# Recent progresses of the radon detector with an electrostatic collection

2022 June 15th (Wed)

Low Radioactivity Techniques (LRT) workshop
(South Dakota Mines/online)

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科研費 KAKENHI
Young research
21K13942

KAMIOKA OBSERVATORY

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  - **Rn removal with activated carbon fiber**
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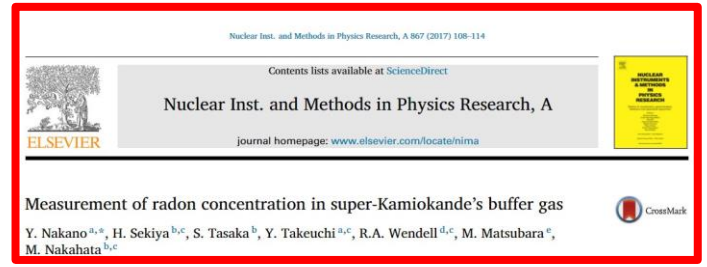
PTEP

Prog. Theor. Exp. Phys. **2015**, 033H01 (7 pages)
DOI: 10.1093/ptep/ptv018

**Development of a high-sensitivity 80 L radon detector for purified gases**

K. Hosokawa[1], A. Murata[1], Y. Nakano[2], Y. Onishi[1], H. Sekiya[2,3], Y. Takeuchi[1,3,*], and S. Tasaka[4]


Nuclear Inst. and Methods in Physics Research, A 867 (2017) 108–114

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

ELSEVIER

Measurement of radon concentration in super-Kamiokande's buffer gas

Y. Nakano[a,*], H. Sekiya[b,c], S. Tasaka[b], Y. Takeuchi[a,c], R.A. Wendell[d,c], M. Matsubara[e], M. Nakahata[b,c]

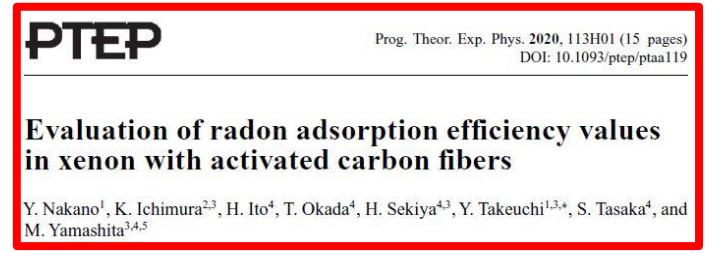

arXiv > physics > arXiv:2112.06614

Physics > Instrumentation and Detectors

[Submitted on 13 Dec 2021]

**Improvement of radon detector performance by using a large-sized PIN-photodiode**

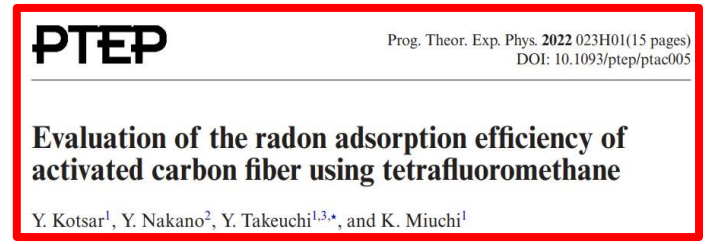
K. Okamoto, Y. Nakano, G. Pronost, H. Sekiya, S. Tasaka, Y. Takeuchi, M. Nakahata


PTEP

Prog. Theor. Exp. Phys. **2020**, 113H01 (15 pages)
DOI: 10.1093/ptep/ptaa119

**Evaluation of radon adsorption efficiency values in xenon with activated carbon fibers**

Y. Nakano[1], K. Ichimura[2,3], H. Ito[4], T. Okada[4], H. Sekiya[4,3], Y. Takeuchi[1,3,*], S. Tasaka[4], and M. Yamashita[3,4,5]


PTEP

Prog. Theor. Exp. Phys. **2022** 023H01(15 pages)
DOI: 10.1093/ptep/ptac005

**Evaluation of the radon adsorption efficiency of activated carbon fiber using tetrafluoromethane**

Y. Kotsar[1], Y. Nakano[2], Y. Takeuchi[1,3,*], and K. Miuchi[1]

# Backgrounds in experiments searching for rare event

## ■ Gases used for underground experiments

- Various gases are used as target for the rare interaction,
  source of the rare decay, and carrier gas of detectors.
- Radioactive decays limits detector's sensitivity below multi-MeV region.

