Study of the ^{222}Rn removal and detection for JUNO

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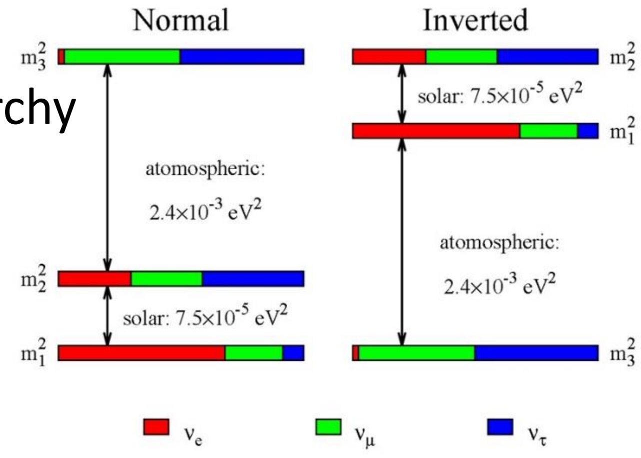
Outline

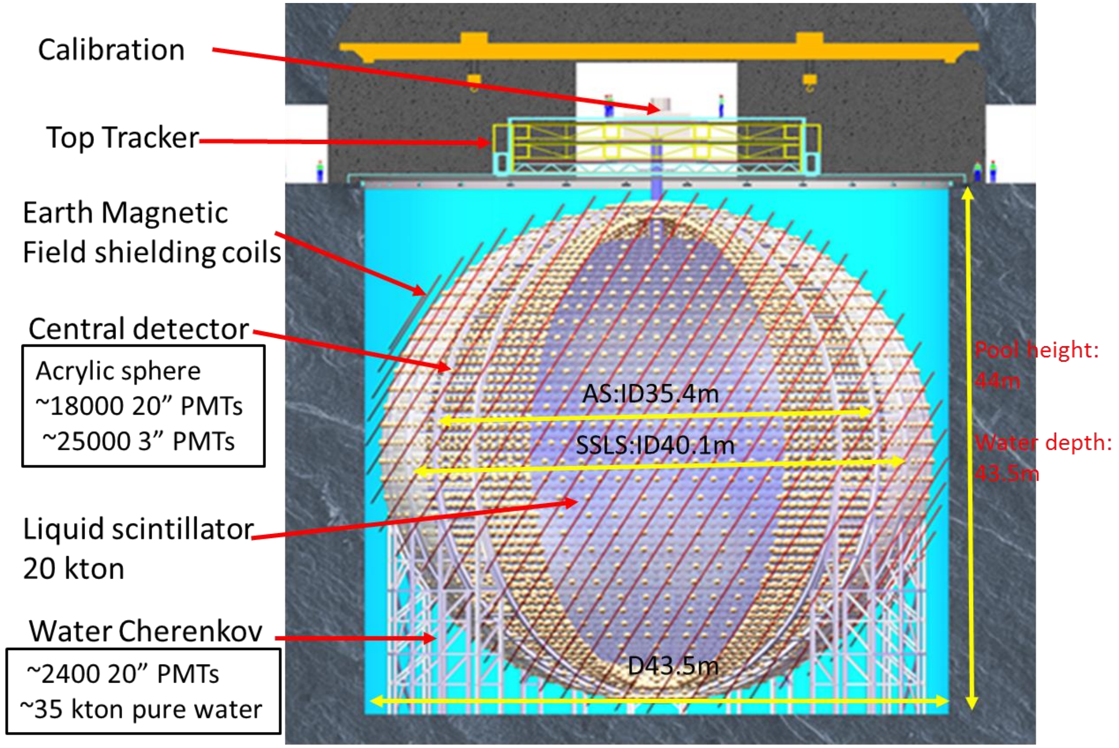
- Motivation
- Radon measurement system
- Radon removal and results
- Summary

Motivation

- The Jiangmen Underground Neutrino Observatory (JUNO) is a multipurpose neutrino experiment.

