NEXT100 Pressure Vessel

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NEXT Collaboration

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1 Status Report and Vendor

The NEXT100 pressure vessel has been fully specified and designed by the Collaboration and is currently awaiting the commencement of fabrication. A User's Design Specification [1] has been written in accordance with ASME Pressure Vessel Code, and awaits review by a Certifying Authority (see contracting section below for explanation). Detailed part and assembly drawings are included. Although internal detector components are still under design, there appear to be no potential problems interfacing with the vessel. The internal flanges by which all internal components are mounted are very robust, and there is substantial extra port capacity for bringing services in and out of the vessel. It is our conviction that the risk of vessel design changes, from this point forward, is very small.

A pressure vessel manufacturer, Movesa, in Madrid has been chosen as having the best expertise and capabilities after several vendor visits to other firms [2], and an exclusive contract is underway. Movesa designs and builds a variety of pressure vessels, primarily for the food and pharmaceutical industry, and we saw a variety of challenging vessels being built, in both carbon steel and in stainless steel. They are used to working closely with clients throughout the fabrication, which we need to have in order to assure radiopure and precise construction, and they have dedicated facilities for stainless steel (needed to avoid iron contamination). Their location in Madrid gives them easy access to subcontractors, and makes it easy and quick for us to visit frequently.

2 Description

The pressure vessel consists of a main cylindrical vessel section and two torispheric heads which each attach to the vessel by bolted flanges. The detector is mounted fully inside the vessel, on internal flanges. Ports are provided, in the form of nozzles, for all services The vessel and detector is shown in the following figures 2,2,2(without ICS copper bars),2(with ICS copper bars),2:

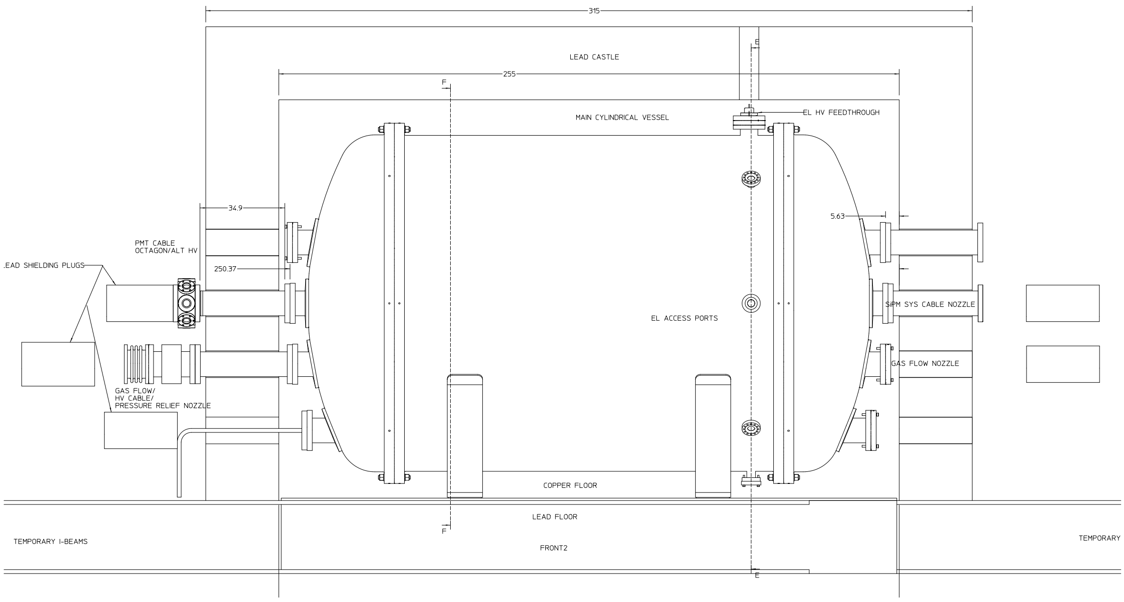

Figure 1: Pressure Vessel, Side view

The internal flanges are machined integral to the main head to vessel flanges, each flange having one internal flange. The heads are identical. The field cage system, with cathode and EL meshes, and the PMT system (energy plane) is mounted inside the main cylindrical vessel, and the SiPM system (tracking plane) is mounted to the tracking side head. The energy side head has an internal copper

