PROCEEDINGS OF SCIENCE

Strategies of radon and cleanliness control at JUNO

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The Jiangmen Underground Neutrino Observatory (JUNO) is building a 20-kt liquid scintillator detector in a laboratory 700 m underground to address many important topics in neutrino and astro-particle physics. A clean and low radon environment is quite important to build an ultra-pure detector with the lowest radioactive background. In this work, we present the main strategies of radon and cleanliness control at JUNO. The total volume of the experimental hall is about 120,000 m^3. We have implemented clean room management in the laboratory, and the final cleanliness can be equivalent to class 10,000-100,000 level. There is a large amount of underground water at the JUNO site, and the flow rate can reach 450 m^3/h with 120,000 Bq/m^3 radon concentration in the water. We have validated that the underground water is a big radon source for radon in underground air. The nominal radon concentration in the main hall is required to be below 200 Bq/m^3 for human beings' health and neutrino physics, and the maximum value should be below 400 Bq/m^3. With great efforts on optimization of the ventilation underground and well isolation of the experimental hall, the final radon concentration in the main hall has reached 100-200 Bq/m^3.

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1. Introduction

The Jiangmen Underground Neutrino Observatory (JUNO) is located in Jinji town, 52.5 km away from Taishan and Yangjiang nuclear power plant in Guangdong province, China. The detector is made of a 20-kt liquid scintillator (LS), and the main target is to determine the neutrino mass ordering [1]. The civil construction has finished by the end of 2021. The detector started construction in 2022 at 700 m underground. There are two accesses to the experimental hall, one tunnel with 1265 m length and 42% slope, the other is a vertical shaft of 563 m height. The fresh air is sucked in from the vertical shaft, and the underground air is exhausted from the sloping tunnel. There are two fresh air cabinets in the main hall, which inlet fresh air through pipes.

The 20-kt LS is contained in an acrylic vessel, and the 20,000 20-inch PMTs are installed on the stainless steel truss. We have different cleanliness requirements for different regions of the detector. The basic principle is the shorter distance to LS, the cleaner the environment. We require the environment inside the acrylic sphere to be equivalent to class 1,000 level [1], and the gap between PMT structure and acrylic to class 10,000 level, while the entire environment should reach better than class 100,000 level. The temperature inside the main hall should be 21°C±1°C, and the radon concentration in the air should be 100 Bq/m^3 level.

2. Cleanliness control

We have implemented the clean room management in the main hall since May 2022. People should wear clean clothes, gloves, and shoes, and go through an air shower before entering the main hall. All the detector components and tools should be well-cleaned and protected in the company. The outer packing should be removed and the cargo should go through an air shower before entering the main hall. Both the cargo and tools are not allowed to be in contact with the floor directly, and they should be covered with a clean cloth during the storage period inside the main hall. No dirty work, such as cutting and welding, is allowed around the main hall. What's more, we have two administrators outside the shower to manage the clean dressing and cargo, and six cleaners working inside and outside the main hall to manage a clean environment. Four temporary cabinets are installed on the corners of the main hall with three-stage filters for circulation to improve the air quality. The ventilation speed is 200,000 m^3/h, and the outlet air quality can reach class 1,000 level.

To provide the acrylic installation with a better environment, we have pulled a pipe from the cabinet outlet to the chimney directly with the best air of fewer particles and low temperature. All the acrylic panels are produced in the company and bonded together at the JUNO site. The surface of the bonding area is treated with sanding, polishing, and cleaning, the same as that done on the panels in the company. Details about the treatments can be found in [2]. After surface treatment of each layer, the inner surface will be protected with a paper film to avoid radon daughters deposition on the surface. This paper film has a little water-soluble glue on one side and can be further removed by the final cleaning without manual operation. The outer surface is protected with polyethylene film, which will be removed after the equator installation.

[1] A class 1,000 environment is equivalent to ISO class 6 according to "Federal Standard 209E".

Since the half veto PMTs are installed on the top hemisphere of the stainless steel truss facing to the top, we have covered them with clean cloths to avoid dust deposition. Ten pieces of clean cloths are fastened on the magnetic field shielding coil, and they will be opened together with the coil installation. After the installation of the whole detector, the clean clothes can be removed by the overhead traveling crane with the rope.

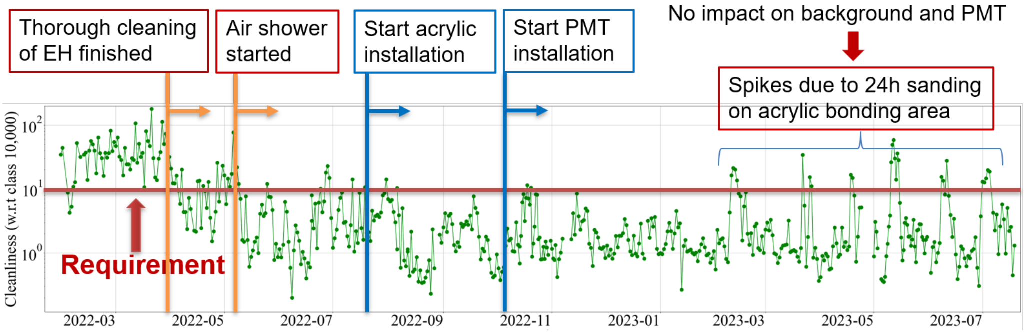

Figure 1: The long-time monitoring of the cleanliness inside the main hall.

