Low Background γ-ray spectrometry

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-Not necessary to promote the technique, everybody is convinced it is indispensable for all low background experiments, not only under-ground, but also many other disciplines!

-I will consider only Ge spectrometers

-I will not try to make any comparison between different set-ups, or different levels of background

-I prefer to explain you how we are working in the LSM, and to give a series of comments based on a long experience both in Ge detectors and material selection.

Main goal for underground experiments: material selection and control

Many advantages with Ge's:

• simple and fast (>1000 samples for Nemo)

• non destructive (enriched isotopes !)

• measurement of large quantities (~ 1 kg) and different geometries (powder, strips,…)

• gives natural and cosmogenics activities in the same measurement

•high energy resolution for an easy isotope identification

• measurement of the non-equilibrium in radioactive families (U/Th/Ra)

Main disadvantages: cooling down, detection efficiency

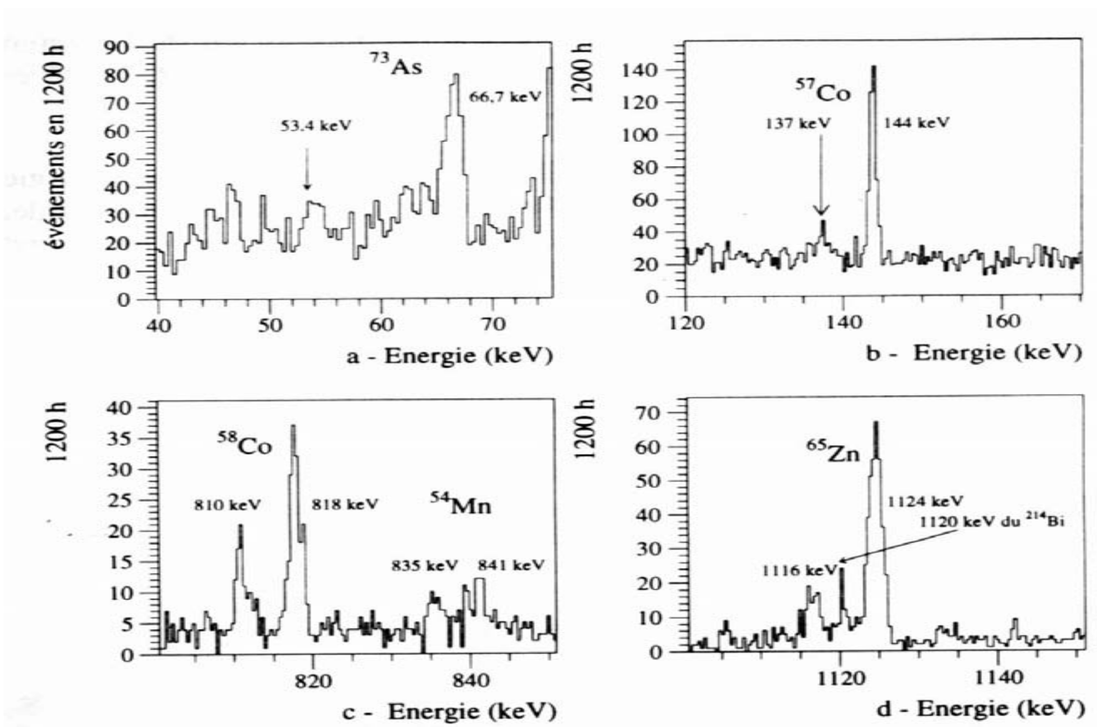
First ultra-low background Ge spectrometers built for our purpose (NEMO) almost 15 years ago
Very close collaboration with M. Berst (Canberra-Eurisys) and J.L. Reyss (LSCE and LSM)

Germanium crystals

- Very high purity crystals (crystal drawing is known as a purification technique!)
- Contain cosmogenics activities:

$T_{1/2}$ = 80 d

$T_{1/2}$ = 271 d



$T_{1/2}$ = 71 d

$T_{1/2}$ = 244 d

Main problem : ^{68}Ge, $T_{1/2}$= 288 d, Q_β = 2.9 MeV

Possible solutions:

1) To draw the crystal, surface shipping, store underground (MPI, Avignone,…)
2) To start with enriched Ge material ?
3) To draw the crystals underground (project in Canfranc?)

The choice of the type of Ge (coaxial « p » or « n », well, planar) depends of what you want to measure (U, Ra, ^{210}Pb, etc…)

Germanium cryostat

Two schools:

1) Al(4%)Si alloy: low Z materials, no cosmogenics (^{26}Al $T_{1/2}$ = 7 10**5 y negligible) but contains weak U and Th contaminations ~ 0.3 ppb. Available commercially but prices become very expansive.

2) Cupper: very pure in U/Th/Ra, but usually contains cosmogenics, specially ^{60}Co (5 y), ^{54}Mn (312 d), and few others.

   US and MPI groups are making their own Cu with success!

   For the future, very interesting is the possibility from the Zaragoza group to make special Cu in Canfranc.

3) Other possibilities: Mg(with few % of Al)? Titanium?