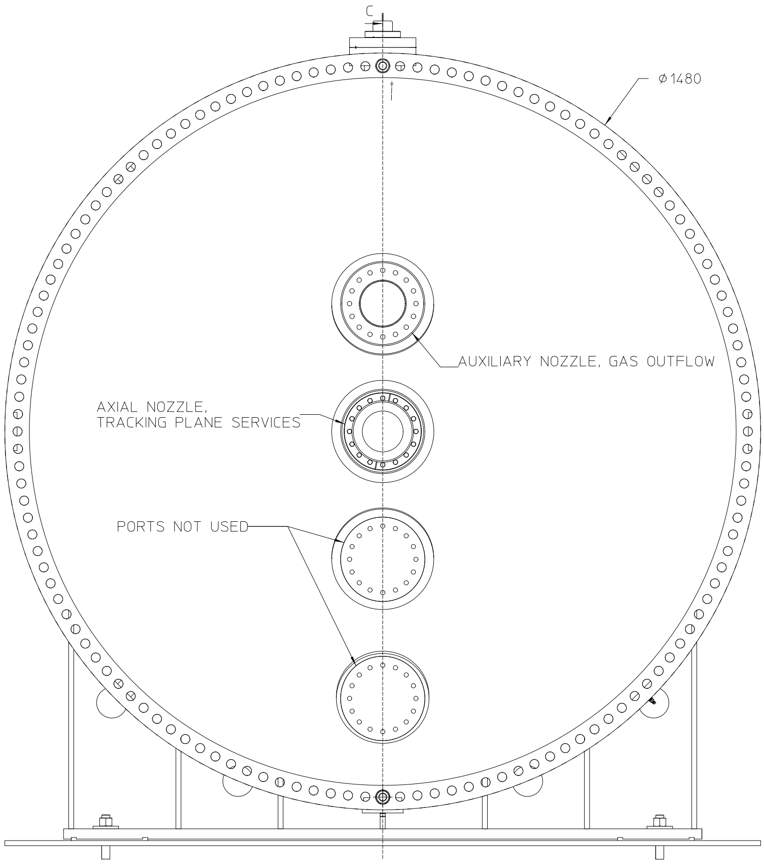

Figure 2: Pressure Vessel, End View, Tracking end

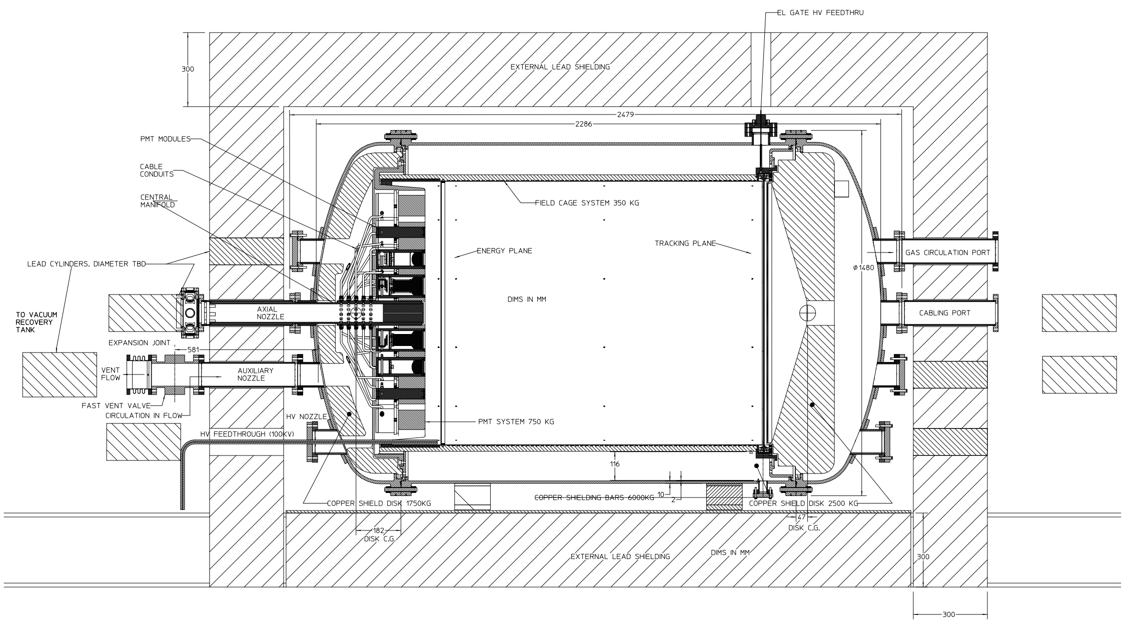

Figure 3: Pressure Vessel/Detector Longitudinal Cross Section, without ICS (Cu) bars

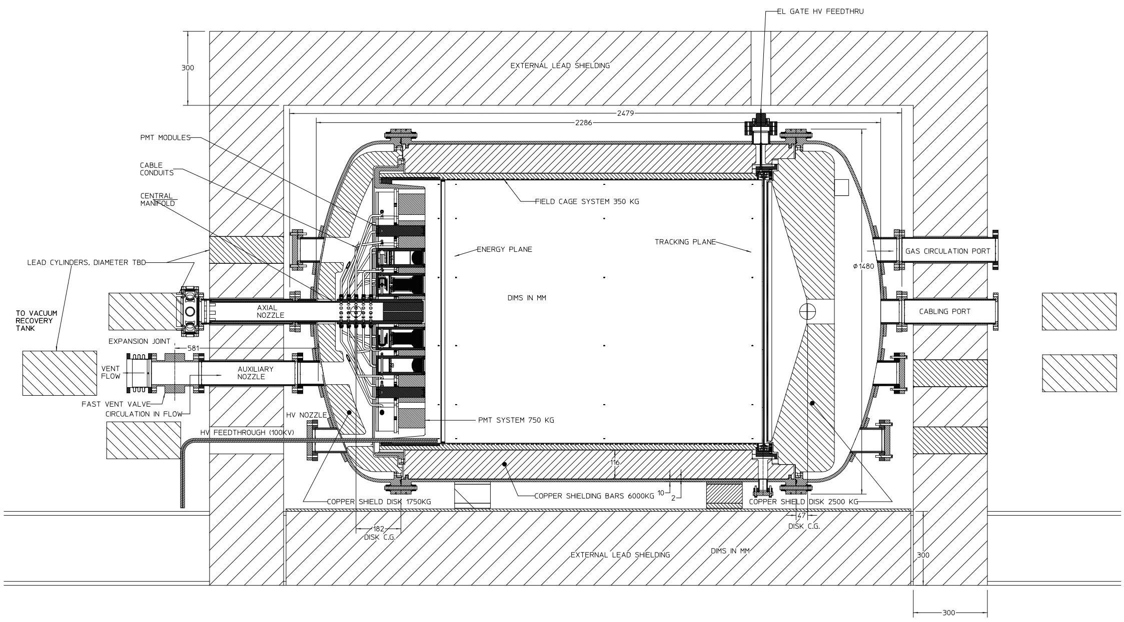

Figure 4: Pressure Vessel/Detector Longitudinal Cross Section, with ICS (Cu) bars

