Extreme Reduction of Radioactive Impurities in KamLAND liquid scintillator by using a Metal Scavenger

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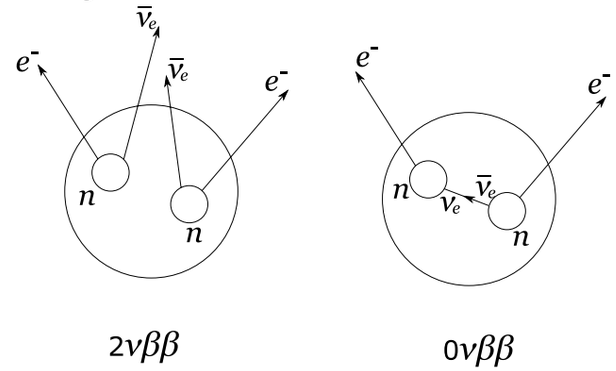
GPPU QE1

Experiment searching for *0νββ* with KamLAND

Neutrino has finite small mass. ⟶ Neutrino is Majorana ??? $\nu = \overline{\nu}$

Neutrinoless double beta decay (*0νββ*)

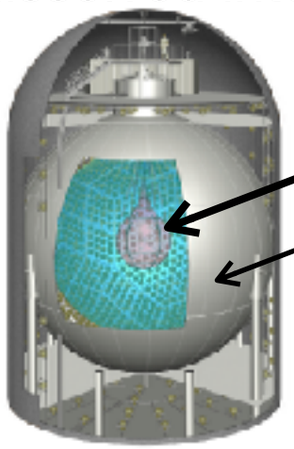
- ＊Physics beyond standard model
- ＊Property of neutrino



KamLAND-Zen experiment

$$^{136}\mathrm{Xe} \rightarrow {}^{136}\mathrm{Ba} + 2e^-$$

0νββ target mass : ^{136}Xe
It dissolved into 30 m^3 LS in inner balloon.



KamLAND achieved low BG environment by LS purification system.

about amount of Xe

KamLAND-Zen 400 reported half life of 0νββ : 1.07×10^{26} yr.
KamLAND-Zen 800 is aiming to half life of 0νββ : $\sim 10^{27}$ yr.

KamLAND2-Zen is aiming to half life of *0νββ* : $>10^{27}$ yr.

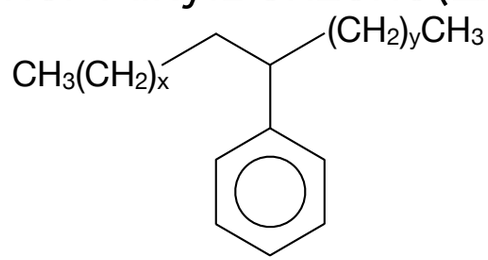
KamLAND2-Zen experiment project

−for development energy resolution−

Large repair

- Xe 1000 kg
- PMT light collecting mirror
- High quantum efficiency PMT
- new LS

Liner AlkylBenzene(LAB)



KamLAND2 needs ultra low radioactivity environment as well!

Issues of current LS purification

＜Current purifications＞

Filtration ⟶ Easy, Inexpensive, Early
Water extraction ⟶ Well reduction ^{238}U, ^{232}Th
Distillation ⟶ Best performance of these

＜Disadvantage of current purification ＞

Filtration

It cannot remove smaller particles and ion than filter size.

Water extraction

^{210}Pb combined with organic matters.

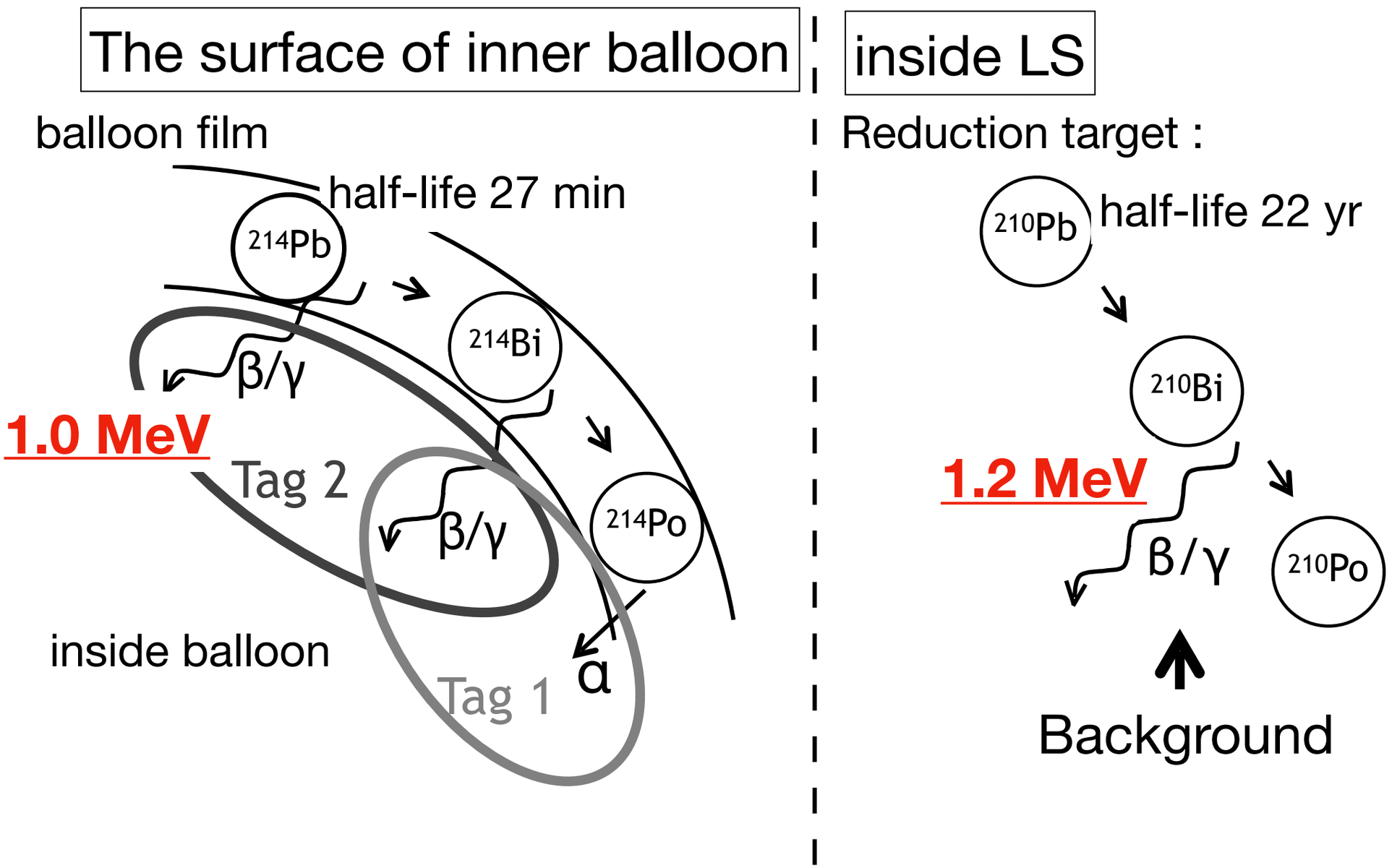
It does not dissolved water.

Distillation

Xe is lost if LS dissolved Xe is distilled.

Pb left after distillation many times → Organic Pb ???

Background of KamLAND-Zen



There's set to be a **90%** reduction **^{210}Pb** for ^{214}Pb-^{214}Bi delayed coincidence.

