Radon and material radiopurity assessment for the NEXT double beta decay experiment



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on behalf of NEXT Collaboration and LSC Radiopurity Service





NEXT: <u>Neutrino Experiment with a Xenon</u> <u>Time-Projection Chamber</u>

- Goal and principle of detection
- Search for $\beta\beta$ of ¹³⁶Xe (Q=2.458 MeV) with ~100 kg at Canfranc Underground Laboratory (LSC, Spain)
- Challenge: measurement of topological signature
 - + optimization of energy resolution
 - + detector = source approach
- **Design:** high pressure gaseous xenon TPC with proportional electroluminescent (EL) amplification



NEXT: <u>Neutrino Experiment with a Xenon</u> <u>Time-Projection Chamber</u>



Sensitivity and background requirements

- Energy resolution: <1% FWHM at Q_{ββ}
- \rightarrow electroluminiscence
- Background level: <6 10⁻⁴ c keV⁻¹ kg⁻¹ y⁻¹
- → pattern recognition + radiopurity control ²⁰⁸TI: 2.615 MeV ²¹⁴Bi: 2.448 MeV

Status

- Work on several prototypes still ongoing
- Installation of **shielding and ancillary system** at LSC completed in 2014





NEXT: <u>Neutrino Experiment with a Xenon</u> <u>Time-Projection Chamber</u>

Status

• Underground commissioning of the **NEW detector** (dowscale 1:2 in size, 1:8 in mass of NEXT-100) underway and first data expected along 2015.





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Radiopurity measurements: techniques

Mass spectrometry

- Glow Discharge Mass Spectrometry (GDMS):
 - Performed by Evans Analytical Group in France
 - Typically used for direct trace analysis of inorganic solids
 - Output: U, Th, K concentrations
- Inductively Coupled Plasma Mass Spectrometry (ICPMS)
 - Performed by CIEMAT (Unidad de Espectrometría de Masas) in Spain
 - Sensitivity at ppt level

Ge gamma-ray spectrometry

- Fast, requiring very small samples
- Several p-type closed-end coaxial HPGe detectors at Canfranc

	Detectors	DAQ	Shielding	Operation	
LSC Radiopurity Service: Oroel, Anayet, Tobazo, Latuca, Aspe	410-420 cm ³ Al cryostats	Canberra DSA 1000 modules	5 or 10 cm Cu + 20 cm low activity Pb + flux of N ₂ gas	Hall C	
U. Zaragoza: Paquito	190 cm ³ Cu cryostat	standard Canberra LA + ADC	10 cm arch. Pb + 15 cm low activity Pb + flux of N ₂ gas	Hall E	

Activity directly assessed through γ emissions

Non-destructive, no sample pre-treatment

Radiopurity measurements: techniques

Ge gamma-ray spectrometry \succ

—	Background	counting	rates:	c d ⁻¹ kg ⁻¹
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		annig rat		²³² Th: ²⁰⁸ Tl	²³⁸ U: ²¹⁴ Bi	⁴⁰ K
Cu (cm)	Detector name	Mass (kg)	100-2700 keV	583 keV	609 keV	1461 keV
5	GeAnayet	2.183	714±3	$3.73 {\pm} 0.40$	$1.76 {\pm} 0.28$	$0.31 {\pm} 0.20$
10	GeAspe	2.187	441 ± 2	$3.77 {\pm} 0.47$	$3.74{\pm}0.45$	$0.58 {\pm} 0.24$
5	GeLatuca	2.187	667 ± 3	$3.02{\pm}0.32$	$5.66{\pm}0.39$	$0.47 {\pm} 0.13$
5	GeOroel	2.230	461 ± 2	$0.98{\pm}0.23$	$2.69{\pm}0.30$	$0.32 {\pm} 0.13$
-	Paquito	1	79 ± 2	$0.27{\pm}0.09$	$0.48 {\pm} 0.21$	$0.25 {\pm} 0.13$

