COSMOGENIC RADIONUCLIDES
in stainless steel and copper

Matthias Laubenstein

Laboratori Nationali del Gran Sasso, LNGS, Assergi, Italy

Gerd Heusser

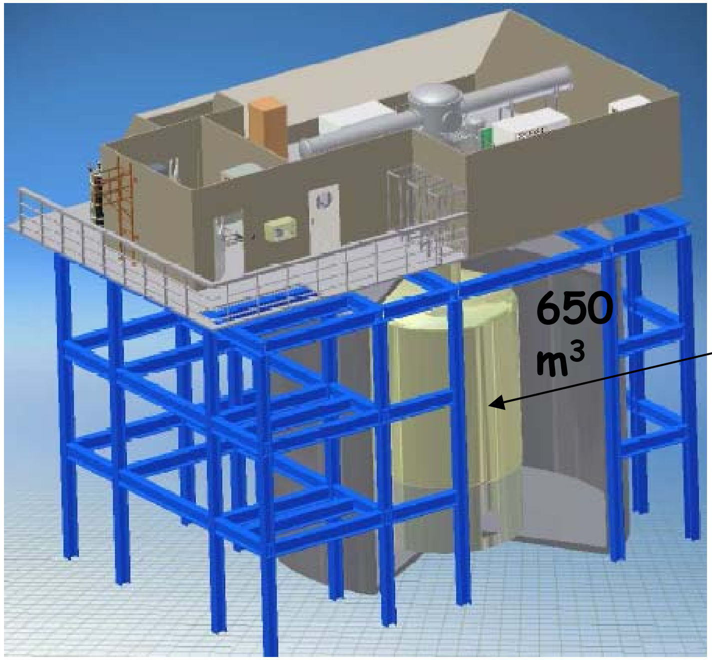
Max-Planck-Institut für Kernphysik, Heidelberg, Germany

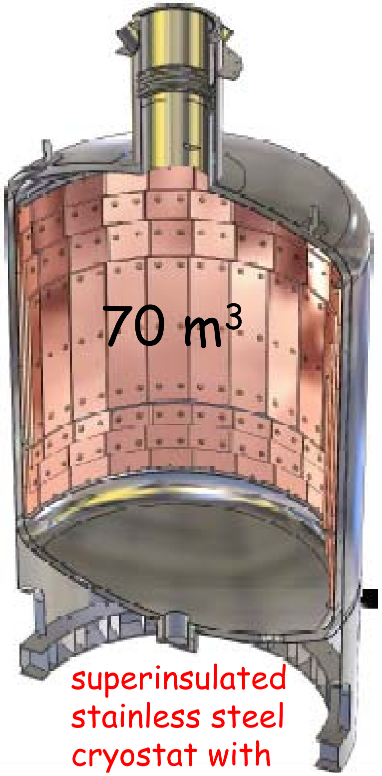
- ***cosmic ray activation analysis at LNGS surface and irradiation ages***
- ***interpretation of deviation from secular equilibrium in U/Th chain***
- ***comparison of cosmogenic production rates in Cu with Monte Carlo simulation***

see also Maneschg et al., NIM A 593 (2008), 448-453

GERDA

GERmanium **D**etector **A**rray for the search of neutrinoless double beta decay of ^{76}Ge



