DRAFT NEXT-100 Conceptual Design Report DRAFT

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1 Purpose and Summary

This is a document listing the requirements for the SAINT option for NEXT100 Xe double beta decay experiment.

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2 Introduction

NEXT (Neutrino Experiment with a Xenon TPC) is an institutional collaboration formed for the purpose of either discovering, or setting new exclusion limits on neutrinoless double-beta decay. The existence of neutrinoless double beta decay will indicate the neutrino is its own antiparticle and allow calculation of its mass, as well as indicate the next direction for physics beyond the Standard Model. A partial list of current collaborating institutions is: Instituto de Física Corpuscular(IFIC), in Valencia, Spain, Lawrence Berkeley National Laboratory, Berkeley, California, and Texas A&M University. Xenon 136 is an isotope of Xenon which can undergo double beta decay; if the neutrino is its own antiparticle, as some theories suggest, a small fraction of these double beta decays will be neutrinoless, instead of the more common 2-neutrino type. NEXT100 is a detector which will contain and observe 100 kg of enriched Xe 136 (EXe) in gas phase, for double beta decay events, measuring both decay energy to high accuracy and event topology by imaging the decay tracks which ionize the surrounding Xenon gas. The SAINT option for NEXT100 utilizes Electroluminescent (EL) light production to provide superior energy resolution. In the EL technology option, primary electrons from Xe136 decay are drifted through the fiducial volume to a pair of highly transparent charged meshes having between them a field region (EL gap) just high enough to accelerate the electrons into stimulating the formation of Xenon excimers (which then decay by emitting 172 nm photons) but not high enough to from avalanches. This subavalanche behavior can be repeated many times across a small gap, thus producing a high number of photons per primary electron. These photons are collected by using large area waveshifting, light guide plastic panels having photomultiplier tubes at one end. The main technical problem with this approach is that the photomultiplier tubes having the lowest known radioactivity are still too active for the the required sensitivity. Our approach is to route the light guide panels behind a large copper shield ring, sitting inside the pressure vessel.

3 Description

The detector consists of a Xenon (containment) vessel that is mounted inside a larger pressure vessel, with nitrogen (buffer) gas filling both the annulus and a second lower region, where the SiPM electronics are located, and maintained at the same pressure as the Xenon. The pressure vessel, in turn, is submerged in a large vat of purified water, for shielding against background radiation. The detector is supported on a ring shaped stand which provides a sealed annular space for services to enter/exit the detector, including electrical cabling, internal electronics cooling and gas plumbing, these are all routed out of the water tank through a set of hollow detector support legs connecting this stand to the base of the water tank.

This nested vessel design has several advantages: by limiting the pressure differential to $\tilde{0}.2$bar across the internal Xenon vessel wall, Xenon vessel can have a very thin wall and be made of a radiopure, nonconducting material (the Xenon vessel serves as the substrate for a field cage) of limited strength (such as acrylic or polycarbonate). The design provides a safety buffer zone to avoid direct loss of Xe to the outside world, should leaks occur, and the Xe is easily separable cryogenically from the N2 buffer gas. Finally, this buffer gas annulus also serves as a high reliability, low mass, high voltage insulator, as the Xenon vessel serves as the structural support for the field cage, with one end at 165 kV. Below is a cross section 1 showing the Xe vessel, pressure vessel and water tank:

The N2 buffer gas pressure must closely match the Xe pressure at all times in order to prevent damage to the Xe vessel. In the event of excessive pressure mismatch, the Xe is allowed to mix with the N2, through a passive relief valve or burst disk system, as Xe is easily separated from N2 cryogenically. During operation of the detector, Xe is circulated continuously through the Xe vessel using a transverse flow pattern; it is fed in on one side and out the other where the effluent is passed through a gas purification system. All gas ports to and from the detector are located