Cu (cm)	Detector	100-2700 keV
10	GeLatuca	313 ± 2
10	GeOroel	148 ± 1



Radiopurity measurements: results

More than one hundred samples analyzed for NEXT since 2011

• Radiopurity control in the NEXT-100 double beta decay experiment: procedures and initial measurements V. Alvarez et al, 2013 JINST 8 T01002

• Radiopurity control in the NEXT-100 double beta decay experiment, V. Alvarez et al, AIP Conf. Proc. 1549 (2013) 46

• Results of the material screening program of the NEXT experiment T. Dafni et al, Proceedings of ICHEP 2014, to appear in NPB (PS), arXiv:1411.1222

• Radiopurity assessment of the tracking readout for the NEXT double beta decay experiment S. Cebrián et al, arXiv:1411.1433



Radiopurity measurements: shielding

Passive shielding:

- External 20-cm-thick Pb
- Internal 12-cm-thick Cu







- Lead and copper from different suppliers (Tecnibusa, Cometa, Luvata) analyzed
- Components for structure also screened: 316Ti stainless steel for walls, structural steel S-275, foam joints, ...

Radiopurity measurements: shielding

• Refurbished **Britannia lead** from the **OPERA experiment** (80 Bq/kg of ²¹⁰Pb) used after brick production (60 t)

• CuA1 (= ETP) **copper** from **Lugand Aciers** used for inner shield.





Material	Supplier	Technique	units	²³⁸ U	²²⁶ Ra	²³² Th	²²⁸ Th	²³⁵ U	⁴⁰ K	⁶⁰ Co	¹³⁷ Cs
Pb	Britannia	Ge	mBq/kg		< 0.83		< 0.48		<1.3	< 0.08	
Pb	Britannia	GDMS	mBq/kg	0.35		0.094			0.12		
Cu	Lugand Aciers	Ge	mBq/kg	<4.1	<0.16	< 0.15	< 0.13	<0.17	< 0.37	0.04±0	.01<0.04
Cu	Lugand Aciers	GDMS	mBq/kg	< 0.012		< 0.004			0.062		

Radiopurity measurements: vessel

Pressure vesel:

- To hold 15 b
- Made of stainless steel

• Samples of 316Ti **Stainless Steel** from **Nironit** initially screened with Ge: for body, endcaps and flanges.

 Complementary results obtained by GDMS analysis

• Samples of other materials (titanium, inconel for bolts, ...) and TIG-MIG welding on the SS also screened





Material	Supplier	Technique units	²³⁸ U	²²⁶ Ra	²³² Th	²²⁸ Th	²³⁵ U	⁴⁰ K	⁶⁰ Co	¹³⁷ Cs
316Ti SS, 10mm	Nironit	GDMS mBq/kg	< 5.0		< 0.12			< 0.16		
316Ti SS, 15mm	Nironit	GDMS mBq/kg	<9.9		< 0.41			< 0.12		
316Ti SS, 50mm	Nironit	GDMS mBq/kg	<7.4		< 0.12			< 0.09		

Radiopurity measurements: field cage and EL

Field cage:

- Using copper rings connected to resistors and HD polyethylene as insulator
- Wire meshes separating the different field regions made of stainless steel
- Reflector panels made of PTFE and coated with a wavelength shifter (TPB)

Several types of plastics screened, HD
Polyethylene from Simona selected for NEW

 Resistors from different suppliers analyzed,
HV chip resistors from Ohmcraft used for NEW





Material	Supplier	Techniq	ue units ²³⁸ U	²²⁶ Ra	²³² Th	²²⁸ Th	²³⁵ U	40 K	⁶⁰ Co	¹³⁷ Cs
Polyethylene	In2Plastics	Ge	mBa/kg <18	< 0.88	< 0.81	< 0.70	< 0.4	<3.4	< 0.14	< 0.14
Polyethylene	Simona	ICPMS	mBq/kg <0.062		< 0.021					
Polyethylene	Simona	Ge	mBq/kg < 10	< 0.46	< 0.58	< 0.36	< 0.25	4.2±0.6	< 0.07	< 0.09
Resistors	Ohmeraft	Ge	µBq/pc 560±150	217±10	44±4	36±3		95±13	<2	<2
S. Cebrián, LRT2015 Workshop, Seattle 18-20 March 2015										

