DRAFT NEXT-100 Gas System Requirements

1 Purpose and Summary

This is a document listing the requirements for a gas control system for the NEXT100 Xe double beta decay experiment.

Contents

2 Description

~~The detector consists of a pressure vessel, with Xe 136 gas filling the entire volume.~~

Below is a cross section Figure 1 showing the detector:

During operation of the detector, Xe is circulated continuously through the Xe vessel using an axial flow pattern; it is fed in on one end and out the other end where the effluent is passed through a gas purification system.

Inside the pressure vessel, mounted to one head is an array of photomultiplier tubes (PMTs). These PMTs are designed to capture the light from electroluminescence of the EXe which is the technique used to count the total number of ionization electrons from a double beta decay event. The PMT's cannot withstand the 15 bar Xe pressure, so they are enclosed in titanium tube pressure-proof enclosure having a sapphire window on one end. Cables from the PMT exit through a flare fiting into a copper tube that connects to a central manifold that is bolted to the underside of the axial flange of the pressure vessel head. Vacuum is is maintained inside this central manifold (and thus to the inside of the PMT enclosures); this allows the enclosures to be sniffed for Xe leakage. The PMT bases will be potted in vacuum qualified epoxy resin to allow them to operate normally with no flashover. All the seals to the outside world on the pressure vessel and the quartz tube assemblies will be helicoflex seals.

During operation, the enriched Xe will be maintained as a gas at room temperature and 15 bar (abs) pressure inside the detector. Xenon is a rare and expensive gas even in its natural isotopic ratio (NXe) for which Xe 136 is 9% of the total. NEXT100 will utilize enriched Xe 136

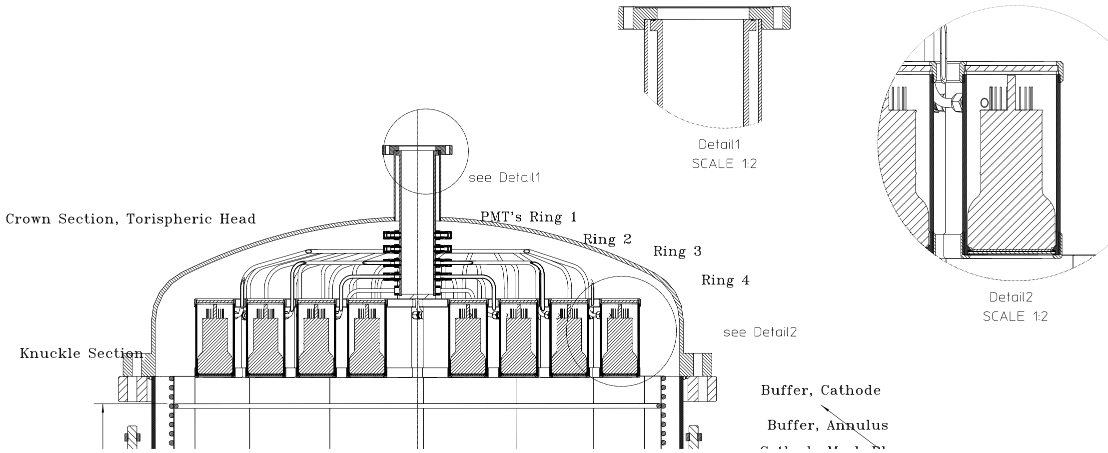

Figure 1: NEXT100, detector cross-section

at a 90% or greater ratio; estimated value is 1.5 M$ for 100 kg EXe. It is imperative that any significant loss of Xe is avoided, under any foreseeable circumstance. This is also true if running with depleted (of Xe136) Xe (DXe), which may be done as an experimental control.

3 Parameters

4 Gas System Requirements

The pressure vessel/gas system must be capable of pressurizing, circulating, purifying, and depressurizing the detector with either EXe, NXe, DXe, He, Ar (for leak checking) with negligible loss, and without damage to the detector. There is a high priority on avoiding loss of EXe, due to its cost and availability. A list of requirements in approximate decreasing order of importance is shown below:

1. Pressurize vessel, vacuum to 15 bar absolute (bara) - 1 hour max. - EXe, DXe, Ar
2. Depressurize vessel, on fault command, 15 bara to 1 bara - 10 sec max. - to closed reclamation system
3. Depressurize vessel, normal operation, 15 bara to vac. - 1 hour max. - to closed reclamation system
4. Pressure relief for fire or other emergency condition (to ASME std.) - vent to closed reclamation system

Table 1: NEXT100 Gas System Parameters

Parameter	amt.	units
Active Mass, Xe	100	kg
Total mass, Xe	140	kg
Maximum Operating Pressure (MOP)	15.0	bara
Maximum Allowable Working Pressure (MAWP)	16.4	bara
Pressure vessel Inner Radius	0.57	m
Pressure Vessel Inner length	1.6	m
Pressure Vessel Volume	1	m^3
Temperature Range, Pressure Vessel	10-30	C

5. Maximum leakage, EXe through seals (total combined) - 100 gm/yr
6. Maximum loss, EXe to atmosphere - 10 gm/yr
7. Accomodate a range of gasses - EXe, DXe, N2, dry air, Ar, 95N2/5H2, EXe/TMA, EXe/CF4
8. Circulate all gasses through detector- 10 SCM/min in axial flow pattern
9. Purify EXe continuously - inlet condition to be $<$ 1ppb O2, CO2, N2, CH4, THC$<$1ppt Ra
10. Pull vacuum $1*10^{-6}$ torr at vessel port
11. Provide 1 bara N2 to PMT enclosure system
12. Provide gas circulation of 1 SCM/min through annulus

