Development of a high sensitivity radon detector for purified gases

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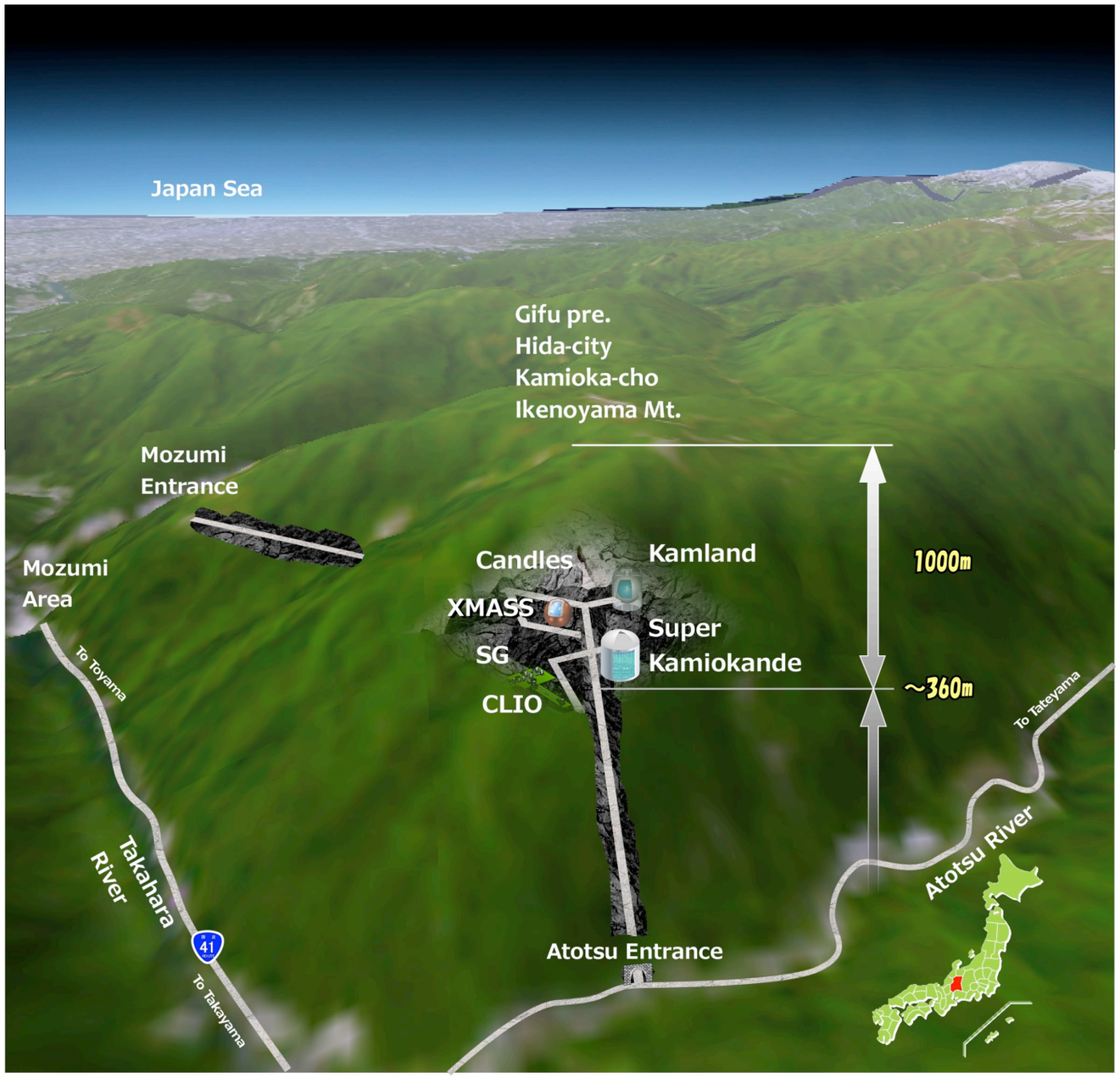
Topics

- ✓ What is radon?
- ✓ Basic performance of new 80L radon detector.
- ✓ Applications for underground experiments in Kamioka.

Radon in underground



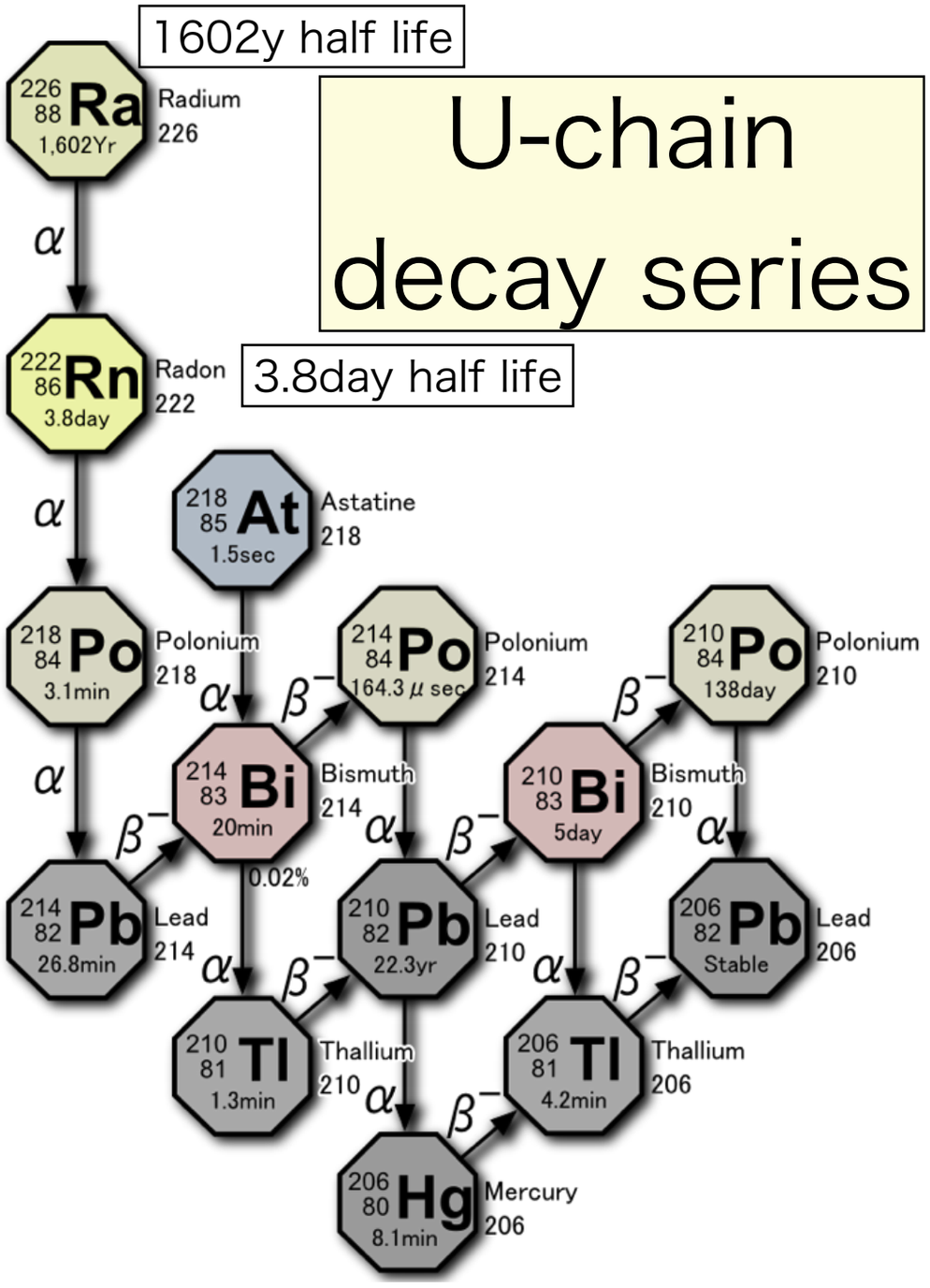
✓ In underground, radon concentration is very huge.

- Especially in summer, the value is at least 2-order bigger than out of mine!!

