Purification strategy of the JUNO liquid scintillator

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REFERENCES
[1] JUNO, *PPNP*, doi: 10.1016/j.ppnp.2021.103927
[2] JUNO, NIM A, 988 (2021) 164823
[3] Zhu *et al.*, NIM A, 1048 (2023) 167890
[4] Landini *et al.*, arXiv:2406.01381
[5] Ye *et al.*, NIM A, 1027 (2022) 166251

THE JUNO EXPERIMENT

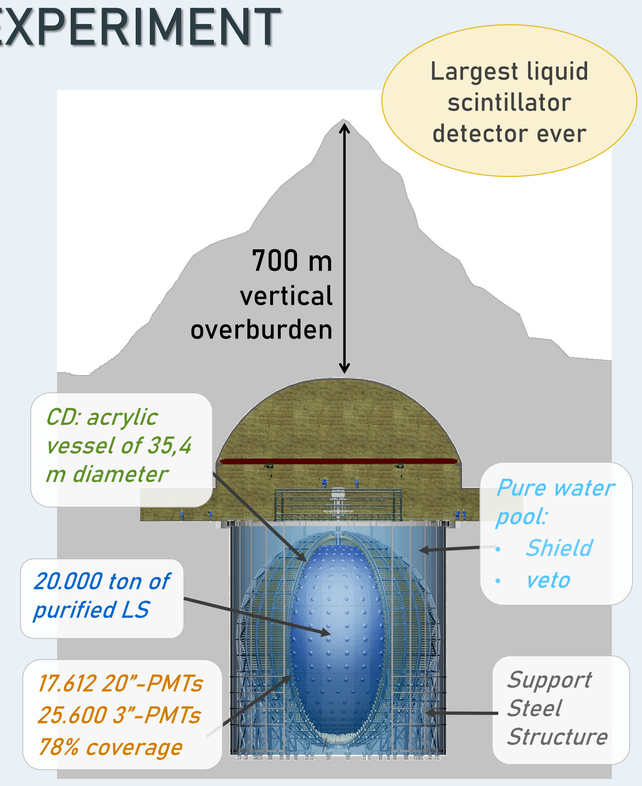
JUNO (Jiangmen Underground Neutrino Observatory) is a medium baseline reactor neutrino experiment [1], under construction near Kaiping (China).

Scientific goals:

- Neutrino mass ordering at 3σ in 6 yrs data taking (reactor $\overline{\nu}$)
- Oscillation parameters at sub-percent level
- Extensive neutrino physics program (solar ν, geo-ν, atmospheric ν, supernovae burst, DSNB)

Main features:

- huge central detector (35,4 m Ø) filled with **20 kt liquid scintillator (LS)**
- Unprecedented **energy resolution of 3% at 1 MeV**
- Extremely low background, high sensitivity



SCINTILLATOR REQUIREMENTS

The LS recipe (**LAB + 2,5 g/L PPO + 3 mg/L bis-MSB**) is optimized [2] to have a high light yield at 430 nm. Given the huge mass and dimensions, stringent optical and radiopurity requirements must be satisfied to achieve the target energy resolution (3% at 1 MeV).

Optical requirements:

- Attenuation length (A.L.) > 20 m @ 430 nm
- Light yield: 1.500 p.e./MeV
- Long term stability (ageing)

Radiopurity requirements:

- Minimum (reactor $\overline{\nu}$): ^{238}U, ^{232}Th < 10^{-15} g/g
- Target (solar ν): ^{238}U, ^{232}Th < 10^{-17} g/g

QA/QC methods:

- ICP-MS
- NAA
- Particle counting
- Attenuation length
- Absorption & emission spectra

Removal of optical and radioactive contaminants via LS purification using 5 different techniques (1_filtration through alumina, 2_distillation, 3_acid washing and mixing, 4_water extraction, 5_gas stripping).

5 large-scale purification plants (flow rate: 7 m^3/h) have been designed and installed at JUNO site, after a test campaign with pilot plants at Daya Bay.

1 ALUMINA FILTRATION PLANT

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

Working principle: the LAB is pumped through a set of 8 columns containing Al_2O_3 powder, which retains optical contaminants and enhances the LAB transparency [3]

AFP parameters	
N° columns	8 (7+1)
Height	2,8 m
Diameter	0,6 m
Bed volume (BV)	0,5 m^3
Flow rate per col.	1 m^3/h (2 BV/h)
Filters	220 nm/50 nm

Status and results:

The plant is installed and fully commissioned.

- successful removal of optical contaminants in the range 360-400 nm, up to 20 BV.
- A.L.: raw LAB ~21 m → after AFP > 23,5 m
- ^{238}U<0,31 ppq; ^{232}Th=0,9±0,1 ppq (preliminary results)

