Radon Removal from Liquid Xenon

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for the **XMASS collaboration**:

1.) Introduction

Despite lining the experimental hall with an effective Radon (^{222}Rn, forthwith: Rn) barrier, introducing especially prepared Rn-free air into the hall, and carefully choosing the detector materials, Rn is continuously emanating from those building materials and in an underground setting from the surrounding rock. Given a noble gas' power to penetrate barriers, it has the potential to become a major component of the background to WIMP searches with our XMASS detector (see posters 160 and 163 for more detail on the XMASS experiment).

In XMASS we therefore plan to actively remove Rn from the liquid Xenon (forthwith lXe) in the detector as we recirculate the lXe throughout the operation of the experiment.

In this poster we discuss the experimental program and ideas designed to remove Rn from the liquid phase of Xenon directly.

Independently from this effort we have the proven capability to remove Rn from the gas phase of Xe by passing it through appropriately designed charcoal filters..

2.) lXe Circulation Test System

An independent lXe circulation test setup was built and is operated near the XMASS experimental hall in the Kamioka mine. Its twofold purpose is to verify the operating parameters for the lXe circulation system components to be used in XMASS and to provide a testbed to evaluate the efficiency of various proposed methods to remove Rn from the liquid phase.

The first phase of experimentation at this facility is concluded and has established the design parameters for the circulation system now nearing completion at the XMASS 800kg detector. The second phase devoted to Rn removal is currently underway and results are imminent. Unfortunately they are not yet available at this time.

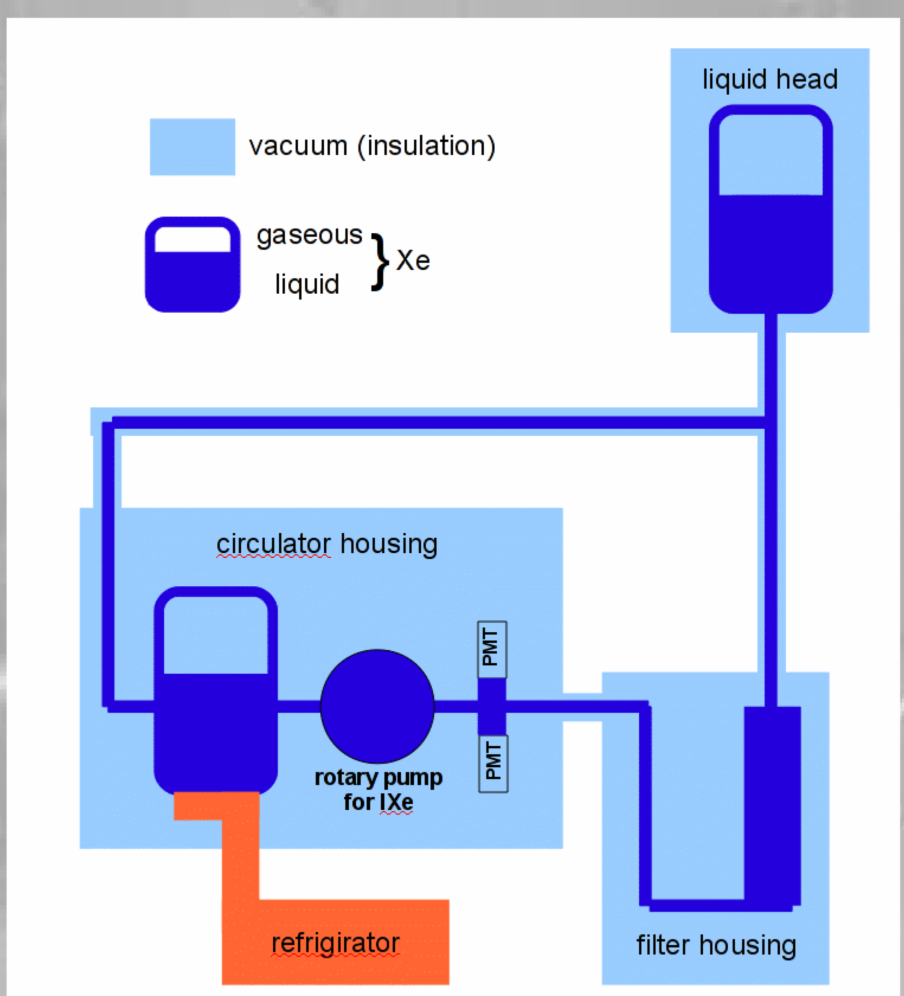

Figure 1: Schematic overview of lXe circulation system

Figure 1 shows a schematic view that summarizes the salient features of this test system. Rn can be injected into the system from a ^{226}Ra source and detected through the Bi-Po coincidence in its decay chain with the photomultipliers reading out the lXe scintillator. The liquid head simply allows the system to reflect the real pressure situation as will be encountered at the XMASS 800kg detector.

The filter housing is designed to allow us to exchange filters or cartridges with e.g. charcoal while maintaining liquid circulation through the rest of the system. Evidently not all connections are shown in figure 1.

3.) Mechanisms for Rn Removal

We are currently exploring two fundamentally different approaches to Rn removal from lXe.

The first is based on the same idea used in the gas phase: By means of a weak induced dipole moment Rn gets loosely attached to the inner surfaces of specially chosen highly porous materials like charcoal or molecular sieves. If this bonding slows the progress of Rn through a column of this material enough to allow most of the Rn to decay before it emerges from the other end of the column, Rn is effectively removed from the Xe.