Radon concentration	above ground	Kamioka mine
summer [Bq/m^3]	0~10	~2000
winter [Bq/m^3]		40

The Super-Kamiokande Collaboration, Phys.Lett.452(1999)418

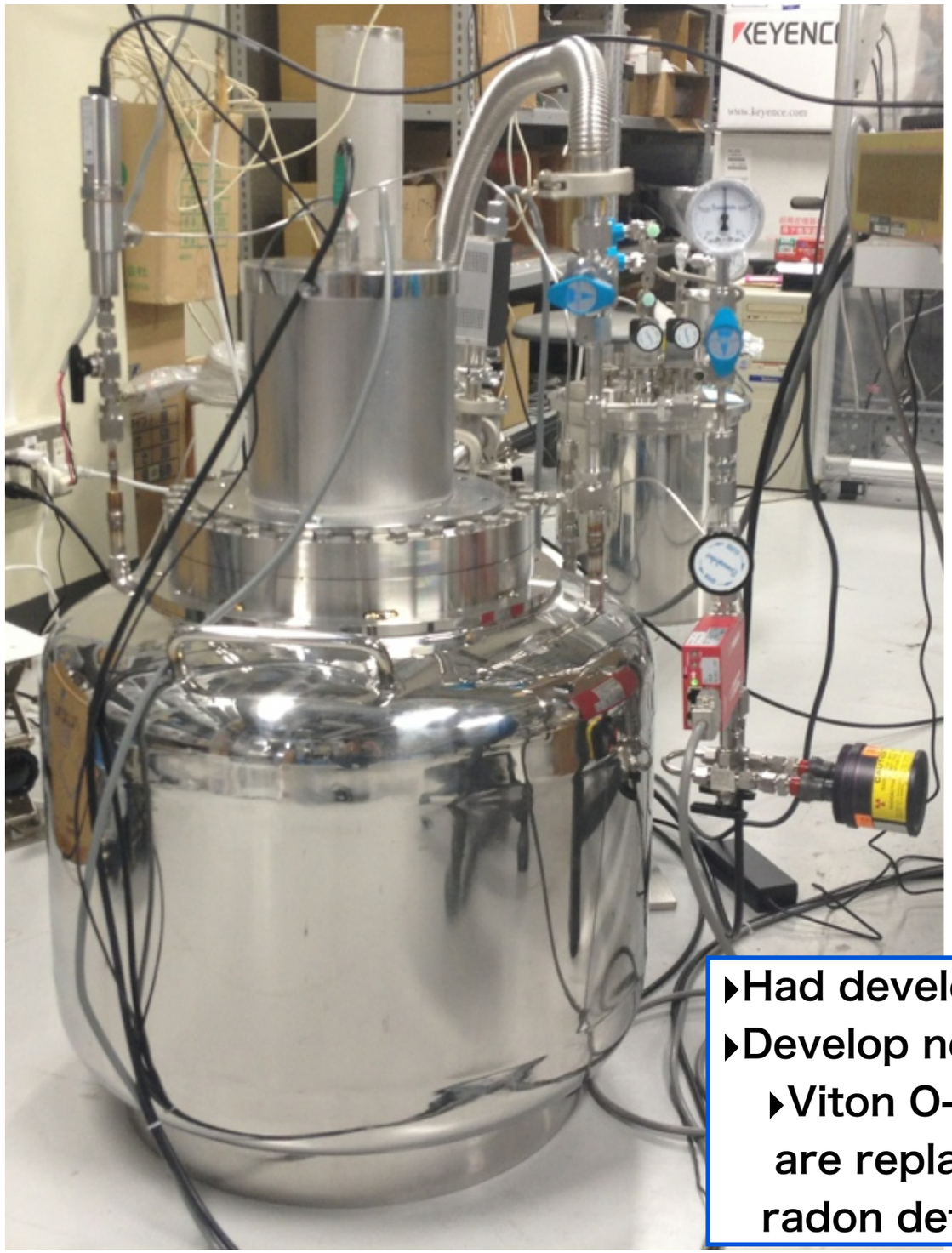
Radon in underground experiments



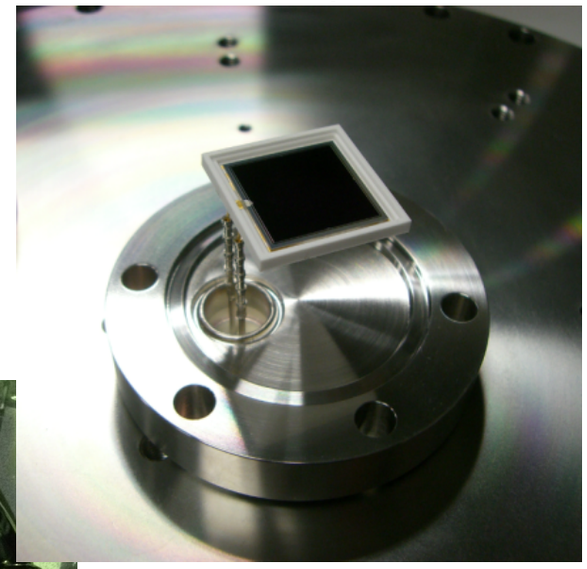
- ✓ Half life:: ~3.8days.
- ✓ Potentially dissolve into purified gases (Xe, Ar, air...) or pure liquids.
  - Super-K
    - Pure water, air in water tank
  - XMASS
    - Xe, pure water
- ✓ ^{222}Rn concentration in underground modulates annually.
  - Need continuous monitoring.

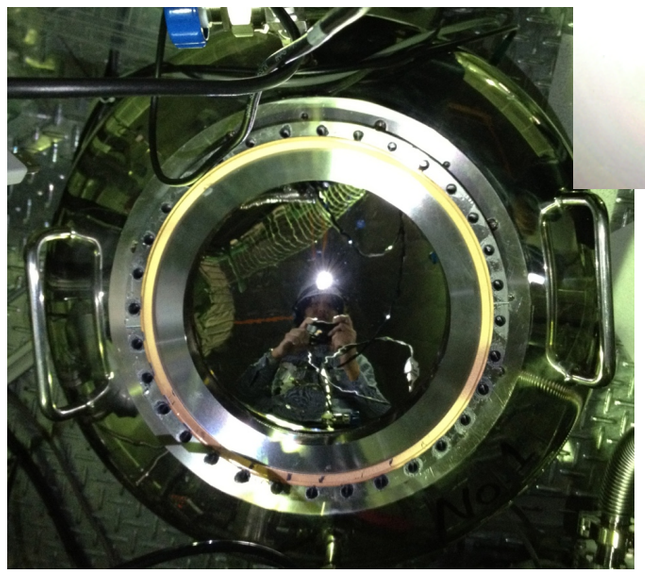
^{222}Rn could be a source of serious background events.

A high sensitivity radon detector



18x18mm PIN photo diode



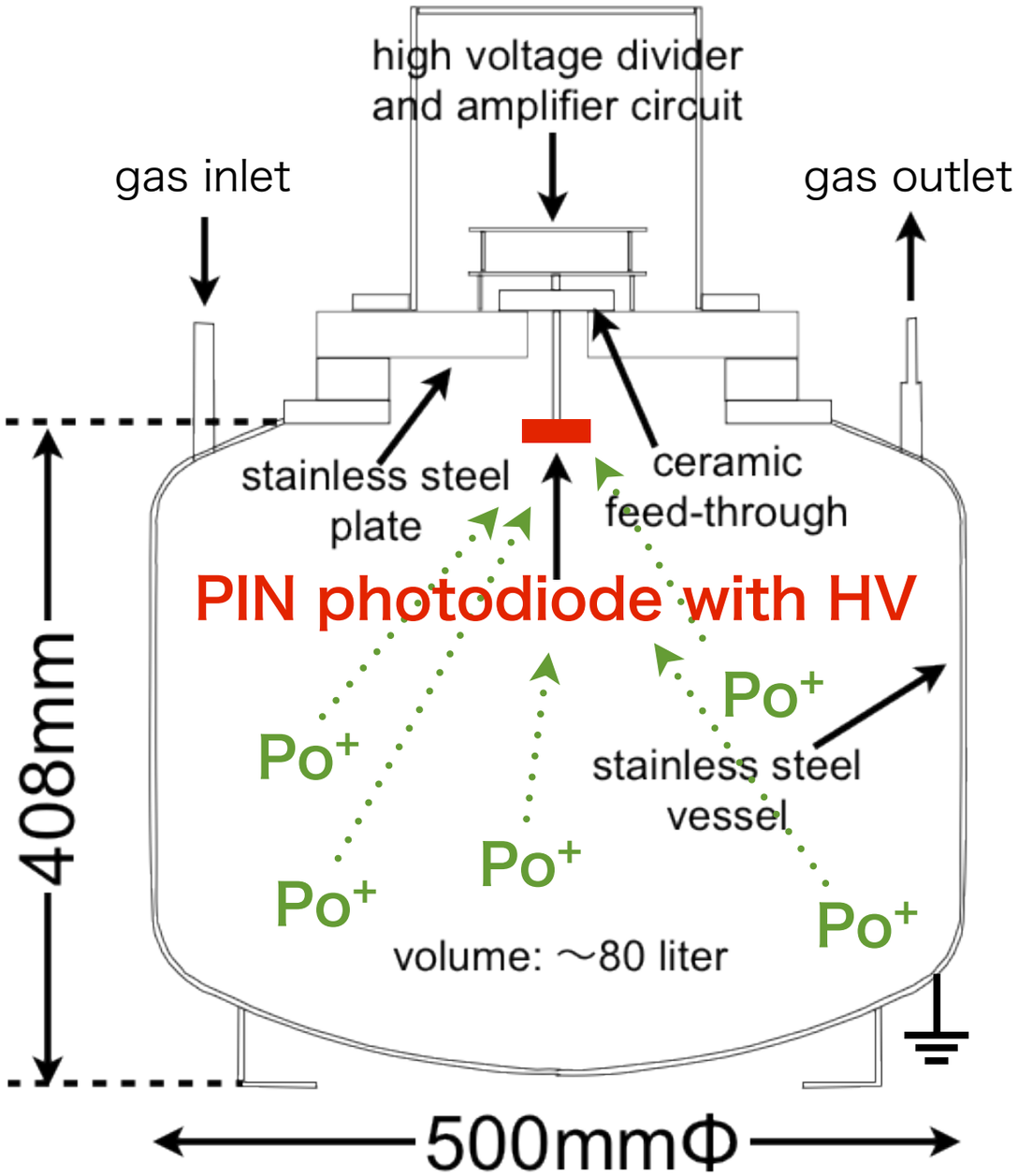


Cf. 70L Rn detector:
NIM A421 (1999) 334

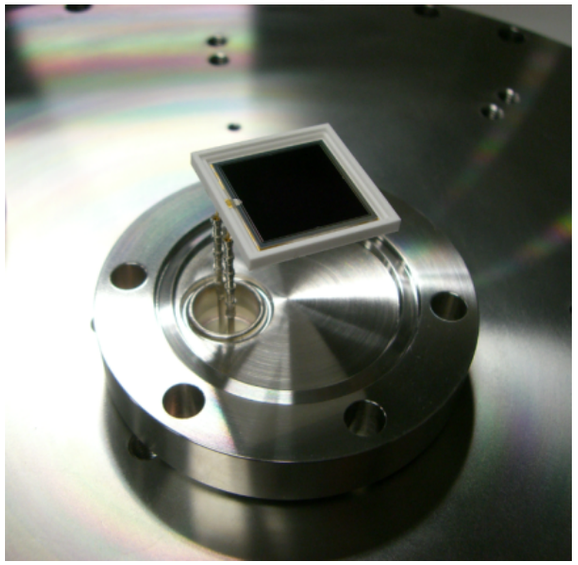
- Had developed 70L detector mainly for Super-K and XMASS.
- Develop new 80L detector.
  - Viton O-rings and an acrylic plate in the 70L Rn detector are replaced with metal seal and ICF flanges in the new 80L radon detector.