^{214}Bi tagging efficiency :∼53%

Reduction ^{210}Pb → **∼85%**

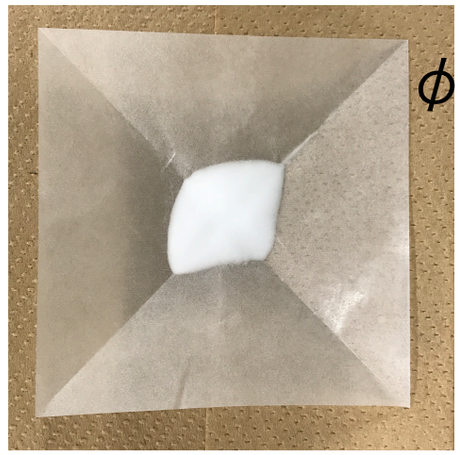
The sensitivity will be 13 – 29 % !

Previous study

Metal Scavenger (MS)

Metal adsorbent commercially available

High removal efficiency ・ Low cost

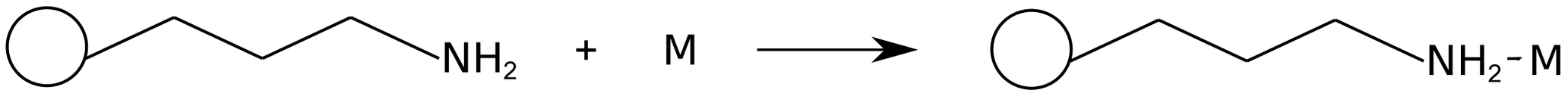


ϕ50 μm

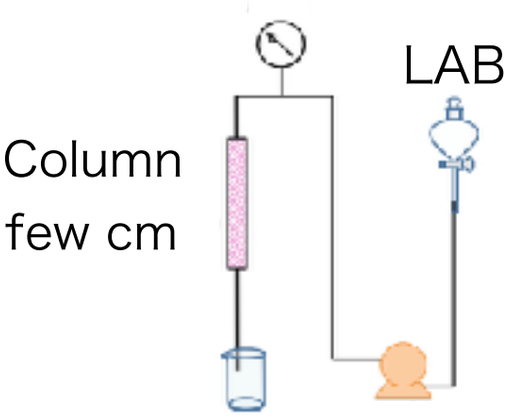
Select MS for KamLAND-Zen

Selected R-Cat-Sil AP™ from 12 products.

It is best performance (High Pb removal efficiency・PPO residual rate).



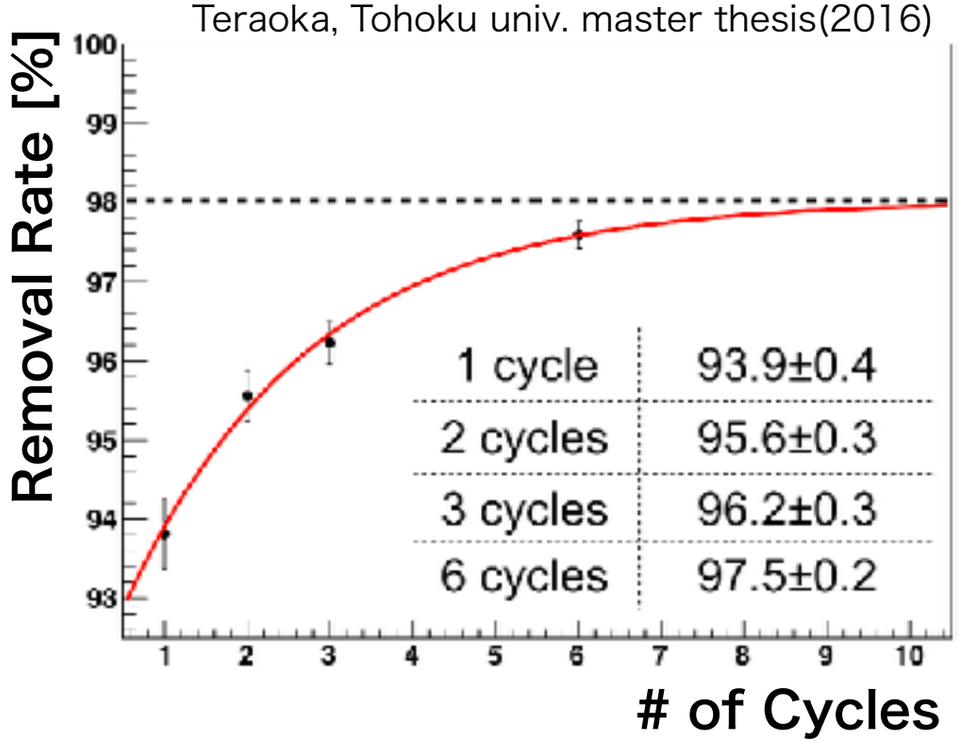
Pb removal test(Scavenging)



Standard parameta

Amount of MS	width 1.5 cm
Flow rate	8.9 mL/min/cm^2
Max pressure	0.10 MPa
Pb removal efficiency	~ 94 %

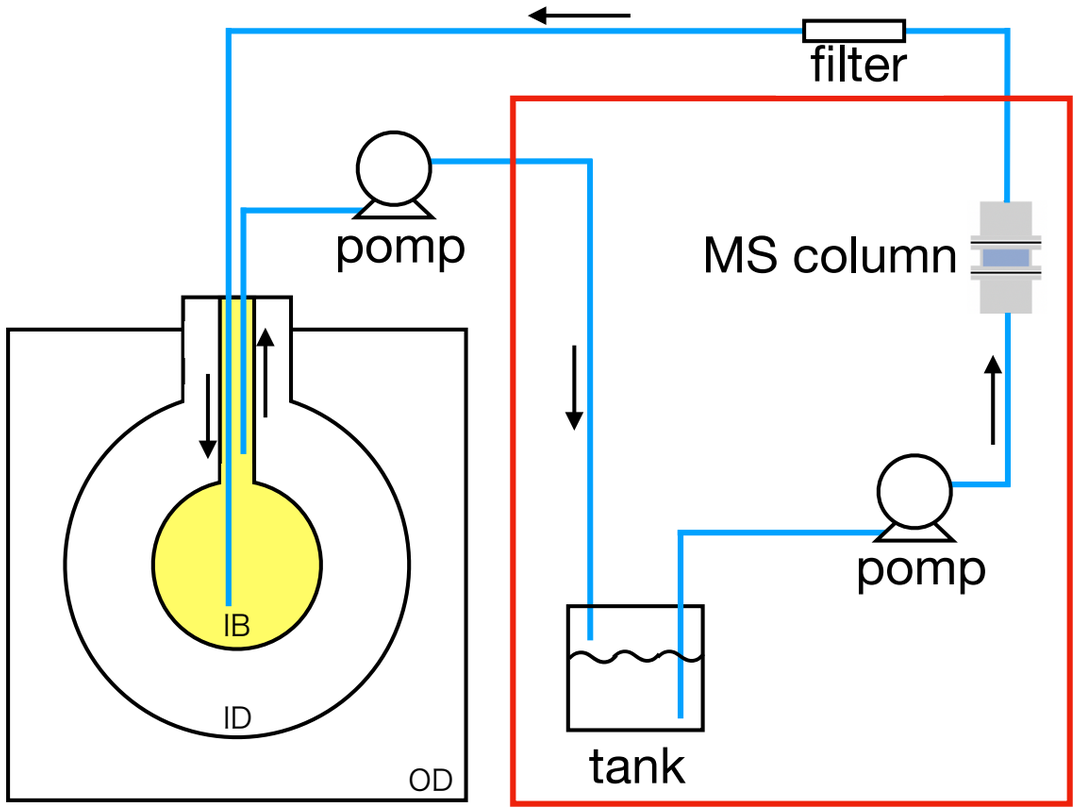
Teraoka, Tohoku univ. master thesis(2016)