Requirement 1 above, is performed with a manual valve and regulator. 1/2" dia connections are sufficient to meet the fill time specification. Requirement 3 is provided by opening a valve to a pre-chilled cryogenic recovery high pressure cylinder, again 1/2 " dia. lines are sufficient for this flow rate. Requirement 2 exists to protect against excessive loss of EXe in case a leak develops. It is provided by opening a fast valve or fast-actuatable burst disk leading to an evacuated recovery cylinder of 15x the pressure vesssel volume; it will require a much larger port in the pressure vessel, 4" dia. There will be anumber of fault conditions that will open this valve, such as high Xe pressure in any of the sniffer ports that are installed between pressure vessel seals to satisfy requirement 5. Requirement 4 is met by having a pressure relief valve or burst disk mounted directly to the pressure vessel, with a low conductance pipe leading to the evacuated recovery cylinder. High reliability of recovery disallows use of an inflatable gas bag as an option to the recovery cylinder.

The general schematic of the gas system is given in Figure 2 and Figure 3 shows the three dimensional engineering model of the gas system showing the main valving and piping. The re-circulation pump, vacuum pump and cold traps are not shown

4.1 Pressure Control

Pressure control for Xenon, (whether EXe, NXe, or DXe) will be a semi-manual open loop control; the Xe pressure will be set to a set point (with a maximum ramp rate).

4.2 Flow control

During normal operation the ^{136}Xe gas circuit is a closed system. Therefore the flow control can be achieved primarily by means of the re-circulation pump and a bypass line. The re-circulation

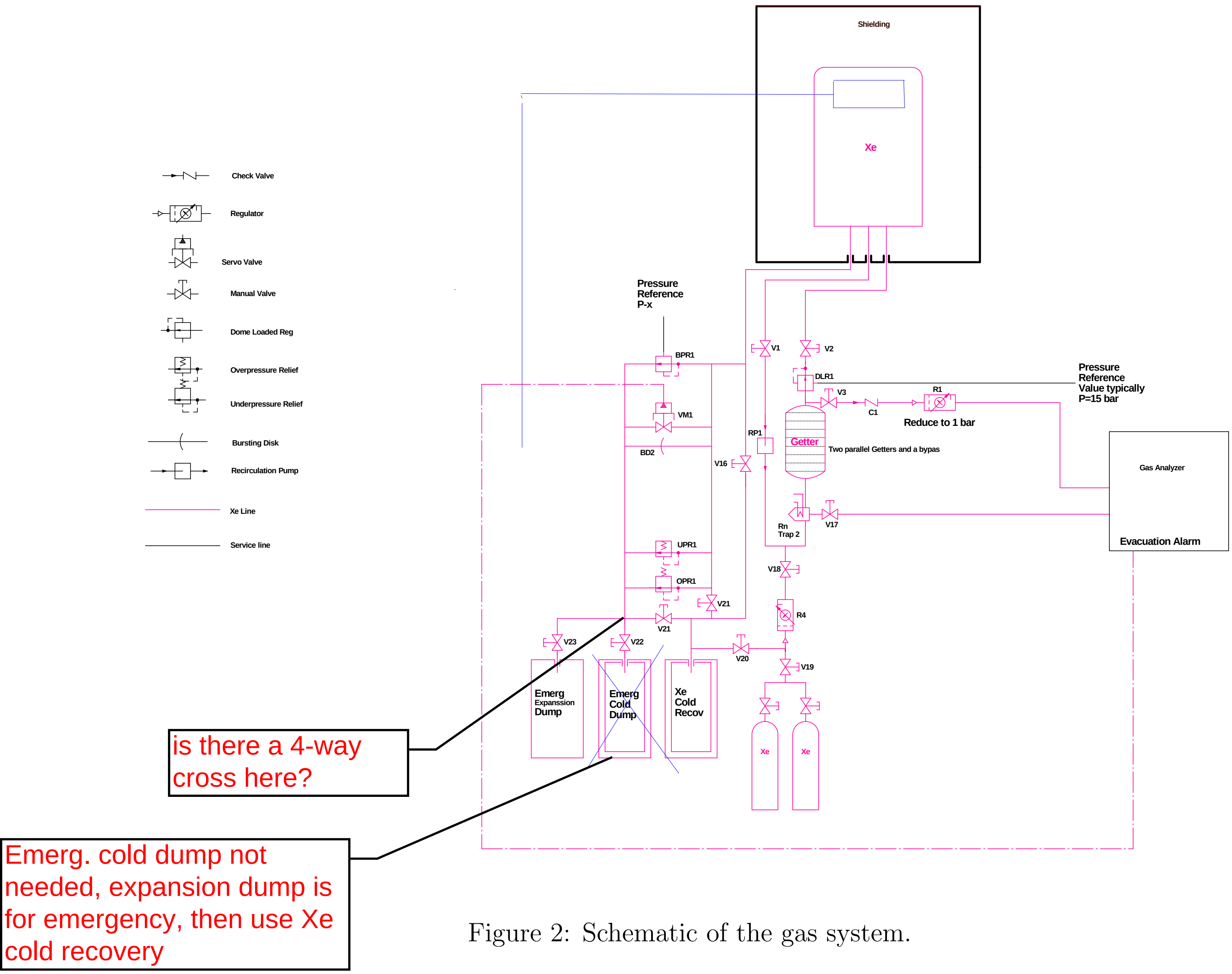

Figure 2: Schematic of the gas system.

operates at a set flow rate of 200 slmp at 15 bar. In order to reduce the flow rate through the system some of the outlet gas can be diverted, by means of a manual bypass valve, into the inlet of the pump. The layout of the valving is shown in Figure 4. As a diagnostic flow rates can be monitored and logged using a Teledyne-HASTINGS HFM-D-301 flow logger Figure 5. However, no active flow control is needed.