Radiopurity measurements: tracking plane

Tracking readout plane:

• Array of 110 "Dice Boards" (DB), behind the EL region

- Each DB contains 8x8 SiPM sensors with a pitch of ~1 cm and is coated with TPB
- The substrate is made of kapton and copper from Flexible Circuits Inc., showing better radiopurity than cuflon boards



• **SiPMs** from **SensL** company (MLP, Moulded Lead-frame Package plastic SMT elements, MicroFC-10035-SMT-GP) chosen after successful radioassay ⁴⁰K activity quantified for TSV (Through Silicon Via) elements





TP NEW

Radiopurity measurements: tracking plane

Component	Supplier	Unit	²³⁸ U	²²⁶ Ra	²³² Th	²²⁸ Th	²³⁵ U	⁴⁰ K	⁶⁰ Co	¹³⁷ Cs
Cuflon	Polyflon	mBq/kg	<33	<1.3	<1.1	<1.1	<0.6	4.8 ± 1.1	< 0.3	< 0.3
Bonding film	Polyflon	mBq/kg	$1140{\pm}300$	487±23	79.8±6.6	$66.0 {\pm} 4.8$		$832 \pm \! 87$	<4.4	<3.8
Cuflon Dice Board	Pyrecap	mBq/pc	< 7.6	$0.28 {\pm} 0.08$	< 0.28	< 0.16	< 0.13	<1.2	< 0.07	< 0.06
Kapton-Cu Dice Board	Flexiblecircuits	mBq/pc	<1.3	$0.031 {\pm} 0.004$	$0.027{\pm}0.008$	$0.042{\pm}0.004$		12.1 ± 1.2	< 0.01	< 0.01
FFC/FCP connector	Hirose	mBq/pc	<50	4.6±0.7	6.5±1.2	6.4±1.0	<0.75	3.9±1.4	< 0.2	< 0.5
P5K connector	Panasonic	mBq/pc	<42	$6.0 {\pm} 0.9$	9.5±1.7	9.4±1.4	< 0.95	4.1±1.5	< 0.2	< 0.8
Thermopl. connector	Molex	mBq/pc	<7.3	$1.77 {\pm} 0.08$	$3.01{\pm}0.19$	$2.82{\pm}0.15$	< 0.31	$2.12{\pm}0.25$	< 0.022	0.27±0.03
Solder paste	Multicore	mBq/kg	<310	<2.7	<4.7	<2.5	<5.2	<13	<1.0	<1.6
Solder wire	Multicore	mBq/kg	<4900	$(7.7\pm1.2)10^2$	<147	<14		<257	<30	<36
Silver epoxy	Circuit Works	mBq/kg	$< 1.0 \ 10^{3}$	13.6 ± 2.8	<18	< 16	<4.5	< 52	<19	<2.2
SiPMs 1×1 mm ²	SensL	µBq/pc	<320	<2.7	<6.9	<2.0	<1.0	<16	<0.8	<2.0
SiPMs 6×6 mm ²	SensL	$\mu \mathrm{Bq/pc}$	<410	<3.2	<12	<2.8	<2.5	<25	<1.2	<1.3
NTC sensor	Murata	μBq/pc	<96	< 0.8	<0.9	< 0.3	< 0.3	<2.9	< 0.2	< 0.2
LED	Osram	$\mu \mathrm{Bq/pc}$	<90	$1.4{\pm}0.2$	$3.5 {\pm} 0.4$	$3.0 {\pm} 0.3$	< 0.6	<4.0	< 0.2	< 0.3
Plexiglas/PMMA	Evonik	mBq/kg	<208	<1.3	<2.2	<1.0	<1.1	<8.1	< 0.4	< 0.6
Ta capacitor	Vishay Sprague	mBq/pc	< 0.8	$0.043 {\pm} 0.003$	$0.034{\pm}0.004$	$0.032{\pm}0.003$	< 0.010		< 0.002	< 0.003

• Other items at DBs also screened: LEDs, temperature sensors, capacitors, ...



