High Purity Nitrogen plant of JUNO

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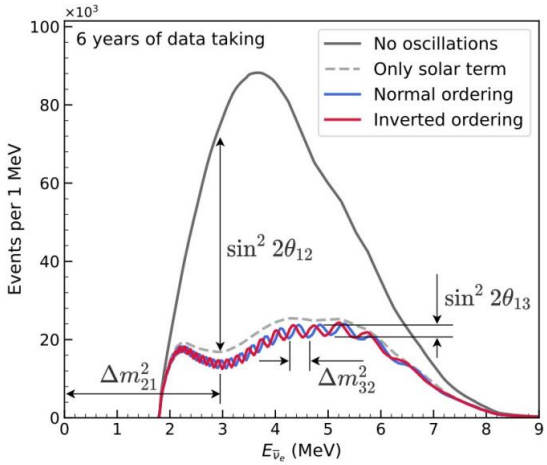
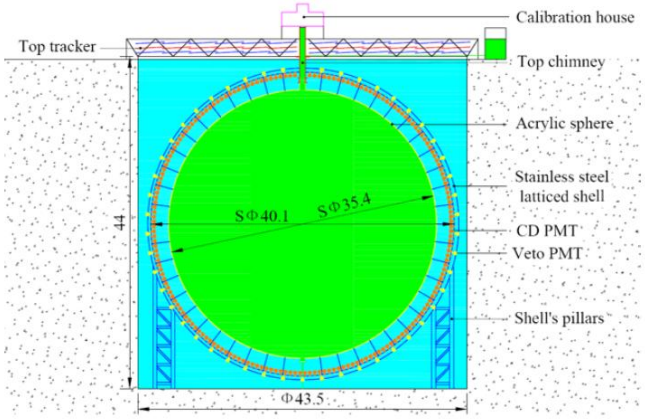
Outline

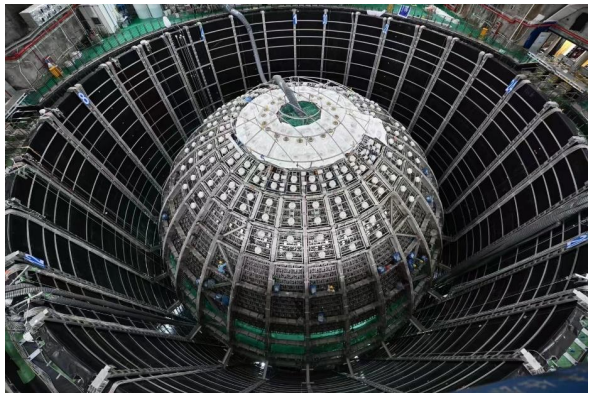
1. Overview of JUNO
2. High Pure Nitrogen plant
3. Rn-222, Kr-85 and Ar-39 measurement
4. Summary

Overview of JUNO

- JUNO's main physics goal is determining neutrino mass ordering.
- The CD of JUNO is a Liquid Scintillator Antineutrino Detector in underground ~650 m deep laboratory.
- 20 kton low-radioactivity background and high transparency liquid scintillator will be used.

