Low Radioactivity Materials

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12th November 2025

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Pacific Northwest
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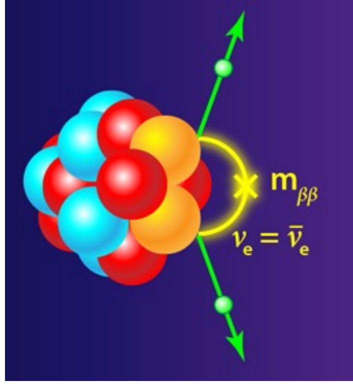
NLDBD Signal



$$\text{Decay Rate} = \left|\frac{dN}{dt}\right| = \frac{N}{\tau}$$

N = Number of isotope atoms

τ = Decay mean life

For ^{136}Xe at the goal of the next generation experiments
($T_{1/2} \sim 10^{28}$ yrs)

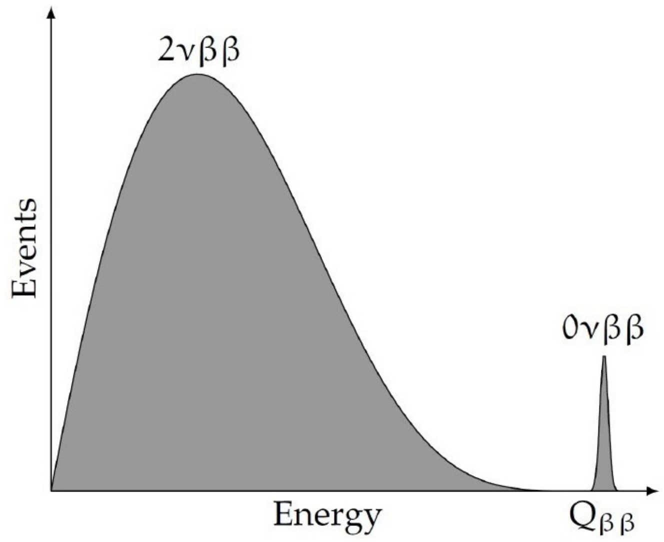
Specific Decay Rate ~ 0.3 events / ton / yr
~ 10 pBq/kg

Natural soil is ~ 10 Bq/kg

Central Challenge for all Experiments: Need ultra-low radioactivity material

Backgrounds to ^{136}Xe NLDBD

- Q_{bb} for ^{136}Xe: **2458 keV**
  Above most, but not all, natural radioactive background emissions
- Most Dangerous Radioactive Backgrounds
  - **^{214}Bi**:
    - Progeny of **^{238}U**, below ^{222}Rn
    - 1.5% gamma emission at 2448 keV (0.4% separation from Q_{bb})
    - Decays in passive material cannot be tagged
  - **^{208}Tl**
    - Progeny of **^{232}Th** (36% BR)
    - Gamma emission at 2615 keV, Compton edge: 2382 keV
  - **^{137}Xe**
    - Formed by neutron capture on Xe136, Half-life: 3.8 min
    - Beta decay with Qb = 4173 keV
  - **^{60}Co**
    - Typically an activation product
    - 2E-6% Gamma emission at 2506 keV, or combination of 1173 and 1333 keV gammas



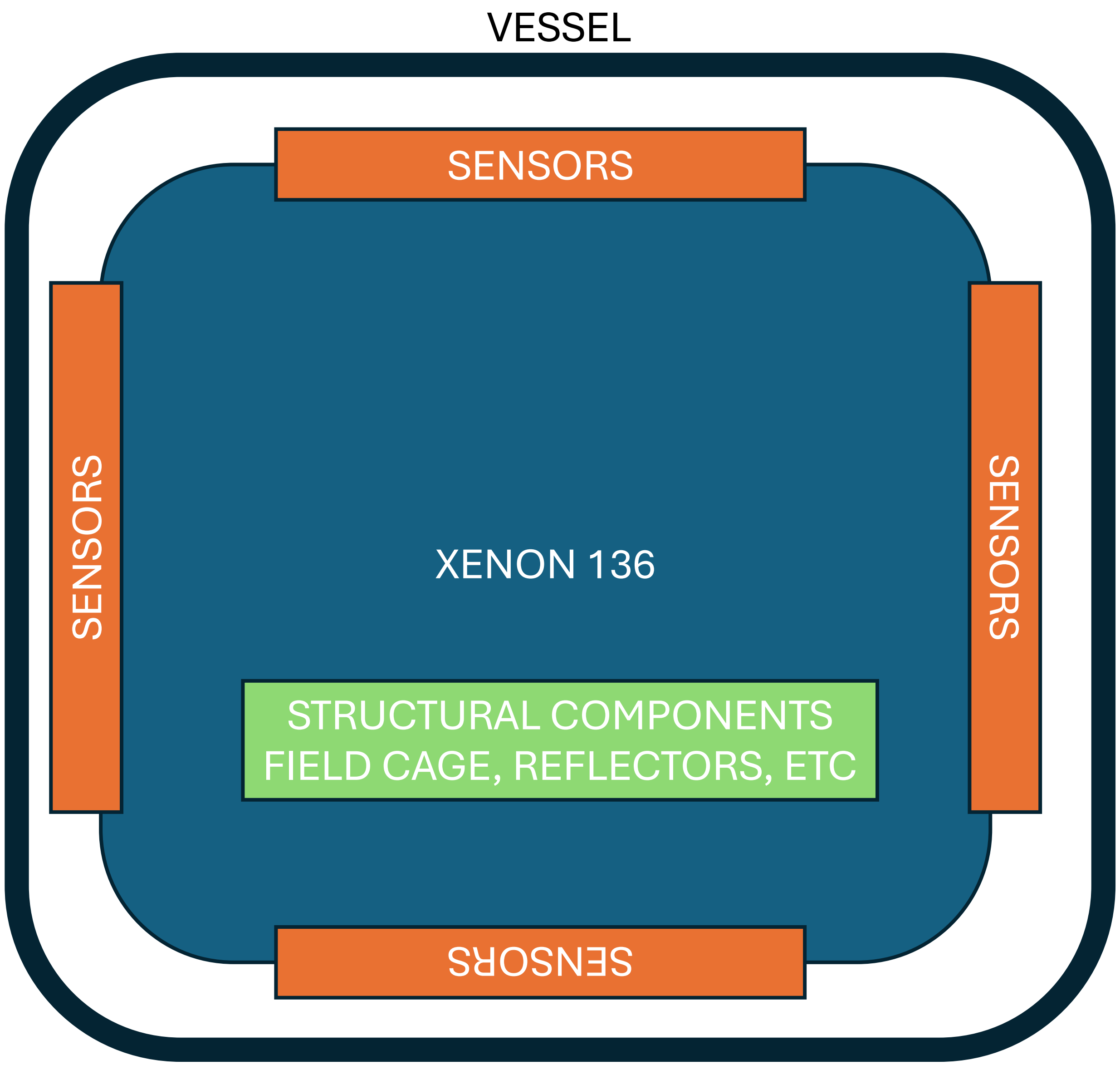
Generic Xenon Detector

What materials can we use to build a NLDBD Xe detector?

Focus on bulk intrinsic radiocontamination

Not covered here:

- Radon emanation
- Cosmogenic activation
- Surface backgrounds
- Cleaning procedures



Radiopure Vessels (for Pressure)

[GERDA] *NIM A* 593, no. 3 (2008): 448-453
[NEXT] 2013 JINST 8 T01002
[Panda-X] 2016 *JINST* **11** T09004
[XENONnT] Eur. Phys. J. C (2022) 82:599
[LZ] Astroparticle Physics 96 (2017) 1-10

Materials used for pressure vessel need to have high yield strength.

Two materials typically used

Stainless Steel

- Most commonly available material
- Best radiopurity found in austenitic 1.4571 material [GERDA]

Titanium

- High strength-to-weight ratio
- Lower Z, fewer activation products
- Best radiopurity found in ASTM Grade 1 titanium with 0% scrap, produced with electron beam cold hearth (EBCH) re-melting [LZ]