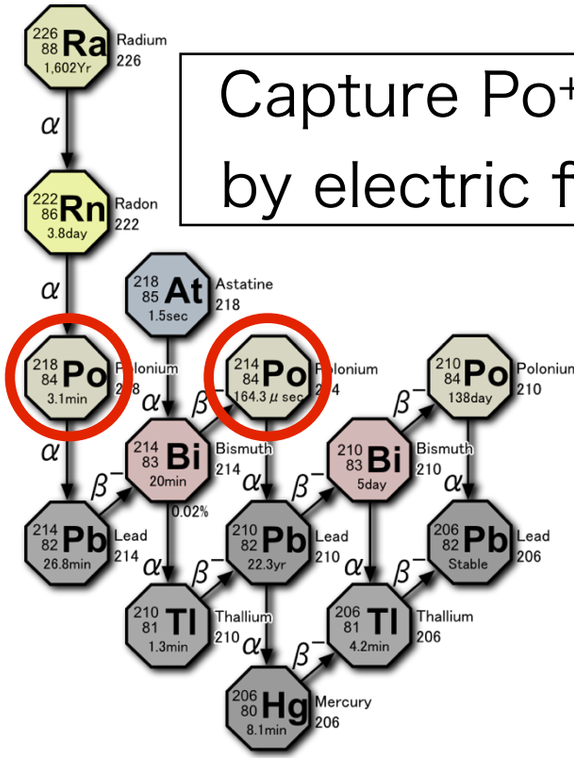
Principle of detection

Method = PIN photodiode + Electrostatic collection



18x18mm PIN photo diode

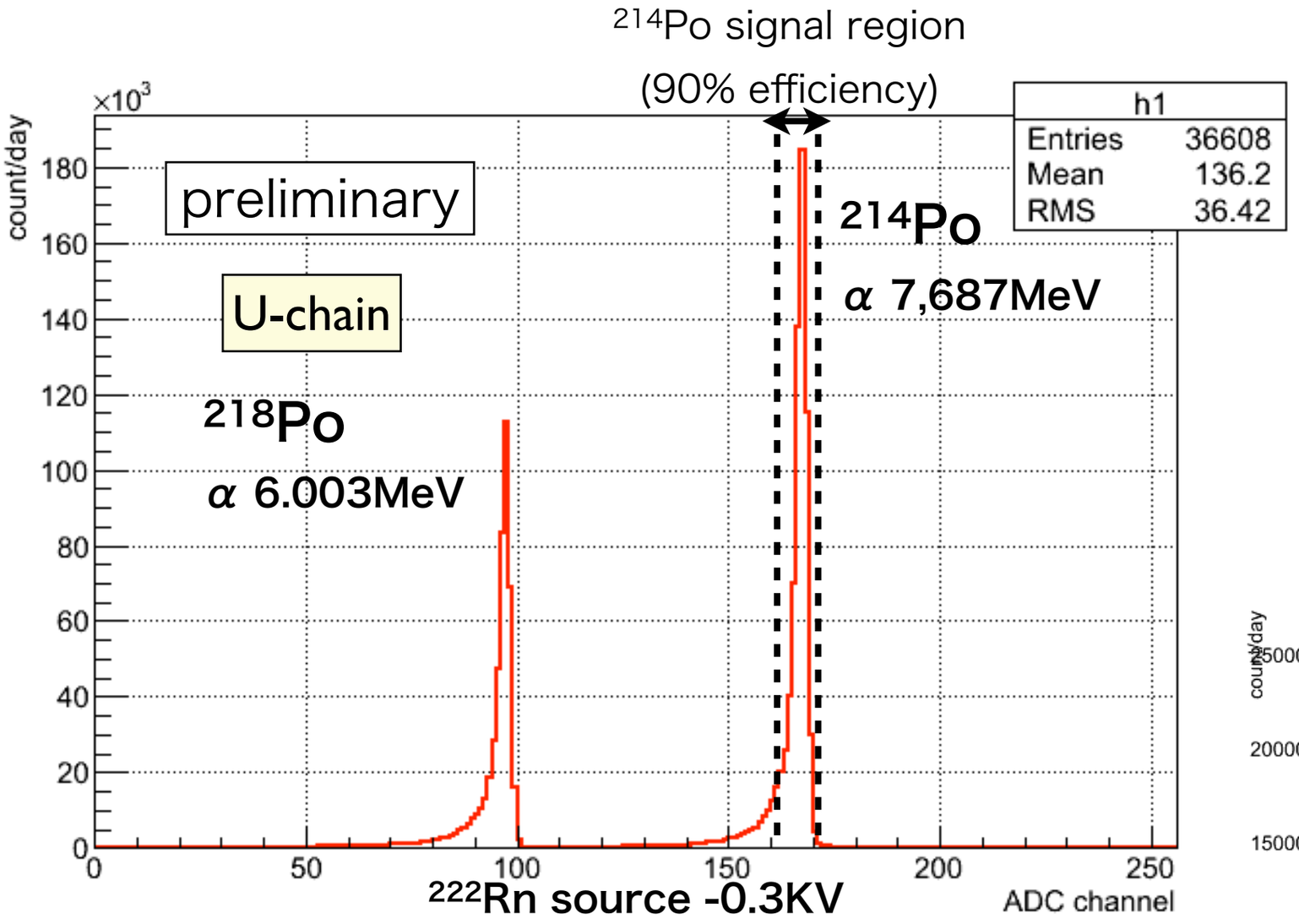




Capture Po^+ ion by electric field.

- ✓ A PIN photodiode is set with feed-through in detector vessel.
- ✓ More than 90% of ^{218}Po atoms tended to become positively charged.
  - P. Kotrappa et al., Health Phys. 46 (1981) 35.
- ✓ Po^+ will be captured by negative HV supplied to PIN photodiode.

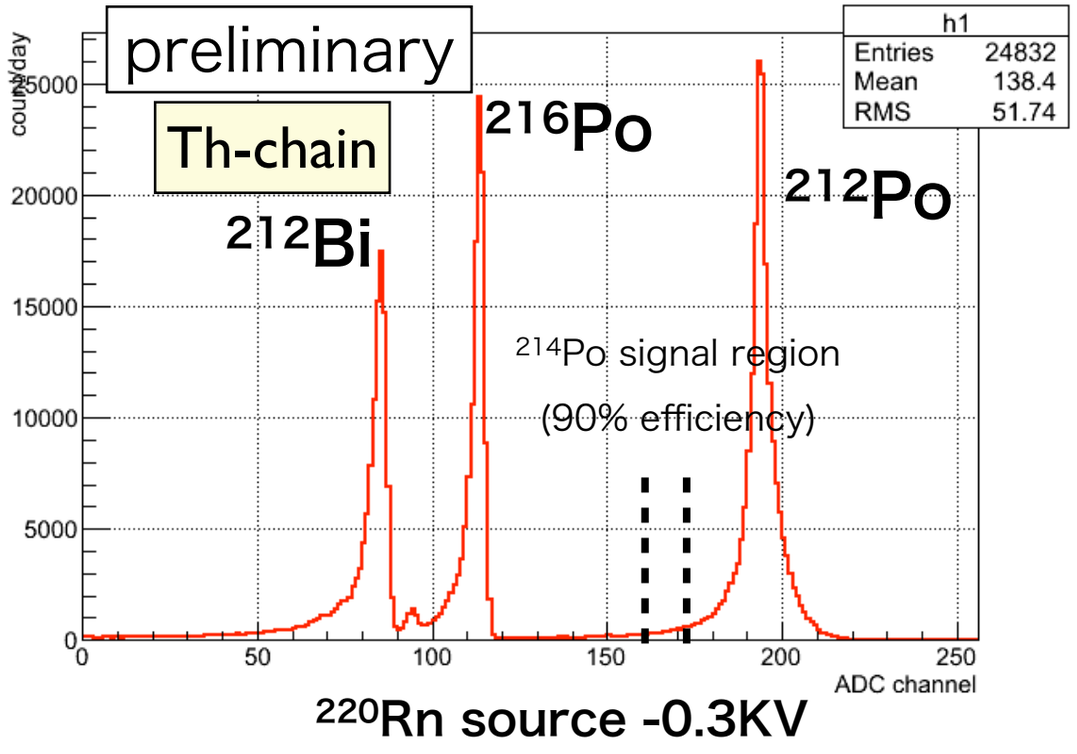
Energy spectrum



purified Ar 1atm

^{222}Rn source (U-Chain)
: PYLON RNC ^{226}Ra

^{220}Rn source (Th-Chain)
: Lantern mantle



✓ Only **^{214}Po signal region is used.**

- **Higher efficiency** than ^{218}Po.
- **Lower ^{232}Th-Chain BG** in signal region.
  - ^{218}Po signals overlap ^{212}Bi signal.