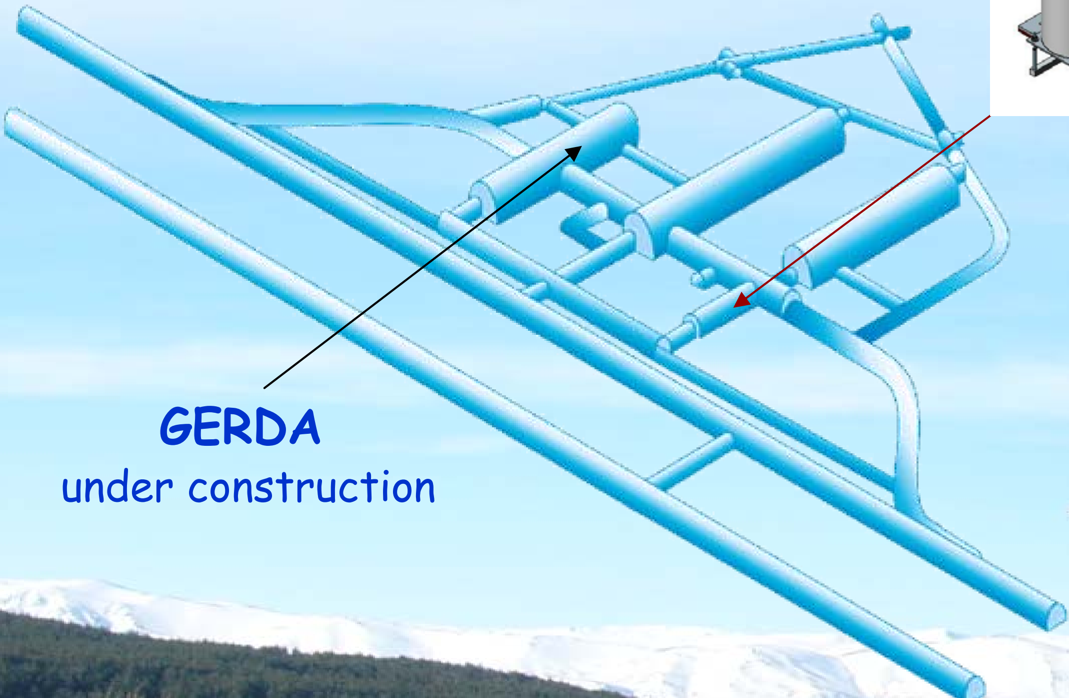


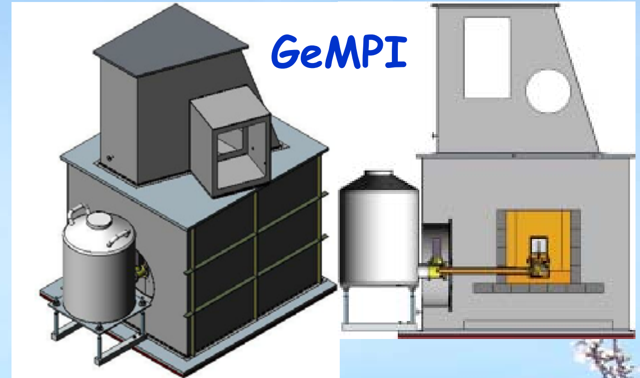
superinsulated
stainless steel
cryostat with
internal Cu shield

low radioactivity stainless steel
($^{228}Th \leq 5$ mBq/kg)

Laboratori Nationali del GranSasso

(3800 mw.e. – 10^6 muon flux suppression)





Cosmic ray induced isotopes in stainless steel (FeCrNiMo) measured for GERDA

Steel 457.1	activity [mBq/kg]					
sample	cosmogenic radionuclide					
$T_{1/2}$ →	^{7}Be 53.3 d	^{54}Mn 312.2 d	^{58}Co 70.9 d	^{56}Co 77.3 d	^{46}Sc 83.8 d	^{48}V 16.0 d
Production → channels	spallation	^{56}Fe(n,p2n) (μ^-,v2n)	^{60}Ni(n,p2n) (μ^-,v2n) ^{58}Ni(n,p)	^{58}Ni(n,p2n) (μ^-,v2n)	^{48}Ti(n,p2n) (μ^-,v2n) spallation on Fe	^{50}Cr(n,p2n) (μ^-,v2n) spallation on Fe
G1	≤ 3.9	1.3±0.4	0.67±0.34	≤ 0.32	≤ 0.35	0.30±0.11
G2	≤ 3.0	1.5±0.1	0.99±0.12	0.17±0.06	0.24±0.06	0.36±0.07
G3	≤ 5.7	0.92±0.24	0.56±0.23	≤ 0.62	≤ 0.54	0.27±0.11
G4	9.6±2.9	2.0±0.3	0.71±0.26	≤ 0.71	≤ 0.67	0.31±0.13
G5	4.8±1.7	1.7±0.2	0.69±0.16	0.28±0.10	0.47±0.14	0.22±0.09
G6	13.6±2.5	1.4±0.2	0.59±0.20	≤ 0.42	≤ 0.31	0.40±0.12
G7	≤ 5.9	1.6±0.3	0.54±0.27	≤ 0.6	0.61±0.26	0.39±0.13
P.Rate *sea level* [(10^3 sec)$^{-1}$ kg^{-1}]	*4.5±0.7*	*2.7±0.3*	*0.6±0.09*	*0.24±0.04*	*0.22±0.04*	*0.4±0.04*

