SK/SK-Gd water system

2018 September 20th (Thu)

European Workshop on Water Cherenkov Precision Detectors for Neutrino and Nucleon Decay Physics

TMEX 2018 WCP @Warsaw, Poland

Yuuki Nakano for the Super-Kamiokande collaboration

(Kamioka Observatory, ICRR, The University of Tokyo)

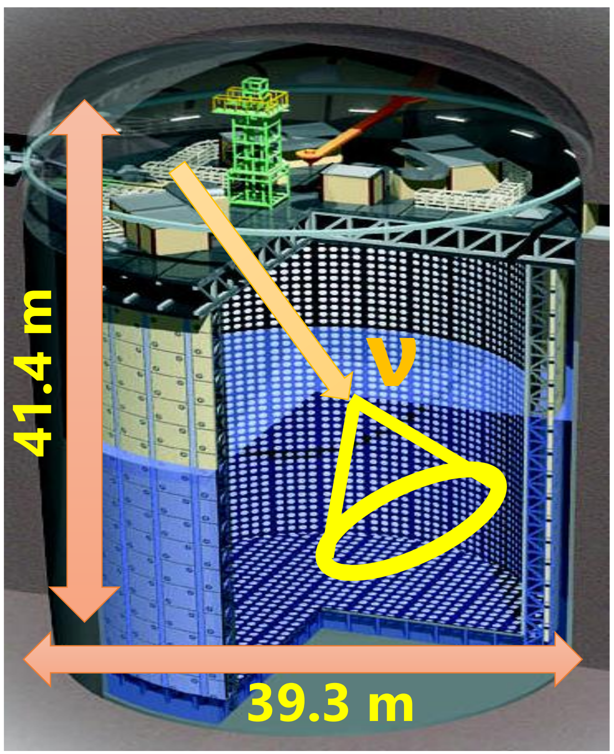
Supported by Grant-in-Aid for Young Scientists (B) 17K17880

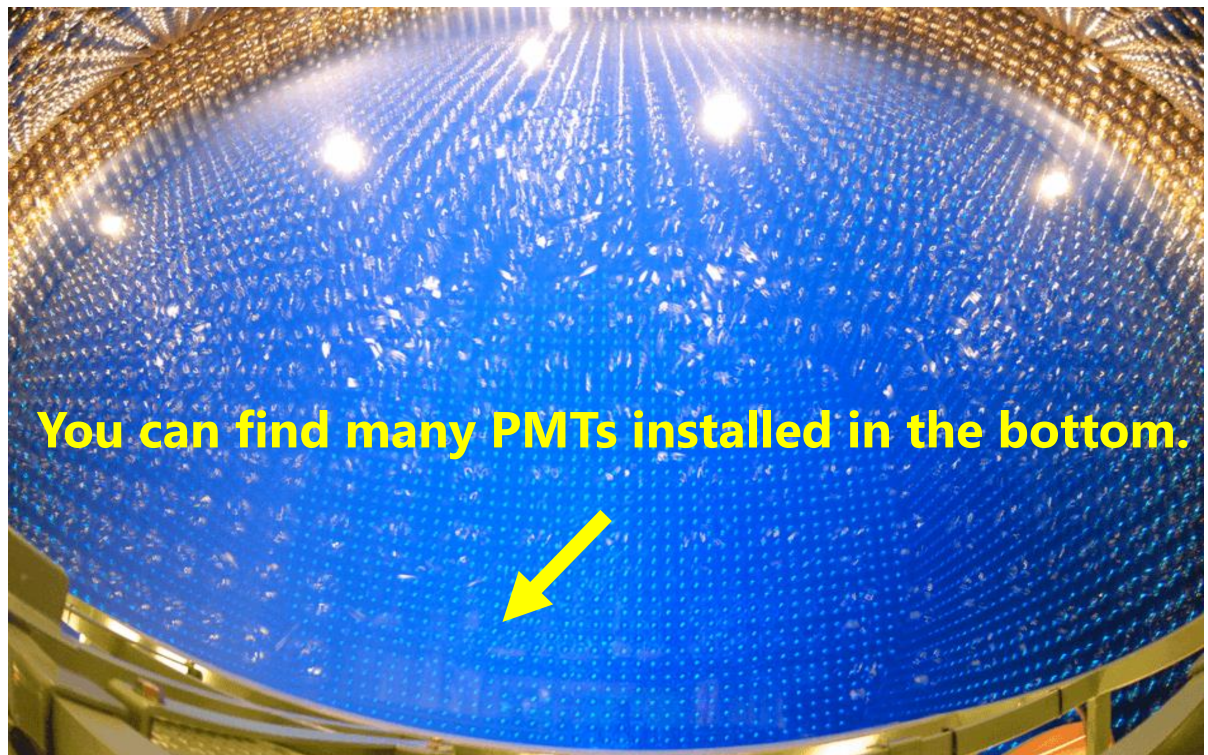
Contents

Introduction

■ Water in Super-Kamiokande

- **Purity of water** in SK is essential for the detector performance.
  - → Interactions are occurred only with water.
  - → Cherenkov light travels through water.
- **Understanding water properties** is required.





Requirements

■ Goal of our study

(1) Lead precise measurements.

→ Precise determination of energy.

→ High resolution for the reconstructions: position, direction.

(2) Achieve low background environment in the detector.

(3) Reduce the uncertainties.

■ Requirements to achieve above

- Understanding the water quality in detail:

→ **Uniformity of the water quality** in the whole tank.

→ **Stability of the water temperature**.

→ **Modeling absorption**/scattering/reflection of photon.

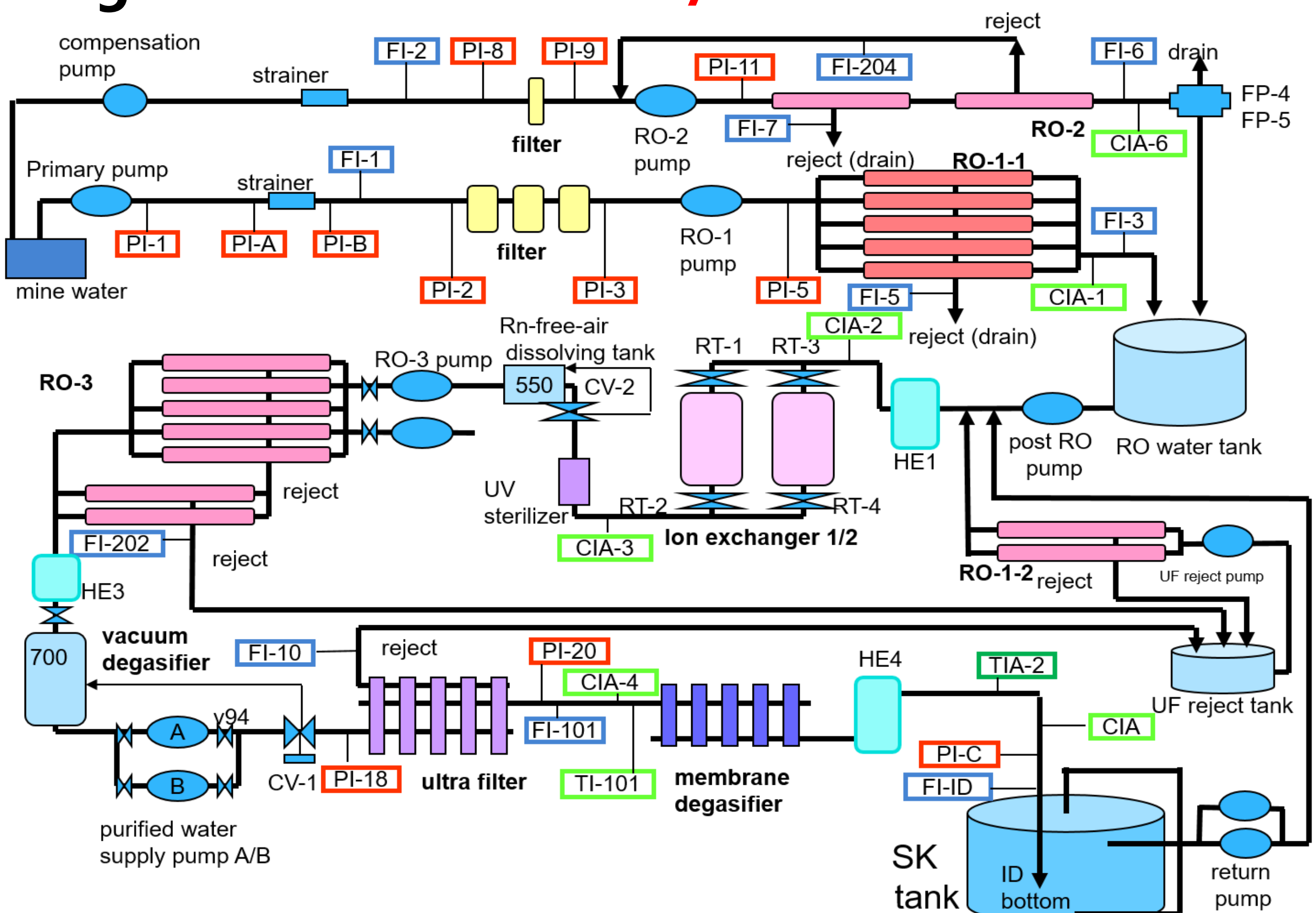
→ **Control of background**, such as ^{222}Rn daughters.