Performance evaluation of 80L radon detector

$$\text{Calibration Factor}\ [(\text{count/day})/(\text{mBq/m}^3)] = \frac{\text{measured } ^{214}\text{Po signal rate [count/day]}}{^{222}\text{Rn concentration [mBq/m}^3\text{]}}$$

✓ Measurement of calibration factor

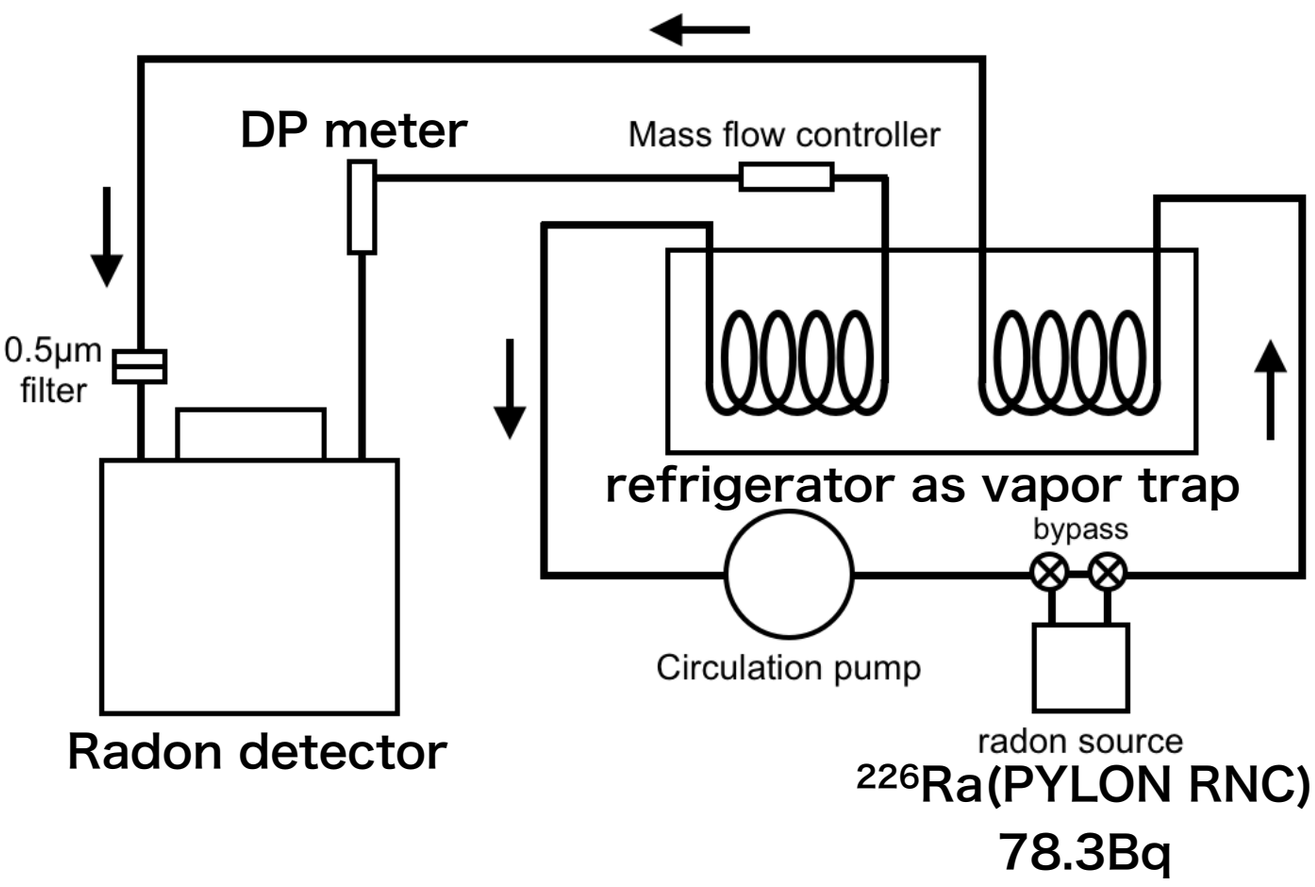
- **Humidity** dependence
  - Po^+ neutralization by H_2O.
- **HV** dependence
  - Using electrostatic collection.

