New
low background
material technologies

Laura Cardani
Sapienza, Università di Roma

IFD2015 – INFN WORKSHOP for FUTURE DETECTORS
Torino, 16/12/2015

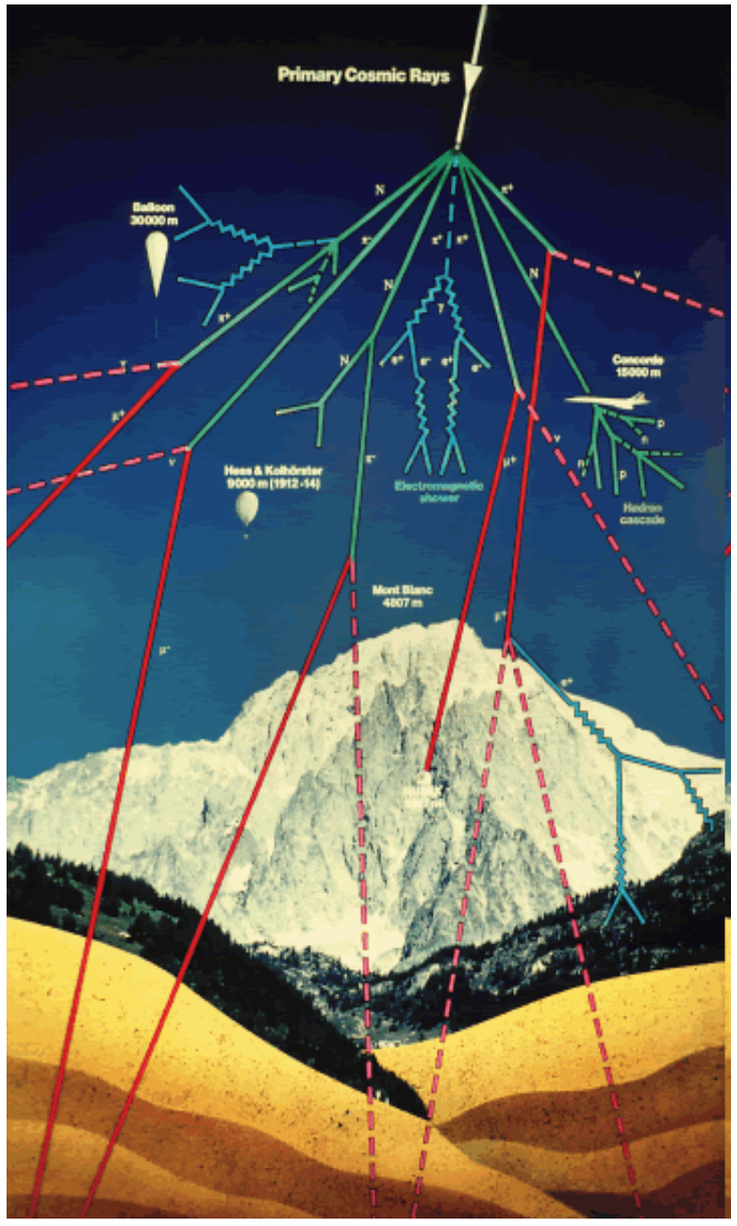
Why “low” background materials?

- Next generation experiments searching for rare events (for example, 0νββ decay or dark matter interactions) are going in the direction of zero background

- External background: going underground, using active/passive shields… it seems that it can be effectively suppressed

- Materials that constitute the detector become the main issue

- All the experiments are trying to purify the detector itself: LXe, LAr, crystals, scintillators… this is a big challenge!



Crystals

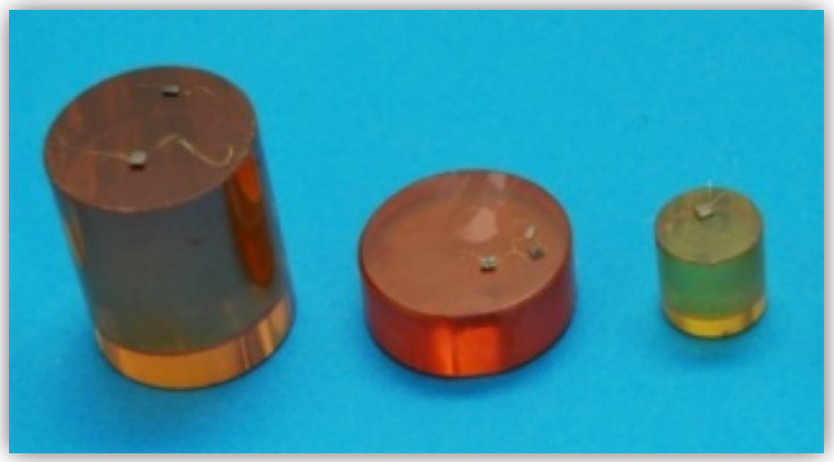
- Used by many experiments as calorimeters, scintillators…