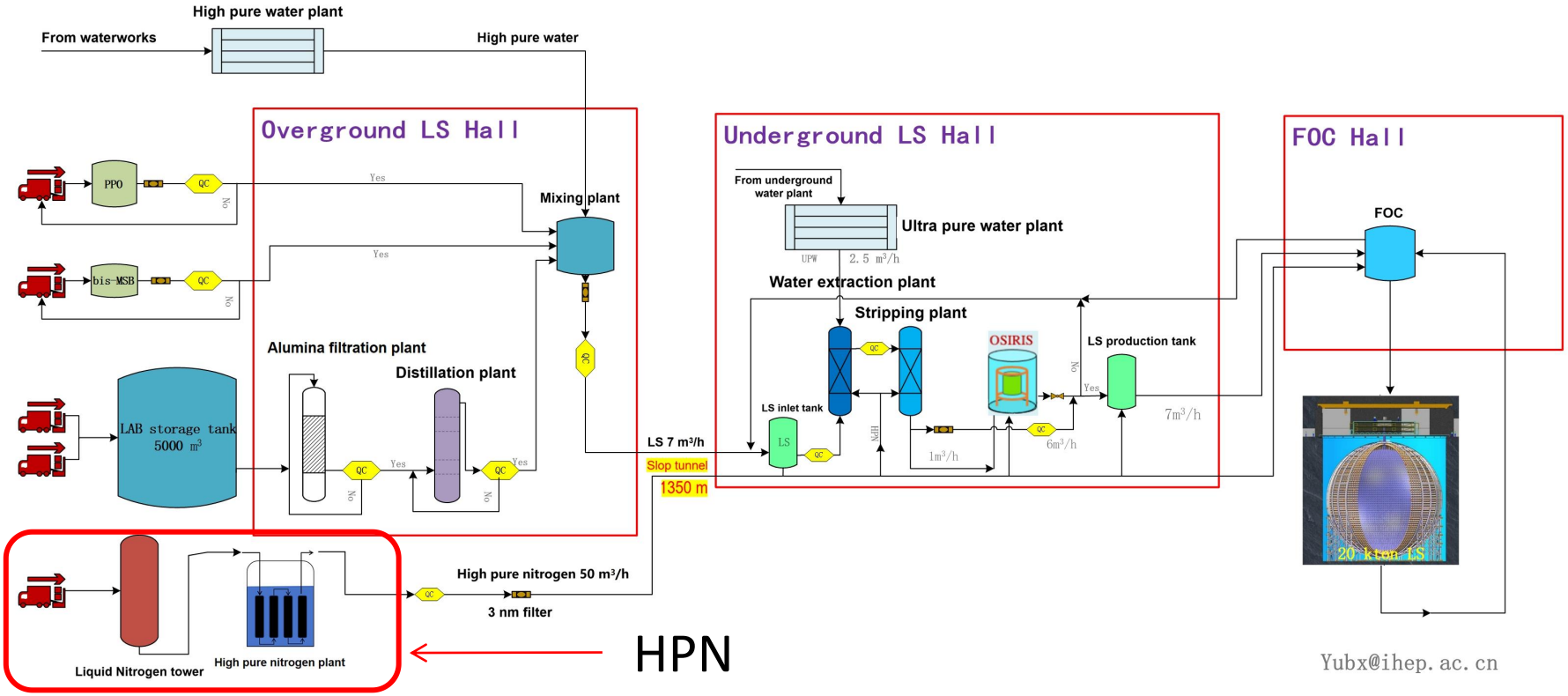






CD of JUNO

JUNO liquid scitillator system

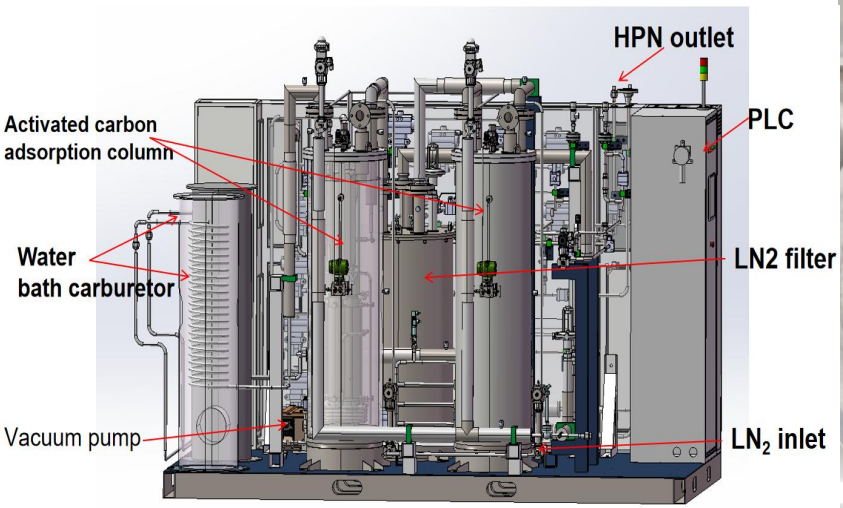


- Five main plants were designed and constructed for JUNO LS purification.
- HPN plant supply the HPN for all LS plants in underground hall including the CD and calibration system.

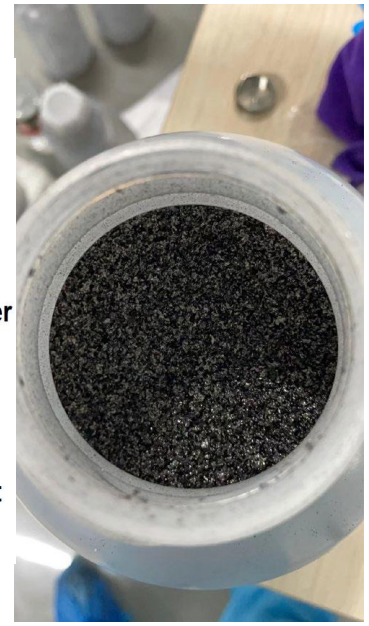
JUNO requirement of High Pure Nitrogen

- Used as cover gas for liquid scintillator systems. Used as stripping gas for removing the ^{222}Rn, ^{85}Kr and ^{39}Ar from LS.
- JUNO requirement of HPN with Rn-222 < 10 uBq/m^3, Kr-85 < 50 uBq/m^3 and Ar-39 < 50 uBq/m^3.
- Two Low Temperature Adsorbers columns , normal flux rate 50 Nm^3/h/column, maximun flux rate 100Nm^3/h.

