

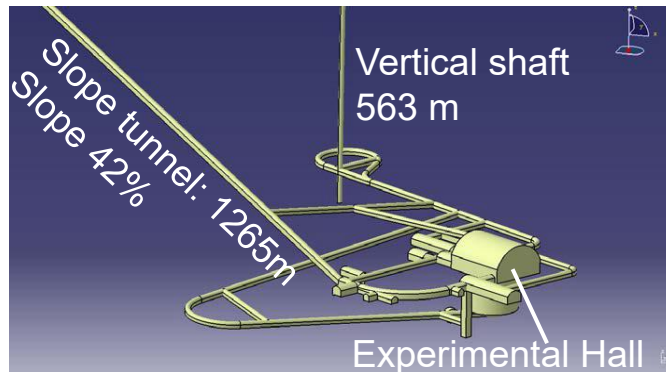
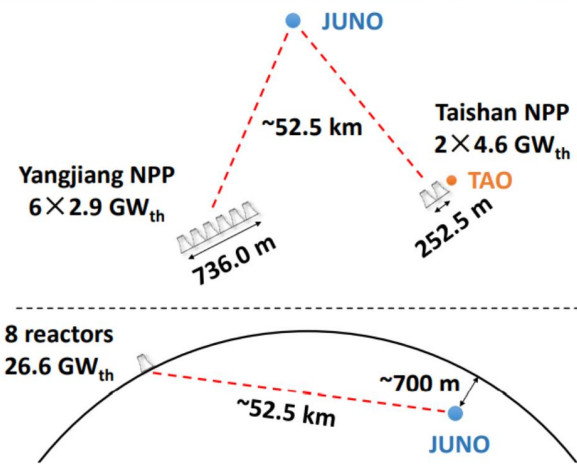
Status of JUNO liquid scintillator

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On behalf of JUNO LS group
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Jiangmen Underground Neutrino Observatory



- 20 kton LS detector of unprecedented 3% energy resolution (at 1 MeV) at 700m underground

JUNO & JUNO Liquid Scintillator (LS)

JUNO physics goal:

- **Neutrino mass hierarchy**
- supernova neutrinos, geo-neutrinos, atmospheric neutrinos, solar neutrinos.

JUNO Central detector:

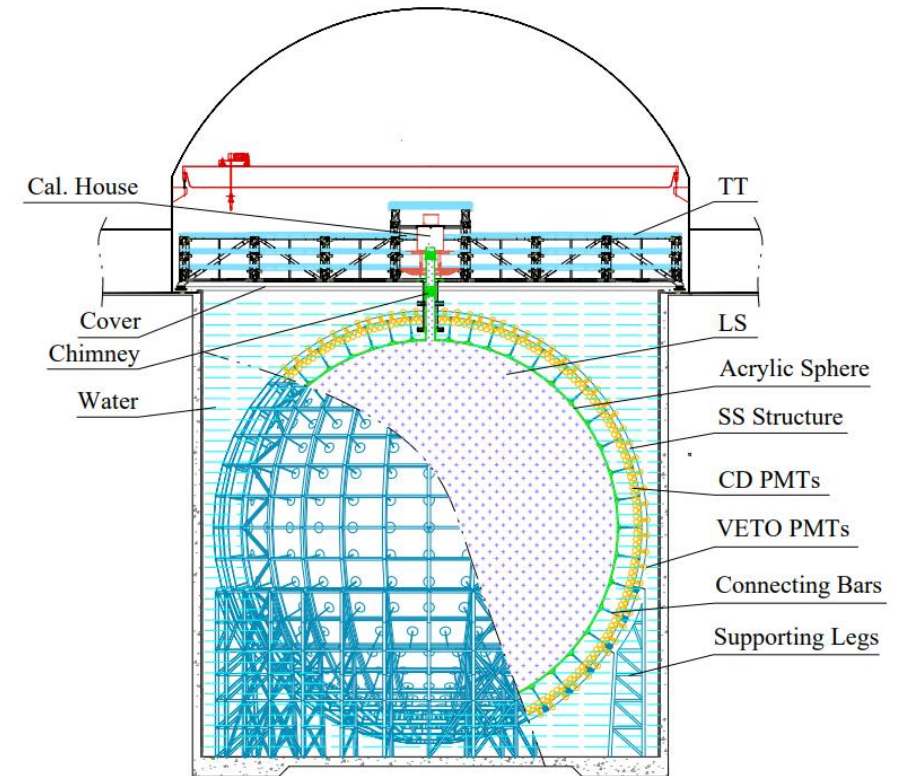
- **Acrylic sphere with 20 ktons liquid scintillator**
- 17612 large PMTs (20-inch)
- 25600 small PMTs (3-inch)
- 78% PMT coverage

LS Requirements:

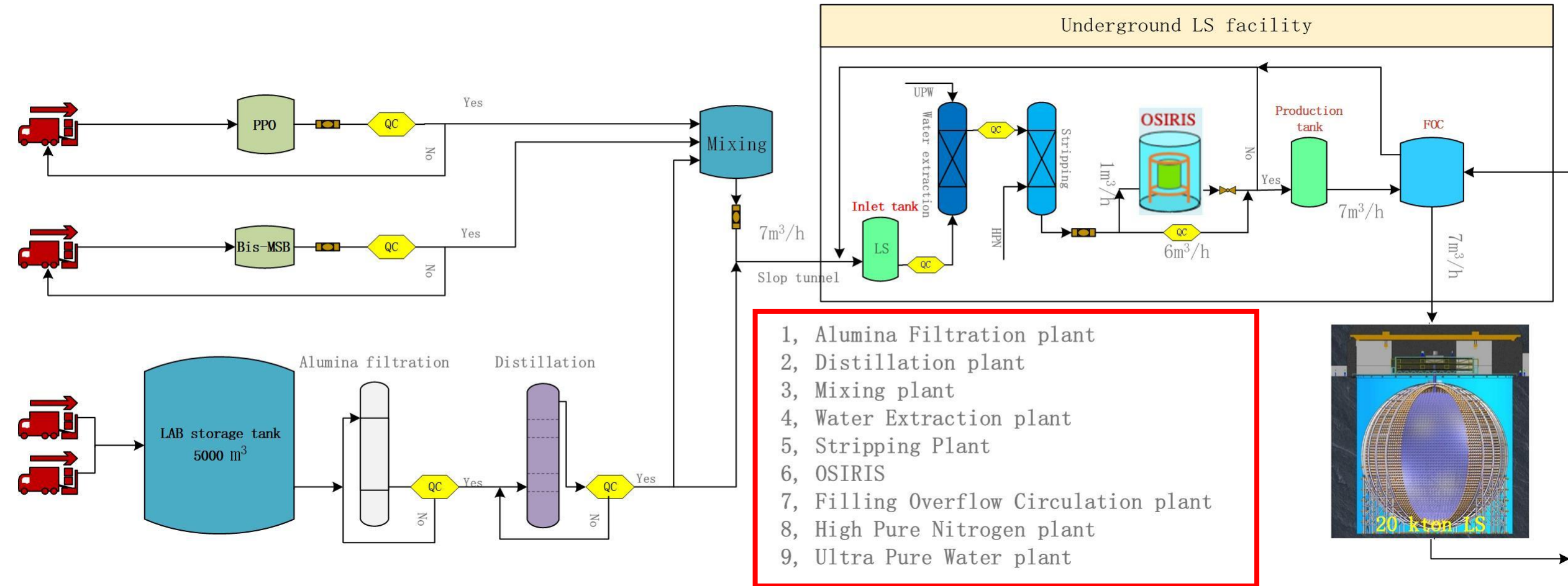
- High light yield: **$\sim 1200 \text{ p.e./MeV}$**
- Long attenuation length: **$>20\text{m}$**
- Low radio-impurity: **$^{238}\text{U}/^{232}\text{Th} < 10^{-17} \text{ g/g}$**