✓ Determination of mass hierarchy
✓ Precision measurements of oscillation parameters
✓ Supernova neutrinos
✓ Geo-neutrinos
✓ …





AS: Acrylic sphere; SSLS: stainless steel latticed shell

- To suppress cosmogenic muons and their induced fast neutrons, the outer of the central detector is the cherenkov detector filled with ultrapure water.
- Requirements for the water pool:

✓ Stable temperature
✓ Good quality, i.e., high transparent
✓ Low intrinsic background

} A reliable ultrapure water production, purification and circulation system

◆ The radon concentration should be less than 0.2 Bq/m^3

• The ultrapure water production and circulation system

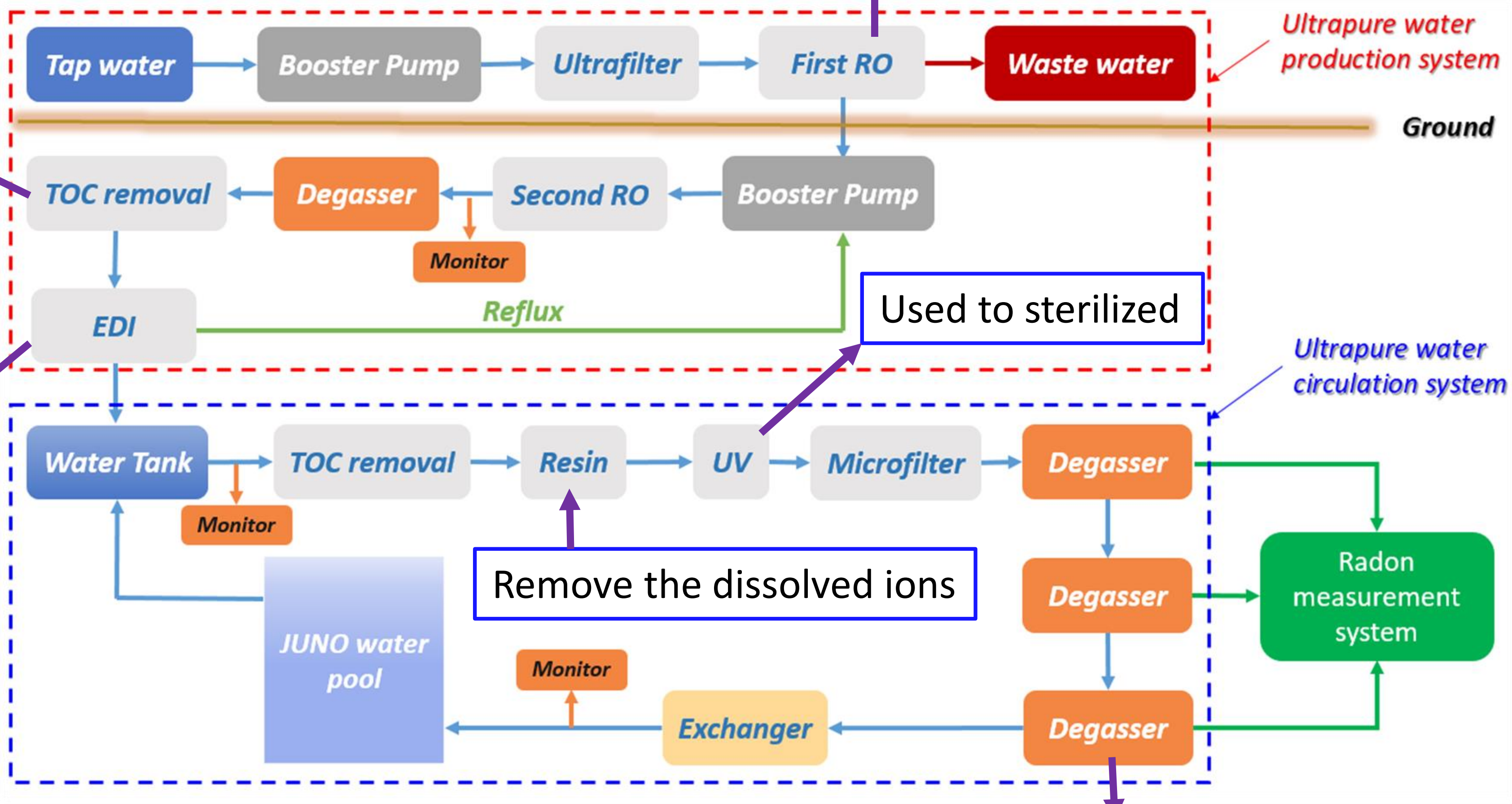
Reverse Osmosis, to remove the dissolved ions as well as the suspended species in water, including bacteria