| Typical gas | Experiments | Physics target | Special BG |
|---|---|---|---|
| He | He-TPC, MIMAC-He3 | Dark matter | $^{2}$H |
| Ne | CLEAN | Dark matter | -- |
| Ar | DarkSide, DEAP, ANKOK | Dark matter | $^{39}$Ar |
| | ICARUS, DUNE | Neutrino interaction | |
| Xe | Xenon, LUX, XMASS, PANDA, LZ | Dark matter (0νECEC, 0ν4β, coherent scattering) | $^{85}$Kr |
| | KamLAND, EXO, NEXT, AXEL | 0ν2β | |
| $CF_4$ | NEWAGE, DRIFT | Dark matter | -- |
| $SF_6$ | Test study | Dark matter | -- |

# Motivation of this study

## ■ Radon as background

- Backgrounds from radioactive contaminants must be kept at a particularly low level.
- Radon ($^{222}$Rn) is produced continuously from radium ($^{226}$Ra) in the detector material.

→ Due to its relatively long lifetime (3.8 days), some reach at the detector fiducial volume.

- Rn should be reduced by material screening before the detector construction.
  by purification process during the detector operation.

## ■ Motivation and goal

- For monitoring purpose, Rn in gas (liquid) is precisely measured in real-time.

  → Development of the Rn detector with an electrostatic collection method.

- Evaluate the detector performance by filling various gases (such as, Ar, Xe, $CF_4$, $SF_6$).
- Develop a purification method and evaluate its Rn removal efficiency.

# Design of radon detector

Nucl. Instrum. Meth. A, 497, 414–428 (2003).

## ■ Requirement

- Monitor the radon concentration in gas with an accuracy of < 1 mBq/m$^3$.

## ■ Main component

(1) Stainless steel vessel

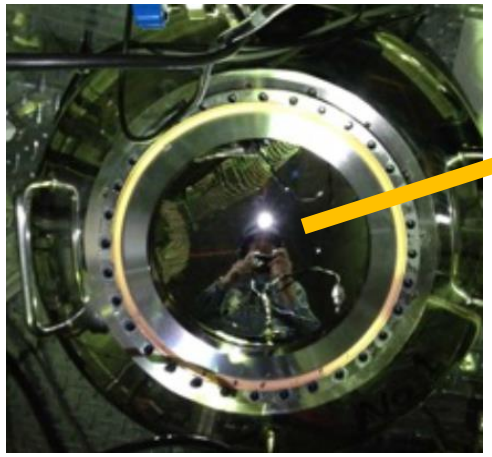
→ Inner surface is electropolished to reduce its intrinsic radon BG.

(2) Volume: 80 L

→ Airtight structure by using VCR/ICF metal gaskets to prevent the outer gas from entering inside.

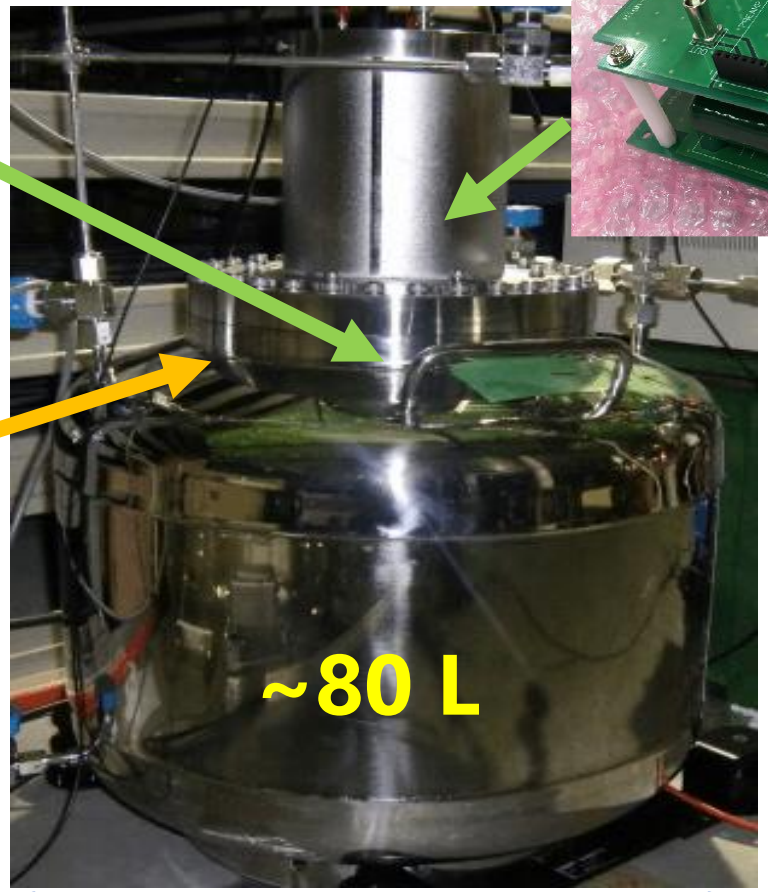
(3) PIN-photodiode and HV divider

→ Form the electrical field and collect Rn daughters.