LS Recipe:

- **Linear alkyl benzene (LAB) + 2.5 g/L PPO + 3 mg/L bisMSB**



Flow chart of JUNO Liquid Scintillator systems

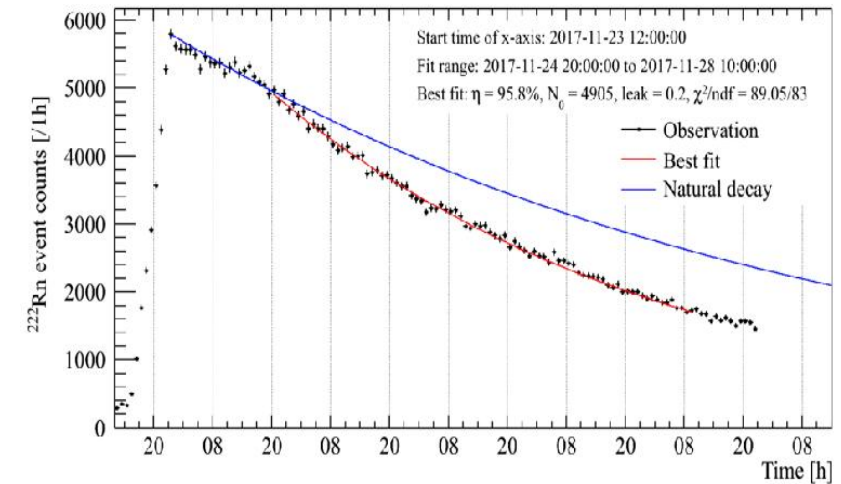


- The total flux rate is 7 m³/h, 6 months filling time from June 2024;
- All LS plants were installed and under commissioning;

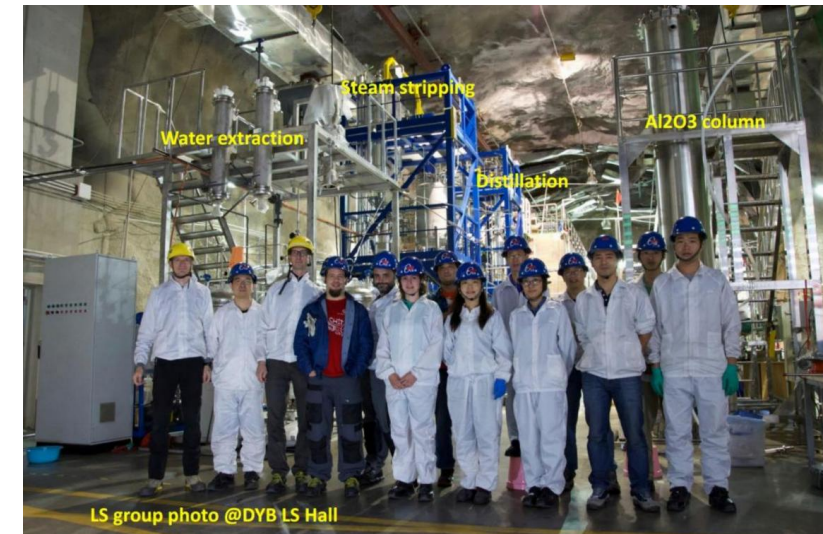
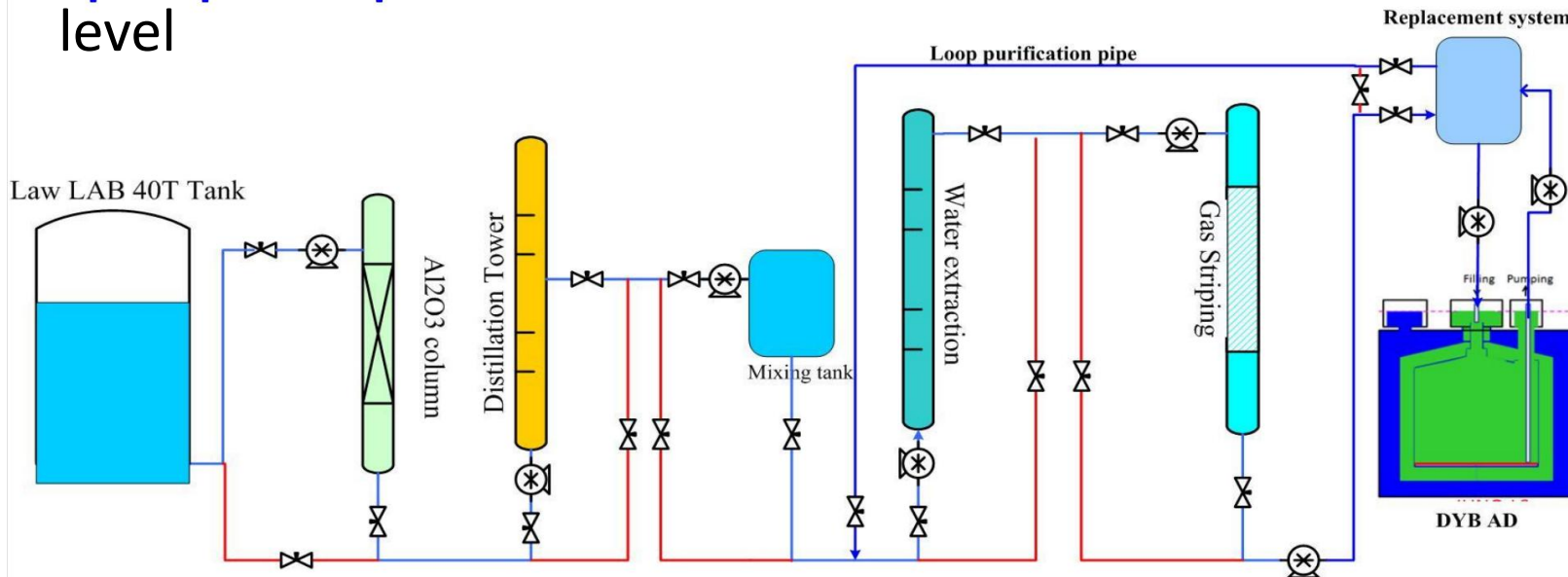
JUNO LS pilot plant experiment in DYB (2015~2017)



- DYB AD was used as the detector check the JUNO LS purification process.
- After experiment, **JUNO LS plant was decided.**
- System cleaning process was tested.
- The Rn purification efficiency for stripping factor between **94 – 98 %**.
- LS after Alumina filtration will keep the U/th at ppq level



Stripping efficiency of experiment



Requirements of LS Plants construction

– Material requirement for LS plant

- Material of tank or pipe: **SS304L or SS316L (Electro Polishing and low background).**
- Material of O ring and other parts: **Viton A or PTFE.**

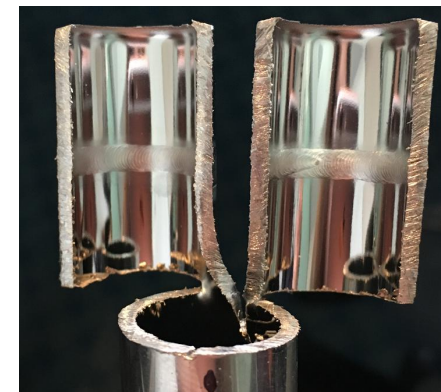
– Cleanness and processing technology requirements

- Residual dust on the surface after cleaning should be **$< 0.1 \text{ mg/m}^2$** , which will lead to 0.08g dust and 10^{-16} g/g U238/Th232 contamination in LS.
- Stainless steel inner surface roughness requirement **$Ra \leq 0.4 \mu\text{m}$** .
- Welding: **Orbital welding**
- The final precision cleaning particle cleanliness level in rinsing water needs to be reached **JUNO 50 level.**

JUNO 50 level for rinsing water.

