Development of high-sensitivity radon detector in water with continuous measurement

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1. Introduction

Radon (Rn) contamination in pure water (or Gd dissolved water) causes serious background (BG) for low energy physics by using water Cherenkov detector. Continuous monitoring of radon concentration is very important.

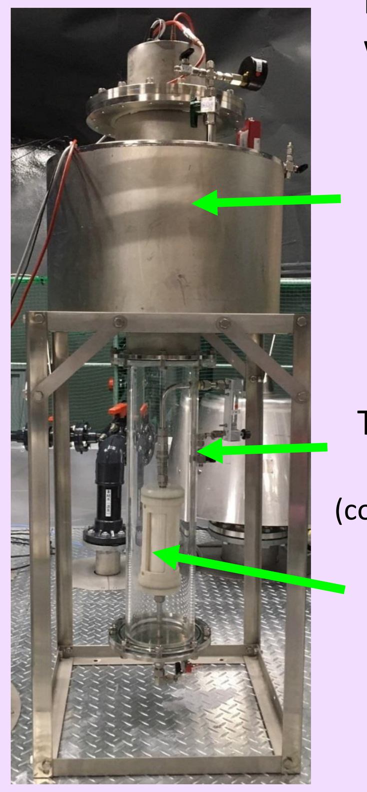
- **Super-Kamiokande (SK):** 50 kton water Cherenkov detector in Japan observing neutrinos and searching for proton decay. One of its physics goals is searching for distortions of the solar neutrino energy spectrum induced by the MSW effect. For this purpose lowering energy threshold which is restricted by Rn BG is indispensable.
- **XENONnT**: direct dark matter search detector with world best sensitivity in Gran Sasso. A Gd dissolved water Cherenkov detector will be used as veto counter for neutron BG (nVeto). Rn contamination in the nVeto will be monitored with water Rn detector.

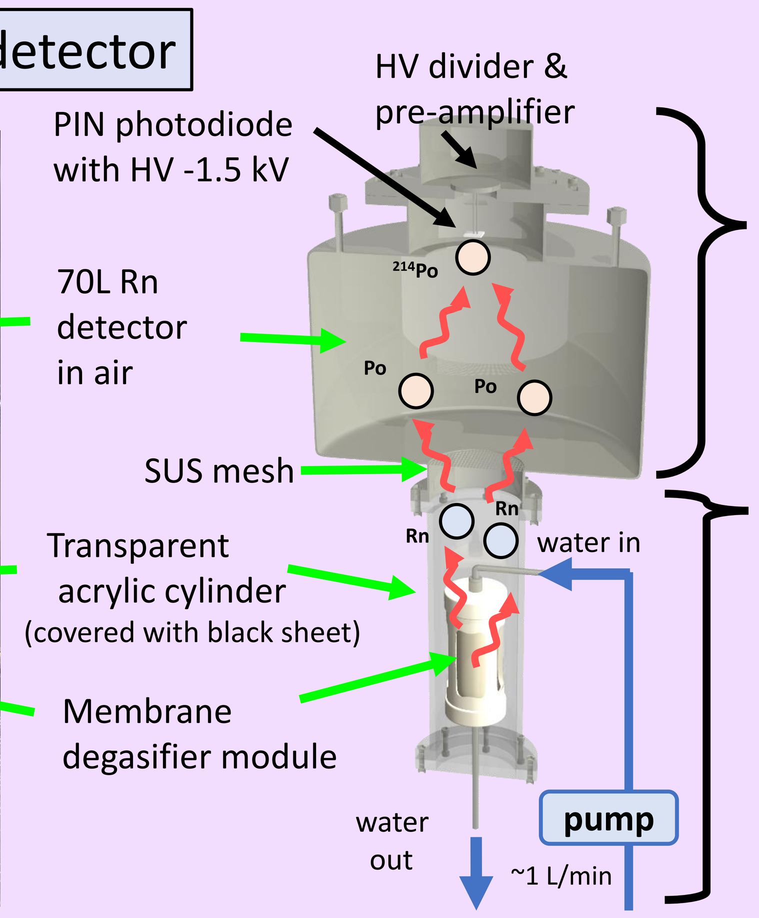
Current water Rn detector for continuous monitoring which has been developed in Japan has enough sensitivity for monitoring Rn concentration in return water (~10 mBq/m^3) from SK tank and the nVeto of XENONnT. But, it has less sensitivity for monitoring Rn in supply water (~2 mBq/m^3) into SK tank and sampling water from the cleanest region of SK tank (< 0.14 mBq/m^3). For these purpose, trap-type water Rn detector with very high-sensitivity (~0.1 mBq/m^3) has been already developed in Japan by using activated charcoal trap with some time delay [1].
In this study, continuous monitoring detector with BG level of < 1 mBq/m^3 especially for measurement of SK supply water is being developed.