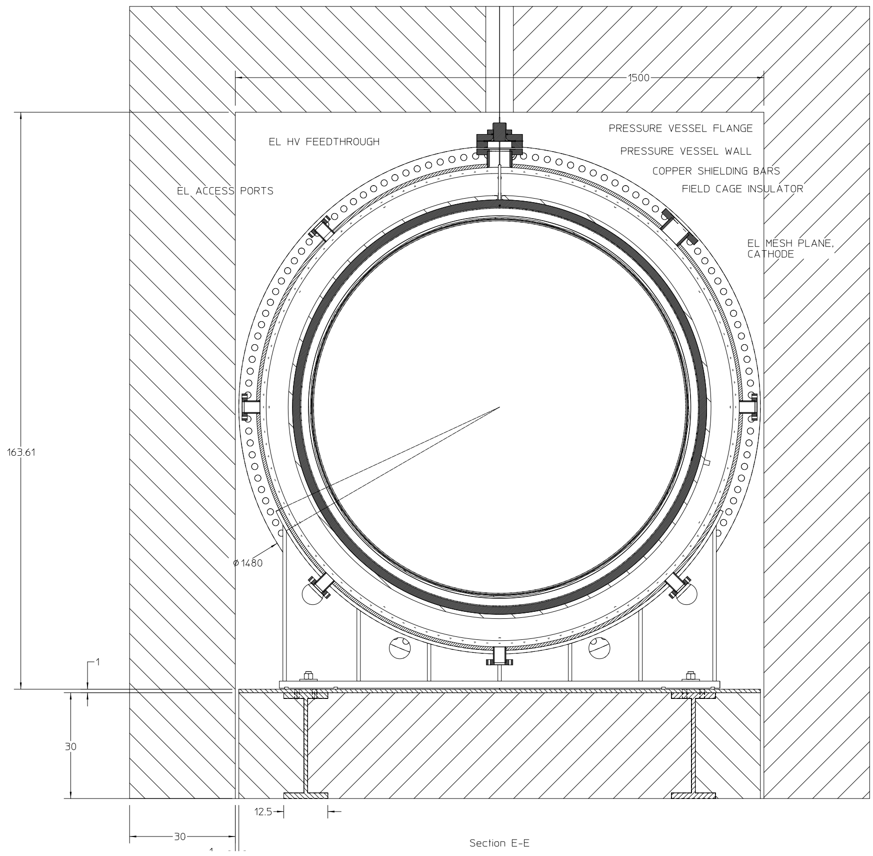

Figure 5: Pressure Vessel/Detector Transverse Cross section, at EL gap

shield attached. The drift section cathode plane high voltage feedthrough is integrated into the energy plane head and makes contact with the cathode plane when the head is assembled.

The vessel is made from 316Ti (EN 1.4571) Stainless Steel, from Nitronit, who supplied similar steel to the GERDA experiment which tested as low as 100 100 μBq/kg, but is typically 1-10 μBq/kg.

We have contracted with Nitronit to reserve enough material in several thicknesses (10, 15, 50 mm) for the construction of the vessel. Samples of each thickness are currently being measured at LSC, and those measured to date (10 mm) are 200 μBq/kg.

To shield a background of 10 μBq/kg, we estimate an internal copper liner of 12 cm radiopure copper (4 attenuation lengths @2 MeV) is required. The vessel has been designed to accommodate this. However, given the low background of actual material, we plan to leave out the copper liner, at least in the main cylindrical vessel, and will mount the internal components to the vessel internal flanges using an intermediate interface plate.

Although the water tank shielding option has been dropped, the vessel will still be designed to withstand 1.5x full vacuum (if there are no significant negative ramifications) such that vacuum may still be applied without the need to drain the water tank, should the experiment ever be upgraded to use water shielding. No additional thickness or reinforcement is required.

The basic parameters and dimensions of the pressure vessel are shown in table 2

Table 1: NEXT100 Pressure Vessel Parameters

Parameter	qty	units
Maximum Operating Pressure (MOP) (differential)	14.0	bar
Maximum Allowable Working pressure (MAWP) (differential)	15.4	bar
Minimum Allowable External Pressure (differential)	1.5	bar
Inner diameter	136	cm
Outer Diameter, Vessel	138	cm
Outer Diameter, Flanges	148	cm
Length, inside shielding	2.28	m
Length, end to end, axial	2.86	m
Vessel wall thickness	10	mm
Head wall thickness	10.5 *	mm
Head crown radius, internal	136	cm
Head knuckle radius, internal	13.6	cm
Flange thickness, head to vessel (both)	4.15	cm
Bolt Diameter, head to vessel flanges	16	mm
Bolt length, head to vessel flanges	11	cm
Number of Bolts, each head to vessel flange	132	
Mass, Vessel and both heads	1200	kg

* satisfies European Standard UNE-13445-3

2.1 Design Standards

The vessel has been designed to ASME pressure Vessel Design Code, sec VIII, division 1, however, other Design codes are acceptable, such as European Standard UNE-13445-3. Design calculations for the vessel are presented in the Appendix of the User's Design Specification [1]. It should be noted that,

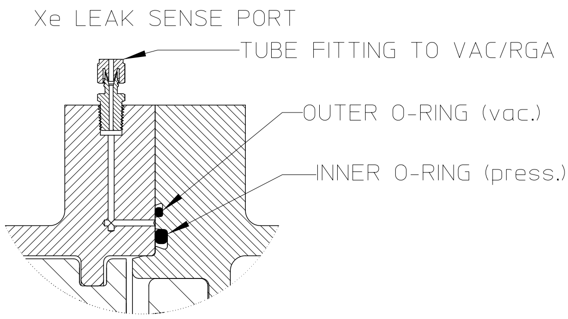

Figure 6: Double O-ring/sense port detail

under ASME rules, the vessel manufacturer is ultimately responsible for the pressure integrity of the vessel, and is responsible for all calculations needed for this purpose. Our purpose in designing the vessel is to understand what the vessel will be (no surprises). However, there is some small risk the manufacturer will require a design change. See section on Fabrication Contracting below.