Cleanliness level	Particle Size. μm	Count per liter
50	5	1660
50	15	250
50	25	73
50	50	10

Orbital welding sample



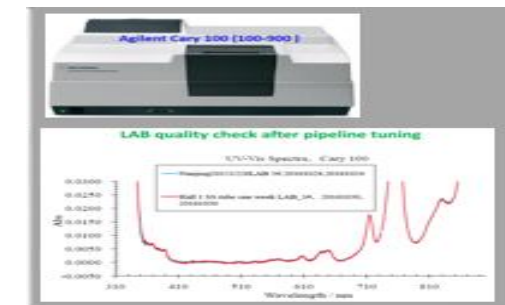
LS plant Stainless steel cleaning process

Step	Cleaning process	Material	QC method
1	Water rinsing and pressure test	HP water	Resistivity test
2	Degrease	Alkali solution (2~3 hours)	Ultraviolet light test
3	Water rinsing	HP water	Resistivity test
4	Pickling	HNO ₃ 5%, HF 0.5% (2~3 hours)	Surface roughness test, Visual inspection Endoscopic inspection
5	Water rinsing	HP water	Resistivity test
6	Passivation	33.0%--34% HNO ₃ (2~3 hours)	Surface roughness test White cloth inspection Blue point test
7	Water rinsing	HP water (until the different conductivity 4MΩ) (5~24 hours)	Resistivity test Particle counter test Absorption spectroscopy ICP-MS measure
8	Nitrogen Drying	Nitrogen replacement (3~5days)	

Cleanning Quality Check



1. Resistivity test for clean water
2. PH test
3. Visual inspection
4. White cloth inspection
5. Ultraviolet light
6. Endoscopic inspection
7. Blue point test
8. Surface roughness test $Ra \leq 0.4 \mu m$
9. Particle counter test in washed water Level 50
10. Absorption spectroscopy
11. ICP-MS measure the U/Th in washed water, residual particle content $U/Th < 0.1 ppt$



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Particle counter test

Absorption spectroscopy

LAB transportation & Storage

- **LAB will be high quality LAB with special process with quality check by company.**
- **200 new ISO tank** will be used to transport LAB from company to JUNO site.
- ISO tank was cleaned according JUNO 50 and sealed with ~ 1 bar N_2 .
- A 5000 m³ tank was constructed, SS304L was used with 0.4 μ m roughness, it was sealed with 15 mbar N_2 for air isolation. 200 tons LAB in tank for commissioning.



PPO status & Quality Check (35.4Tons/60Tons PPO)



- **PPO adopts vacuum packaging to ensure air isolation.**
- 72 kg bis-MSB has signed a contract with the company.

- **Determination of Th&U in PPO**

- Method detection limit:

- **0.033 ppt for ^{232}Th**

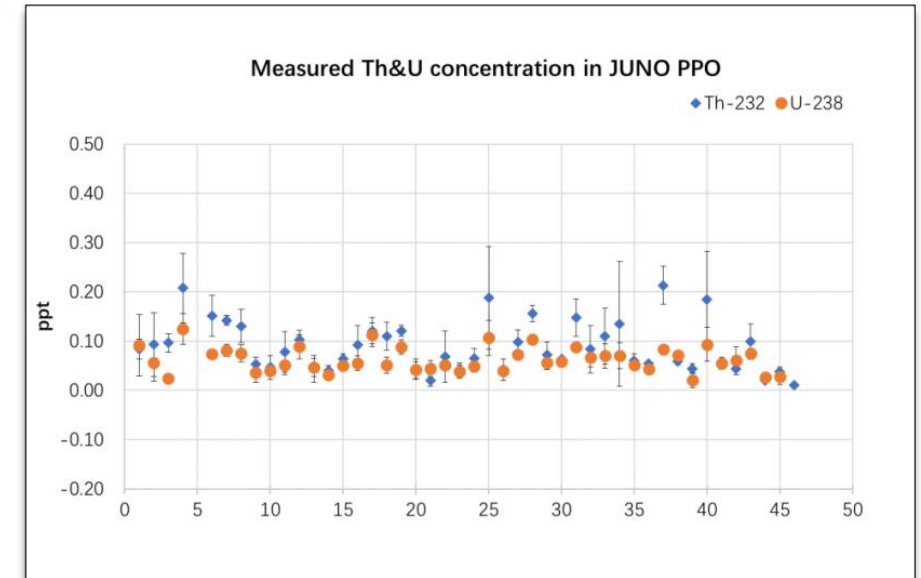
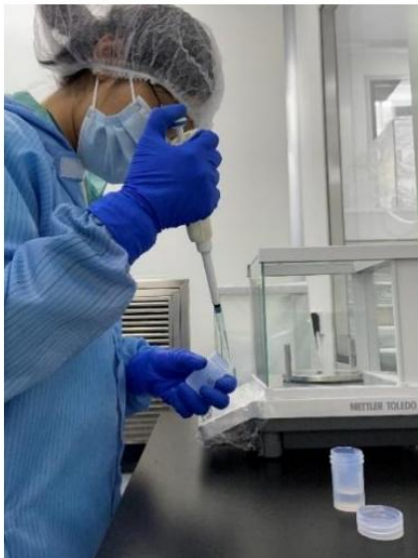
- **0.040 ppt for ^{238}U**

Measuring Th and U contaminants in PPO to 10^{-14} g/g level via acid extraction, M. Liu, Y. Ding et al., NIMA 1041 (2022) 167323*

- Mass weighted mean value for 35.4t PPO

Th=0.099 ppt

U=0.066ppt



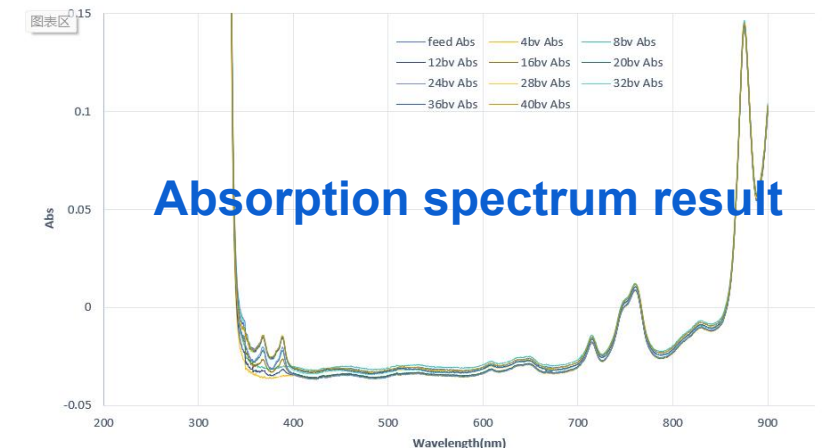
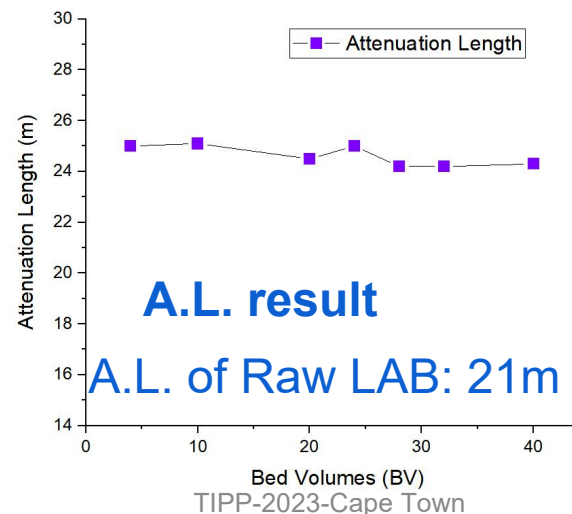
Status of Alumina Filtration Plant (AFP)

- Alumina Filtration Plant use the alumina powder to adsorb the light impurities in the LAB .
- Two commissioning was done, 40 m³ LAB has been purified.
- The attenuation length of AFP purified LAB is better than 24 meters.
- ²³⁸U and ²³²Th in purified LAB is fit design requirement, the result is about several ppq.

