Gamma- and X-ray spectrometry setup with very low background at LNE-LNHB

The Laboratoire National Henri Becquerel (LNE-LNHB) has a gamma- and X-ray spectrometer used to provide environmental laboratories with radioactive standards. This facility is installed in the LNHB building basement under 65 cm of soil and 75 cm of barium concrete (density 2.3 g.cm^{-3}). The measuring system consists of a 198 cm^3 coaxial N-type HPGe detector with a relative efficiency of 51.6% with a combination of passive and active shielding to reduce the detection background, and consequently, to improve the detection limits.

➔ Shielding characteristics for reducing the background

Passive shielding from outside to inside:

- 10 cm low activity lead: 99.23% attenuation of 3-MeV external gamma rays
- 3 mm cadmium alloy: neutron absorber whose stable isotope ^{113}Cd has a giant resonance of 10 000 barns for thermal neutrons
- 5 cm of very low activity lead: attenuation of the gamma radiation emitted by neutron-activated cadmium. The two layers of lead makes it possible to attenuate the 3-MeV gamma-rays by 99.93%
- 4 mm copper: 93% attenuation of lead X-rays around 80 keV

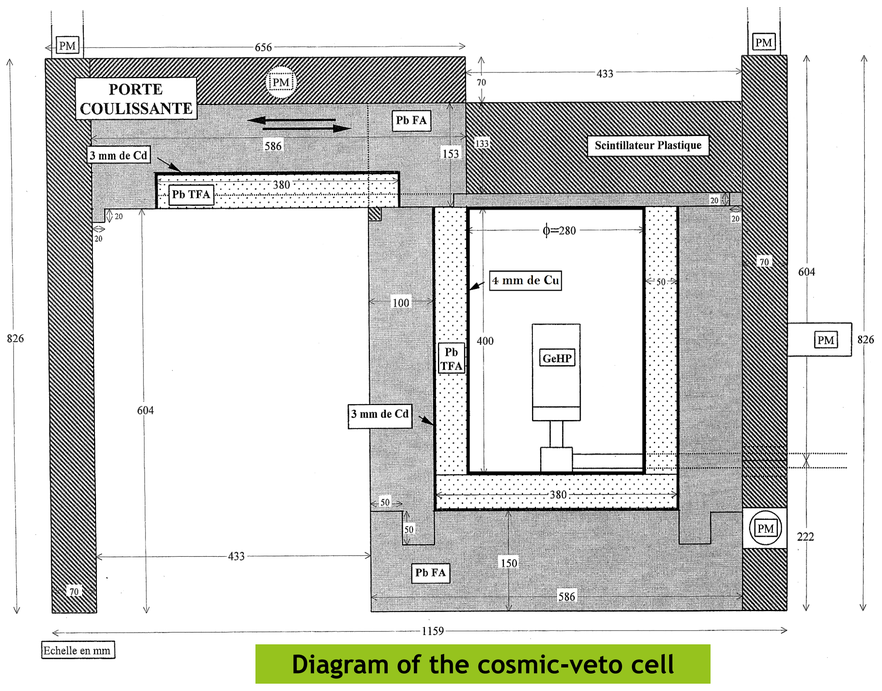


Diagram of the cosmic-veto cell

Active shielding using plastic scintillators (cosmic veto)

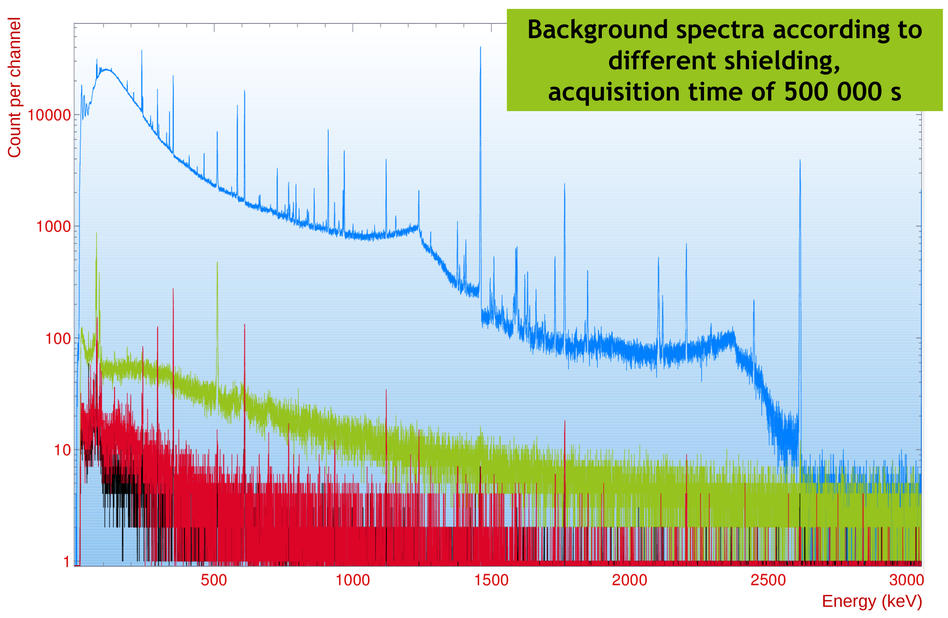
- Each external side of the lead cell (except the one under the detector) is covered with 5-cm thick plastic detector (Type BC-408) whose light signals are collected by a photomultiplier (PMs)
- The signals from the PMs are summed and amplified before being processed by the electronics developed at LNE-LNHB which apply a *veto* using an extendable dead time (*Applied Radiation and Isotopes (2015) 109, 425-429).*