Liquid nitrogen tower

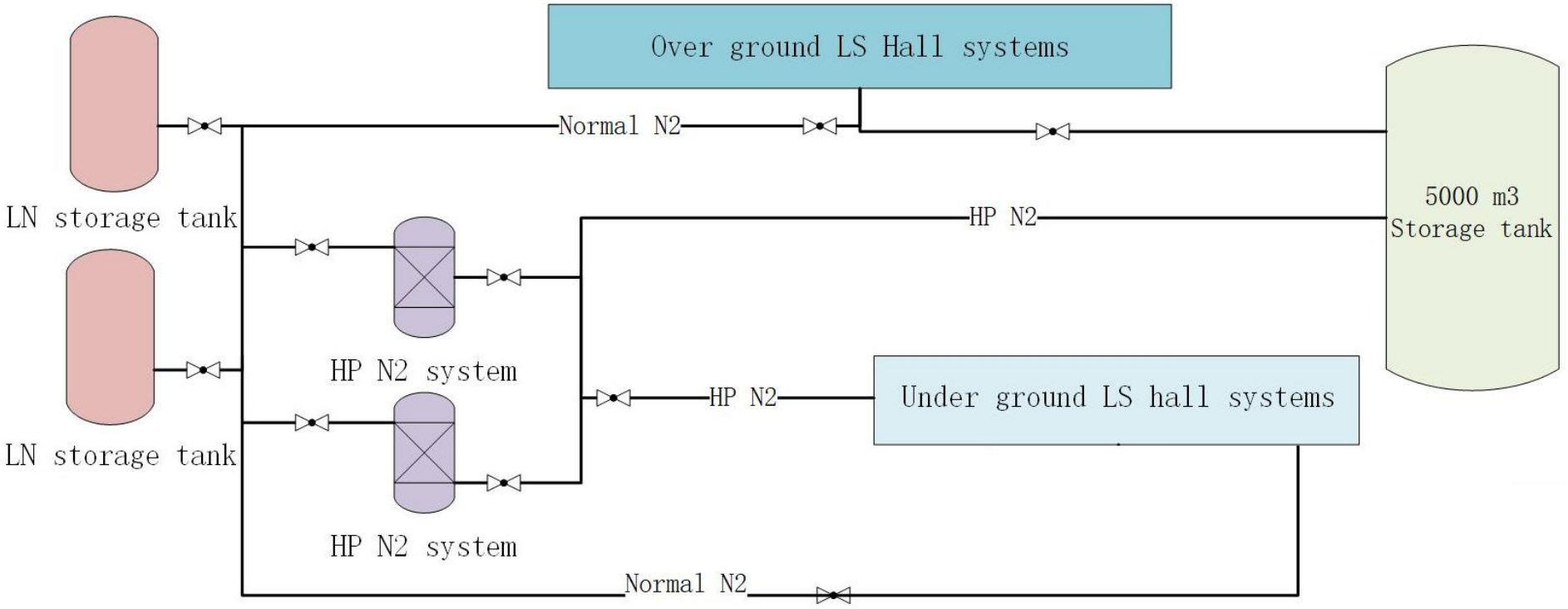


HPN Plant



Activated carbon

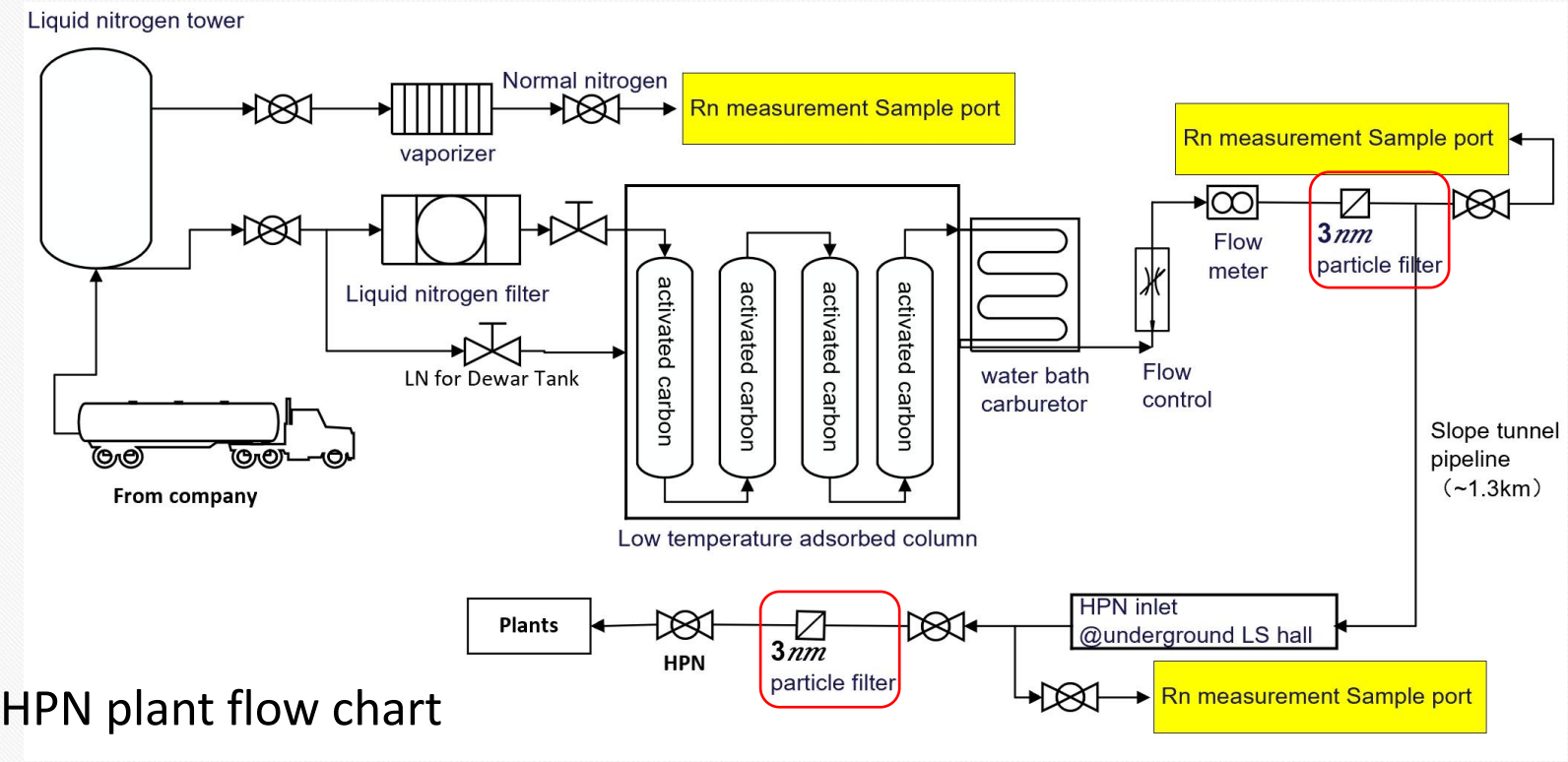
Overview of JUNO nitrogen system



- Normal nitrogen is used for the plants in overground LS hall.
- HPN is used for all plants in underground LS hall.
- 10 m^3/h HPN will supplied to 5000 m^3 storage tank.