The most vulnerable component of the gas system is the re-circulation pump. The enriched ^{136}Xe used in NEXT 100 project is very expensive and therefore the pump to move the gas through the re-circulation loop must have sufficient redundancy to minimize the probability of failure and leakage. Furthermore, to preserve the purity of the gas all metal to metal seals must be used. A pump manufactured by Pressure Products Industries [1]. This pump is made with metal-to-metal seals on all the wetted surfaces. The gas is moved through the system by a triple stainless steel diaphragm. Between each of the diaphragms there is a sniffer port to monitor for gas leakages. In the event of a leakage automatic emergency shutdown can be initiated Figure 6.

In terms of redundancy and reliability Figure 7 is showing failure curve for a single diaphragm.

[1] http://www.pressureproductsindustries.com/compressors/diaphragm_compressors.html

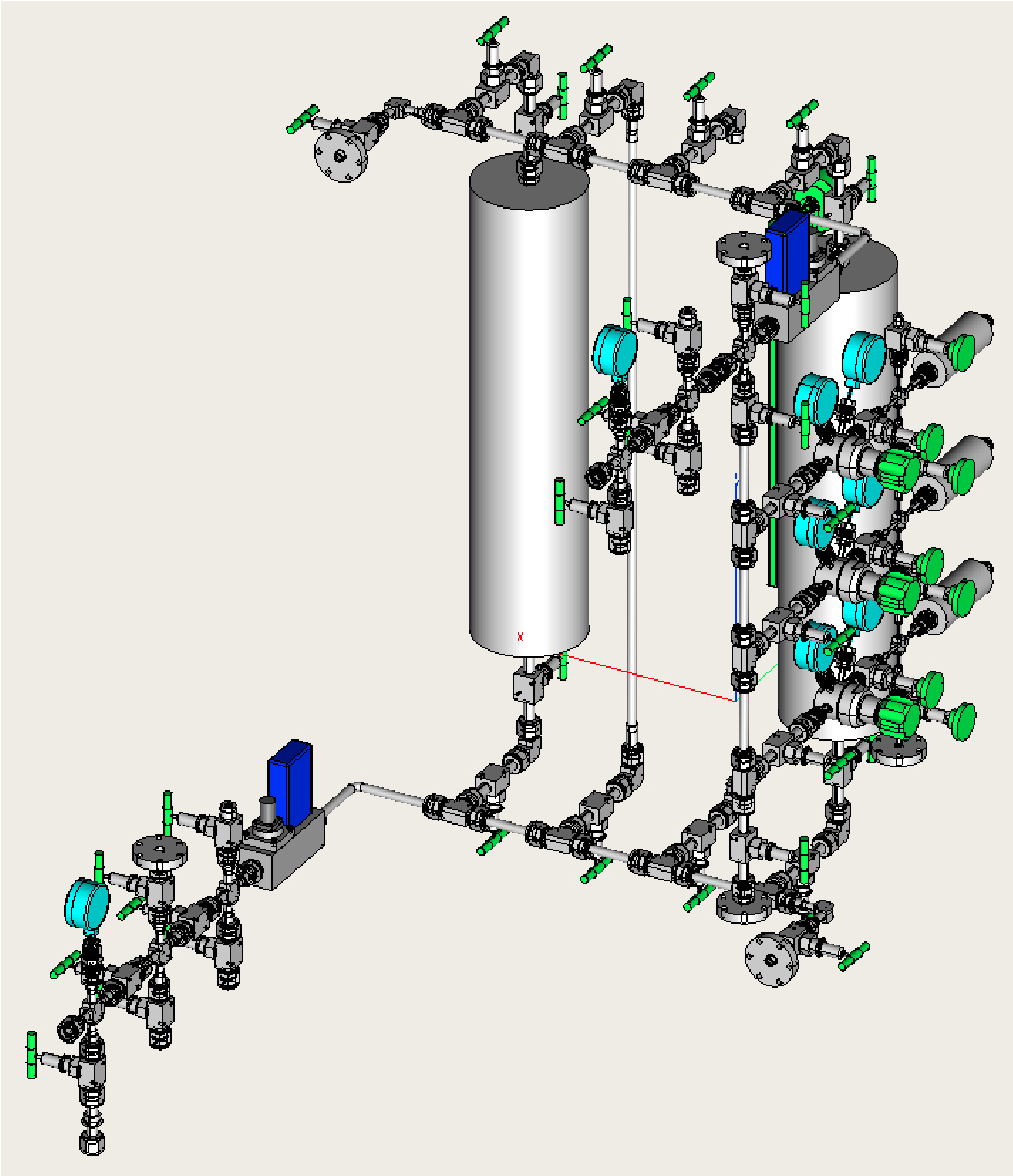

Figure 3: Three dimensional engineering model of the gas system piping.