18×18 mm$^2$
PIN photodiode (PD)

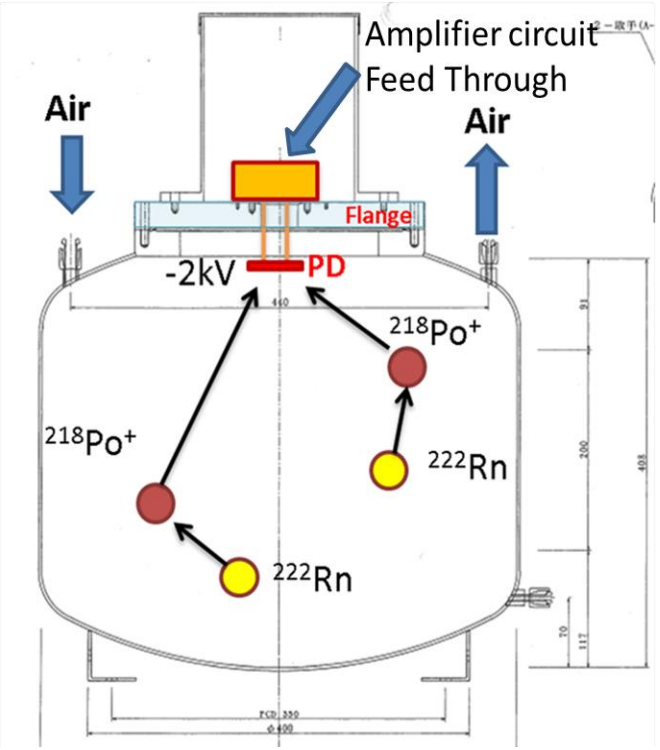
High voltage divider




40.8 cm

50.0 cm

# Electrostatic collection

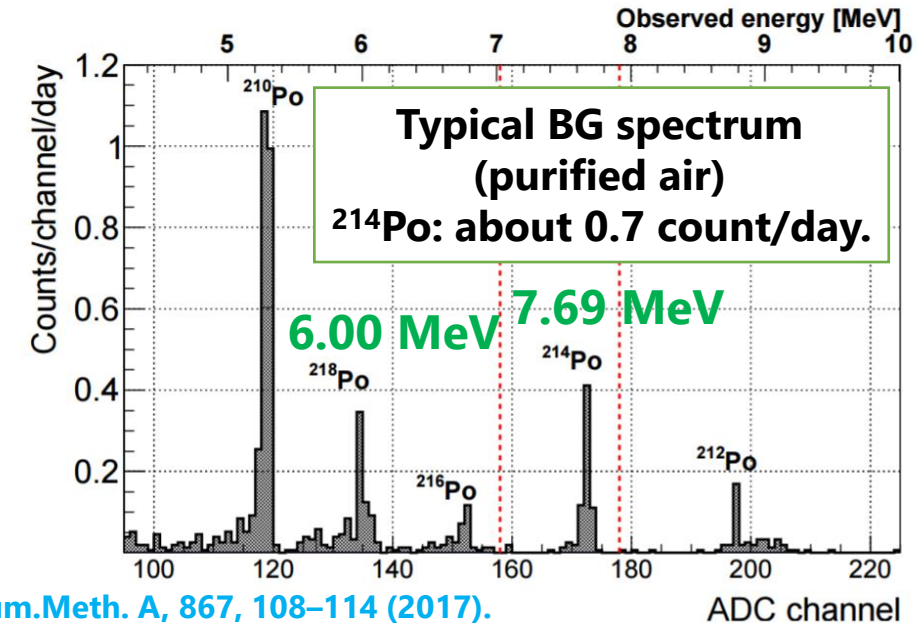



## ■ Electrostatic collection

- **Positive ions** from $^{222}$Rn decay ($^{218}$Po$^+$, $^{214}$Po$^+$, $^{210}$Po$^+$).
- Collect positive ions on PIN photo-diode by forming an electrical field inside the detector.
- Measure energy of **α particle**.

