1 Pressure Vessel

1.1 Summary of Changes from CDR

- Vessel design simplified.
- Vessel axis changed from vertical to horizontal
- Vessel material changed to stainless steel, from titanium
- A copper liner has been added to shield the higher background stainless steel

1.2 Description of Changes

The pressure vessel configuration has been simplified to consist of a cylindrical main vessel section having near identical torispheric heads on each end; the support plate in figure 3.16 of the CDR has been eliminated. Both heads are now convex (as viewed from outside) and each have two nozzles, one for for services (power and signal cabling) and the other for gas flow/pressure relief. The PMT modules are now independent from the head, and are located fully inside the vessel allowing for a much simpler head design. The vessel orientation is now horizontal, so as to minimize the overall height, which reduces the shielding cost and allows essentially unlimited length on each end for cabling and service expansion. The vessel is shown in the following figures 1.2,1.2,1.2,1.2:

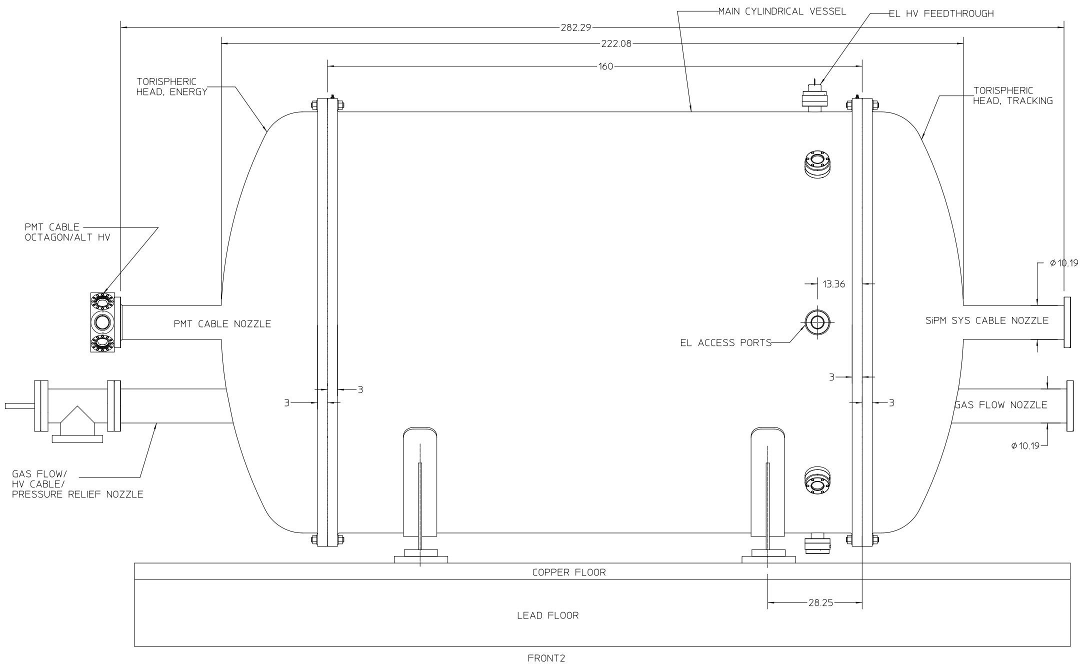

Figure 1: Pressure Vessel, Side view

The vessel still serves to support all internal components, and the design is quite modular; one head fully supports and contains the entire PMT system (energy plane), the other head fully supports and