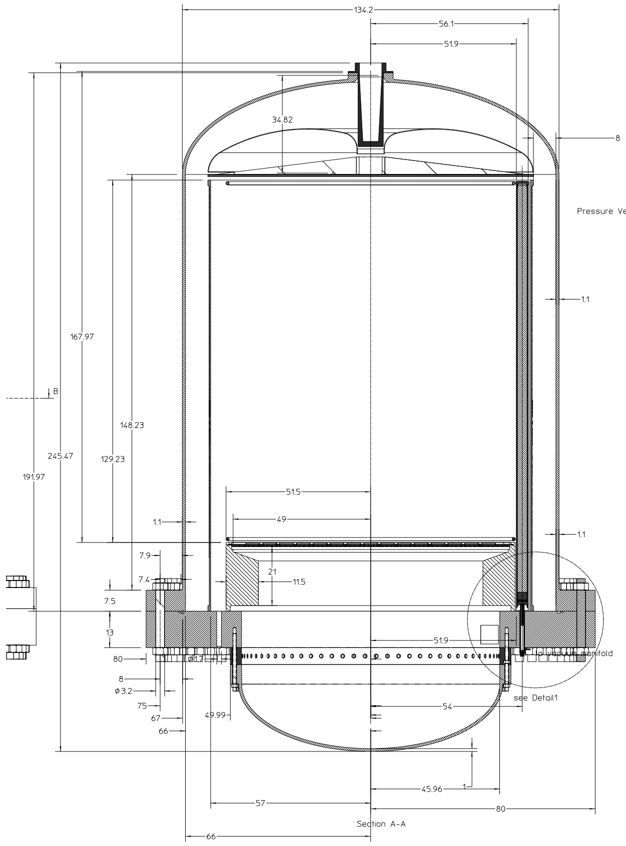

Figure 1: NEXT100, detector cross-section

on the main service flange.

Inside the Xenon Vessel, lining the inner radius is an circular array of quartz tubes, each tube having a wavelength shifting plastic bar with a photomultiplier tube (PMT) on one end. These assemblies 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 a the quartz tubes are sealed and a low vacuum is maintained inside the tube, just good enough to allow leak detection (Xe into tube. All seals to the outside world on the pressure vessel and the quartz tube assemblies will be double seals and vacuum will also be supplied to the space between them in order to detect either Xenon or N2 leaking out or water leaking in

During operation, the EXe 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 at a 70% 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.

4 Quartz Tube/WLS (QT/WLS) Bar Assemblies

The QT/WLS assemblies were designed to perform several functions simultaneously:

Table 1: NEXT100 SAINT Basic Parameters

Parameter	amt.	units
Active Mass, Xe	100	kg
Xenon Vessel Volume	1.0	m^3
Xenon Vessel inner Radius	0.61	m
Xenon Vessel Inner Length	1.6	m
Pressure vessel Inner Radius	0.70	m
Pressure Vessel Inner length	1.8	m
Maximum Operating Pressure (MOP)	15.0	bar (abs)
Maximum Operating Differential Pressure on Xe Vessel (MODP)	0.2	bar

- capture VUV light and transmit to PMTs
- protect PMTs from overpressure
- protect WLS bars from Xe diffusion damage

We are limited in our choice of low background PMT's. Our preferred PMTs are Hamamatsu 8520, which are rated only to 5 bar external pressure, yet we have 15 bar Xe and N2 pressure inside the pressure vessel. It is infeasible to try to locate the PMTs outside the pressure vessel due to the large area of vessel penetration required for efficient light piping, so they are located inside. Some method of protecting them from full pressure is required.

Furthermore, Xe has a high diffusion into polymers, and there is some evidence that this may compromise optical transmission of the WLS bars**??**; we thus desire a barrier between the WLS material and Xe. This material will then need high transmission to 172 light. T solve these two problems, we encase the WLS bar/PMT assembly in a synthetic quartz tube (QT) to protect the PMT from overpressure and the WLS from contact with Xe. The QT's are made from Suprasil 310 synthetic silica quartz, which has the highest light transmission at 172 nm of any available material in tube form. We specify 3mm thick in order to provide a high degree of safety against collapse from Xenon pressure. The inside of the tube is evacuated to be able to detect any Xe leakage into the WLS/PMT assembly. The PMT is potted to its base to prevent sparking in a low quality vacuum; the potting compound is a high thermal conductivity epoxy, in order to dissipate the resistor chain heat of 1/3W. A diagram of the QT/WLA assembly is shown below in fig.2:

A third problem is the method of light collection; as per typical scintillating panels, this is done by generating secondary light within an optically smooth bar or plate of fluorescent material from the primary light, a large portion of this secondary light then being reflected internally down the length of the bar to the PMT for capture. Most scintillating plastics are designed to waveshift Cerenkov light emanating from particles traversing the material, in our case we want to waveshift VUV light produced outside the scintillating material. Since all plastics strongly absorb VUV light, and there are large reflection losses at this wavelength from almost any type of surface, it is necessary to partially wavelength shift (waveshift), as soon as possible, by internal fluorescence, photons to a longer wavelength, which can then survive several reflections before penetrating deep into the WLS bar for final waveshift (to 420 nm) and transmission to the PMT. We perform this primary waveshift by coating the outside of each QT with a coating of p-terphenyl (TPH) embedded in a polyethyl methacrylate (PEMA) polymer matrix. This polymer has the highest known transmission below 200 nm and has been used successfully with TPH in other similar applications [3] [4], [5]. The PEMA matrix protects the TPH from evaporating and provides