[1] Y. Nakano et al., arXiv:1910.03823

2. Improvement of water radon detector

Current detector

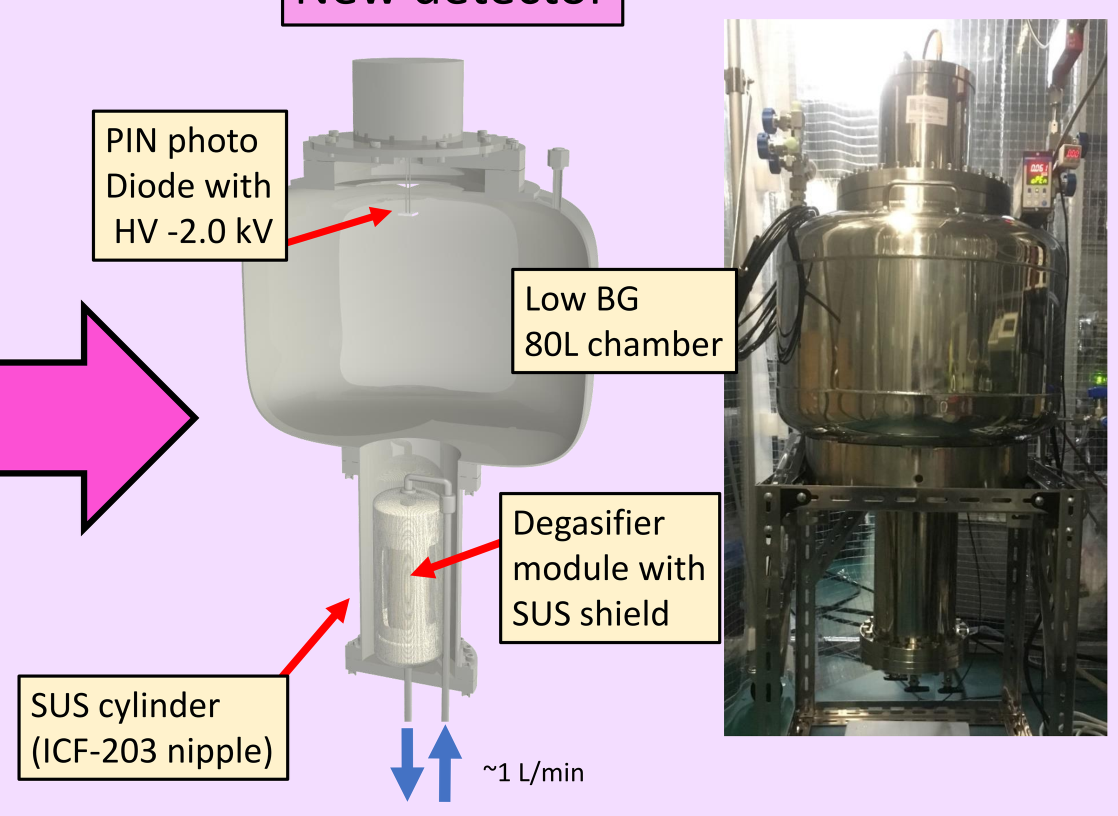




Water Rn detector consists of;
- electrostatic collection unit and
- Rn extraction unit.

Rn is transferred from water to air with membrane degasifier and positively charged daughter nuclei (^{218}Po/^{214}Po) of Rn are collected around PIN photodiode owing to negative HV.