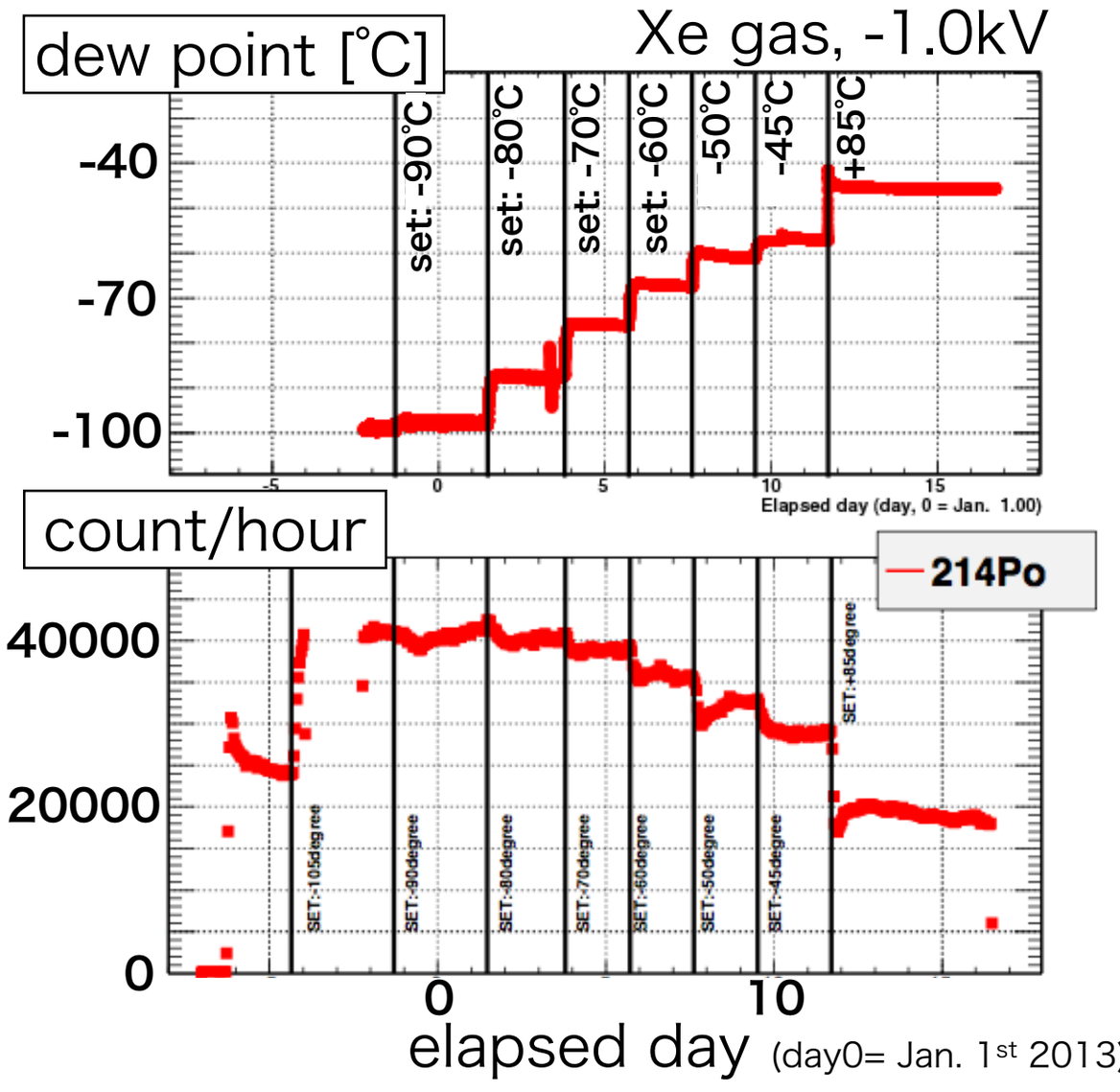
Neutralization of Po^+

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

Kai-Dee Chu et al.,
Environ. Sci. Technol., Vol. 22, No. 6,1988 711

Calibration system

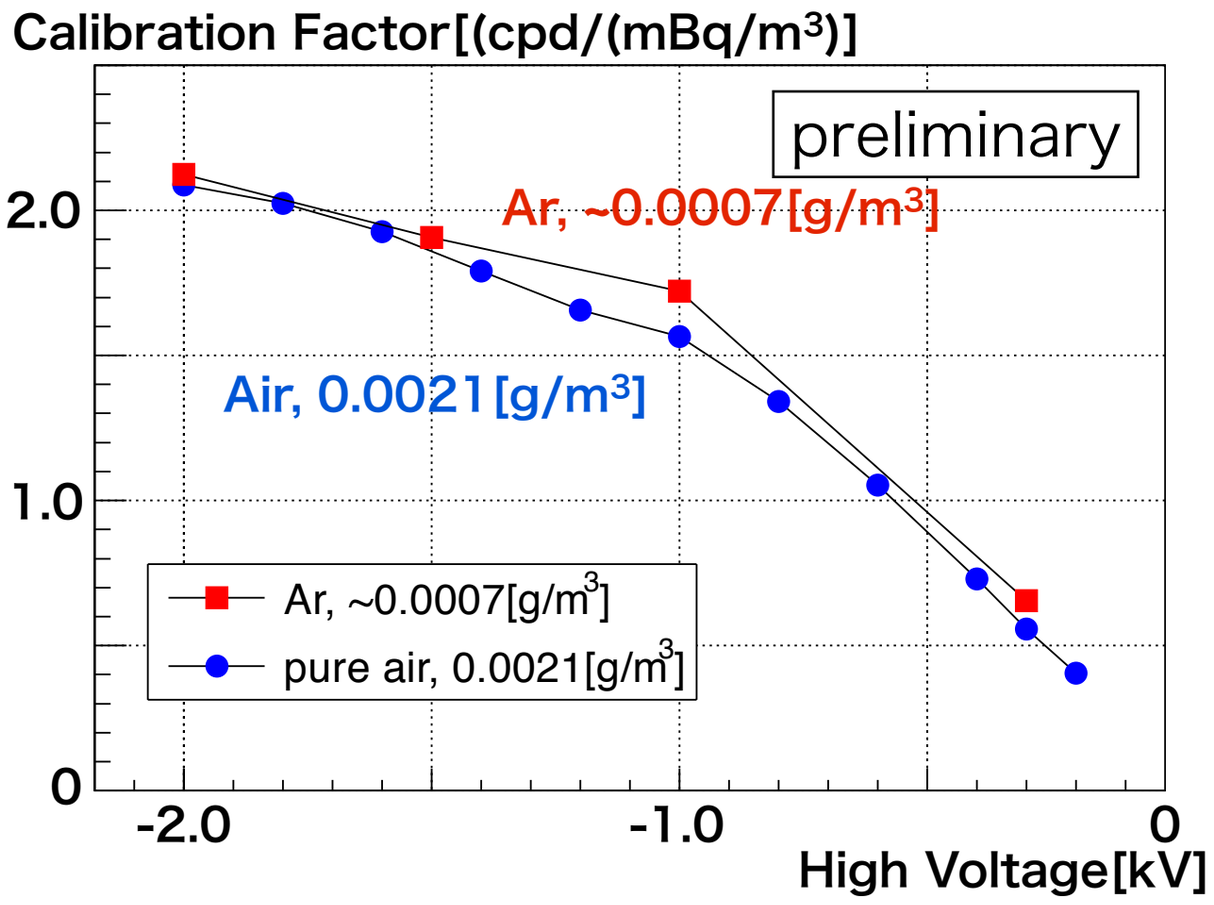


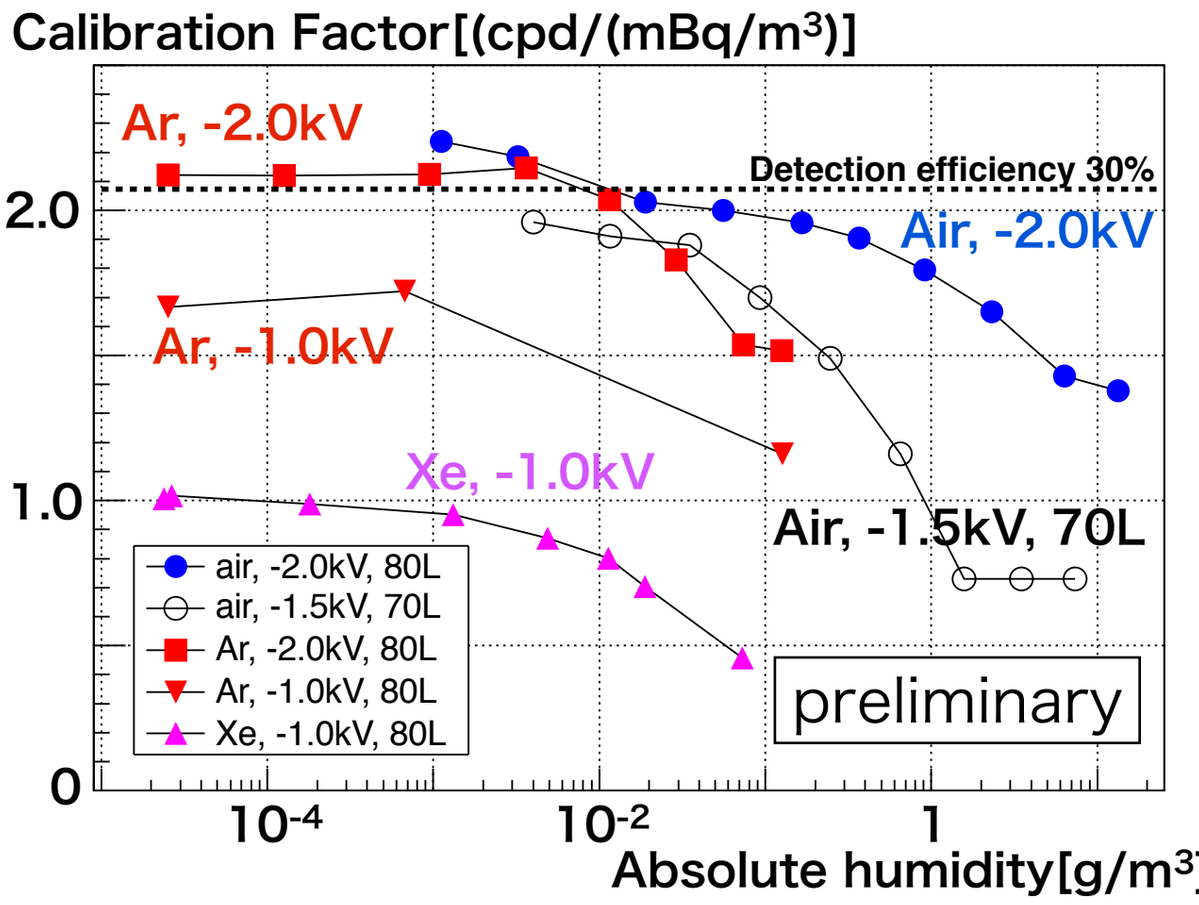


✓ Control dew point by a refrigerator as vapor trap.

✓ With higher dew point, count rate with same Rn concentration getting worth.

HV & Humidity dependence



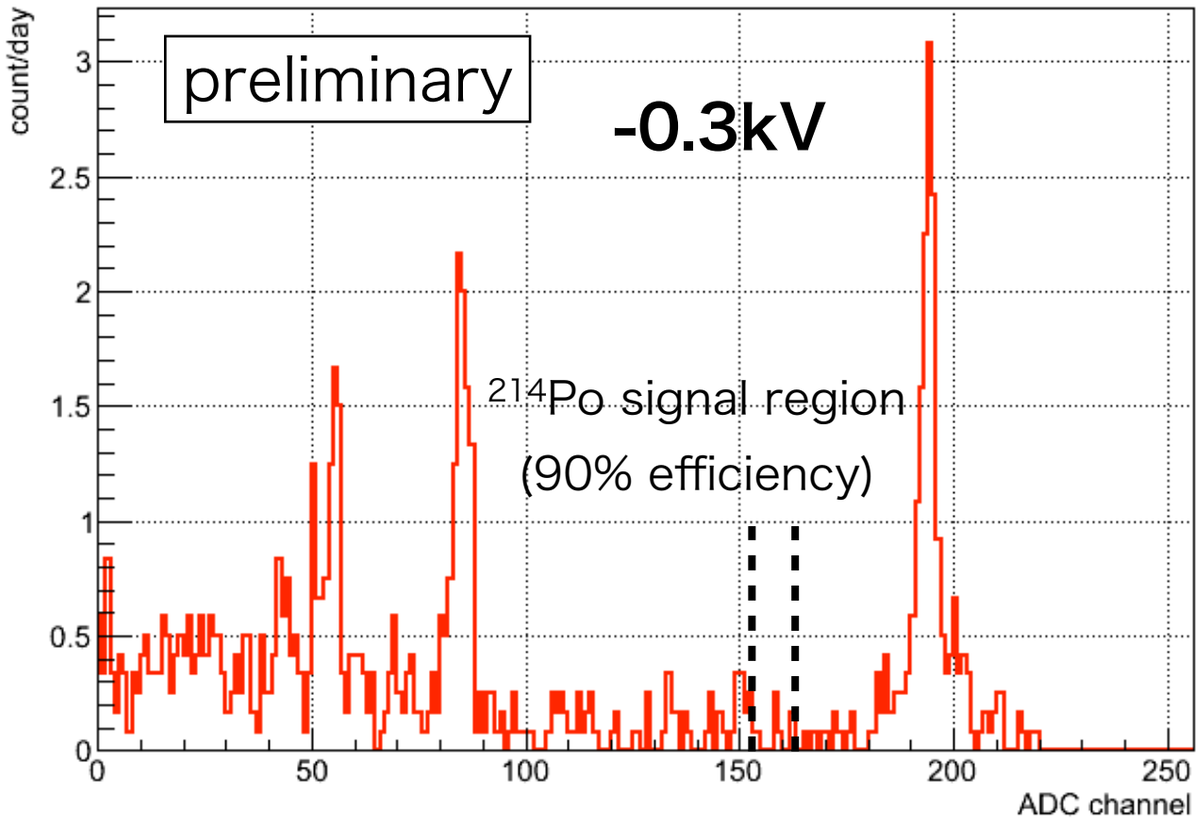


- ✓ With higher voltage supplied, higher CF is obtained.
- ✓ Could not supply higher voltage than -2.0kV, because of sparks.

