Status of the Liquid Scintillator for JUNO

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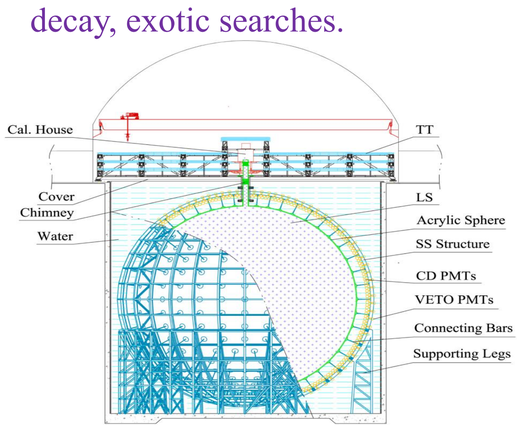
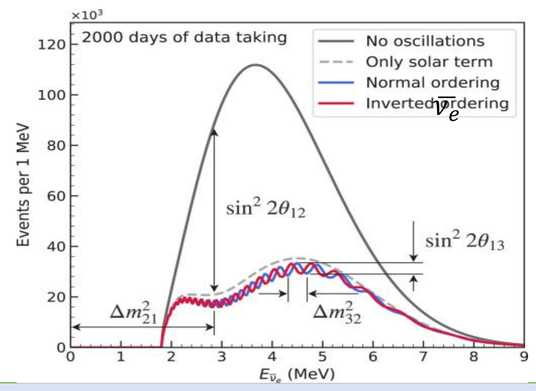
1 The Juno Experiment

- The Jiangmen Underground Neutrino Observatory (JUNO) is a 20 kt liquid scintillator (LS) detector for studies of various neutrino physics topics. The level of radioactivity background is an essential factor for the sensitivities.
- Determine mass ordering by $3\%/\sqrt{E}$ with 3σ in 6 yrs data taking. Rich physics programs in solar, supernova, atmospheric, geo-neutrinos, proton decay, exotic searches.



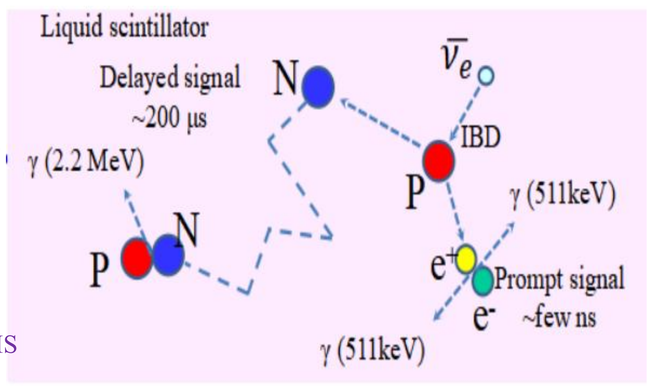


2 Liquid Scintillator for Juno

Features:

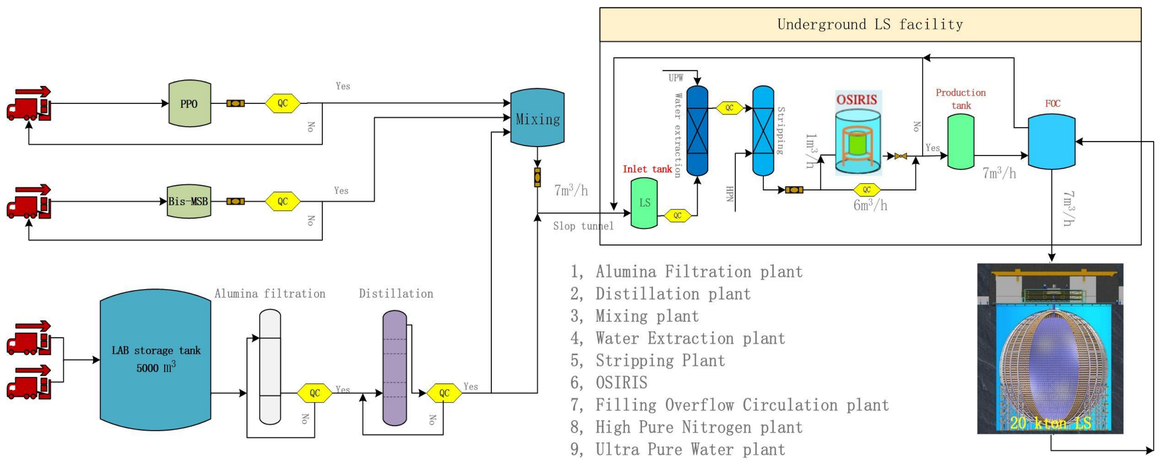
- 20 kton, long term stability;
- LS attenuation length (A.L) >20 m @ 430nm;
- Light yield: 1665 p.e./MeV;
- ^{238}U, $^{232}Th < 1\times10^{-15}$ g/g (Min) , < 1×10^{-17} g/g (Max)
- Recipe: LAB + 2.5 g/L PPO + 3 mg/L bis-MSB

