Next100 Pressure Vessel - User's Design Specification (PRELIMINARY, DRAFT, NOT COMPLETE)

Derek Shuman and Sara Cárcel

Instituto de Física Corpuscular (IFIC), CSIC, Univ. de Valencia, Valencia, Spain,
Lawrence Berkeley National Laboratory, Berkeley CA, USA

13 October 2011

1 Introduction

This is a preliminary specification for a pressure vessel to be used in a (neutrino) physics experiment. It is for the purpose of obtaining a preliminary quote for fabrication (price and schedule), and to find potential Manufacturers who have the necessary capabilities and are interested in submitting an offer to build. Prospective Manufacturers are encouraged to provide feedback on details of fabrication, as well as preliminary cost and schedule estimates. The final specification is expected to be released for RFQ approx. 2 months after this release.

2 Purpose

The NEXT Collaboration is a group of physicists and engineers affilitated with Institute of Particle physics/ University of Valencia, (IFIC) (principal institution), LBNL, Texas A&M, and others. The NEXT-100 experiment ia a proposal funded by this collaboration to build a detector to look for a phenomenon called neutrinoless double beta decay. The experiment requires a pressure vessel, to be used for gas containment, and additionally as the housing and support for a neutrino detector installed inside. Figure 1 below shows a cross section of the detector inside the pressure vessel. This pressure vessel is the subject of this Specification

3 Introductory Requirements Description

The pressure vessel has the following general requirements:

1. Size, shape, orientation: 1.14m inner diameter x 2.2m inside length, cylindrical, horizontal axis, with detachable torispheric heads on each end. Welded-in nozzles on both main vessel and heads extend the overall size to 2.2m overall length x 1.5m high. Supports will be welded to the main vessel.
2. Assembly Configuration: 3 parts, a main cylindrical vessel with bolted flange (flat- faced) connections to the torispheric heads. Double O-rings or, possibly for small flanges only, a Helicoflex C-ring/O-ring double provide pressure and vacuum seal.