## ■ Performance

- High resolution of energy measurement.
  → $^{214}$Po (7.69 MeV) is used as signal.
- The background rate is quiet low (0.7 count/day).
  → Intrinsic background is estimated as ~0.3 mBq/m$^3$ for a single day measurement.

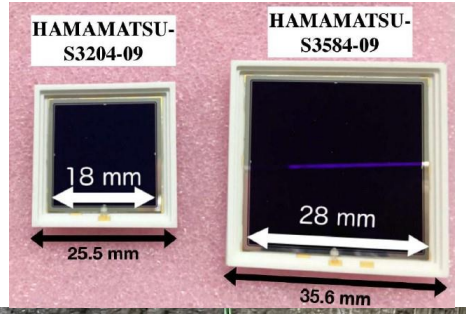



Nucl. Instrum.Meth. A, 867, 108–114 (2017).

- To convert the count rate to the Rn concentration, **the calibration factors** were evaluated.

$$calibration\ factor = \frac{^{214}\text{Po count rate [count/day]}}{\text{Rn concentration [mBq/m}^3\text{]}}$$

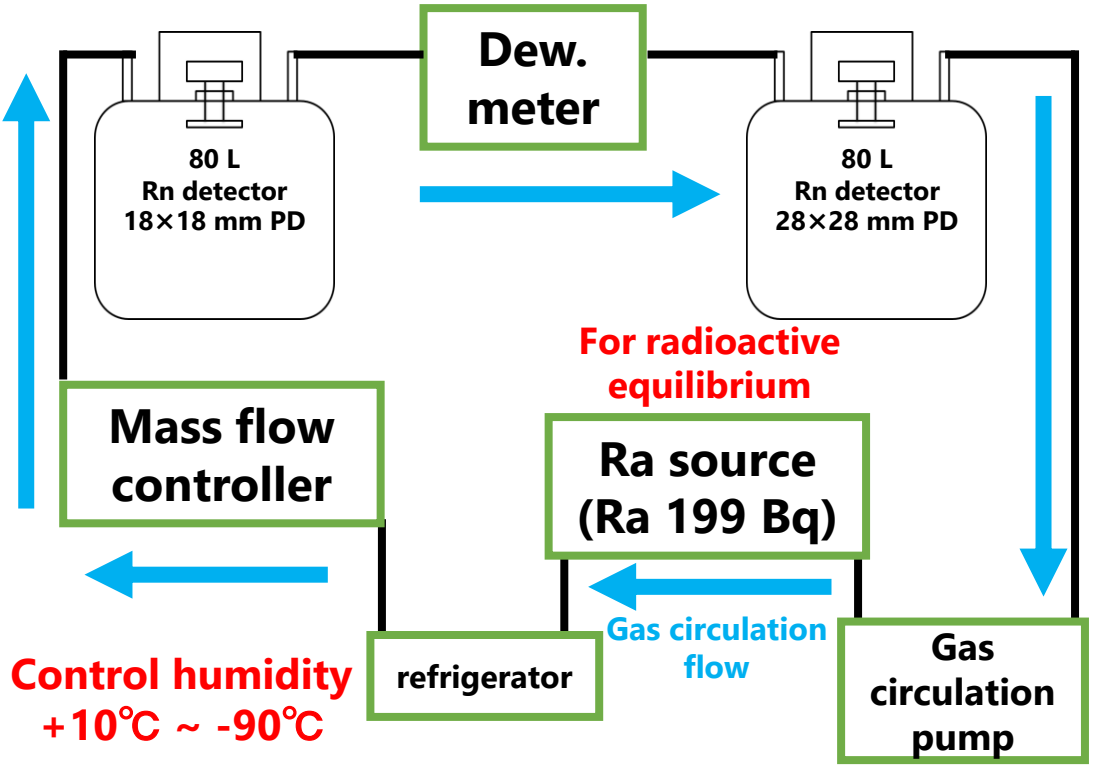
# Calibration system

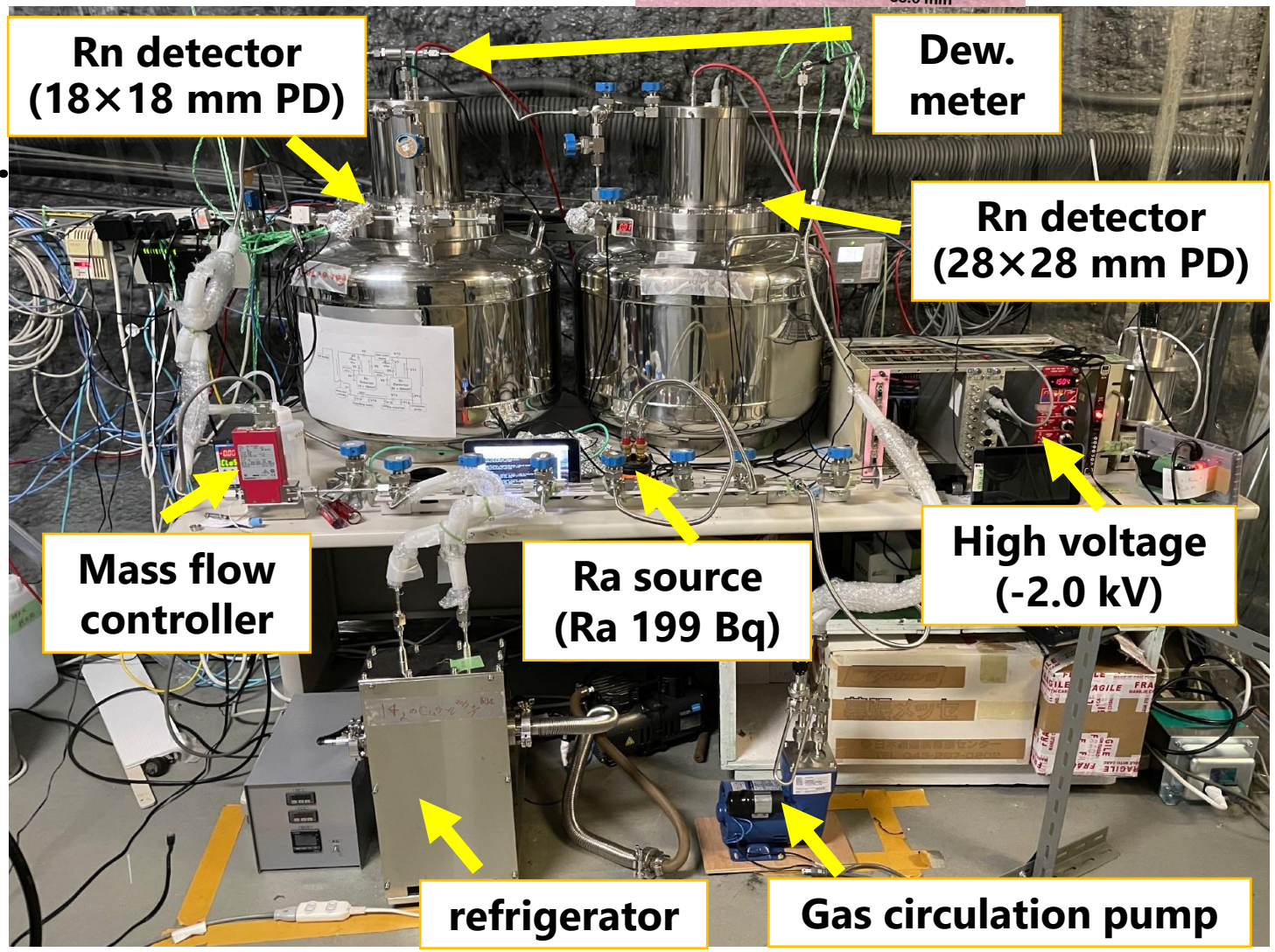



## ■ Setup and requirement

- Kamioka observatory in the Super-Kamiokande area.
- Calibration with different conditions.

$$calibration\ factor = \frac{^{214}\mathrm{Po\ count\ rate\ [count/day]}}{\mathrm{Rn\ concentration\ [mBq/m^3]}}$$