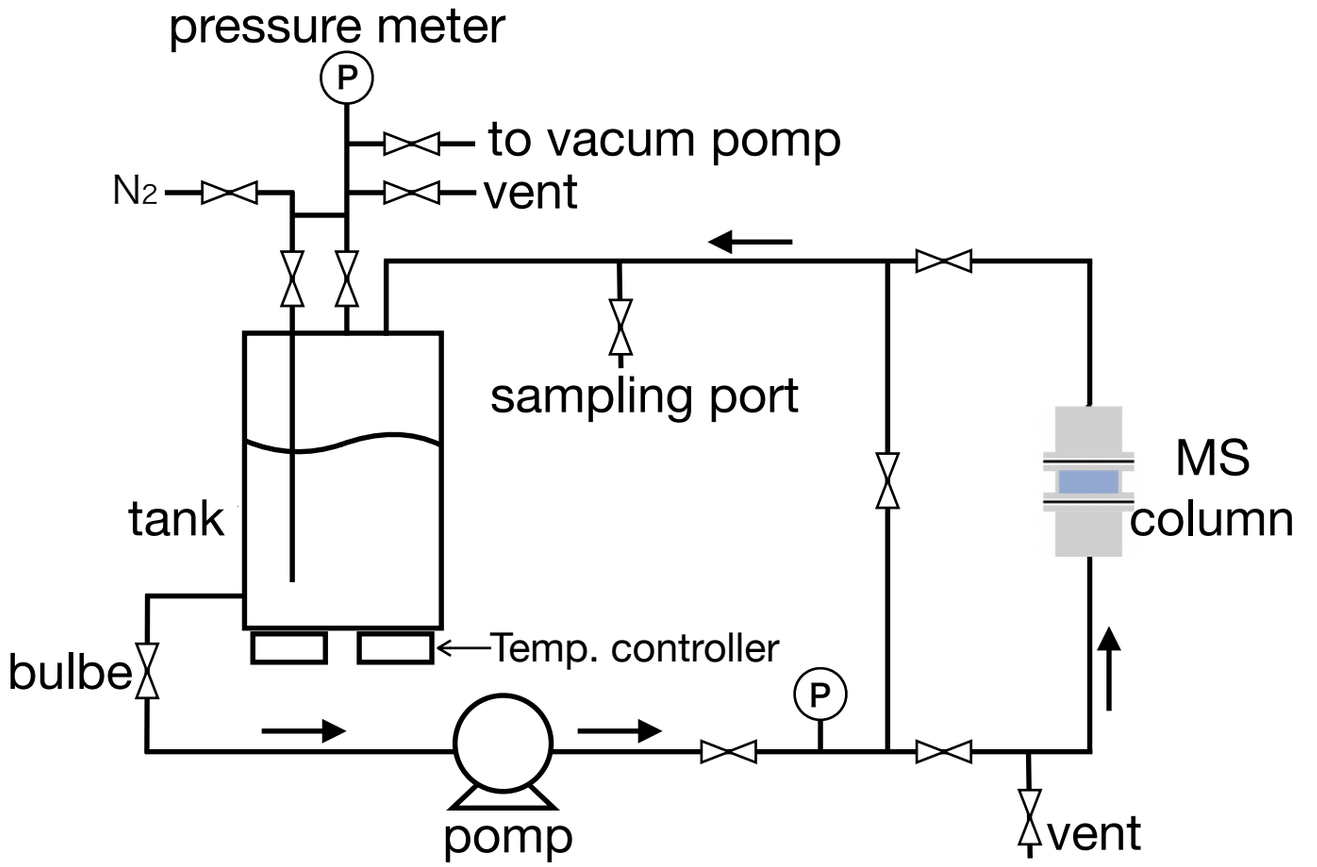


Achieved **~94 %** reduction by once scavenging !