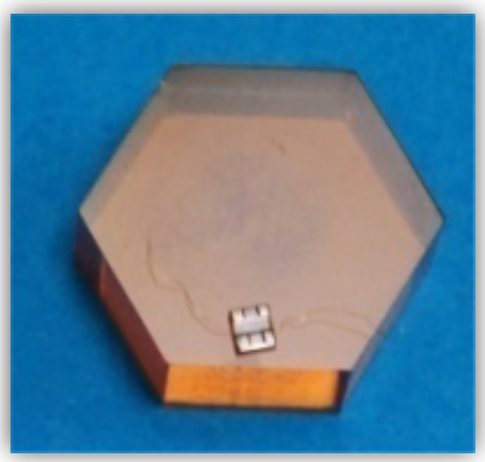
- CUORE (TeO_2), CUPID (now investigating also ZnSe and $ZnMoO_4$), AMoRE ($^{40}Ca^{100}MoO_4$), GERDA and Majorana (Ge)…

- CRESST ($CaWO_4$), Edelweiss, CoGeNT (Ge)…

- NaI (DAMA, SABRE, ANAIS, DM-Ice..)

…and many others





Crystals

- Used by many experiments as calorimeters, scintillators…
- CUORE (TeO_2), CUPID (now investigating also ZnSe and $ZnMoO_4$), AMoRE ($^{40}Ca^{100}MoO_4$), GERDA and Majorana (Ge)…
- CRESST ($CaWO_4$), Edelweiss, CoGeNT (Ge)…
- NaI (DAMA, SABRE, ANAIS, DM-Ice..)

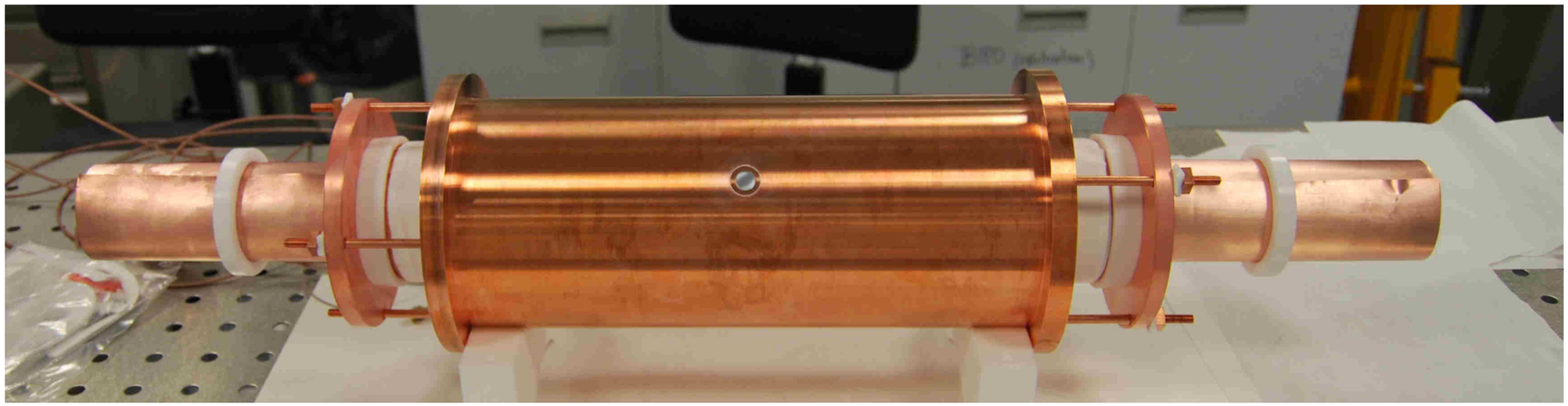
…and many others

- Contaminations from ^{40}K, ^{238}U, ^{232}Th and daughters
- Cosmogenic activation of materials
- Selection and monitoring of all materials, tools and facilities for crystal growth
- Selection of equipment for chemical and mechanical processing, storage

A famous example…NaI

- DAMA/LIBRA experiment (NaI(Tl) crystals) measured an annual modulation with high statistical significance in the low energy signal region: possible Dark Matter signal?