View of the inside of the cell

Removal of radon from the measuring cell

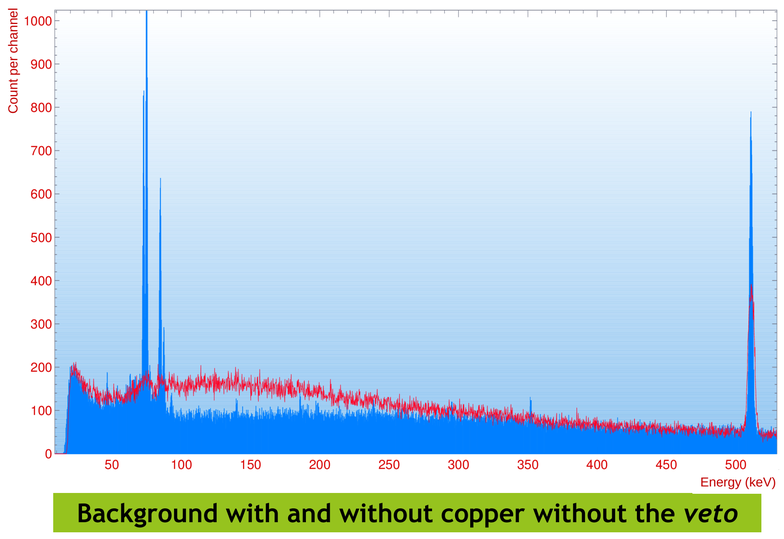
- The detector cell is flushed with gaseous nitrogen from the detector Dewar® (30 L.h^{-1}). This permanent nitrogen injection avoids waiting for the total renewal of the inside atmosphere of the cell after it has been opened (1 h with nitrogen evaporated from the Dewar ®).

➔ Shielding effects



Background spectra according to different shielding, acquisition time of 500 000 s

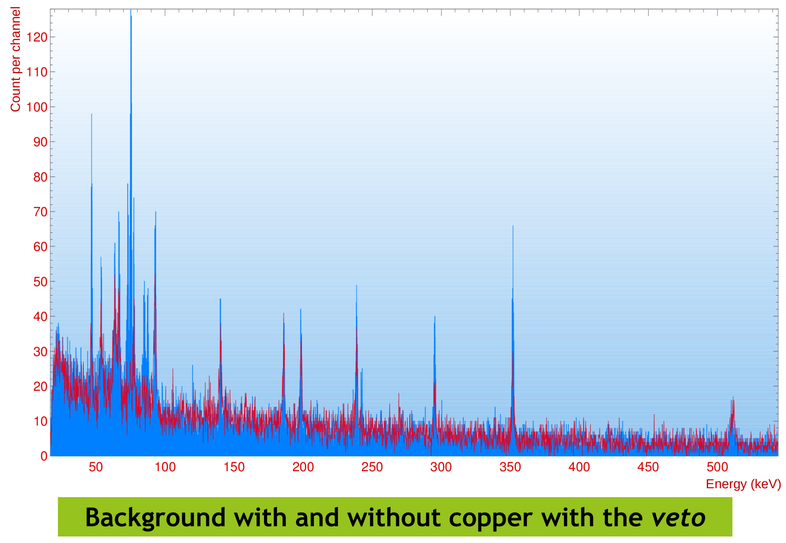
- Blue spectrum: background without any shielding, with strong presence of all the peaks characteristic of natural radioactive decay chains (^{238}U, ^{235}U and ^{232}Th) and of ^{40}K.
- Green spectrum: addition of passive shielding (except copper) allows reduction of the background by a **factor of 140**. In this spectrum, the K X-rays from lead and the 511-keV peak with a continuous contribution due to the interaction of cosmic radiation with the lead of the shielding are still present.
- Red spectrum: *veto* active shielding eliminates a large part of the cosmic radiation and reduces the previous background by a **factor of 6**.
- Black spectrum: removal of radon from the measuring cell with nitrogen flush induces reduction of the previous background by **a factor of 2**. The average activity concentration of ^{222}Rn measured over 1 year is 25 Bq.m^{-3}, the highest activity recorded being 80 Bq.m^{-3}.
- *NOTE: The LNE-LNHB's electronics have made it possible to reduce the total background by a factor of 2 and the peak of 511 keV by a factor of 5 compared with the electronics initially provided when the detector was installed. The saturating peaks have also been eliminated from the spectrum.*



Background with and without copper without the *veto*

If it is thick enough, the internal copper shielding removes all lead X-rays. However, as shown on the pictures, it should only be used if the *veto* system correctly eliminates the 511-keV contribution:

- Left panel: effect of copper (in red) without cosmic *veto*: a tail appears due to the interaction of the 511 keV in the copper layer,
- Right panel: effect of copper (in red) with the cosmic veto, the tail is no more visible because the 511-keV emission is almost completely eliminated by the *veto*.