TOC used to remove the organic from the water

Used to sterilized

Electrode ionization, to remove the dissolved ions from the water

Remove the dissolved ions

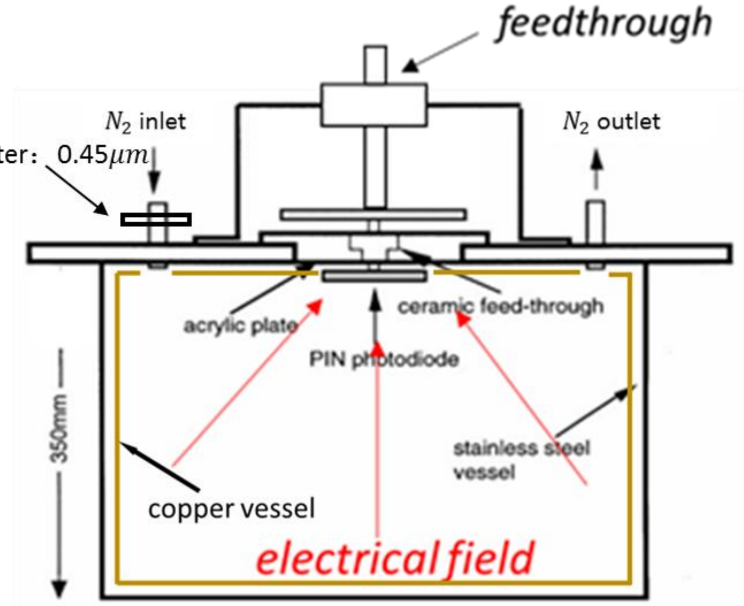


Used to remove the gas in the water, including O_2,CO_2, Rn etc.

Radon measurement system

Detector

^{222}Rn	α(3.8d) 5.590MeV →	^{218}Po	α(3.1min) 6.115MeV →	^{214}Pb	β(26.8min) 1.024MeV →	
^{214}Bi	β(19.9min) 3.272MeV →	^{214}Po	α(164.3μs) 7.833MeV →	^{210}Pb	β(22.3y) 0.064MeV →	
^{210}Bi	β(5.013d) 1.163MeV →	^{210}Po	α(138.4d) 5.407MeV →	^{206}Pb		



- ✓ Si-PIN: S3204-09 (Hamamatsu);
- ✓ Stainless steel chamber: 35.8 L;
- ✓ Copper chamber : 31 L;
- ✓ Leak rate: < 10^{-5} ml/s;
- ✓ Seal: VCR gasket, CF flanges;

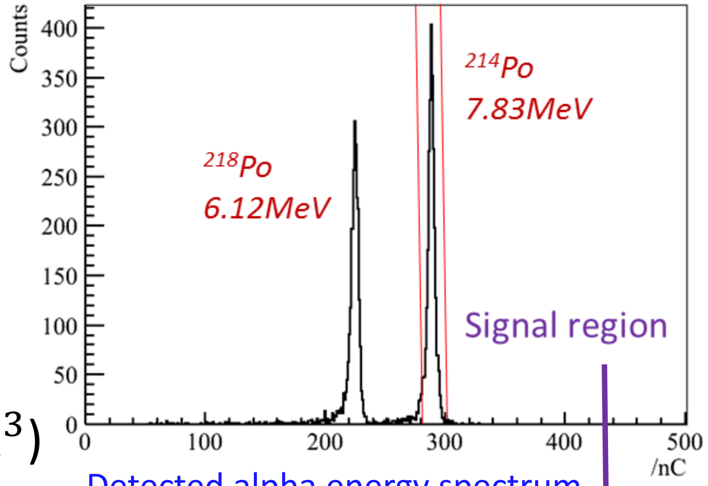
Calibration

- Radon source:

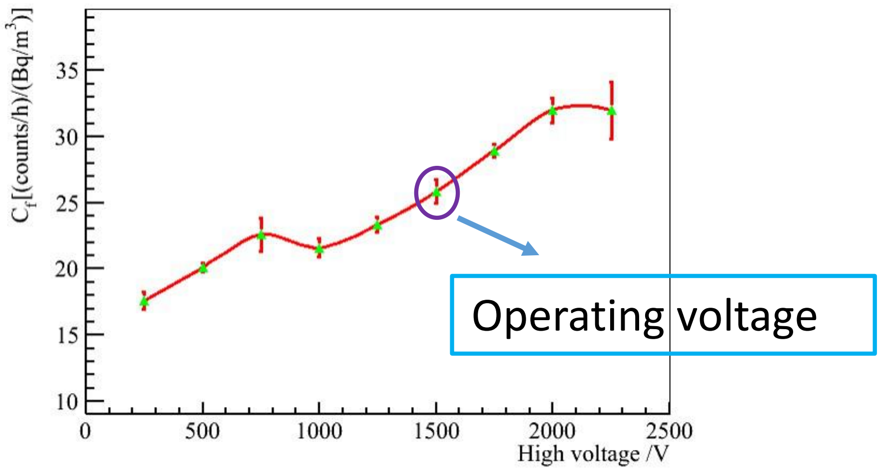
(84.80±4.55) Bq/m^3(RAD7*)

- Calibration factor(CF):

26.38±1.56 (counts/h)/(Bq/m^3)



Detected alpha energy spectrum



- ✓ No other α peak overlapped
- ✓ Higher collection efficiency than ^{218}Po

*: http://durridge.com/products_rad7.shtml

Background

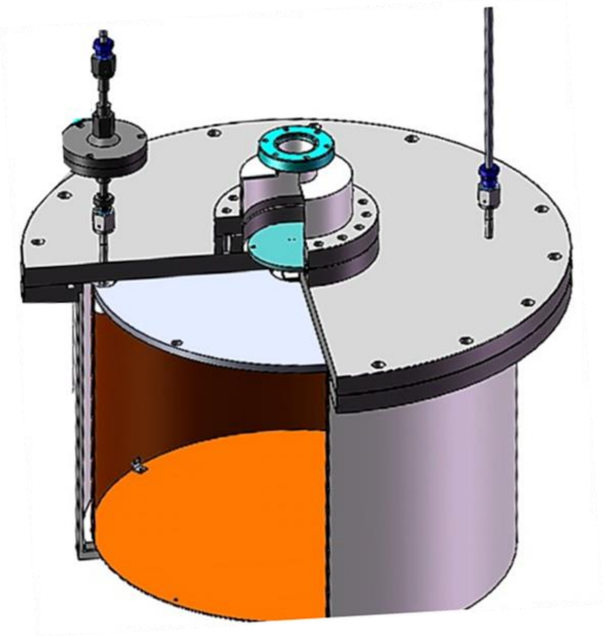
✓ Detector filled with evaporated nitrogen

- ^{214}Po rates:

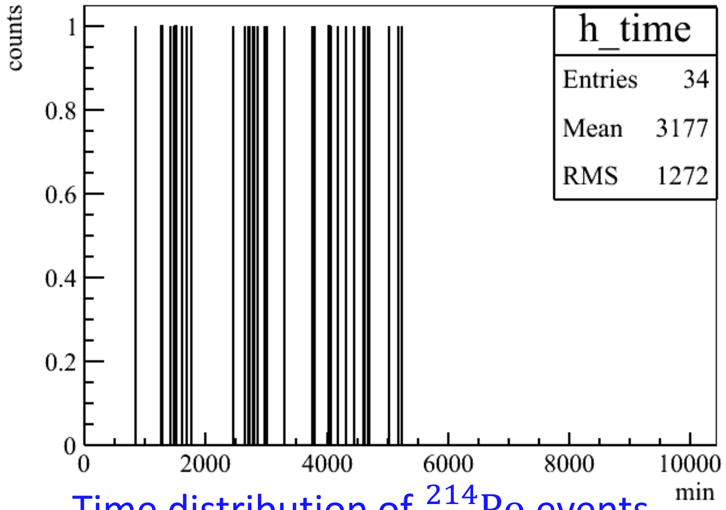
  (0.39±0.067) counts/h

- Sensitivity :