- Crystals contaminations limits the sensitivity of similar experiments



- KIMS collaboration: the best crystal has a contamination in ^{40}K ~2 times larger than DAMA (but some of them 10 times larger). They think the powder itself is the problem http://dx.doi.org/10.1063/1.4927984

- ANAIS collaboration: again contaminations in ^{40}K ~2 times larger than DAMA http://dx.doi.org/10.1063/1.4928001

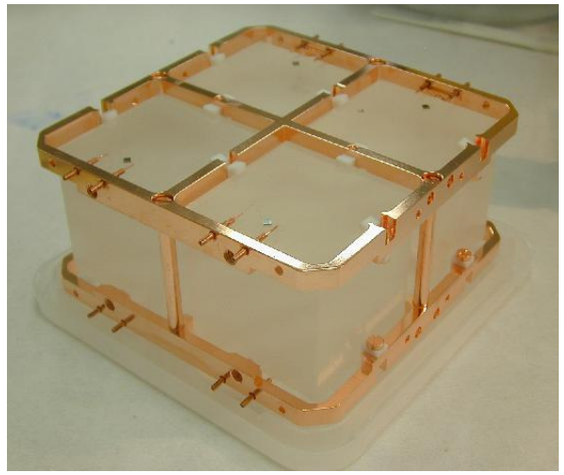
A famous example…NaI

- Another attempt from SABRE: producing clean powders is feasible
- Nevertheless, from these powders crystals again with 30 ppb of ^{40}K http://dx.doi.org/10.1063/1.4927983
- Test crystal (to be reproduced) with same K contamination as DAMA (talk at LNGS scientific committee)

	DAMA CRYSTALS [ppb]	DAMA [ppb]	Seastar-MV Lab [ppb]	Sigma Aldrich Astrograde [ppb]
[K]	13	100	12	3.5-18
[Rb]	<0.35	N/A	14	0.2
[U]	0.0005-0.0075	~0.02	0.0035*	<0.001*
[Th]	0.0007-0.01	~0.02	<0.001*	<0.001*

A good result: TeO_2

- Deeply investigated by CUORE over 20 years
- Must be $<3\times10^{-13}$ g/g in ^{238}U, ^{232}Th
- Strict protocol for each step of crystal production



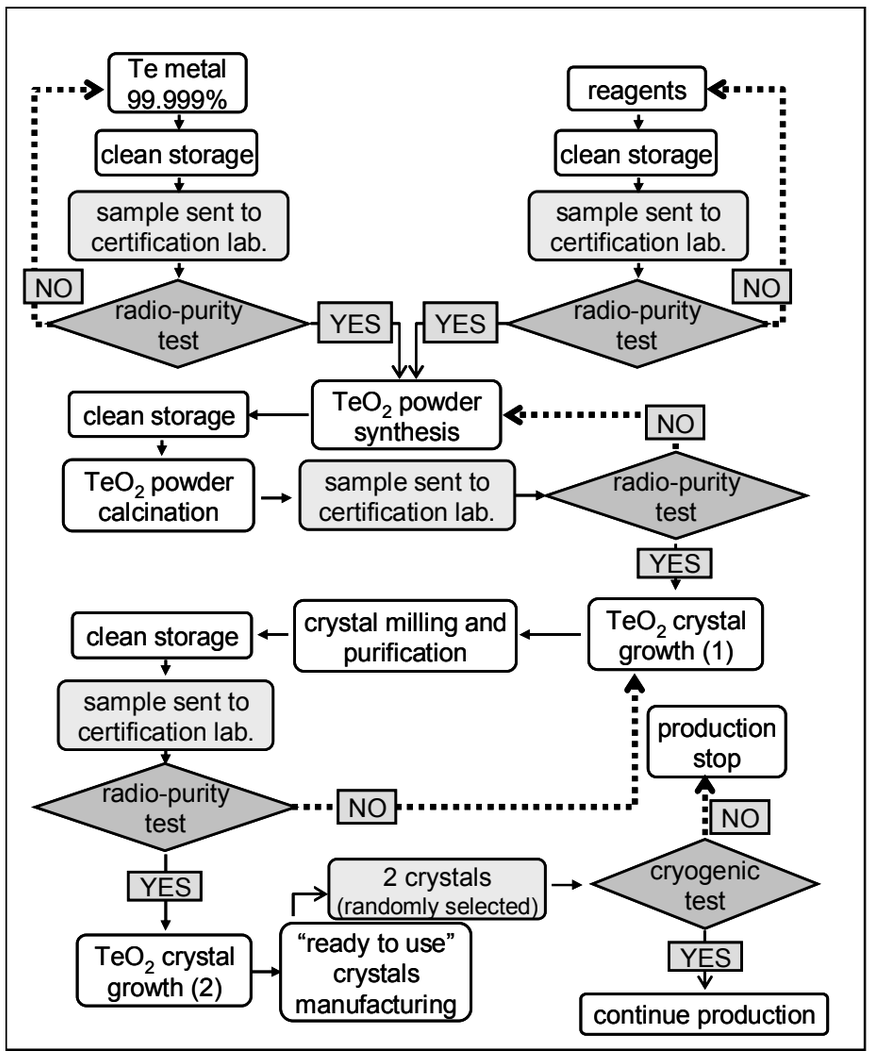


Fig. 2 Radio-purity certification protocol applied for TeO_2 crystals.