2.2 Flanges and Sealing

All pressure sealing flange joints that are exposed to atmosphere on the outside are sealed using double O-rings in grooves turned in what are termed flat-faced flanges. This choice was driven by reliability concerns, for ease of assembly, and to reduce the flange thickness, as O-rings are self-energizing and need negligible compression force (over and above that required for maintaining joint closure under internal pressure). The inner O-ring is for pressure sealing; the outer O-ring serves not only as a backup, but also to create a sealed annulus which can be continuously monitored for leakage by pulling a vacuum on it with an RGA monitor (sense port). Xenon will permeate through these O-rings and will need to be recovered in a cold trap, the total amount is estimated to be <200 gram/year (butyl O-rings). Figure 2.2 shows a cross section detail of the head to vessel flanges; nozzle flanges are similar.

The O-ring grooves have an undercut lip on the non pressure side which holds the O-ring in place during assembly; this is necessary due to the horizontal vessel axis. A metal C-ring gasket (Helicoflex) of special low force design may be substituted for the inner O-ring to reduce permeation; the flanges have been designed for the additional gasket compression force required. Standard high force Helicoflex gaskets were found to substantially increase the flange thickness and outer diameter. Double O-ring seals will also be used on the nozzle flanges, however, the flanges welded to the pressure vessel will be flat faced, and the O-ring grooves and sense ports will be added to the covers and nozzle extensions. To prevent damage to the exposed sealing surfaces, the vessel flanges incorporate a step to recess the sealing surface by 1mm.

2.3 Ports

Ports are added to the vessel in the form of "nozzles". The main cylindrical vessel has two possible ports of 75mm bore to accommodate the EL gate feedthrough, one on top (0 deg.) and one at 45 deg to the side. The other 6 radial locations at 45 degree intervals are provide for quick access to the EL meshes for diagnostic purposes; they utilize a CF flange bolt pattern of size DN40 so as to be able to utilize CF hardware for a variety of purposes. Figure 2.3shows a bored-through interface flange with a (pressure tested) CF window for possible EL spark diagnosis; interface flanges will be blanked off in

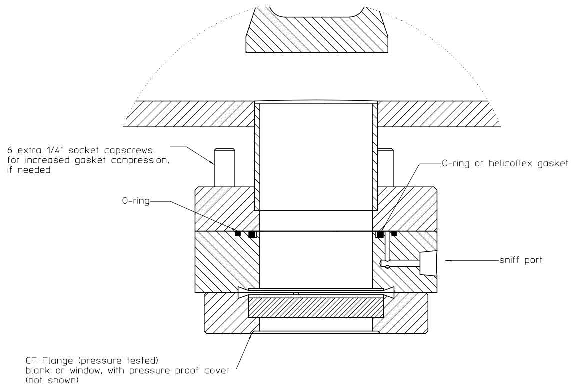

Figure 7: EL Access Port/Interface flange with CF window

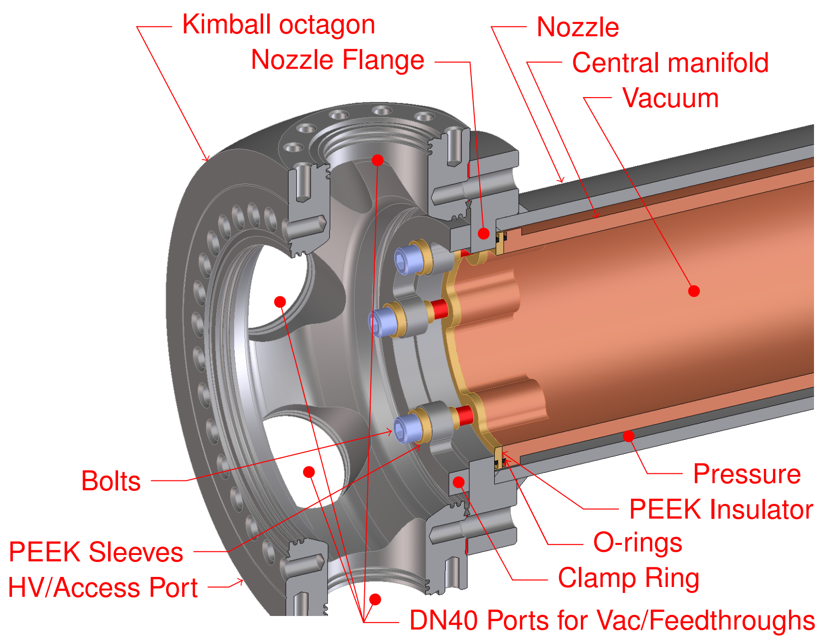

Figure 8: Central Manifold/ Nozzle Flange Seal

actual use with EXe.

The energy plane and tracking plane services and the gas flows (normal and relief) all utilize nozzles welded to the heads. There are four on each head. Nozzle extensions are added to bring services through the external lead castle shielding (LCS). Similar to the EL access nozzles, these flanges utilize a CF DN100 bolt pattern

The central nozzle extension of the energy head (and possibly the tracking plane head) has a CF knife edge flange (DN100) on one end, as it is a vacuum, not a pressure sealing surface; pressure is sealed by the Central Manifold which bolts to the underside of this flange, inside the vessel, sealing with a single O-ring. The central manifold seals with a single O-ring as there is a vacuum inside which leads to a large evacuated recovery cylinder, so any xenon leakage can be sensed and recovered in a cold trap (see pressure relief section). Figure2.3 shows the central manifold sealing arrangement (with an optional electrical break).