New detector



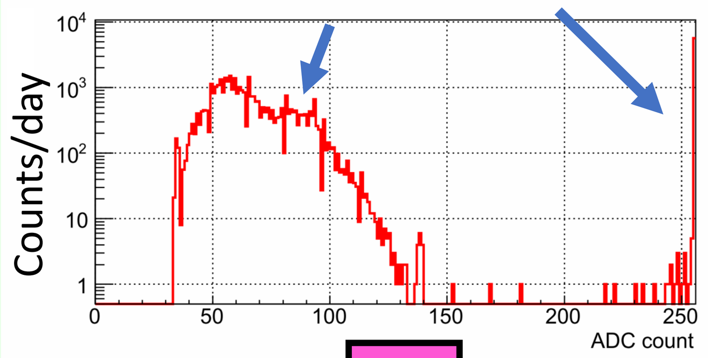
70L Rn detector has higher BG mainly due to rubber sealing and corner shape of chamber → Lower BG 80L Rn detector [2]
Acrylic housing for membrane is also sealed with rubber O-ring → Replaced with stainless steel (SUS) housing.

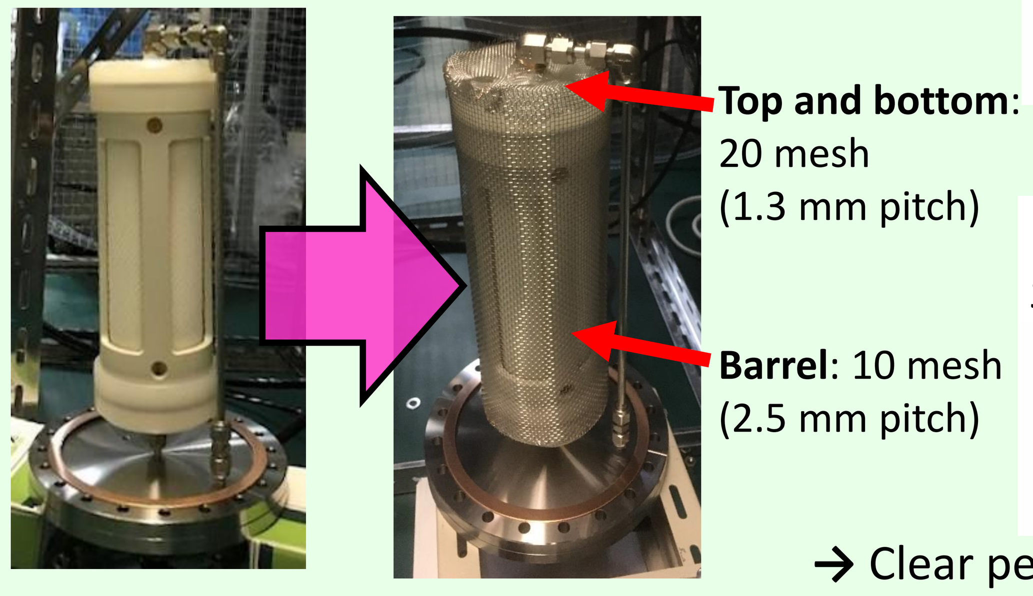
[2] K. Hosokawa et al., PTEP (2015) 933H01

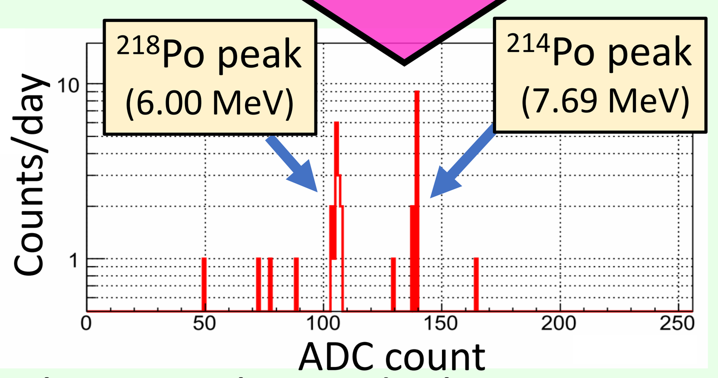
3. Electrostatic shield

The membrane was surrounded with SUS electrostatic shield avoid noise that were thought to be related to charge-up.

Noise was gradually increased after applying HV.