Water system for SK

Design of the current water system

■ Overview

- Raw mine water is drained.
- Removing several contaminations.
- Recirculating at rate **about 60 ton/hour**.



Water system and its performance

■ Main components

Item	Targets	Comment
Micro meter filter	Dust (>1.0 μm)	Series of mesh filter
Ion Exchanger	High molecular Heavy metal	Resin Remove ions in water (Na^+, Cl^-, Ca^{2+})
UV sterilizer	Bacterias	Radiate ultraviolet light to kill bacterias survive in water
Reverse Osmosis	>1000 molecular	
Vacuum Degasifier	Oxygen, Radon	
Nano meter filter	Dust (>10 nm)	
Membrane degasifier	Radon	
Heat exchanger	Heat	Control water temperature with an accuracy of 0.01℃.

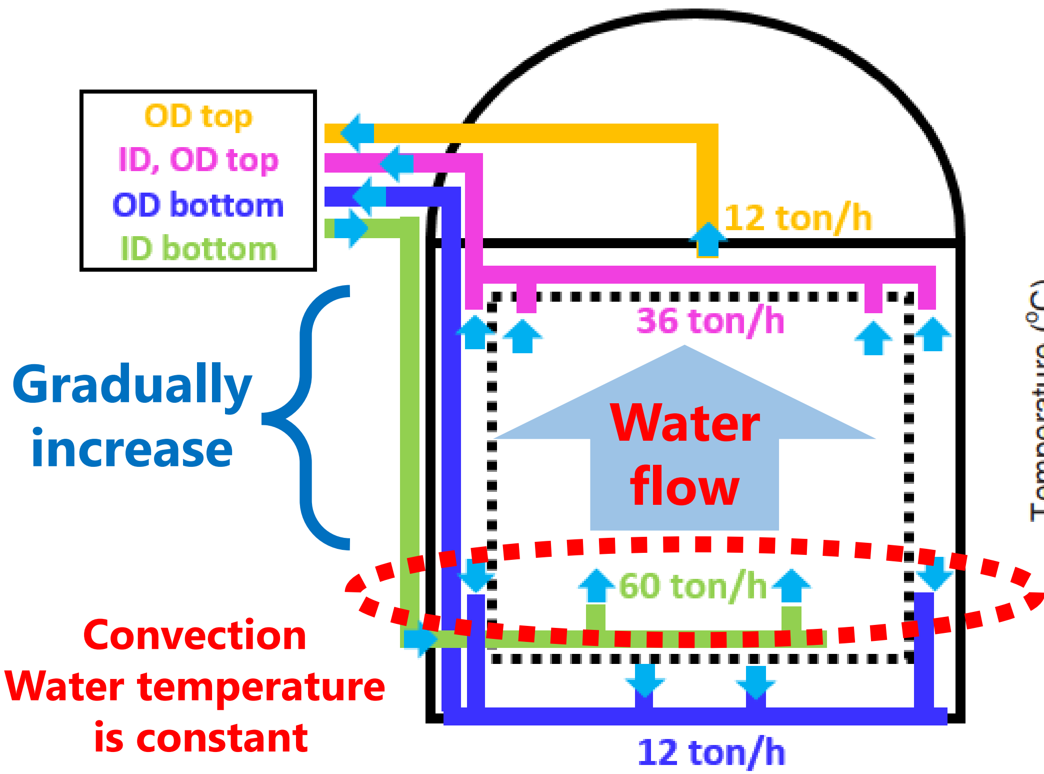
- Resistivity becomes 18.24 MΩ.
- Water temperature of the supply water is controlled at 13.06℃.

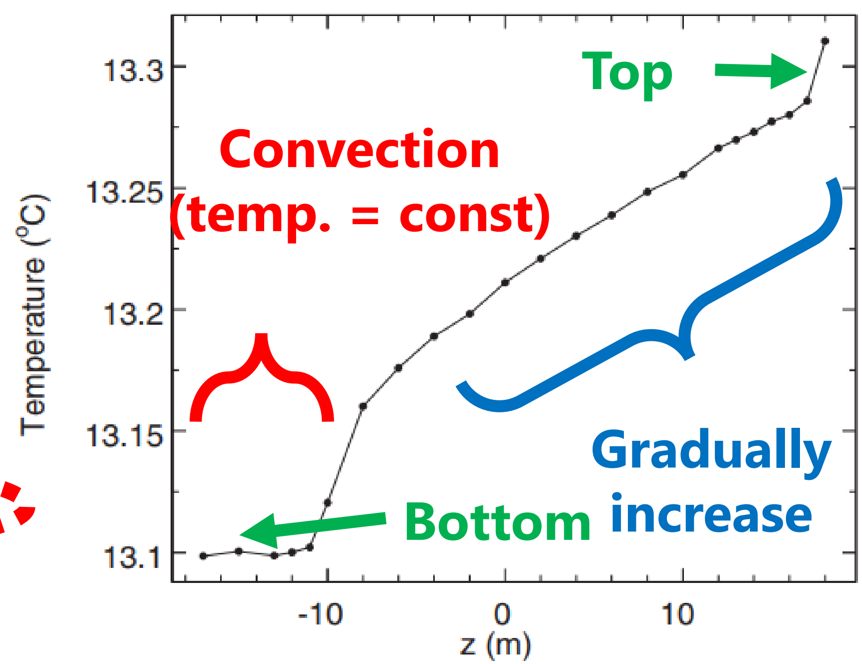
Water temperature in the tank

■ Temperature control

- Supply water is controlled at 13.06℃ with the heat exchanger.
- Water is basically supplied (drained) from the bottom (top).
- Below z=-11m, convection due to the constant temperature.
- Above z=-11m, water temperature gradually increases.

  → Water flows from the bottom to the top.





Phys. Rev. D 94, 052010 (2017).