The second idea is based on the electronic properties of liquid noble gases. It is found that all liquid noble gases exhibit an electronic structure akin to a solid state insulator or semiconductor with a fully occupied valence band and an – at zero temperature – unoccupied conduction band. Impurities or contaminants introduce defects in this electronic structure that will trap either electrons or holes that may be moving through the liquid. Unlike in the crystalline structures of solids the positions of individual atoms or molecules are not constraint by a rigid lattice, and once a charge is attached, the contaminants can be drifted through the liquid by means of an electric field [1]. If for example a hole can be attached to a Rn atom, Rn can be drifted out of the main flow into some dedicated volume where it awaits decay.

4.) Status of the Projects

A variety of charcoal samples and molecular sieves are ready for deployment in our circulation test setup, and their respective efficacy should be known within the next few weeks.

The main challenge for “sweeping” out the Rn by means of drifting after attaching electrical charge to it is posed by uniform injection of these charges into the liquid from an extended electrode. Field emission of both hole and electrons into both lAr and lXe is proven from a single tip [2]. The challenge now is to provide sufficiently uniform injection of charges over a suitably large area so that impurities from a whole volume can be swept out.

The current best idea for a device to inject such currents is shown in figure 2. With the help and advice of Prof. Y.H. Kim and his student at SNU, who produced the samples shown in figure 2, we are replicating their process [3] in our lab.

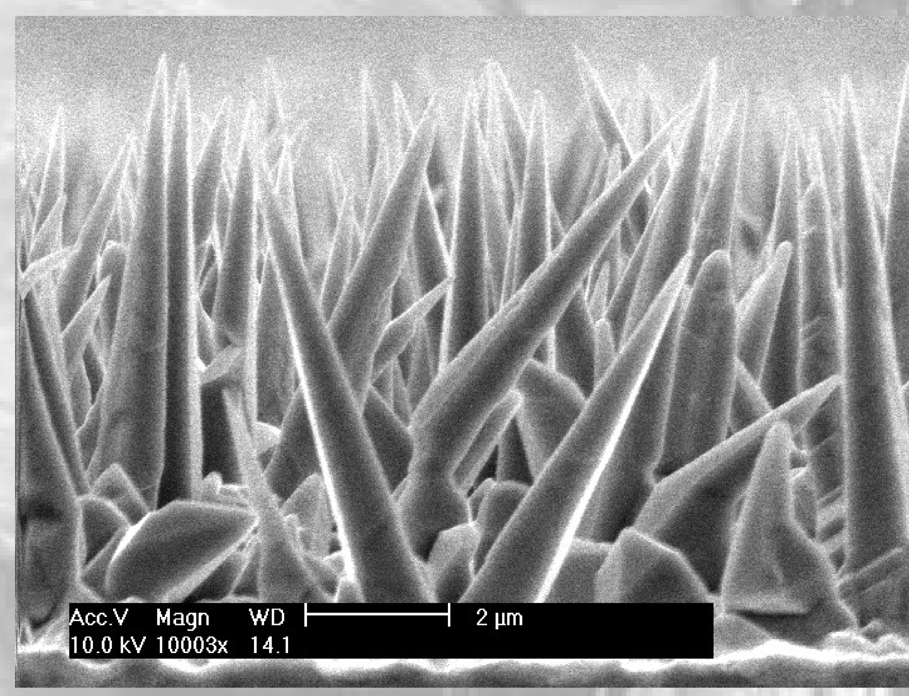

Figure 2: Copper micro-tips grown at SNU in Korea (reproduced with permission)

Once the first tips are electroformed in our own lab verification of both hole and electron current injection will be sought in lAr. If successful, Rn removal from lXe will subsequently be directly tested in our circulation test system.

5.) Prospects for further Developments

While Rn removal is particularly challenging as Rn itself is an inert gas that cannot simply be bound chemically, it also offers a break as it will decay. If it can be cornered, waiting will see it disappear of its own. The same is not true for other contaminants that may be emanating from surfaces and materials. While they can typically be bound chemically though, so called “getters” will typically be most efficient at high temperature, incompatible with the liquid phase of Ar or Xe.

The drift of charged ions of molecules like for example O_2^- has been documented in the literature. We can therefore envision a setup where in consecutive volumes first electrons and later holes are driven through the primary circulation flow, drifting impurities out of that primary flow into a smaller secondary flow that can then be evaporated into hot getter and other dedicated units to remove the concentrated contaminants. If funding can be secured, we plan on investigating the potential of this idea in the near future.

6.) Conclusions

The XMASS collaboration is currently testing various schemes to drastically reduce if not eliminate background events induced by Rn decay. These experiments will come to a conclusion within the next couple of weeks, in time to install the most reliable method at the XMASS 800kg (100kg fiducial) detector which will be operational this fall.

If the current injection method is proven to be effective, it can certainly also be used in lAr experiments. If furthermore it can be proven to be effective in concentrating other impurities which do not simply decay away with time, it may open up a new and highly efficient way to continually purify the bulk of the detection medium in the more massive next generation lXe and lAr experiments, helping to maintain their optical as well as their charge extraction properties over extended periods of time.

XMASS at the Kamioka Observatory is well on its way towards exploring its part of the WIMP Dark Matter parameter space and establish its readily scalable technologies for the next round of WIMP searches, low energy solar neutrino measurements, and neutrinoless double beta decay searches that can all be simultaneously targeted with a future 20 ton (10 ton fiducial) lXe experiment at the Kamioka Observatory.

References:

[1] W.F. Schmidt, O. Hilt, E. Illenberger, A.G. Khrapak, Radiation Physics and Chemistry 74 (2005) 152
[2] K. Arii, W.F.Schmidt, IEEE Transactions on Electrical Insulation E-19 No.1 (1984) 16
[3] W.Y. Sung, W.J. Kim, S.C. Yeon, S.M Lee, H.Y. Lee, Y.H Kim, Proceedings of the 19th International Vacuum Nanoelectronics Conference (IVNC) & 50th International Field Emission Symposium (IFES) (2006) 101