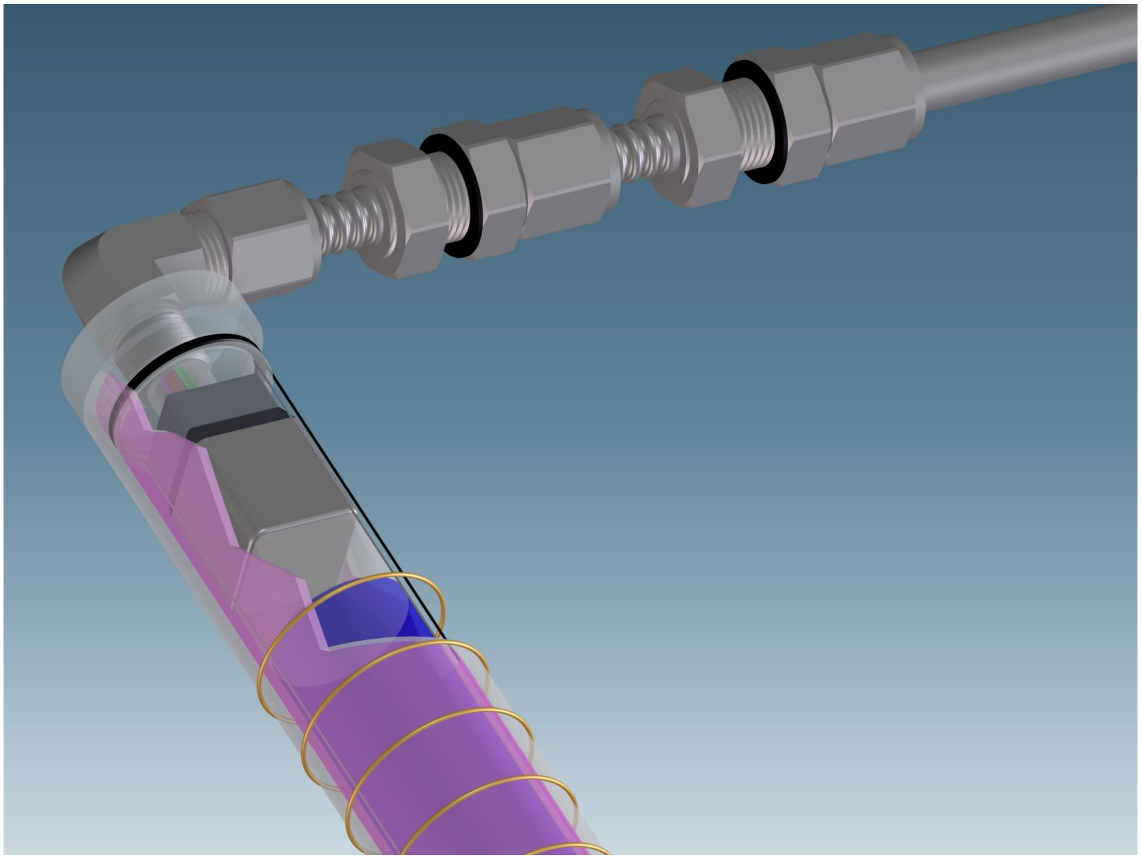

Figure 2: NEXT100, detector cross-section

mechanical strength. This coating is typically diffuse which helps to avoid light trapping within the QT wall. Below is a figure showing the apparatus for coating the quartz tubes

5 Pressure Vessel Design

5.1 Layout

The pressure vessel has three sections, an upper "Bell Jar" section, which lifts off to expose the detector, a main service plate, upon which the detector is mounted, and which is, in turn supported by the stand inside the water tank, and a lower lid, which provides access to the Silicon Photomultipliers (SiPM) and their electronics.