BG control in the water tank

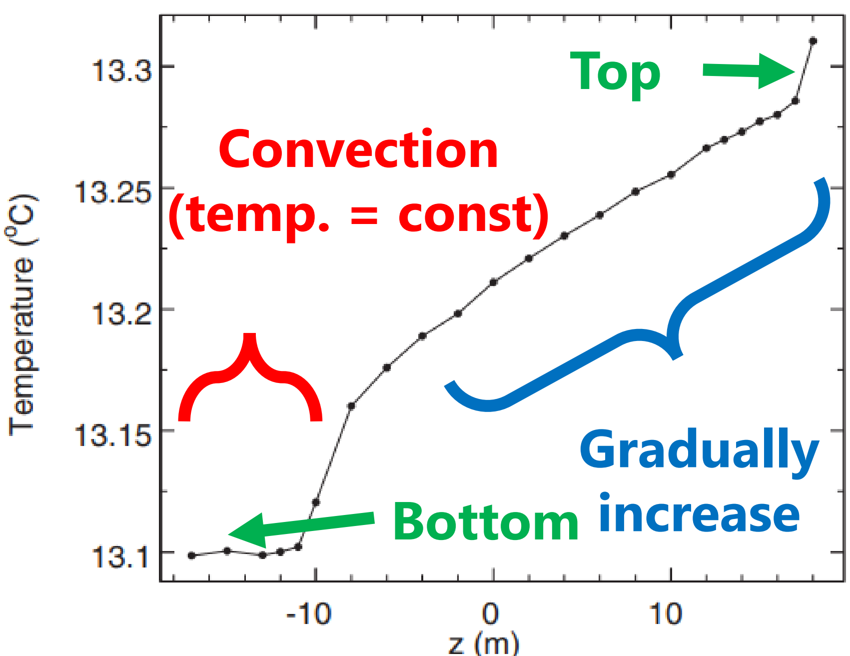
■ Radon concentration

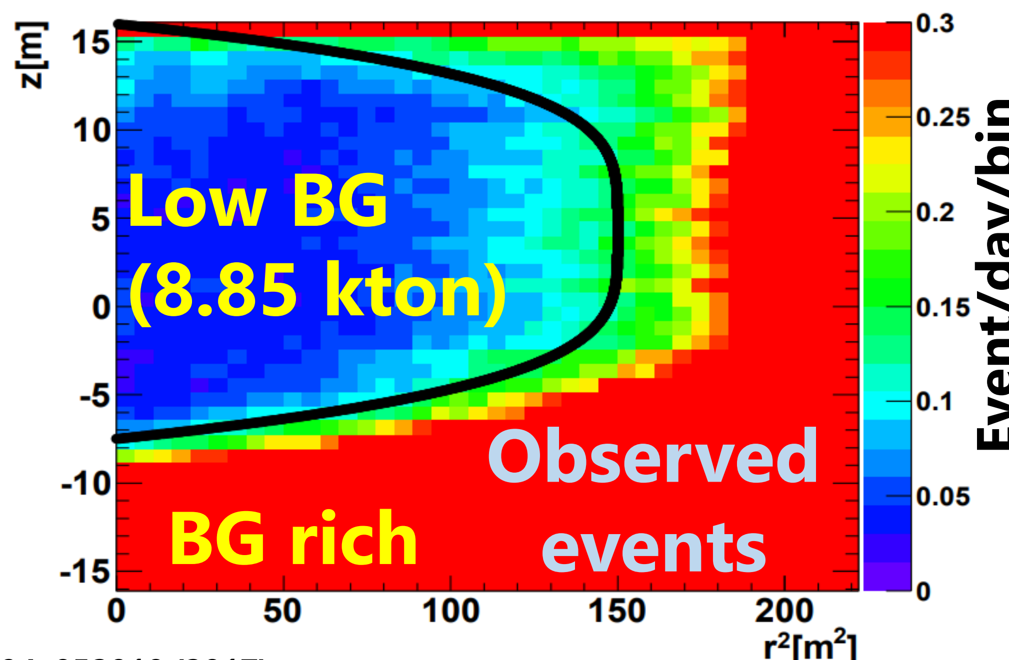
- Due to the convection, radon is located at the bottom region.
  → Successfully reduce radon background in the center region.

Position	Center region	Bottom region
Rn concentration	0.34±0.06 mBq/m^3	2.80±0.48 mBq/m^3

J. Phys. Conf. Ser. 888, 012191 (2017).

- Background for solar neutrino is 3-4 times lowered than SK-I.





Phys. Rev. D 94, 052010 (2017).

BG control in the water tank

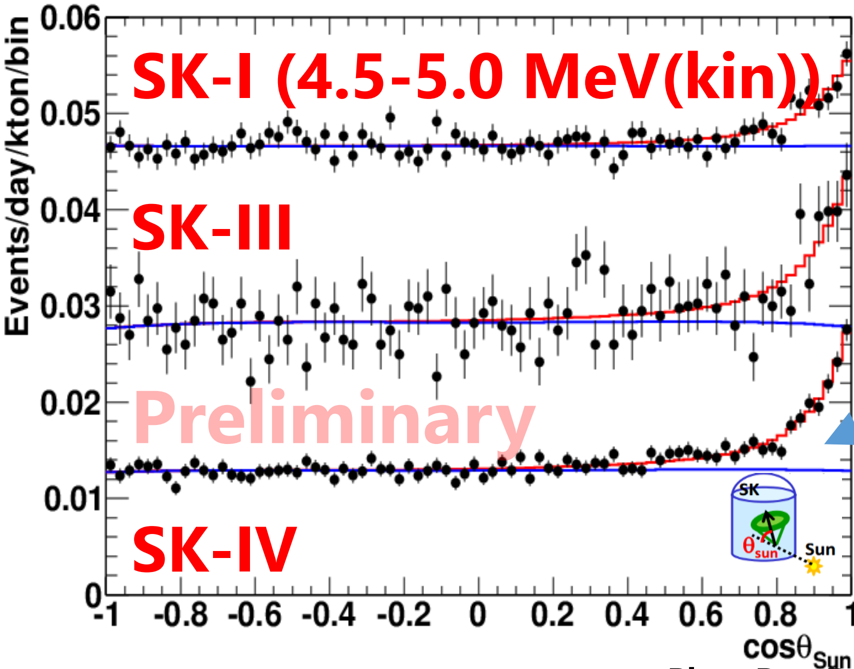
■ Radon concentration

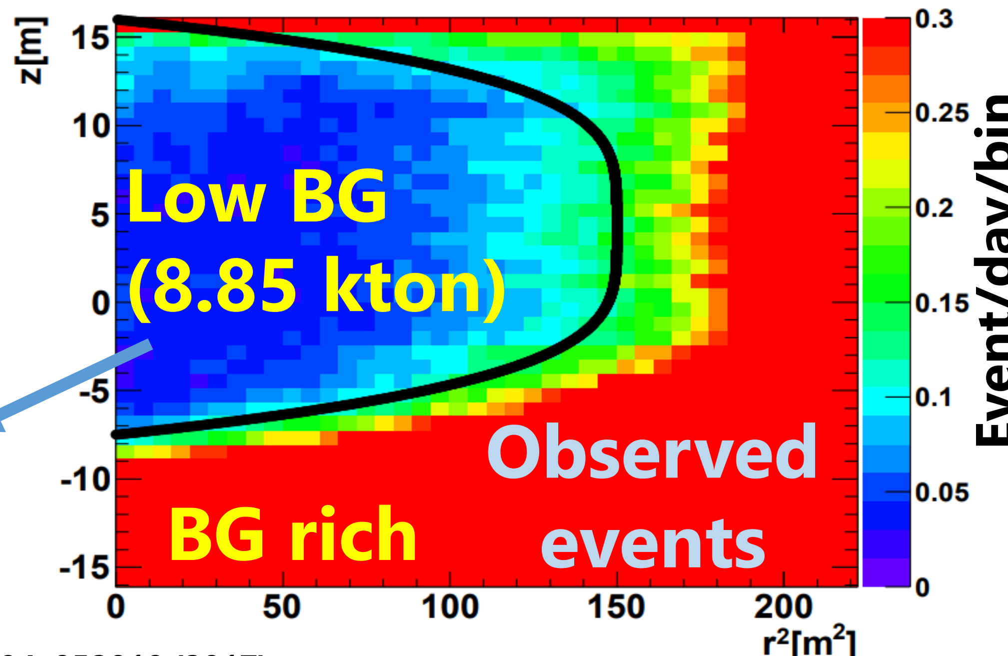
- Due to the convection, radon is located at the bottom region.
  → Successfully reduce radon background in the center region.

Position	Center region	Bottom region
Rn concentration	0.34±0.06 mBq/m³	2.80±0.48 mBq/m³

J. Phys. Conf. Ser. 888, 012191 (2017).

- Background for solar neutrino is 3-4 times lowered than SK-I.