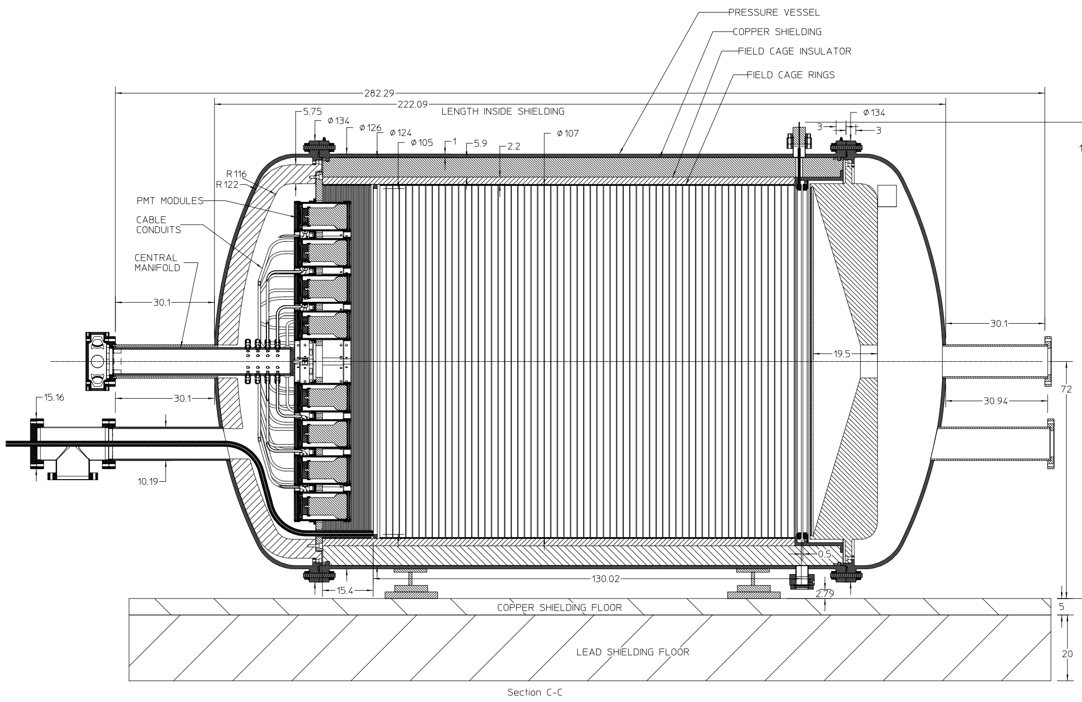

Figure 1: Detector Cross section

3. Material: vessel: Stainless Steel, either 304L(UNS S30403) or 316L(UNS S31603) per ASME specifications SA-240; all bolting: Inconel 718 ASME specification grade (UNS N07718).
4. Fluid: gaseous xenon (primary), argon, neon, nitrogen, dry air, with small amounts of CF4, CH4, H2, at room temperature to 50C (negligible corrosive, flammable or toxic hazard).
5. Pressure Range: -1.5 atm to 16.4 bara (15.4 barg)
6. Leak Tightness (1X10^{-6} torr*L/sec
7. Design Standard: ASME Pressure Vessel Code section VIII, division 2 part 4 rules, primarily, with use of part 5 (design by analysis, and/or (section VIII) division 1 rules, where necessary.
8. Low residual background radioactivity; additional material and process screening, over and above that required by ASME Pressure Vessel Code, will be performed by the Collaboration; full co-operation of Manufacturer is required. Nominal design may be impacted by (now pending) test results.
9. Internal detector components will be supported on internal flanges on the vessel (on both main cylindrical and on torispheric heads), and nozzle flanges. Total weight of detector inside vessel does not exceed 1 tonne.

These requirements and others are fully detailed in the Requirements section below. This includes requirements outlined in ASME PV code sec VIII, div 2 part 2.2.2 "User's Design Specification". We continue with the general description:

There are two unique and noteworthy aspects of this vessel; the first is a radiopurity requirement and, the second to a lesser extent, the need to mount internal components. Our detector is highly sensitive to trace amounts of radioactive materials, most notably uranium (U) and thorium (Th). Most metals and alloys contain uranium and thorium in trace amounts, from several parts per billion (ppb) to hundreds of parts per million (ppm). Typical austenitic stainless steels have a range of background radioactivities

, only the lower end range is acceptable. To assure radiopurity of materials the Collaboration will require samples from all raw material lots (bar, plate, tubing, forging ends, etc.) of several kg. each to perform background radiation counts prior to the material be accepted for fabrication, These counts take 2 weeks each to perform and we can only perform 4 simultaneous sample measurements at one time, so adequate material procurement scheduling is required. Regarding manufacturing, thoriated TIG welding electrodes, and guns that have been used with such electrodes must not be used. Ceriated or lanthanated electrodes are acceptable. The pressrue vessel also serves to support the detector inside. The detector is very lightweight, but will need precision positioning. However there is also a large amount of radiation shielding, in the form of copper tiles and plates, over 4500 kg of copper in all. The vessel flanges incorporate internal flanges for mounting of both this copper shielding and the detector components. As such all final machining must be performed only after a full stress relief anneal is performed after welding operations. Head to vessel flanges are nominally bolted; a flat faced flange design is used having 2 O-rings for seals, with a vacuum sense port in between them to detect leakage. The inner groove will be compatible, if feasible, with a Helicoflex gasket, loaded to its Y1 unit force. Manufacture must only demonstrate proper sealing performance using O-ring seals in both grooves. Manufacturer is invited offer some details as to preferred fabrication details before final specification is issued.

4 Scope of Contract

Manufacturer is to supply the complete vessel, with all flange bolts and nuts, and all blank-off plates used for the hydrostatic testing.

5 Responsibilities

5.1 Manufacturer

Manufacturer is to procure all raw materials. All materials are subject to approval by the Collaboration, both raw materials that will be part of the vessel, and all other materials and equipment used in the manufacturing process.

Manufacturer is responsible for the pressure integrity of the vessel and is required to perform all necessary calculations and analyses not provided by the Collaboration. The design must be according to the rules of ASME sec VIII division 2 to the greatest extent possible, and to the rules of section VIII division 1 and/or division 2, part 5 (design by analysis) where needed. Fabrication and inspection will be performed according to rules of division 2, even for any sections designed to div. 1 rules. The pressure vessel is being designed primarily by the Collaboration with regards to materials, overall dimensions. Detailed calculations have been made for the purpose of obtaining prior knowledge of the final pressure vessel design, however the manufactuer is ultimately responsible for the pressure safety of the vessel. Manufacturer may elect to use these calculations from the Collaboration, but is responsible required to approve these calculations and must supply any remaining calculations and design feature details such as weld joint design, which will be subject to Collaboration approval.

5.2 Collaboration

Collaboration is responsible for choosing the grade of stainles steel (304L or 316L) in timely manner prior to scheduling construction

6 ASME User Design Specification

2.2.2.1 ASME required specifications

a) **Installation Site**

1) **Location -** Installed location - Canfranc Spain, inside Canfranc Under Ground Laboratory in LSC Hall 1. Vessel may be staged temporarily at some other location, perhaps for pressure testing, and/or for trial assembly of detector. This location will be either at IFIC in Valencia, or perhaps at University of Zaragoza.