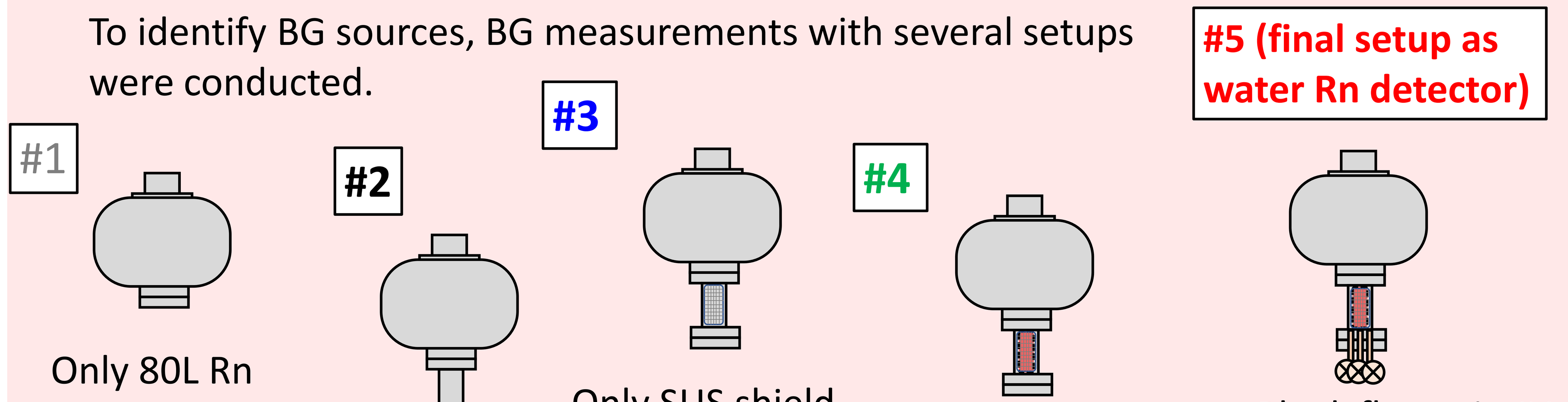




→ Clear peaks were obtained. The count rate of ^{214}Po is used for measurement of Rn

4. Background measurements

To identify BG sources, BG measurements with several setups were conducted.



#1: Only 80L Rn detector in air

#2: #1 + ICF 203 nipple (w/o EP)

#3: Only SUS shield was put into #2

#4: Membrane with SUS shield was put into #2

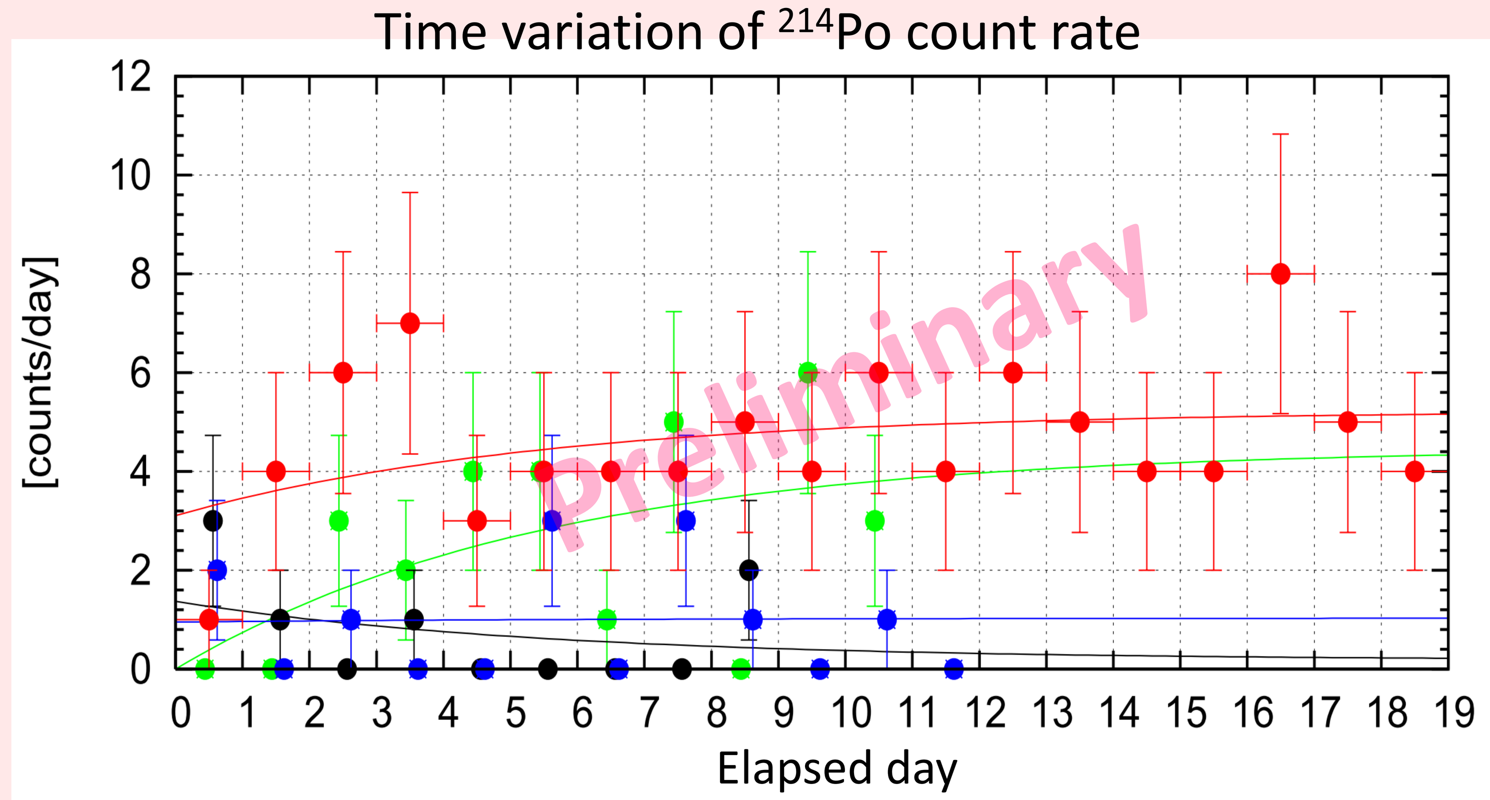
#5: Blank flange in #4 was replaced with flange with water pipes