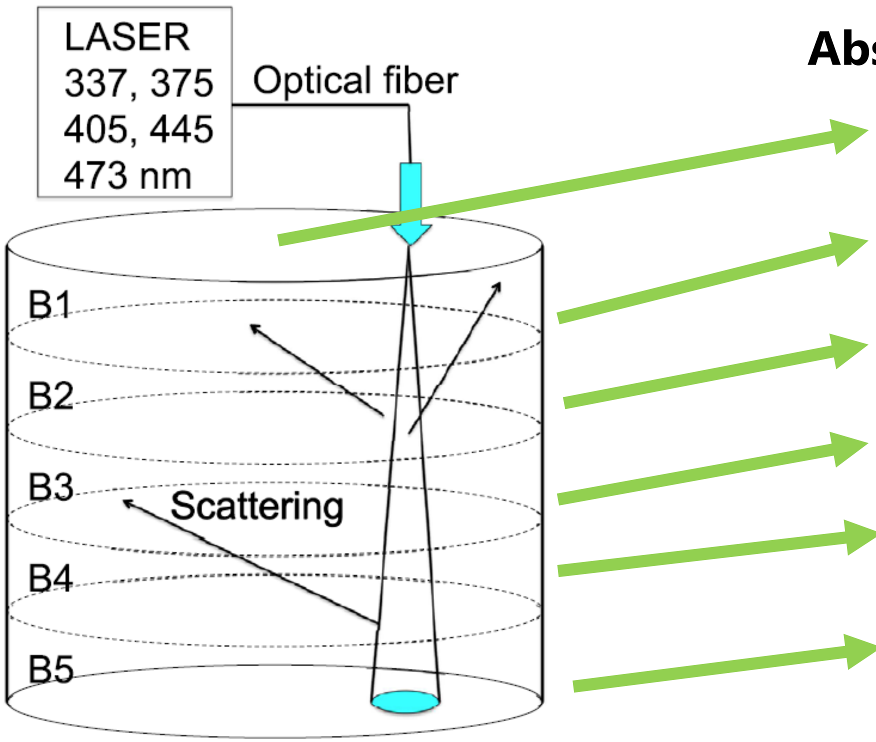
Phys. Rev. D 94, 052010 (2017).

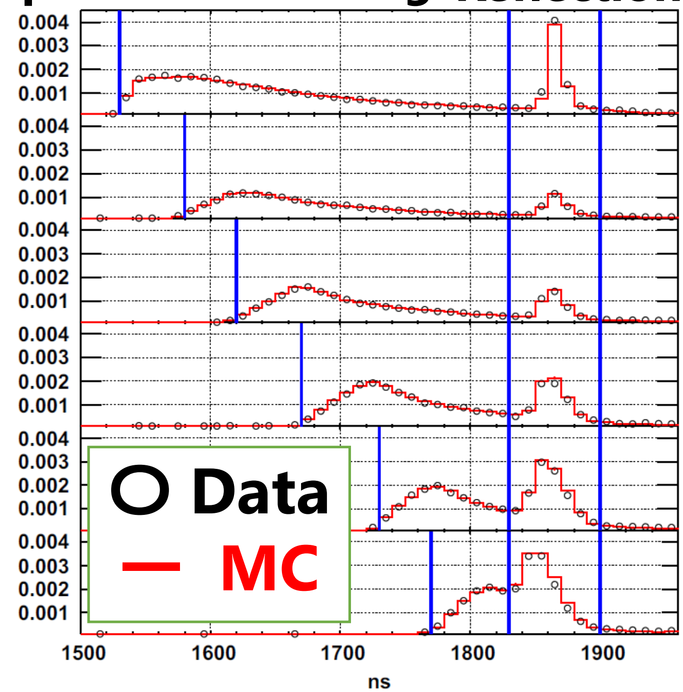
Attenuation length (1)

■ Component of attenuation

- Light attenuation occurs by **absorption and scattering**.
  → Rayleigh scattering and Mie scattering.
- Modeling with empirical function:
  (does not represent real physical properties)

$$L(\lambda) = \frac{1}{\alpha_{abs}(\lambda) + \alpha_{sym}(\lambda) + \alpha_{asy}(\lambda)}$$





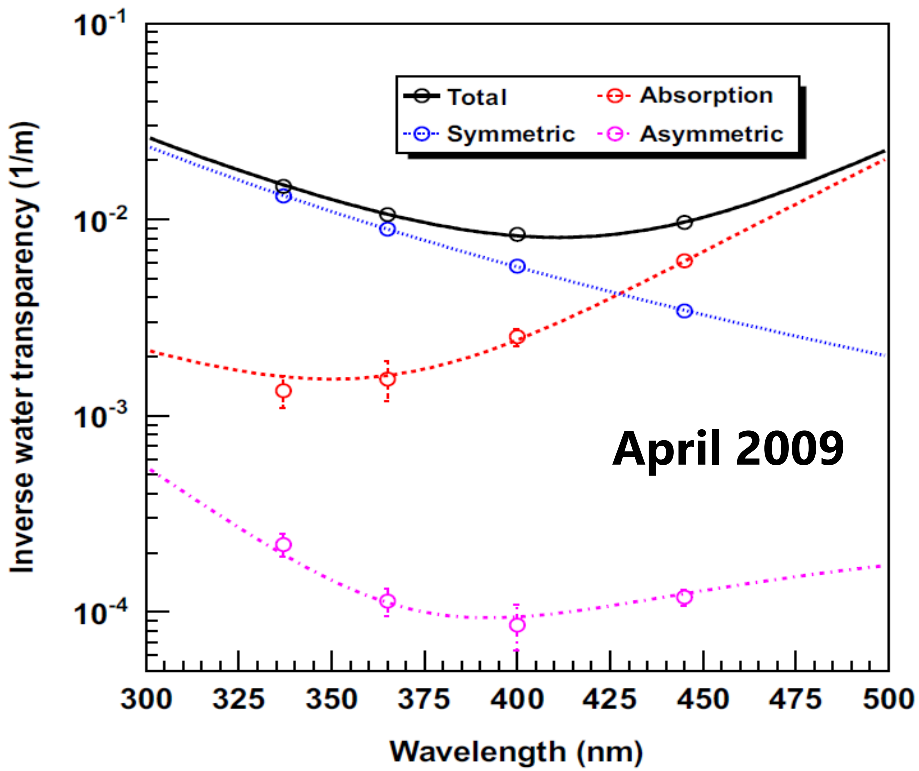
Timing distribution (TOF subtracted)

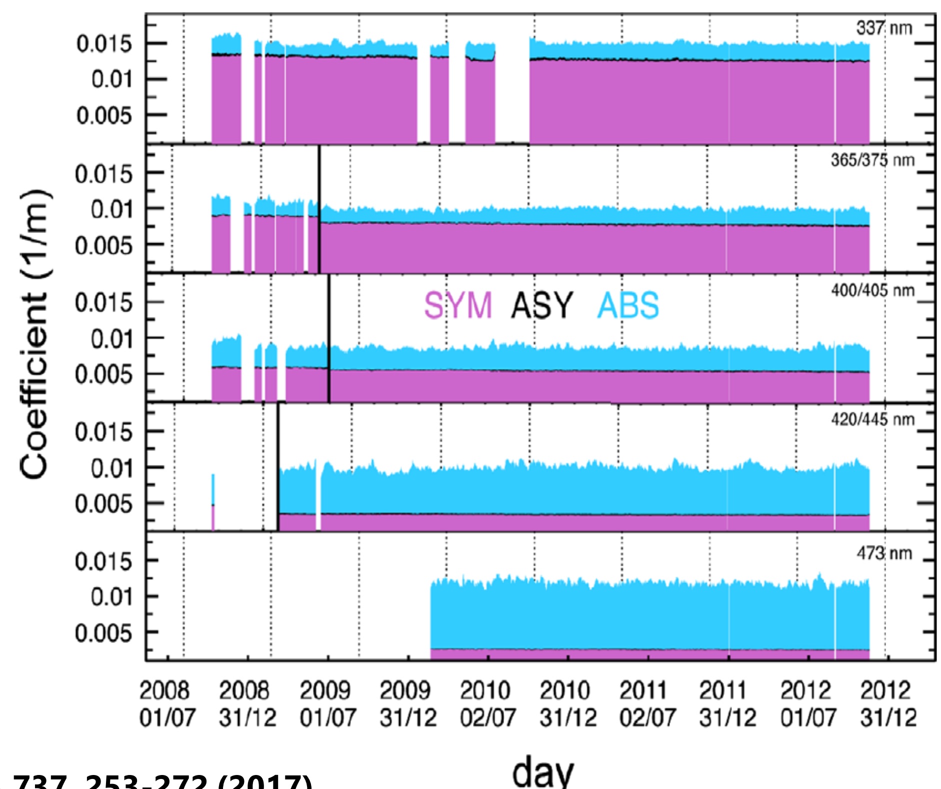
Nucl. Instrum. Meth, A 737, 253-272 (2017).

Attenuation length (2)

■ Modeling of water

- Using calibration data, parameters are determined.
  → These parameters are used in the MC simulation in SK.
- Asymmetric is relatively stable for every wave length, while others have large time dependence (correlated with purity).