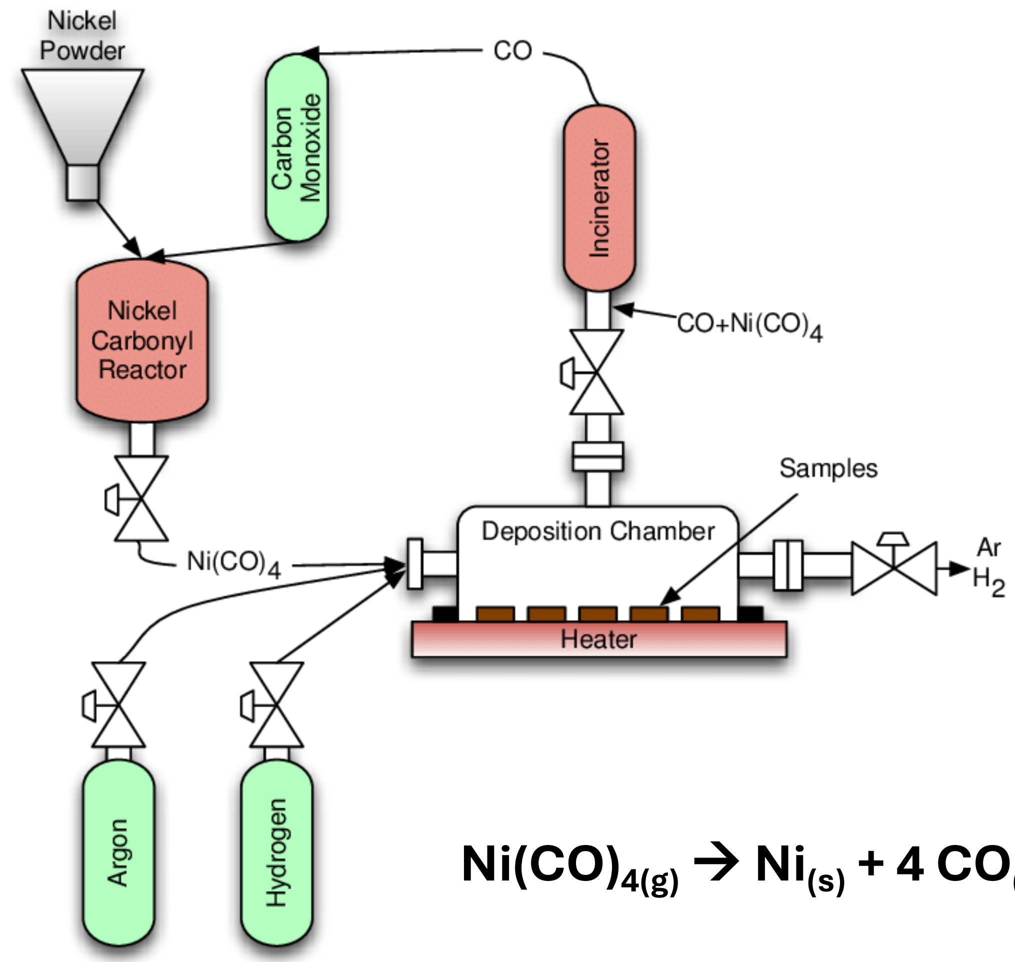
Experiment	Type	Mass (kg)	^{238}U (mBq/kg)	^{232}Th (mBq/kg)	^{60}Co (mBq/kg)	^{40}K (mBq/kg)	^{46}Sc (mBq/kg)
DarkSide50 [29]	SS	175	< 1	< 1	13.1 ± 1	–	–
XENON100 [27]	SS	74	< 1.8	< 0.03	5.4 ± 0.5	< 9	–
XENON1T [30]	SS	870	2.4 ± 0.7	0.21 ± 0.06	< 0.36	9.7 ± 0.8	2.7
XENONnT.	SS		0.3 +/- 1	0.6 +/- 0.2	2.4 +/- 2	1.6 +-/ 0.6	
PandaX-II	SS		< 1.9	< 3.0	< 0.7	< 16	
NEXT	SS		< 0.46	< 0.69	4.4 +/- 0.3	< 1.0	
LUX [11]	Ti	230	< 0.25	< 0.2	–	< 1.2	2.5
LZ (this work)	Ti	1,827	U_e < 1.6 U_l < 0.09	Th_e: 0.28 ± 0.03 Th_l: 0.23 ± 0.02	< 0.02	< 0.54	2.0 ± 0.1

Chemical Vapor Deposition (CVD)

- Start with element you want to deposit
- Create reactant gaseous compound
- Decompose that gas mixture over a heated substrate to leave behind the atoms of interest

Both the formation of the gaseous compound and decomposition on the substrate depend on the chemistry and thermodynamics of the process, allowing for deposition of extremely high purity materials

$$Ni_{(s)} + 4CO_{(g)} \rightarrow Ni(CO)_{4(g)}$$



$$Ni(CO)_{4(g)} \rightarrow Ni_{(s)} + 4\ CO_{(g)}$$

Generalized schematic of Mond, or carbonyl, process used by CVMR (Muralidharan et al., 2011)

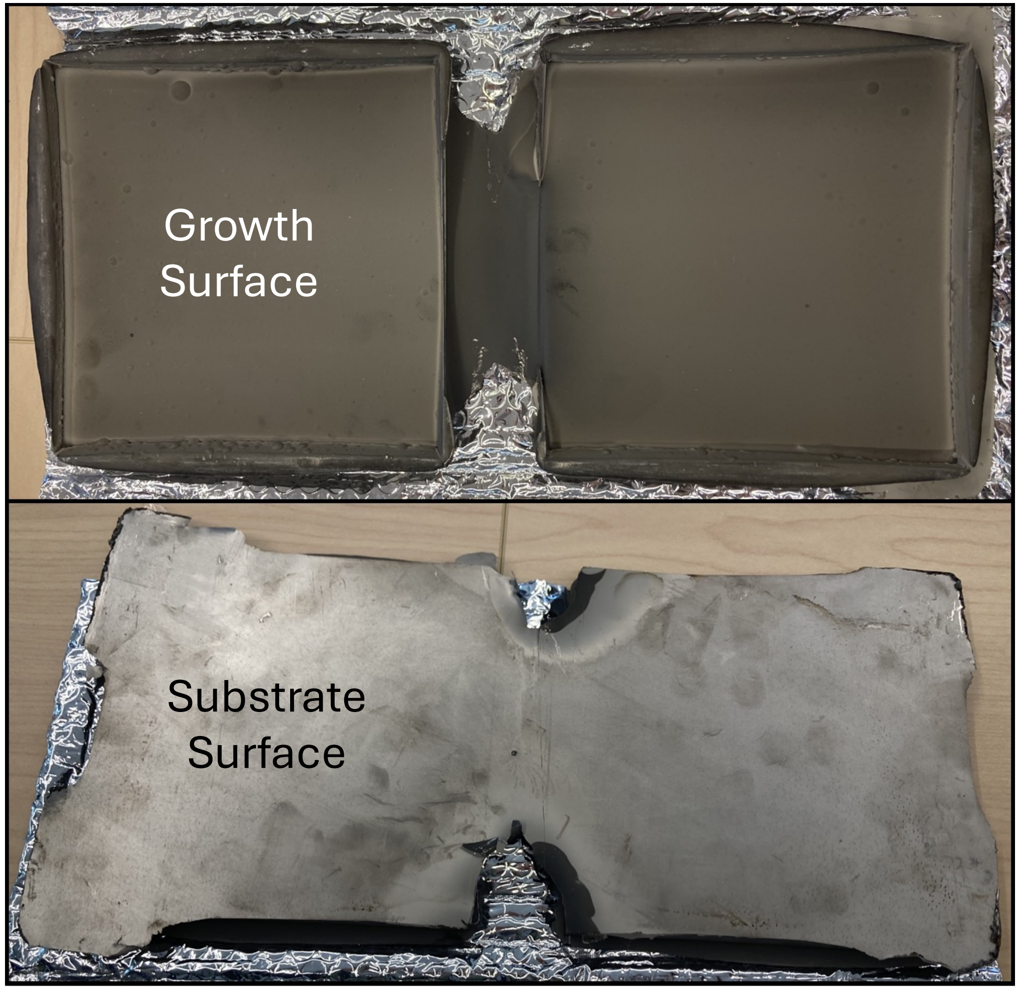
CVD Nickel

CVD Nickel produced by CVMR was used for the SNO ^{3}He proportional counter tubes

Produced through the MOND process with nickel carbonyl (extremely hazardous)

Recently explored by nEXO for cryostat vessel arXiv:2508.08230 [nucl-ex]

Deposition rates can be as fast as 0.75 mm/hr, with achievable thickness over 5 cm



Material	238U [uBq/kg]	232Th [uBq/kg]	40K [uBq/kg]	Yield Strength [MPa]
SS (XENONnT)	300 +/- 100	600 +/- 200	1600 +/- 600	200-240
Titanium (LZ)	< 90	230 +/- 20	< 540	170-310
CVD Nickel	**< 1.2***	**~0.3***	**~30**	**~400****

*Bulk contamination determined by ICP-MS (top of the chain)

** Unwelded, Property Characterization of CVD Nickel, Masters Thesis, Patrice Bansa, University of Toronto

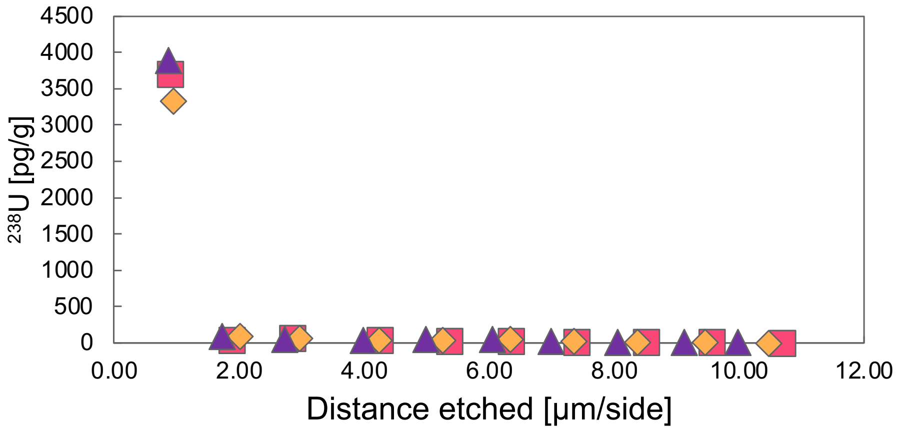
CVD Nickel

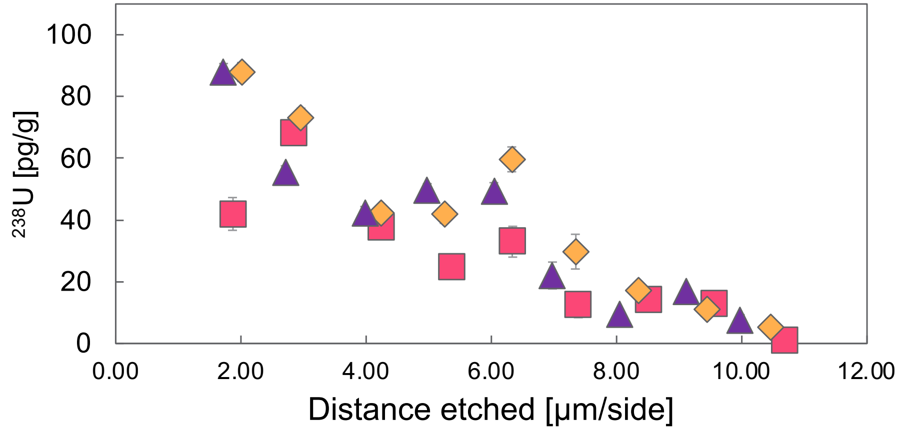
Investigations into CVD Nickel still in early stage – lots to explore