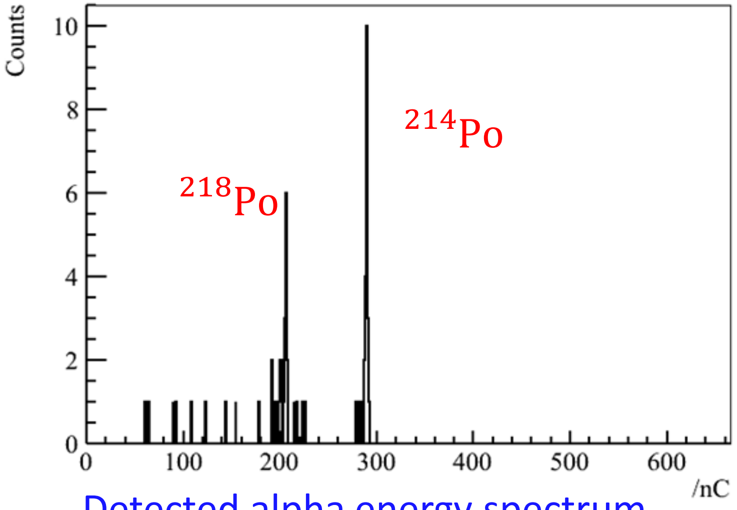
$$L_c[Bq/m^3] = \frac{1.64\ \sigma_{BG}[counts/h]}{CF[(counts/h)/(Bq/m^3)]} \Rightarrow 9.0\ mBq/m^3$$



◊ As a result, 1.64 times standard deviation excess of signal above the background should be for 9.0 mBq/m^3 in a one-day measurement.

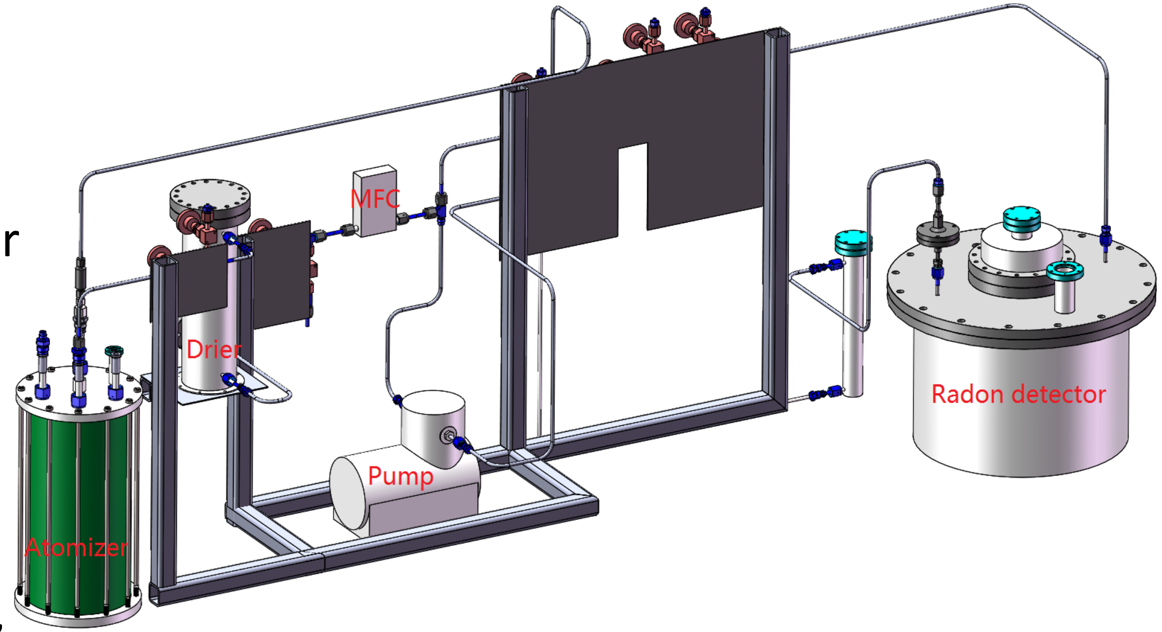


Time distribution of ^{214}Po events



Detected alpha energy spectrum

Measurement system



- The atomizer is used to transfer the radon from water into air
- In diffusion equilibrium and at 20 ℃(Ostwald Coefficient)