HPN plant flow chart

- Three sampling port for monitor Rn-222 of normal nitrogen and HPN.
- Two stages of 3 nm filter for removing particles in nitrogen.



HPN plant flow chart

Selection of activity carbon

- Activated carbon from CARBO_ACT International.
- With very low ^{222}Rn emanation rate.
- 6 kg Activated carbon was used.

Table 1
Radionuclide concentration of some charcoal samples, measured by Ge low level gamma spectrometry. Typical sample size was 19–60 g. ^{222}Rn was measured after heat extraction in gas counters

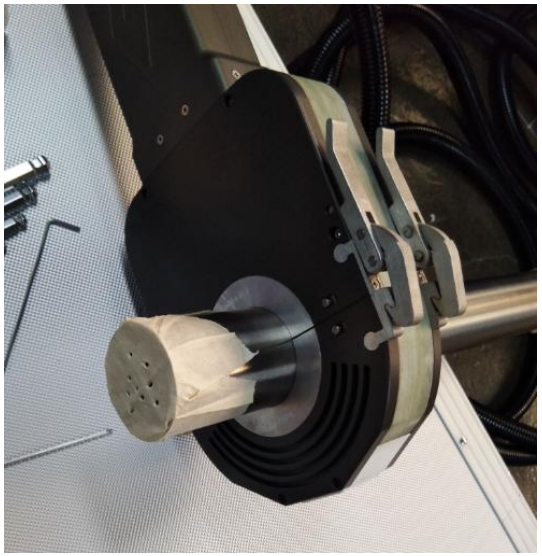
Applied Radiation and Isotopes 52 (2000) 691±695

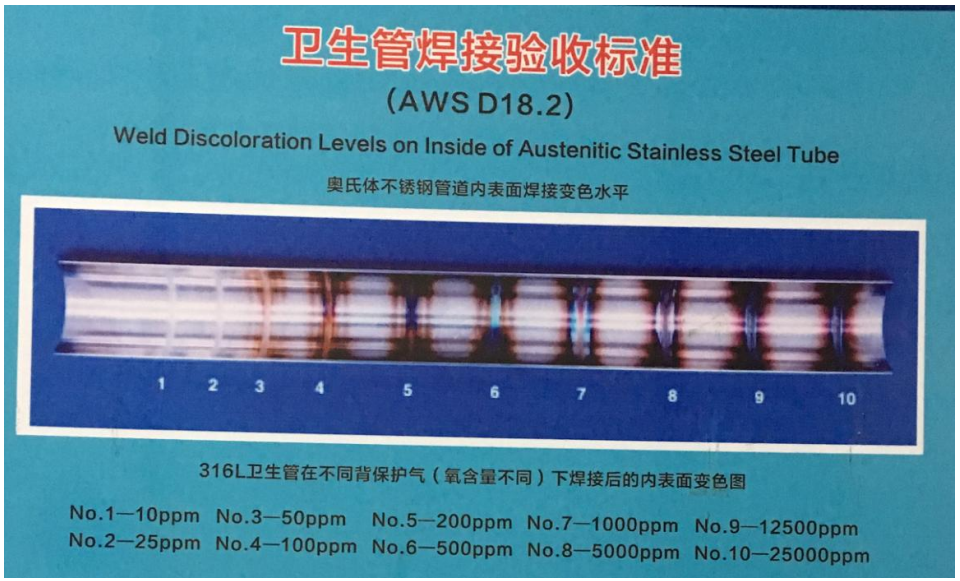
Charcoal sample	Specific activity (Bq/kg)				
	^{137}Cs	^{228}Th	^{40}K	^{226}Ra	^{222}Rn
Silcarbon Sil40	≤ 1	28 ± 2	80 ± 3	28 ± 2	
Silcarbon C46	1.2 ± 0.2	1.0 ± 0.2	380 ± 15	1.0 ± 0.2	
Silcarbon K48	≤ 1	0.5 ± 0.3	10 ± 0.7	0.4 ± 0.3	0.28 ± 0.05[a]
Hydraffin CC8x30	1.3 ± 0.2	1.2 ± 0.3	275 ± 14	1.0 ± 0.3	0.33 ± 0.02[a]
Hydraffin UV43	3.4 ± 0.2	0.7 ± 0.3	1130 ± 44	0.5 ± 0.3	
Model PCB616	5.3 ± 0.3	0.18 ± 0.12	120 ± 7	0.37 ± 0.09	
Model 1193	0.6 ± 0.1	≤ 0.3	360 ± 20	0.20 ± 0.11	
Alcarbon 12x20	0.1 ± 0.06	≤ 0.3	590 ± 24	≤ 0.3	0.17 ± 0.02[a]
Alcarbon 7x16	1.5 ± 0.2	≤ 0.4	690 ± 28	≤ 0.3	0.10 ± 0.02[a]
Activated Carbon	≤ 0.5	≤ 0.5	≤ 2	≤ 0.3	0.0003 ± 0.0001

[a] Wetterauer (1994).

HNP plant construction: SS orbital Welding

- Low background 316L SS materail was used (**10 times reduction**), Electro Polishing was used.
- Orbital welding is both clean and smooth.
- 5N argon was used in welding process.
- The welding sample is better than ASME BPE level 3.
- La-W welding electrode was used.