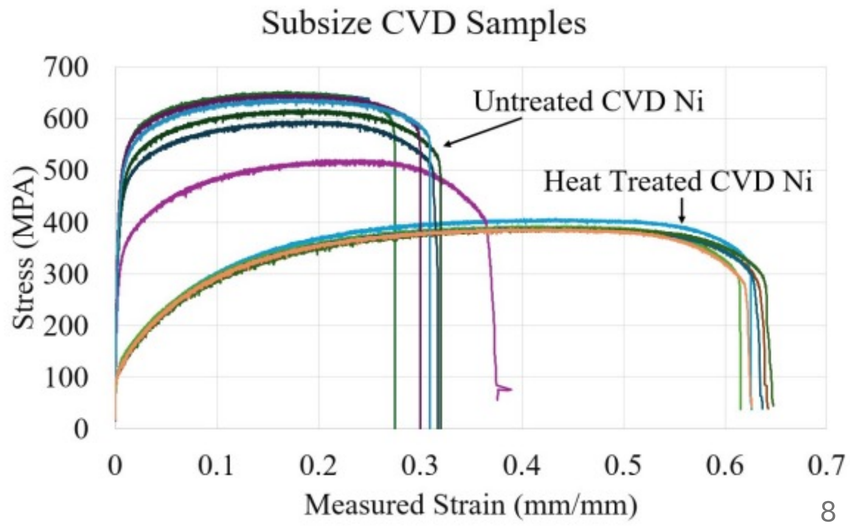
- Surface contamination detected, likely from Al substrate (other substrates are possible)
- Does secular equilibrium hold?
- CVD Ni is stronger than conventional nickel, but loses strength when heat treated – impact on welded pressure vessels?
- Can be grown quickly, but production scale limited by available chambers
- Expensive compared to SS and Ti

Ultra-pure Nickel for Structural Components of Low-Radioactivity Instruments

arXiv:2508.08230

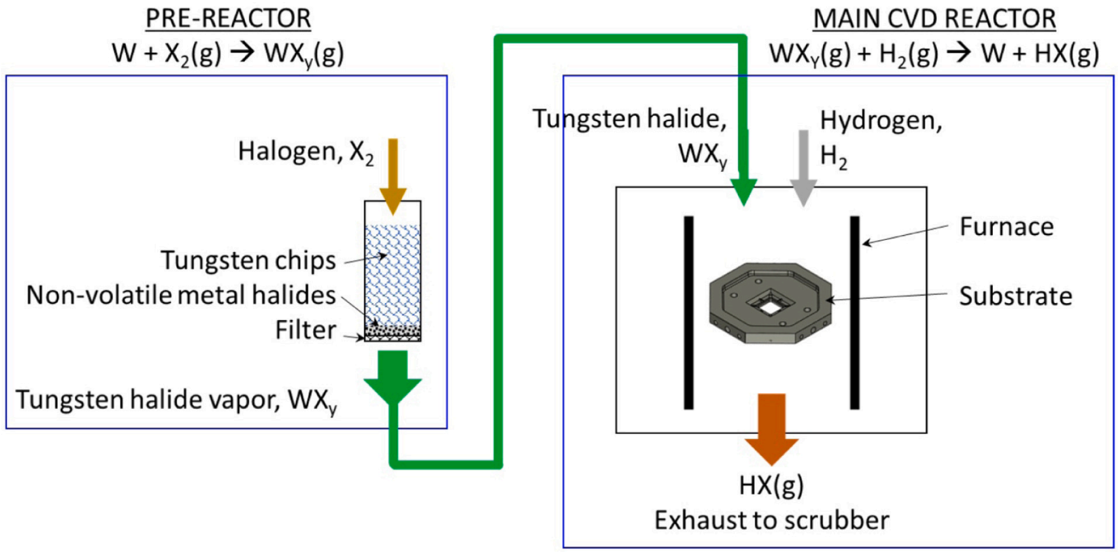


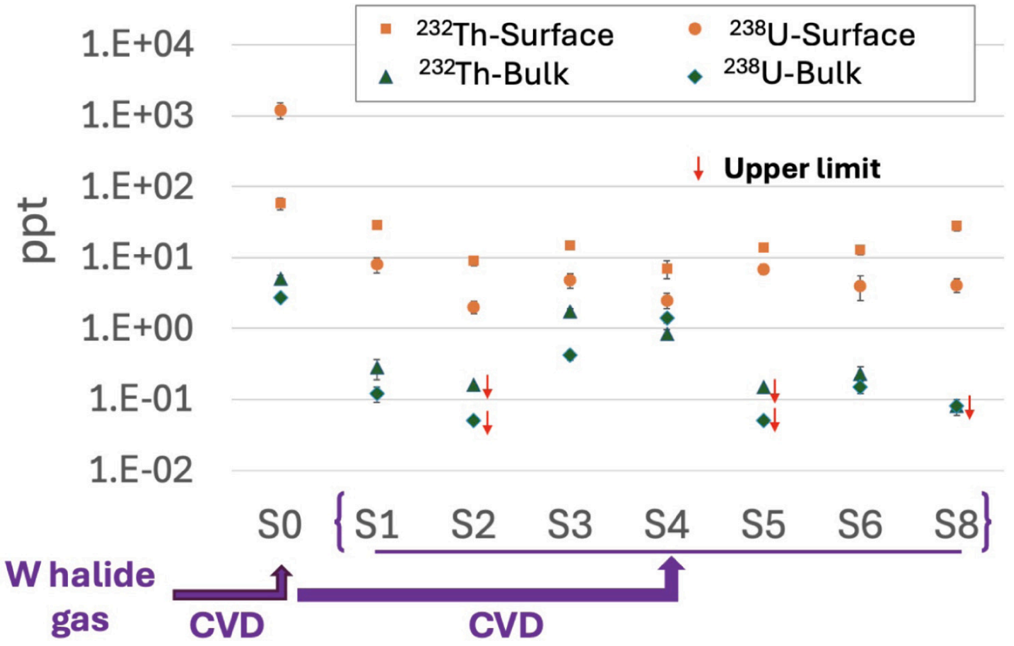




Other CVD materials

- PNNL staff recently worked with Ultramet through an SBIR grant to develop **CVD tungsten** with radiopurity levels at **~ 1 uBq/kg U and Th**
- Currently limited to 1-2 mm thick at Ultramet
- High density of tungsten (19.3 g/cm^3, 1.7x denser than lead) makes it attractive for shielding
- Details can be found in:
  High-purity tungsten produced via chemical vapor deposition for use in low-background detectors
  NIM A 1082 (2026) 171018

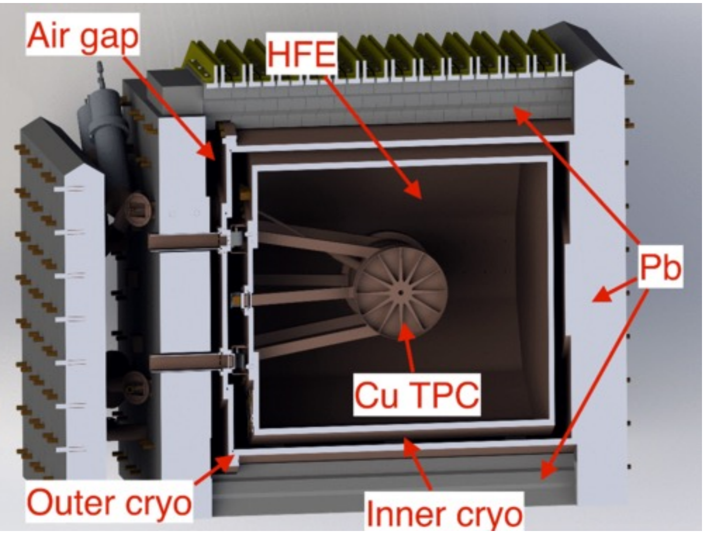


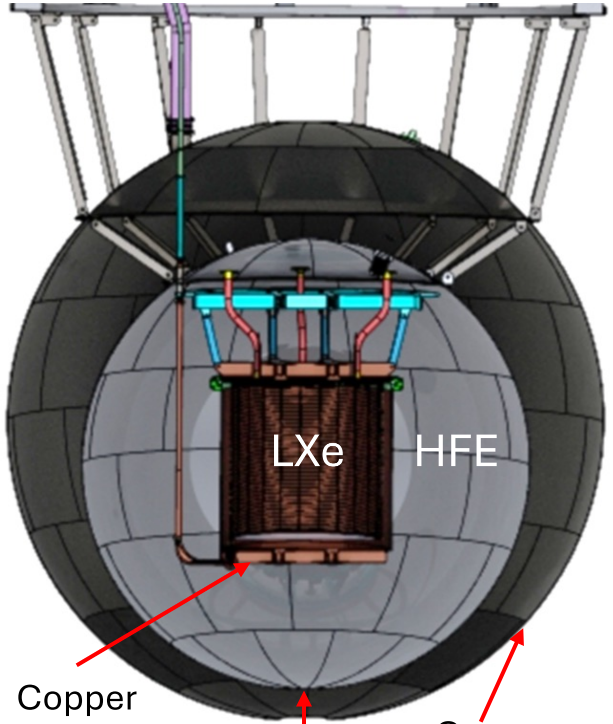


CVD can also be used for other materials such as tantalum....

Vessels – Low Pressure

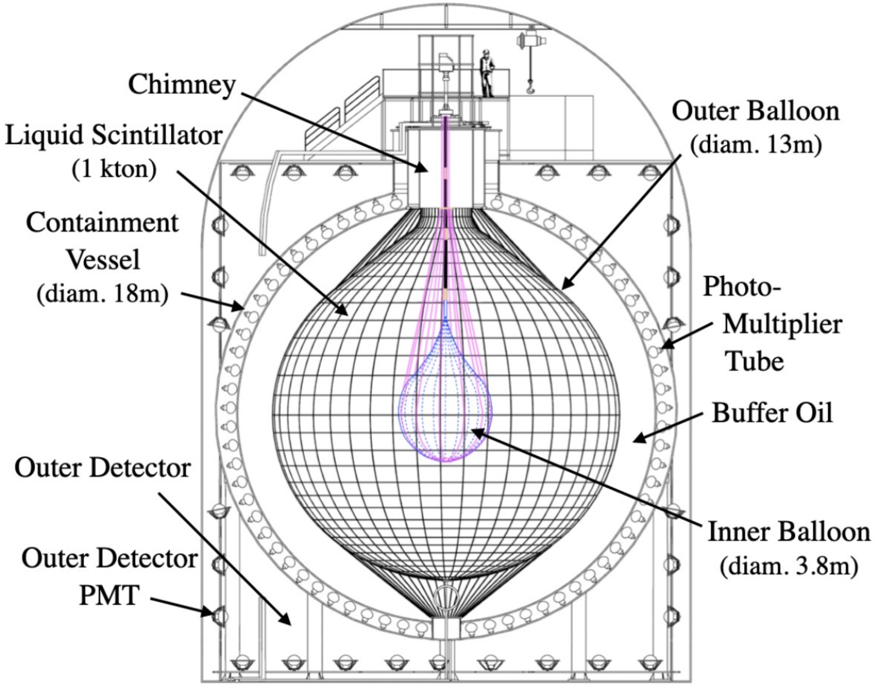
Copper





EXO-200, nEXO design have a thin (few-mm) copper vessel with a refrigerant (HFE) balancing the pressure on the outside

Nylon



2021 JINST 16 P08023

Figure 1. Schematic view of KamLAND with the IB for KamLAND-Zen 800.

