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Alternative isotopes for double-beta searches

Minfang Yeh (BNL)

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Physics Opportunity of Large Liquid Scintillator Detectors (II)



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$0\nu\beta\beta$ Isotopes and Experimental Approaches

DBD isotope	$Q_{\beta\beta}$ (MeV)	Natural abundance	Major experiments / projects	Detector approach
48Ca	4.268	0.19%	CANDLES, ELEGANT VI	CaF ₂ crystal scintillator
76Ge	2.039	7.8%	LEGEND, GERDA, Majorana Demonstrator	HPGe semiconductor
82Se	2.998	8.8%	SuperNEMO, NEMO-3, CUPID-0	Source foil / ZnSe bolometer
96Zr	3.356	2.8%	NEMO-3	Source foil
100Mo	3.034	9.7%	CUPID-Mo, AMoRE, NEMO-3	Mo-containing bolometer / source foil
116Cd	2.813	7.5%	Aurora, COBRA	CdWO ₄ / CdZnTe
130Te	2.528	34.1%	SNO+ , CUORE, JUNO	Te-loaded LS / TeO ₂ bolometer
136Xe	2.458	8.9%	KamLAND-Zen , EXO-200, nEXO, NEXT	Xe-loaded LS / Xe TPC
150Nd	3.371	5.6%	NEMO-3; original SNO+ program	Source foil / Nd-loaded LS R&D

The isotope choice is determined by Q-value, natural abundance, enrichment cost, achievable loading, radiopurity, light yield, attenuation length and chemical stability.

What have been demonstrated in liquid scintillators?

^{136}Xe — the benchmark (KamLAND-Zen demonstrated large-scale Xe-loaded LS)

- Xe is physically dissolved rather than chemically complexed (~3 wt%).
- **KamLAND-Zen 800** dataset used **745 kg of enriched xenon (from ~9% to ~90%)**.
- Very little chemical impact on scintillation and easy recovery.

^{130}Te — chemically loaded (SNO+ developed/present: JUNO future opportunity)

- Baseline development around **0.5 wt% natural Te**; Te-diol soluble in LAB with DDA to improve stability and light output.
- Long-term stability demonstrated.
- Recent work continues toward higher-loading formulations (**R&D up to 3 w% natural Te**)

^{150}Nd — technically demonstrated (SNO+ originally developed Nd-loaded LS with carboxylates)

- High Q-value ~3.371 MeV providing a favorable background window.
- Rare-earth loading chemistry is comparatively familiar because related approaches have been developed from early LENS works and recent Gd-loaded reactor neutrino experiments.
- The loading chemistry became quite mature; SNO+ changed isotope primarily because **large-scale ^{150}Nd enrichment was impractical/costly**.

Largely Unexplored Opportunity for High-Q Isotopes

Isotope	$Q_{\beta\beta}$ (MeV)	Natural abundance	Status in LS	Key opportunity / challenge
100Mo	3.034	9.7%	Mo-loaded LS demonstrated at R&D scale	Attractive Q-value and established enrichment; need high loading with good LY, transparency, and stability
82Se	2.998	8.8%	Very limited homogeneous LS development	Attractive Q and enrichment available; aqueous/WbLS chemistry could provide a new loading route
96Zr	3.356	2.8%	Zr-loaded and ZrO ₂ nanoparticle LS studied	High Q; nanoparticle or WbLS loading promising, but enrichment and optical performance remain challenges
48Ca	4.268	0.19%	Homogeneous (Wb)LS approach; CaF ₂ used in CANDLES	Highest Q-value , but extremely low natural abundance makes enrichment the dominant challenge

100Mo and **82Se** are probably the most interesting ones to emphasize as new opportunities, while **96Zr** provides a nice bridge to **nanoparticle loading**, and **48Ca** represents the highest-Q but **enrichment-limited** extreme.

Takeaways

- **There is no single “best” DBD isotope.** Sensitivity is determined by the combination of Q_{bb} isotope abundance/enrichment, achievable loading, radiopurity, light yield, optical transparency, and detector scale.
- **^{136}Xe and ^{130}Te currently provide the most mature paths for large LS detectors.** Xe offers simple physical dissolution and isotope recovery, while Te benefits from high natural abundance and demonstrated large-scale loading chemistry.
- **Chemistry/Cost can be as important as nuclear physics.** ^{150}Nd is a good example: attractive Q_{bb} and demonstrated LS loading, but enrichment and optical considerations limit scalability.
- **High Q_{bb} isotopes remain an important opportunity,** but their large-scale LS loading remains comparatively underdeveloped.
- **New loading technologies could change the isotope landscape.** WbLS aqueous loading, nanoparticle dispersion, and improved purification may enable isotopes that are difficult to incorporate using conventional organometallic LS chemistry.