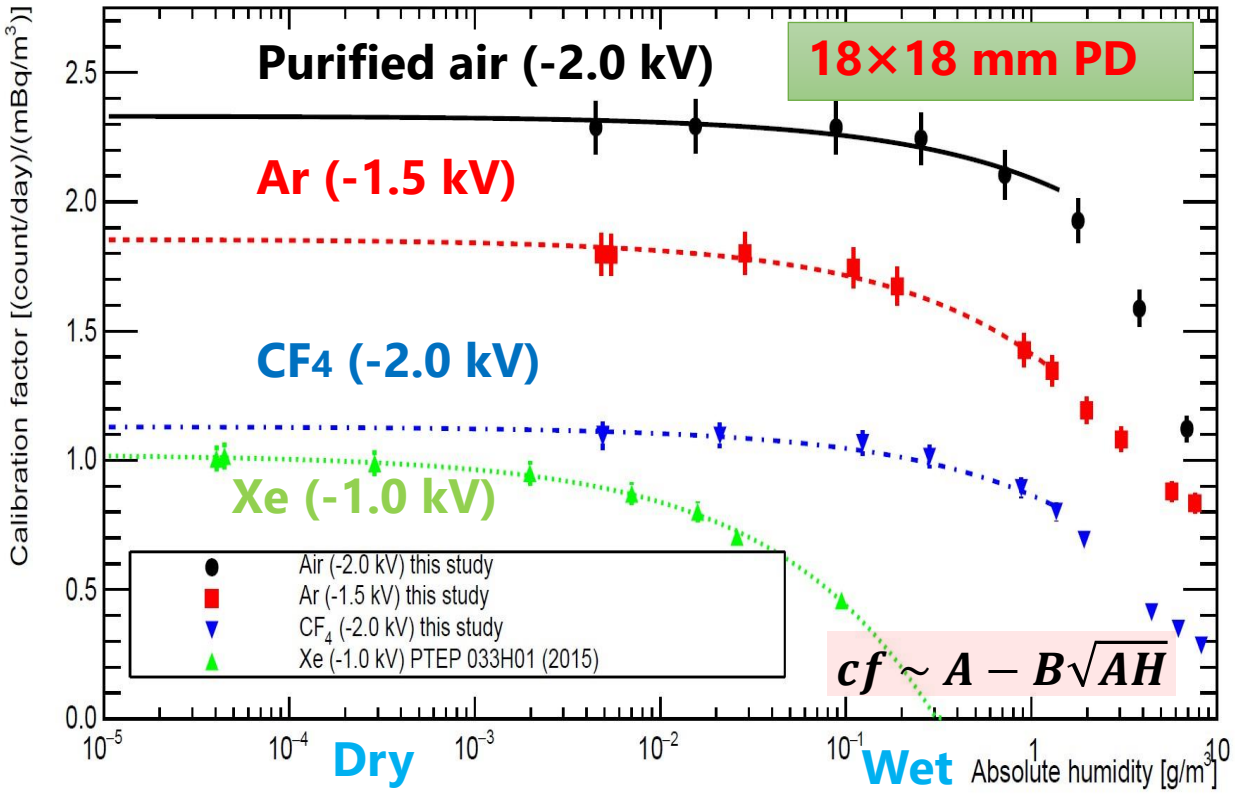

28×28 mm Rn detector (purified air), arXiv:2112.06614.

