# Surface Purity Control during XMASS Detector Refurbishment

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**Abstract.** The XMASS project aims at detecting dark matter, pp and $^{7}$Be solar neutrinos, and neutrino less double beta decay using large volume of pure liquid xenon. The first physics target of the XMASS project is to detect dark matter with 835 kg liquid xenon. After the commissioning runs, XMASS detector was refurbished to minimize the background contribution mainly from PMT sealing material and we restarted data taking in November 2013. We report how we control surface purity, especially how we prevent radon daughter accumulation on the detector copper surface, during XMASS detector refurbishment. The result and future plan of XMASS are also reported.

## INTRODUCTION

The XMASS project aims at detecting dark matter, pp and $^{7}$Be solar neutrinos, and neutrino less double beta decay using large volume of pure liquid xenon. The original idea is presented in Ref. [1]. The first physics target of the XMASS experiment is to detect dark matter. In the commissioning run, we found major background coming from the PMT part. To minimize the background contribution, detector refurbishment (RFB) is performed. Although PMT part is the current major background source, surface background is one of the possible main backgrounds in the future analysis or future detector. If the radon daughters are accumulated on the detector surface, $^{210}$Pb and the daughter particles could be backgrounds, especially in case that the backgrounds are not in the active PMT surface. Therefore we tried to minimize the background in RFB mainly by controlling the environment of the detector assembly.

## XMASS DETECTOR

The XMASS detector [2] is located in the Kamioka mine 1000m underneath the top of Mt. Ikenoyama (i.e. 2700 m water equivalent underground) in Japan. The detector consists of two components, the inner and outer detectors (ID and OD, respectively). The ID is equipped with 642 inward-facing photomultiplier tubes (PMTs) in an approximate spherical shape in a copper vessel filled with pure liquid xenon. Six hundred and thirty hexagonal PMTs (HAMAMATSU R10789-11) and twelve round PMTs (HAMAMATSU R10789-11MOD) are mounted in an oxygen free high conductivity (OFHC) copper holder with an approximately spherical shape called a pentakis-dodecahedron. The entire structure is immersed in liquid xenon. The amount of liquid xenon in the sensitive region is 832 kg. The vessel which holds liquid xenon and the PMT holder is made of OFHC copper and the size is 1120 mm in diameter. To reduce the amount of liquid xenon, an OFHC copper filler is installed in the gap between the

PMT holder and the inner vessel. The vessel is covered with another vessel for vacuum insulation. The ID is installed at the centre of the OD, which is a cylindrical water tank with seventy two 20-in. PMTs. The OD is used as an active shield for cosmic ray muons and a passive shield for low-energy gamma rays and neutrons. Construction of the detector started in April 2007 and was completed in September 2010. Commissioning runs were conducted from October 2010 to June 2012.

## DETECTOR REFURBISHMENT

During the commissioning run, detail study for background was performed. Then we found that the main background comes from the aluminium sealing material at PMT photocathode. To minimize the background contribution from the sealing material, it is covered with copper ring as shown in Fig. 1 and also high purity aluminium is evaporated around it. In addition, since the background from grooves and gaps can mimic the dark matter signal, electro-polished copper plates were put on the surface as shown in Fig. 2. Surface background especially from copper plates is one of the possible main backgrounds in the future analysis or future detector, because PMT PE distribution of surface background events is relatively uniform and it is hard to remove all the events by fiducial volume cut. Therefore environment to prevent surface radon daughter accumulation is required.