ICP-MS result of purified LAB

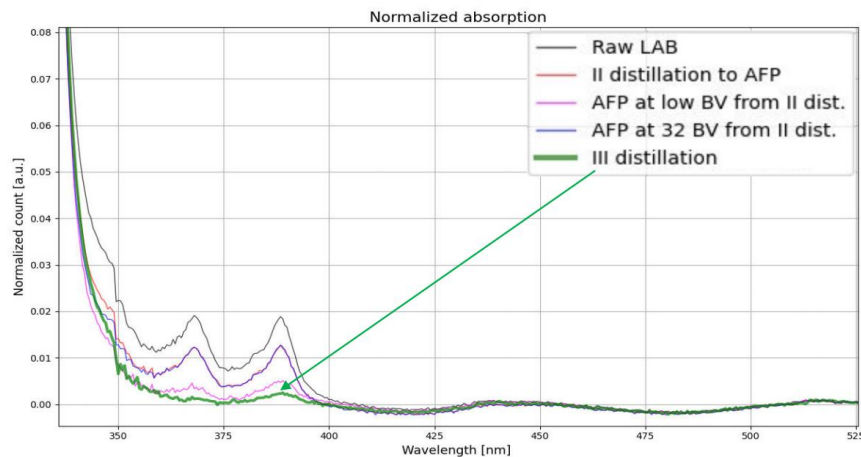
	²³⁸ U/(ppq)	²³² Th/(ppq)
Mass	42.216g	
Raw LAB	<3.2	<2.4
Mass	50.041g	
Al ₂ O ₃ LAB	<2.6	<2.0

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Status of distillation plant

- The distillation system is used to remove U, Th, Ra and Pb in liquid scintillator.
- From Borexino experiment result, this system can remove 99.9% radioactive metal impurity.
- **Distillation plant fully commissioned.**
- Absorption spectra of purified LAB meet expectation.
- A.L. measurement result of purified LAB is about 22m.
- **ICP-MS result of stripping LS is still on the way.**



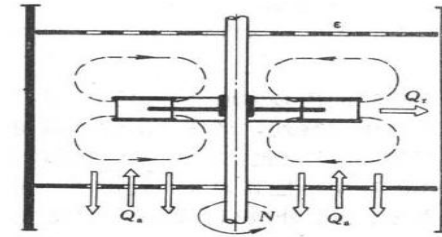
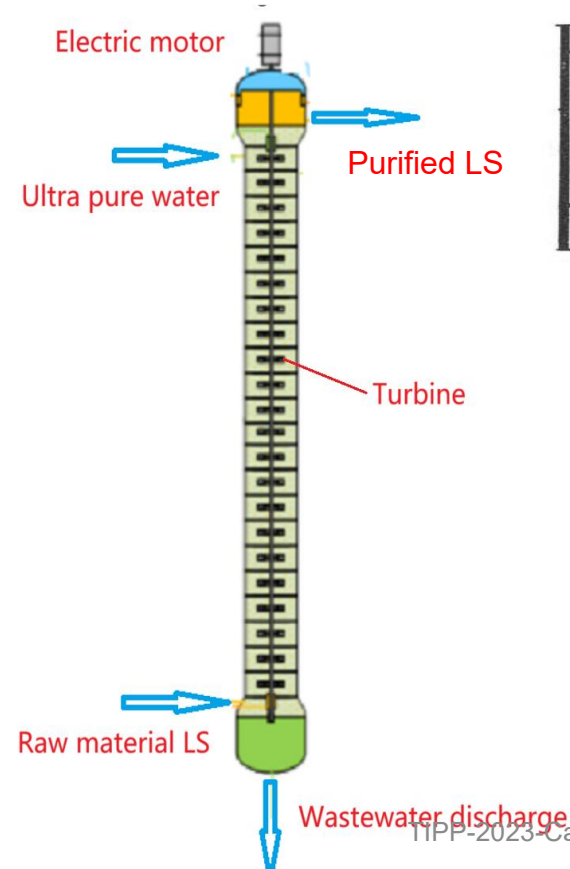
Turns raw materials into liquid scintillator and purify the master solution

- **Dissolving**
 - 60 tones PPO (2.5 g/L)
 - 70 kg bis-MSB (3 mg/L)
- **PPO purification**
 - Water/acid washing
 - Filter (Functional Group Filters)
- **All equipment and functions fully realized**
- **Completed First round of Joint Commissioning**
 - ✓ Production LS 28.6 m³, pumped 28.2 m³ underground.
 - ✓ Master solution dissolution with 206kg PPO in 2000L LAB
 - ✓ Acid extraction 1 time and water extraction 2 times in 40°C



Water Extraction plant

- Water extraction is use of high-purity water to clean the liquid scintillator and remove radioactive metal ions from LS.
- Target: Uranium and Thorium levels in LS from 10^{-16}g/g to 10^{-17}g/g



Indicators:

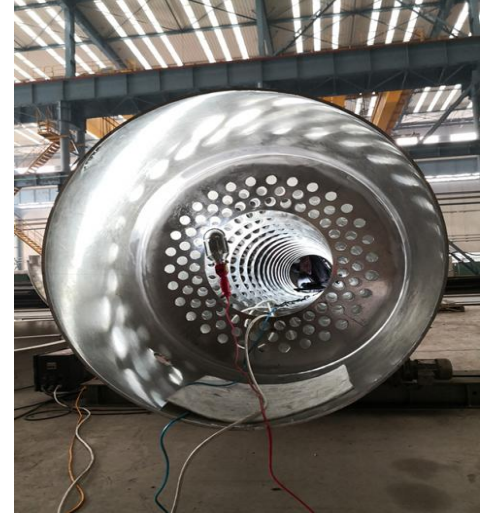
Height: 13 m

Diameter: 1 m

Turbine: 30 stages

LS flow rate: $7 \text{ m}^3/\text{h}$

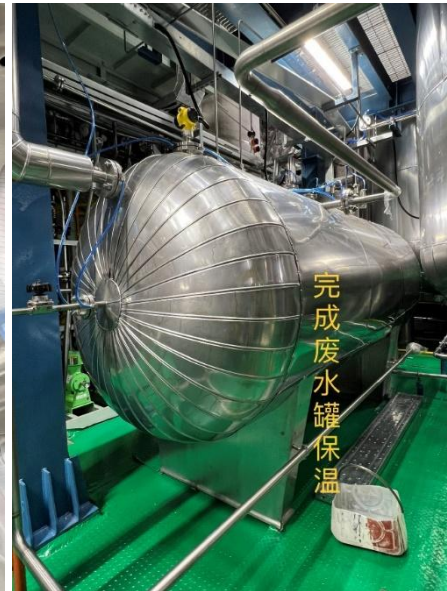
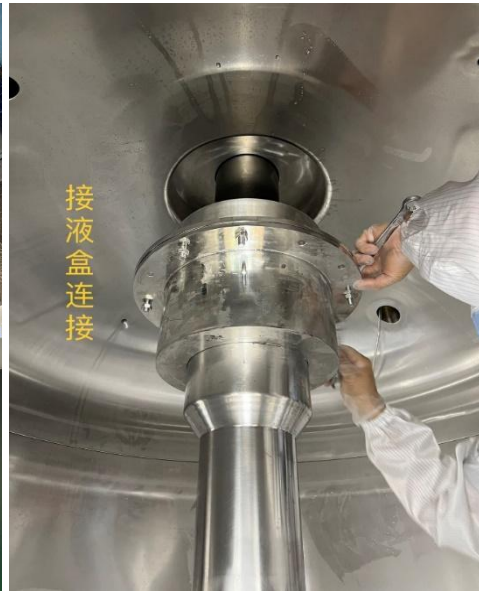
Water flow rate: $2.3 \text{ m}^3/\text{h}$



Status of Water Extraction plant



- The installation of the water extraction plant is completed on May 2023.
- The leakage rate is better than 10^{-7} mbar.L/s.
- 90% of the functional test of the water extraction plant has been completed.
- Next, LS commissioning.