Germanium cryostat (bis)

Few other materials have also to be checked (Insulators, glues, strings, O-rings, Pb plates, etc…)

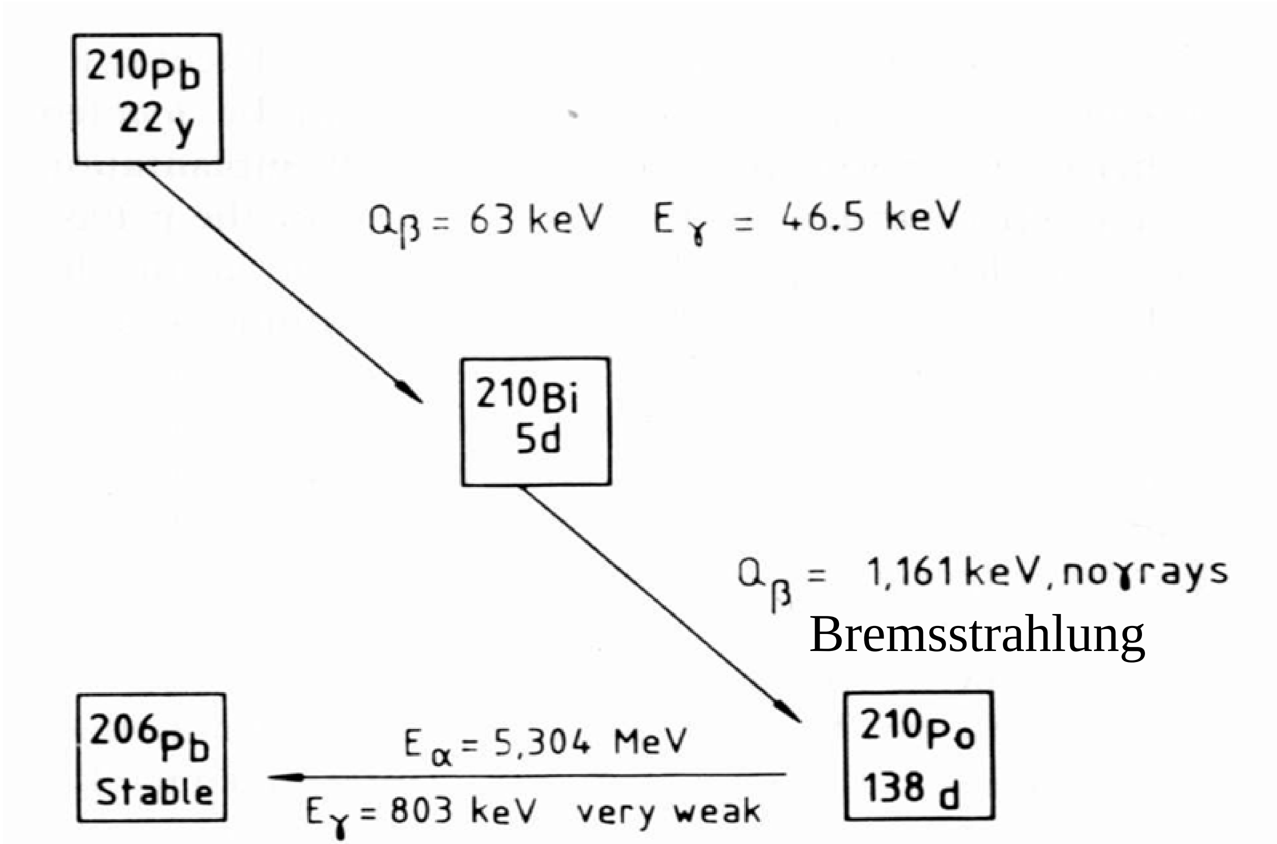
For our Ge, we choose to keep the best energy resolution by cooling the first stage of the preamp → this had implied to find non-radioactive resistances, condensators, FET, and a special support.

Remarks:
-Remember that as far as I know, only Canberra (in Belgium with cupper or in Strasbourg with Al(Si)) is making very low background Ge!
-Ortec company does not want to make Ge « à la carte », so usually their performances are not competitive!
-PGT in the US?

Our strategy: make very low background Ge for our purposes (Nemo and SuperNemo), but also commercially available for other disciplines!