5.2 Design Requirements

The pressure vessel is designed to safely maintain a maximum operating internal pressure of 15 bar (absolute), with atmospheric pressure on the outside, and also to withstand an external pressure of 1.5 bar (5m H2O hydrostatic pressure on outside, with full vacuum on inside). It also serves as ground potential, on its inside surface for the field cage, and must be compatible with the insulation gas and withstand any breakdown. It is designed, to the fullest extent possible, in accordance with American Society of Mechanical Engineering (ASME) Pressure Vessel Code, section VIII- Division 1. There are only two known feasible materials to construct it from, due to the high radiopurity requirement, OFE copper and commercially pure (CP) Titanium. Our best value for radiopurity of CP Ti (grade uncertain, but all thought to be similar) is 170 μBq/kg (U) and 244 μBq/kg (Th) [1]. The higher strength and lower density compensate (by a factor of 4-5) such that grade 3 Ti is equivalent to 80 μBq/kg Cu, and an acceptable overall background of $\sim$1 Bq is achievable for the pressure vessel. In addition, titanium results in a much lighter pressure vessel which is far easier to fabricate and support; the high heat conductivity of copper, combined with the thick sections required make electron beam welding almost infeasible. By contrast, titanium is very easily e-beam welded, even in thick sections, with excellent resulting properties. Electron beam (or laser) welding in vacuum is the only method which can preserve radiopurity; inert gas fillet welding is many orders of magnitude more contaminating. Titanium has excellent corrosion resistance in pure water; copper corrodes in ultrapure water. It is not clear whether Titaium has better spark damage resistance, it has a higher melting point, but lower thermal conductivity relative to Copper. The only other material which might be feasible is a carbon/epoxy composite vessel; this would need a metallic liner to withstand HV breakdown; however, we have not measured the radiopurity of composites to date, so this option is not being pursued.

the pressure vessel

6 Gas System Requirements

6.1 General

The 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. In addition, the gas system must also perform continuous leak checking of a number of safety buffer zones in the detector where gases or liquids may breach seals.

6.2 Parameters

Table 2: NEXT100 Gas System Parameters

Parameter	amt.	units
Active Mass, Xe	100	kg
Maximum Operating Pressure (MOP)	15.0	bar (abs)
Maximum Allowable Working Pressure (MAWP)	16.4	bar (abs)
Maximum Operating Differential Pressure on Xe Vessel (MODP)	0.2	bar
Maximum Allowable Differential Working Press. Xe Vessel (MADWP)	0.3	bar
Xenon Vessel Gas Volume	1.0	m^3
Buffer Gas Volume	1.0	m^3

6.3 Pressure Control

Pressure control for Xenon, (whether EXe, NXe, or DXe) will be a semi-manual control; the Xe pressure will be set to a set point (with a maximum ramp rate, when either filling or reclaiming); the N2 buffer gas pressure will then closely track this Xe pressure, as it is raised or lowered, by either feeding in N2 from a high pressure source or venting it to a vacuum tank. In the event that the N2 buffer gas system cannot closely track the Xe pressure, a set of bi-directional high flow burst disks or valves will allow the two gases to mix, equalizing their pressures. Xe can then be easily separated cryogenically. Pressure control for the buffer gas volume is provided by a tracking regulator; this is a combination of a conventional (downstream reducing) regulator and a back pressure regulator (essentially a relief valve). If the gas volume is to low, compared to a setpoint, the conventional regulator opens to admit higher pressure (feed) and if the pressure becomes to high relative to the setpoint, the back pressure regulator opens to exhaust to a lower pressure region. The setpoint may be an electronic pressure signal, or a pilot pressure which acts to control the regulator (e.g. a dome loaded regulator) There will be a small deadband region between the differential pressure required to open either valve, in order to avoid oscillatory "pumping" action. This deadband region is determined by the maximum allowable differential pressure across the Xenon vessel wall (including the SiPM window).

By Though the Xenon pressure is set is one exception, in that the buffer gas pressure must be able to feedback to the Xe semi-manual pressure control in such a way to limit the raising or lowering of Xe pressure, in the case that the buffer gas control cannot

Since Xenon must be reclaimed cryogenically in order to provide high pressure feedstock for pressure control, it is advantageous to control

Since this process

6.4 Flow control

6.5 Gas Purification

6.6 Xenon Reclamation

6.7 Vacuum

7 R&D

7.1 Quartz Tube/WLS Assemblies

7.1.1 WLS Coating Performance and Longevity

We need to measure the efficiency of th e QT/WLS assembly in capturing, converting, and delivering light to the PMt's. Several issues arise:

- Determine efficiency of primary waveshifting coating
- Method for applying primary coating
- Ability of QT to capture primary (172 nm) light (how reflective can surface be?
- Ability of TPH/PEMA (or other) coating to resist possible Xe diffusion damage.
- Resistance of QT's to Super-Kamiokande type chain reaction (should one break under pressure)

To this end we have designed and commissioned a 172 nm low intensity light source and PMT inside a vacuum chamber. The light source is a common short arc Xenon microscope lamp with a Suprasil envelope; these bulbs typically have a needle shaped cathode and a blunt shaped anode. Fig 3 shows the experimental setup.