Stripping System

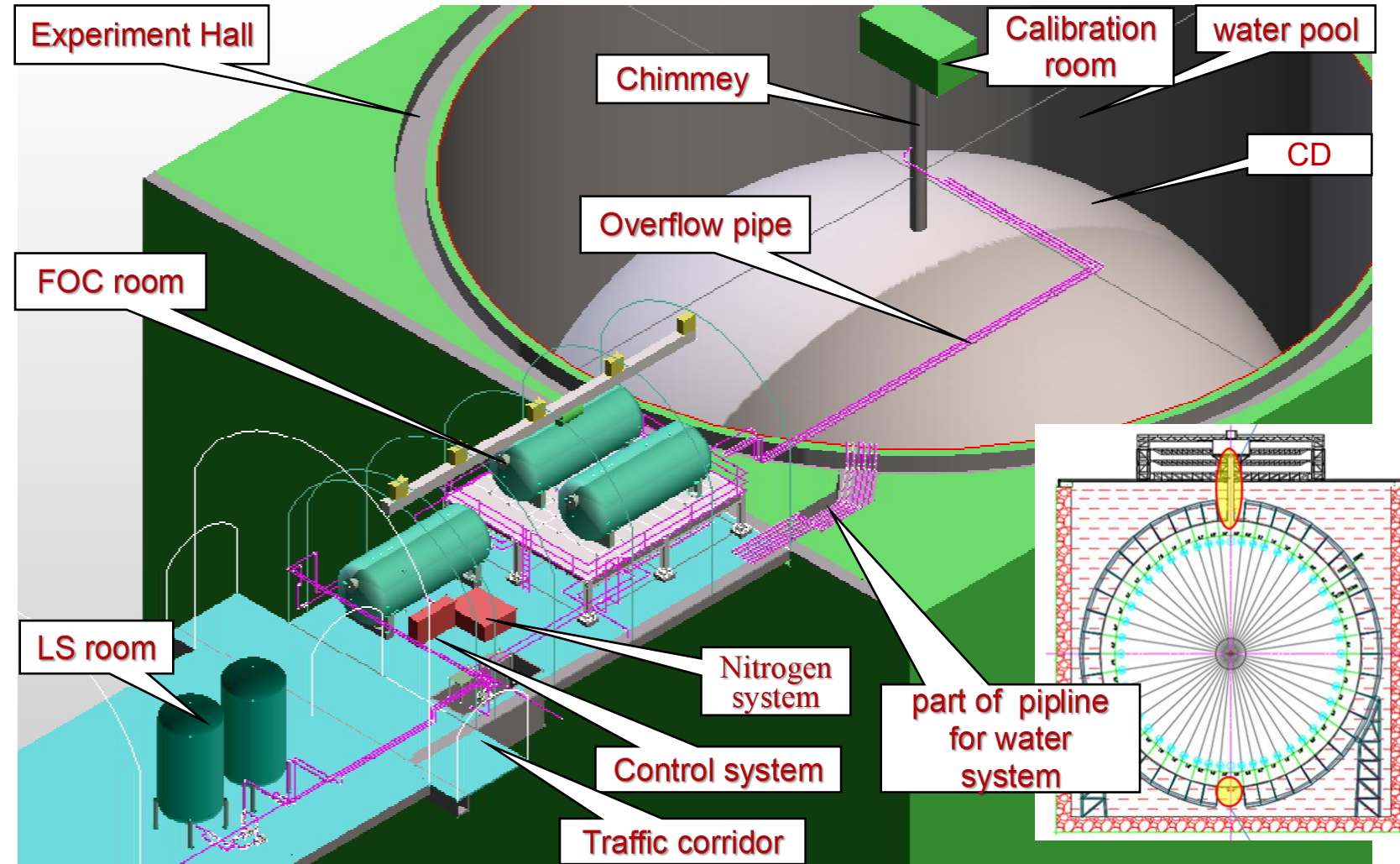


- The stripping system is for removing radon(^{222}Rn), Krypton (^{85}Kr) and Argon (^{39}Ar) from LS.
- Commissioning with hot oil device and cooling water device has been done.
- Stripping process tested both with HP-N₂ and with HP water steam.
- About 28,5 m³ LS was stripped during joint commissioning.
- **Optical quality of stripping LS is fit the requirement. A.L. is 20.7 meters.**
- **ICP-MS result of stripping LS is still on the way.**



Filling Overflow Circulation (FOC) plant

- **Function**
 - Water filling, LS/water exchange
 - Overflow and circulation
 - Cover gas for FOC and CD
- **Low background**
 - Compatible with LS
 - Tank&pipe: 316L SS, 0.7ppb U238, Ra<0.4um
- **Leak-tightness**
 - $<1 \times 10^{-6}$ mbar*L/s(single parts)

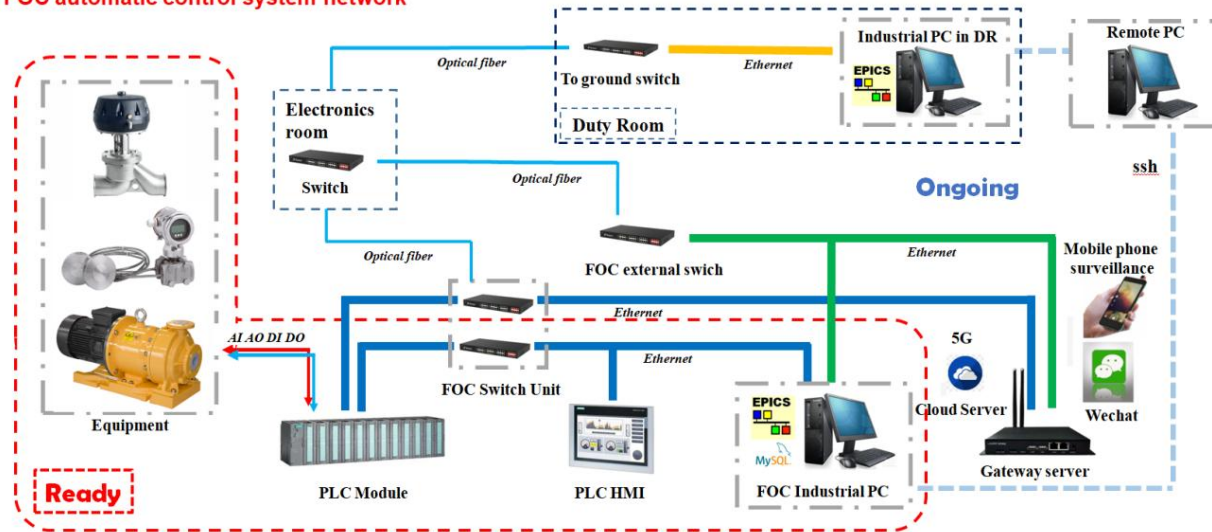


Status of FOC plant



- System installation almost finished in FOC room
 - Pre-installation on-site
 - Tanks&pipes cleaning
 - Installation
 - ...
- System testing with pure water finished
- Waiting for LS tuning