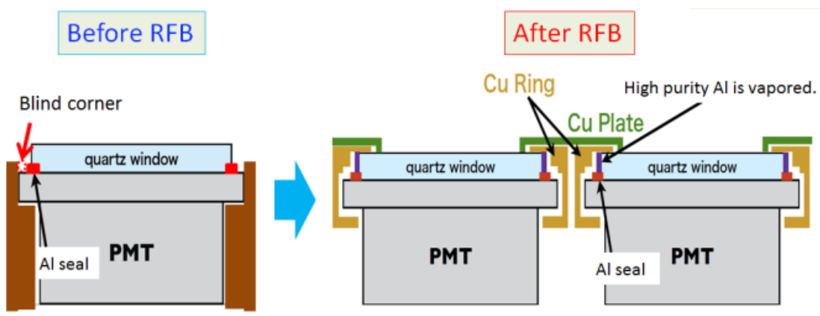


**FIGURE 1.** Schematic view of the ID PMT covers before and after RFB.

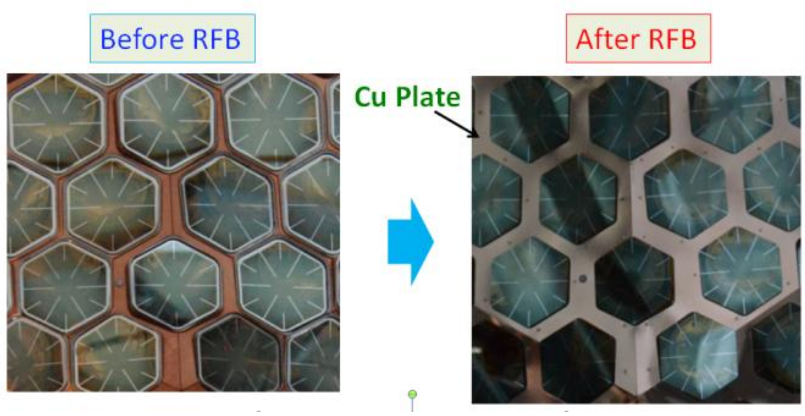


**FIGURE 2.** Photos of the ID surface before and after RFB. Copper plates are installed on the surface of detector to reduce the grooves and gaps between PMTs.

## SURFACE PURITY CONTROL

PMTs were cleaned by sinking and wiping using $HNO_3$. In our test, ~70% of surface $^{210}$Po can be removed in this method. Copper plate was newly made by oxygen free copper and electro-polished. After the plate is electro-polished, it is kept in the EVOH bag. During PMT and copper plate assembly, radon daughter accumulation on the surface can be expected. In order to prevent the accumulation, it is important to keep clean environment where there is low aerosol particles and low radon in the air.

## Low radon air and clean environment

After the commissioning run, we made various efforts to clean experimental hall and succeeded in reducing number of particles in the air down to <$10^3$ /ft (class 1000) as shown in Fig. 3. Figure 4 shows the radon concentration in the experimental hall and the water tank measured by 1 L and 70 L radon detector [3], respectively. Radon concentration in the experimental hall is kept as that in the atmosphere out of mine by purging the outside air by ~5 $m^3$/min. PMT and copper plate assembly was conducted in the water tank [2] located in the experimental hall. Low radon air is flowed with 10 $m^3$/hour into the water tank where the radon concentration succeeded in being kept ~0.2 Bq/$m^3$ during the assembly. In the water tank, we have made a clean booth using ULPA filter for the assembly. With the various efforts to reduce the aerosol, we have achieved to keep <10 /$ft^3$ (class 10) in the clean booth during the assembly.

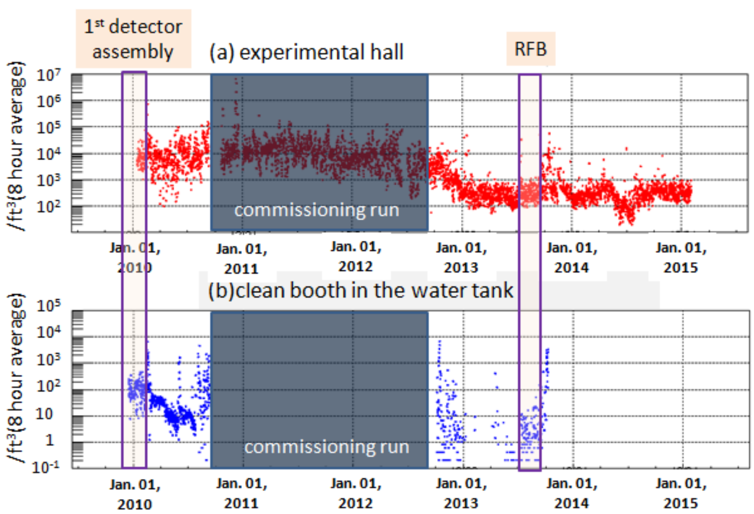


**FIGURE 3.** Number of particles in the air from the 1st detector assembly period is shown. Upper figure shows number of particles in the experimental hall and lower figure shows number of particles in the clean booth in the water tank. Both are measured by Met One Model 227 made by Hach Ultra Analytics, Inc.