QA/QC: ICP-MS(1e-15 g/g for LS; 1e-16 g/g for UPW), NAA, customized devices(A.L, Rn, Ra), Spectral analyzer, particle counting, OSIRIS



Purification system

- 5 purification sub-systems + 1 QC system+3 auxiliary system
- 7 m3/h for filling 6 month
- All LS plants were installed and under commisstioning



3 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.

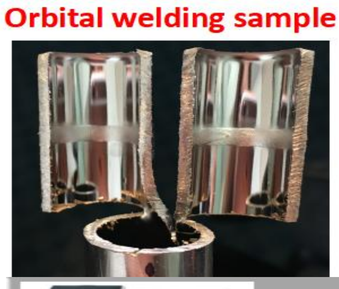
Cleanness and processing technology requirements

- Residual dust on the surface after cleaning should be **< 0.1 mg/m²**, which will lead to 0.08g dust and 10^{-16} g/g U238/Th232 contamination in LS.
- Stainless steel inner surface roughness requirement **Ra≤0.4μm .**
- 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



Cleanning Quality Check

- Resistivity test for clean water
- PH test
- Visual inspection
- White cloth inspection
- Ultraviolet light
- Endoscopic inspection
- Blue point test
- Surface roughness test Ra≤0.4μm
- Particle counter test in washed water Level 50
- Absorption spectroscopy
- ICP-MS measure the U/Th in washed water, residual particle content U/Th<0.1ppt

4 Alumina Filtration Plant

Goal: Removes optical impurities and increases the attenuation length of LAB

Principle: Al_2O_3 powder retains optical contaminants and enhances the LAB transparency when LAB pumped through it

Status:

- Fully commissioned
- Successful removal of optical contaminants in the range 360-400 nm, up to 20 BV.
- A.L.: raw LAB from ~21 m to >23.5 m after AFP
- No extra ^{238}U, ^{232}Th contamination introduced

U: <0.31ppq, Th: 0.9±0.1ppq

AFP parameters	
N° columns	8 (7+1)
Height	2.8 m
Diameter	0.6 m
Bed volume (BV)	0.5 m³
Flow rate / col.	1 m³/h (2 BV/h)
Filters	220 & 50 nm

5 Distillation Plant

Goal: Removes heavy metals(^{238}U, ^{232}Th, ^{40}K) from LAB and further improves the optical properties

Principle: Fractional distillation of LAB in partial vacuum, inside a column with 6 sieve trays and 30% internal reflux; only the purest vapours are extracted from the top. High-boiling contaminants accumulate in the un-evaporated liquid phase to be discharged.

Status:

- Fully commissioned
- absorption spectra of purified LAB meet expection.
- A.L. measurement result of purifed LAB is about 22m.

U: <0.28ppq, Th: <0.22ppq

Distillation column parameters	
N° trays	6
Height	7 m
Temperature	210-220 °C
Pressure	5 mbar
Internal reflux	~30%; max 50%
Bottom discharge	max 100 L/h

6 Mixing Plant

Goal: Removes 238U and 232Th from PPO and bis-MSB and dilute and dissolve into LAB to produce LS.