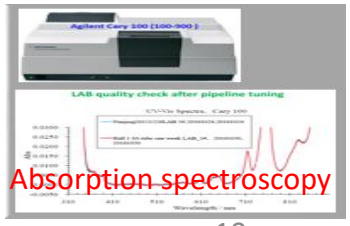
Cleaning Quality control And Inspection Method

清洗步骤（工作量20天）

1. 脱脂（去除油脂）
2. 酸洗（去除焊斑）
3. 循环水冲（去除酸洗杂质）
4. 钝化（产生保护层）
5. 循环水冲（去除钝化杂质）
6. 不锈钢表面粗糙度检测
7. 检测冲洗的水样

JUNO cleaning standard

1. Resistivity test (Delta 4MO)
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≤0.4μm
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<0.1ppt



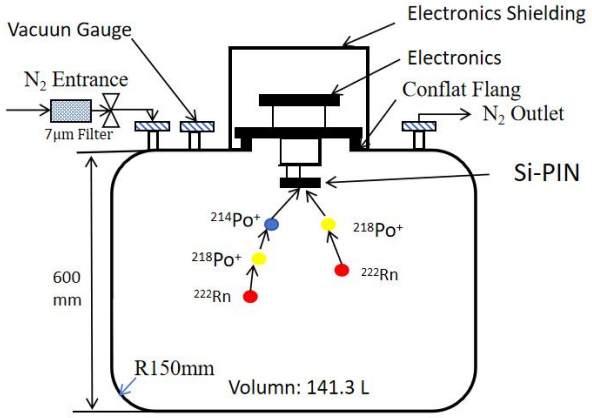
Commissioning of High Purity Nitrogen plant

- In February 2023, the equipment passed the acceptance test.
- The HPN plant participated in three joint commissionings and successfully completed the tasks.
- In the past two months, HPN plant has completed two months of continuous running.The interim test results meet the JUNO requirements.

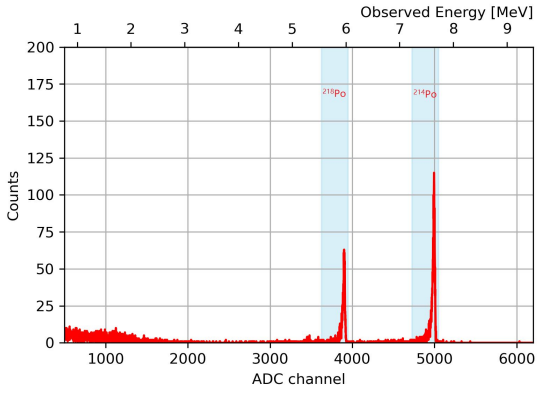
HPN Radon measurement system

- A Si-PIN is used to measures the count of the α particles released by the polonium nucleus (radon daughter), and the radon concentration is calculated by Po-214 α peak.

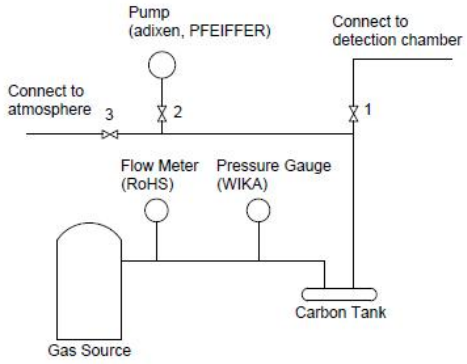
- The radon enrichment system increases the sampling volume by activated carbon to adsorb radon in nitrogen at low temperature.



Detection chamber



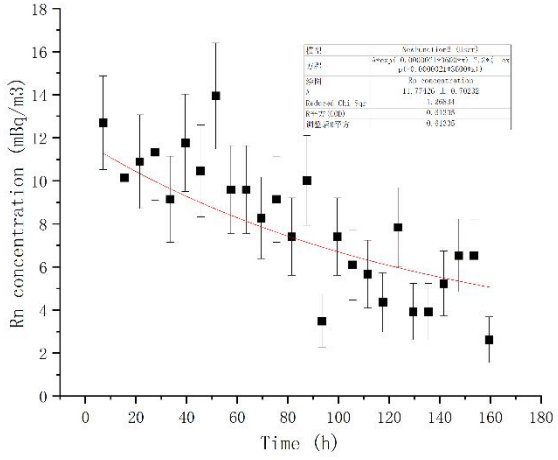
Energy spectrum



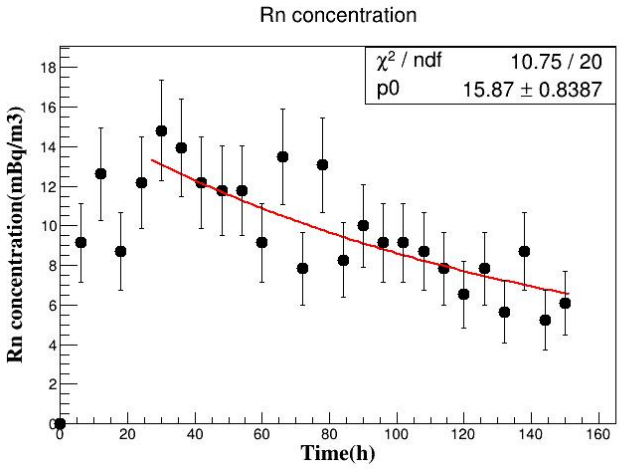
Enrichment system

Radon of raw nitrogen from liquid nitrogen

- LN Tower 1# raw nitrogen radon concentration is 19.9 ± 1.2uBq/m3, The start time of the enrichment measurement was 3 days after the liquid nitrogen columnwas filled again with liquid nitrogen.
- LN tower 2# raw nitrogen radon concentration is 37.5± 2.0uBq/m3, The start time of the enrichment measurement after the liquid nitrogen column was filledagain with liquid nitrogen.