Under normal condition the time between failures during continuos operation per diaphragm is in excess of 40 years. Therefore this is a very safe, clean and reliable pump with a nominal maximum flow rate of 200 slpm.

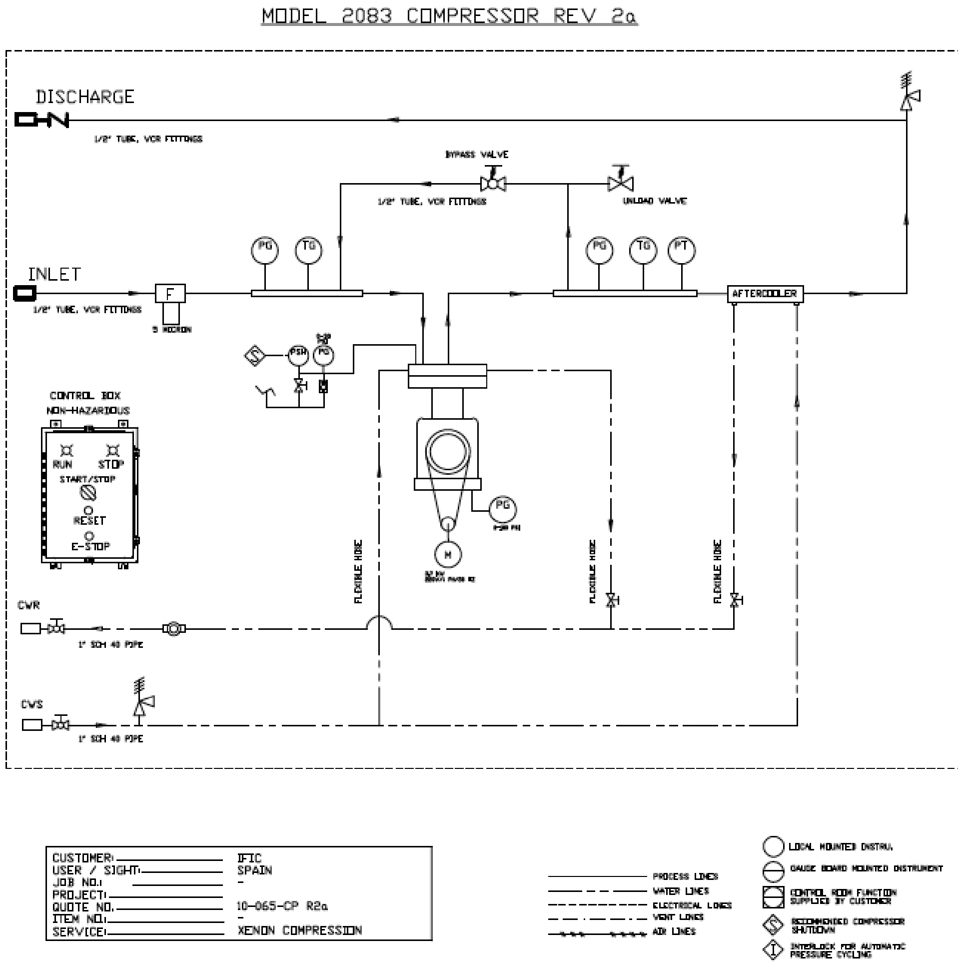

Figure 4: Schematic for the re-circulation pump.

4.3 Gas Purification

MicroTorr cold getter model number MC4500-902FV has been chosen as the purification filter for the Xe gas. Capable of removing electron negative impurities to less than 1 ppb the model chosen has a nominal flow rate of 200 slpm well in excess of the required flow rates for NEXT 100 offering sufficient spare capacity. The gas system will contain two such getters in parallel with a bypass. This configuration has been developed and used by the smaller gas systems operating at UNIZAR and IFIC. The second spare getter is placed in parallel in the event of accidental contamination of one of the getters allowing uninterrupted running. The ability to bypass the getters will allow the testing of the purification of the gas and aid in diagnostic and monitoring of the gas system. A drawing of the MC4500-902FV getter is shown in Figure 8.

While cold getter technology is capable of reaching the required purity levels in water and oxygen a hot getter, like one shown in Figure 9, can also remove nitrogen and methane. Furthermore, 362 g of cold getter material has been measured to emit 1.64 atoms of Rn [RnI]. In that regard a future upgrade to a hot getter technology has been considered. However, the high cost of hot getter may not be justified if other effective means of removing Rn can be found like a Rn cold trap (§4.3.1).

Figure 5: Example of a Teledyne-HASTINGS flow sensor for the NEXT 100 gas system. The pressure drop across this unit at 10 bar is approximately 0.03 bar.

Figure 6: Example of the re-circulation pump chosen for the Xe purification gas system. This is a triple stainless steel diaphragm pump capable of 200 slpm flow rates.