Rn concentration $\longrightarrow \frac{C_{water}}{C_{air}} \sim 0.25$

- ~ 90% of the radon daughters($^{214}\mathrm{Po}$ and $^{218}\mathrm{Po}$) are positive, the drier is used to keep the relative humidity below 3%;

- Gas flow influence

✓ Using radon source

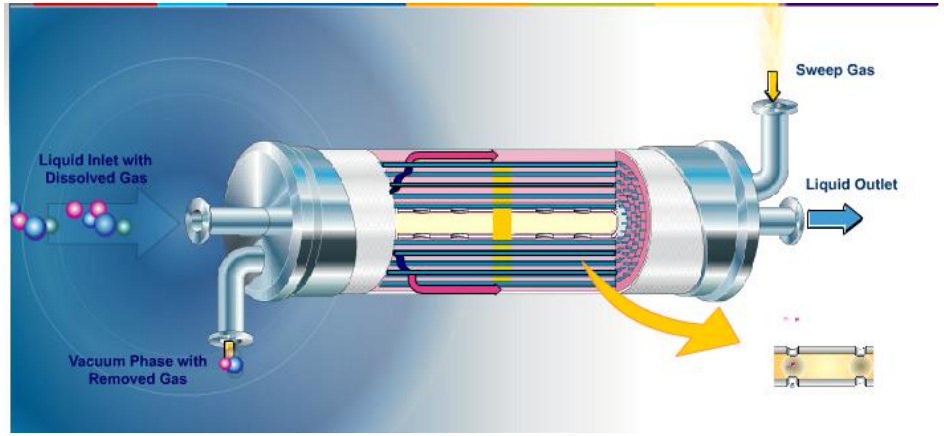
Condition	Counts/h	C_f [(counts/h)/(Bq/m^3)]
1 L/min	2236.74 ± 55.87	26.38 ± 1.56
static	2362.04 ± 53.78	27.85 ± 1.62

- The gas flow (1L/min) in the chamber has no effect on the collection efficiency of the daughter.

➢Radon removal

✓ Liqui-Cel Membrane Contactors

- Aim: remove gases from liquids



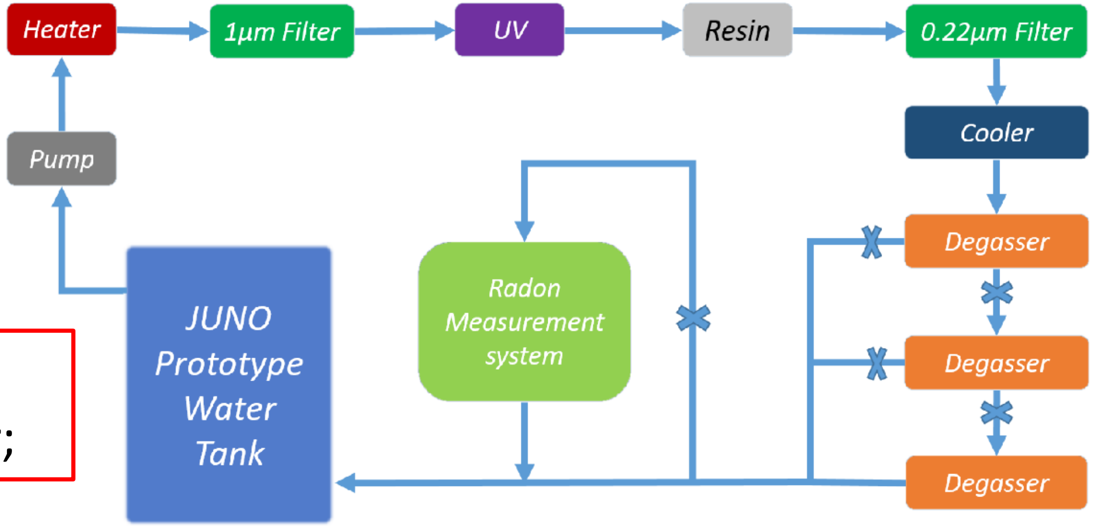
Principle :

a) Use a microporous hollow fiber membrane to remove gases from liquids and the membrane is hydrophobic.

b) Applying a higher pressure to the liquid stream relative to the gas stream creates the driving force for dissolved gas in the liquid to pass through the membrane pores.