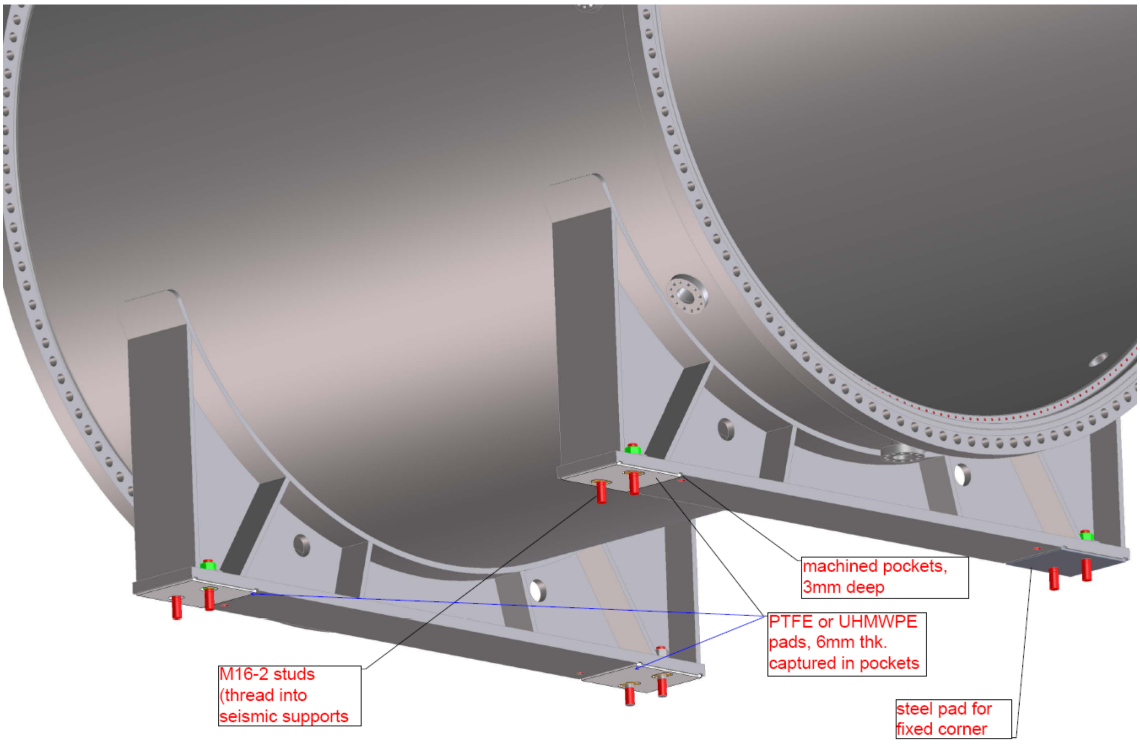

Figure 9: Vessel (quasi) Kinematic Support design

2.4 Bolting

The head to vessel flange bolts are Inconel 718; this is the highest strength noncorrosive bolting material allowed in the ASME code. Flange thickness and outer diameter are substantially minimized by using highest possible strength bolting. Recent results show Inconel 718 to be in the 5-10 mBq/kg range. Nuts will also be Inconel 718. total mass is 60 kg. Nozzle flange bolts may be stainless steel, except for the energy head auxiliary nozzle, where high strength fasteners are required.

2.5 Supports

Supports are an I-beam saddle type design. The central cylindrical vessel will be bolted directly seismic platform; this platform incorporated beams located under the vessel supports for this purpose. The vessel has four points of connection ("corners") to the seismic platform, two on each saddle support. Pressurization or thermal excursion (bakeout, cryogen spill) will result in dimensional changes of the vessel, so, to minimize stresses on attachment points, the vessel supports use low friction pads (PTFE, UHMWPE) to allow controlled sliding under the supports to constrain the vessel in a 2D kinematic fashion. One corner is fixed, two others are slotted to allow sliding in one direction (orthogonal to each other), and a full clearance hole pattern at the fourth corner allows sliding in both directions. Figs.2.5 2.5 2.5 2.5 shows the design.

Supports will be welded to the vessel wall, as is standard practice. We are calling for the manufacturer to weld the supports first, then weld to the vessel, to minimize distortion.