The long-time monitoring of the cleanliness inside the main hall is shown in Figure 1. The value of the Y-axis is calculated as the total volume of real-time monitored particles divided by the particle volume at the class 10,000 level. Many spikes in 2023 are due to the 24-hour surface treatment of the acrylic bonding area, and the acrylic powder will affect the air particle counting. Anyway, the acrylic powder has a negligible effect on the background compared to the dust. The entire environment has reached our requirement. It is difficult to implement pipes for ventilation in the gap between acrylic and PMT modules, because the long pipes will conflict with the installation on the truss. Considering the average dust cleanliness is around class 10,000 level for most of the time, there is no special ventilation in the gap. For the volume inside the acrylic sphere, we plan to seal the sphere after the whole installation, and spray inside the sphere to let the dust to fall down. The preliminary result shows that spray can reduce the concentration of particles in the air by 2-3 orders in a 2 m height tent. Another test in a 5-meter diameter sphere is in progress.

3. Radon control

The radon inside the main hall has once reached 1600 Bq/m^3 in May 2022. All the fresh air is sucked in from the bottom of the vertical shaft before July 2023, and we found out that the environment on the ground can affect the ventilation in underground. We have screened the radon concentration distribution underground, and we found two high radon sources, one is the No.1 construction tunnel, and the other is the No.2 drainage gallery. There is no ventilation design in the two tunnels, and there is a large amount of underground water in the tunnel. We have measured that the radon concentration in fresh underground water can reach 120,000 Bq/m^3, while it is 38,000 Bq/m^3 in the ditch. That means a large amount of radon emanated from water to air. Good ventilation is the only way to reduce the radon concentration underground. We have deployed many powerful fans in the tunnel and screened the wind speed underground to make sure the wind direction is correct and the wind speed is effective. After optimization, the radon concentration in the tunnel air has decreased from 1200-1800 Bq/m^3 to 100-300 Bq/m^3.

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The design of fresh air underground is from the cabinets on the ground of vertical shaft through pipes. The construction of these cabinets and facilities lasted for about 3 months from April to June 2023, and the fresh air flow in the vertical shaft from ground to the main hall directly through pipes started from June 27 with 40,000 m^3/h.

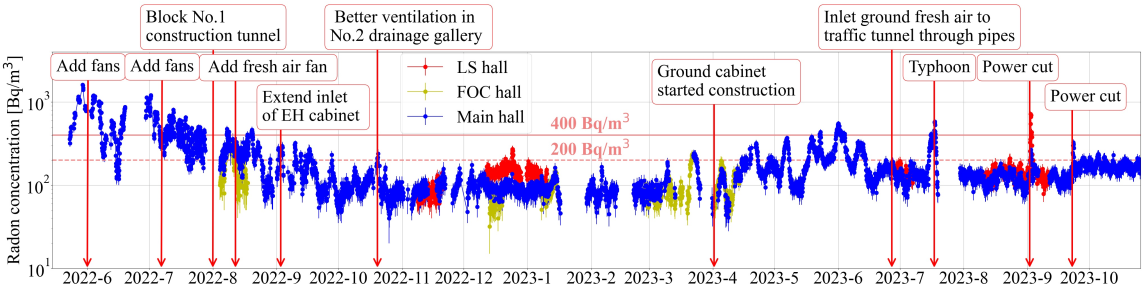

Figure 2: The long-time monitoring of the radon concentration inside the main hall.

The long-time monitoring of radon concentration inside the main hall is shown in Figure 2. There is a great improvement on the radon concentration after deploying powerful fans underground last year. The radon concentration started fluctuating since April 2023, when the room for the ground cabinets started the installation, and that will affect the fresh air sucking in through the shaft. After the construction of the cabinets on the ground of the vertical shaft, the fresh air was supplied from the ground to the main hall directly through pipes. Therefore, the radon concentration in the main hall became more stable, except the special period during the typhoon. The extreme weather ground can still have some impact on the entire ventilation underground. Details about the radon control at the JUNO site can be found in [3].

4. Summary

Strict clean room management has been carried out at JUNO laboratory since May 2022, and the cleanliness inside the main hall can reach the equivalent to class 10,000-100,000 level. There is a large amount of underground water at the JUNO site (450 m^3/h) with 120,000 Bq/m^3 radon in the water, and we have validated that the underground water is a large radon source. We have deployed powerful fans in the underground tunnel to decrease the radon concentration in underground air, and the final radon level reached 100-200 Bq/m^3.

Acknowledgements

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