KamLAND-Zen use a thin (25 um) nylon vessel to separate the loaded scintillator from standard LS

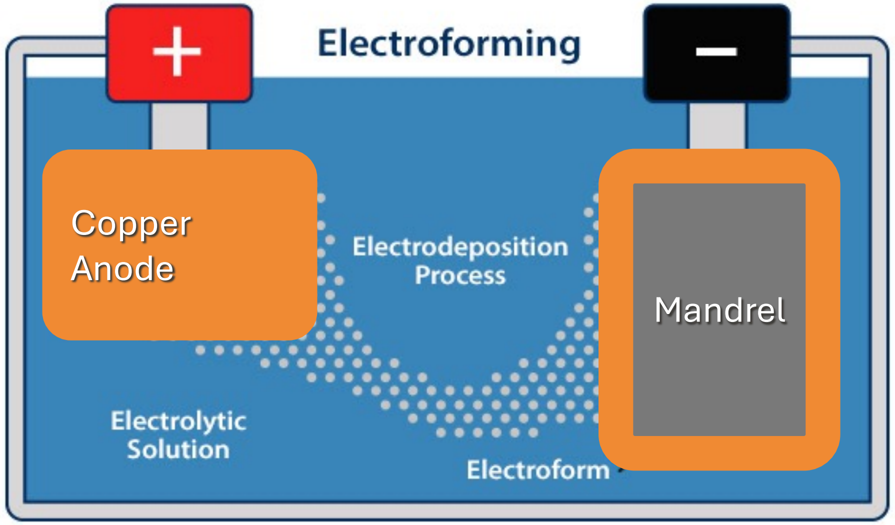
Electroformed Copper

- Electroforming takes advantage of the relatively high reduction potential of copper compared to most radioisotopes to produce copper with very high purity.

- Reduction potential is not the only consideration (otherwise all electroplated copper would have negligible U & Th), mass transport and other factors play a critical role

- By carefully setting the electroplating voltages and bath parameters, PNNL chemists have developed custom **electroformed copper (EFCu)** that has been demonstrated to have > 25x lower radiocontamination than even the cleanest commercial copper

Reductants		Oxidants	E^0 (V)
$Cu^{2+} + 2e^-$	$\leftrightharpoons$	Cu	+0.34
$Pb^{2+} + 2e^-$	$\leftrightharpoons$	Pb	−0.13
$U^{3+} + 3e^-$	$\leftrightharpoons$	U	−1.80
$Th^{4+} + 4e^-$	$\leftrightharpoons$	Th	−1.90
$K^+ + e^-$	$\leftrightharpoons$	K	−2.93



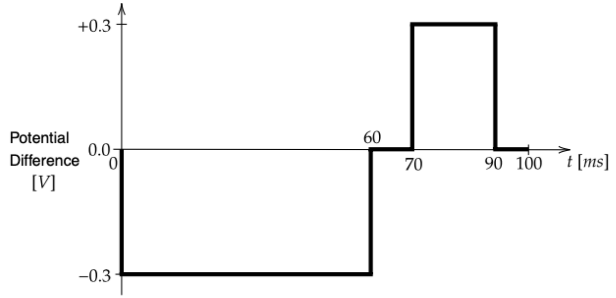
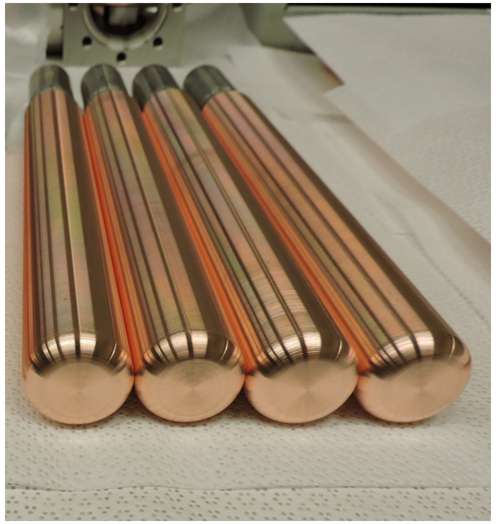


Figure 5: Waveform used in the electroplating. The negative terminal was attached to the cathode.

Electroformed Copper

- Electroformed copper can be made in different shapes and forms
- Used by several low-background experiments
- Radiopurity values limited by assay sensitivity



1” diameter gas proportional counters

13” diameter cylinder
PNNL Shallow Underground Lab

Material	238U [uBq/kg]	232Th [uBq/kg]	40K [uBq/kg]	Tensile Strength [MPa]
SS (XENONnT)	300 +/- 100	600 +/- 200	1600 +/- 600	200-240
Titanium (LZ)	< 90	230 +/- 20	< 540	170-310
CVD Nickel	< 1.2*	~0.3*	~30	~400**
Aurubis Copper	3.1	0.53	< 28	~33 (annealed)
EFCu	**< 0.12**	**< 0.04**	**< 68**	**~60**

Electroforming baths, SURF

- Limited by growth rate of ~ 1 mm/month. Expensive

Electroformed Copper R&D

Reducing Cost

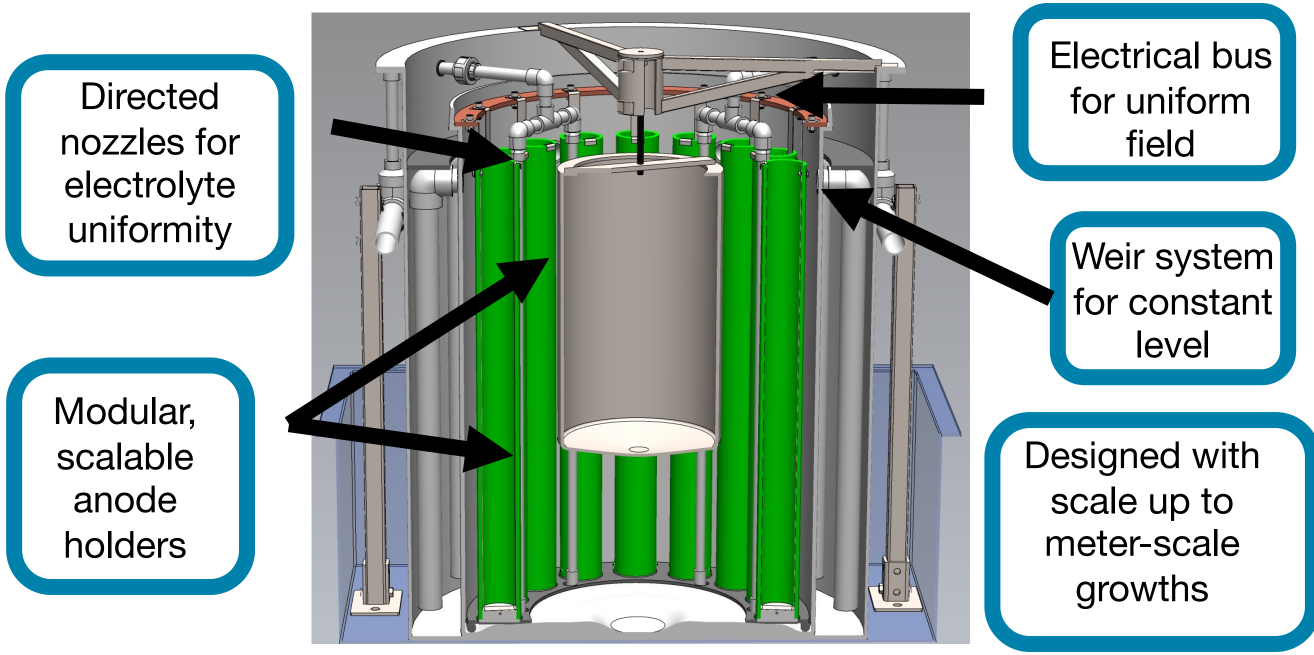
- ~40% of EFCu fabrication cost is due to highest purity acid
- Initial R&D results indicate that lower grade acid (10x cheaper) does not limit purity
- Publication in progress

Developing high-purity, high-strength copper-based alloys

- Investigating Cu-Cr alloy manufacturing via co-plating
  - Other potential alloys Ni, Ag, Zr
- Improve strength, reduce fabrication time and costs

Increasing Scale

- Redesign electroplating bath to enable meter-scale vessels

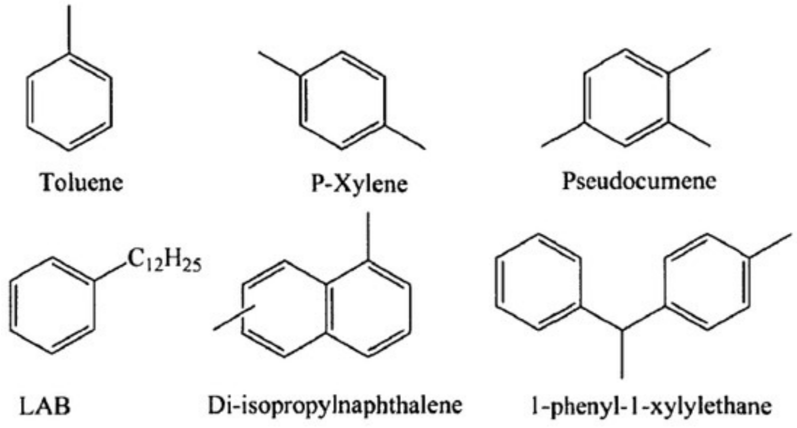


Nuclear Inst. And Methods in Physics Research, A 1003 (2021) 165291

External Fluid

- **HFE-7000**
  - 3M Novec 7000 Engineered heat transfer fluid (1-methoxyheptafluoropropane)
  - Liquid at both room temperature and LXe temperature
  - Extremely radiopure **238U: 42 +/- 6 nBq/kg, 232Th: < 3 nBq/kg**