FOC automatic control system network



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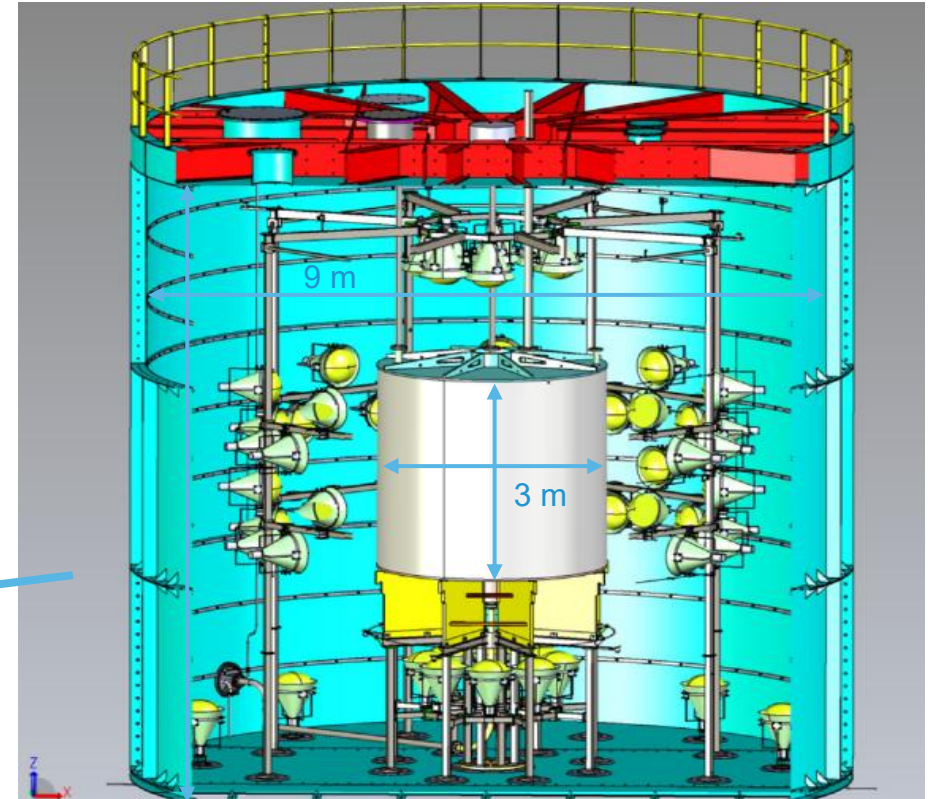
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Online Scintillator Internal Radioactivity Investigation System (OSIRIS)

A 20-t detector to monitor radiopurity of LS before and during filling to the central detector

- ✓ Few days: U/Th (Bi-Po) $\sim 1 \times 10^{-15}$ g/g (reactor baseline case)
- ✓ 2~3 weeks: U/Th (Bi-Po) $\sim 1 \times 10^{-17}$ g/g (solar ideal case)
- ✓ Other radiopurity can also be measured: ^{14}C , ^{210}Po and ^{85}Kr

Eur.Phys.J.C 81 (2021) 11, 973



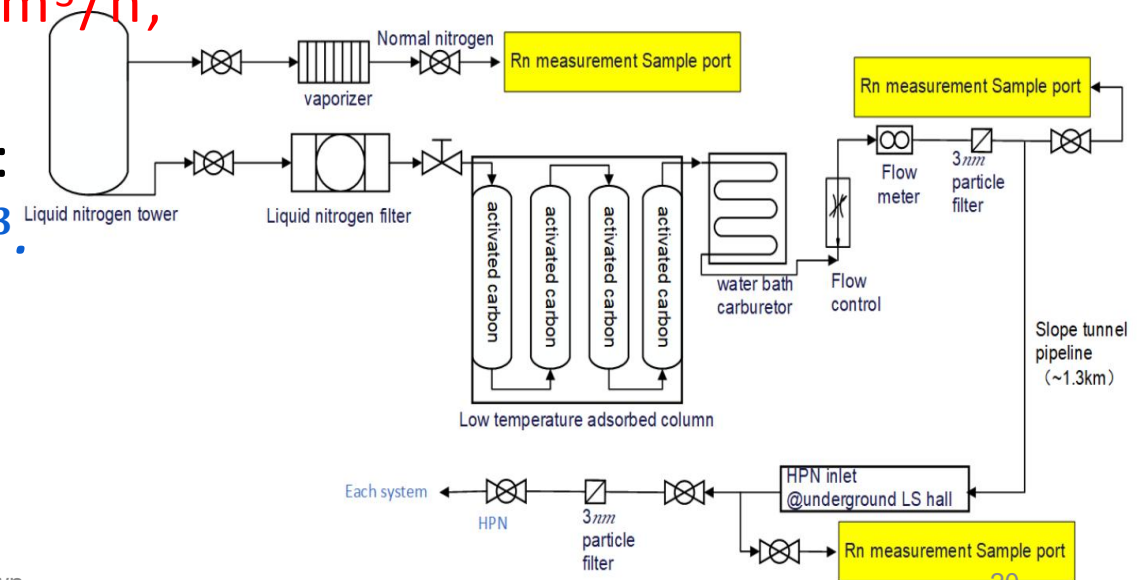
Expect to start LS filling in October.

- Installation of LS tank and 20 inches PMT is completed. Cleaning of tank is completed. 1st Dry Run of detector is completed.

High Pure Nitrogen Plant



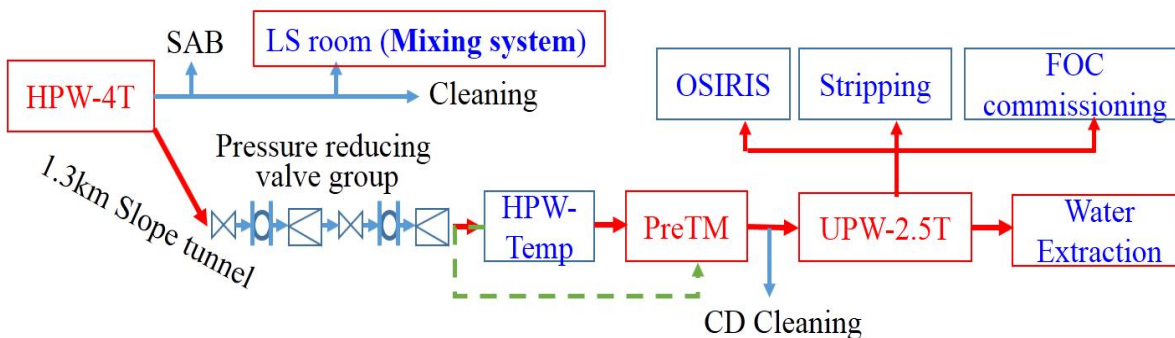
- Using as purge gas for Central Detector, Water Extraction, Stripping, OSIRIS, UPW and FOC;
- The HPN plant uses activated carbon to adsorb radon at low temperature to purify nitrogen;
- Used for stripping LS for removing Rn, Kr and Ar from LS;
- Normal flux rate: $50 \text{ Nm}^3/\text{h}$, maxium: $100 \text{ Nm}^3/\text{h}$, passed the test.
- The commissioning result (after 10 days running):
 - a. Radon concentration: $5.5 \pm 0.6 \text{ uBq/m}^3 < 10 \text{ uBq/m}^3$.
 - b. Krypton concentration: $18.5 \text{ ppt} < 50 \text{ ppt}$.
 - c. Argon concentration is under test.