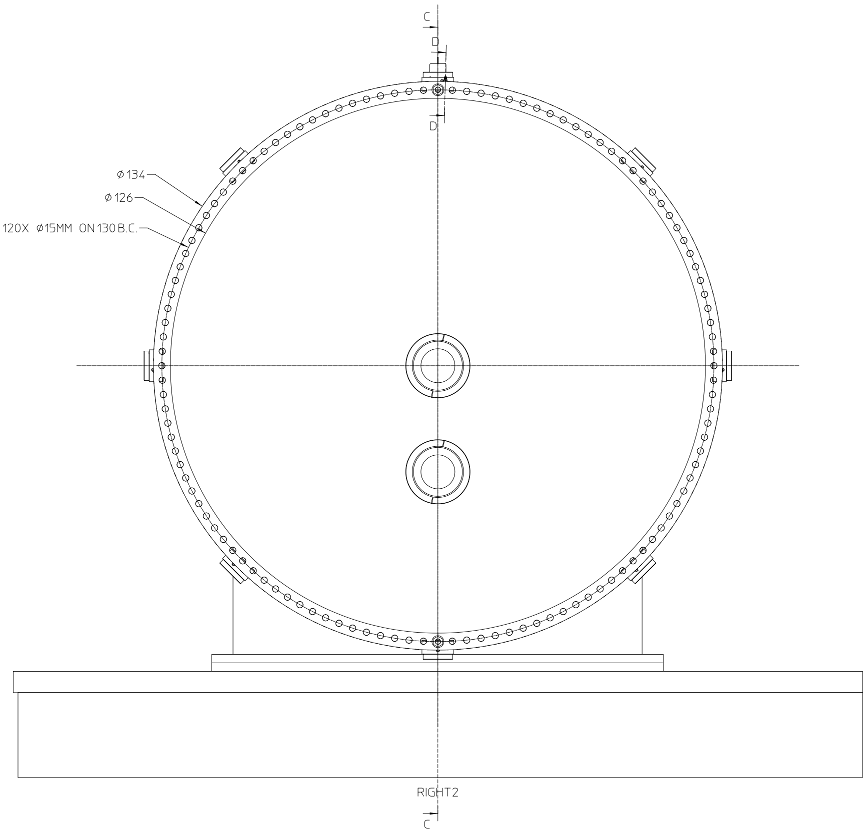

Figure 2: Pressure Vessel, End View, Tracking end

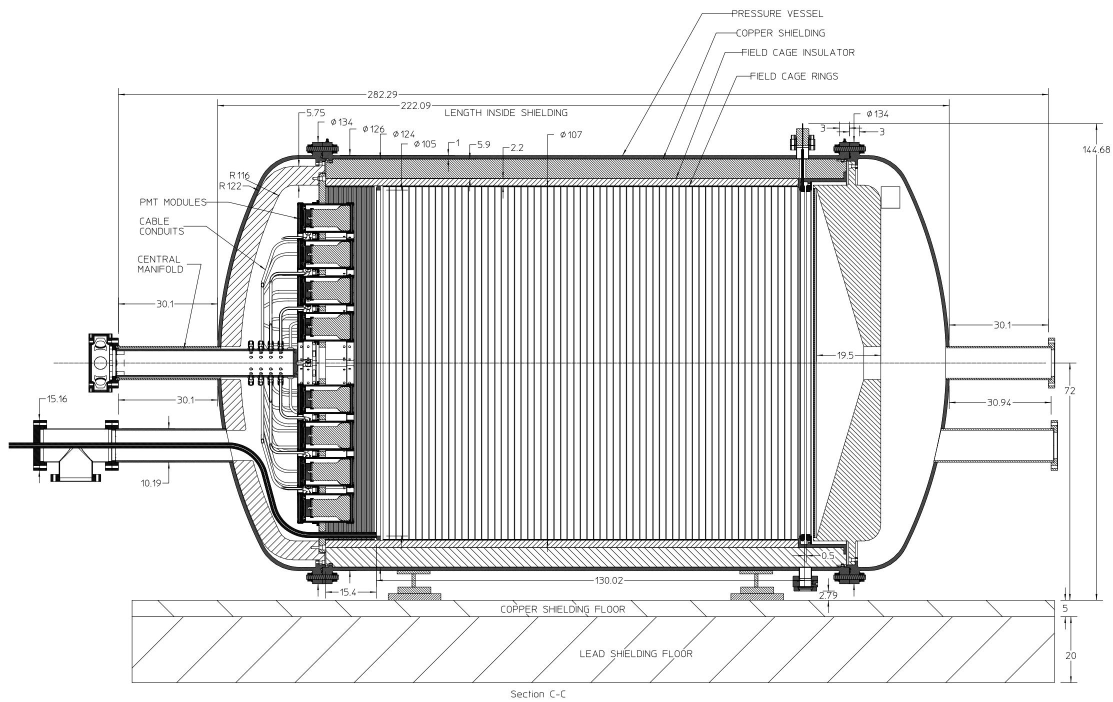

Figure 3: Pressure Vessel/detector Longitudinal Cross section

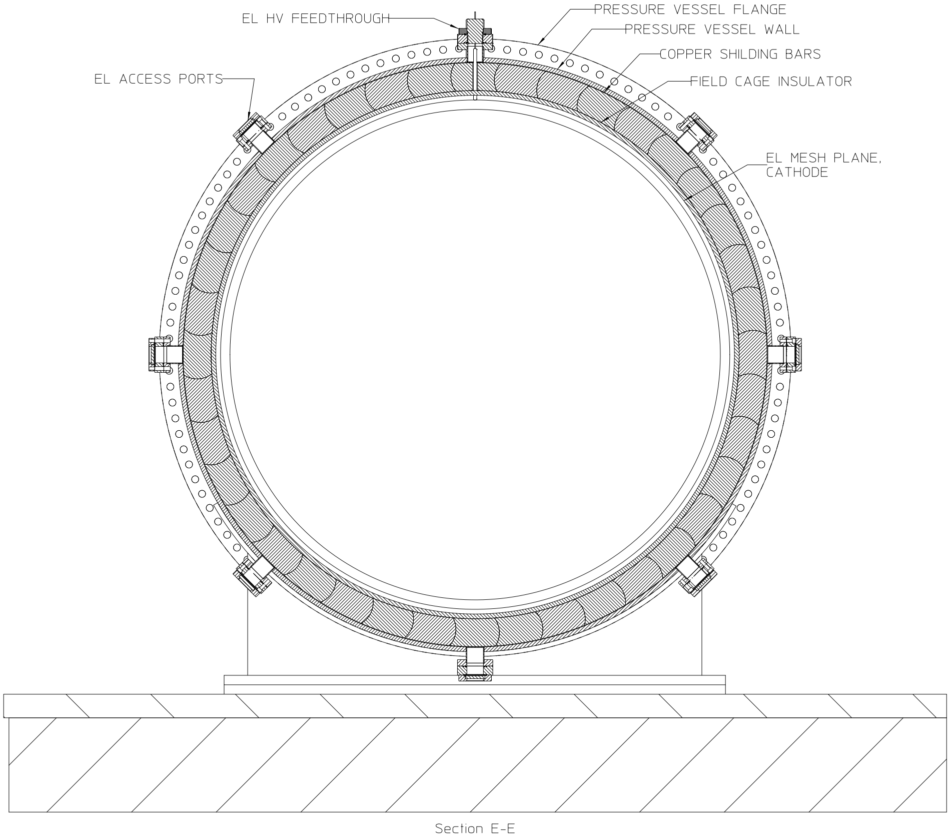

Figure 4: Pressure Vessel/detector Transverse Cross section, at EL gap

contains the SiPM system (tracking plane), and the main vessel fully supports and contains the field cage and mesh plane system. 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 supports for these internal systems are a set of internal flanges, one incorporated into each main flange (4 total).

The simpler vessel design will significantly reduce cost, time, and risk in the fabrication; it is now very similar to a standard pressure vessel design, which all qualified manufacturers will be familiar with. The decoupling of the vessel from the internal systems allows us to get an early start on the vessel fabrication, and allows for further refinement and development of these systems, should this be necessary. The main drawback is that there is more inactive gas space inside the detector; this may eventually require the design of radiopure gas fillers. It is likely that radiopure acrylic can be used; it should be possible to copper plate it in order to eliminate gas permeation into the plastic.