- Metallic Te dissolved in HCl and precipitated with NH_4OH is washed and calcinated for 1st growth
- Ingots of the 1st crystal re-treated for a 2nd growth
- Cutting, orienteering, shaping
- In clean room, etching and polishing (10^4 atomic layers to be removed)
- Packaging and underground storage

doi:10.1016/j.jcrysgro.2010.06.034

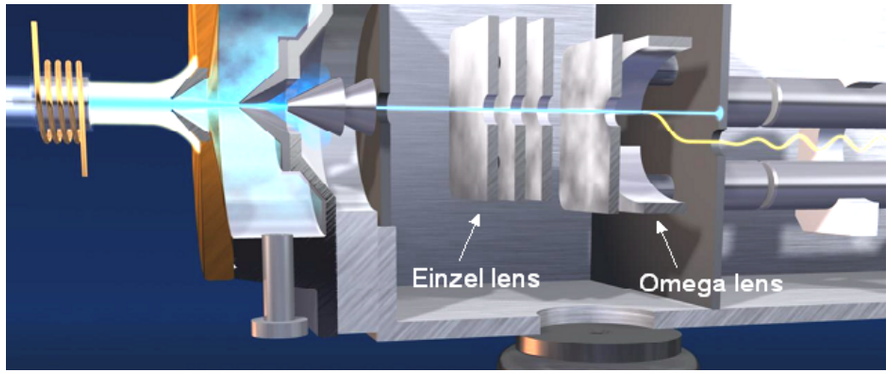
A good result: TeO_2

Each stage of production is monitored accurately:

- ICP-MS for contaminations in ^{232}Th and ^{238}U in Te, TeO_2 and consumables and in all other reagents. Sensitivity of 10^{-12} g/g achievable.

- HPGe to be sensitive also to broken chains and ^{40}K. For our purposes, 10^{-10} g/g on Th and U was enough, but 10^{-12} g/g achievable (long run)

- SBD for surface contaminations of specific materials ad monitoring of selected components (in particular for lapping cloths, packaging…)

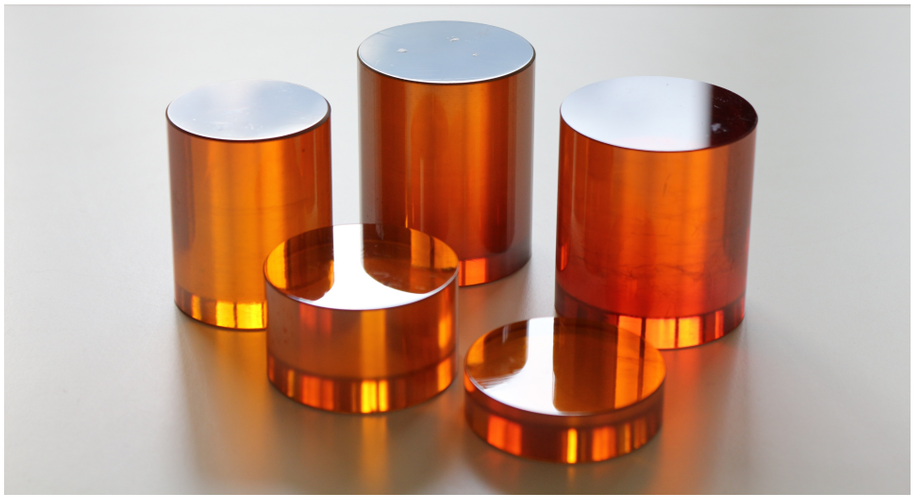


Cryogenic test

Bulk: <1.8x10^{-14} g/g in ^{238}U and <5.5x10^{-14} g/g in ^{232}Th

Some complications

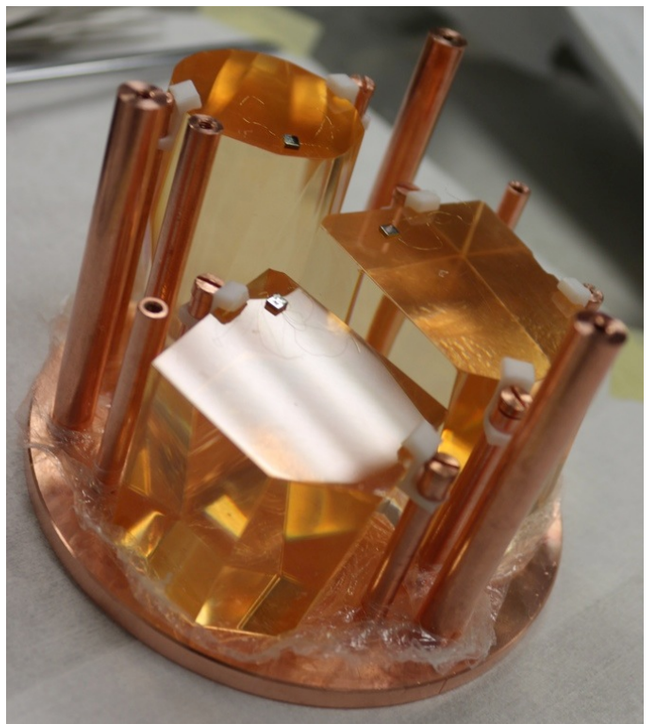
Many experiments will enrich the natural abundance of isotopes used in crystal growth