Radiopurity measurements: energy plane

Energy readout plane:

• 60 Hamamatsu R11410-10 PMTs behind the cathode to detect EL light and primary scintillation

• Each PMT sealed into individual, pressure resistant Cu cans, coupled to the sensitive volume through a sapphire window coated with TPB.





• 48 PMTs screened the along 2013-2014 finding equivalent activity

Material	Supplier	Technique units	²³⁸ U	²²⁶ Ra	²³² Th	²²⁸ Th	²³⁵ U	⁴⁰ K	⁶⁰ Co	¹³⁷ Cs
PMTs	Hamamatsu	Ge mBq/PMT	<67	< 0.94	<2.2	0.6±0.1	0.6 ± 0.1	11.8±1.7	3.7±0.3	< 0.3

Only ⁶⁰Co activity can be quantified at each run ⁶⁰Co activity ~4 times higher than the one measured by XENON1t for version R11410-20



Radiopurity measurements: energy plane

• **Sapphire windows** screened using a Ge detector, but more sensitive analysis pursued by ICPMS



Material	Supplier	Techr	nique units	²³⁸ U	²²⁶ Ra	²³² Th	²²⁸ Th	²³⁵ U	⁴⁰ K	⁶⁰ Co	¹³⁷ Cs
Sapphire	Prec. Sapp. Tech.	Ge	mBq/kg	<275	<2.7	<7.6	<5.5	<2.1	<18	<0.7	<1.0

• Copper for PMT cans (CuA1=ETP) and for plates (CuC1=OF) analyzed by GDMS

Material	Supplier	Technique units	²³⁸ U	²²⁶ Ra	²³² Th	²²⁸ Th	235 U 40 K	⁶⁰ Co	¹³⁷ Cs
Cu	Lugand Aciers	GDMS mBq/	kg <0.012		< 0.004		0.062		
Cu	Lugand Aciers	GDMS mBq/	kg 0.025±0.00	05	0.015 ± 0.004	1	0.19		



Radiopurity measurements: energy plane

• Many other items related to **PMTs and bases** studied with Ge detectors or by GDMS

Material	Supplier	Technique	units	²³⁸ U	²²⁶ Ra	²³² Th	²²⁸ Th	²³⁵ U	⁴⁰ K	⁶⁰ Co	¹³⁷ Cs
Capacitors	AVX	Ge	µBq/unit	<360	72±3	749±3	32±2		71±9	<1	<1
Resistors	Finechem	Ge	μ Bq/unit	85±23	4.1±0.3	5.6 ± 0.5	4.4 ± 0.3		83.6±8.7	< 0.2	104 ± 11
Pin receptacles	Farnell	Ge	μ Bq/unit	217 ± 42	<1.1	5.6 ± 0.5	4.5 ± 0.4	6.1±0.5	20.5 ± 2.4	< 0.3	< 0.2
Thermal epoxy	Electrolube	Ge	mBq/kg	$(1.0\pm0.2)10^3$	169.4±7.9	52.1±3.7	54.4±3.2		105 ± 12	<1.1	<1.3
SS screws		GDMS	mBq/kg	3.25±0.25		0.57±0.08			< 0.19		
Brass bolts		GDMS	µBq/kg	8.9±0.7		6.9±0.2			<31		
Brazing paste		GDMS	µBq/kg	55±10		49±4			<31		
Optical gel N	lye Lubricants	Ge	mBq/kg	<1.7 103	<22	<49	<18	<16	<173	<4.5	<5.8



Radon and material radiopurity assessment for the NEXT double beta decay experiment

- **NEXT** experiment
- **Material radiopurity measurements**
 - Techniques
 - Results
 - Shielding, Vessel, Field cage & EL
 - Energy & Tracking readout planes
- **Radon control**
- **Background model** \checkmark
- **Summary and outlook**