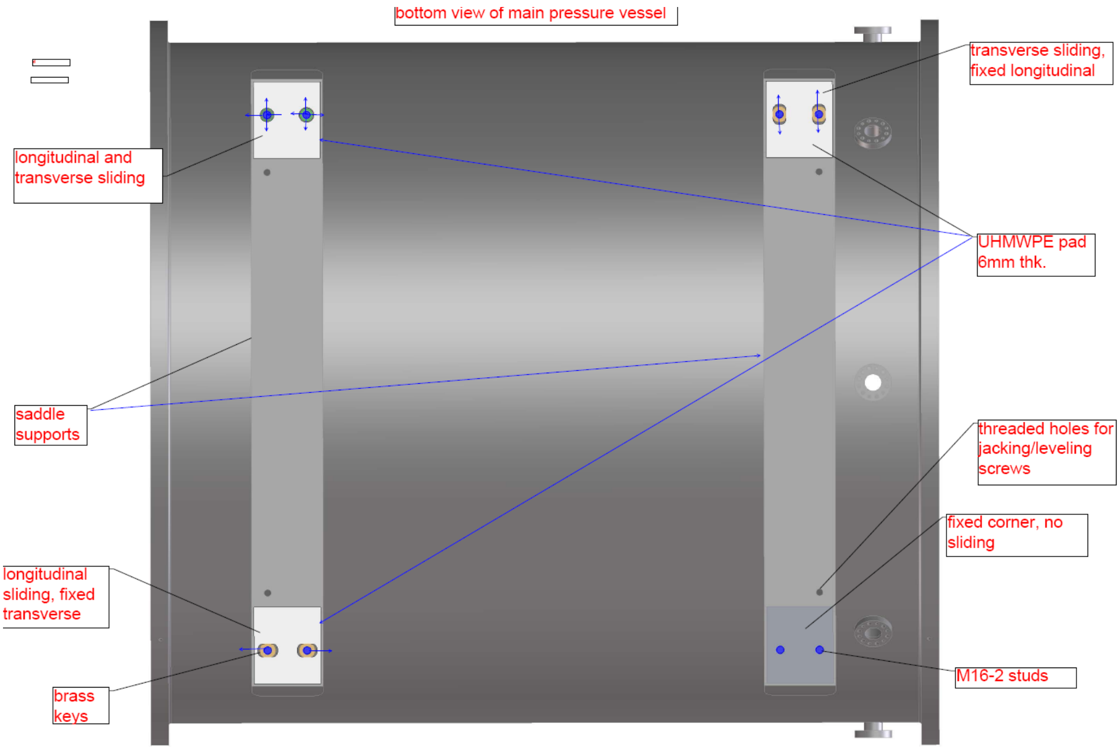

Figure 10: Vessel (quasi) Kinematic Support design, bottom view

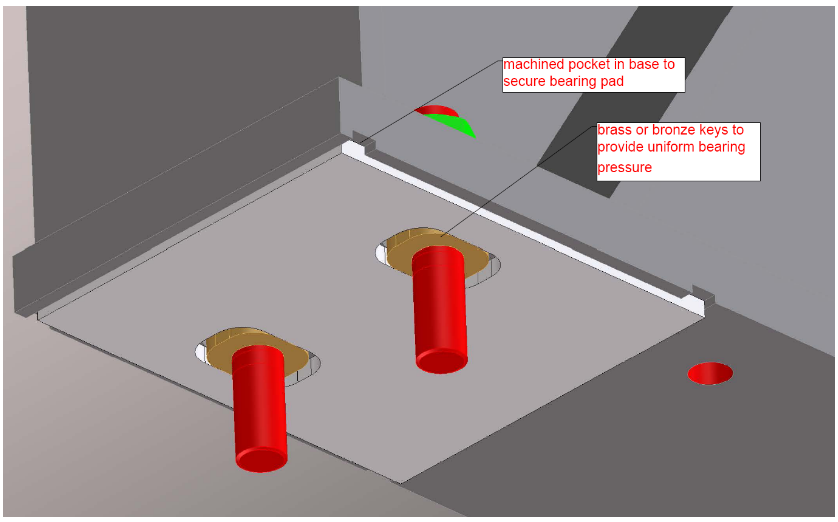

Figure 11: Vessel (quasi) Kinematic Support design Bottom Detail

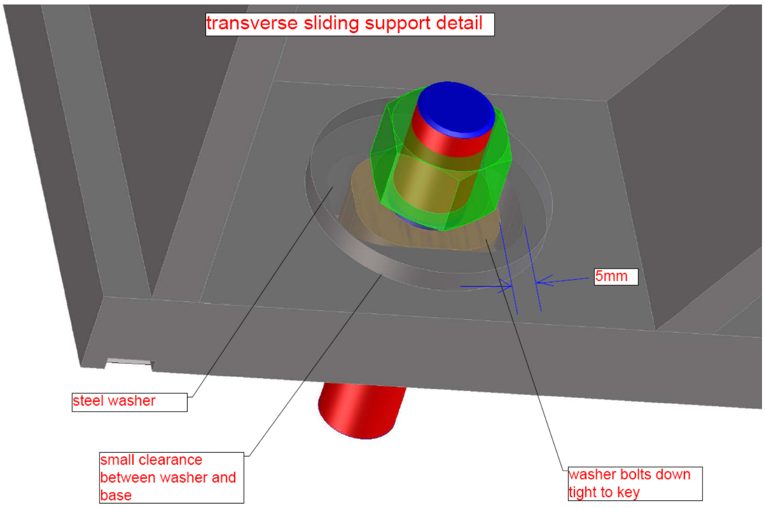

Figure 12: Vessel (quasi) Kinematic Support design, top Detail

2.6 Pressure Relief

Pressure relief is provided though one or more of the auxiliary nozzles. All pressure relief is piped to a large vacuum tank to avoid loss of EXe. Fig. 2.6 shows how the vessel is connected to the gas system (purification loop and gas supply shown here are generic, see Gas System Report for correct system)

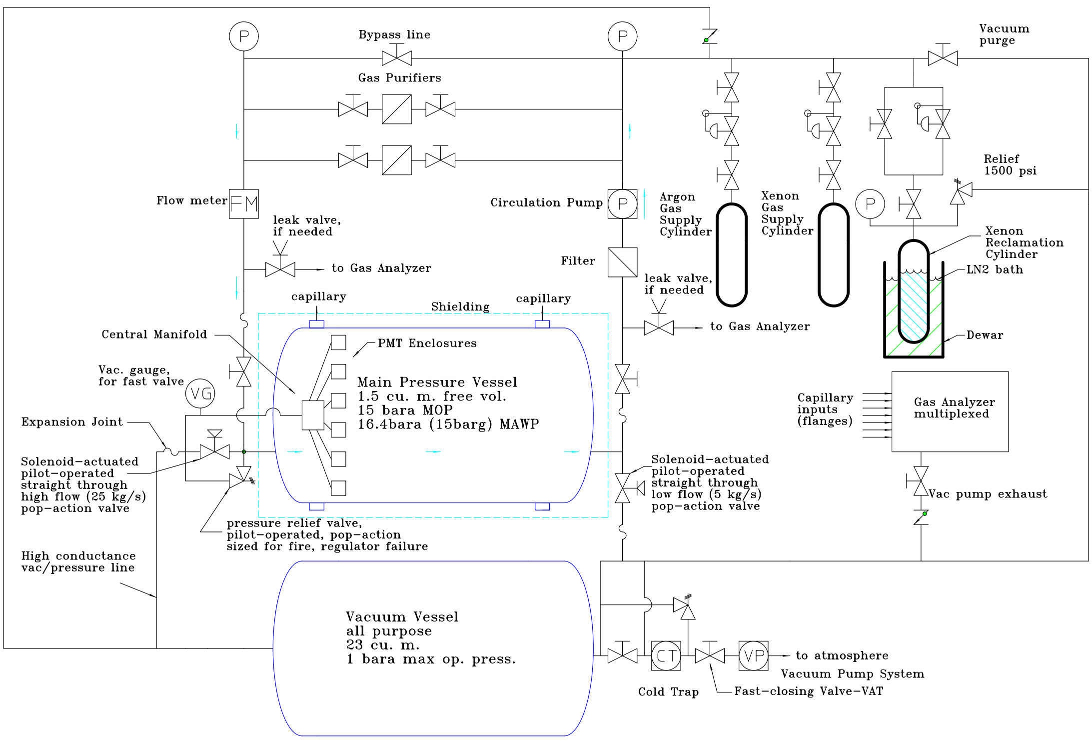

Figure 13: Gas System Interface with vessel

The energy plane head lower auxiliary port will have, in addition to the standard pressure relief valve rated for overpressure in the event of a fire or regulator malfunction, a solenoid actuated high flow capacity valve which will vent all EXe to the recovery cylinder in 10 sec or less, limiting loss of xenon through the broken feedthrough to no more than 10% of total. Reaction force is considerable, approx 3.5 kN, thus a straight-through valve is specified; this minimizes moment on the nozzle. An expansion joint follows this valve to piping which is mounted to the work platform, all reaction force is carried by this piping, and it will require bracing.