Nucl. Instrum. Meth, A 737, 253-272 (2017).

Top-bottom asymmetry

■ **Uniformity of response**

- Water pattern in the tank may affect the detector performance.

→ Monitoring the hit probability of PMTs:

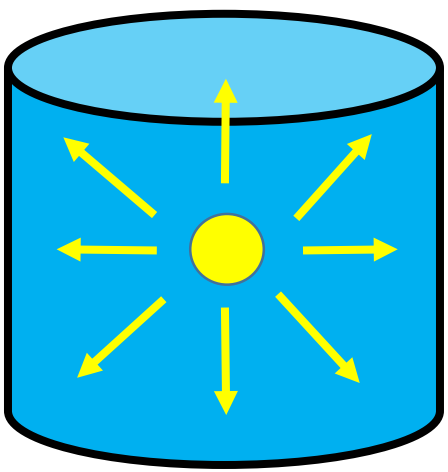
with **Xe-light** source (every 1 second).

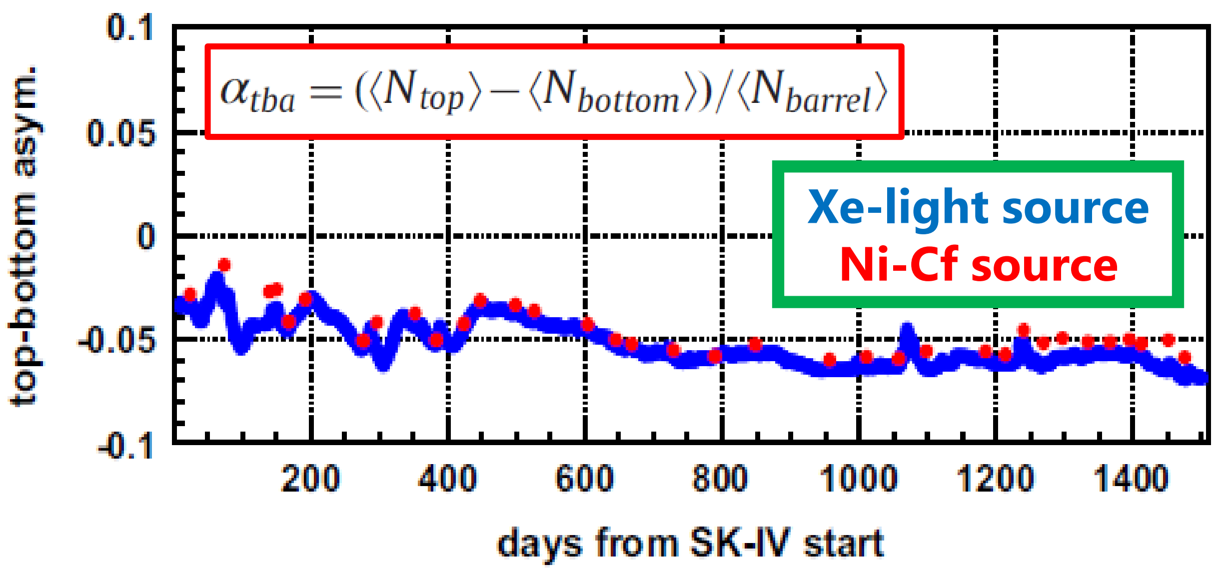
with **Ni-Cf** calibration source (Monthly).

→ **5% level of difference** is observed with two calibration sources.

(Attenuation length in the bottom is better).

With uniform light source
(same response is expected)





Nucl. Instrum. Meth, A 737, 253-272 (2017).

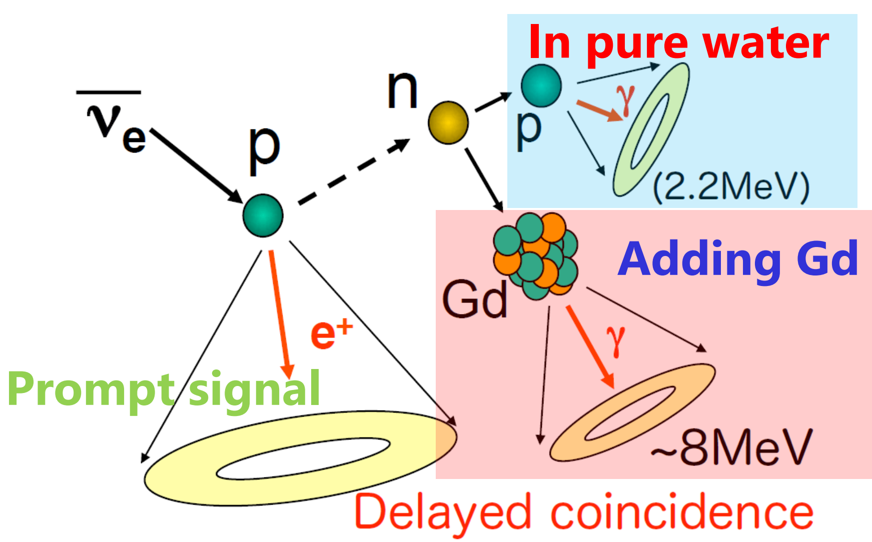
Water system for SK-Gd

Why Gadolinium (Gd)

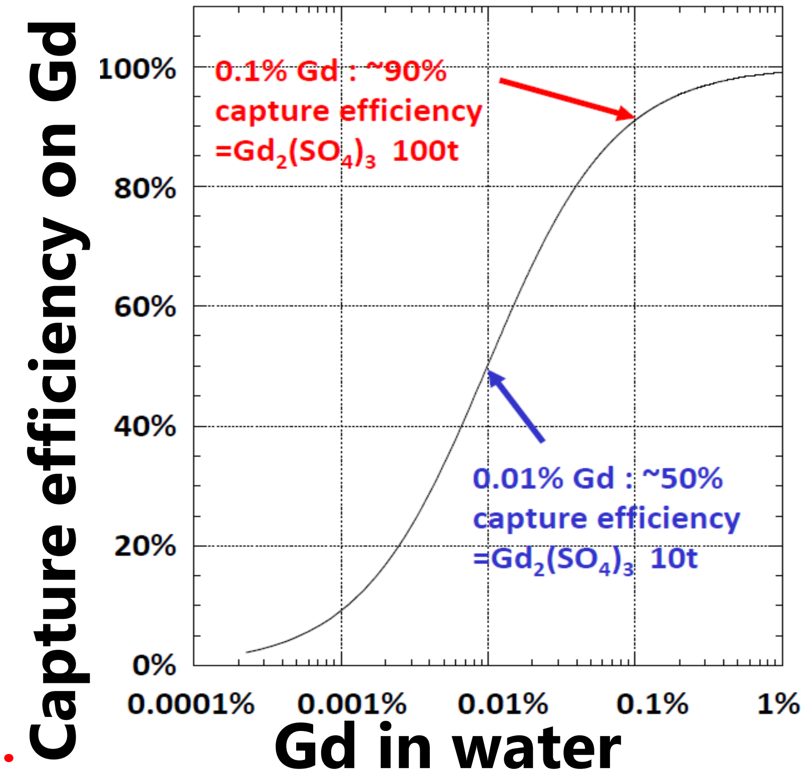
■ Neutron tagging

- N-tagging on hydrogen (free proton) is **only ~18% efficient in SK.**
  → Because of small energy of γ-ray (2.2 MeV).
- Gd has a large thermal-neutron cross section.
  → Possible to **identify $\bar{\nu}_e$ interaction** with delayed coincidence.
  → Large background reduction is expected for $\bar{\nu}_e + p \rightarrow e^+ + n$.

$$\boxed{\bar{\nu}_e + p \rightarrow e^+ + n}$$



Time difference: ~30 μsec, Vertex : ~50 cm.



Requirements for SK-Gd

■ From SK to SK-Gd

(1) Environmental safety.
(2) Minimize negative impacts to current physics program.
(3) Further physics potential with Gadolinium.