BG level was consistent with [3] within statistic error.

No significant contributions from ICF 203 nipple and SUS shield within statistic error.

Main BG source is membrane degasifier module.

This value was higher than previous Rn emanation measurement of only membrane module (identical membrane was not used). There is possibility that one used for this system was contaminated .



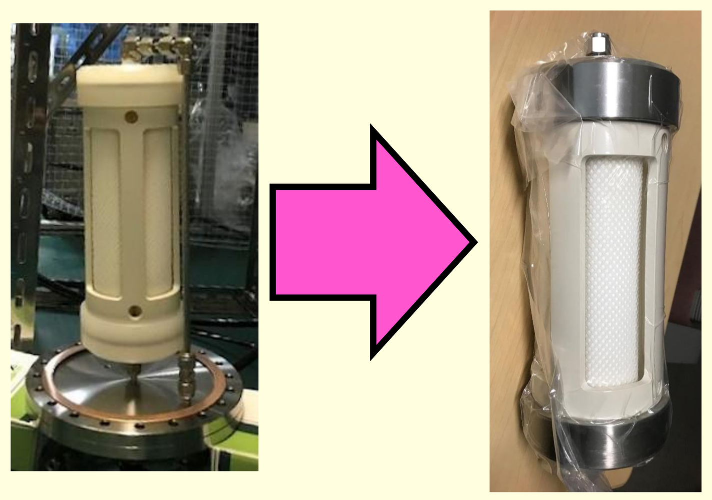
#	Setup					Date in 2020	Rate of ^{214}Po [counts/day]
	ICF nipple (w/o EP)	SUS シールド	膜モジュール	ICF flange (blank)	ICF flange (with pipe)		
1				O		3/02–3/16	0.80 ± 0.23
2	O			O		4/10–4/17	0.18 ± 1.06
3	O	O		O		4/17–4/29	1.04 ± 0.78
4	O	O	O	O		3/27–4/06	4.48 ± 0.88
5	O	O	O		O	5/08–5/27	5.22 ± 0.50

Preliminary

→ The BG level for final setup was 5.22 counts/day (in dry air). It corresponds to 0.9 ~ 1.7 mBq/m^3 in moist assuming same detection efficiency of water Rn detector.