Radon control

In-situ measurements of **radon activity** levels and **gamma background rates** at the NEXT lead castle in different conditions performed before the NEW detector commissioning at LSC in order to efficiently design their mitigation

- From October 2014 to February 2015
- Using two **AlphaGuard detectors** from LSC (at hall A and inside the castle) and a low backgrund 3"x3" **Nal(TI) detector**





S. Cebrián, LRT2015 Workshop, Seattle 18-20 March 2015

Radon control

					Nal detector	AlphaGuard detectors			
	Situation	Start date	Stop date	Time	Rate	Hall A		NEXT castle	
				(d)	(Hz)	mean activity	σ	mean activity	σ
1	Open castle	29/10/14	03/11/14	4.76	59.56 ± 0.01	(Bq/m^3)		(Bq/m^3)	
2	Closed castle	04/11/14	01/12/15	27.08	$1.089 {\pm} 0.001$	80	29	79	28
3	Better closed castle	03/12/14	16/12/14	3.43	$0.694{\pm}0.002$	74	26	30	11
4	After N_2 purge	16/12/14	08/01/15	21.38	$0.658 {\pm} 0.001$	66	25	30	12
5	N_2 purge+flux 180 l/h	08/01/15	14/01/15	3.54	$0.600 {\pm} 0.001$	66	25	22	9
6	Without N_2 flux	14/01/15	10/02/15	3.92	0.638 ± 0.001	59	18	26	10
$\overline{7}$	N_2 purge+flux 900 l/h	10/02/15	12/02/15	1.68	0.350 ± 0.002	73	26	4	3
8	Without N_2 flux	12/02/15	16/02/15	2.45	$0.894{\pm}0.002$	80	$\overline{24}$	47	15

- **Closing the castle**, the gamma rate is reduced two orders of magnitude and the radon activity more than a factor 2, being insensitive to external fluctuations
- A N₂ purge and even a low constant N₂ flux produce only marginal reductions
- A high constant N₂ flux reduces at least one order of magnitude the radon activity inside the castle

Installation of a radon supression machine at LSC foreseen for 2016



Energy (keV)

Radon and material radiopurity assessment for the NEXT double beta decay experiment

- **NEXT** experiment
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 - Shielding, Vessel, Field cage & EL
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- \checkmark **Background model**
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Background model

• Geant4 simulation of the NEXT-100 and NEW detectors including a detailed geometry description and background discrimination power



• Contribution of major subsystems to background rate of **NEXT-100** at Rol

count/(keV kg y)	TI-208	Bi-214	Total	
Pressure vessel	2.3E-05	7.2E-06	3.1E-05	Total internal
Energy plane	3.8E-05	1.3E-04	1.7E-04	S 10 - Cathode
Tracking plane	9.9E-06	2.2E-05	3.2E-05	ap 10-5
Field cage	1.4E-05	9.3E-05	1.1E-04	
Copper shield	1.7E-05	7.0E-05	8.7E-05	
Lead shield	2.5E-06	2.5E-05	2.8E-05	
Total	1.0E-04	3.5E-04	4.5E-04	2 ²² Rn Activity (Bq/m ³)

PMTs (33%), Cu shield (19%) and field cage polyethylene (10%) are main contributors

Summary and outlook

✓ An extensive material screening process is underway for the NEXT experiment, based mainly on ultra-low background Ge γ -ray spectrometry at LSC but also on complementary results from GDMS and ICPMS.

It helps in:

- ✓ the design of the set-up
 - Adequate materials for shieldings, vessel and field cage were identified
 - Thorough selection of in-vessel components for energy and tracking planes was performed too, checking radiopurity of PMT units and choosing kapton-copper boards and SiPMs

 \checkmark the construction of the **background model**: the required background level seems to be at reach

✓ Radon activity and gamma background rates have been measured inside the NEXT lead castle in Canfranc at different conditions to optimize the radon supression system based on the injection of N_2 gas