- Chemical purity may become an issue
- Keep low radioactive contaminations
- High quality of the final crystal
- Minimal loss of enriched material

Example: Mo-based crystals

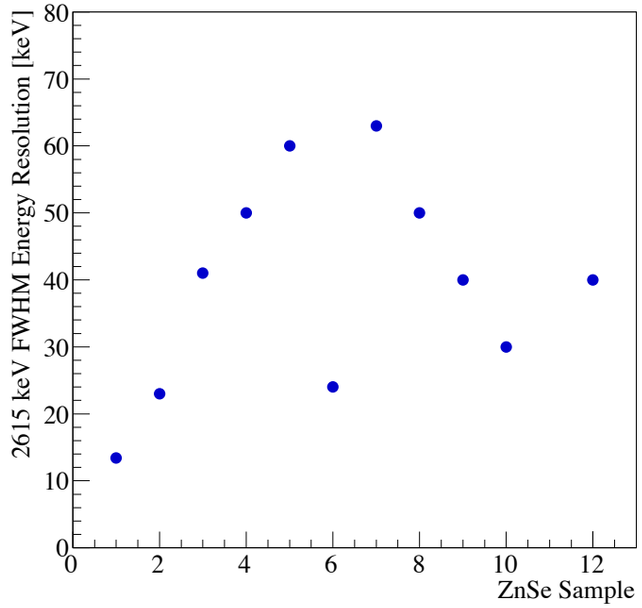
- typical purity level of enriched Mo is 99.9%
- tens-hundreds of ppm of transition metals
- 1% of high purity ZnMoO4 added to MoO_3 for sublimation (suppresses contaminations) + annealing
- double recrystallization in aqueous solution by re-precipitation of impurities on sediments

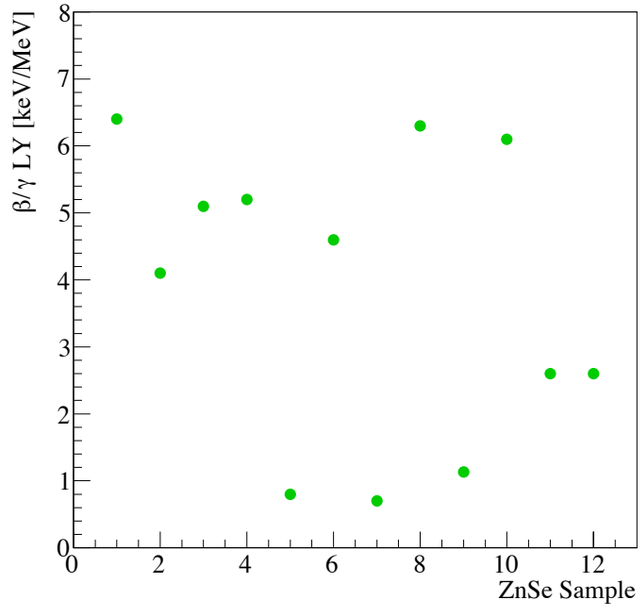


Some complications

- Performance improvements

- Mono-crystalline structure is favorable, but difficult to obtain for large-size crystals





- Maintain the achieved purity

- The experience of TeO_2 shows the importance of avoiding cosmic activation, Rn-implantation, re-contamination due to human activities

Disposing of a large amount of pure enriched material, growing crystals with better and better chemical and radio-purity, and avoid crystal activation and re-contaminations, could eventually require an underground site for crystal production

Passive material: copper

Good mechanical/thermal properties radio-pure —> structural parts of many detectors

Example with a well known copper: NOSV (Electronic Though Pitch)

Neutron Activation Analysis and HPGe spectroscopy showed no traces for contaminations

	µBq/kg	g/g
^{232}Th	<2	$<0.5\times10^{-12}$
^{238}U	<70	$<6\times10^{-12}$

Passive material: copper

Good mechanical/thermal properties radio-pure —> structural parts of many detectors

Example with a well known copper: NOSV (Electronic Though Pitch)

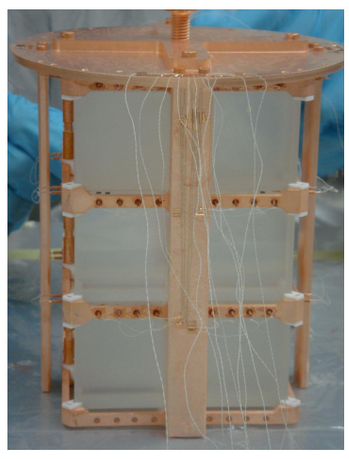
Neutron Activation Analysis and HPGe spectroscopy showed no traces for contaminations