Purification system w/ Actual column

Established purification system w/ MS assuming KamLAND-Zen

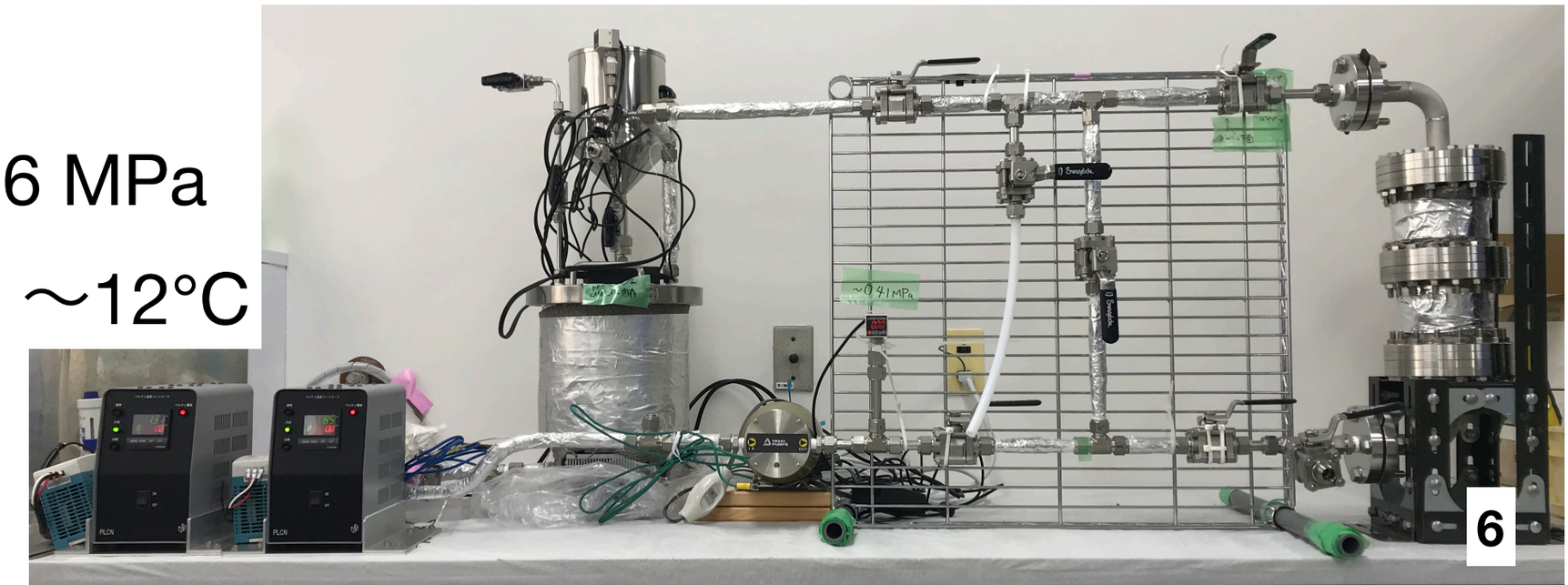




Flow rate：150 L/hr

Delivery pressure：0.6 MPa

Temp. under control : ～12°C



Guarantee LS quality after scavenging

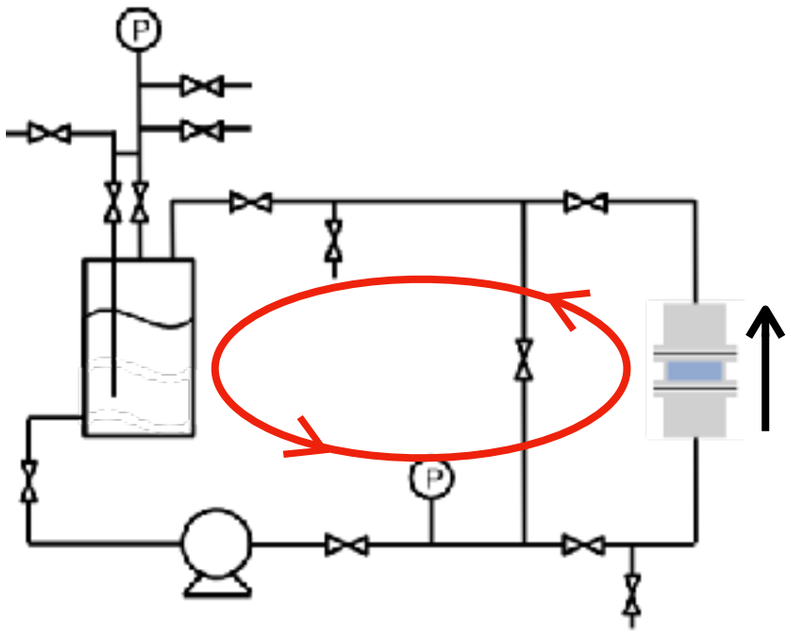
LS quality

- light transparency
- light yield
- few radioactive impurities

<u>Assuming purification of 30 m³ LS in IB</u>

3 L LS was cycled in system for 9 days (150 L/hr). → 30 m³ LS scavenging

Comparing quality before/after scavenging



Circulation 3 L LS

→ Results were **cumulative.**

concentration factor

$$\frac{3\,\mathrm{L}}{30\,\mathrm{m}^3} = \frac{3\,\mathrm{L}}{30000\,\mathrm{L}} = 10^{-4}$$

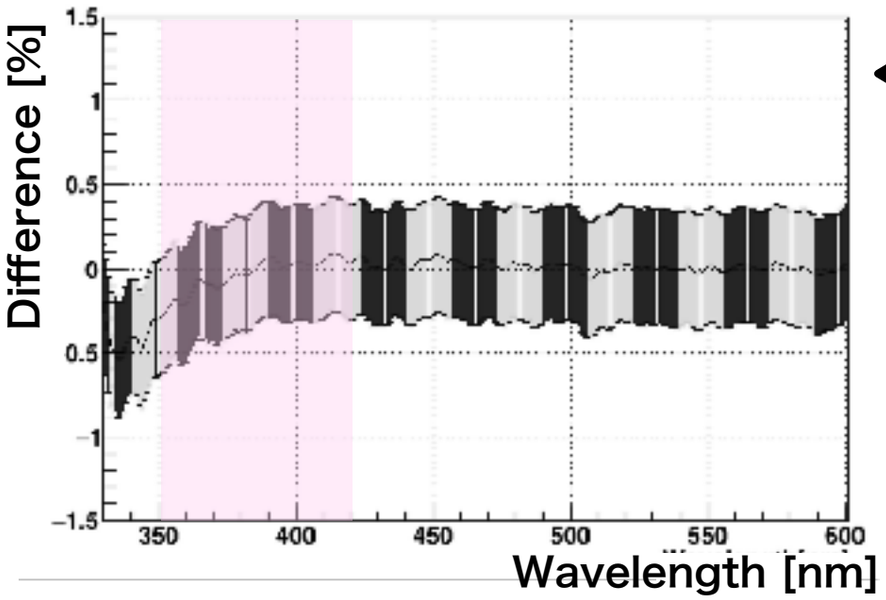
Component of LS

LS is a liquid solution of PPO in LAB. Its concentration is 2 g/L.

→ **Quantitative analysis** of PPO in LS after scavenging by **GC**

Light transparency / Light yield

Light transparency (9 cm) of LS after purification comparable to 30 m³



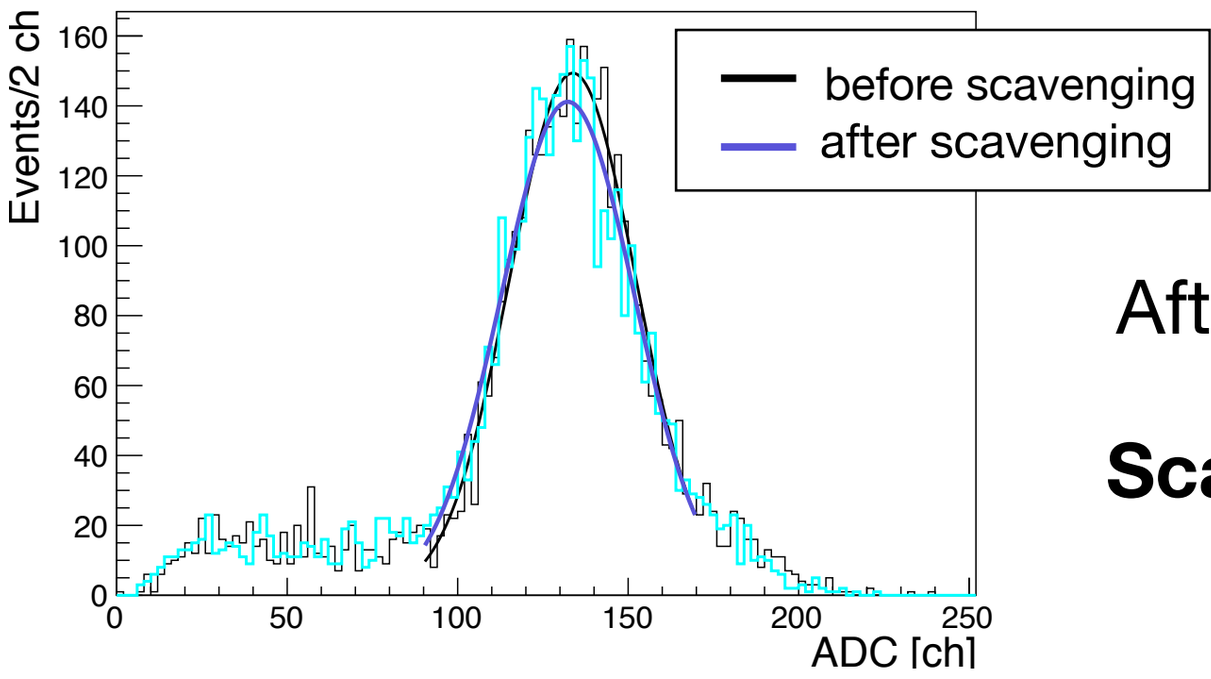
← $T_{after} - T_{before}$

Sensitive region：350 - 420 nm

Stable in **0.24%**

Scavenging don’t affect LS transparency!!

Light yield of LS after purification comparable to 30 m³



After value/Before value：**0.99 ± 0.02**

Scavenging don’t affect LS light yield!!

Impurities after scavenging

Radio active impurities of LS after purification LS comparable to 30 m^3

by ICP-MS

Unit : $\times 10^{-15}$ g/g

Element	If 60 g MS dissolve	after scavenging	KamLAND-Zen400
^{40}K	0.21	< 0.006	0.030
Th	31	< 1	0.13
U	1.2	< 1	1.8

Th : Sensitivity was insufficient.