- **Organic Liquid scintillator**
  - Many options:
  - Extremely radiopure
    - **KamLAND 238U: 61 +/- 2 pBq/kg; 232Th: 53 +/- 4 pBq/kg**
    - **Borexino: 238U: < 1 pBq/kg; 232Th: < 4 pBq/kg**
    - 210Po out of equilibrium

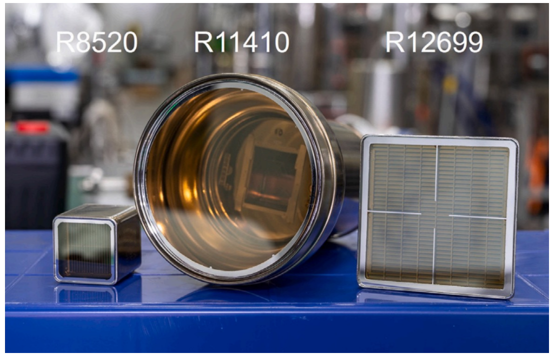


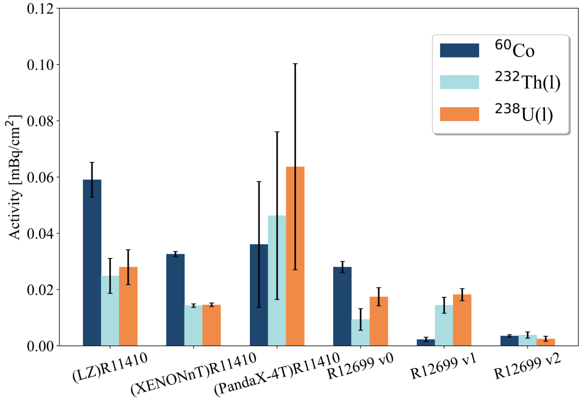
Photosensors

Custom development of VUV, in-LXe PMTs has led to significant improvements in radiopurity

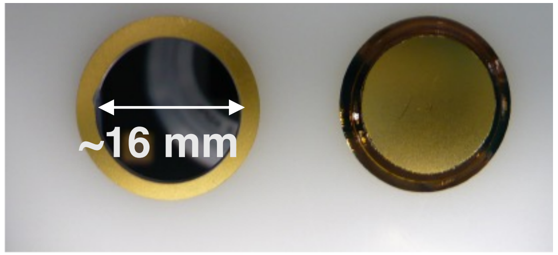
Silicon-based sensors (especially VUV-sensitive **SiPMs**) are still *orders of magnitude* less radioactive.

		Activity [uBq/cm²]			
TYPE	Model	238U	232Th	40K	60Co
PMT	R11410-10 (LZ)	28 (6)	25 (6)	380 (30)	59 (6)
PMT	R11410-20 (XENONnT)	15 (2)	14 (1)	440 (20)	33 (1)
PMT	R11410-23 (PandaX-4T)	< 120	< 95	< 690	< 73
PMT	R13111 (XMASS)	11 (2)	4 (1)	52 (13)	3 (1)
PMT	R12699-406-M4 (v2)	3 (1)	-	1500 (100)	4 (1)
LAAPD	API SD630-70-75-500 (EXO-200)	< 0.1	< 0.1		
SiPM	63XFBK VUV-HD (nEXO)	0.00068 (4)	0.00012 (3)		

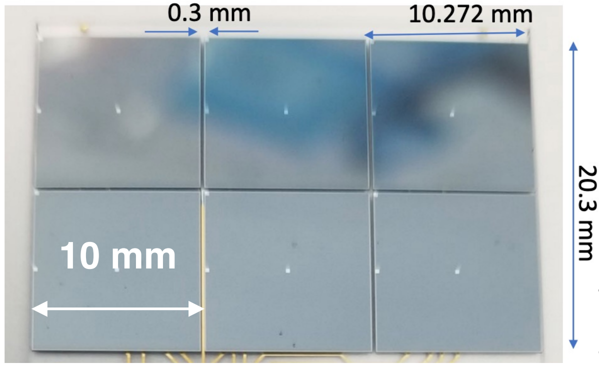




Hamamatsu Xe PMTs NIM A 1073 (2025): 170290



Advanced Photonix LAAPD (NIM A 608, 68 [2009])



HPK 1 cm² VUV-sensitive SiPMs (nEXO)

Electronics

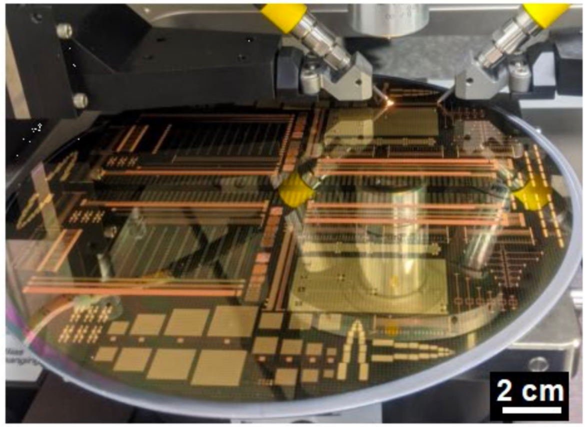
- **Silicon** is very clean (eg. ASICs)
- Circuit substrates
  - NOT FR4 or G10
  - **Silicon, Fused Silica** are extremely radiopure options
    Development of a Silicon Interposer: Toward an Ultralow Radioactivity Background Photodetector System IEEE TRANS. ON NUCLEAR SCIENCE, VOL. 70, NO. 2, 2023

Cirlex: Commercial Kapton is not very clean - typically 1000 ppt 238U

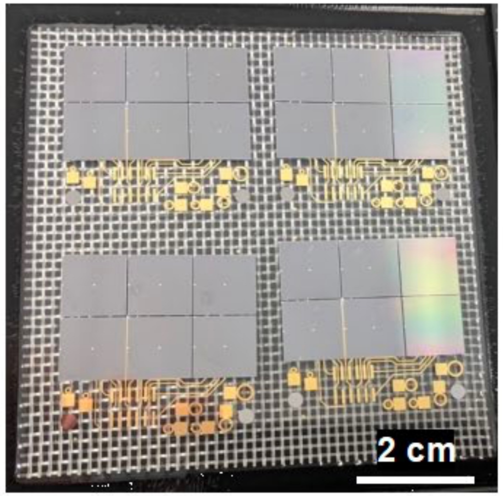
Collaboration with DuPont and study of the manufacturing process led us to identify the dominant source of contamination in Kapton material: DCP a slip additive used to improve processing yield

Special production of DCP-less Kapton and Kapton-copper laminates showed ~20x reduction in radiocontamination

Ultra-low radioactivity Kapton and copper-Kapton laminates
NIM A 959 (2020): 163573



Wafer with test structures for silicon interposer development, fabricated by Fraunhofer IZM



Double-sided fused silica tiles with through fused silica vias (TFVs) and 1 cm2 SiPMs mounted in a 3x2 array. Four tiles are shown, with wiring layers visible in gold and test structures at the bottom (the fused silica substrates are transparent)

	^{238}U [pg/g]	^{232}Th [pg/g]	^{nat}K [ng/g]
Commercial Kapton HN	1080 +/- 40	250 +/- 8	44 +/- 18
R&D Kapton	12.3 +/- 1.9	19 +/- 2	34 +/- 14
Commercial Kapton-Cu Laminate	158 +/- 6	24.1 +/- 0.9	< 210
R&D Kapton-Cu Laminate	9 +/- 4	20 +/- 14	160 +/- 80

Electronics

Capacitors and Resistors

- **Ceramics** are typically not very radiopure
- **Silicon**-based components are now available, but can be expensive
- Thin film components seem to be better?

Custom Development

High voltage capacitors for low background experiments, Eur. Phys. J. C (2013) 73:2445

Small Business Innovation Research (SBIR)

“Radiopure electronic components … for reading out sensors for neutrinoless double beta decay detectors and possibly quantum sensors. Of specific interest are capacitors, resonators, circuit substrates, connectors, and cables. The desired radioactivity of these components is **typically < 100 parts-per-trillion 238U & 232Th (< 1 mBq/kg)**, though the exact requirements depend on the mass and location of the component with respect to the sensitive volumes of the experiment.”