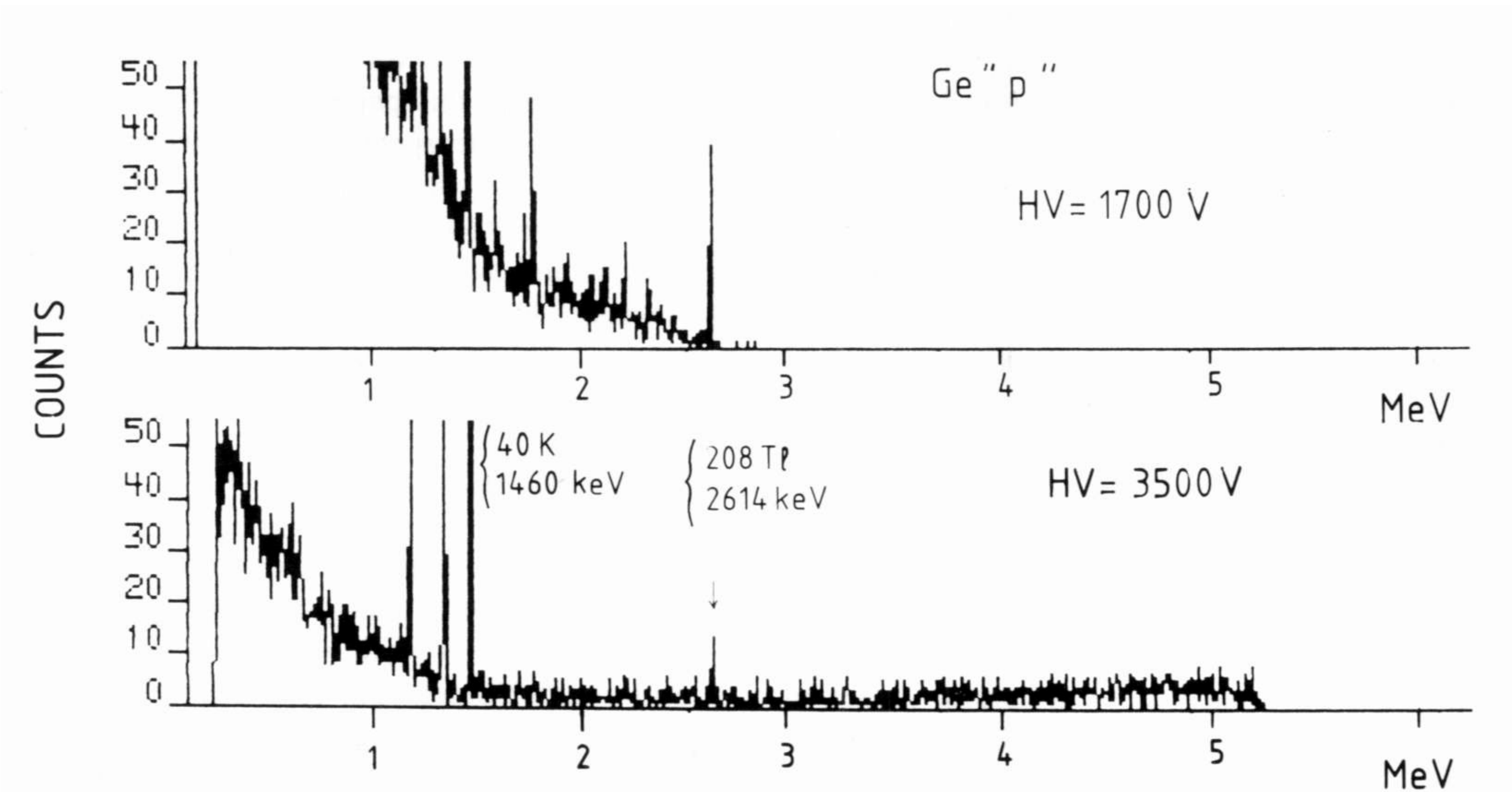
The ^{210}Pb :

Very often surface contamination due to radon deposit.
Very important for the materials used in making the electrical contact



Continuous bkg up to 5.3 MeV

^{210}Pb alpha component: comparison with different HT values



External shielding

I suppose in this talk all the Ge's are underground, no external veto is needed !

- External shielding is generally made with 15-20 cm of standard or low activity Pb, depending of the money available.

- I think it is better to avoid the Pb bricks, the free space between successive bricks or layers can be a source of radon.

- The mechanical device has to be carefully studied in order to be able to change a sample in an easy and quick way and should be "radon-tight"!

Internal shielding

- Internal shielding is generally made with 5-10 cm of OFHC cupper. However:

1) Beside the cosmogenics activities, most of the Cu samples I measured contain surface contamination with ^{210}Pb. This is due to the radon deposit. Which physical effect?

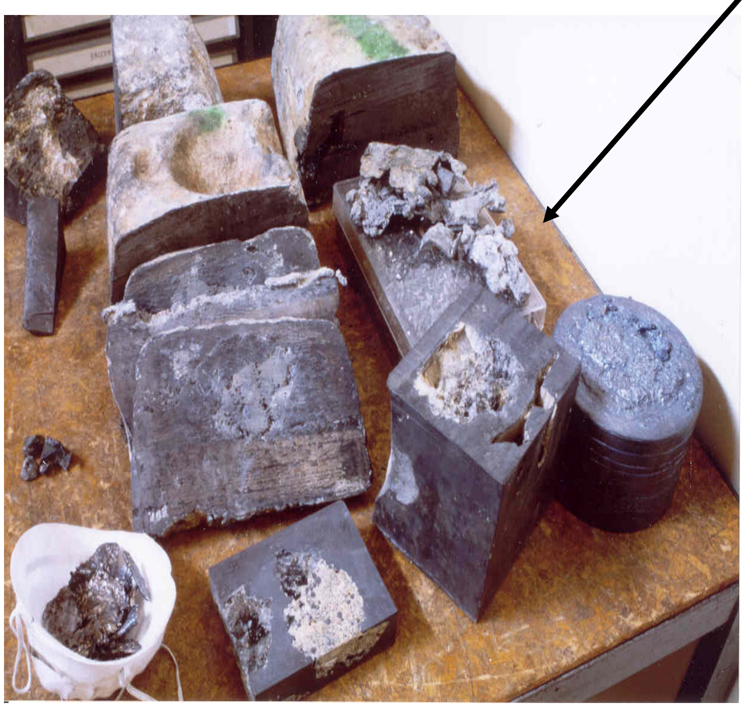
2) After any cleaning with alcohol there is a rather strong deposit of radon (not only daughters!) isotopes on the Cu surfaces.