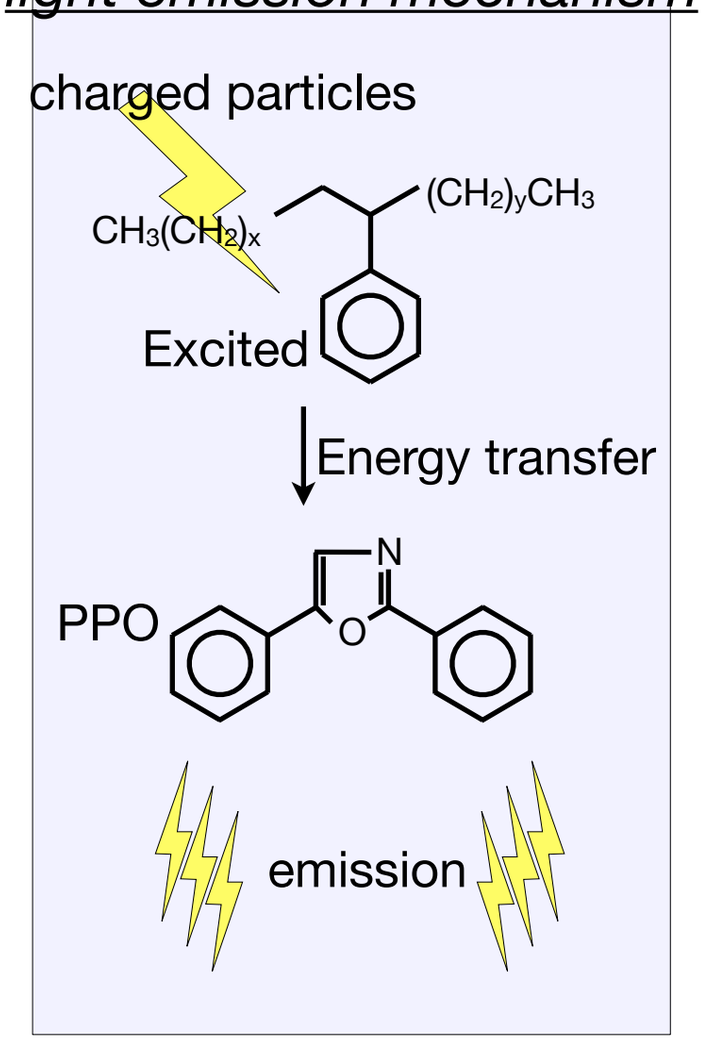
^{40}K、U : Same or less order to KamLAND-Zen400

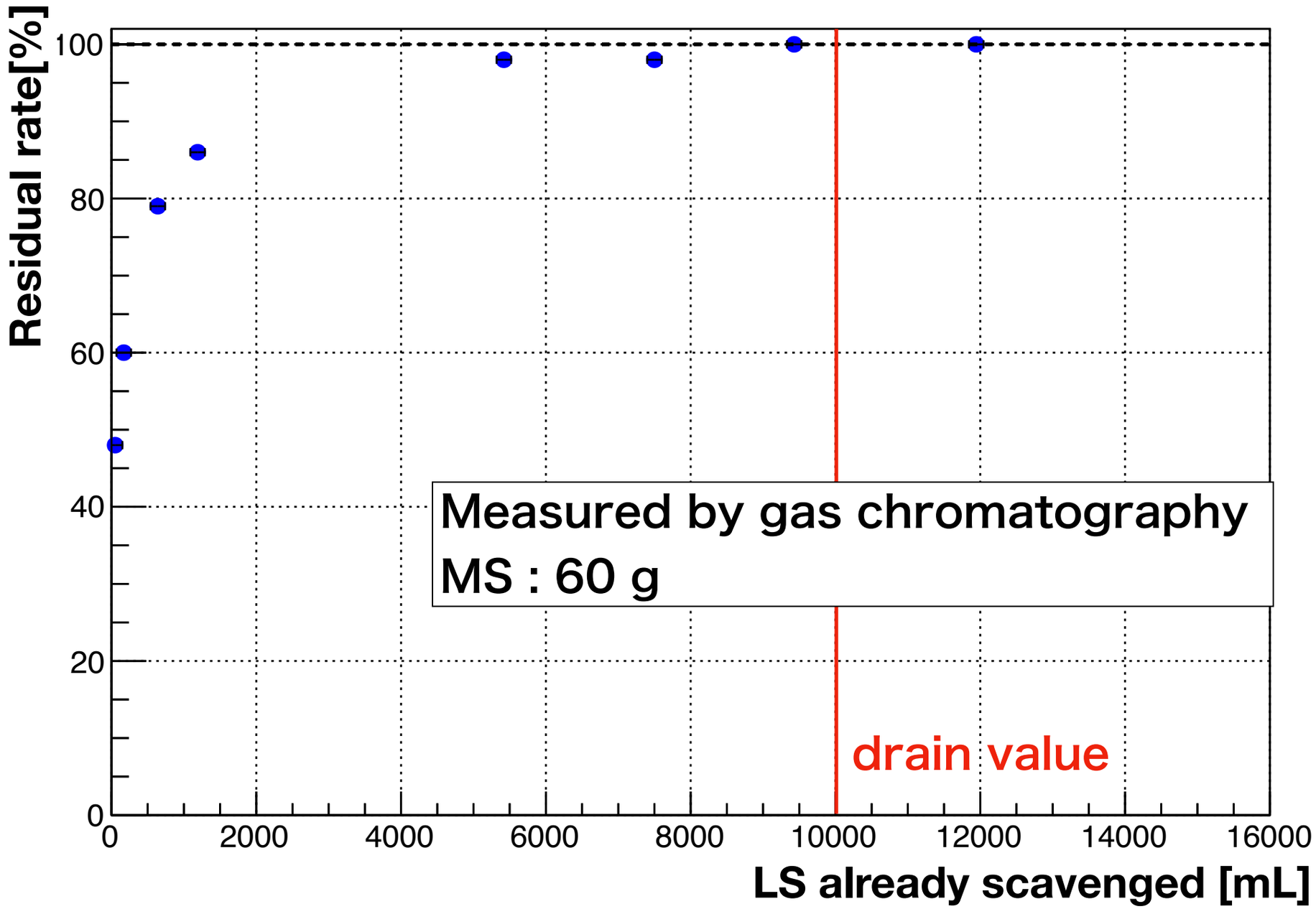
⟶ **^{40}K, U** don't affect experiment!

Absorbing PPO

LAB-LS components；LAB, 2 g/L **PPO** (2,5-diphenyloxazole)