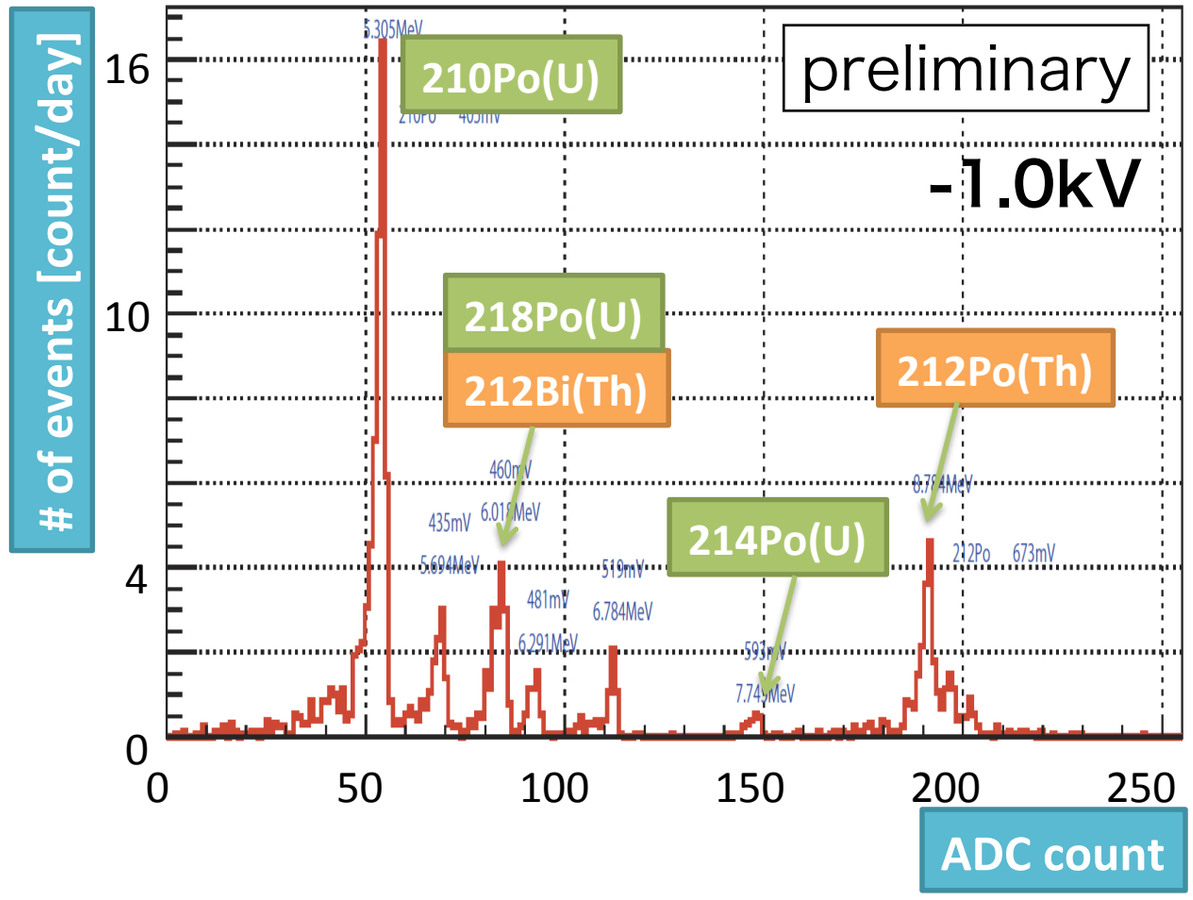
- ✓ ~70% Po^+ ion is collected in low humidity.
  - Half of α-ray emitted from Po^+ at diode surface is directed to diode.
  - Signal region covers 90% of ^{214}Po signal.

Background level

BG run with Ar



BG run with pure air



- ✓ 80L detector, with both of Ar gas and pure air, achieved lower background level than 70L detector.
  - Pure air run maybe taken with RI contamination, because of source calibrations before the background run(mine rock etc... in the vessel.).

	70L	80L
pure air	2.4 ± 1.3 [cpd]	2.26±0.42 [cpd]
	-1.5kV	-1.0kV, (with RI contamination?)
Ar	-	1.1 ± 0.4 [cpd]
		-0.3kV

Performance summary

	70L	new 80L detector		
	pure air	pure air	Ar	Xe
CF	1.96±0.02 @ -1.5kV, 0.004[g/m³]	~ 2.24 @ -2.0kV, 0.0011[g/m³]	~ 2.12 @ -2.0kV, 2.5x10^{-5}[g/m³]	~ 1.02 @ -1.0kV, 2.6x10^{-5}[g/m³]
BG	2.4 ± 1.3 [cpd] @-1.5kV	2.26±0.42 [cpd] @-1.0kV (with RI contamination?)	1.1 ± 0.4 [cpd] @-0.3kV	-

Application for experiments

✓ Radon detector is applied for underground physics experiments in Kamioka.

✓ **Super-K**

- Need radon concentration less than 0.1~1mBq/m^3 in purified water for solar neutrino analysis.
- **Radon measurement in water and air.**

✓ **XMASS**

- Purpose less than ~7μBq/m^3 in gas xenon.
- **Material screening.**
- **Radon measurement in xenon.**
  - Radon extraction from xenon with activated charcoal.

Measurement of Rn concentration in the air layer of SK tank

◆The air layer of SK tank

-60cm air layer between the surface of SK water and the top of SK.

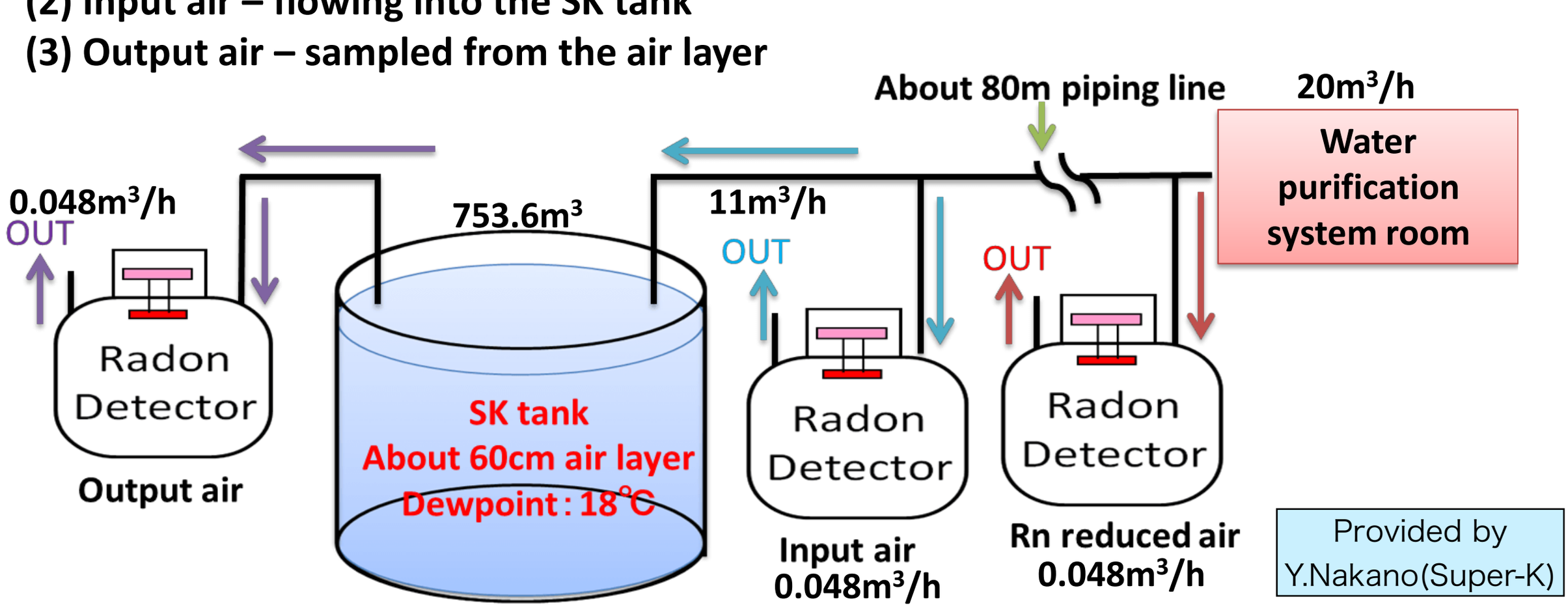
-Rn reduced air is always flowing to SK tank