^{51}Cr: *2.0±0.7* ^{52}Mn: *0.35 ± 0.25* ^{56}Ni: *0.17 ± 0.05* [mBq/kg]

3.2 mBq/kg (Heusser, 1994)

^{60}Co before: **11.1±0.5** after: **11.5±0.6** [Bq/kg]

irradiation time

← 327 d at sea level

at underground than exposed for 314 d at LNGS surface (≈ 907 g/cm2)

≈ 200 d

≈ 600 d

all others are compatible with saturation

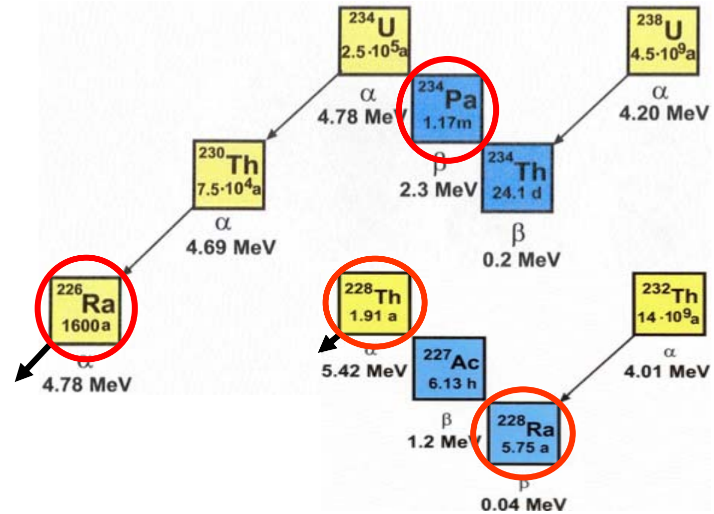
34.6 ± 5.3 measured at Heidelberg 63 days earlier

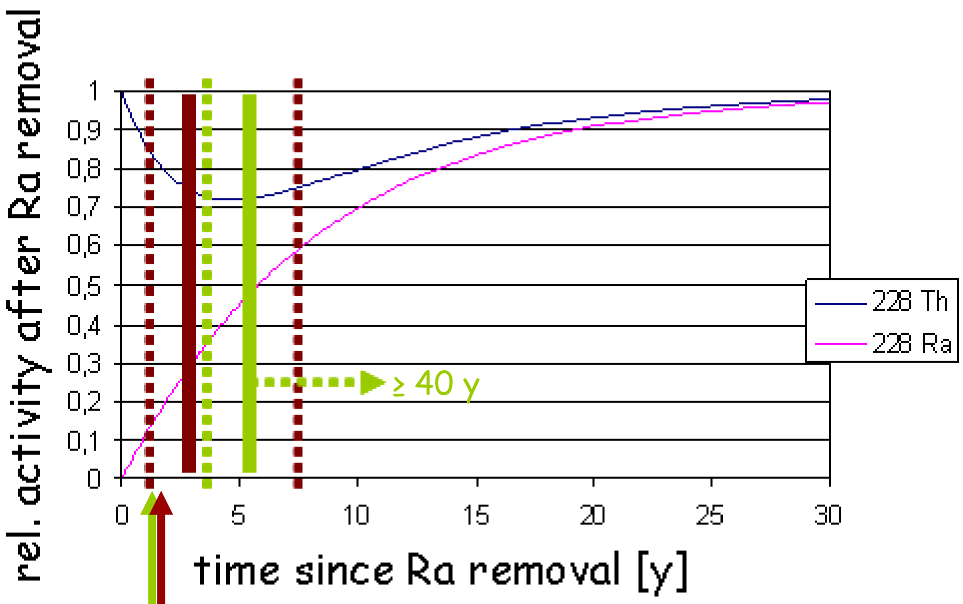
⇒ ^{7}Be produced in cito, but contamination from filtration dust (up to 40 kBq/kg, Wershofen PTB)