Principle: PPO and bis-MSB are added in high concentrations (105 g/L and 126 mg/L) to produce the Master Solution, then washed with HNO3 and rinsed twice with water. Finally, diluted with LAB to obtain the LS

Recipe:(2.5 g/L and 3 mg/L).

1 MS batch/day (420 kg PPO + 504 g bis-MSB + 4 m³ L

Status:

- Fully commissioned
- ^{238}U, ^{232}Th reduced by both acid washing (1-2 orders) a filtering (1 order).

U: <0.30ppq, Th:< 0.24ppq

Mixing plant parameters	
Master Solutes	105 g/L PPO 126 mg/L bis-MSB
Dissolving T	40°C
Acid washing	40°C with 5% HNO_3
N° acid washing	1 time1:2 (2 m³ acid)
N° water washing	2 times, 1:1

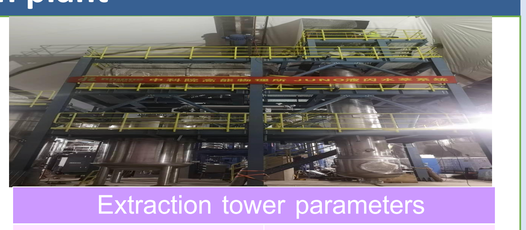
7 Water Extraction plant

Goal: Removes polar contaminants and metal ions with ^{238}U, ^{232}Th and ^{40}K from LS

Principle: Use of high-purity water to clean the liquid scintillator and remove radioactive metal ions from LS.

Status:

- Fully commissioned
- Water content <200 ppm after filters
- A.L. and absorption spectra OK
- Extraction eff is 50%~70% @ ~1ppq level
- **U: <0.30ppq, Th:< 0.24ppq**



Extraction tower parameters	
Water-LS ratio	1:3
Height	13 m
N° turbines	30
Temperature	Up to 70°C
Rotation speed	25-60 r/min

8 Gas Stripping Plant

Goal: Removes gaseous impurities: 222Rn, 85Kr, 39Ar and O2 (oxidation, photon quenching)

Principle: Gaseous impurities in the ĮS are transferred to the stripping gas (high purity N2) by desorption mechanisms.

Status:

- Fully commissioned
- Good H_2O removal efficiency: 154 ppm 20 ppm Excellent particle counting (no particles ≥ 0.3 μm)

U: <0.30ppq, Th:< 0.24ppq

Stripping column parameters	
Packing	Pall Rings, 13mm
Height	9 m
Diameter	500 mm
Temperature	70°C
Pressure	250 mbar
N_2 flow rate	15 Nm³/h

9 OSIRIS system

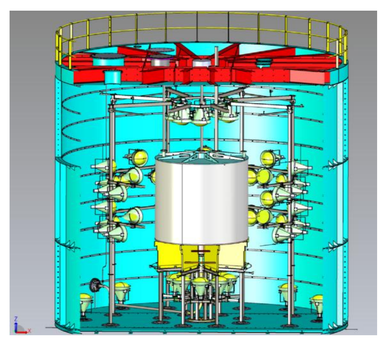
Goal: A 20-t detector to monitor radiopurity of LS before and during filling to the central detector

Principle:

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

Status:

- Fully commissioned



10 HPN

Principle: The HPN plant uses activated carbon to adsorb radon at low temperature to purify nitrogen

Status:

The commissionning result (after 10 days running):

a. Radon concentration: $5.5\pm 0.6 uBq/m^3$ $<10\ uBq/m^3$.
b. Krypton concentration: 18.5 ppt <50 ppt.
c. Argon concentration : 18 ppt <50 ppt

11 UPW

Goal: Ultra pure and low radioactivity water for Water Extraction: U&Th < 1e-16 g/g; Rn < 1mBq/m^3;

UPW flow rate	2.5 m³/h
Particle	<200 @>0.05um
Radon level	<1 mBq/m^3
Radium level	<10 μBq/m³
U & Th	<2×10⁻¹⁶ g/g