	µBq/kg	g/g
^{232}Th	<2	$<0.5\times10^{-12}$
^{238}U	<70	$<6\times10^{-12}$

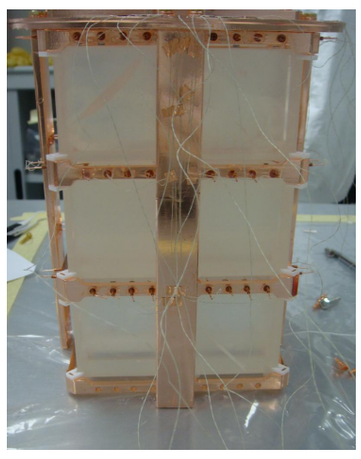
Study of surface contaminations is difficult

doi:10.1016/j.astropartphys.2013.02.005

T1



T2



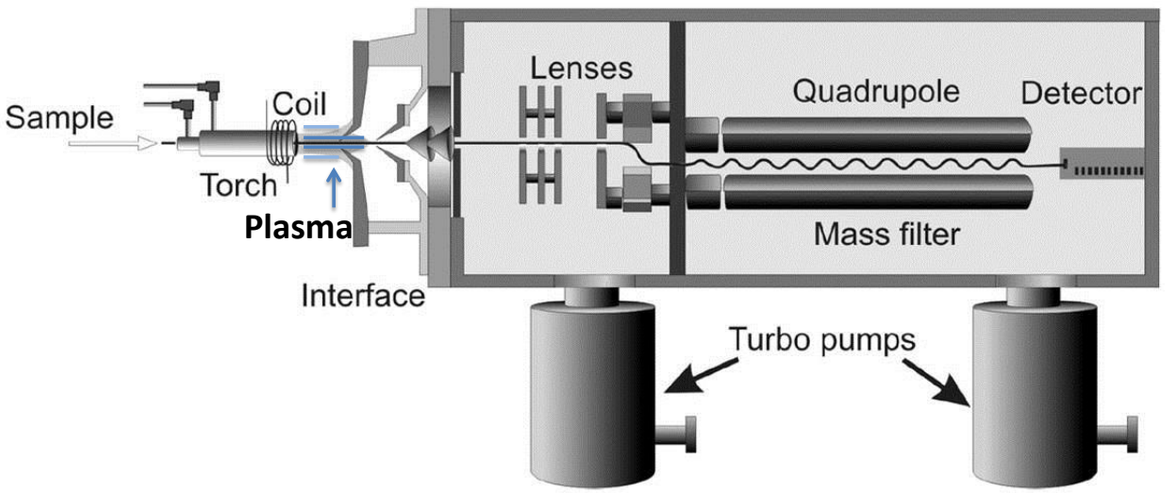
T3

Large arrays provide sensitivities of tens of nBq/cm^2

For next generation detectors, we must ensure an even better purity (~ a factor of 10)

This becomes a problem also for assay

Improving the sensitivity: bulk



- Liquid sample sprayed into a hot plasma, where it is ionized
- Mass spectrometer separates iones (mass/charge ratio)
- Tracers can be added for isotope dilution

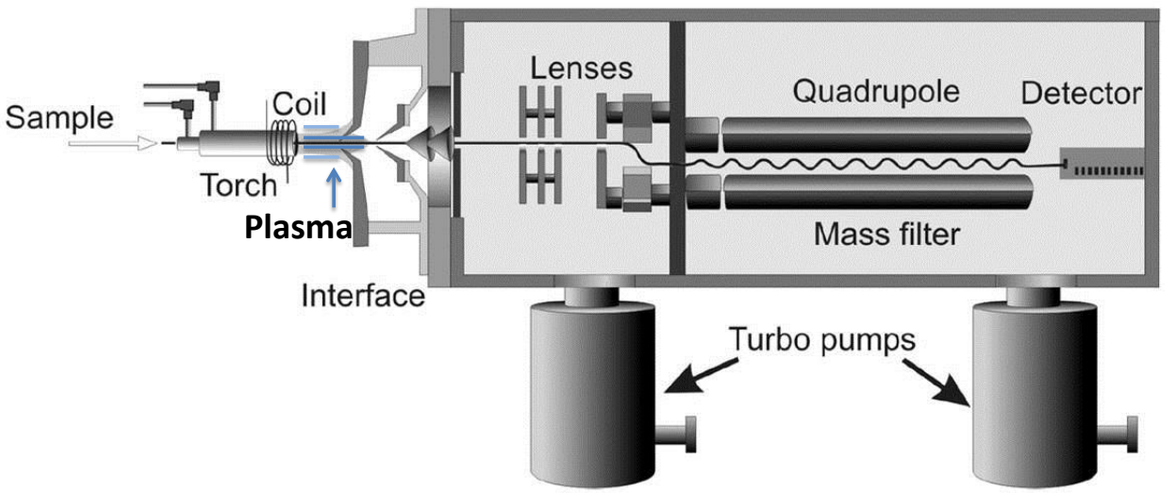
- Copper: concentrate the analytes while reducing the matrix levels
- Sample + tracers into vials.
- Dissolve in nitric acid: Th and U negatively charged
- Pass through anion-exchange column and analyze the eluent