Ultra Pure Water (UPW) for LS water extraction

- **Goal: ultra pure and low radioactivity water for Water Extraction: $U\&Th < 1e-16$ g/g; $Rn < 1mBq/m^3$;**
- UPW finished commissioning in May, 2023. Now it is running for Water Extraction and FOC commissioning.
- **Most of indexes (online measurement) are qualified now, Particles count 50% lower than design. Anions/metals, U&Th&Rn will be measured in this September.**

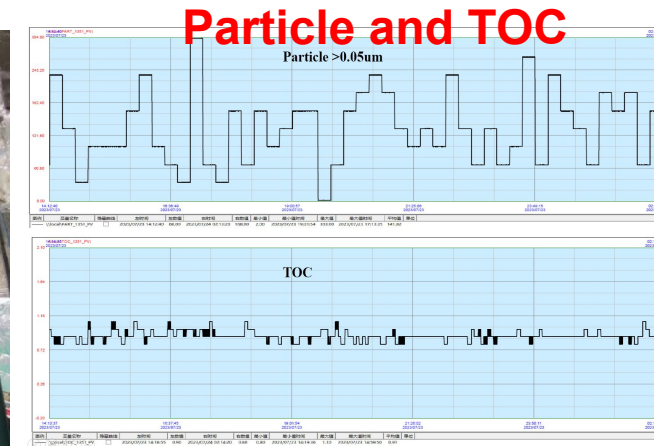
UPW quality					
	Item	Unit	Value	Measured	
1	Pressure/flow	MPa, t/h	0.3, 2.5	0.3, 3.2	Qualified
2	Temperature	°C	22	32	Accepted
3	Resistivity@25°C	MΩ.cm	≥18.2	18.2	Qualified
4	Particles >0.05um	pcs/L	≤500	<300	Qualified
5	TOC	ug/L	≤1.0	0.7~0.9	Qualified
6	DO	ug/L	≤1.0	12~15	Waiting
7	Anions/metals/SiO ₂	ug/L	Long list	TBD	TBD
8	Uranium	g/g	≤1e-16	TBD	TBD
9	Thorium	g/g	≤1e-16	TBD	
10	Radon	mBq/m ³	≤1	TBD	TBD



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Summary

- JUNO LS systems was constructed under strict material and cleaning requirements
- All JUNO LS plants have been installed in JUNO site.
- AFP, Distillation plant, Mixing plant, stripping plant, HPN plant and UPW plant have been joint commissioned.
- Water extration plant, OSIRIS and FOC will join the joint commissioning in this October.
- The test results of purified LAB/LS preliminary meet expectations.



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Thanks!

江門中微子實驗

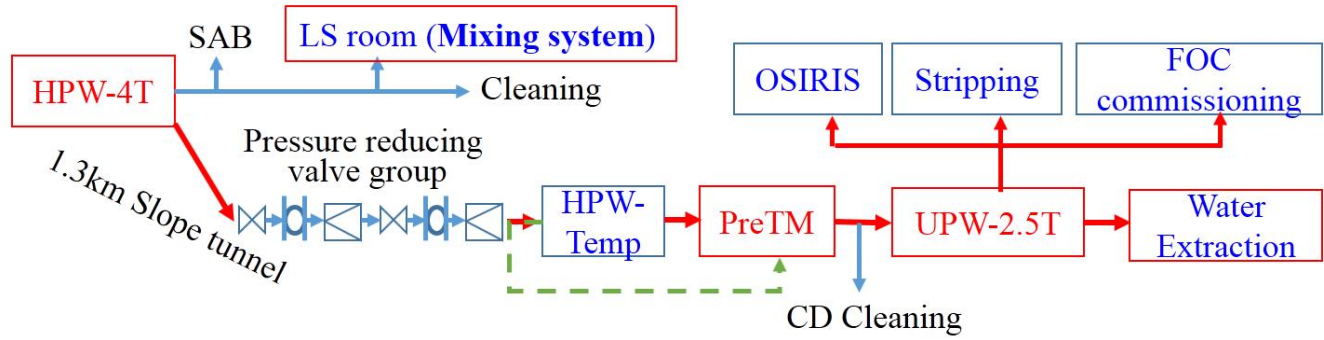
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Backup

Pure water systems for LS purification

1. System configuration

- High purity water 4t/h on ground (HPW-4t)
- Pre-treatment module of UPW (PreTM)
- Ultra pure water 2.5t/h underground (UPW-2.5t)

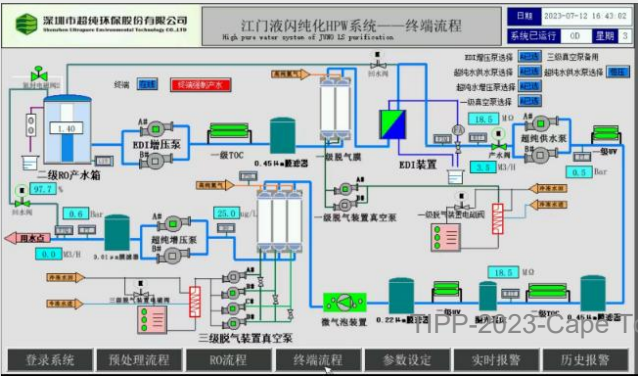


2. HPW-4t

- For equipment cleaning and LS mixing
- All indexes were reached, U, Th and Rn are better than background control requirement!
- Now HPW-4t is keeping running continuously in a good status, roles:

1) Equipment and pipes cleaning: all done! 2) Mixing system and UPW commissioning done! 3) UPW running.

Index	Design(EW-I)	Measured
Flow rate (t/h)	4	3.8
Pressure (MPa)	0.4	0.4
Resistivity MΩ.cm (25℃)	≥18 (≥17 for ≤5% time)	18.2
TOC(μg/L)	≤20	10.2
DO≤μg/L	50	4
Tsilica≤μg/L	2	0.2
Particle>0.5μm ≤p/L	4	TBD
Bacteria≤c/L	10	10
Anions/metals/ U(ppq,1e-15)	0.2~1.0	0.02~0.1
Th(ppq)	≤3	1.6
Rn(mBq/m^3)	≤3	0.68
	≤10	8



Distillation and Stripping plants: Starting Point



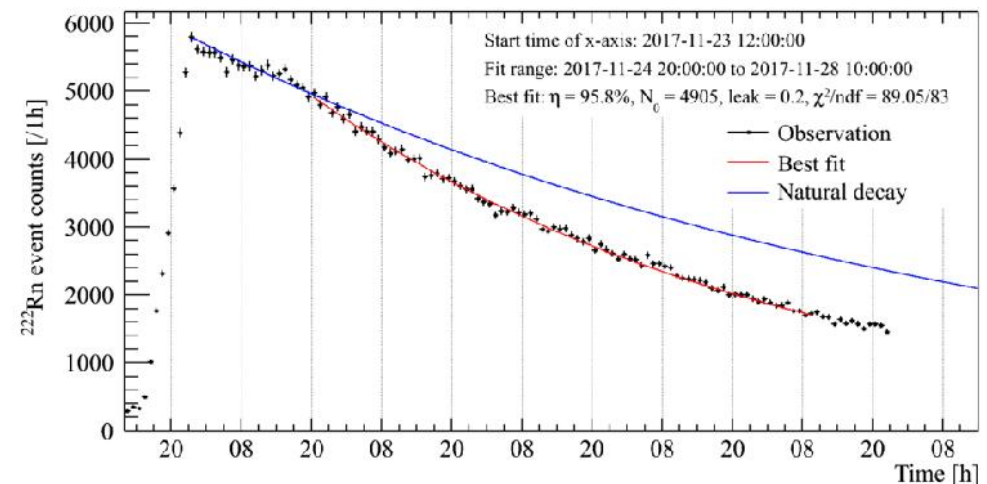
Since November 2017 we have started the design of the Distillation and Stripping plants for JUNO with the same company that realized the pilot plants:

Polaris s.r.l. - > **trustable, reliable and already trained company**

The final design is based on the best present knowledge and the experiences done so far at **Daya Bay**. The design adopt also most of the Borexino and SNO+ technical developments for their own purification plants.

Concerning the Stripping plant we have done a dedicated test at Daya Bay to prove the stripping efficiency. Results gave a Rn purification factor between **94 – 98 %**. Final column will be 50% higher so we expect even better results.