■ Requirements for SK-Gd

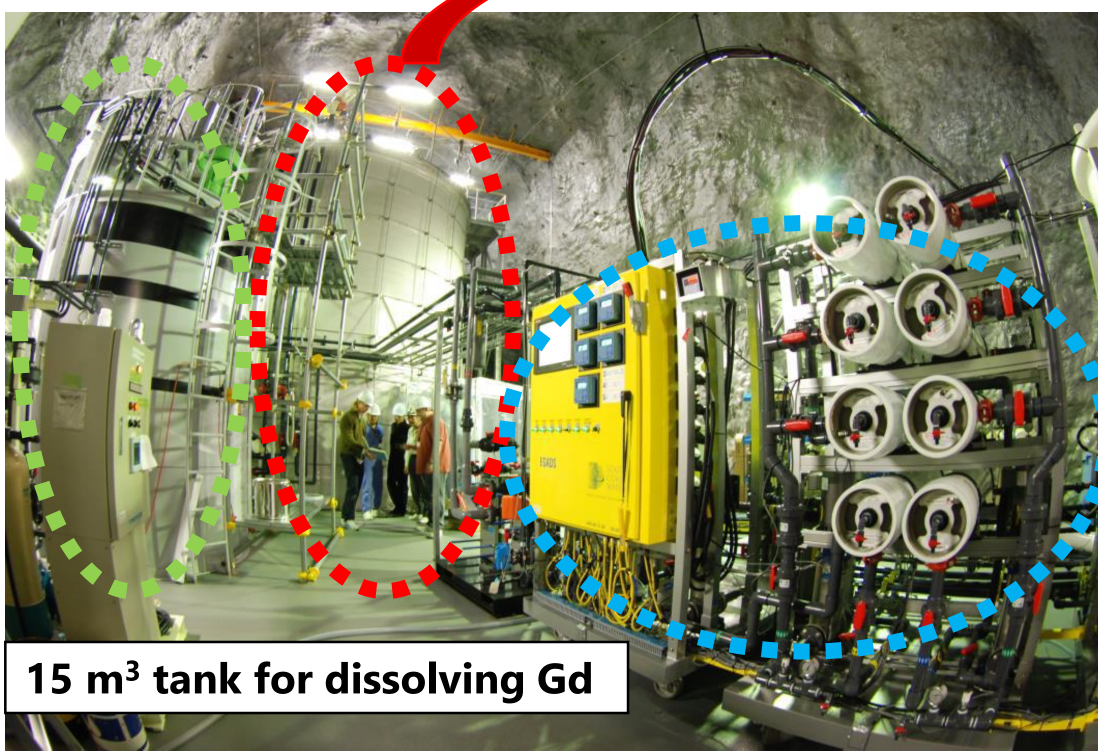
- Stopping the water leakage.
  → Currently, we try to fix it during the refurbishment work.
- Reduce background from radioactive impurities in $Gd_2(SO_4)_3$.
  → Next talk given by Prof. Luis Labarga.
- Monitoring water quality and Gd concentration.
  → Test tank (EGADS) is used for these demonstrations.
- Design/construction of the new water system.

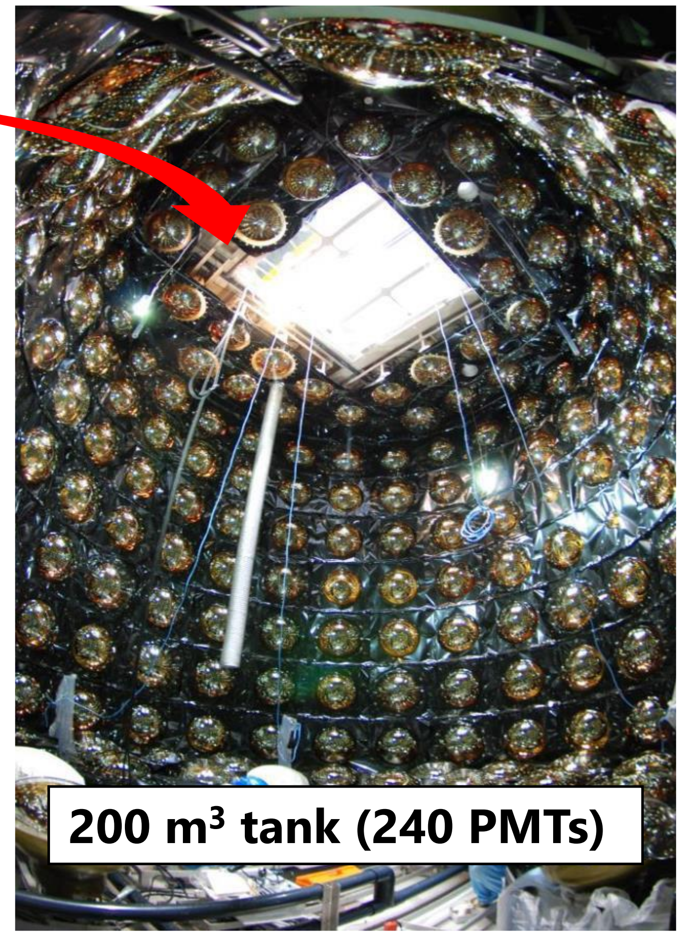
EGADS detector (test tank)

■ Evaluating Gadolinium's Action on Detector System (EGADS)

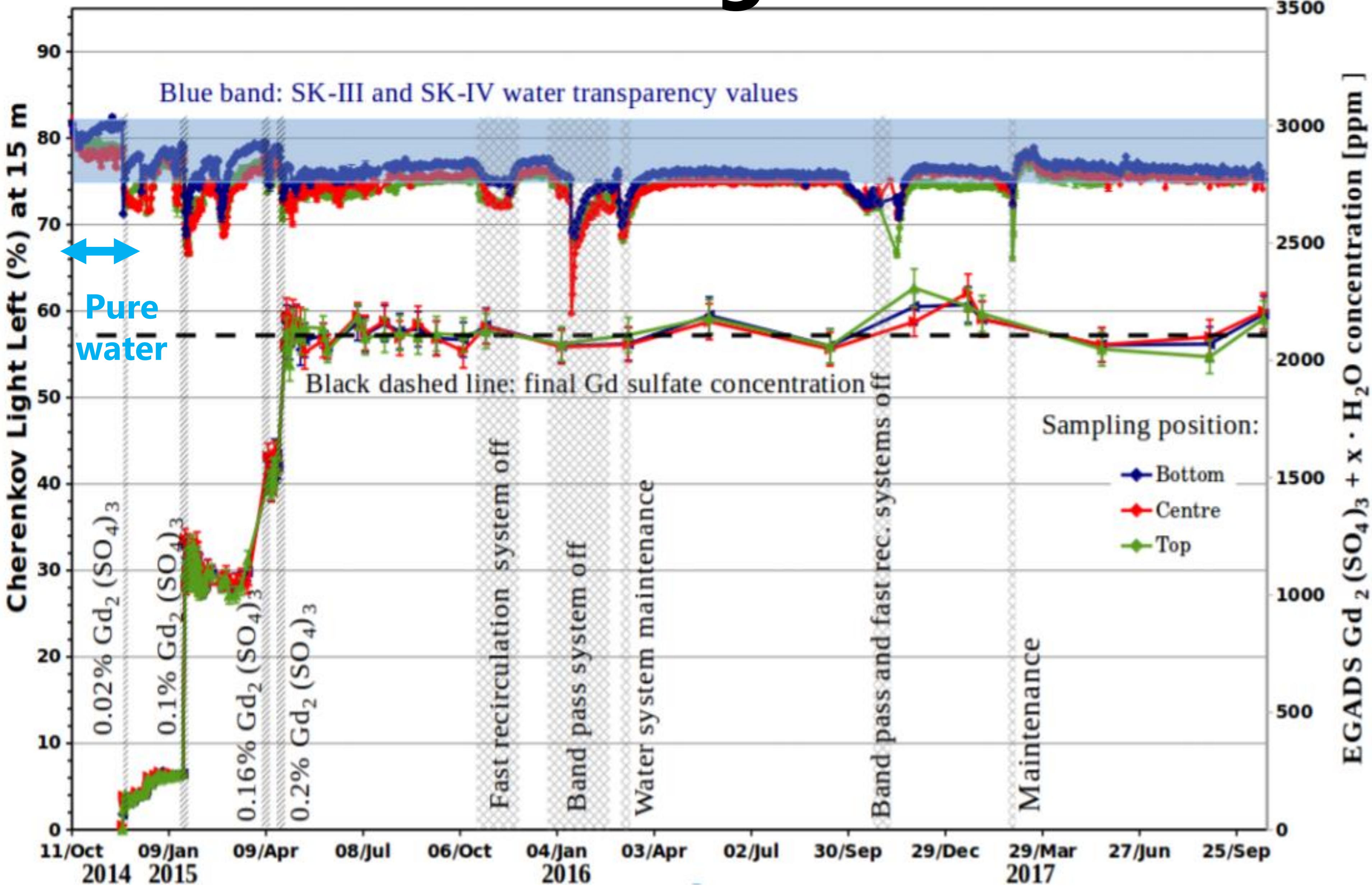
- Test tank using actual detector materials.
- Study for Gd-water (quality/concentration monitoring).