Radiopure Cables

Worked with commercial company (through SBIR grant) to investigate radioactive contamination in each individual fabrication step

Developed new radiopure fabrication process that resulted in 5-100x reduction in U/Th/K contamination

Cable	Copper layers [μm]	Polyimide layers [μm]	Coverlay	Surface finish	^{238}U [pg/g]	^{232}Th [pg/g]	^{nat}K [ng/g]
nEXO SiPM	**18 (x2)**	**50.8 (x1)**	**No**	**No**	**20 ± 2**	**<12.3**	**40 ± 12**
nEXO SiPM [Com.]	18 (x2)	50.8 (x1)	No	No	1300-6200	16-63	
DAMIC-M CCD	**18 (x2)**	**50.8 (x1)**	**x2**	**ENIG**	**31 ± 2**	**13 ± 3**	**550 ± 20**
DAMIC-M CCD [Com.]	18 (x2)	50.8 (x1)	x2	ENIG	2600 ± 40	261 ± 12	170 ± 50
EXO-200 [3, 12]	18 (x1)	25.4 (x1)	No	No	412 ± 47	<117	
EDELWEISS III [7, 14]	18 (x4)	25/125 (x3/x4)	No	No	650 ± 490	3700 ± 2500	2100 ± 840
DAMIC at SNOLAB [4]	18 (x5)	25.4 (x4)	x2	ENIG	4700 ± 400	790 ± 120	940 ± 60

Have manufactured radiopure cables for SiPMs and CCDs

Just received a SBIR Phase IIB grant to develop radiopure controlled-impedance stripline cables

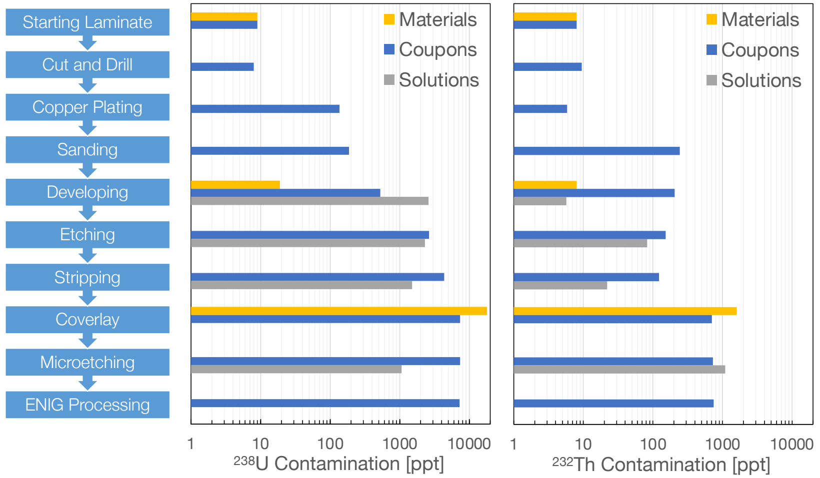
U.S. DEPARTMENT OF ENERGY

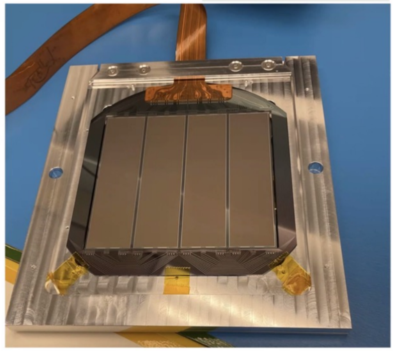
SBIR · STTR America's Seed Fund

Arnquist et al. EPJ Techniques and Instrumentation (2023) 10:17
https://doi.org/10.1140/epjti/s40485-023-00104-6
EPJ Techniques and Instrumentation
EPJ.org
RESEARCH ARTICLE Open Access

Ultra-low radioactivity flexible printed cables

Isaac J. Arnquist[1], Maria Laura di Vacri[1], Nicole Rocco[1], Richard Saldanha[1*], Tyler Schlieder[1], Raj Patel[2], Jay Patil[2], Mario Perez[2] and Harshad Uka[2]



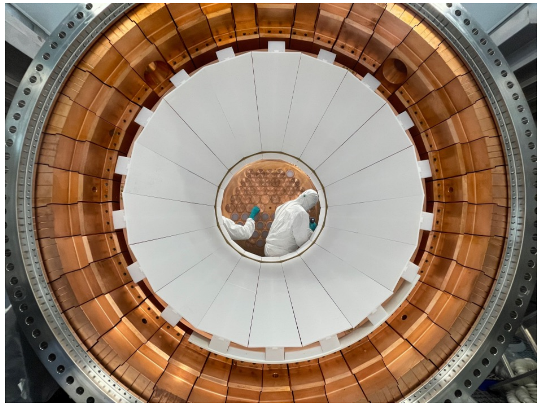


Delivered **28x 1.5-meter-long** flexible cables that met the radiopurity requirements for DAMIC-M.
10x reduction compared to off-the-shelf options
Now only ~3% of DAMIC-M background budget

Reflectors

PTFE

- > 95% (> 90%) reflectivity at LXe (visible) wavelengths
- Need ~ 1(5) mm thickness at 175 nm (420 nm)
- Radiopurity very good



Al + MgF_2

- 85% reflectivity at LXe wavelengths
- Need ~ 100 nm thickness Al+ ~ 100 nm MgF_2 protective layer
- Radiopurity not very good – gets better with higher purity Al J. Radioanaly. and Nucl. Chem. (2019) 322:1447–1454

Material	U [uBq/kg]	Th [uBq/kg]	40K [uBq/kg]
DuPont TE-6472 (EXO-200)	< 10	< 1	56 (6)
DuPont NXT75 (EXO-200)	< 23	< 6.5	100 (30)
Amsler & Frey (XENONnT)	< 60	50 (20)	
DuPont NXT85 (LZ)	< 21	28 (4)	122 (1)

Material	U [uBq/kg]	Th [uBq/kg]	40K [uBq/kg]
Alfa Aesar 3N	3000 +/- 1200	110 +/- 47	
Materion 5N (nEXO)	900 +/- 500	2000 +/- 500	4000 +/- 2900
Al-LAURAND 6N	< 5.2	< 1.8	

Per unit surface area, Al (100 nm) contributes less background than PTFE UL (1 mm)!

Support Structures - Polymers

Plastics are often used for internal insulating components

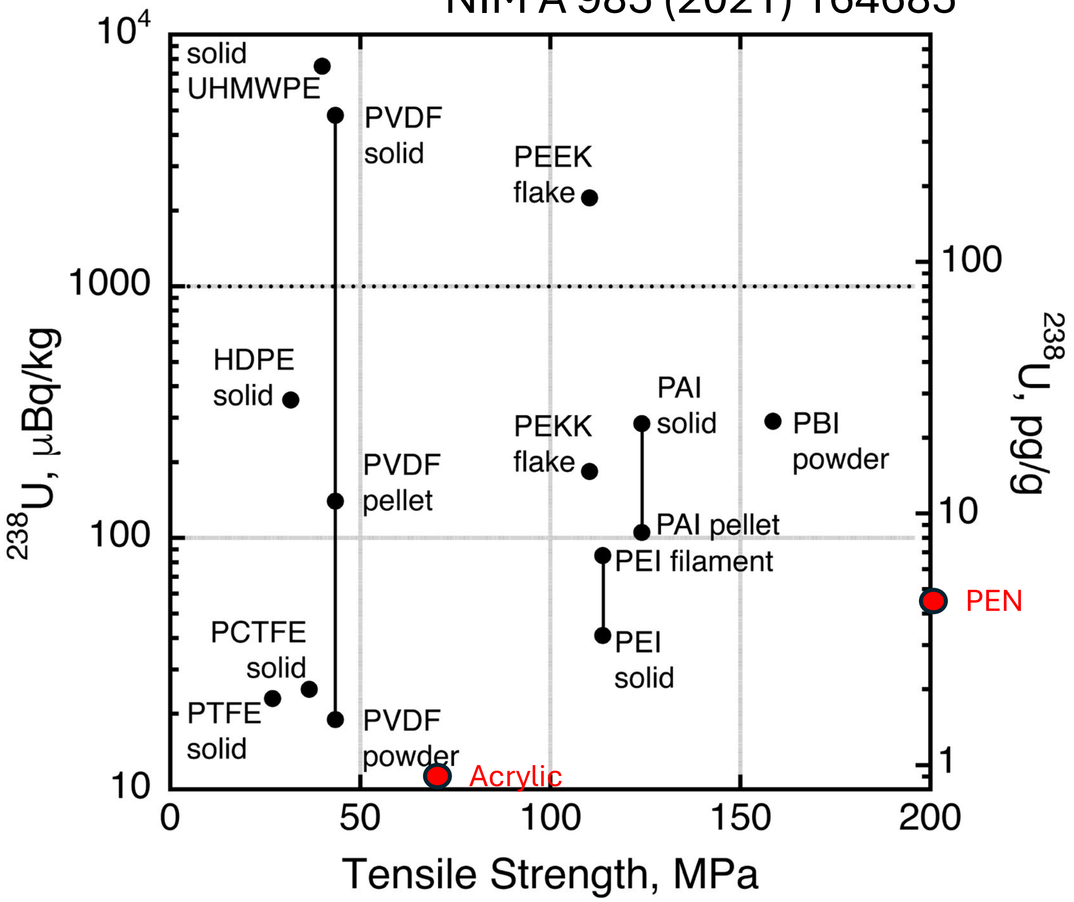
PTFE, PCTFE, Acrylic, are great options if mechanical strength is not a requirement

For stronger material, engineered plastics such as **Ultem 1000** (PEI, polyetherimide) can be obtained at ~60 uBq/kg , ~ 30uBq/kg Th of uranium and thorium

PEN, poly(ethylene naphtalate), is a strong scintillating plastic that can be used to self-veto activity with radiopurity of ~60 uBq/kg U, 30 uBq/kg Th
2022 JINST 17 C03031

Rules of Thumb:
Choose natural grades (unfilled, undyed)
Plastics can absorb water – bake if possible

NIM A 985 (2021) 164685




ULTEM 1000


PEN

Support Structures

For insulating support structures fused silica is a good option, but not very strong under tension

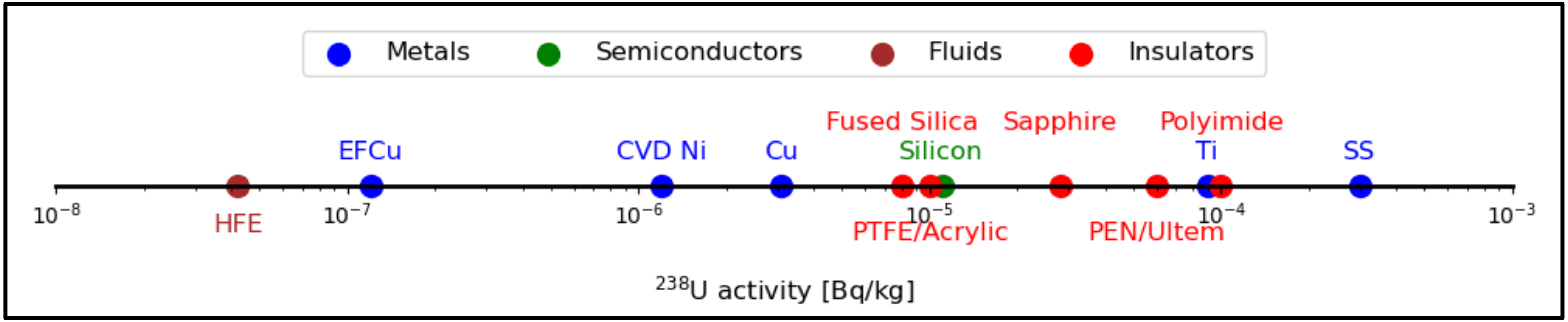
Sapphire is extremely strong under both tension and compression (300-400 MPa tensile strength)