4.3.1 Rn Trapping:

Radon is a natural by product in the decay chain of Uranium. Therefore most materials will emanate Rn adding to the radioactive background. Several research groups in the word have

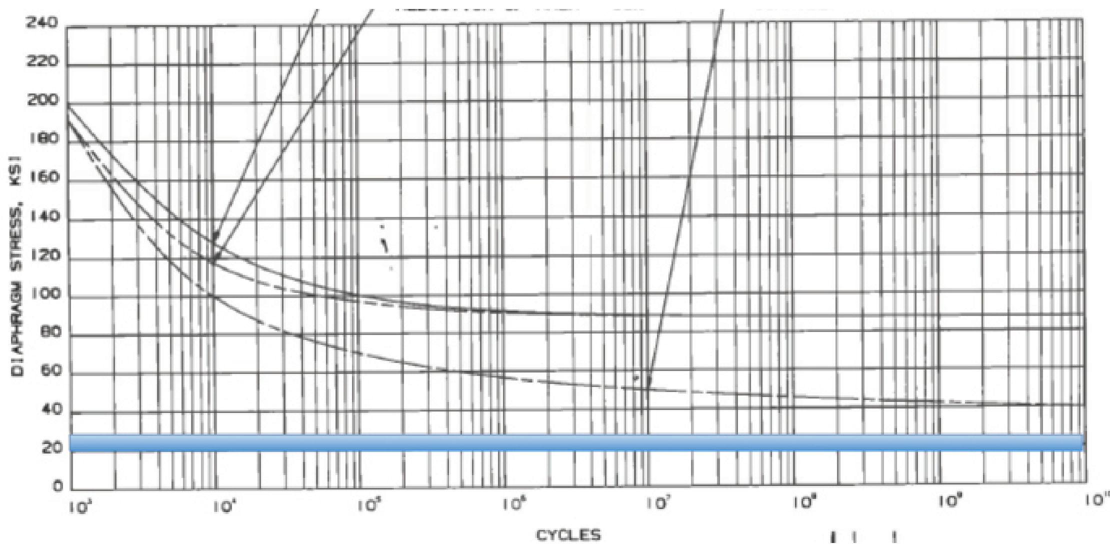

Figure 7: Failure curve for the single stainless steel diaphragm as a function of operating cycles. The pump is designed to operate in the shaded band. This translates into an expected time to failure of continuos operation in excess of 40 years.

been interested in developing methods of trapping Rn and preventing its entry into ultra low background detectors. A group at Queens University, Kingston Ontario, Canada has recently produced such a device [O'D11]. Figure 10 shows such a trap. The trapping mechanism operates by passing the gas being filtered through a cooled column of activated carbon spheres. The carbon slows the diffusion of Rn and the low temperature retains the atoms in the trap.

The trap was tested with Ar gas containing 1 mBq/m^3 activity due to ^{222}Rn isotope. Figure 11 illustrates the efficiency of this setup for ^{222}Rn trapping.

It would be useful for NEXT 100 to develop and test a ^{222}Rn trap similar to one describe above for use with Xe. The operating temperature of this trap needs to be higher that one developed by the Queens University as Xe will also freeze at -110°C. This can prove a very cost effective way of reducing radioactive background due to ^{222}Rn in the NEXT 100 detector.

Another possibility for a ^{222}Rn trap is a chamber filled with copper wool kept at a temperature where Rn freezes and Xe remains gaseous. The large surface area of the copper wool would offer condensation sites for the Rn. This may be a preferable trap to one utilizing activated carbon. For the carbon to be effective in removing Rn it needs to be loaded with an amount of Xe. This Xe would effectively be wasted particularly when NEXT 100 will be filled with enriched Xe.

Thus a Rn trap development and characterization would be a very important project to be undertaken by the collaboration.

Implementation:

First Stage Commission the system with cold getters and determine whether they would be suitable for the NEXT-100 vessel.

Second Stage Develop and test Rn trap

Third Stage Change to hot getters should it result necessary.

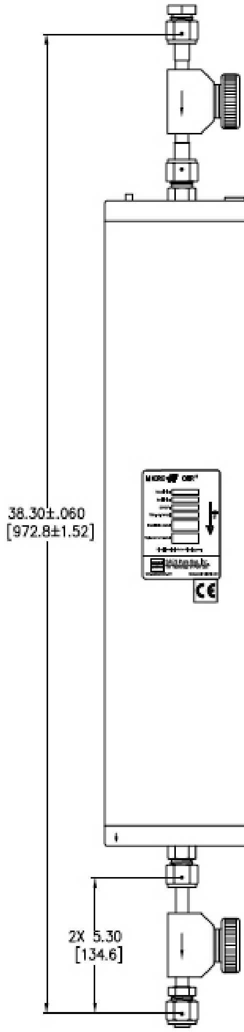

Figure 8: Drawing of the MC4500-902FV SAES Pure Gas getter, with VCR valves, to be used for the purification of the Xe. The gas system will contain two such parallel getters.

Figure 9: Example of a heated SAES getter model number PS4-MT50 with nominal flow of 150 slpm. This is a possible future upgrade to the gas system. The hot getter has been reported to be better at filtering out ^{222}Rn and therefore can be preferred purification technology to achieve ultra low radiation background rates.

Figure 10: ^{222}Rn trap operated at SNO lab.The trap uses activated carbon spheres to slow transmission of radon atoms. The trap tested on removing Rn from Ar gas and operates at a $-110°$C.