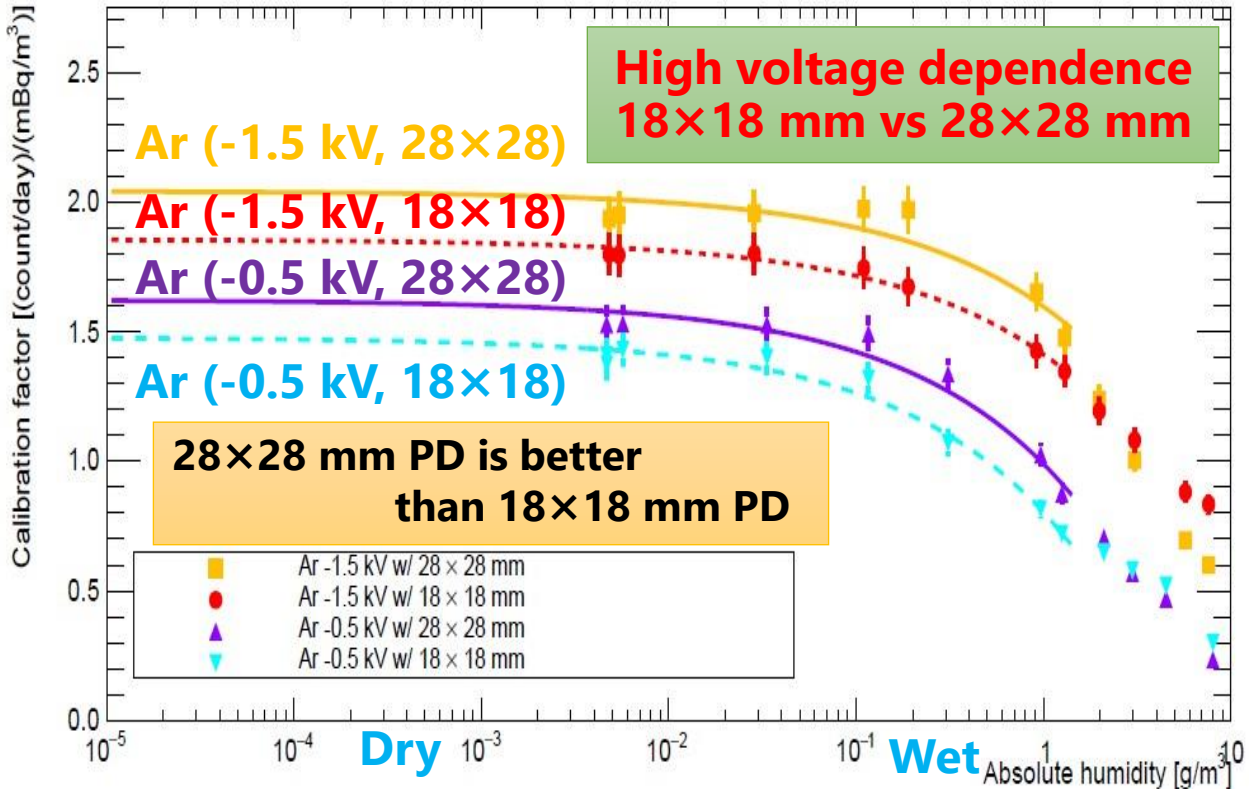
# Results of calibrations

## ■ Calibration factor

- We conducted many calibrations by filling with purified air, Ar, $CF_4$, Xe (past study).
- Difference of calibration factors may come from the molecular size of gases.
- The Rn detector can monitor the Rn concentration in those gases.
- Next step: calibration with Xe and $SF_6$.

Po neutralization
$H_2O \rightarrow H^{\cdot} + {}^{\cdot}OH$
${}^{\cdot}OH + e^- \rightarrow {}^{\cdot}OH^-$
${}^{\cdot}OH^- + Po^+ \rightarrow Po + {}^{\cdot}OH$

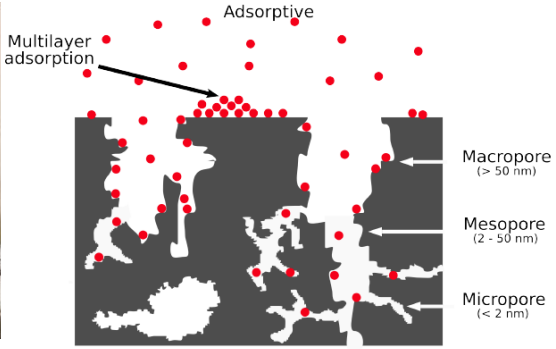


# Rn removal with activated carbon fiber

## ■ Activated carbon fiber (ACF)

- Ingrained with micropores that significantly increase the surface area available for adsorption.
- Widely used for removing Rn from gas.





PTEP Prog. Theor. Exp. Phys. 2020, 113H01 (15 pages) DOI: 10.1093/ptep/ptaa119

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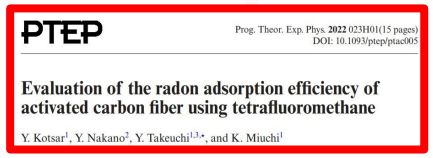

PTEP Prog. Theor. Exp. Phys. 2022 023H01(15 pages) DOI: 10.1093/ptep/ptac005

Evaluation of the radon adsorption efficiency of activated carbon fiber using tetrafluoromethane

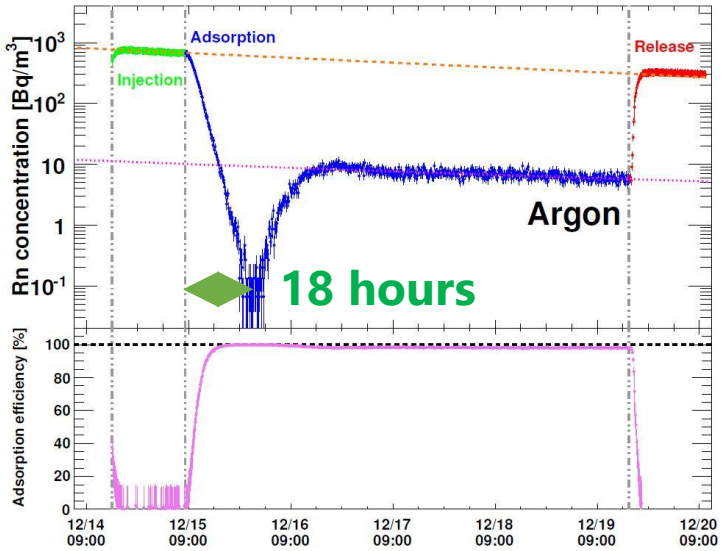
Y. Kotsar[1], Y. Nakano[2], Y. Takeuchi[1,3,*], and K. Miuchi[1]