→ Main tank (200 m^3), Circulation system and 15 m^3 tank for dissolving Gd.

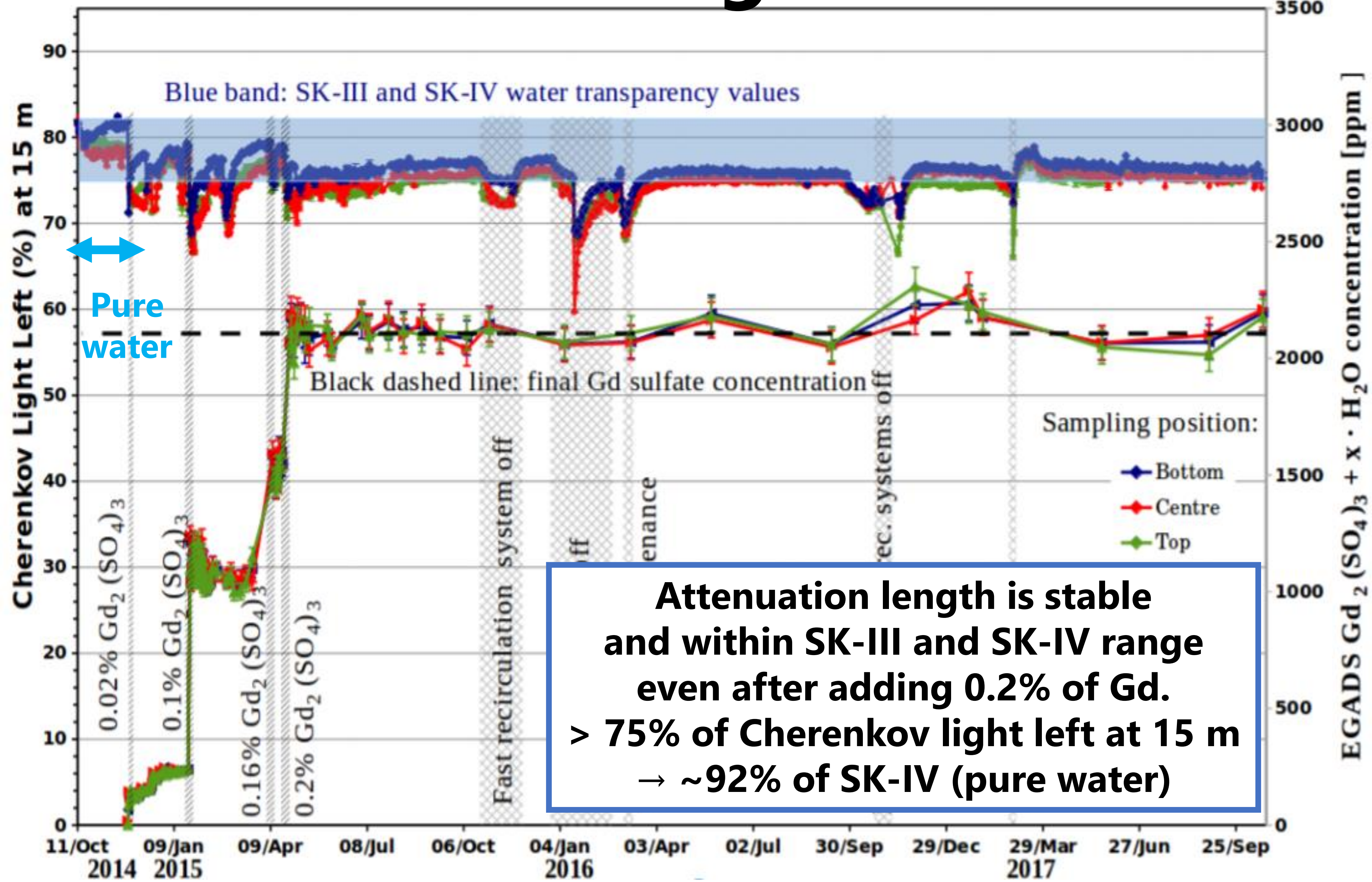




Monitoring results



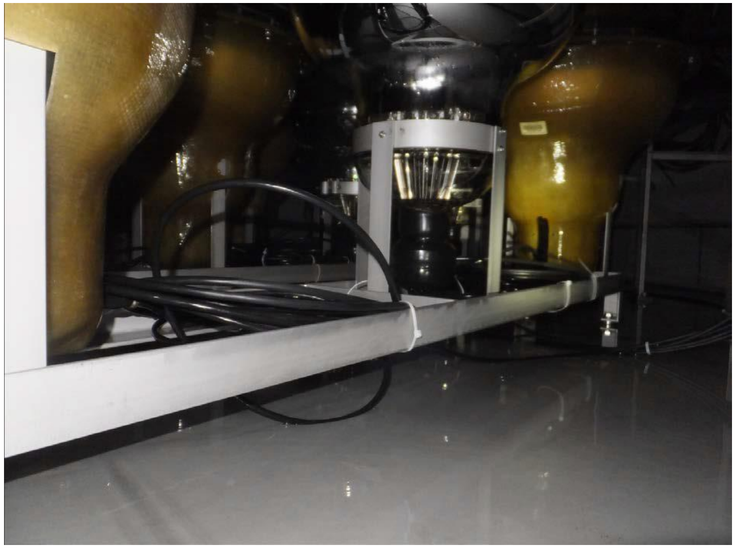
Monitoring results



Attenuation length is stable and within SK-III and SK-IV range even after adding 0.2% of Gd.
> 75% of Cherenkov light left at 15 m
→ ~92% of SK-IV (pure water)

After 3 years operation


Very clean (no damage to the detector)



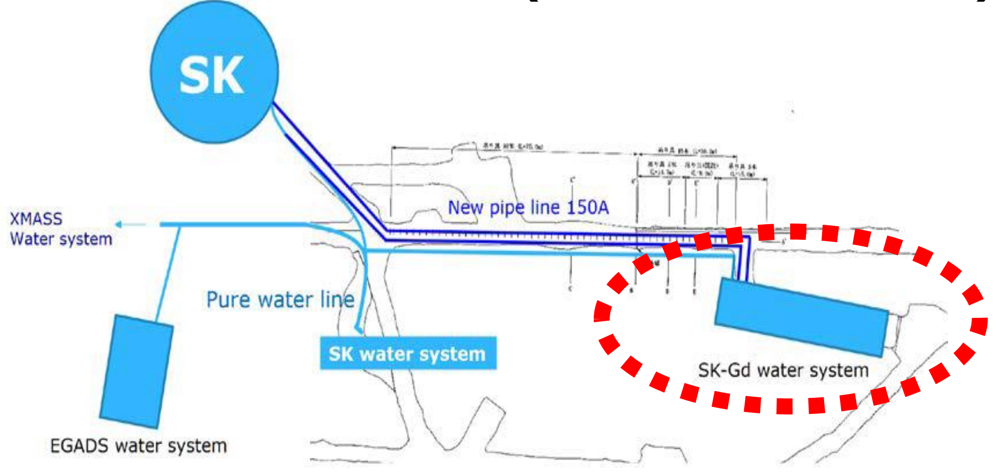

Water system for SK-Gd

■ Location and Design

- System for dissolving Gd is newly constructed.