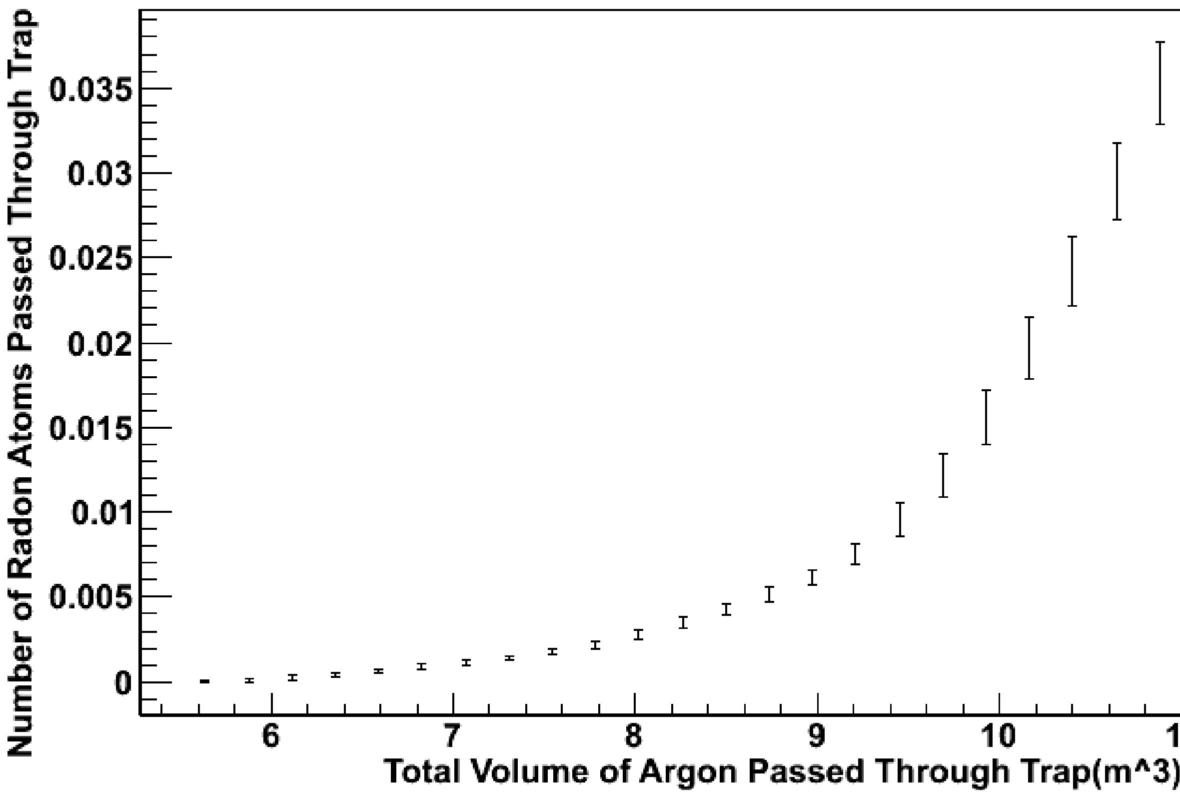

Figure 11: Total number of ^{222}Rn atoms that got through the trap as a function of the amount of argon gas for a 1 mBq/m^3 assumed radon concentration in the argon supply.

4.4 Xenon Reclamation

As the Xe gas that will be used in the NEXT-100 is expensive an automatic recovery system will be needed to evacuate the chamber in a case of an emergency condition. We are discussing the solution has been proposed by the LUX collaboration where a permanently chamber cooled by liquid Nitrogen will be used.

We have identified two primary conditions to trigger automatic evacuation. The first condition is an overpressure that could potentially cause an explosion. Because the gas system for NEXT-100 will be operated in a closed mode the overpressure condition could occur only under two possible conditions. The first is during the filling stage of the operation, when the system is being filled with gas and the second in the case of thermal expansion of the gas due to laboratory fire. In the case of overpressure we will have an electromechanical valve, activated by a pressure switch, that will open a pipe from the NEXT 100 chamber to a permanently cold recovery vessel. This will then cryo-pump Xe into the recovery vessel, causing the Xe to freeze in the recovery tank. In the event of the electromechanical valve failing, a mechanical spring-loaded relief valve, mounted in parallel to the electromechanical valve, would open and allow the Xe to be collected in the recovery vessel. As a final safety feature in case both the electromechanical and spring-loaded valves fail a bursting disk, also mounted in parallel to the electromechanical and spring-loaded valves, will burst connecting the NEXT 100 chamber with the recovery vessel causing the Xe to be thus evacuated.

The second emergency condition would be detected as under-pressure indicating a leak in the system. which would require evacuation of the NEXT 100 chamber to prevent Xe loss. If this is detected an electromechanical valve sensing under-pressure will open and evacuate the Xe into the recovery vessel.

As the recovery vessel is to be used for safety there cannot be a valve to close once the emergency recovery has been completed. Therefore in the event an automatic system is triggered a signal will be sent to an operator to arrive at the laboratory to supervise post recovery procedures. The aim of post recovery is to move the collected Xe from the recovery vessel to a closable gas bottle for future purification and use once the problems that caused the emergency conditions have been rectified. This operation must be conducted by the responsible person and would involve cryo-pumping the gas collected in the recovery vessel into a stainless steel bottle which will be valved off post transfer.

The same system can be used for controlled recovery of Xe if work needs to be done on the NEXT-100 chamber.

