Development of Hermetic Xenon Detector for XLZD

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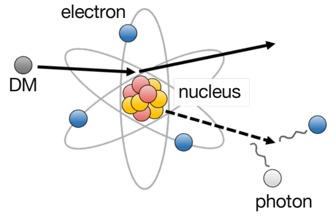
Abstract

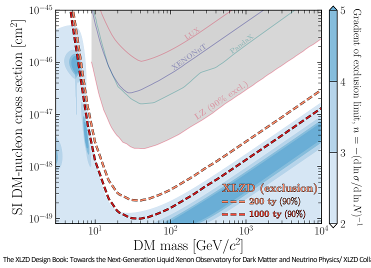
For the direct dark matter search using liquid xenon, the β decay of 214Pb, the daughter nucleus of radioactive radon, is a major background event. For the XLZD experiment, a future dark matter experiment with 50 tons of LXe, it is necessary to reduce the radon concentration in the detector to 10% of XENONnT. To reduce it, a hermetic xenon detector, which seals the center of LXe with high purity quartz and PTFE and prevents contamination of radon originating from other detector components, has been proposed.

In this poster presentation, I will report on developing a small hermetic detector made of quartz and PTFE and its hermeticity evaluated by measurement of the ratio of radon concentration in gaseous xenon inside and outside the chamber.

1. XLZD experiment

- Direct dark matter (DM) search :
  Observe signals of photons and electrons due to scattering between nucleus and DM.
- XLZD :
  A future direct dark matter(DM) search after XENONnT or LZ with 50 ton liquid xenon.





The XLZD Design Book: Towards the Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics/ XLZD Collaboration

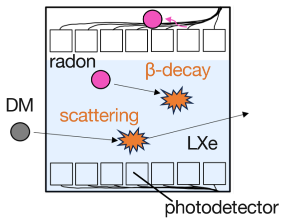
- Our target is probing WIMPs down to the neutrino fog, which is a region made difficult to explore by the neutrino background(BG).
- Radioactive BG need to be reduced to be less than neutrino BG and to achieve our goal. One of the largest radioactive BG is radon.

2. Radon BG

- β decay of ^{214}Pb, the daughter nucleus of radon, causes a signal similar to the ones caused by the scattering of DM.
- Radon emanates from the detector components(PMT cable, cryostat, etc.), which is similar to outgas.

In the XLZD experiment, the radon concentration in liquid xenon(LXe) should be reduced to 10% of that in the XENONnT experiment.

In XENONnT, radon BG was reduced by the xenon purification system, but we need a new way to further reduce the radon concentration to achieve our goal.



	radon concentration
XENONnT	4 μBq/kg
XENONnT (using radon distillation colume)	1 μBq/kg
XLZD (requirement)	< 0.1 μBq/kg

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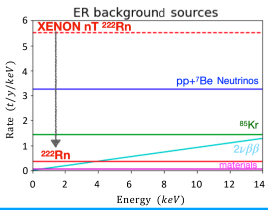


3. Hermetic liquid xenon detector

Conventional xenon detector

Radon emanates from detector components and it contaminates the sensitive volume.

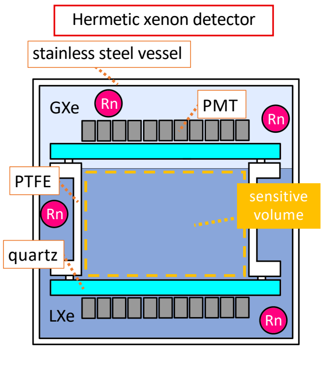
Hermetic xenon detector

Seal the sensitive volume with high purity quartz and PTFE to prevent radon contamination.

<Requirements>

- Achieve radon concentration inside the hermetic detector to 1% of the outside.
- The top and bottom flanges must be transparent to xenon scintillation light (175 nm).
- The material must be low radioactive.

Material: Quartz and PTFE (already used for PMT windows and reflective materials in XENONnT)



4. Development of a hermetic chamber

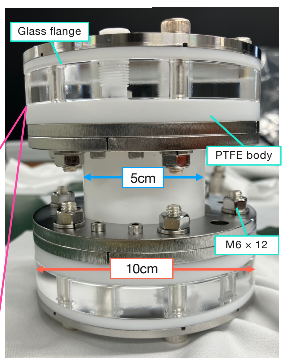
<Key points in development>

- To prevent the quartz from breaking, we need to tighten the flange with as little force as possible.
- Gasket material has to be softer than quartz and PTFE, and remain functional at low temperatures (≈-100°C) and high pressure(≈2 atm).