For Distillation we plan to have a dedicated test at Daya Bay and a feedback from SNO+ at the beginning of next year 2019

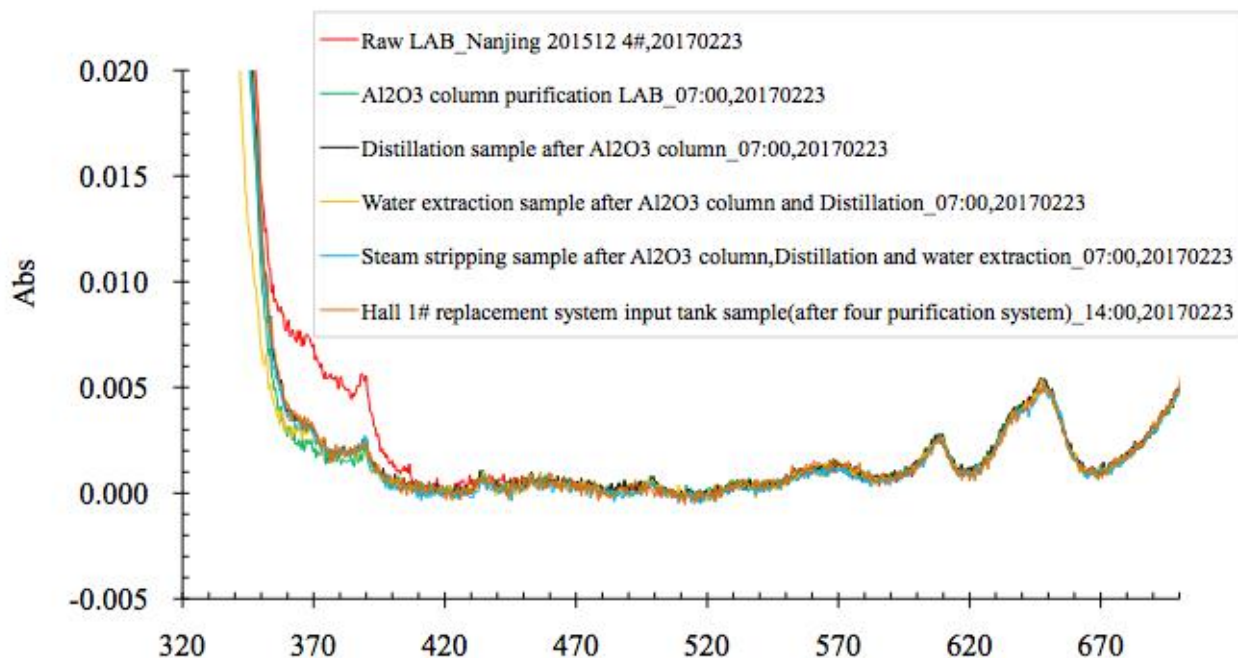


Distillation quality:



Absorption/A.L. measurements Radio-purity

Final Quality Check before Filling



Sample	Attenuation length (m)
Raw sample	16.08
LAB in 4# after distillation	25.31
LAB in 4# after stripping	24.35

Wavelength / nm

Radio-purity

For what concern radio-purity there is only a global indication of the level reached during the first filling: 2×10^{-15} g/g U

Some considerations:

- Daya Bay AD was not designed for 10^{-16} level
- Small contamination left in AD from LS + Gadolinium
- AD cover gas showed a significant Rn leakage
- Water plant was not at the required level during the first filling but improved later

We expect that the real purification capability of the distillation plant itself should be at least in the range of 10^{-16} as required by the Juno experiment. A dedicated test would give a final prove.

OSIRIS



Top clean
Room

Water Tank

Steel frame

Acrylic vessel
~20 tons of
PS

Optical
separation

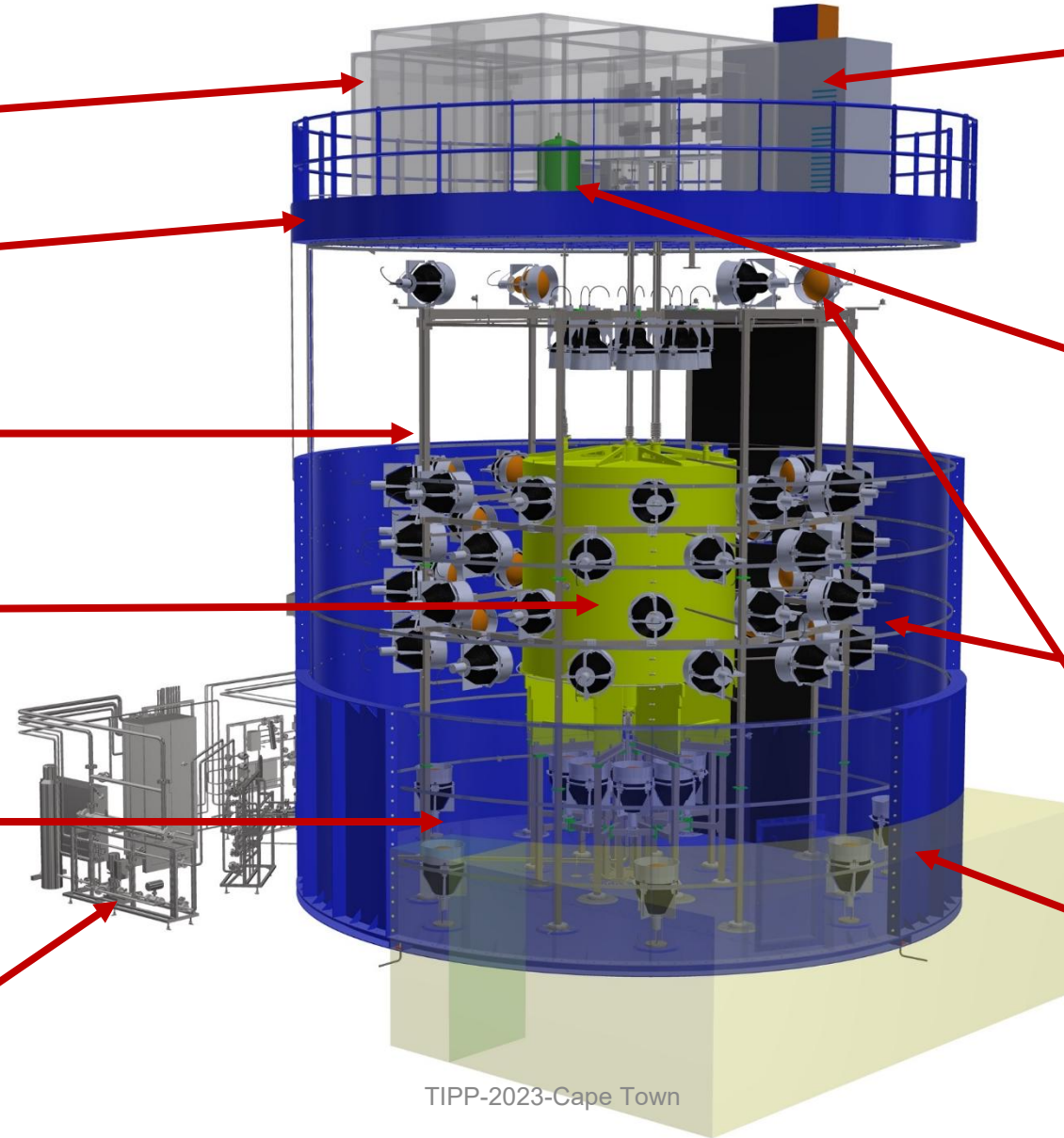
Liquid handling
system

Electronics
cabinet
DAQ

Automatic
calibration
unit

Inner PMT
array (64)

Veto PMT
array (12)



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Detector Installed

- 76 20" NNVT PMTs installed with magnetic shielding and reflectors
 - 12 top LPMTs
 - 8 for LS
 - 4 for VETO
 - 48 side LPMTs for LS
 - 16 bottom LPMTs
 - 8 for LS
 - 8 for VETO
- 2 inside cameras
- 49 temperature sensor (in detector)
- 24 Laser capsule
- Liquid level sensors
- 26+1 GCUs + 2 LVPs + 1 BEC (+1 WR switch)