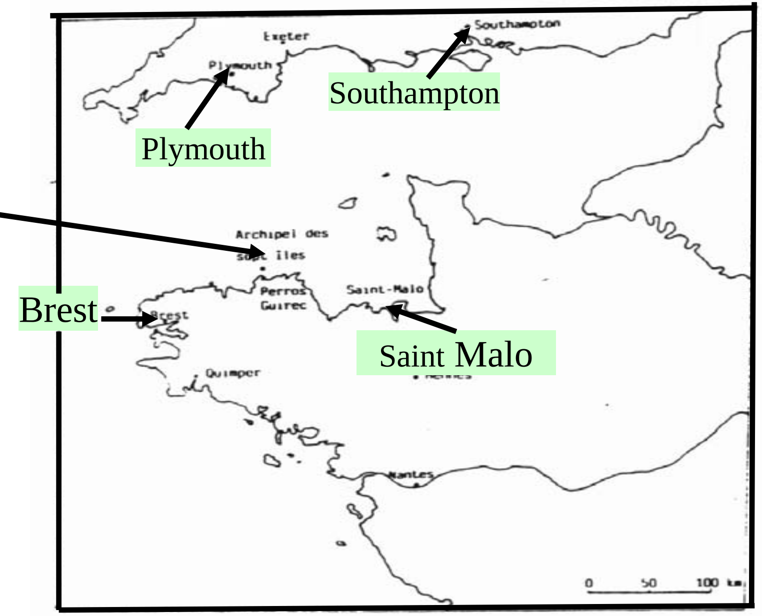
3) The bremsstrahlung of the ^{210}Bi β-ray (Q_β 1.1 MeV) gives a continuous bkg up to 0.5 MeV !

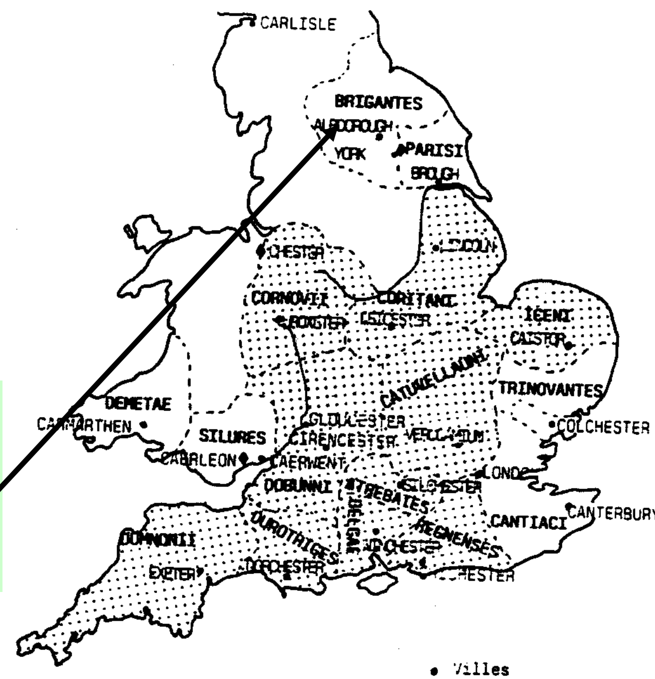
4) Much better if available, is the old Pb: very pure after one or several fusions, does not contain any cosmogenics, no visible trace of ^{210}Pb.

Origin of the LSM archeological lead

In 1983 was discovered in
the « Sept Iles »
a wreck which delivered 271 lead ingots







These ingots bear many inscriptions
Celtic tribes of roman Britain Brigantes and Icenes
Exploited lead mines (14C ⇒ fourth century)

Internal shielding (suite)

Questions: Do we need a neutron shield? If yes where?