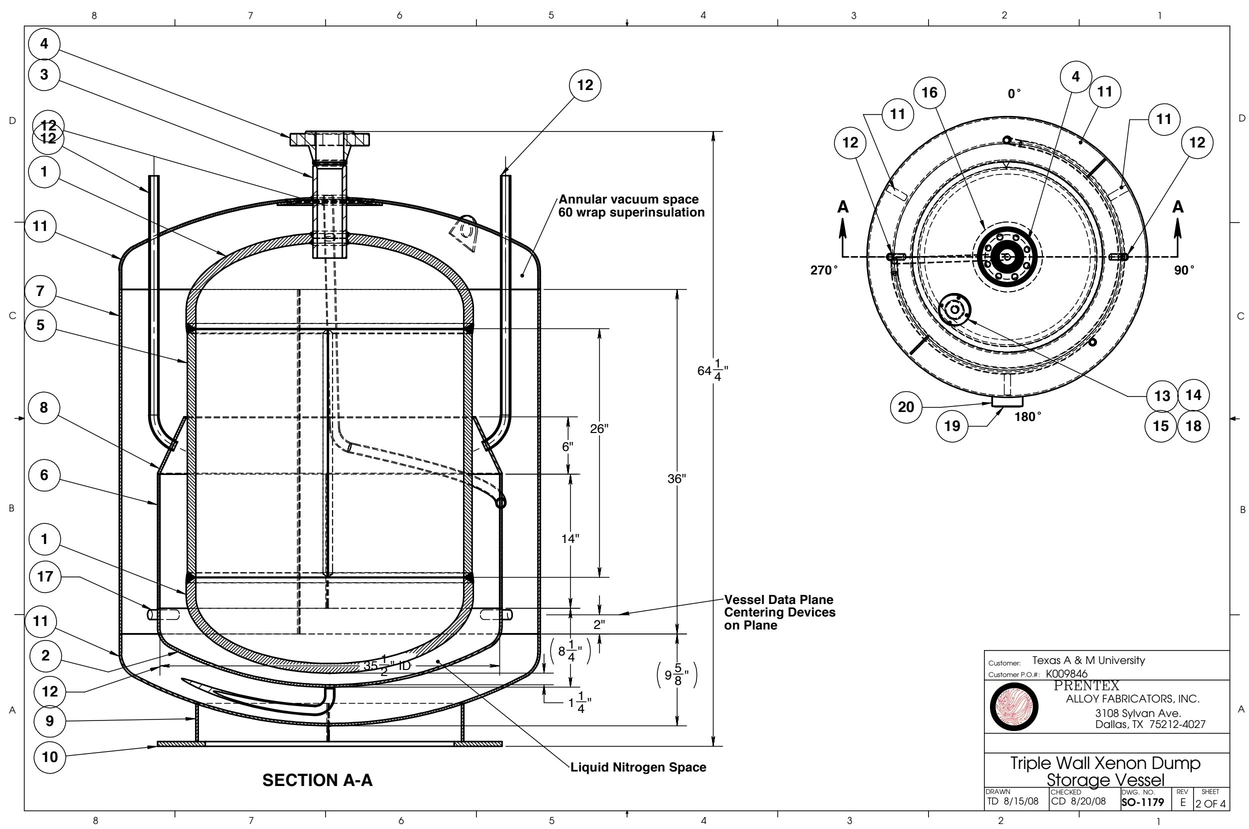

Figure 12: Example of a Xe cryo-recovery vessel. This vessel is part of LUX recovery system.

An alternative or an addition to the Xe reclamation system could be a large expansion tank(s) similar to that used by the ZEPLIN II and III experiments. Figure 13 show a picture of one of these tanks. The aim of an expansion tank would be to quickly reduce the Xe pressure in the system down to 1 bar to prevent gas escaping through a breach. The advantages of such a devise would be the ability to reduce the pressure much more quickly that would would be possible with a cryo-dump described above. The disadvantage, however, would arise due to the large necessary volume of such an expansion tank and the difficulty associated with vacuum evacuation and backing such large volume.

Perhaps the most prudent avenue here would be to have both systems: cryogenic and expansion dumps but deploy them staged in time as resource become available.

Figure 13: Example of an expansion tank that can be used for reducing the pressure in the NEXT 100 detector in an event of breach. One of the expansion tanks, from a set of two, used for ZEPLIN II and III is seen on the far background right.

The other issue that may need to be consider is the reclamation of Xe that may be leaking through porous seals into the vacuum or a buffer gas. For instance in the design for the energy plane shown in Figure 1 Xe could leak through the photomultiplier reinforcement can. If the buffer gas is present on the other side of the seal ^{136}Xe will mix with that gas. Although, the buffer gas will be continuously sniffed by the RGA to quantify and minimize such leakages. Nonetheless, through the use of a cold trap as one shown in Figure 14 ^{136}Xe can be reclaimed. The double concentric coils seen in the figure, by having a liquid at a Xe freezing temperature going through them, would freeze ^{136}Xe on the coils as the buffer gas circulates through the trap. Periodically the trap will be heated to evaporate the trapped ^{136}Xe into the holding vessel for re-purification. However, if instead of the buffer gas the volume behind the energy plane will be continuously vacuum pumped. By pumping through the trap ^{136}Xe will also condense on the cold and can be subsequently reclaimed.

