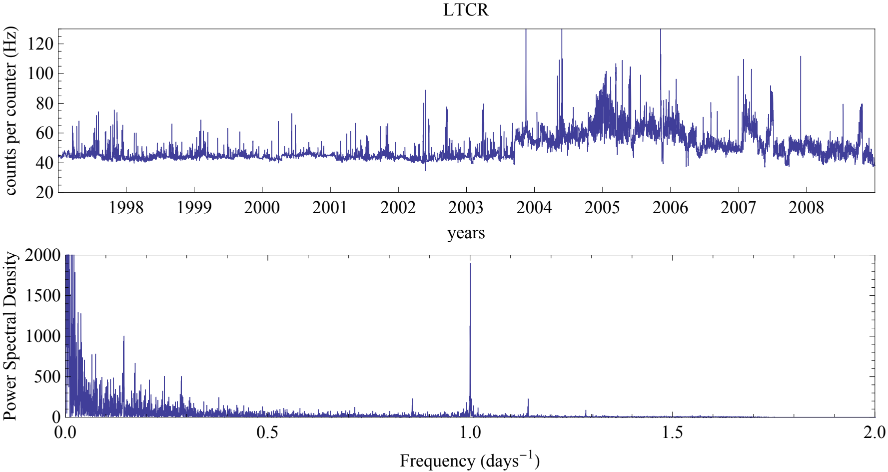




Counting rates versus time of a standard counter (**red line**) and a counter filled with Gd loaded scintillator (**blue line**) collected during a period of transition between high and low Rn contamination. Since we are studying the Rn contribution the spectra are background subtracted.

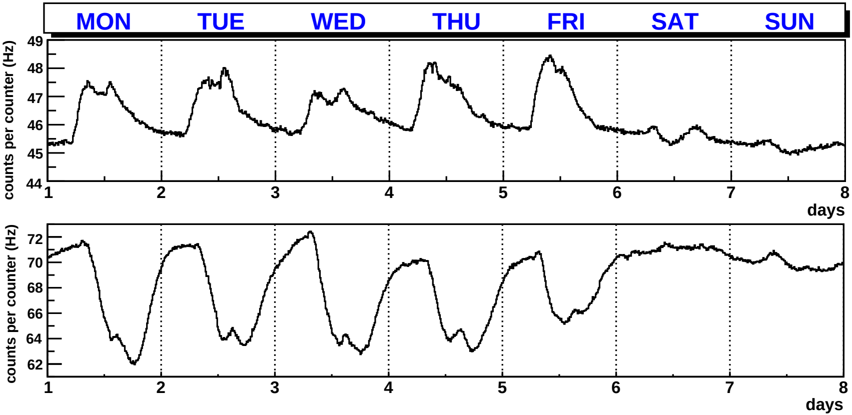
From the two spectra, after Background subtraction, we can argue that the contribution of n from (α, n)-reactions is negligeable.

12 years of data series



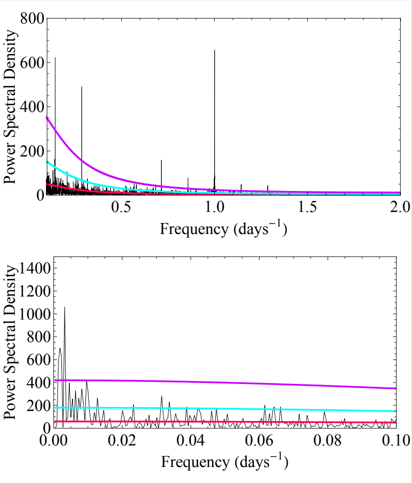
We report the counting rate collected since 1997 up to 2009 and the power spectral density obtained applying DFT algorithm. The discontinuity in the middle of 2003 is related to upgrade in the ventilation system.

Weekly modulation



The counting rate behaviour of the average week is inverted before and after the discontinuity of 2003.

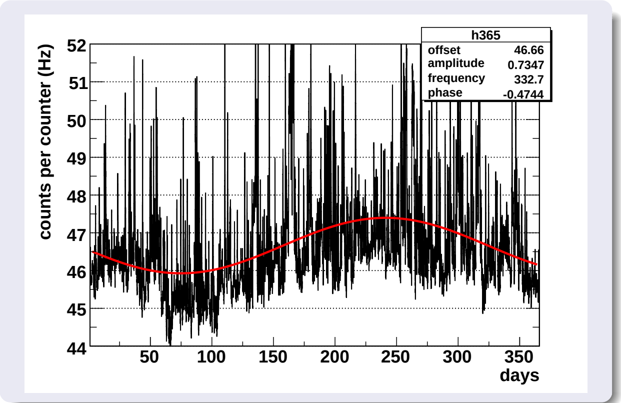
Power Spectral Density (data since 1997 to 2003)



Notations: background level, 3σ c.l., 7σ c.l.

1. The 4 peaks in simmetrical position with respect to the 1 day^{-1} frequency exceeding the 7 σ c.l. are related to the daily signal structure.
2. The remaining two peaks represents the weekly modulation (0,14 day^{-1}) and its higher harmonic.
3. In the low frequency spectrum the higher peak corresponds to a frequency compatible with an annual modulation:
   - frequency: 365$\pm$32 d
   - amplitude: 1.5 – 2.5 Hz
4. The peaks exceeding 3 σ c.l. in the frequency region between 0.03 and 0.04 day^{-1} correspond to a monthly periodicity and are under study (they could be related to a tidal effect).

Annual Modulation



Counting rate of 6 years averaged and fitted by sinusoidal function:

$$k + A \cdot sin(2\pi(\frac{t}{T} + \phi))$$

obtaining: T = 333 $\pm$ 32 d, maximum = 240 $\pm$ 32 d

Conclusions

We have analyzed the LVD Counting Rate measured at $\mathcal{E}_L > 0.5$MeV during 1997 – 2009.

- the sensitivity in terms of Rn activity has been measured for each counter.
- the analysis of the time delay in the radon component conferms that we are counting gammas from ^{214}Bi.

- The spectral analysis shows evidence ($> 7\ \sigma$ c.l.) of annual modulation during 6 years, with:
  1. T $= 333 \pm 32$ d
  2. Amplitude $\simeq 1.5 - 2.5$ Hz $\Longrightarrow 5 - 8 Bq/m^3$
  3. Maximum at 28^{th} August ($\pm$ 32 days)

- a candidate signal ($3\ \sigma$ c.l.) compatible with monthly periodicity has been found and could be related to a tidal effect