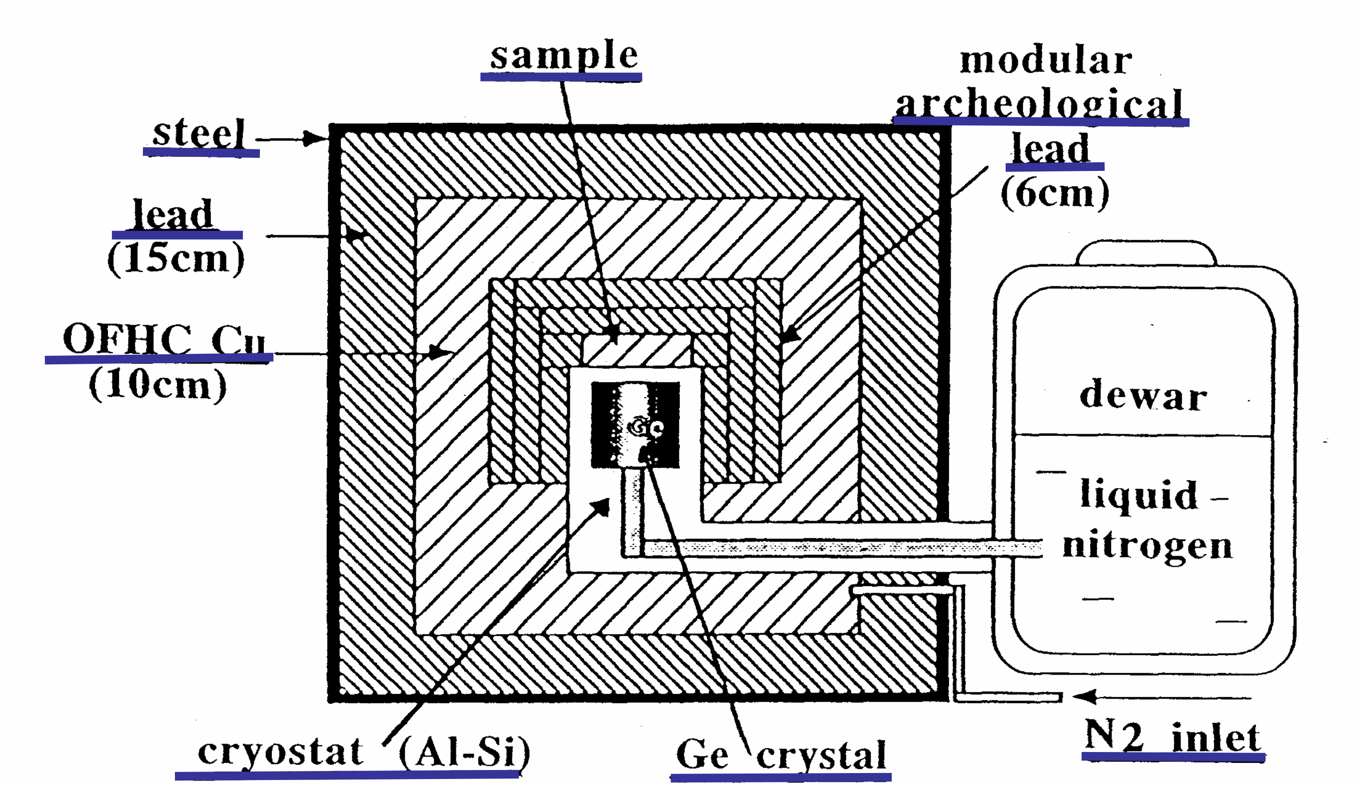
We planned to study this bkg component in the LSM with a new shielding now under construction.

Our preference is to insert a boron polyethylene layer between the internal and external Pb!

Such a neutron shielding is very useful for our Bordeaux Ge in the basement of a research building (~2.5m of concrete)

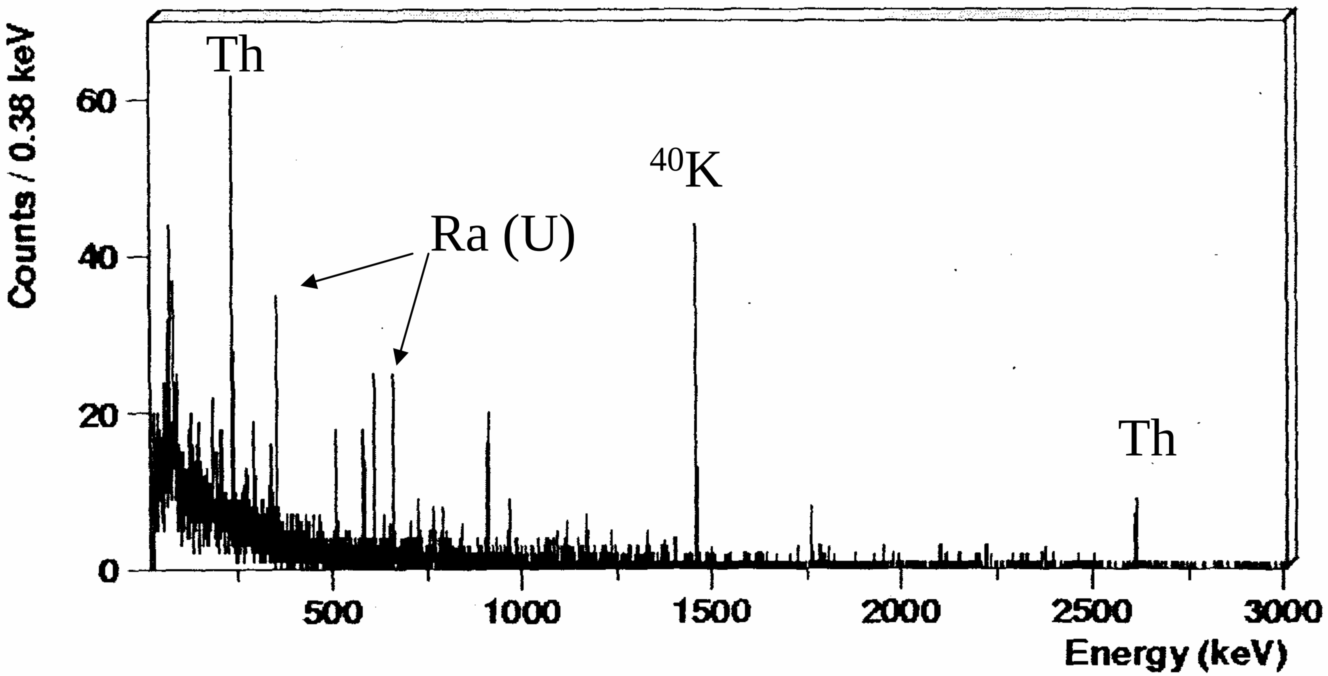
Ultra low background Ge spectrometer in the (LSM)

→ No cosmic rays, very weak neutron flux



- Selection of materials for the cryostat using an iterative procedure
- Reduction of the radon level :- no free space
  - nitrogen pressure
  - alu or plastic sheets to airtight the shielding