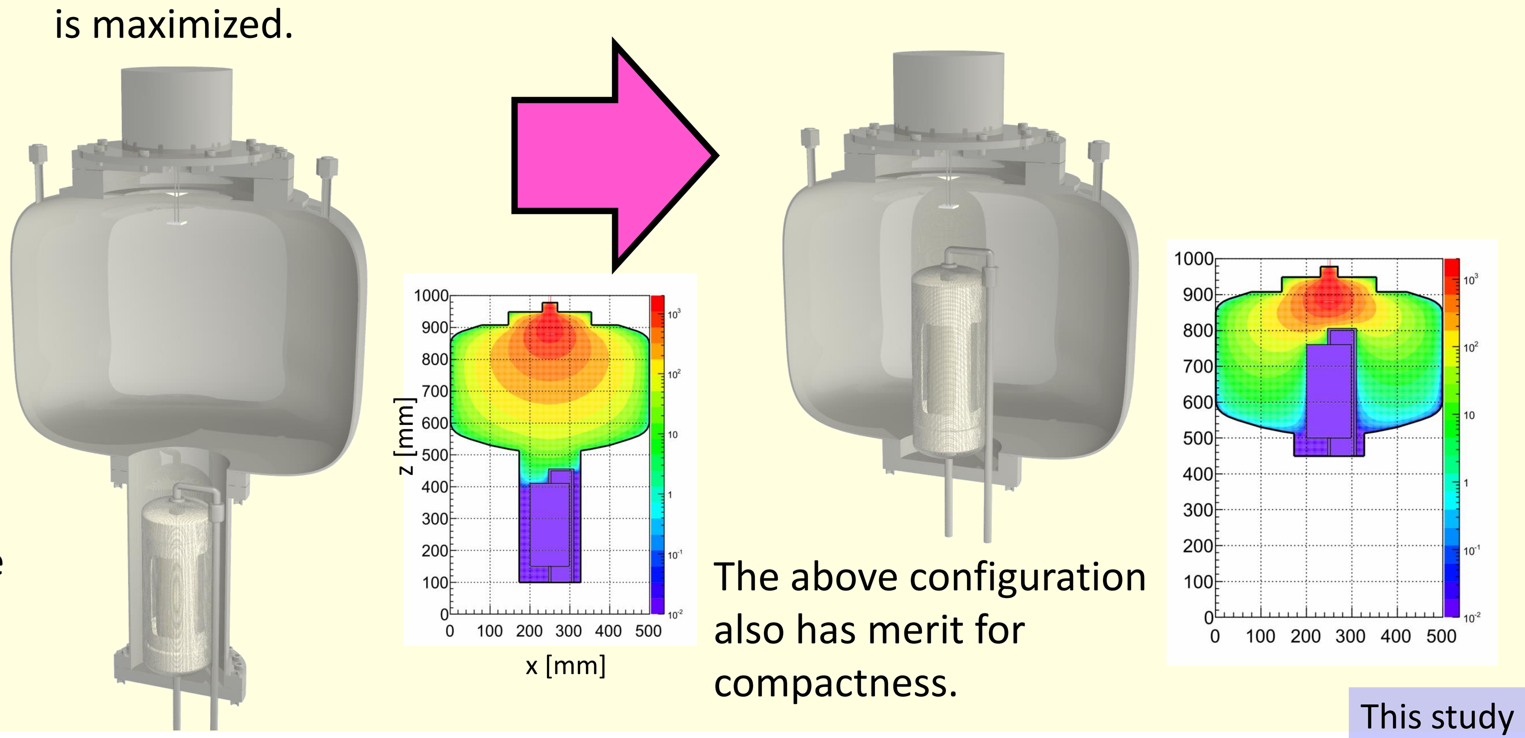
5. Further improvements

The membrane module used for this study might be contaminated
It should be replaced with brand new one.



Now, new membrane module has being developed which has SUS cap.
The radon emanation from the new membrane module will start.

The position of membrane module can be optimized so that detection efficiency is maximized.



The above configuration also has merit for compactness.

6. Conclusion

New water radon detector aiming BG level of < 1 mBq/m^3 has being developed.
The obtained BG level was 5.22 ± 0.50 counts/day (in dry air). It corresponds to 0.9 ~ 1.7 mBq/m^3 in moist air assuming the same detection efficiency of current water Rn detector.
The main BG source was identified and it will be replaced with cleaner one including some improvement.
The detection efficiency of new water radon detector will be evaluated with some optimization of position of membrane module.

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