← normalized to sea level (× 0.42)

Attempt to date steel production by disequilibrium in the Th-chain

sample	primordial radionuclides [mBq/kg] and ratios					
	^{234m}Pa	^{226}Ra	^{234m}Pa/^{226}Ra	^{228}Th	^{228}Ra	^{228}Th/^{228}Ra
old ship steel	5.7±1.4	0.15±0.02	38±11	0.46±0.07	0.47±0.05	0.98±0.18
G5	54±16	1.0±0.6	54±36	1.5±0.2	1.0±0.5	1.5±0.77
G7	≤ 56	3.9±1.6	≤ 10-24	5.2±0.5	1.9±1.0	2.7±1.5





according to experts most likely the disequilibrium is introduced through additives in the iron-steel conversion.

Since electric furnace melting uses a large fraction of scrap, the mean age will be higher

⇧

Ra removal seems not be connected with steel production

⇧

sea level exposure age via ^{54}Mn

Cosmogenic activation of Cu during 270 days at LNGS surface (≈ 930 g/cm2)

radionuclide	halflife	(saturation) activity [μBq/kg]		
cosmogenic		exposed	estimated from Cu used in HDM	estimated
^{56}Co	77.31 d	230 ± 30		557 X2
^{57}Co	271.83 d	1800 ± 400	2100	2147 ✓
^{58}Co	70.86 d	1650 ± 90	3600	3878 X2
^{60}Co	5.27 y	2100 ± 190	2100	2367 ✓
^{54}Mn	312.15 d	215 ± 21	700	791 X3
^{59}Fe	44.5 d	455 ± 120		157 :4
^{46}Sc	83.79 d	53 ± 18		93 ✓
^{48}V	15.97 d	110 ± 40		
primordial				
^{226}Ra (U)	1600 y	< 35	< 16	
^{228}Th (Th)	1.91 y	< 20	< 12	
^{40}K	1.277×10^{9} y	< 120	< 110	

Monte Carlo simulation of hadronic interaction **Cebrian S.**, 2006. (IDEA-Projekt),. http://idea.dipscfm.uninsubria.it/frontend/docs/reports/report_upgrade_codes.pdf

applying:

activity = PR/2.1 × $(1-e^{-\lambda t})$

⇨ ≤ 37 days exposed at sea level

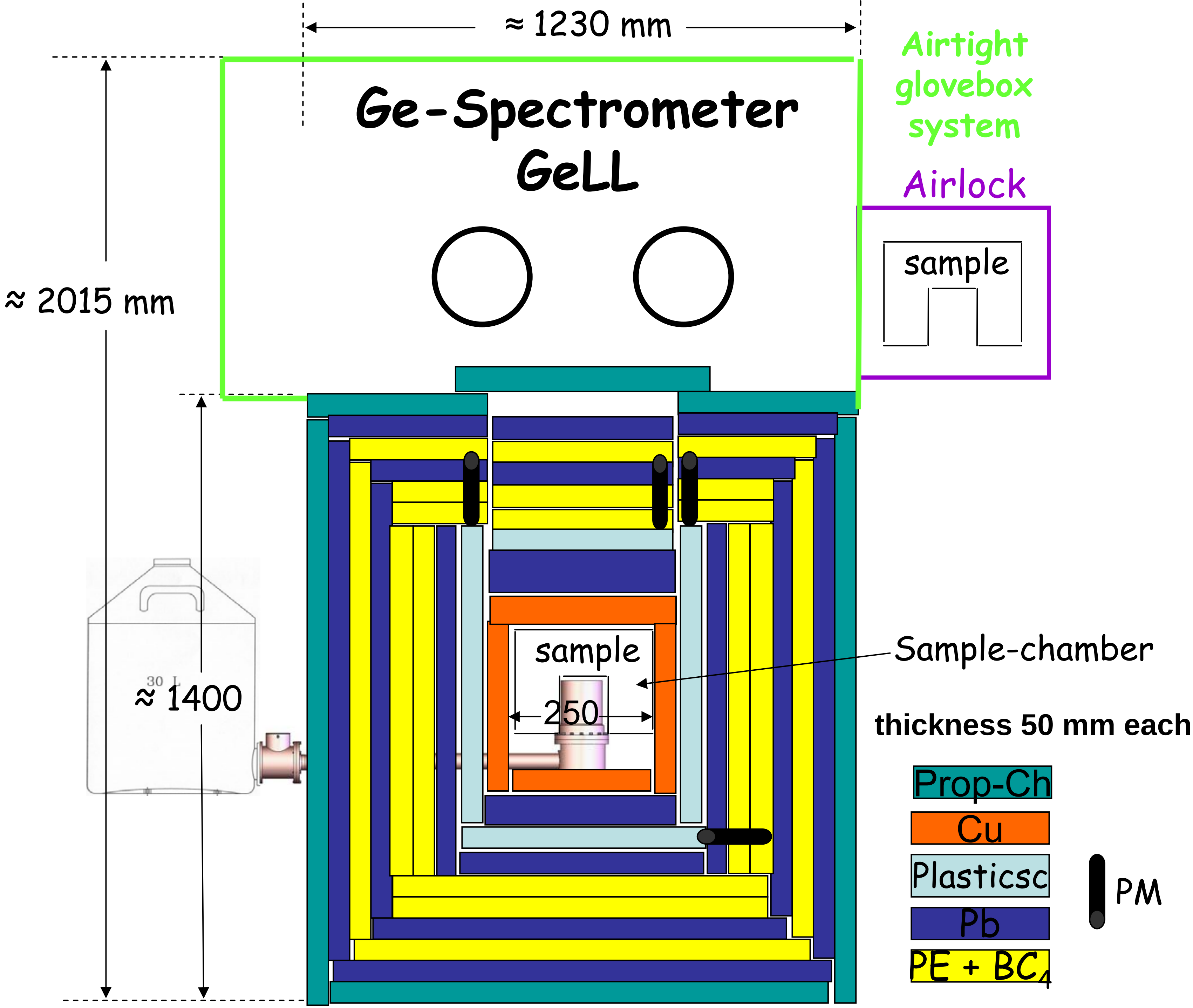
summary

- cosmic activation of metals is measurable with high sensitive Ge-spectrometry
- the exposure history of the investigated samples is accessible
- deviation from secular equilibrium in the primordial decay chains cannot be used for dating stainless steel production, but seems to reflect a mean age of the scrap material
- cosmogenic production rates in Cu can be rather well estimated by the Monte Carlo method

Further possible metal targets:

Al, Au, Cr, Co, Hg, Mn, Ni, Ti, V, W and Zn

enlarge the database on cosmic induced production rates
also for testing the Monte Carlo methods


≈ 1230 mm
Airtight glovebox system
Ge-Spectrometer GeLL
Airlock
sample
≈ 2015 mm
≈ 1400
sample
250
Sample-chamber
thickness 50 mm each
Prop-Ch
Cu
Plasticsc
Pb
PE + BC4
PM