In such an emergency vent scenario, there is a concern that the tracking plane daughterboards could encounter high pressure differential, therefore a second solenoid vent valve, located on the tracking plane auxiliary nozzle, is wired to open in conjunction with the main high flow valve. The flow capacity of this second valve is low, and is sized in proportion to the gas volumes on each side of the tracking plane, such that flow velocity across the tracking plane will be nominally zero when both valves are simultaneously opened. No such concerns of high gas flow damage exist for the mesh planes and energy plane.

The standard pressure relief valve is also of a low flow capacity, since the only known condition creating an overpressure would be a fire in the LSC hall or broken supply regulator. We have only a limited amount of xenon, so a broken regulator cannot create an overpressure condition, but this may not be true for Ar. Sizing for fire, using American Petroleum Institute (API) methodology, a 1 cm dia. vent line is required. Reaction force for this condition is very small.

3 Handling and Assembly

The heads will be attached to carriages that slide on precision rails that are temporarily bolted to the shielding floor. These carriages will attach to the heads by threading some of the flange clearance holes to a single size larger bolt, this allows any type of lifting fixture to be designed for the heads. The carriage will have adjustment capability to precisely line up the head to the flanges so they come together without binding. There is an internal lip on the head flanges that must fit precisely into the vessel flange bore, this lip is for the purpose of providing a shear support for the head, so as to prevent any chance of the heads (which are heavy from the copper shields) slipping onto the bolts. Figures 14 and 15 show the concept of head/shield removal.

Once the torispheric head has been retracted from the vessel and clears the central manifold, a crane hook interface fixture (not shown) is bolted to the upper flange bolt holes, allowing removal from the work platform.

4 Vessel Construction

As part of the UDS, the manufacturer is required to submit a plan of fabrication for approval. This is so we can identify the preparation processes, and inspections that must take place.

The current drawings show integral flanges and vessel/head shells, however the fabrication drawings will need to detail a double weld joint that meets ASME design standards. The details of this joint will be worked out with the manufacturer. The use of a welding hub is disallowed and so the shells must be welded directly to the flanges, a process with high heat and potentially large distortion. Thus a stress relief heat treat cycle of 85% minimum is specified to follow. Details will be worked out with the manufacturer.

The vessel will be welded using the gas tungsten arc (GTAW) process. All major welds will be double welds and must be fully radiographed. The vessel is required to be vacuum tight to high vacuum specification; the double O-ring seals will allow reduction of permeation; allowing a better pressure