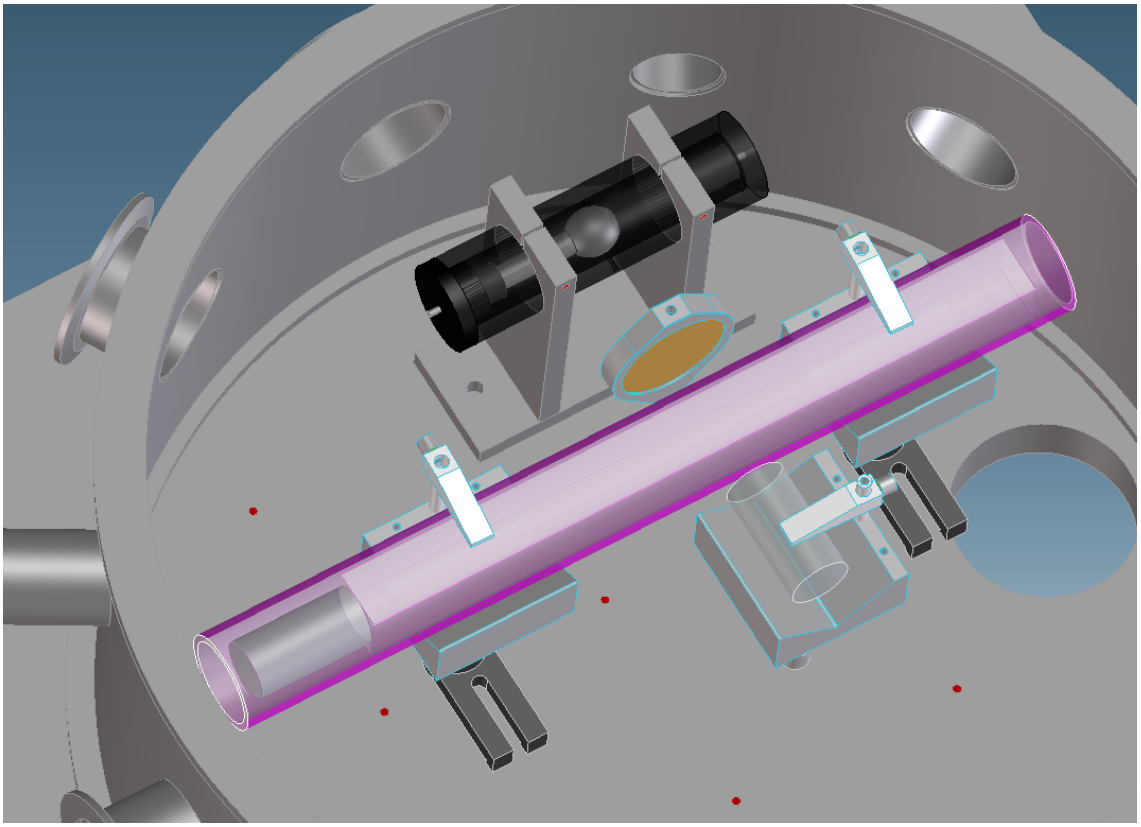

Figure 3: QT/WLS prototype measurement setup

We apply a high positive voltage (9-11 kV) to the blunt electrode, and stimulate a 1-2 nanoamp current using a UV LED placed close to the bulb, shining on the blunt cathode. If we raise the voltage $\sim 5\%$ we can initiate a 20-80 nA current, and turn the LED off This produces no visible light; we collimate the bulb and place a 172nm bandpass filter between the collimator and the PMT; the result is a strong signal, indicating the production of 172 light. We are now in the process of measuring the relative attenuation of the proposed coating.

7.2 Pressure Vessel

7.3 High Voltage Insulation

We need to assure that the final dimensions of the vessel provide sufficient electrical strength. This requires choosing an insulation gas, finalizing a field cage design and building a prototype to test. This prototype may be useful for testing other components as well, such as QT/WLS assemblies.

7.3.1 Manufacturing Feasibility

We need to work with potential vessel fabricators to verify that the proposed vessel can be properly built and certified for use. We need to maintain radiopurity throughout the fabrication, from material procurement to final testing, and will need to identify all issues and potential problems and then develop a quality control plan to assure the vessel meets our requirements.

7.4 Xenon Vessel

7.5 SiPM

Some

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