◆Measurement position

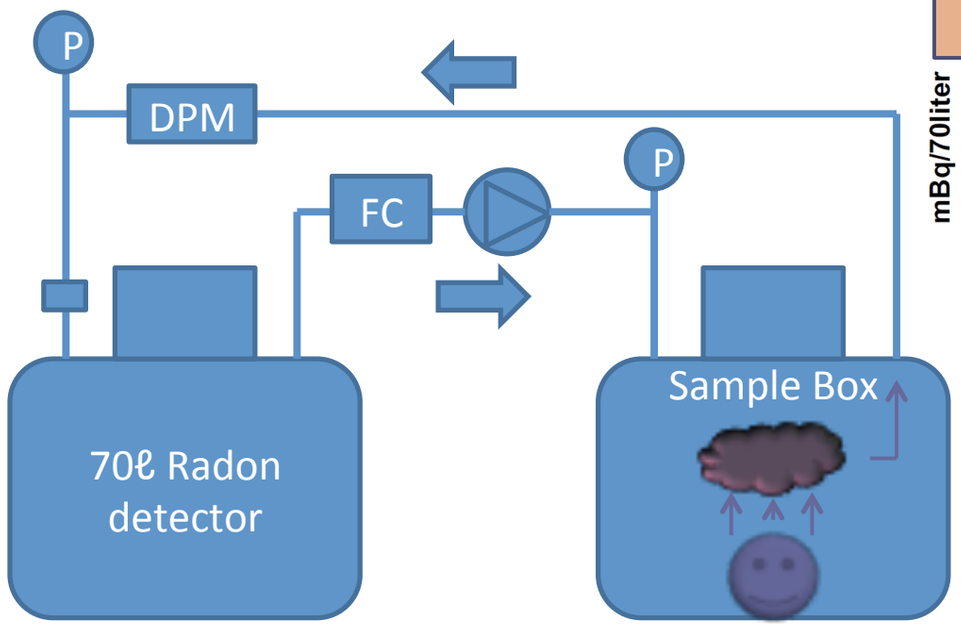
(1) Rn reduced air – made in Water purification system room

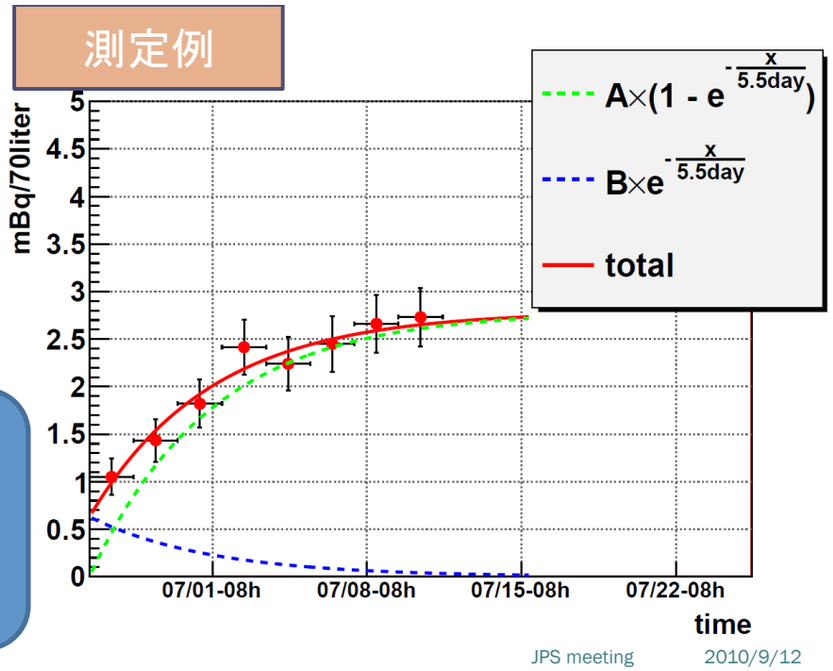
(2) Input air – flowing into the SK tank

(3) Output air – sampled from the air layer



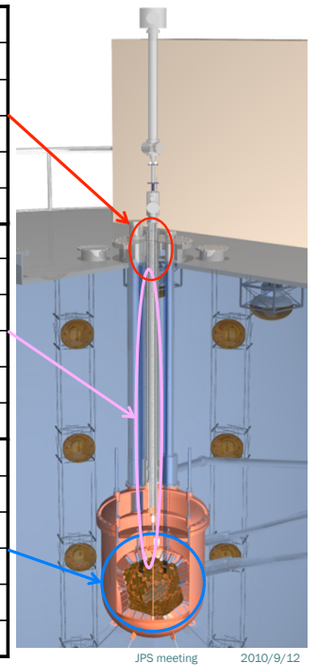
Material screening for XMASS





JPS meeting 2010/9/12

ガス	HV/signal コネクタ	<1.18mBq
	HV/signal フィードスルー	<0.09mBq
	モニタフィードスルー(1)	0.06+/-0.01mBq
	モニタフィードスルー(2)	<0.11mBq
	モニタ用コネクタピン	0.05+/-0.02mBq
	PMT駆動装置駆動部	<0.76mBq
ガス液両方	PMT HV cable	<9.1mBq
	PMT signal cable	<3.4mBq
	モニタ用cable (1)	0.57±0.3mBq
	モニタ用cable (2)同軸	<0.25mBq
	SUS配管溶接	0.58±0.23mBq
	ファイバースコープ	<1.02mBq
液内	温度計	<0.12mBq
	PMT基板	<10.9mBq
	PMT	<12.7mBq
	GOATEX（クッション材）	<1.9mBq
	コネクタピン	<0.31mBq
	LEDホルダ（PTFE）	<1.25mBq



JPS meeting 2010/9/12

D.Motoki JPS meeting 2010

evacuation

↓

fill with pure air

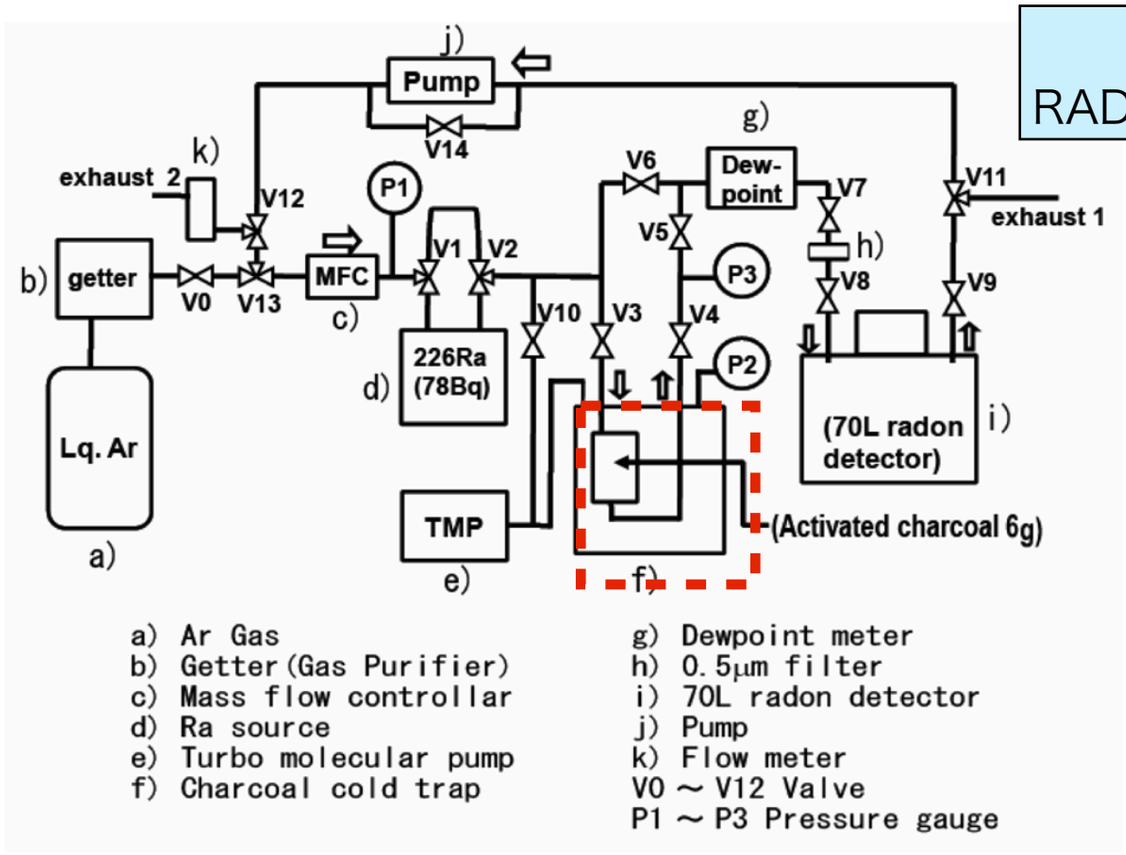
↓

measurement with air circulation

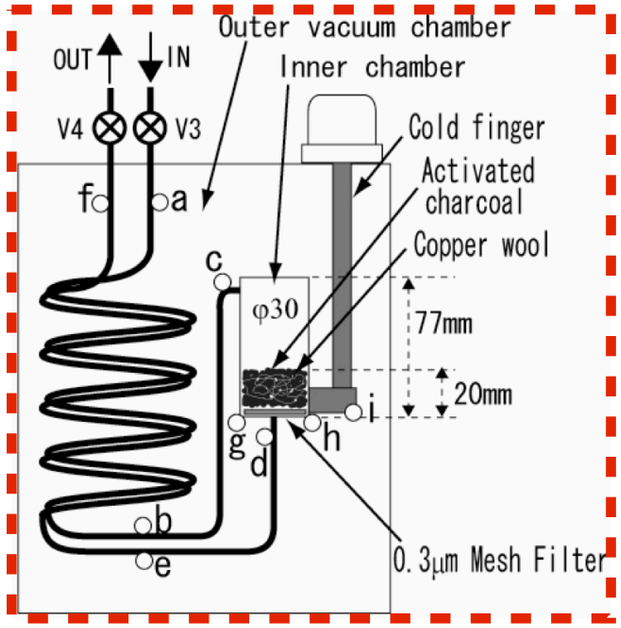
- ✓ Radon detector could screen materials for detector construction.
- ✓ Measurement for XMASS materials which touch xenon directly was done.