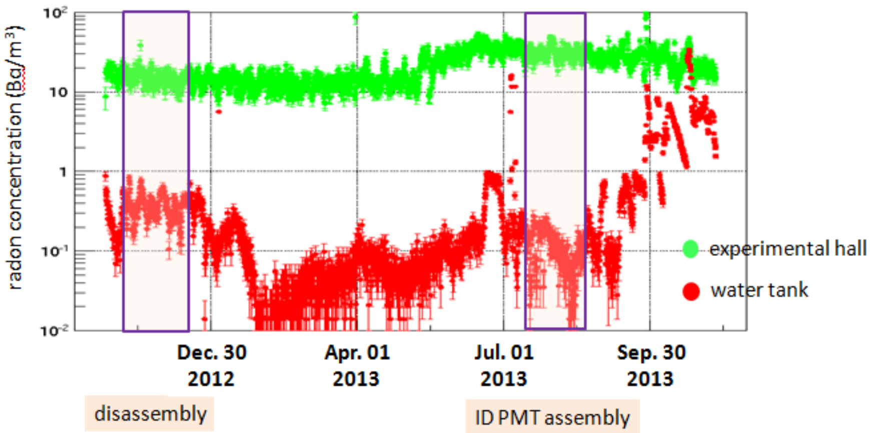


**FIGURE 4.** Radon concentration during RFB is shown. After the detector assembly, radon concentration in the water tank became higher because the materials for OD assembly were installed from the opening. The ID is insulated during the OD installation.

## Current background level

The detector RFB has finished and we have started data taking in November 2014. We have already taken more than one year of data. The event rate after standard data reduction above 5 keV became lower by one order of magnitude. To check the surface background, we estimated $^{210}$Po alpha candidate events. Figure 5 shows scaled energy vs. maximum PE of a PMT / total PE in the alpha-like events sample which is selected using decay constant from waveform fitting. Surface $^{210}$Po alpha events are expected around 3MeV. If the $^{210}$Po alpha events occur on the surface of the PMT, the signal of the PMT is very large. Therefore maximum PE of a PMT / total PE becomes large, ~0.18. On the other hand, if the $^{210}$Po alpha events occur on the surface of the copper plate, maximum PE of a PMT / total PE is not so large, ~0.01. After selecting the events above the red line in Fig. 5 and using maximum and second maximum PE ratio, PMT surface activity is estimated to be 6.42+0. /-0.45 (sys.)±0.13 (stat.) mBq. Copper plate surface activity is estimated to be 1.09+0.88/-0. (sys.)±0.04 (stat.) mBq using the events below the red line in Fig. 5. We observed non-negligible amount of copper plate surface background candidate events. However, the cause has not been identified.