Expanded PTFE(ePTFE) fits these criteria.

The pressure on the gasket increased by using the nallow gasket.

The hermeticity of this hermetic chamber needs to be estimated.



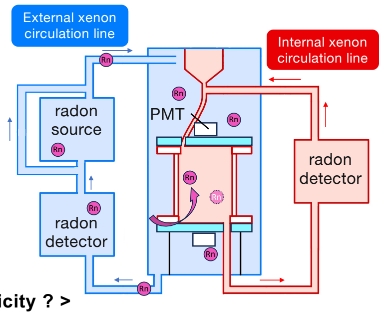
5. Estimation of the hermeticity

< How to estimate the hermeticity >

- Measure the radon concentrations inside/outside the chamber when radon is injected only outside the chamber.

The more tightly sealed the chamber, the less frequently radon decays inside it.

The setup has two independent circulation line for xenon inside/outside the chamber.



< What is the indicator of the hermeticity ? >

The indicator of its hermeticity is the leak rate of volume of xenon, which is obtained by dividing the leak rate of radon by the density of radon.

$$V_{in}\tau\frac{dC_{in}}{dt} = -V_{in}C_{in} + f\tau C_{out} - f\tau C_{in}$$

Variation the number of radon inside the chamber / decay / leak

f : leak rate of volume of xenon
τ : lifetime of radon = 132 h
C_{in} : radon concentration inside it
C_{out} : radon concentration outside it
V_{in} : inner volume

$$\Leftrightarrow \frac{C_{in}}{C_{out}} = \frac{f\tau}{V_{in}+f\tau}\left\{1-\exp\left(-\frac{V_{in}+f\tau}{\tau V_{in}}t\right)\right\} \cdots ①$$

$$\therefore \lim_{t\to\infty}\left(\frac{C_{in}}{C_{out}}\right) = \frac{f\tau}{V_{in}+f\tau}$$

As time passes, the concentration ratio is approached to a steady-state value

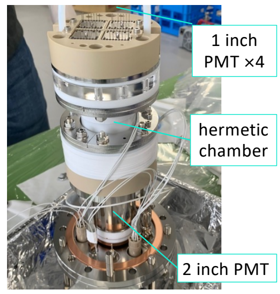
< detector of radon concentration >

- The setup has two types of detectors.

Radon detector : The daughter nuclides of radon are collected on the surface of the photodiode by applying an electric field. And then their alpha decays are observed.

PMT : The scintillation lights due to alpha decay of radon are observed by PMT through the quartz flange.

Inside the chamber : radon detector & PMT
Outside the chamber : only radon detector



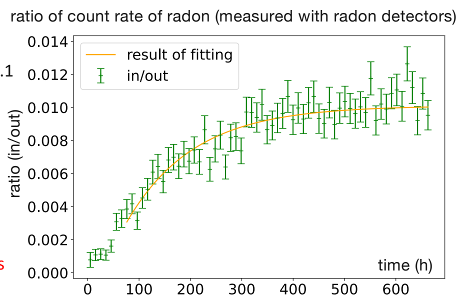
< Results >

- The radon concentration was measured for 670 hours (~5τ).
- The ratio is fitted by the equation.1

$$f = (2.9 \pm 0.4)\times 10^{-8}\ \mathrm{L/s}$$

$$\lim_{t\to\infty}\frac{C_{in}}{C_{out}} = (1.08 \pm 0.04)\times 10^{-2}$$

We can keep the radon concentration inside the chamber as 1% of that outside the chamber.



< Estimation of the radon concentration in XLZD >

The leak rate should increase when the chamber is enlarged because the length of the gasket increases.

The radon concentration inside the hermetic chamber in XLZD is estimated to be 6.9×10^{-3} μBq/kg. (Requirement : $< 10^{-1}$ μBq/kg)

radon concentration can be achieved 10 times lower than the requirement.

	leak rate	Amount of emanated radon	inner volume
Scaling	× 200	× 3	× 10^6
Increases in...	length of the gasket	amount of detector component	-
Impact for radon concentration	negative	negative	positive

6. Conclusion

- In the XLZD experiment, the radon concentration should be reduced to 10% of that in the XENONnT experiment. One of the most promising solutions is the hermetic xenon detector.
- We developed a small hermetic detector made of PTFE and quartz.
- Its hermeticity was estimated by measuring the ratio of radon concentration inside/outside the chamber and it is enough to achieve the requirement in XLZD.
- Estimation of the hermeticity in liquid xenon is ongoing.