light emission mechanism



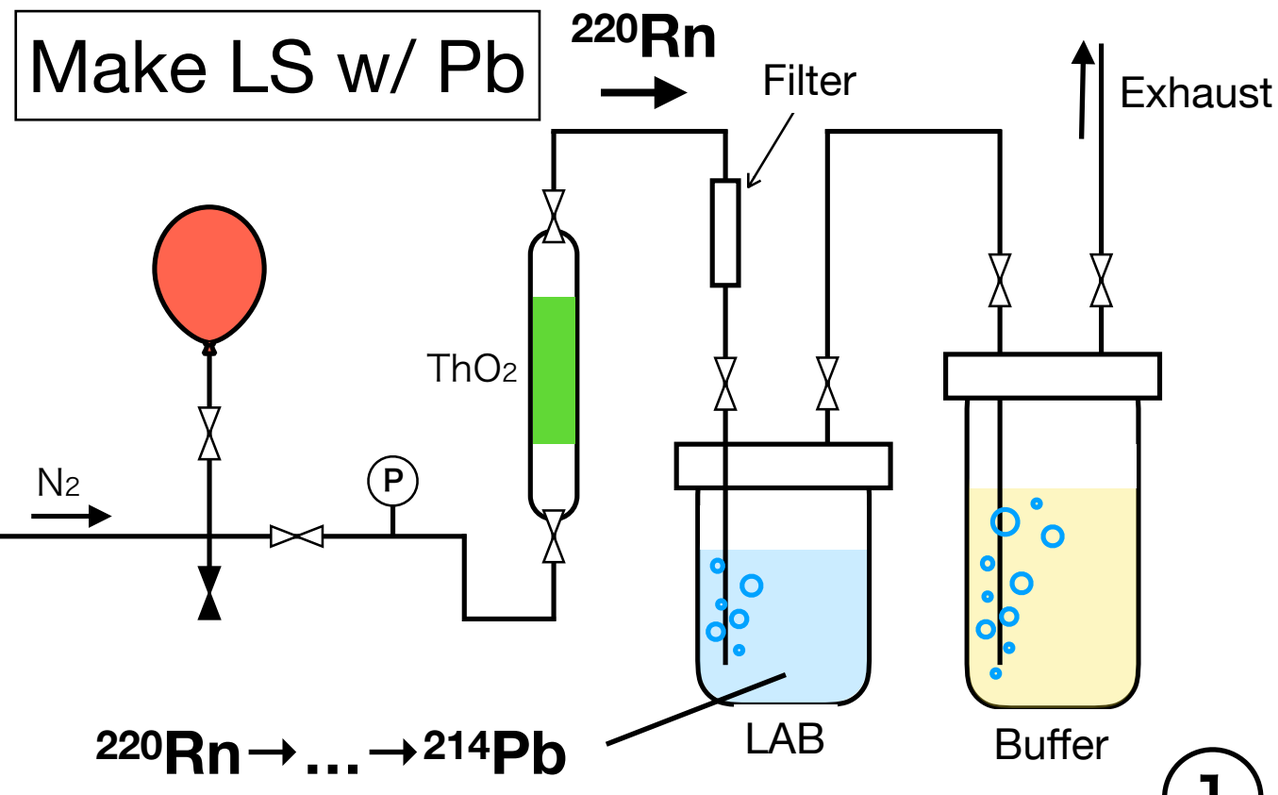


→ **PPO absorption saturated by ～10 L LS(2 g/L PPO).**

Need drain；～0.17 L/MS 1 g

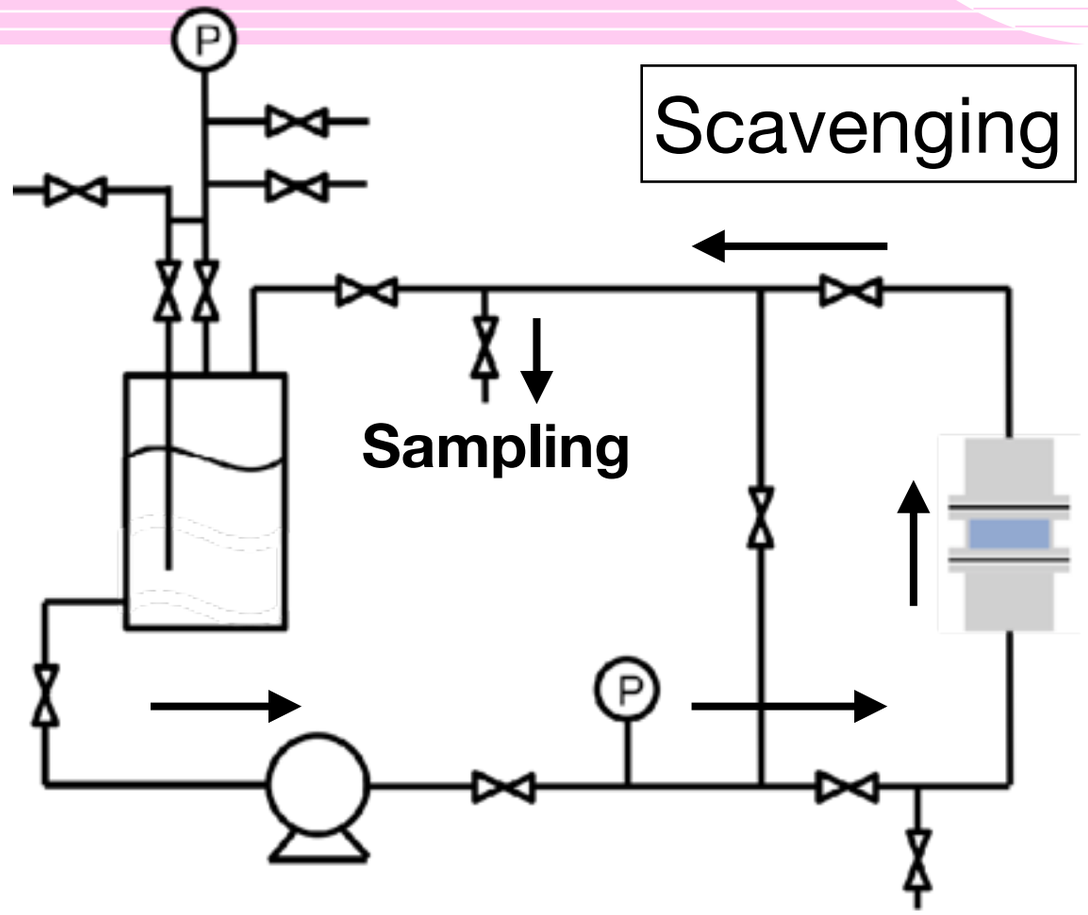
Reduction Pb

Make LS w/ Pb



①

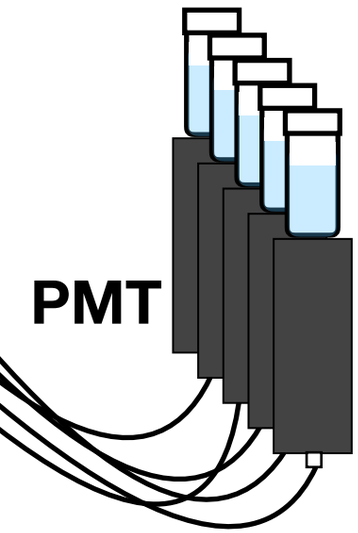
Scavenging



②

Measurement

③



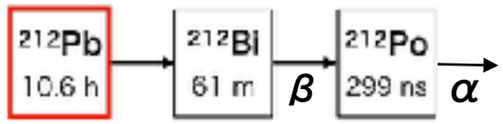
100 mL LAB(PPO 2 g/L) × 5

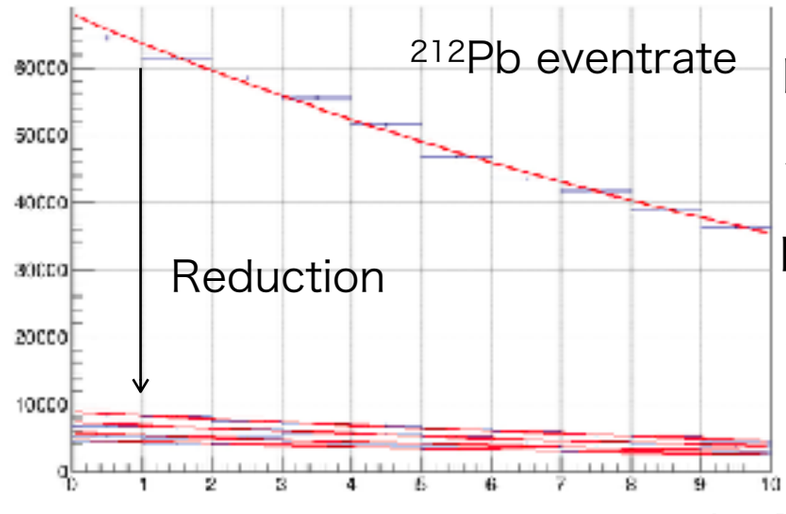
20 h measuring

Sample :