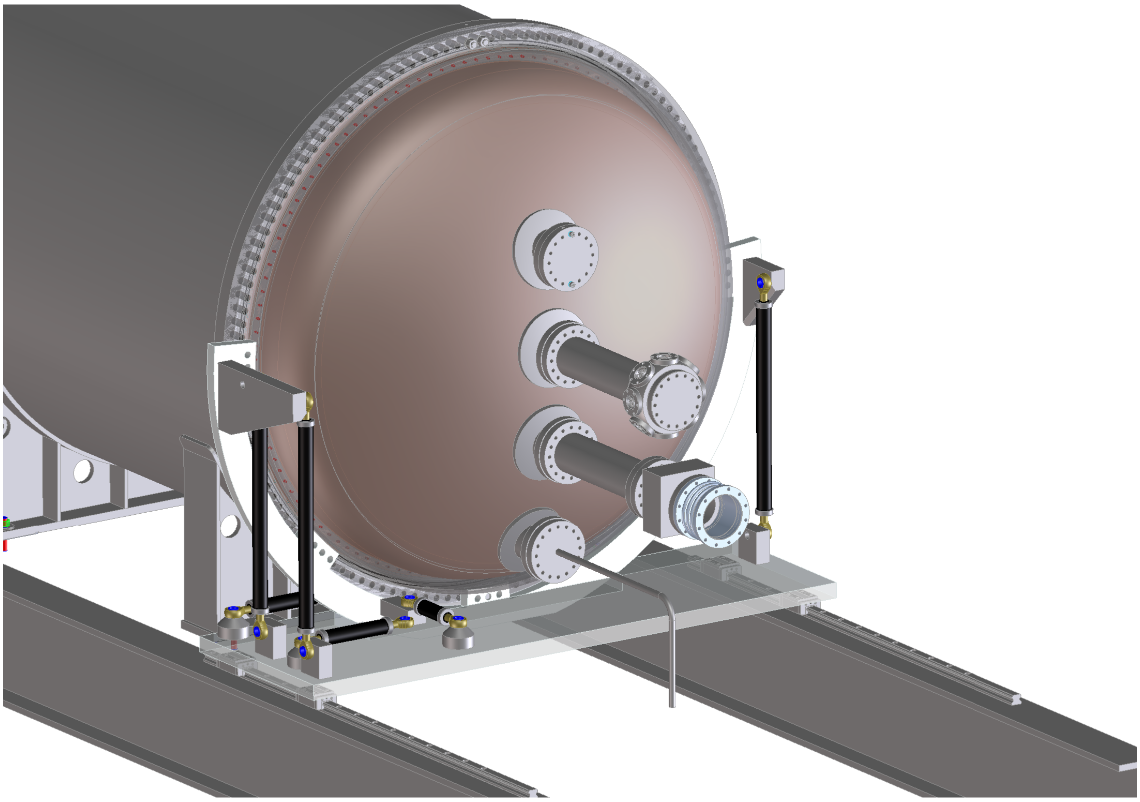

Figure 14: Hexapod Support Fixture, Attached to Torispheric Head

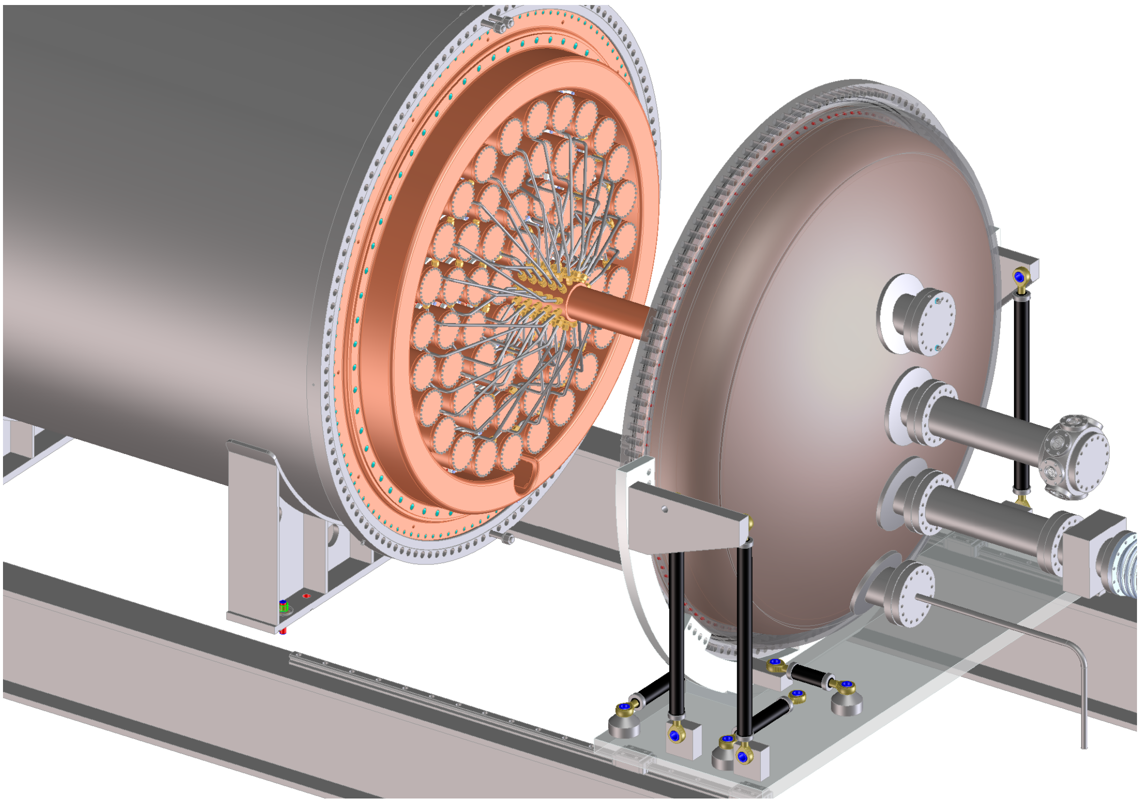

Figure 15: Hexapod Support Fixture, Attached to Torispheric Head

measurement to be made. Particular care will be take to avoid use of thoriated tungsten electrodes, (and guns used with such), however these are now prohibited in Europe. Cleaning of joints prior to welding is very important, and we also specify acid etching after weld joints are prepared.

5 Fabrication Contracting Process

The vessel design, contracting and fabrication process is defined in ASME code and is as follows:

- We write a User's Design Specification for the Vessel which includes all (user required) dimensions, media, conditions, loads, load history, etc. that the vessel will be subject to. ASME PV code sec VIII div. 2, par. 2.2.2 is a specification for what needs to be included, and allows for additional requirements. We will add additional conditions that allow us to assure quality in particular, for radiopurity, from material purchase, through all cleaning, joint preparation, welding, stress relieving, machining, pressure testing steps. Normally the Manufacturer performs (or contracts) the calculations to determine wall, flange and nozzle dimensions and thicknesses, however by agreement, we can perform these. However, the Manufacturer is responsible for the pressure retaining integrity of the Vessel (par. 2.3.1.1), and may well want to to do their own. The manufacturer will choose whether to accept our calculations or submit their own.
- The User's Design Specification must then be certified by an independent Certification Authority to assure that the vessel is fully specified. The individual(s) in charge of certifying the Users Design Specification must be a licensed Professional Engineer.
- The Manufacturer must provide a Manufacturer's Design Report, which includes final as-built drawings, design calculations and analyses. This Manufacturer's Design Report must be certified by a Certifying Authority. So, even if the manufacturer, by agreement accepts our calculations, they must be Certified. The individual(s) in charge of certifying the Manufacturer's Design Report must be a licensed professional Engineer, and must not be the same person who certified the User's Design Specification.
- A Certified Inspector must be hired to inspect all stages of the fabrication, and certify the vessel is being built in accordance with Specification; we will also perform our own inspections of the fabrication process. The same Certification firm can provide the Inspector.
- The Manufacturer must be certified to perform all the operations specified in the User Design Specification. They must have a certified Quality Assurance Program in place that can track progress and demonstrate compliance with the requirements for fabrication.

Due to the nature of the vessel, we are taking a much stronger hand in the design and fabrication than is usually done (this will be made clear in the user's Design Specification), however this does not absolve Manufacturer of their responsibilities, so they may well elect to do all their own calculations.

References

[1] Shuman, D. Carcel, S. Martinez, A. *NEXT100 User's Design Specification*

[2] Shuman, D. *Vendor Visit: Movesa*