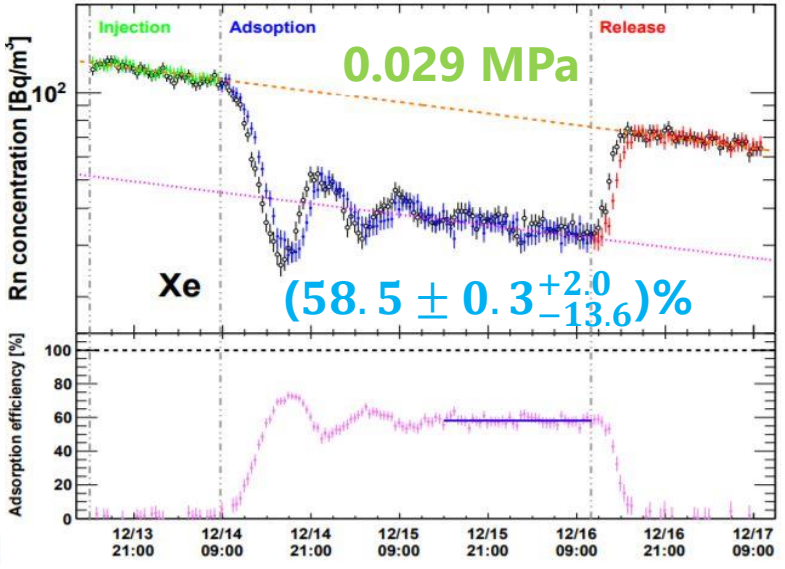
## ■ Results

- Found **low intrinsic background ACF**.
- **High removal efficiencies** for air/argon/$CF_4$ while $\left(58.5 \pm 0.3^{+2.0}_{-13.6}\right)\%$ for Xe.

| | A-7 | A-10 | A-15 | A-20 | A-25 | S-25 |
|---|---|---|---|---|---|---|
| Specific surface area [$m^2/g$] | 850 | 1300 | 1700 | 2000 | 2667 | 1744 |
| Average pore diameter [nm] | 1.7 | 1.7 | 1.9 | 2.2 | 2.5 | 5.3 |
| Pore volume [$cm^3/g$] | 0.35 | 0.55 | 0.80 | 1.11 | 1.65 | 2.30 |
| Meso pore volume ratio [%] | 4 | 6 | 10 | 21 | 37 | 67 |

| | Method | Weight [g] | Duration [day] | Uranium series [mBq/kg] | Thorium series [mBq/kg] | $^{40}K$ [mBq/kg] |
|---|---|---|---|---|---|---|
| A-10 | HPGe | 6.65 | 12.4 | < 352 | < 305 | $< 4.31 \times 10^3$ |
| A-15 | HPGe | 160.0 | 10.1 | < 11.9 | < 12.2 | < 142 |
| A-20 | HPGe | 267.4 | 11.6 | < 5.5 | < 10.4 | < 49 |
| A-25 | HPGe | 8.4 | 14.9 | < 269 | < 261 | $< 4.31 \times 10^3$ |
| Shirasagi $G_{2X}$ 4/6 | HPGe | 95.0 | 7.0 | $67 \pm 15$ | — | — |
| Shirasagi $G_{2X}$ 4/6 | PC | — | — | $62 \pm 4$ | — | — |
| Blücher 100050 | PC | — | — | $2.6 \pm 0.3$ | — | — |



# Summary

- Radon (Rn) is serious background in rare event experiments.
- To improve the detector's sensitivity, the Rn concentration should be reduced and monitored.

- Rn detector is widely used for such monitoring purpose.
- We have developed the low background Rn detector and evaluated its performance by filling with various gases.

- We have estabished the calibration method to systematically evaluate its performance.
- Based on the calibration results, we found several dependence of its performance.

- Using the Rn detector, a Rn removal test with ACF was also conducted.
- Further studies with difference gases are scheduled.