- original LAB w/ Pb
- LAB after 1st scavenging
- LAB after 2nd scavenging
- ⋮
- LAB after 4th scavenging

④ Bi-Po delayed coincidence Analysis





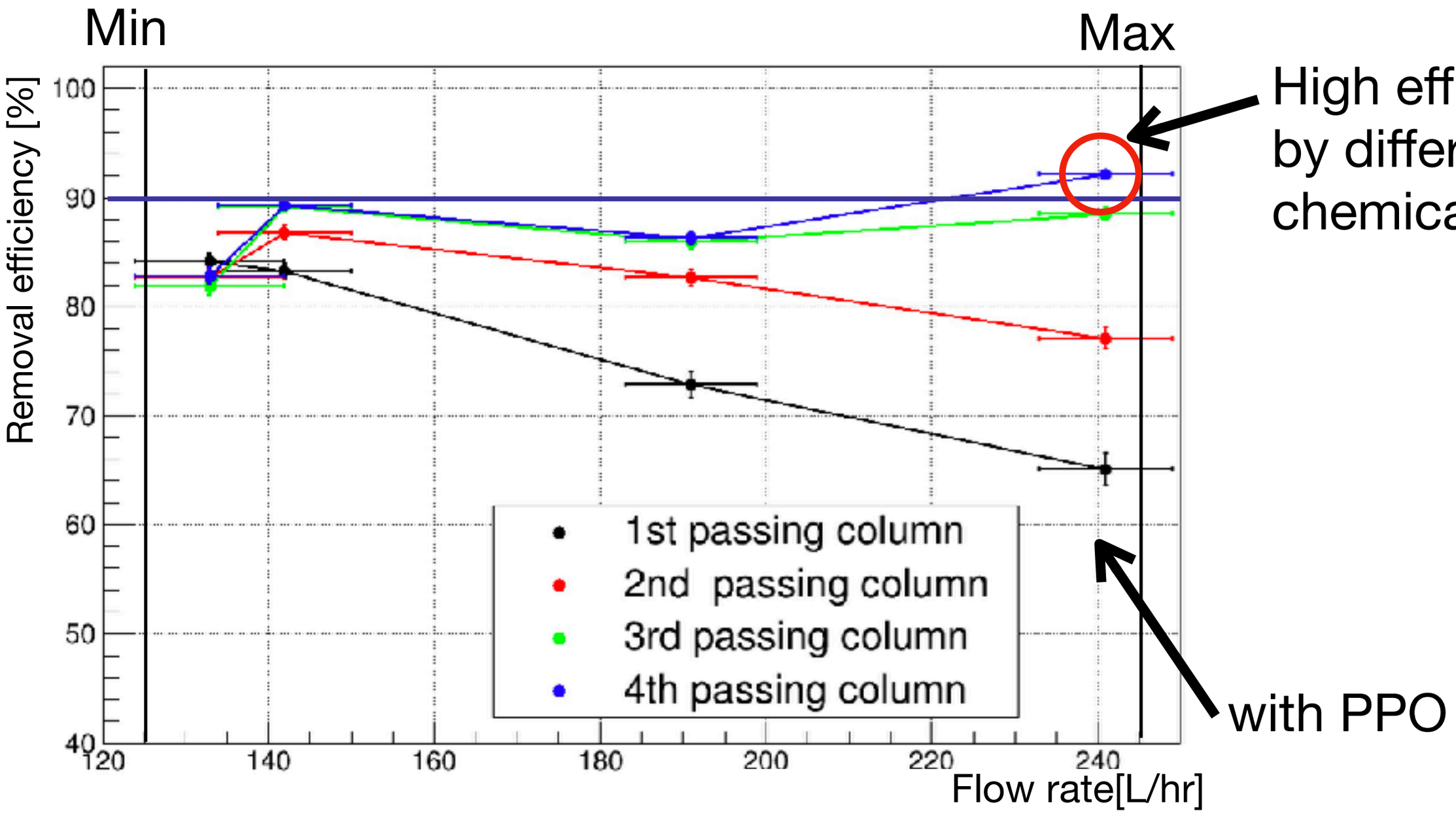
Fitting ;

$$A = A_0 e^{-\lambda t} + \text{const.}$$

Removal efficiency ;

$$R = \frac{A_{0,\text{before}} - A_{0,\text{after}}}{A_{0,\text{before}}}$$

Optimization of flow rate



For ideal KamLAND2 purification…

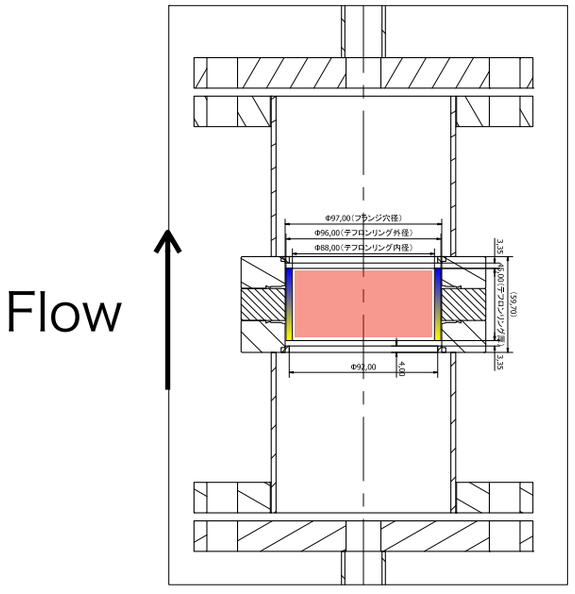
＊ It is better with fewer scavenging.

＊ PPO is added to LAB in latter operation.