Background with and without copper with the *veto*

➔ Background results

Origin	Energy (keV)	h^{-1}.kg$_{Ge}^{-1}$	Origin	Energy (keV)	h^{-1}.kg$_{Ge}^{-1}$
^{70}Ge(n,γ)^{71m}Ge	23.4	-	^{228}Ac	338.3	0.15
^{210}Pb	46.5	1.08	^{214}Pb	351.9	1.36
^{214}Pb, ^{72}Ge(n,γ)^{73m}Ge	53.2 - 53.4	1.30	Annih.	511.0	1.69
^{234}Th	63.3	1.04	^{206}Pb(n,n',γ)^{206*}Pb	537.4	-
^{73m}Ge (13.3 keV + 53.4 keV)	66.7	1.02	^{207}Pb(n,n',γ)^{207*}Pb	569.7	0.14
^{73}Ge(n,n',γ)^{73*}Ge	68.7	-	^{208}Tl	583.2	0.54
Pb-X$_{KL}$	72.1 - 72.8	-	^{74}Ge(n,n',γ)^{74*}Ge	595 - 650	-
Pb-X$_{KL}$, ^{212}Pb, ^{214}Pb	75.0	0.43	^{214}Bi	609.3	1.53
^{212}Pb, ^{214}Pb	77.1	0.79	^{137}Cs	661.7	0.48
Pb-X$_{KM}$	84.1 - 85.5	0.18	^{72}Ge(n,n',γ)^{72*}Ge	680 - 740	-
Pb-X$_{KM}$, Pb-X$_{KN}$, ^{212}Pb, ^{214}Pb	87.1 - 87.9	0.14	^{76}Ge(n,n',γ)^{76*}Ge	691.0	-
^{234}Th	92.6	1.43	^{214}Bi	768.4	-
^{74}Ge(n,γ)^{75m}Ge	139.7	0.24	^{206}Pb(n,n',γ)^{206*}Pb	803.3	0.05
^{235}U	143.8	0.14	^{234}Pa	880.5	-
^{76}Ge(n,γ)^{77m}Ge	159.7	-	^{228}Ac	911.1	0.21
^{71m}Ge	175.0	-	^{214}Bi	934.1	-
^{235}U, ^{226}Ra	185.7 - 186.2	1.27	^{228}Ac	968.9	-
^{70}Ge(n,γ)^{71m}Ge	198.3	0.98	^{214}Bi	1120.3	0.15
^{77m}Ge	215.5	-	^{60}Co	1173.2	-
^{212}Pb	238.6	0.37	^{214}Bi	1238.1	0.11
^{214}Pb	241.9	0.23	^{60}Co	1332.5	-
^{208}Tl	277.4	-	^{40}K	1460.8	0.81
^{214}Pb	295.2	0.85	^{214}Bi	1764.5	0.08
			^{208}Tl	2614.5	0.38

List of peaks present in the background, t = 2 500 000 s

The result tables present the different counting rates obtained during a background acquisition, the dead time was 0.5 (3) % coming mainly from the *veto*, we observe:

- Radionuclides in the natural chains of ^{238}U, ^{235}U and ^{232}Th that come from lead in the cell, radon progenies and detector materials;
- Some of the lead X-rays that pass through the copper, their elimination would be complete by increasing the thickness of the copper to 12 mm;
- Neutron interactions: some neutrons have not been absorbed by cadmium (need to add more cadmium or boron);
- The cell or the detector presents a light contamination (some µBq of ^{137}Cs) that appeared after 16 years of operation; this shows the sensitivity of such an installation, a regular cleaning and a containment of the sources make it possible to limit these problems.

Values with a " - " indicate that these emissions are not visible on the spectrum: no ^{60}Co peak visible after 2 months of cumulative background.

A finer tuning of the electronics should allow to improve the results. However, this is a time-consuming testing process which requires background measurements after each tuning. This is carried out according to the availability of the installation.

Energy (keV)	h^{-1}.kg$_{Ge}^{-1}$	min^{-1}.kg$_{Ge}^{-1}$
15 - 3300	244.8 (6)	4.07 (1)
15 - 1600	222.5 (6)	3.70 (1)
20 - 2500	233.9 (6)	3.90 (1)
40 - 2500	220.5 (6)	3.68 (1)
15 - 100	58.6 (3)	0.977 (5)
100 - 400	86.4 (4)	1.441 (6)
400 - 1400	71.4 (4)	1.190 (6)
1400 - 2500	19.8 (2)	0.330 (3)
2500 - 3300	8.5 (1)	0.142 (2)

Background for some energy ranges

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