Background spectrum
Ge 400 cm^3 - LSM - 42 days

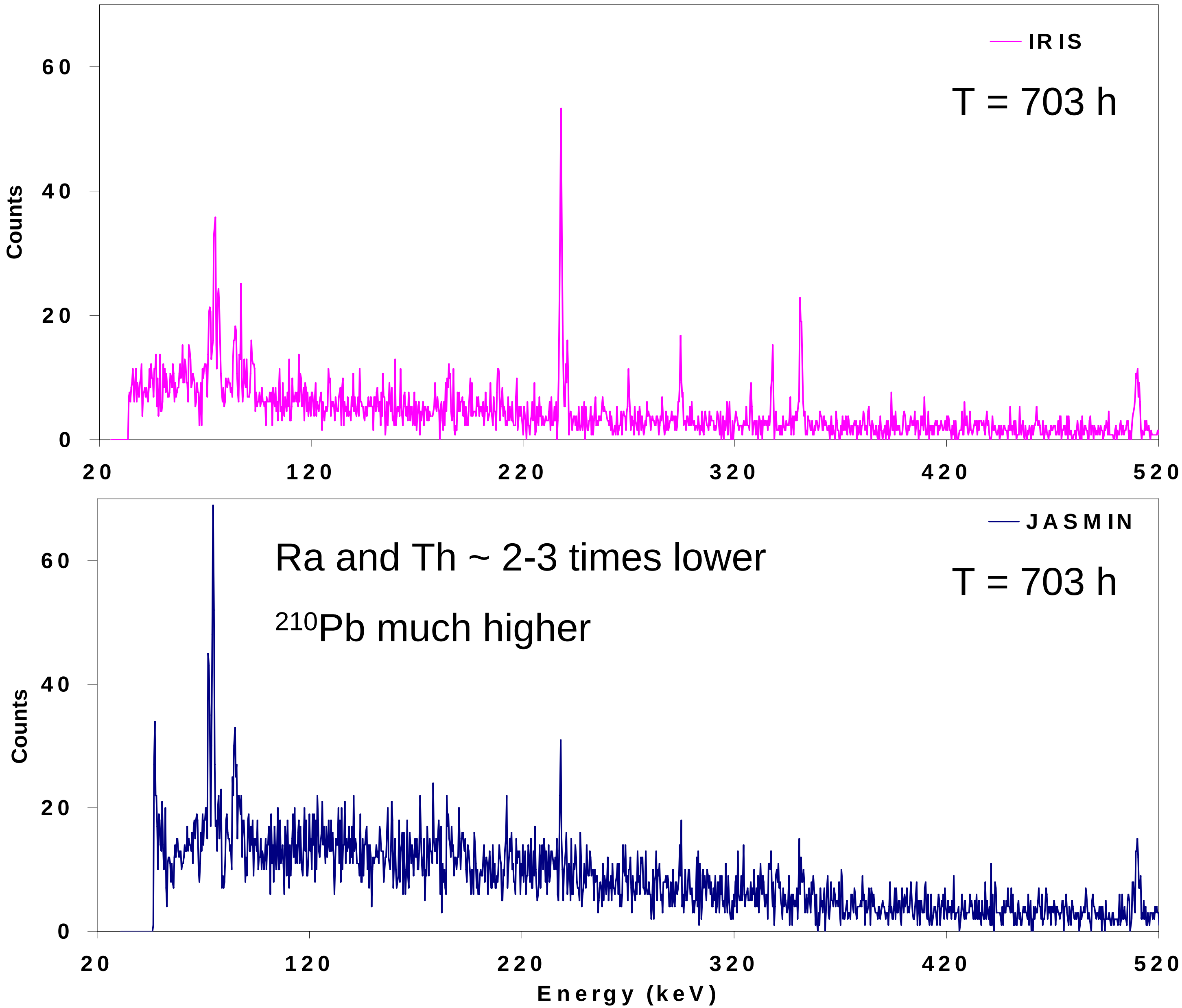


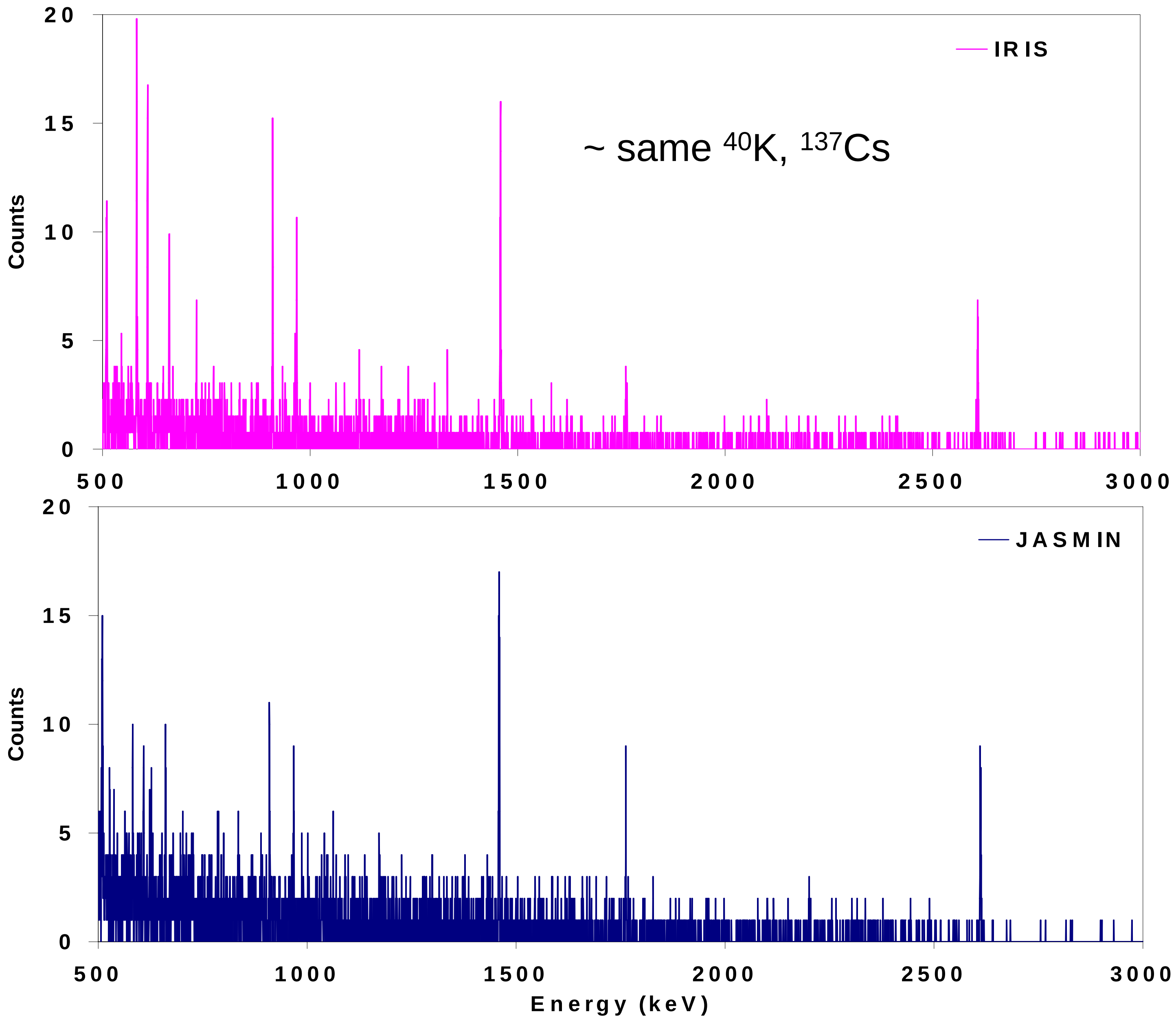
Sensitivity (1 month and 1 kg ^{100}Mo powder):

^{214}Bi < 0.2 mBq/kg , ^{208}Tl < 0.06 mBq/kg

(~ 10^{-11} g/g U) , (~ 10^{-11} g/g Th)

Background spectra of our two 400 cm3 Ge in the LSM




~ same ^{40}K, ^{137}Cs
IRIS
JASMIN
Counts
Counts
Energy (keV)
0
5
10
15
20
500
1000
1500
2000
2500
3000

Sample preparation

1) Most of the time samples are set in (non-radioactive) boxes made in plexiglas, commercially available. These boxes are not airtight, so some radon can escape outside!

   Dimensions phi = 70 cm, h = 2 cm ; weight ~ 100 g

2) This box is itself wrapped inside an usual bag used for freezing

3) After 1 or 2 weeks the plastic box (without the bag) is set as fast as possible on top of the endcap, then the shielding is close again. This operation takes no more than 1 or 2 mn

4) This procedure a) minimizes risks of contamination of the spectrometer, b) avoid radon deposit and c) allows us to start immediately to take useful data.

Measurement procedure

Spectra are recorded through a home made standard NIM/VME or NIM/PC data acquisition system

1) Each spectrum is recorded every day, the counting rate and the energy resolution are checked and must stay constant.