Hard to assay – but recent NAA + gamma coincidence method has shown that sapphire can be produced with radiopurity levels of **^{238}U < 28 uBq/kg, ^{232}Th < 1 uBq/kg**

arXiv:2508.04232
PRC 10.1103/zgzm-w5f4

Supplier	Experiment	Assay method	Th [ppt]	U [ppt]	Ref.
Single Crystal Technology (Holland)	CRESST	NAA	< 33	< 40	[34]
Crystal Systems (USA)	CRESST	NAA	< 2.3	< 20	[34]
RSA (France)	ROSEBUD	Ge	< 1200	< 400	[3]
RSA (France)	ROSEBUD	Ge	< 500	< 160	[3]
Russia	ROSEBUD	Ge	< 1200	< 400	[3]
Swiss Jewel Company (USA)	EXO-200	NAA	30 ± 7	< 25	[35]
Marketech Intern. (Taiwan)	Majorana	NAA	< 21	< 300	[36]
Hamamatsu (Japan), for R11410-20	LZ	Ge	3500 ± 740	2800 ± 240	[37]
Hamamatsu (Japan), for R11410-30	XENON1T	Ge	1200 ± 310	3600 ± 200	[38]
Precision Sapphire Tech. (Lithuania)	nEXO	NAA	410 ± 41	990 ± 99	[39]
GTAT Corporation (USA), crackle	nEXO	Ge	< 1100	< 270	[39]
GTAT Corporation (USA)	nEXO	NAA	6.0 ± 1.1	$< 8.9^*$	[39]
Saint Gobain (USA), alumina	nEXO	Ge	1800 ± 580	< 270	[39]
Saint Gobain (USA), alumina	nEXO	Ge	6500 ± 1100	2600 ± 520	[39]
Saint Gobain (USA)	nEXO	NAA	< 0.26	< 2.3	This work

Material Radiopurity Takeaways

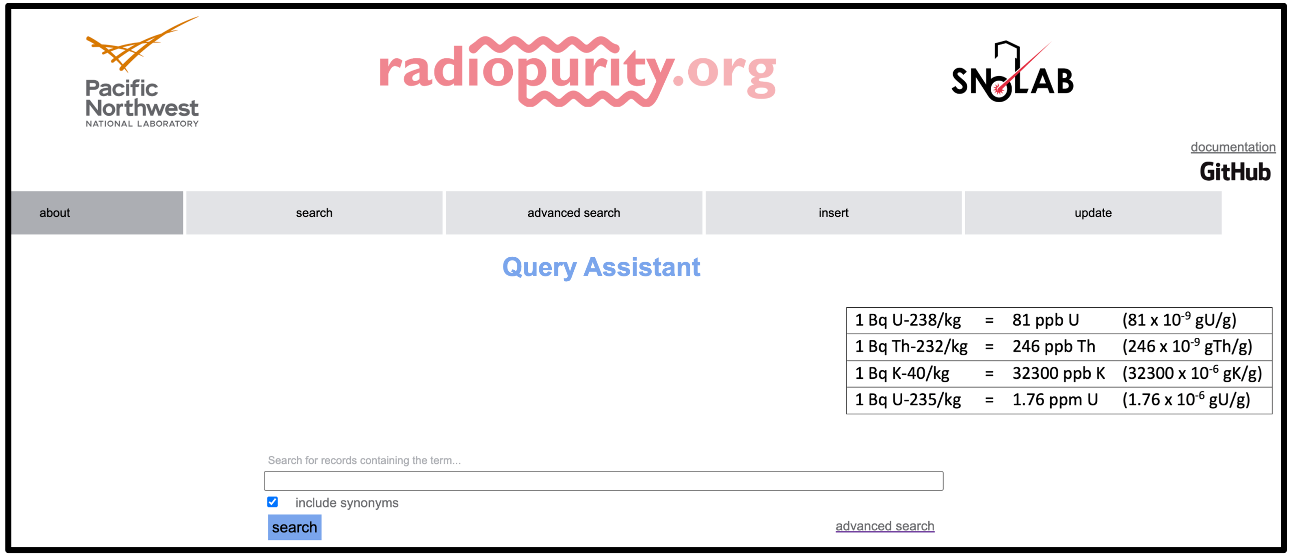


* Values shown at UL, top of chain, if no other info

- Material radiopurity should be kept in mind from the very beginning
  - Not going to reach 10^{28} yr sensitivity with radiopurity as an afterthought
- New radiopure materials are being identified all the time
  - CVD nickel, tungsten, sapphire, polyimide, PEN, etc…
- If commercial products are not radiopure enough, there is still hope
  - Work with vendors: PMTs, Radiopure cables, titanium, polyimide
  - Look at alternative fabrication techniques: CVD, crystal growth,
  - Make your own: Electroformed copper, PEN, etc.

Radiopurity Assay Results

- **Common need for all detector technologies**
  - Huge potential area for collaboration!
- Tends to be lower priority publication but is extremely important
- Suggest to share results on radiopurity.org

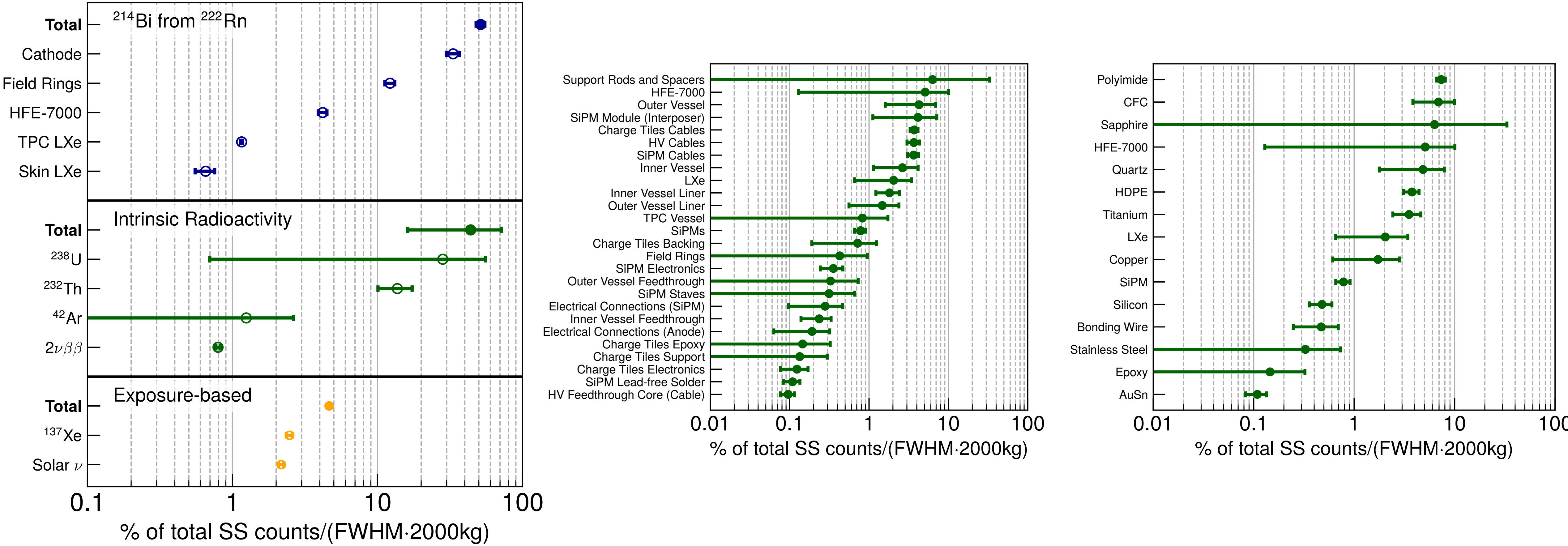


1 Bq U-238/kg	=	81 ppb U	(81×10^{-9} gU/g)
1 Bq Th-232/kg	=	246 ppb Th	(246×10^{-9} gTh/g)
1 Bq K-40/kg	=	32300 ppb K	(32300×10^{-6} gK/g)
1 Bq U-235/kg	=	1.76 ppm U	(1.76×10^{-6} gU/g)

EXO-200:
NIM A591:490-509,2008
NIM A871:169-179, 2017
nEXO:
J. Phys. G: Nucl. Part. Phys. **49** 015104
All measurements to be published soon
NEXT:
2013 JINST 8 T01002
JHEP05(2016)159
XENON1T:
Eur. Phys. J. C (2017) 77:890
XENONnT:
Eur. Phys. J. C (2022) 82:599
LUX:
Astropart. Phys. 62 (2015) 33-46
LZ:
Eur. Phys. J. C (2020) 80:1044
MAJORANA DEMONSTRATOR:
NIM A828:22-36,2016
and many more....

