

Purpose: keep a JUNO detector **CLEAN (ultra-low radioactivity)**, not only control bulk radioactive background from material and environment, but also need control surface cleanliness due to dust fallout during manufacture, installation, commissioning and etc. In order to reach 10^{-15} g/g U/Th background for neutrino mass hierarchy determination, we will investigate both effective cleaning methods and evaluation techniques. We will do more effort to achieve 10^{-17} g/g U/Th background to explore more physics.

Background consideration

Total radioactive budget for the JUNO detector:

9.6 Hz (in fiducial volume (FV) and >0.7 MeV)

Radioactive budget for the surface cleanliness contribution:

Dust contribution inside CD: < 0.32 Hz (in FV and >0.7 MeV)

Dust contribution outside CD: < 0.25 Hz (in FV and >0.7 MeV)

Dust fallout models

General Model:

Class 10000, dust fall rate: 0.09 mg/m²/day

$$M_{\text{dust}} = D_{\text{clean_level}} \times V_{\text{accumulation_rate}} \times \text{Area} \times \text{Time}$$

M_{dust} : Mass of accumulated dust

$D_{\text{clean_level}}$: density of dust under a clean level

$V_{\text{accumulation_rate}}$: wind speed assume all the dust accumulated

Daya Bay Model:

Class 10000, dust fall rate: 0.14 mg/m²/day

During one Daya Bay acrylic vessel (AV) production and assembly, dust could fallout on the AV surface. γ from ²³²Th and ²³⁸U decay chains can be seen. The time of production and assembly for each AV is different, ²³⁸U/²³²Th contaminations could be observed. Then fallout rate can be estimated.

Measured dust radioactivity :

U-238: 9.7ppm, Th-232: 26.6ppm, K-40: 5.1ppm

Evaluation methods

1. Conductivity monitoring

Resistivities of water before and after cleaning surface will be measured, the difference should be less than 4-6 M Ω -cm (circulation or rinse method). Original cleaning water quality should be 18.2 M Ω -cm.



2. Light absorption spectra comparison

Compare the light absorption spectra with rinsed water before and after cleaning surface. The spectra are in a good agreement.



3. Suspension particulate counting

A. Verification with rinsing water measurement

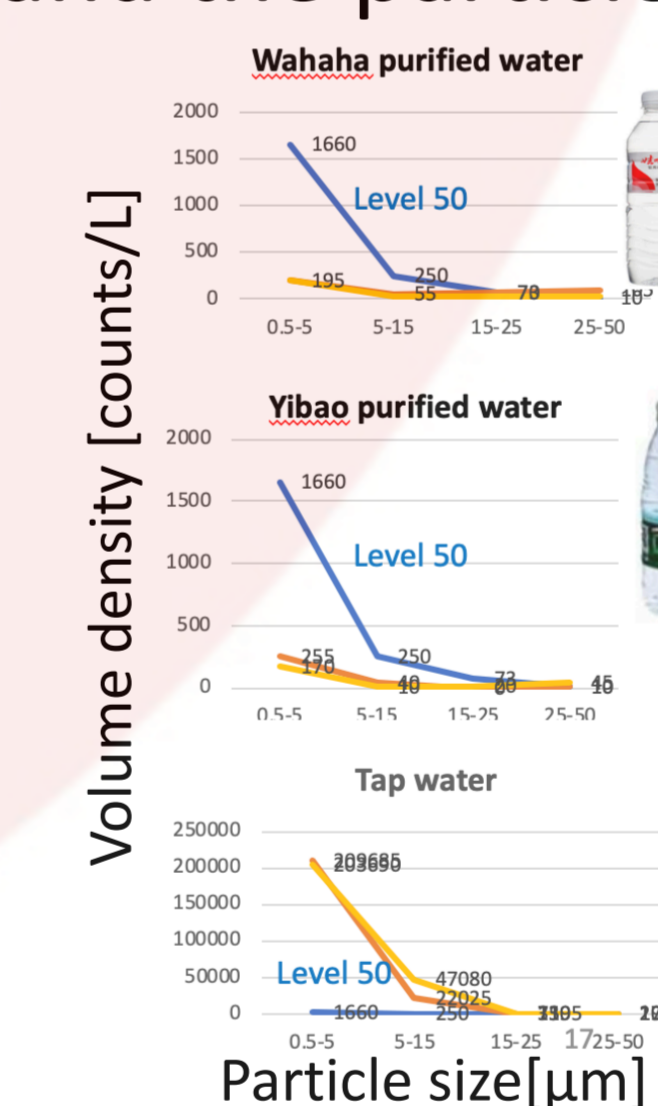
- Detector: Silicon Photodetector, Photodiode
- Measuring range: 0.5 μ m to 400 μ m
- Light obscuration(extinction) and angular scattering combination advanced technologies make the measuring wider and accurate.
- Repeatability deviation: $< 5\%$
- Particle size, cleanliness level and the particle size distribution can be obtained.