NIM A 775 (2015) 93-98

- MTD of 0.034 μBq/kg ^{232}Th
- MTD of 0.131 μBq/kg ^{238}U

applied to NOSV, may result in encouraging values also for this material!

Improving the sensitivity: bulk



- Liquid sample sprayed into a hot plasma, where it is ionized
- Mass spectrometer separates iones (mass/charge ratio)
- Tracers can be added for isotope dilution

It applies also to:

- Lead (0.4 μBq/kg ^{232}Th and 17 in ^{238}U)
- Titanium (6 μBq/kg ^{232}Th and 30 in ^{238}U)
- Stainless Steal (4 μBq/kg ^{232}Th and 62 in ^{238}U)

E. Hoppe's talk, LRT 2015

But:

- Systematics to be better understood
- Not sensitive to "broken" chains

Electro-formed copper

At the moment, we do not have more precise measurements on NOSV copper.

Alternative: electro-formed copper

- When electro-plating copper from a solution onto cathodes, most of the contaminants do not follow copper (different electrochemical value)

- Electrodeposition OFHC copper on stainless steel forms
- Everything done underground (reduce activation)
- Outstanding purity: 0.3 μBq/kg for ^{232}Th and ^{238}U
- Can we reach the same purity with NOSV?

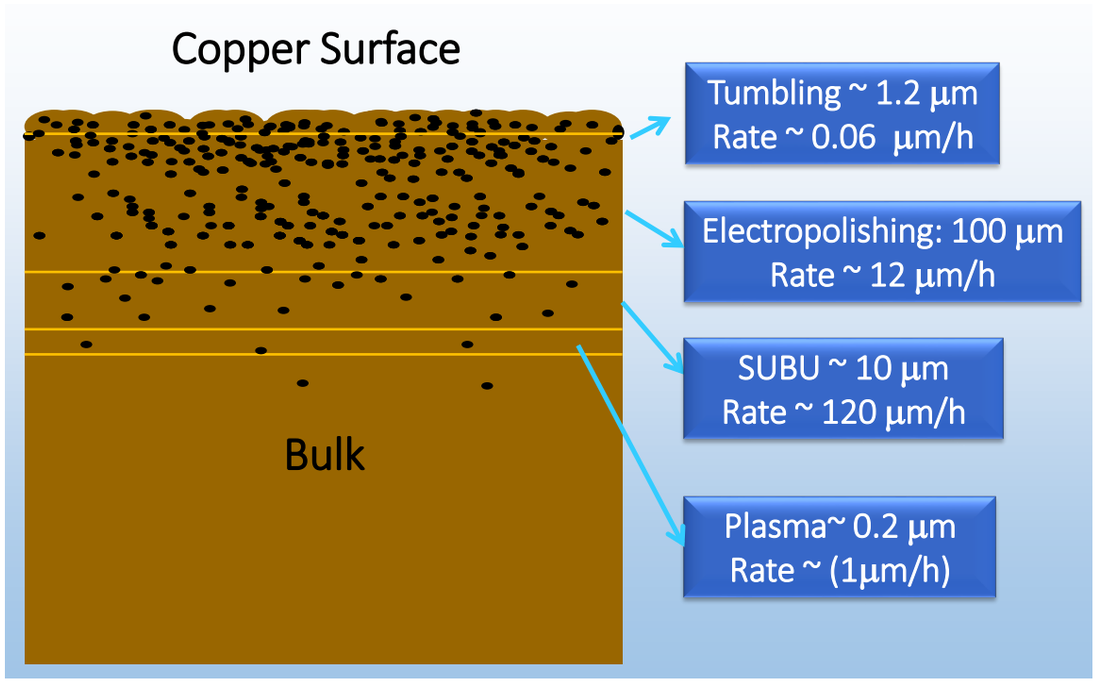
Electro-formed copper (2)

If NOSV copper turns out to be too “dirty” for next generation experiments, can we use electro-formed copper?

Yes, but we might have to check other features: surface, in principle, could be as contaminated as those of NOSV.

Cleaning of NOSV made with TECM:

- Tumbling
- Electropolishing
- Chemical etching
- Magnetron Plasma etching



on courtesy of A.Camacho (LNL)

resulted in tens of nBq/cm^2 of contaminations

Is there a way to have a similar sensitivity on electro-formed copper in a reasonable time?