The vessel is now made from 304L or 316L Stainless steel. Radiopurity testing on grade 2 and 3 titanium did not yield the desired value in the 100 μBq/kg range, as has been found by others for some, but not all samples of grade 1 Furthermore, after investigating potential vendors in Spain for pressure vessel fabrication, it appears that a high level of expertise in fabricating with titanium is not available, and our confidence in being able to maintain high radiopurity throughout the fabrication process was low. Therefore we decided to take the approach taken by the GERDA collaboration and fabricate a reasonably radiopure stainless steel vessel then line it with radiopure copper for shielding.

These two materials, 304L and 316L appear easy to obtain in the 1-2 mBq/kg background range (U, Th each) which is an order of magnitude higher than for titanium ASTM grade 1. To shield this higher background, we have lined the inside walls with 6 cm radiopure copper (2 radiation lengths) to shield this higher background. Although the radius and length of the vessel have been increased, the outside shielding castle inner walls have been reduced by the same amount, making this essentially a no-cost penalty. The increase in vessel radius is not a significant factor in its cost, as the size is still quite modest. The copper liners are in the form of easy to install straight bars, and are straightforward to make; material cost will likely dominate.

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.

The basic parameters and dimensions of the pressure vessel are shown in table 1.2

Table 1: NEXT100 Pressure Vessel Parameters

Parameter	qty	units
Maximum Operating Pressure (MOP)	15.0	bar (abs)
Maximum Allowable Working pressure (MAWP)	16.4	bar (abs)
Minimum Allowable Pressure (external	1.5	bar (abs)
Inner diameter	124	cm
Outer Diameter, Vessel	126	cm
Outer Diameter, Flanges	134	cm
Length, inside shielding	2.22	m
Length, end to end, axial	2.85	m
Vessel and head wall thickness	10	mm
Head crown radius, internal	124	cm
Head knuckle radius, internal	12.4	cm
Flange thickness, head to vessel (both)	3.0	cm
Bolt Diameter, head to vessel flanges	14	mm
Bolt length, head to vessel flanges	8	cm
Number of Bolts, each head to vessel flange	120	
Mass, Vessel and both heads	1100	kg

1.3 Design standards

As in the CDR, the vessel will be built strictly to ASME pressure Vessel Design Code, sec VIII. There are two divisions to this section: division 1, which is entirely rule based and has higher safety factors, but lower quality control standards; and division 2 which is either rule or (finite element) analysis based, with lower safety factor, and higher QA standard. Typically, flanges and wall thicknesses are lower using division 2, but in the case of austenitic stainless steels, little difference is found. We use division 2 rules (part 4) primarily, but for flange design, we must use division 1 rules, as we are using flat-faced flanges instead of raised face flanges, and there are no design rules in div.2 for this type of flange. Given that div. 1 gives more conservative thickness that div 2 this is justified. An alternative is to design using finite element analysis (div. 2, part 5), however, this has, so far been unnecessary. Design calculations for the vessel are presented in the Appendix [?]. It should be noted that, 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). See section on Fabrication Contracting below.

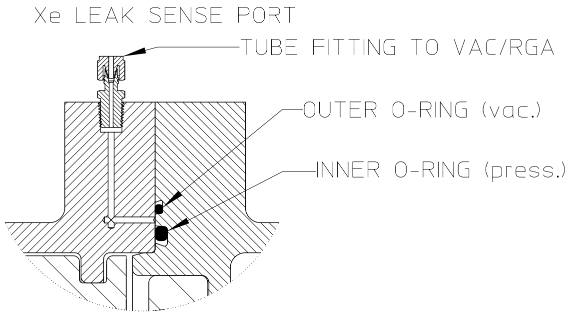

Figure 5: Double O-ring/sense port detail

1.4 Sealing

All pressure sealing flange joints that are exposed to atmosphere on the outside are sealed using double O-rings in grooves. 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). The use of CF knife edge flanges for pressure sealing is possible, however, the bolt holes in CF flanges are very close to the gasket and there is no room to add an O-ring to create the leak check annulus. A CF flange may be vacuum tight under vacuum, but leak under pressure, due to flange flexure. Figure 1.4 shows a cross section detail of the head to vessel flanges; nozzle flanges are similar.