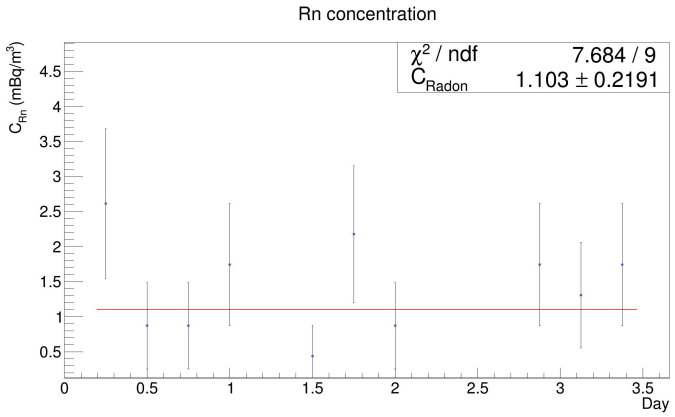
1# LN tower raw nitrogen radon concentration



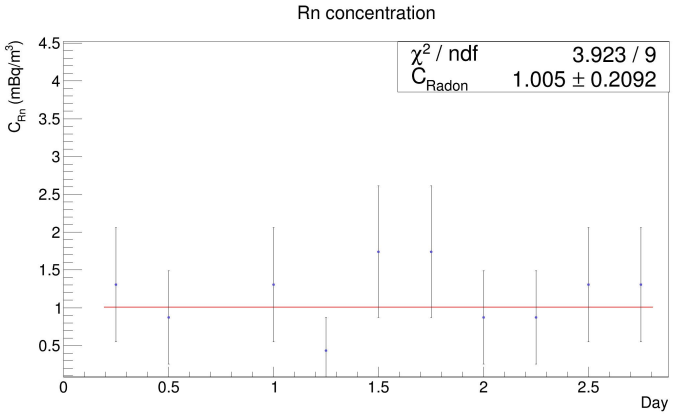
2# LN tower raw nitrogen radon concentration

Radon concetration of HPN

- At the HPN flux rate of 50 NM^3/H of a single LTA can be operated for 10 days, and the radon concentration should be less than 10 uBq/m3.
- After A LTA Purified nitrogen enrichment, the detector average radon concentration is 1.1 ± 0.2 mBq/m^3. Enrichment volume: 242 m^3.
- After B LTA Purified nitrogen enrichment, the detector average radon concentration is 1.0 ± 0.2 mBq/m^3. Enrichment volume: 242 m^3.
- Detector detection limit is 1.33 uBq/m^3.



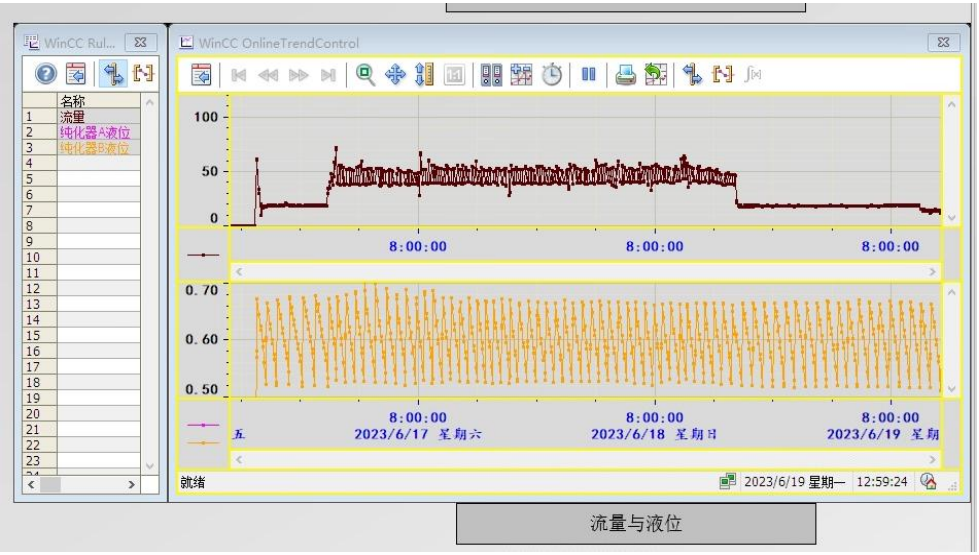
Column A HPN radon contentration



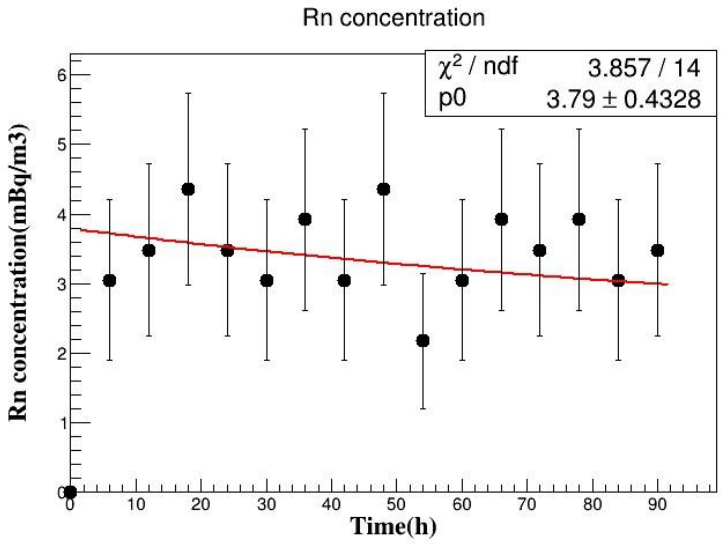
Column B HPN radon contentration

HPN radon concetration in undrgroud hall

- HPN flow rate: 50 m^3/H.
- Radon concentration of HPN:5.49±0.62uBq/m^3
- Detection limit @1.75uBq/m^3
- Enriched nitrogen volume is 216m^3.