Improving the sensitivity: surface

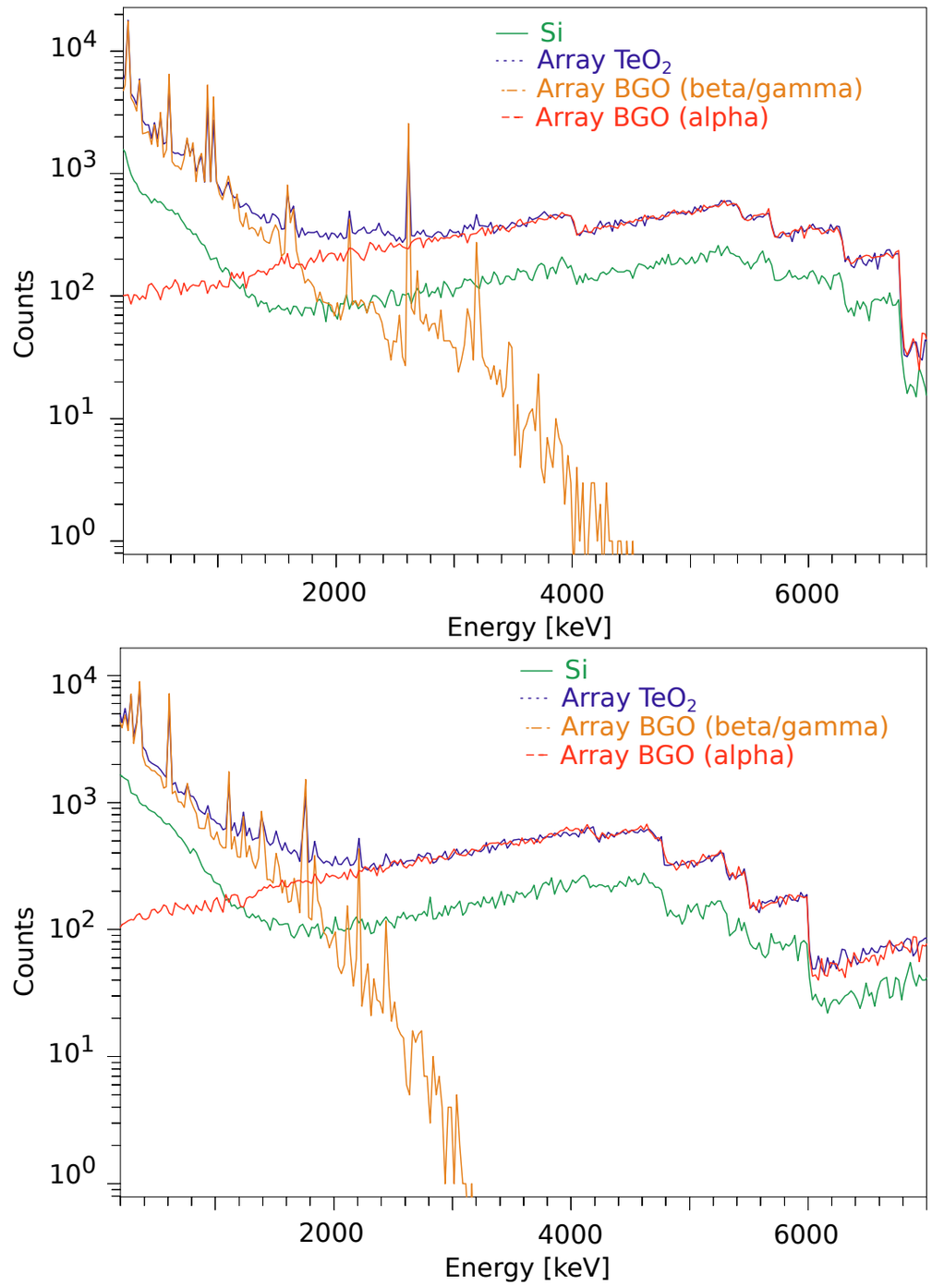
Scintillating bolometers allow to achieve an extremely high sensitivity on surface contaminations in a few weeks of measurements.

Advantages:

- Simultaneously α and γ spectroscopy
- Wide active surface (hundreds of cm^2)
- No dead layers
- Excellent energy resolution (< %)
- Low intrinsic background

with these features, we can achieve a ~tens of nBq/cm^2 in a few weeks

http://stacks.iop.org/1748-0221/7/i=10/a=P10022



Conclusions

- **The development of pure material is crucial for many experiments in different fields**
- **The production of large amount of radio-pure material will likely demand for dedicated underground structures**
- **Most of the purity levels are extremely difficult to assess with conventional techniques**
- **New, versatile technologies have been proposed**