■ Main upgrade

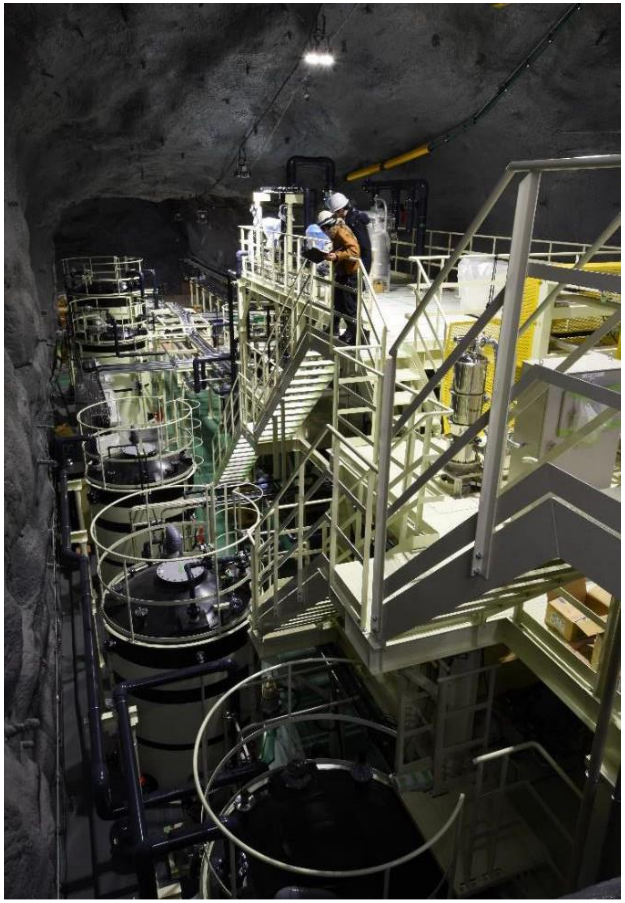
- Powder transportation system.
  → Dissolving Gd-sulfate.
- Pretreatment system.
  → Mixed with pure water (High Gd concentration).
- Fast circulation system (bandpass system).
  → Get target Gd concentration (0.02% and 0.2%).

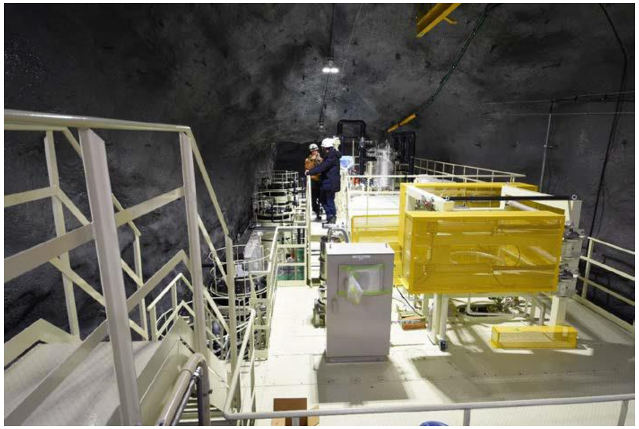


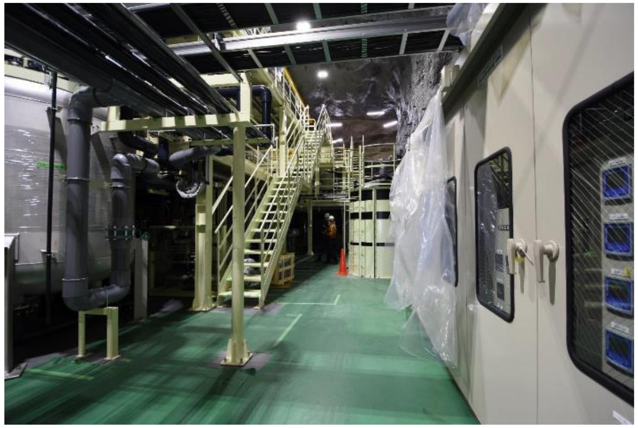
Water system for SK-Gd

■ Construction

- Experimental area has been excavated since 2015.
- Construction work has started since October 2016.



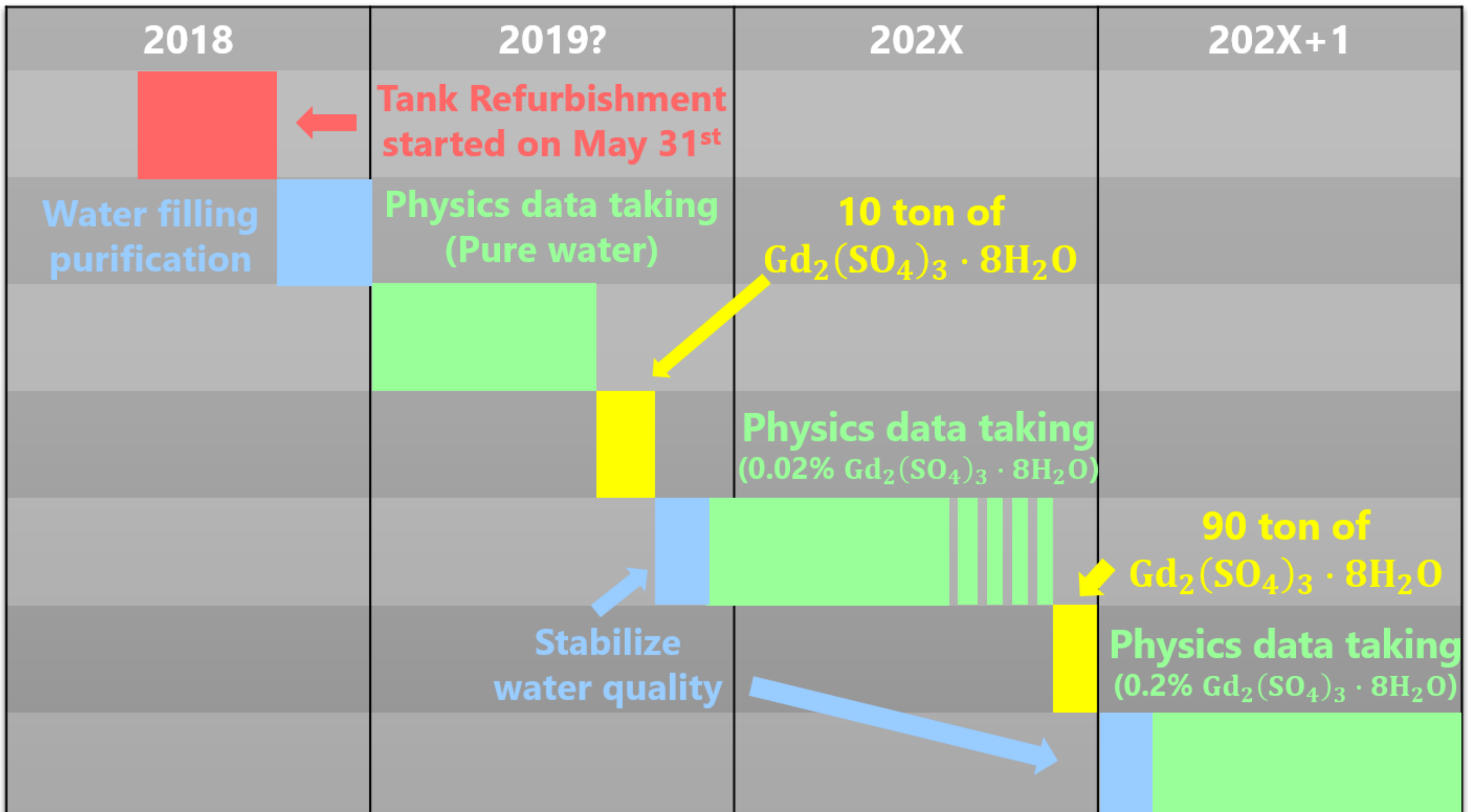




Time table for SK-Gd project

■ Tank refurbish work and future plan

- Refurbish work has started since May 31st.
  → For water leakage fixing & replacement of broken PMTs
- Dissolving Gd into SK is expected in late 2019 (earliest case).



Summary

- Purity of water is essential for detector performance.
  → Precise measurement, low background….

- Super-Kamiokande's water system successfully produces the highest purified water.

- The properties of pure water are well studied:
  (1) Water temperature is well monitored.
      → This helps to control radon background in the tank.
  (2) Detector response are understood with several calibrations.

- For SK-Gd, several studies has been made:
  (1) Demonstrate the stability of water quality with Gadlinium.
  (2) No damage for the test tank (EGADS) after 3 years operation.
  (3) New water system has been constructed.

Back up slides

How to measure Rn in SK water

(1) Sample water w/ water pump
(2) Mix water with pure air w/ mixer
(3) collect Rn with activated charcoal
(4) Rn form activated charcoal
(5) Fill Rn detector with pure air
(6) Count α-ray of ^{214}Po decay