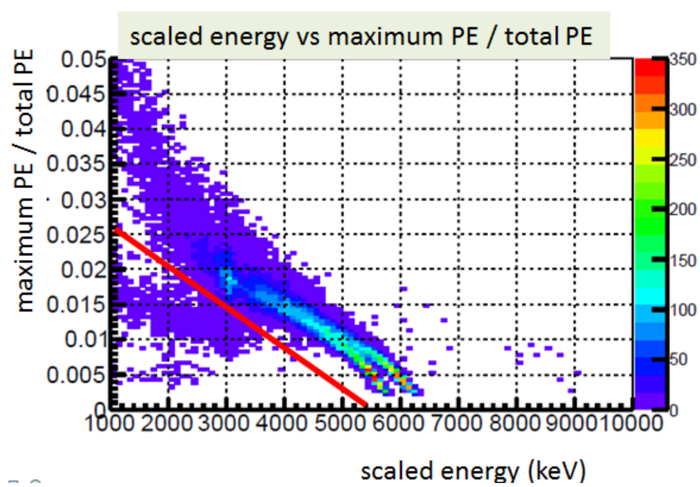


**FIGURE 5.** Scaled energy vs. maximum PE / total PE in XMASS data after RFB.

## Alpha counter measurement

To investigate the cause of the current surface background and also for future study, we have installed a low background alpha counter, XIA UltraLo-1800 in the clean room Kamioka underground in January 2015 as shown in Fig. 6. Figure 7 shows the energy distribution of the background measurement using very low background copper disk. Because we have installed it underground and also minimized background from upstream line of Ar gas which is used in the alpha counter, the achieved background level is estimated to be $(1.4\pm0.3)\times10^{-4}$ alpha/cm$^2$/hr, that is lower than observed background in XMASS, $2.7\times10^{-4}$ alpha/cm$^2$/hr. We are now studying the origin of the background using the alpha counter.

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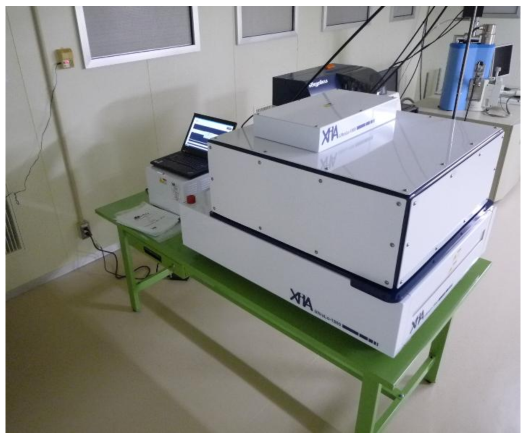


**FIGURE 6.** Photo of UltraLo-1800 (XIA) installed in clean room underground Kamioka.

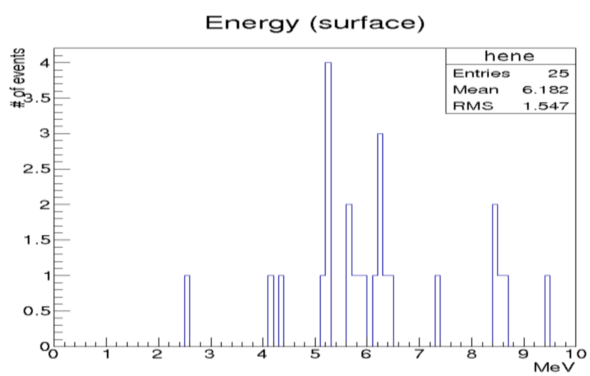


**FIGURE 7.** 12.2days background data taken with clean copper disk provided by XIA.

## FUTURE PROSPECT

We are planning to make a ton scale fiducial volume (5 tons in full volume) detector, XMASS 1.5. The detector structure of XMASS 1.5 is similar to the current one. The main difference is the PMT. We plan to use low background aluminium and also the round shape of PMT photocathode, which is sensitive to the light emitted around the side of PMT. It would help to reduce the surface background. The target sensitivity is $\sim10^{-46}$ cm$^2$ for 100 GeV WIMP as shown in Fig. 8.

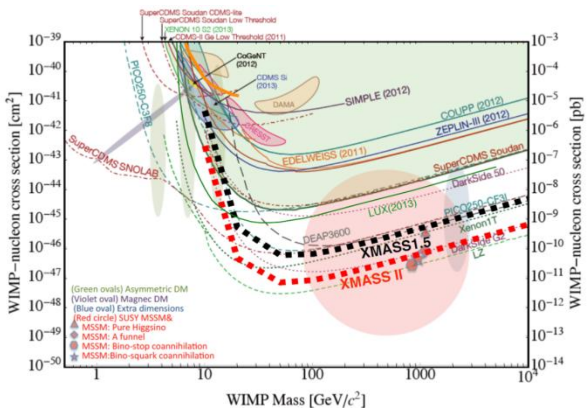


**FIGURE 8.** Sensitivity of XMASS 1.5 and XMASS II.

## REFERENCES

1. Y. Suzuki, arXiv:hep-ph/0008296.
2. K.Abe *et al*, Nucl. Instrum. Methods A 706, 78 (2013).
3. Y. Takeuchi *et al*, Nucl. Instrum. Methods A 42, 334 (1999).