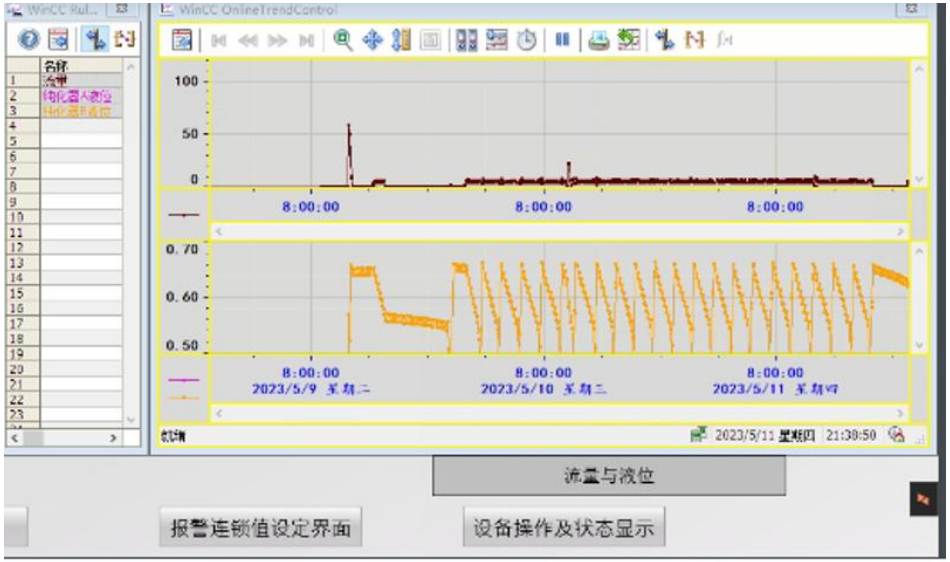
Flux rate of HPN Plant

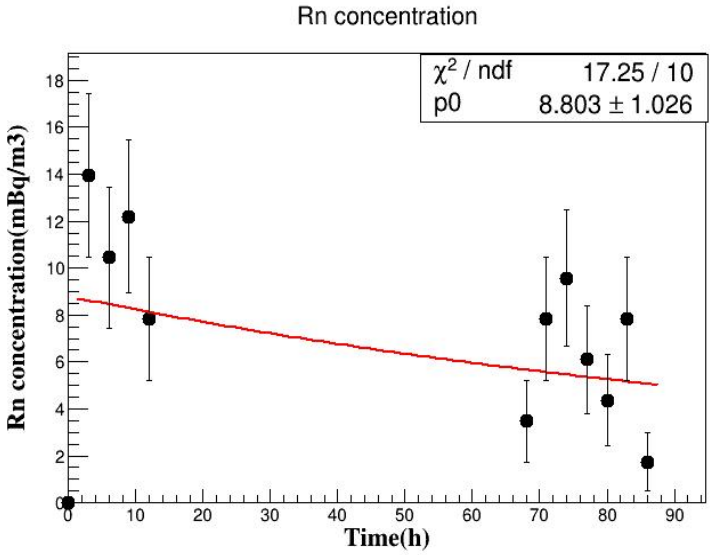


Rn-222 measurement result

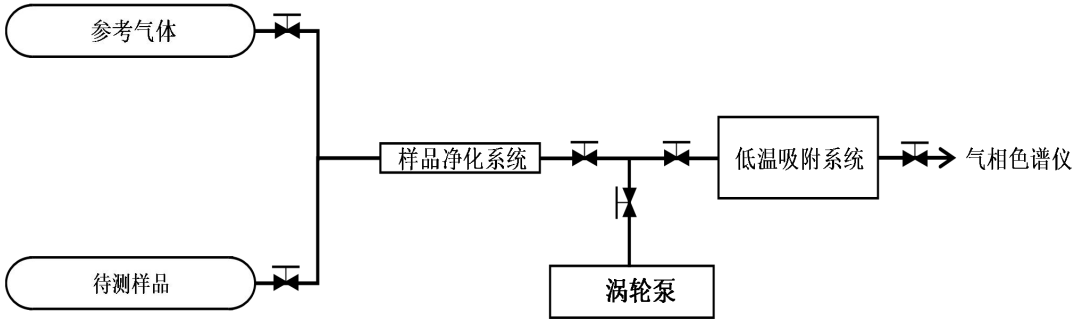
HPN radon concetration at low flow rate

- HPN flow: 6 m^3/h
- 20-50 hours measurement time： Count reduction due to energy peak drift . Measurement of electronic humidity due to underground humidity.
- Radon concentration of HPN@underground LS hall is **12.83±1.46 uBq/m^3** (Detection limit @1.5uBq/m^3 , Enriched nitrogen volume is 255m^3 ）