2) If not constant means problems with radon or electronics (microphonic or electromagnetic parasitic pulses for ex.)
3) Duration of measurements are variable, from few days till 1 or 2 months, depending of the activity or of the "goal" of the sample in the experiment

Remarks:

-*Plans are to switch soon to an event by event data acquisition system.*

-*Tests have been done with digitalization of the pulses after the preamp, with an improve of the energy resolution. But commercial units very expansive!*

-*Until now I did not see any need of a pulse shape analysis?*

Few comments on the most interesting γ-rays

Uranium chain : ^{238}U activity (head of the family) :

- 63 keV (^{234}Th) : pure but strong self absorption, need n-type or well crystals

- 93 keV (^{234}Th) : all the time mixed with ^{235}U, ^{228}Ac, …difficult to use

-186 keV (^{235}U) : can be used for U activity measurement after correction of the ^{226}Ra component. With enriched materials, the factor 21 between U5 and U8 activities is not valid!

- 1001 keV (^{234}Pa^{m}) : very weak branching 0.8%

Usually we consider all lines and look carefully if they is full agreement!

For the ^{238}U measurement, the LSM ordered a new large volume planar Ge.

Uranium chain : ^{226}Ra activity (rarely in equilibrium!) :

295 keV, 351 keV (^{214}Pb) and 609 keV (^{214}Bi) are generally considered

Be careful of the radon which can break the equilibrium!