2 DISTILLATION PLANT

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

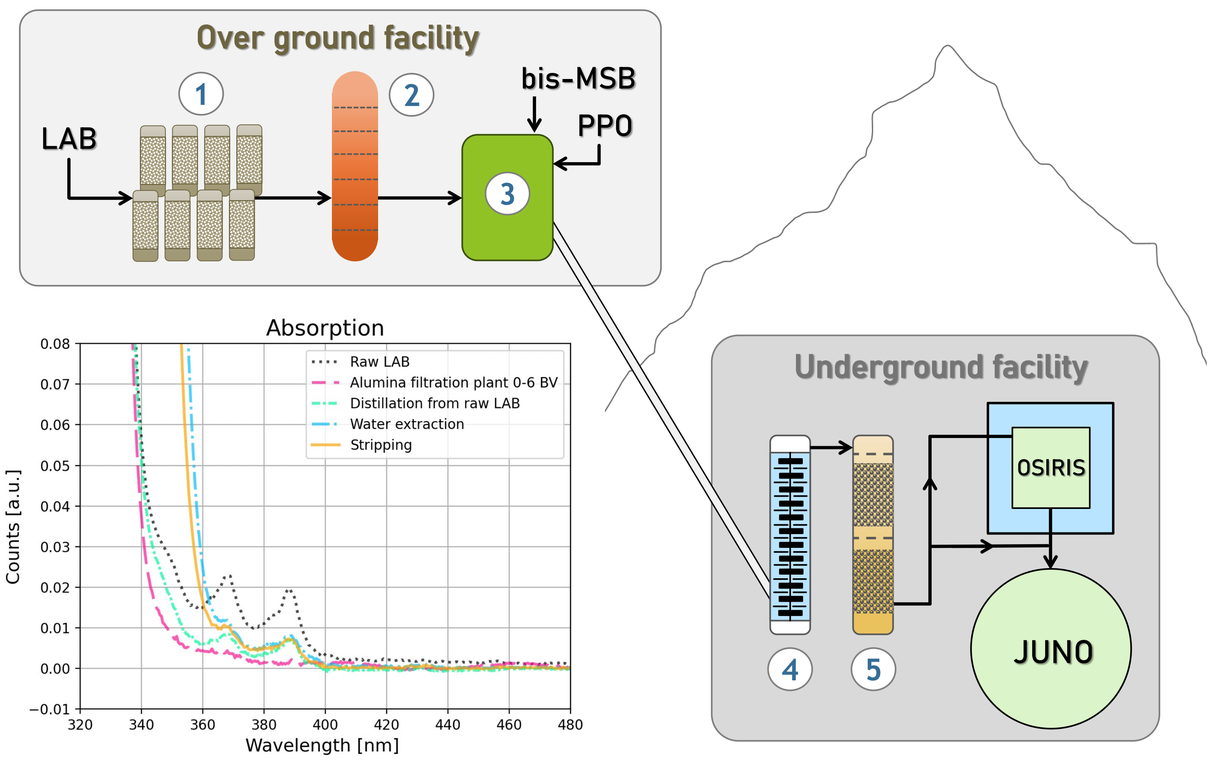
Working principle: fractional distillation of LAB in partial vacuum, inside a column with 6 sieve trays and 30% internal reflux [4]; only the purest vapours are extracted from the top. High-boiling contaminants accumulate in the un-evaporated liquid phase.

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

Status and results:

The plant is installed and fully commissioned.

- ^{238}U<0,28 ppq; ^{232}Th<0,22 ppq (preliminary results)
- Absorption peaks in 360-400 nm range further reduced



3 MIXING PLANT

Goal: ^{238}U, ^{232}Th removal from PPO and bis-MSB and dilution to produce the JUNO LS mixture

Working principle: PPO and bis-MSB are added in high concentrations (105 g/L and 126 mg/L) to produce the Master Solution, which is washed with HNO_3 and rinsed twice with water. Finally, it is diluted with LAB to obtain the JUNO LS recipe (2,5 g/L and 3 mg/L).

1 MS batch/day (420 kg PPO + 504 g bis-MSB + 4 m^3 LAB)

Mixing plant parameters	
Master Solution	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 time 1:2 (2 m^3 acid)
N° water washing	2 times, 1:1

Status and results:

Plant ready. Already produced 2 batches of LS.

- Dilution process tested
- ^{238}U, ^{232}Th reduced by both acid washing (1-2 orders) and filtering (1 order).
  Preliminary results: ^{238}U < 0,30 ppq; ^{232}Th < 0,24 ppq

5 GAS STRIPPING PLANT

Goal: removes gaseous impurities dissolved into the LS, mainly ^{222}Rn, ^{85}Kr, ^{39}Ar and O_2 (oxidation, photon quenching)

Working principle: gaseous impurities dissolved into the LS are transferred to the stripping gas (high purity N_2) by desorption mechanisms. The LS and gas are contacted in counter-current flow mode inside a stripping column with unstructured packing [4].

Stripping column parameters	
Packing	Pall Rings, 13mm
Height	9 m
Diameter	500 mm
Temperature	70°C
Pressure	250 mbar
N_2 flow rate	15 Nm^3/h

Status and results:

Plant fully commissioned, parameters optimized.

- Good H_2O removal efficiency: 154 ppm → 20 ppm
- Excellent particle counting (no particles ≥ 0,3 µm)
- ^{238}U < 0,30 ppq; ^{232}Th < 0,24 ppq (preliminary results)

4 WATER EXTRACTION PLANT

Goal: removes polar contaminants and metal ions that may contain ^{238}U, ^{232}Th and ^{40}K from LS

Working principle: LS and high-purity water are mixed and stirred together inside an extraction tower [5]. The LS is spread in 2-3 mm droplets (dispersed phase) and the removed polar contaminants are transferred to water (continuous phase).

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

Status and results:

The plant is installed underground.

- Internal commissioning still ongoing to optimize the operating parameters (T, stirring speed,...)
- Water content ~100-200 ppm after filters
- ^{238}U < 0,30 ppq; ^{232}Th < 0,24 ppq (preliminary results)
- No worsening of A.L. and absorption spectra