Kr-85 Ar-39 concetration in HPN



空气	浓度	^{84}Kr	^{39}Ar
Kr	1.14×10^{-6}	57%	
Ar	9.34×10^{-3}		99.6%

Flow chart of Kr-85 measurement

^{85}Kr/Kr=1×10^{-11} L/L，比活度为1 Bq/m^3

^{39}Ar/^{40}Ar=1×10^{-16} L/L，比活度为10 μBq/m^3

Kr-85 results

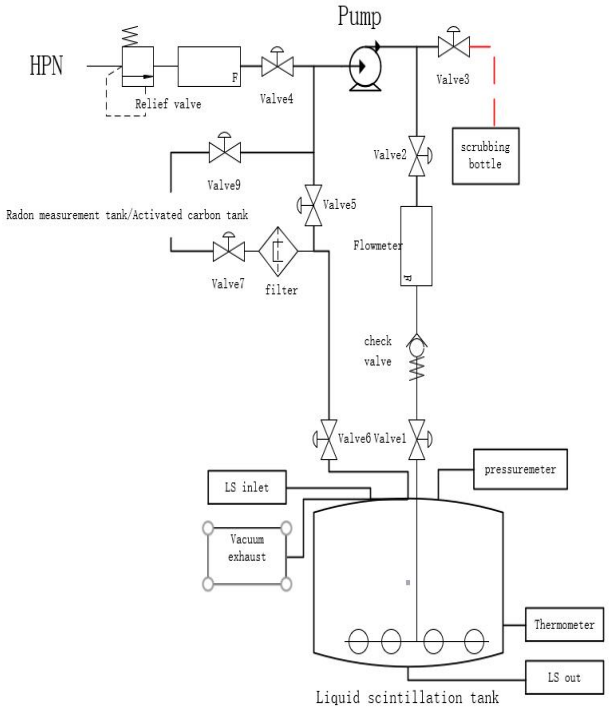
样品名称	^{84}Kr体积比浓度	^{85}Kr体积比浓度
地面普通氮气	56.1 ± 5.61 ppt	98.42 ± 9.84 μBq / m^3
地面高纯氮气（三月）	3.9 ± 0.39 ppt	6.84 ± 0.86 μBq / m^3
地面高纯氮气（七月）	1.5 ±0.15 ppt	2.63 ± 0.26 μBq / m^3
地下高纯氮气	17.9 ± 1.79 ppt	31.4 ± 3.14 μBq / m^3
地下液闪厅空气	1.09 ± 0.1 ppm	1.91 ± 0.19 μBq / m^3
椰壳活性炭	0.26 ± 0.03 ppt	0.46 ± 0.04 μBq / m^3

Ar-39 results

样品名称	^{40}Ar体积比浓度	^{39}Ar体积比浓度
地面普通氮气	4.28 ± 0.43 ppm	4.28 ± 0.43 μBq / m^3
地面高纯氮气（三月）	3.6 ± 0.36 ppm	3.6 ± 0.36 μBq / m^3
地面高纯氮气（七月）	15 ± 1.5 ppm	15 ± 1.5 μBq / m^3

The measurement of LS radon

- Detector has been assembled at JUNO site.
- Using nitrogen stripping radon form LS and measuring the Rn-222 in nitrogen
- Preliminary result show that Rn-222 detection limit in LS is 40mBq/m^3



Summary

- Consider the SS materail, active carbon, welding, cleaning and leackage test, a high pure nitrogen plant was constructed.
- The measurement result show the concetration of Rn-222, Kr-85 and Ar-39 in HPN is very low and meeted JUNO's requirement.
- This plant has passed long time running test (two months) .

Thanks!

微信二维码

Backup

Overview of HPN Plant

- Used as flushing and purgeing nitrogen for water extraction, stripping, OSIRIS, UPW and FOC system;
- Used for removing radon from LS(stripping);
- The system passed on-site acceptance in February 2023

Item	Parameter	New data
High purity nitrogen nitrogen production （ Nm^3/h）	50×2	Satisfy, max 80Nm3/h
Raw nitrogen ^{222}Rn activity (mBq/Nm^3)	≤1	satisfy,37.54±1.54uBq/m3
Purified Nitrogen ^{222}Rn activity ($\mu Bq/m^3$)	≤ 10	<1.33uBq/m3
Continuous operation time (d)	≥ 10	10 days
Regeneration time of activated carbon (h)	≤ 20	Satisfy,19h
Inlet/outlet pressure (MPa)	> 1.1 / 0.8	satisfy
Cooling LN2 consumption (L/h)	< 30	Satisfy
System leakage rate	< 10-7 mbar•l/s	2.0*10-8mbar•l/s
Electric Power	< 12kW	satisfy

@1.33uBq/m3 will shows Backup

JUNO HPN system design

Design Parameter

Item	Paremeter	Remark
High purity nitrogen gas production （Nm^3/h）	50×2	
Nitrogen sample ^{222}Rn activity (mBq/Nm^3)	≤1	
Raw nitrogen purity	> 99.999%	
Purified Nitrogen ^{222}Rn activity ($\mu Bq/m^3$)	≤ 10	
Continuous operation time (d)	≥ 10	
Regeneration time of activated carbon (h)	≤ 20	
Inlet/outlet pressure (MPa)	> 1.1 / 0.8	
Cooling LN2 consumption (L/h)	< 30	
Quantity of activated carbon (kg)	2.5×2	CARBO_ACT International
System leakage rate	< 10-7 mbar•l/s	
Electric Power	< 12kW	

JUNO cleaning requirement

- Resistivity test (Delta 4MO)
- 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

Detector detection limit calculation

$$dA'(t) = -\lambda A'(t)dt + \frac{6*0.9*a}{3600*1000}\mathrm{dt} \quad (1)$$

a is purified gas radon concentration(uBq/m^3)

$A'(t)$ is Radon atomic activity that has been enriched in the activated carbon tank at t time

$\frac{6}{3600}m^3/s$=100slm, This is the rate of enrichment gas

0.9 is enrichment efficiency

Integral Equation 1, divide by the volume of the measuring tank

$$R(\mathbf{t}) = \frac{A(t)}{0.279} == 2.56\mathbf{a}\left(1 - \mathbf{e}^{-\lambda \mathbf{t}}\right) \quad (2)$$

$\boldsymbol{R}$ （t ）is Radon concentration in radon measurement tanks is elevated

When R(t) is 1.04 m$\boldsymbol{Bq/m^3}$ (Confidence Interval,90%) [1],t is 48h

a=1.33 $\boldsymbol{uBq/m^3}$