4.5 Vacuum

To insure the cleanliness of the chamber and the Xe gas system prior to the introduction of Xe both the chamber and the Xe gas system need to be vacuum evacuated to as low pressure as possible. A reasonably good vacuum is in the range of 10^{-5} to 10^{-6} mbar. To achieve this the turbo-molecular pump needs to be positioned as close as possible to the vessel being evacuated. For that reason the turbo-molecular pump station will be directly connected to the NEXT 100 vessel through a large conductance valve rated for vacuum and pressure as close as possible to the vessel inside the shielding. The valve satisfying this requirement is shown in Figure 15, it is rated

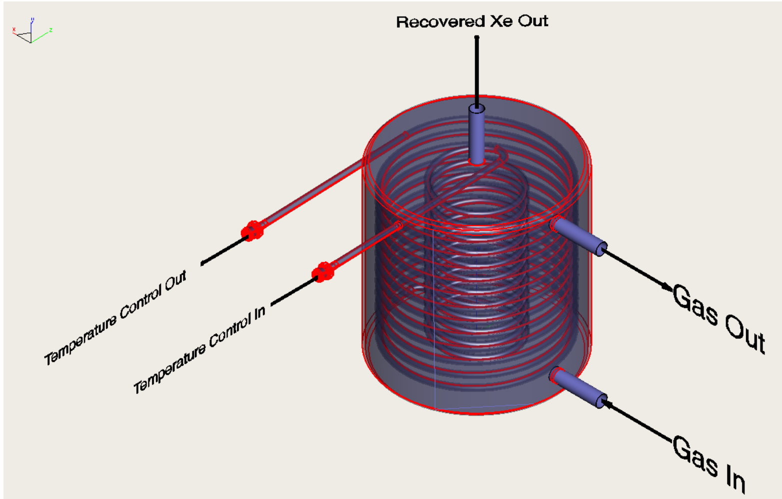

Figure 14: Example of a Xe cold trap.

down to high vacuum and up to 25 bar pressure. It has a 100 mm orifice and thus well suited to the vacuum needs of the NEXT 100. A smaller valve of the same type has been extensively used by out Laurence Berkeley Laboratory collaborators. After reaching desired vacuum the valve will be closed, the pumping station removed and the valve enclosed in a radio pure cap to shield the detector from the radioactive impurities in the materials that make up the valve.

However, many internal structures of the NEXT 100 detector, such as the light pipe surrounding the active volume will now allow good conductance for vacuum evacuation. Therefore, the chamber will be flushed with Ar and again evacuated a number of times. Furthermore, continuos re-circulation of the Xe gas will further aid it cleaning the system of impurities.

The Xe gas system constructed from 1/2" pipe will have low conductance for vacuum evacuation and therefore instead of evacuating the system from a single point the vacuum manifold will be connected to several points simultaneously and the system heated to 200°C to remove water. Also flushing with Ar several times to air in the cleaning process. Finally, as in the case of the main detector, continuous gas re-circulation will clean the Xe gas system.

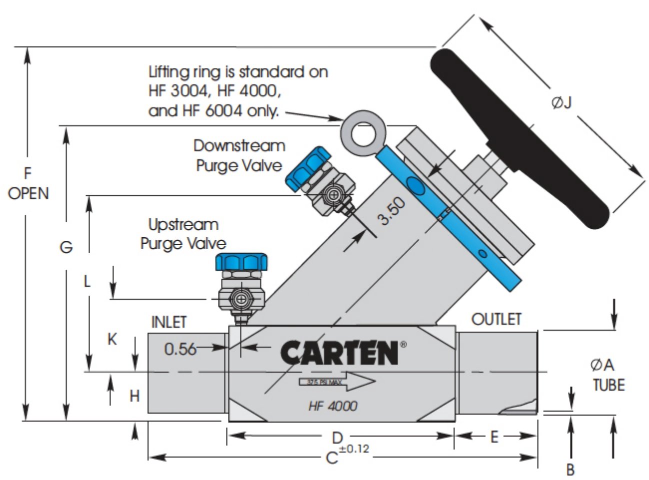

Figure 15: The HF4000 CARTEN valve.

4.6 Pressure relief, emergency conditions

1. Fire
   The emergency evacuation system can be connected to the LSC automatic fire control. In the event of a fire alarm being received emergence evacuation procedure will be implemented. In addition electro-pneumatic valves, a relief valve and bursting disks would be placed between the gas system and the emergency evacuation vessels. THese will be set so that each would open at a slightly higher pressure. Thus in case of overpressure due to fire, a direct path to Xe evacuation will be open.
2. Earthquake
   Full seismic risk analysis will be performed for the entire NEXT 100 system and its recommendations implemented.
3. Leak sense
   In the event of ^{136}Xe leaking into the Buffer Gas/Vacuum a Residual Gas Analyzer (RGA) similar to one shown in Figure 16 would sense this. If the leak would be detected an alarm would be sent to the operate on duty to effect controlled evacuation. As long as there is no leaks to the environment external to the detector and the gas system all of ^{136}Xe can be recovered However, if an external leak is detected such as an ingress of air an automatic emergency evacuation protocol can be initiated.
   As this particular RGA is capable of sensing several gas lines simultaneously it can also be used to monitor for air leaking into the detector. Additionally monitoring for Rn in the Xe or the Buffer gas can be implemented.

Figure 16: The ProLine Process Mass Spectrometer is capable of monitoring up to 16 gas lines for contamination and leakages at ppb level. In an event of detected leakage of ^{136}Xe an automatic gas evacuation procedure could be implemented. Additionally continuos monitoring for ^{222}Rn in the ^{136}Xe can be performed.

References

References

[O'D11] E. O'Dwyer, *Radon Background Reduction in DEAP-1 and DEAP-3600*, Ph.D. thesis, Queens University-Kingston, Ontario, Canada, 2011.

[RnI] *Unpublished Report.*