Ex : before measurement of an enriched powder we wait ~ 2 weeks
Ex : for thin foils the radon daughters may escape outside?

Large volume p-type Ge are well adapted, together with a Marinelli geometry!

Uranium chain : ^{210}Pb activity :

Only the 46 keV line is measurable, the new planar Ge will be good also for this line.

<u>Thorium chain</u> : ^{232}Th activity (head of the family) measured only through the ^{228}Ac, assuming equilibrium?

3 γ-rays : 338 keV, 911 keV and 969 keV

<u>Thorium chain</u> : ^{228}Th (1.9 y), lower part of the family.

238 keV (212Pb), 583 and 2614 keV (208Tl) are generally considered

Large volume p-type Ge are also well adapted, together with a Marinelli geometry!

Conclusions

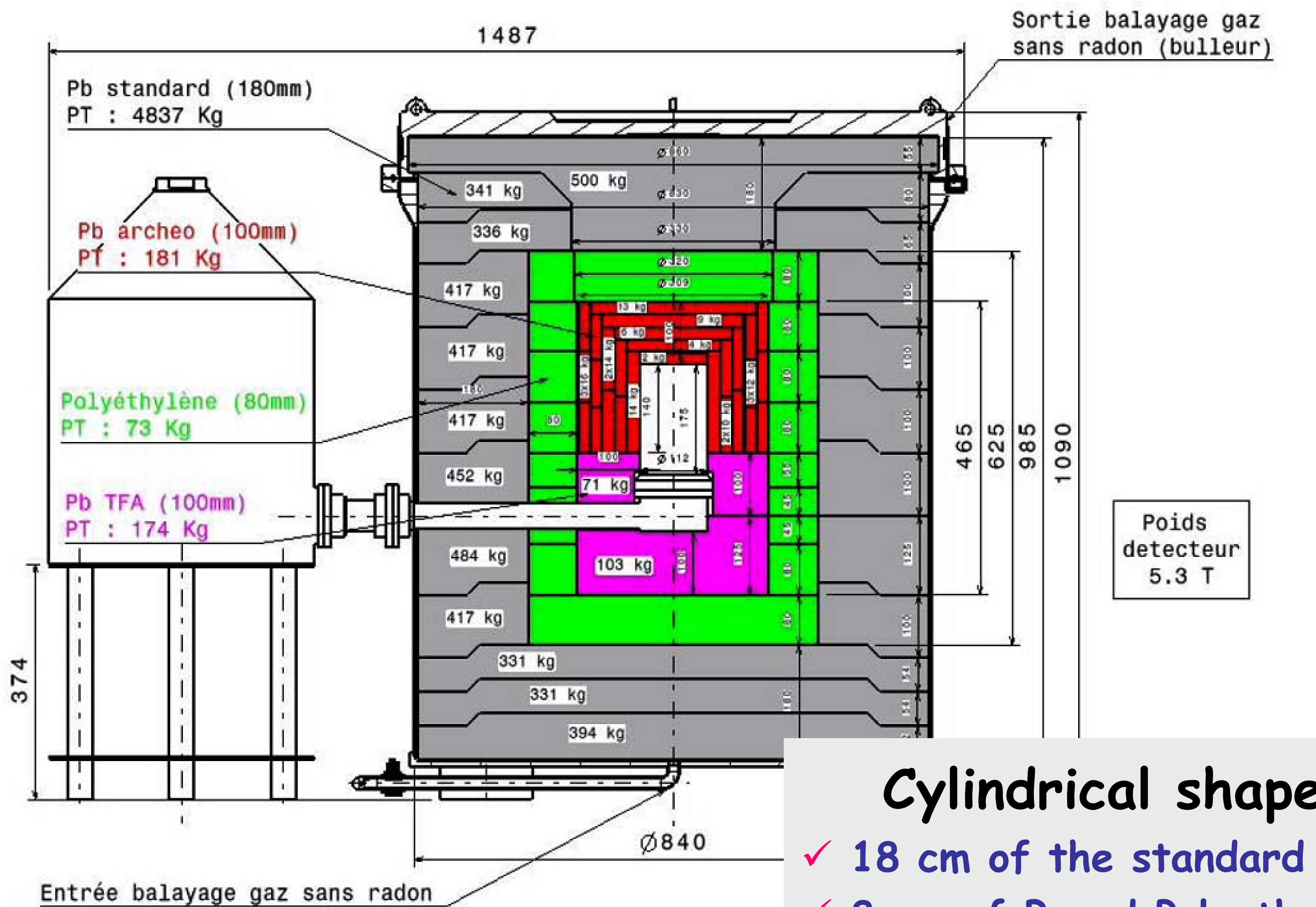
A lot of work has been done in the LSM, but already ~10 years ago.

Each time a colleague ordered a new detector, we try to improve the quality of the cryostat.

But for SuperNemo we will have to improve again our sensitivity, which implies a new cycle in material measurements and very close collaboration with all the other European groups.

In the meantime we plan to use of the same Ge’s, but with new shieldings (increase thickness, lower radon, neutron component, and larger samples (up to 5 kg!)

Design of a new configuration (with S.Jenzer, J.Forget)



Cylindrical shape

- ✓ 18 cm of the standard Lead,
- ✓ 8 cm of Bored Polyethylene ,
- ✓ 10 cm of the archaeological Lead.