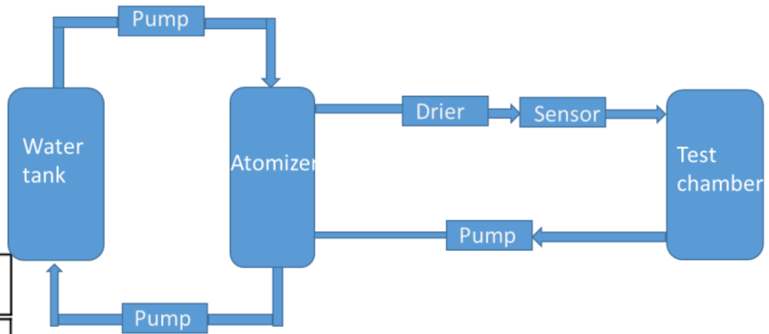
c) The gas is carried away by the vacuum pump or sweep gas;

d) Dissolved oxygen in water production: <10 ppb



✓ The Rn removal efficiency is correlated with the gas concentration in the water and the inlet pressure of the water;

➢Results



Inlet pressure

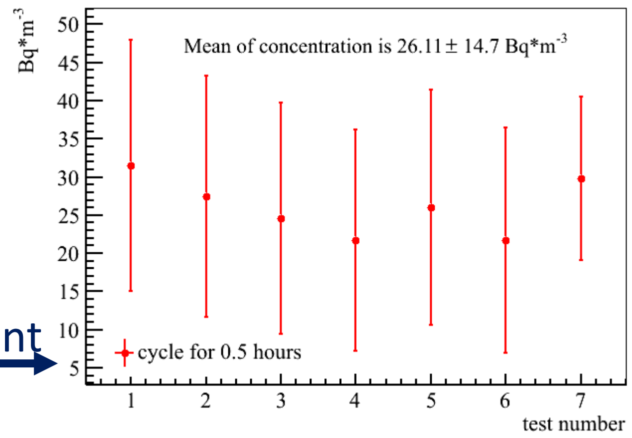
0.15MPa → Case 1, Case 2

0.35MPa → Case 3

Case 1	Rn concentration in water of JUNO prototype	
condition	Counts/h	Concentration(Bq/m^3)
Degasser "OFF"	101.40 ± 7.80	0.96 ± 0.093
One stage degasser "ON"	36.00 ± 4.65	0.34 ± 0.048
Degasser "ON"	24.00 ± 3.79	0.23 ± 0.039
Case 2	**Rn concentration in water of small vessel**	
condition	Counts/h	Concentration(Bq/m^3)
Degasser "OFF"	498.65 ± 20.11	4.73 ± 0.34
Degasser "ON"	25.80 ± 3.93	0.24 ± 0.039
Degasser "ON" and CO_2	10.20 ± 2.47	0.097 ± 0.024
Case 3	**Rn concentration in water of Daya Bay 5th hall water system**	
condition	Counts/h	Concentration(Bq/m^3)
Degasser "OFF"	2574.00 ± 124.27	24.39 ± 1.86
Degasser "ON"	15.00 ± 3.00	0.14 ± 0.029

consistent →

RAD7:



- Loading CO_2 into the water and increasing the inlet water pressure could help to increase the efficiency of the degassing membrane.
- The radon concentration can be reduced to less than $0.2 Bq/m^3$, fulfilling the requirement of JUNO.

➢Summary

- ✓ The water cherenkov detector is of utmost importance for a success of the JUNO physics performance. The Rn monitor and control of the ultrapure water is the key.
- ✓ The Si-PIN Rn detector has been developed for Rn concentration measurement of JUNO with a sensitivity of 9mBq/m^3.
- ✓ To satisfy JUNO’ water requirement of Rn concentration, We have implemented the Rn removal techniques using the liqui-Cel membrane in the ultrapure water production and circulation system.
- ✓ Loading CO_2 into the water and increase the inlet water pressure could help to increase the efficiency of the degassing membrane and the Rn concentration can be reduced to less than 0.2Bq/m^3. It can satisfy the requirement of JUNO.

Thanks!