Particle Size [μ m]	Surface density [counts/0.1m ²]	Volume density [counts/L]
5	179	1660
15	27.0	250
25	7.88	73
50	1.01	10

JUNO Level 50

Particle Size μ m	Volume density [counts/L]			
	5	5-15	15-25	25-50
WaHaHa bottle water 1	195	55	70	105
WaHaHa bottle water 2	200	35	25	20
Yibao bottle water 1	255	40	0	10
Yibao bottle water 2	170	10	20	45
Tap water 1	209685	22025	350	195
Tap water 2	203690	47080	1195	270

Repeatability check and water quality comparison



B. Particulate counting with monitoring witness plates

- High speed camera + microscope + algorithm
- Measuring range: 1 μ m to 10000 μ m
- Repeatability deviation: $< 1\%$
- Sampling speed: 10000 counts/min
- Enlargement factor: 30-1000
- Duration: 10 mins



Liquid particulate counter



Surface particulate counter

Cleaning methods

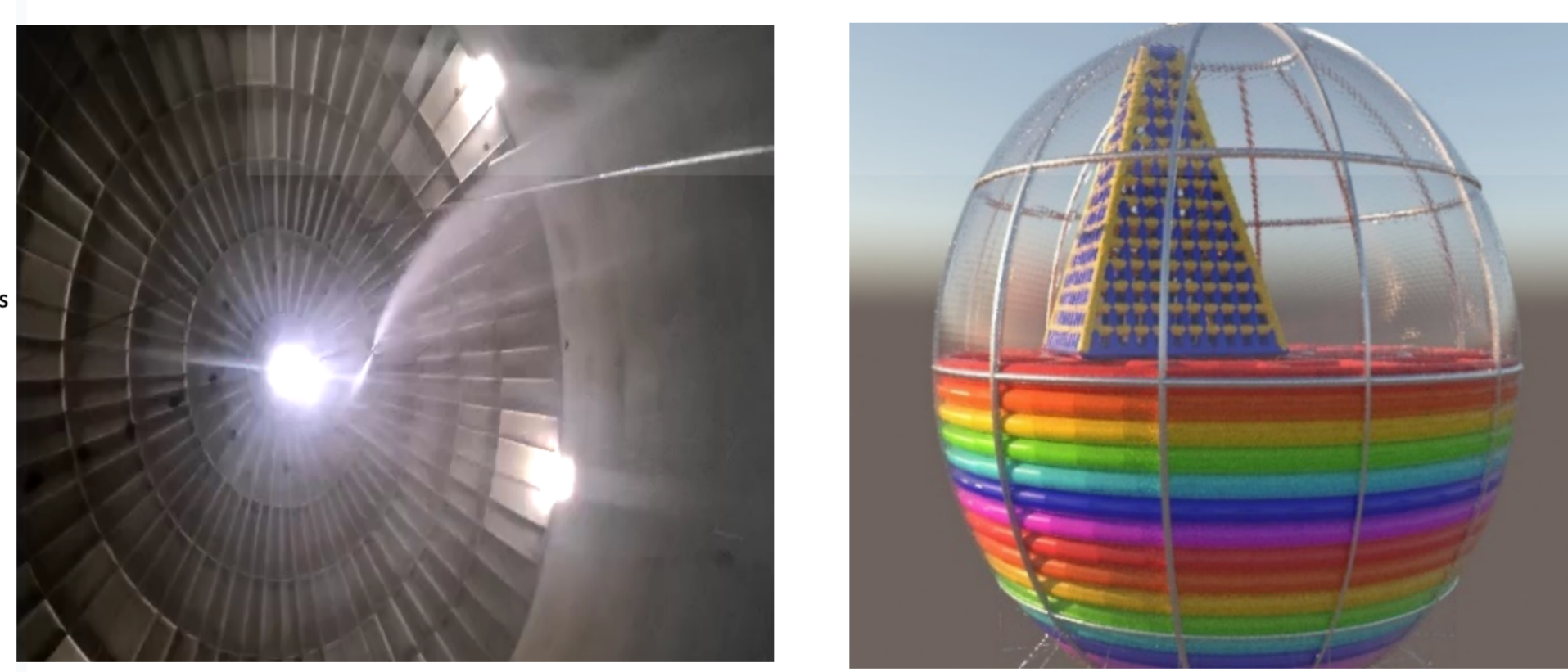
Acrylic clean strategy

Acrylic panel cleaning

Surface of panels cleaning process



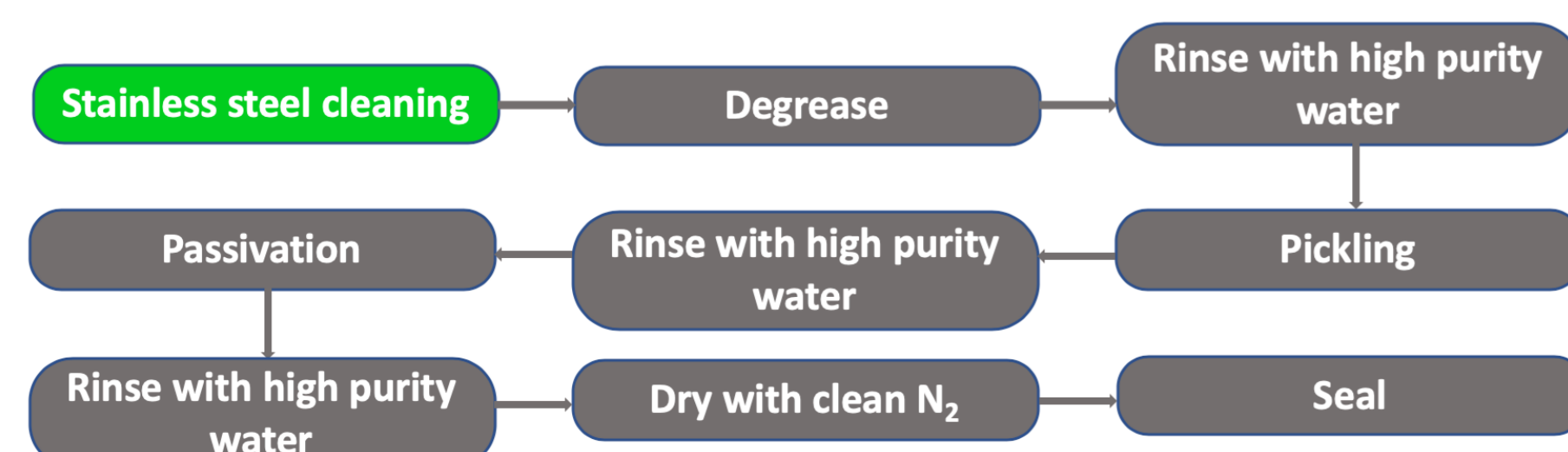
Acrylic sphere cleaning



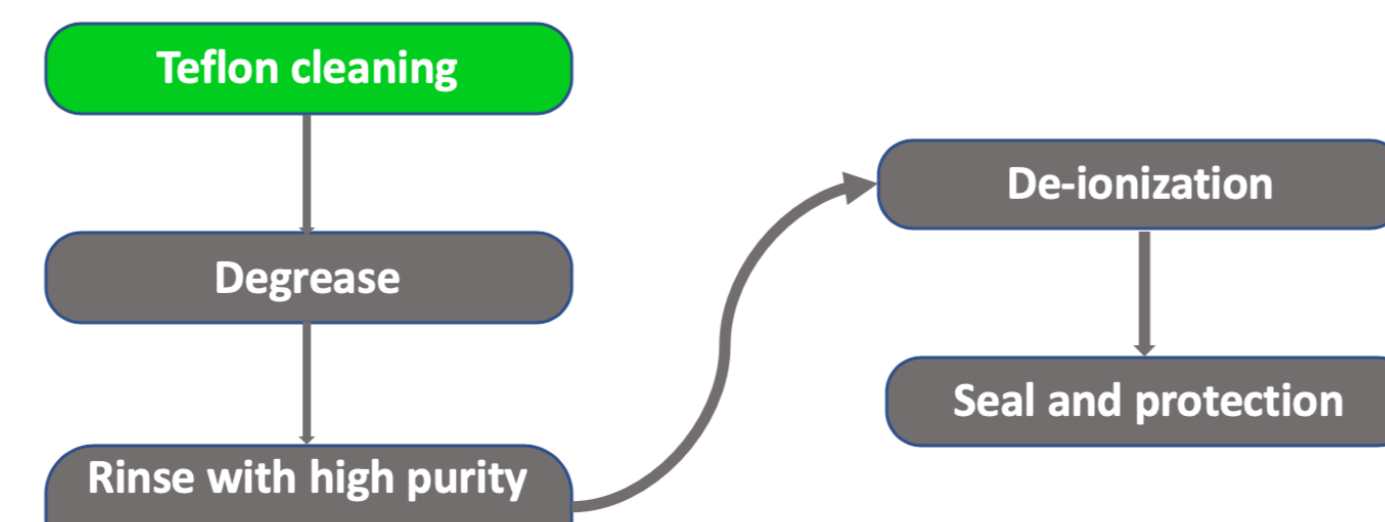
Water spray

Wipe with air cushions

Stainless steel cleaning



Teflon cleaning



4. ICP-MS measurement: sensitivity: 10^{-13} g/g for ²³⁸U and ²³²Th

Cleanliness requirement

	Purification and filling system	Acrylic sphere (inner surface)	Acrylic sphere (outer surface)	Calibration system	
Area	772 m ²	4000 m ²	4000 m ²	< 2 m ² (cable & source capsule)	< 4 m ² (cable & positioning system)
Surface dust requirement for cleaning	< 0.1 mg/m ²	< 1.7 mg/m ²	< 3.1 mg/m ²	< 0.1 mg/m ²	< 1.7 mg/m ²
Allow exposure in class 10000 space after cleaning	< 0.15 days	12 days	6 months	< 0.15 days	12 days
Total surface background budget (Singles in FV)	< 0.22 Hz	< 0.1 Hz	< 0.25 Hz	< 0.4 mHz	< 0.4 mHz

Preliminary results of acrylic panel test

1. Conductivity monitoring
Measured resistivity of rinsing water before and after cleaning is less than 4M Ω -cm
2. Light absorption spectra
UV-Vis Spectra: UV-2550
Absorbance vs Wavelength (nm) graph showing Ultrapur water and Ultrapur water after acrylic clean.
3. Particulate counting, better than JUNO level 50
Acrylic 5*5*1cm
Rinsing water measurement and Surface measurement graphs.
4. ICP-MS measurement, the rinsing water before and after acrylic cleaning

Conc. [ppt]	Before	After
²³⁸ U	< 0.17 @90% C.L.	0.13 ± 0.01
²³² Th	< 0.01 (MDA)	< 0.18 @90% C.L.