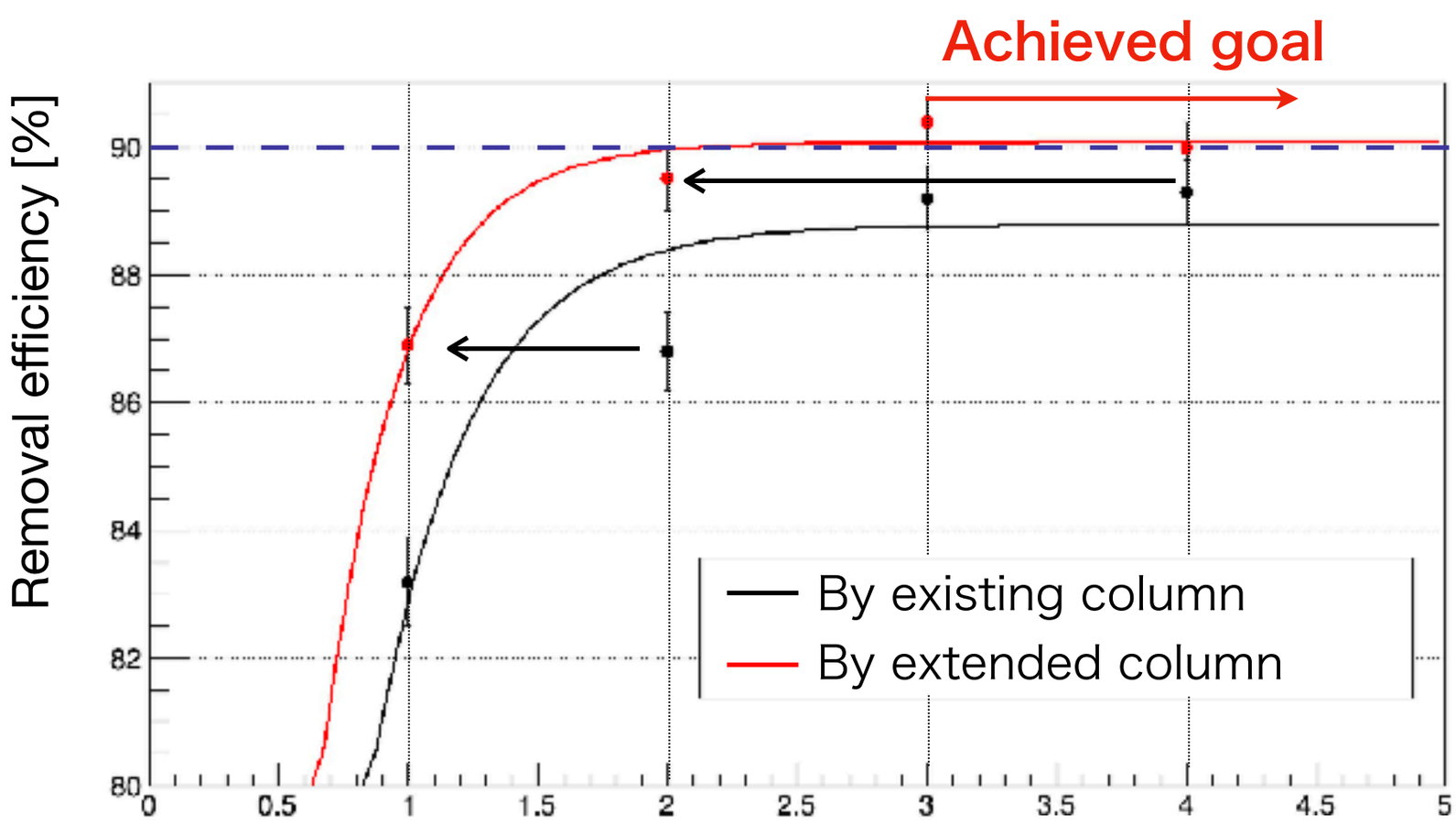
⟶ **Low flow rate is optimal ！**

Development of MS column

For getting 90% removal efficiency by fewer scavenging...



Adsorbing part was extended to 4 cm from 2 cm.
Total MS is ~120 g.

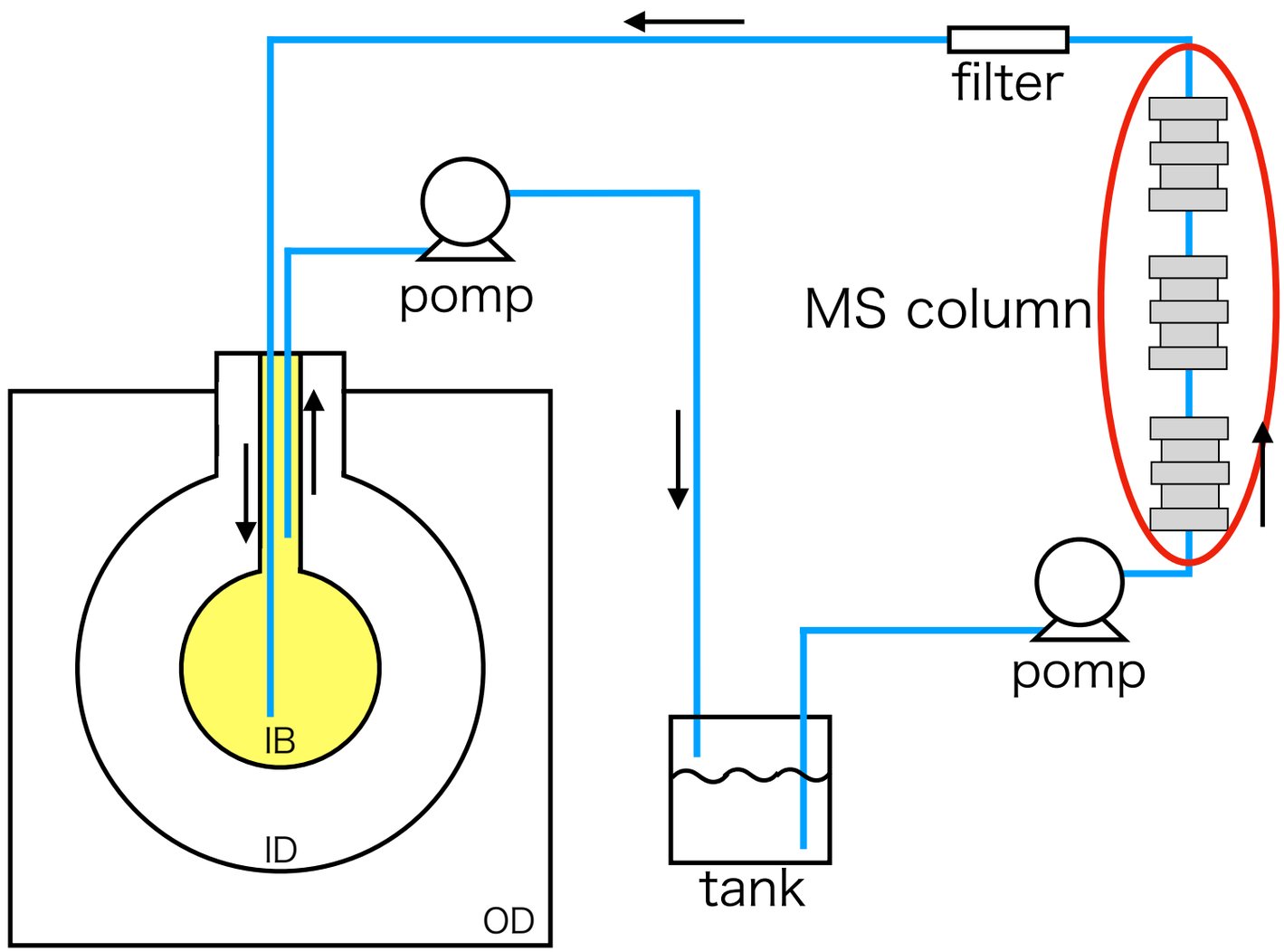


# of scavenging became 1/2 by twice MS.

Got 90% removal rate by 3rd scavenging at 140 L/hr.

Design of purification system for KamLAND

- Achieved target removal efficiency by 3 times scavenging with MS 120 g.



- MS is 120 g per 1 column.
- Connect 3 columns in series.
- Flow rate : 140 L/hr

→ **30 m³ purification for 9 days !**

cf.

Distillation purification : several months

Achieve target removal efficiency by 1 time scavenging !

Summary

Aiming to...

- Reduce 90% ^{210}Pb in LAB-LS
- Establish method of LS purification by metal scavenger

Result

- Scavenging don't affect LS performance
  (light transparency, light yield, PPO amount)

- **^{40}K、U in scavenged LS** are enough few.
  Need high sensitivity for Th measurement

- Achieved target Pb removal efficiency.

- Scavenging will be available to KamLAND2.