Radon extraction from gas/water

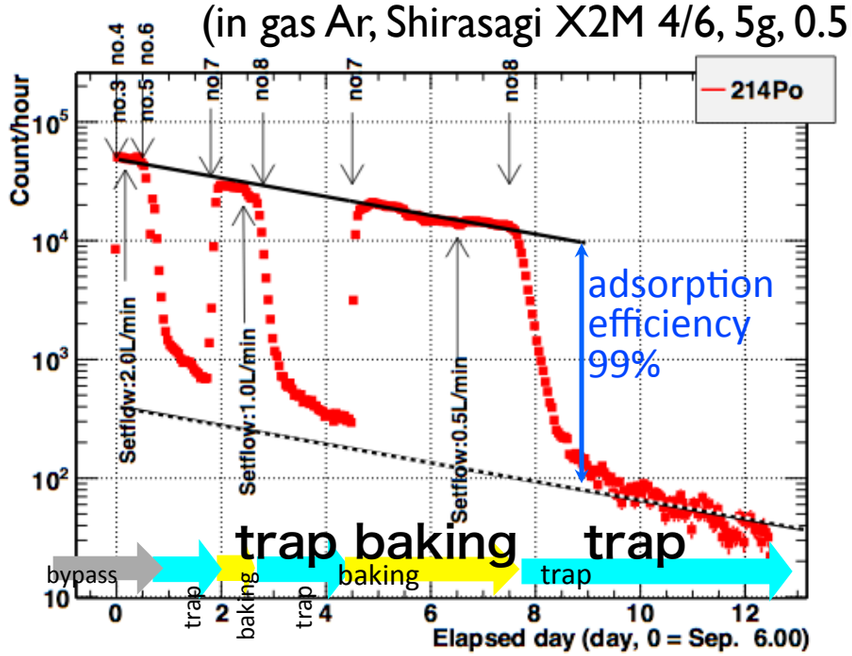
M,Ikeda et al.
RADIOISOTOPES, 59, 29-36 (2010)



a) Ar Gas
b) Getter(Gas Purifier)
c) Mass flow controllar
d) Ra source
e) Turbo molecular pump
f) Charcoal cold trap
g) Dewpoint meter
h) 0.5μm filter
i) 70L radon detector
j) Pump
k) Flow meter
V0 ～ V12 Valve
P1 ～ P3 Pressure gauge



(in gas Ar, Shirasagi X2M 4/6, 5g, 0.5L/min)



provided by A.Murata (Kobe-U)

- ✓ Activated charcoal has strong absorption ability also for radon in purified gas.
- ✓ Extraction tech. from air and Ar gas was developed.
  - **Rn absorption rate** from Ar gas with cold trap(-105℃) is **>90%**.
  - **Release rate** with 85℃ baking is **>99%**.
- Rn detection limit ~14μBq/m3 with activated charcoal trap in Ar gas.

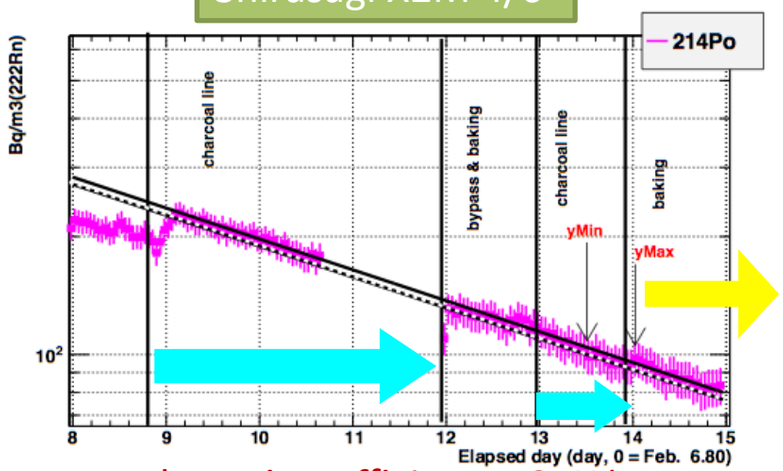
Radon measurement in xenon

Some trap test data

(in gas Xe, 0.9L/min, 5g)

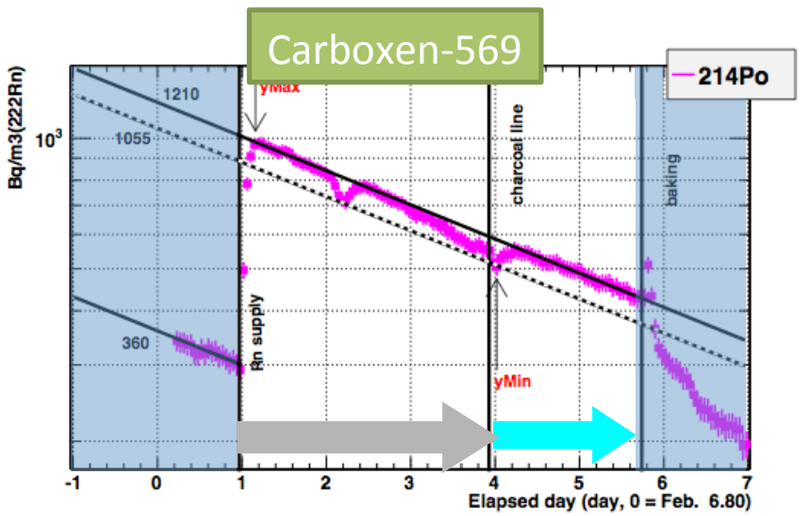
(very preliminary)

Shirasagi X2M 4/6



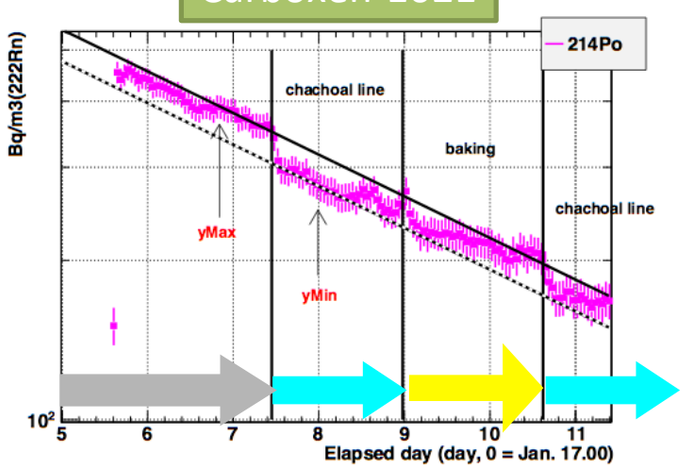
adsorption efficiency: 0-4%

Carboxen-569



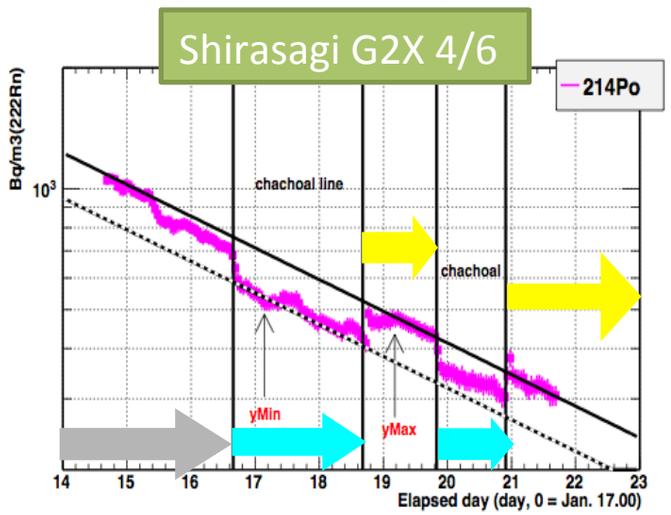
adsorption efficiency: 0-13%

Carboxen-1021



adsorption efficiency: 6-13%

Shirasagi G2X 4/6



adsorption efficiency: 7-23%

provided by A.Murata (Kobe-U)

- ✓ XMASS purpose 7 μBq/m^3 radon concentration in xenon.
- ✓ Developing radon enrichment technology from xenon with activated charcoal.
  - Very challenging topic!!
  - Achieved ~ 30% absorption rate.
    - K. Abe et al. NIMA 661 (2012) 50–57
- ✓ Highly efficient Rn trap in Xe is under development.

Summary

- ✓ ^{222}Rn could be a source of serious background events in underground experiments.
- ✓ 80L radon detector was developed and its basic performance was studied.
  - 2.24[(cpd)/(mBq/m^3)] for pure air.
- ✓ 70L & 80L radon detectors are used in Kamioka.
  - Radon measurement system.
  - Material screening.
  - Radon enrich technology with activated charcoal.