Thank You

nEXO Background Budget



nEXO: neutrinoless double beta decay search beyond 10^{28} year half-life sensitivity

2022 *J. Phys. G: Nucl. Part. Phys.* **49** 015104

NEXT-100 Background Budget

Detector subsystem	Material	Quantity	^{208}Tl (mBq)	^{214}Bi (mBq)
Pressure vessel				
Total	Steel 316Ti	1310 kg	< 197	< 603
Energy plane				
PMTs	R11410-10	60 units	11(3)	21(5)
PMT enclosures	Copper CuA1	60×4.3 kg	< 0.36	< 3.1
Enclosure windows	Sapphire	60×0.14 kg	0.34(8)	< 2.6
Tracking plane				
SiPMs	SENSL 1 mm^2	107×64 units	< 0.2	< 0.6
Boards	Kapton FPC	107 units	1.11(12)	7.5(5)
Field cage				
Barrel	Polyethylene	128 kg	< 1	< 8
Shaping rings	Copper CuA1	120×3 kg	< 0.5	< 4
Electrode rings	Steel 316Ti	2×5 kg	< 1.5	< 5
Anode plate	Fused silica	9.5 kg	0.32(4)	2.0(5)
Resistor chain	1-GΩ resistors	240 units	< 0.0026	< 0.02
Shielding				
Inner shield	Copper CuA1	9620 kg	< 13	< 120
Outer shield	Lead	60700 kg	2060(430)	21300(4300)

Table 3. Radioactivity budget of the NEXT-100 detector. The figures in parentheses after the measurements give the 1-sigma uncertainties in the last digits. The upper limits in the activity of most subsystems originate in the 95% CL limits set on the specific activity of the corresponding materials quoted on table 2.

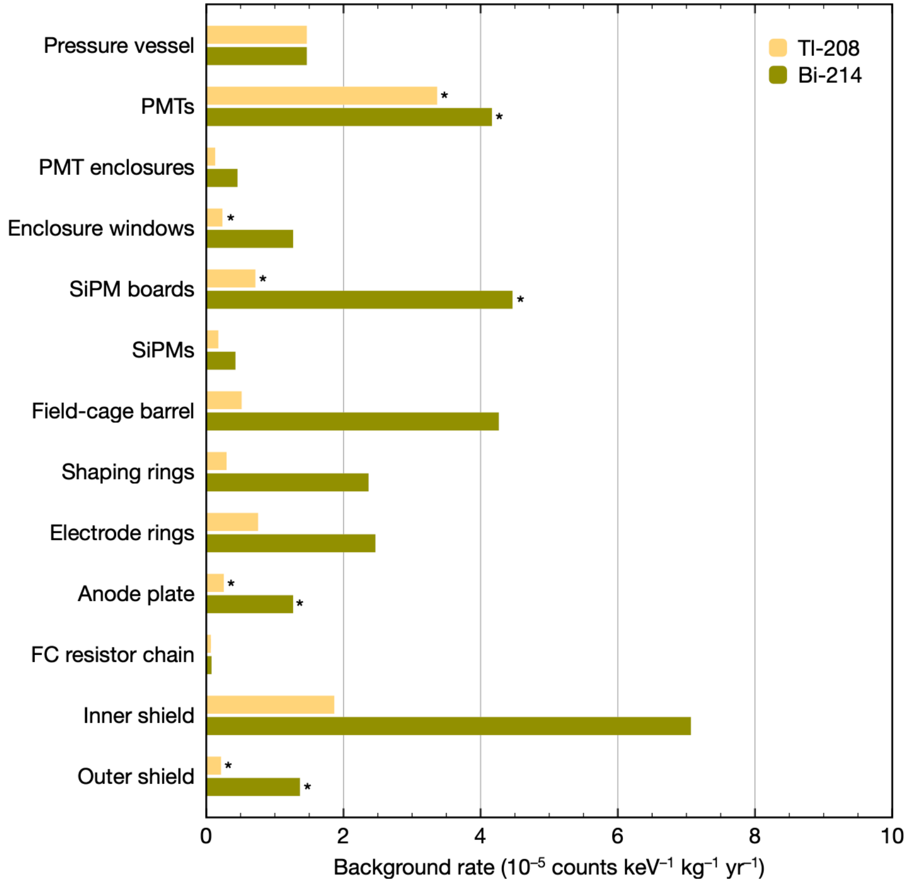


Figure 9. Contribution to the background rate of NEXT-100 of the different detector subsystems considered in our background model. An asterisk (*) next to a bar indicates that the contribution corresponds to a positive measurement of the activity of the material.

Sensitivity of NEXT-100 to neutrinoless double beta decay
JHEP05(2016)159

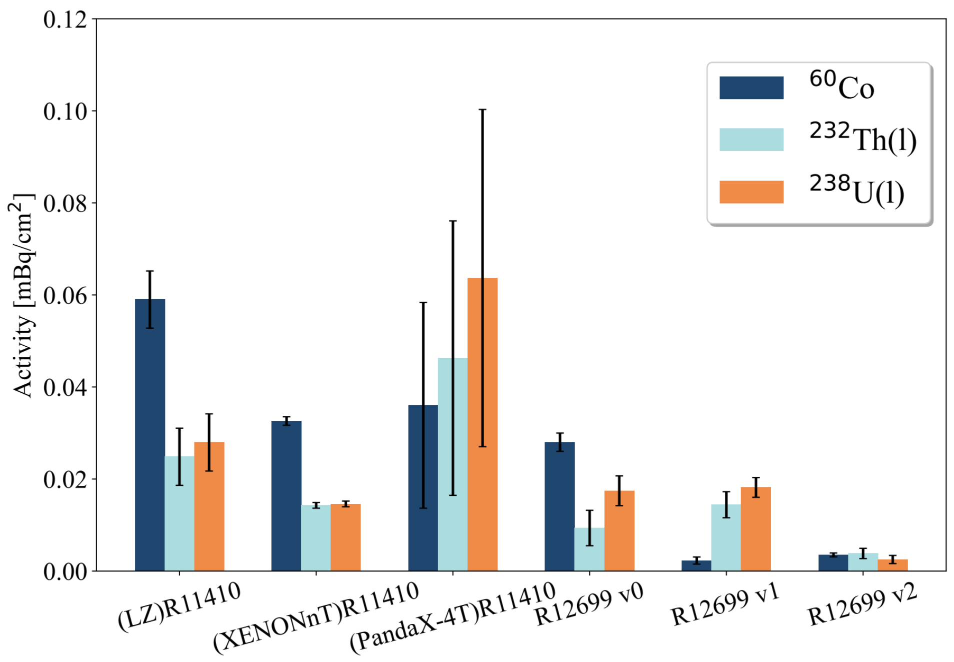
XLZD Background Budget

	^{214}Bi events		
	LZ (967 kg × 1000 d)		XLZD (8.2 t × 10 years)
Component	Nominal	Reduced	Projected
TPC PMTs	2.95	0.98	0.61
PMT structures	2.75	0.54	0.33
Field-cage resistors	2.46	0	0
Internal sensors	1.81	0.22	0.14
PMT bases	1.52	0.39	0.24
Cryostat	1.26	0.82	0.51
PMT cables	1.01	0.16	0.10
Field-cage rings	0.97	0.40	0.25
OD tank supports	0.73	0	0
OD foam	0.71	0	0
Skin PMTs	0.69	0.06	0.04
Other skin parts	0.68	0.05	0.03
Other components	3.56	1.42	0.88
Total	21.10	5.05	3.15

Table 1. Simulated background of single scatter events from ^{214}Bi 2448 keV γ-rays originating from the decay of ^{238}U in detector materials in the LZ experiment. Listed are the highest contributors to the $0\nu\beta\beta$ search, with the corresponding expected number of events in the $\pm 1\sigma$ ROI (assuming 1.0% energy resolution) and in the 967 kg inner fiducial volume of LZ, for a 1000 live days run [11]. Smaller contributors grouped under 'Other components' are listed in the text. The third column shows the expected number of events after application of the mitigation strategies described in the text, resulting in an overall radioactivity reduction of approximately 75%. The fourth column shows the projected events in the 8.2 t fiducial volume of a 60 t XLZD (see section 4) in 10 years under this scenario.

Neutrinoless double beta decay sensitivity of the XLZD rare event observatory
2025 J. Phys. G: Nucl. Part. Phys. 52 045102

PMT Components



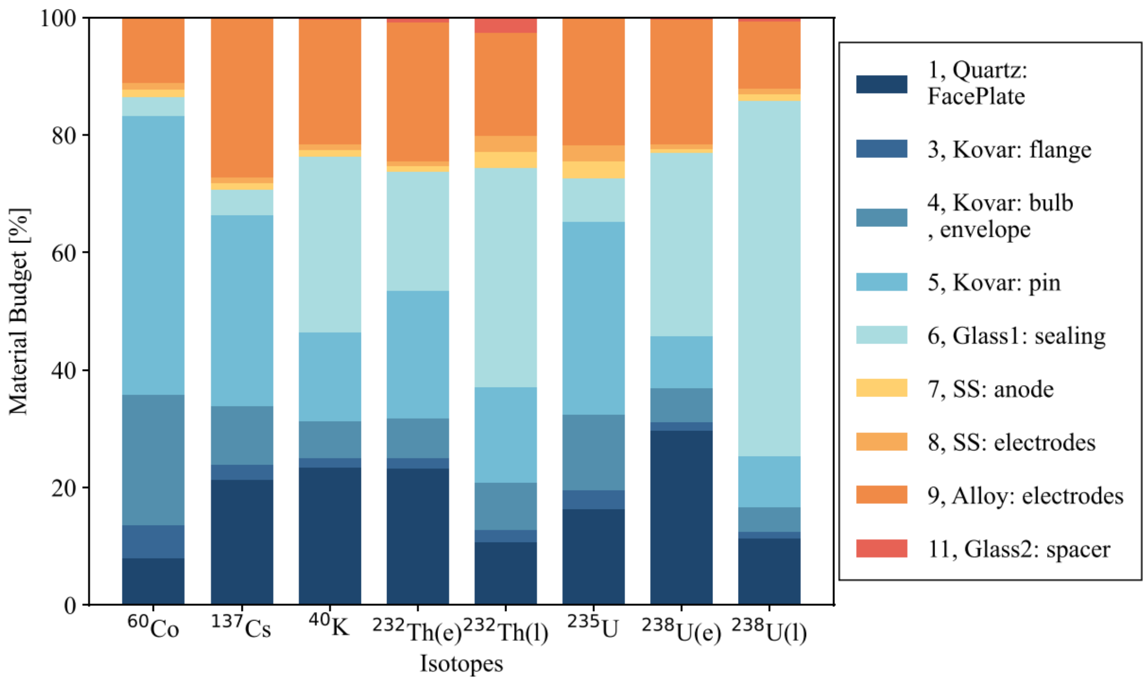


Fig. 4. The material radioactivity budget of R12699 PMT.