2) **Jurisdictional Authority**

3) **Environmental conditions**

i) **Wind loads -** none

ii) **Earthquake Design Loads -** 0.2g maximum vertical and/or horizontal acceleration. Vessel will be mounted on a shock isolating platform, and will be elevated above the hall floor by 1.2m

iii) **Snow Loads -** None

iv) **Lowest one day mean temperature-** 15C . Note - possibility exists of cryogen spill underneath pressure vessel, with temperature unknown. To mitigate, vessel will be immediately vented to 0 barg upon receiving a fault signal.

b) **Vessel Identification**

1) **Vessel Number -** "NEXT100-PV1"

2) **Fluids -** gaseous xenon (primary), argon, neon, nitrogen, dry air, with small amounts of CF4, CH4, H2 (<5%), at room temperature to 50C (negligible corrosive, flammable or toxic hazard). No liquids will be introduced into the vessel, other than cleaning, in the dissassembled condition or perhaps in an assembled condition, unpressurized. Although not presently planned, the vessel may be immersed in a fluid bath, of either ultrapure water, or scintillator fluid (as yet unknown) while in either the pressurized or vacuum condition. Maximum fluid pressure of this bath will be, at the lowest point of the vessel no higher that 0.35 barg.

c) **Vessel Configuration and Controlling Dimensions -** The vessel will be oriented with its axis of revolution in the horizontal direction.

d) **Design Conditions**

e) **Operating conditions**

Table 1: Required Geometric Values

Inside diameter	B=1220mm (not including shear lips on head flanges)
Inside Length, including Heads	G= 2200mm
Inside Length between Head Flanges	G= 1600mm
Center axis height above floor	C=720mm

Table 2: Design Pressure,(gauge)

Internal Pressure,Mpa	Ext.Pressure,Mpa
1,54	0,15

1) **Maximum Operating Pressure -** 1,40 barg Maximum Operating Pressure (MOP)

2) **Maximum Allowable Working Pressure -** 1,54 barg Maximum Operating Pressure (MAWP)

3) **Operating Temperature -** 15C-30C Temperature may rise to 50C under a vacuum (-1.0 barg) condition, but not under pressure

4) **Fluid Transients and Flow -** Vessel will be pulled to vacuum condition and held for several days. Xenon gas will then be introduced at a slow fill rate, no less than 1 hr to fully pressurize. Vessel will be vented by opening a valve connecting to a cryogenic recovery cylinder, this is expected to take at least several minutes.

f) **Design Fatigue life -** The vessel is estimated to undergo not more than 50 full pressure cycles, at most. Additionally, there will be not more than 50 pressure fluctuations of 20% or more design pressure. It is not expected that

g) **Materials of Construction**

1) **Vessel -** Stainless Steel, either 304L(UNS S30403) or 316L(UNS S31603) (choice to be made by Collaboration upon radiopurity measurements) per ASME specifications: all vessel shells, nozzles and head-to vessel flanges.

2) **Bolting -** Inconel 718 (UNS N77180) to ASME standards, studs, nuts and washers

3) **Flange Seals -** O-rings, butyl, nitrile, Viton, Buna-N, possibly PCTFE or polyimide or, for the smaller flanges only, Helicoflex type HN200, aluminum jacket. Main head to vessel flanges will be double O-ring sealed, the larger cross section O-ring for pressure, the outer, smaller cross section for vacuum. The annulus between them will incorporate a sense port for leak checking the O-rings. All nozzle flanges will be sized to ASME standards using a DN40 bolt pattern. The flange sealing faces shall be flat faced, to be used only with special interface flange plates having double O-ring/Helicoflex seals. Design gasket force shall be for Helicoflex Y2 values, if feasible, but at least 3x Y1 value.

h) **Loads and Load Cases**

i) **Overpressure Protection -** There are no conditions, short of a fire in the LSC hall that can lead to an overpressure condition. There are no flammable gas mixtures, no oxidizing gases inside the vessel at any time. there are only metals and common plastic materials such as PEEK, PTFE, PMMA, epoxy, etc. inside There are electrical components inside generating no more than 1 kW of heat dissipation, these will be actively cooled with water cooling circuits, either inside the vessel, or outside, using the vessel as a heat transfer surface (10C maximum allowable temperature rise above ambient; 30C actual temp). Fast vent capability is incorporated solely for the purpose of minimizing gas loss in the case of an unexpected leak, as the gas is very expensive and the Hall is an enclosed space. Fast venting, in an emergency, will be done by actuating a fast vacuum valve leading directly to a large evacuated recovery cylinder of 30 m^3 (thus reducing pressure to <1 bara). The high cost of the gas, and the enclosed underground cavern combined with the potentially dangerous anesthetic properties of the gas preclude venting directly to atmosphere. There will be three relief devices, 2 passive and one active:

1) Burst Disk 100 mm dia. - Set to 105%MAWP (passive protection)

2) Fast-acting Valve, VAT - Set to 100%MAWP (active protection)

3) Spring loaded reclosable relief valve, back pressure insensitive - set to 105% MOP (95%MAWP) (passive protection, insensitive to presence or absence of vacuum in vent vessel

2.2.2.2 Additional Specifications

a) Use of Plate Stock for Flanges -

Roll forgings and bar stock are the preferred materials for the main and nozzle flanges, pending radiopurity clearance. In ASME PV code sec VIII, div. 2, plate stock is not allowed for flanges. The flat faced flange design used is designed to div. 1 rules, Appendix Y, since no equivalent rules are present in div. 2. Div. 1 allows flanges to be made from plate if no hub is present (which is the case in this design). Plate stock is not ideal, and leakage paths from laminar flaws inside the plate may compromise the vacuum tightness of the vessel. If plate stock is chosen for vessel and head mating flanges, raw plate stock shall be helium leak checked through the thickness before purchase, either before or after the ultrasonic inspection required by ASME Pressure Vessel Code sec VIII div. 2. This shall be done by:

1) Prior to plate purchase, obtain 4 samples cut from each of the four corners (or from immediately adjacent stock) of 2 cm width along plane of each plate, x 10 cm. minimum, along plane of plate x plate thickness. Attach a vacuum manifold to one side and vacuum leak using a helium leak detector of $1^* \ 10^{-10}$ torr-L/sec sensitivity. If all four samples show leakage less than $1^* \ 10^{-9}$ torr-L/sec, the plate may then be further inspected given an ultrasonic inspection per the requirements of ASME PV code sec. VIII div. 2.

2) If pass then check bonding or otherwise sealing vacuum manifolds to the four edges of the plate, and using a helium leak detector of $1^* \ 10^{-10}$ torr-L/sec sensitivity on one manifold while flowing helium into the other three manifolds, in successive manner. If leakage is less than $1^* \ 10^{-9}$ torr-L/sec, the plate may then be given an ultrasonic inspection per the requirements of ASME PV code sec. VIII div. 2. If plate passes, it shall then be rough machined to Manufacturer's dimensions.

3) Plate shall then be Helium leak checked again, using a pair of plates sealing on the two planar surfaces with full vacuum applied to the ID. Helium shall then be applied to the OD, using a gas bag or other manifold sealed to the full OD. Total leakage shall be less than $1^* \ 10^{-9}$ torr-L/sec

b) Radiopurity Assurance -

In order to assure that all materials used to fabricate the vessel are of high radiopurity and do not become contaminated in the fabrication process, there will be additional material checks of both raw material, and of samples from each fabrication process along the way. Every effort will be made to determine the scope of these checks. Therefore Manufacturer has a responsibility to disclose any and all fabrication processes to be used, both prior to start of fabrication, and through fabrication, inspection and testing. Each material sample test takes 3 weeks to perform, so Manufacturer must be forthcoming in disclosures. Tests will be performed on the following items:

1) Tests on Materials

- **i)** ends from all raw plate used to fabricate vessel shells, flanges, attachments and supports
- **ii)** ends from all finished rollings and spinnings after welding, cylinder and both heads
- **iii)** ends from all bar, pipe and tube stock used for nozzles and nozzle flanges
- **iv)** ends or samples from all bar stock used to fabricate flange bolts and nuts, if applicable

2) Procedures -

- **i)** All welding shall be of the gas tungsten arc (GTAW) n accordance with ASME procedures.
- **ii)** All parts shall be thoroughly cleaned prior to assembly for welding per process XXX
- **iii)** Thoriated electrodes, and guns and shields previously used with thoriated electrodes must *NOT* be used. Plain tungsten, ceriated, yttriated or lanthanated electrodes are acceptable.

c) Precision Tolerances - To assure that vessel is fabricated on time, and to avoid unnesssary rework, it is imperative to follow a well thought out sequence of fabrications.

- **1)** all welding to be performed with flanges in rough machined condition. No flange bolt holes must be present in head to vessel flanges before full solution anneal, below. Nozzle flanges may be prewelded to nozzles, finish machined, then welded to main vessel and heads after solution anneal below.
- **2)** torispheric head shells shall be in fully solution annealed prior to welding to head flanges.
- **3)** main vessel shell shall be fully solution annealed prior to welding to vessel flanges.
- **4)** Vessel shall be full solution annealed after welding (1050C-1120C) for 1 hr minimum, followed by a slow cooldown period of not less than 8 hrs (4 hrs/25mm of section); vessel and heads shall be placed with axes vertical on flat surfaces, in a free unstressed, and unconstrained condition for the duration of this this operation. Specification to be determined. Nozzles shall be straightened, if necessary