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). The use of an ultralow permeability polymer such as PCTFE is being explored. 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.

It is possible to substitute Helicoflex metal C-ring gaskets on the small nozzle flanges which should reduce permeation to a negligible level. An effort to procure a low-force Helicoflex gasket for the head to vessel flanges has been unsuccessful; Helicoflex will only recommend using such a large diameter gasket at a very high sealing force; this almost doubles the flange thickness and bolt diameter, and adds several cm to the flange OD. Furthermore, the gaskets are one-time use and cost approx. $1000 each. Given that we know how to recover xenon, these are unnecessary.

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 an interface flange. Figure 1.4shows a bored-through interface flange with a (pressure tested) CF window for possible EL spark diagnosis; interface flanges will be a blank-off version in actual use with EXe. These interface flanges are used in 7 small access ports for the EL region, and in the port for the EL cathode high voltage feedthrough; given that the gap is particularly sensitive to foreign matter and may need cleaning; the hope is that cleaning tools might be designed to utilize these ports. They will also be used at the auxiliary nozzle flanges, as these are pressure inside/atmosphere outside joints.

The central nozzle of the energy head (and possibly the tracking plane head) has a CF flange (DN100) as it is not a pressure sealing surface; instead pressure is sealed by the Central Manifold which bolts to the underside of this flange, inside the vessel. 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. Figure 1.4

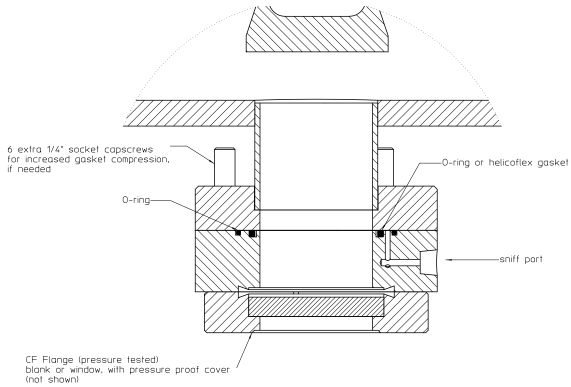

Figure 6: EL Access Port/ interface flange with CF window

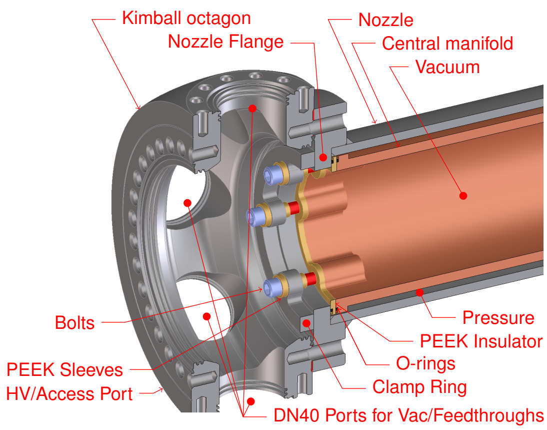

Figure 7: Central Manifold/ Nozzle Flange Seal

Figure 8: Pneumatic Torque Wrench

The recovery cylinder is large enough to vent the entire vessel of 15 bar such that the resulting pressure is no more than 1 bar absolute. The flange to octagon joint is however strong enough to withstand the full 15 bar.

1.5 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. The O-ring sealing allows bolt tension to be reduced from the CDR design, and these bolts are tightenable by hand using large wrenches; the hydraulic bolt tensioners shown is sc 8.2.5 are not needed. There are 120 bolts per flange, however and it is recommended to use a pneumatic torque wrench instead, as shown in figure 1.5. These are not the common pneumatic impact guns used for auto wheels but give repeatable, precise torquing.

1.6 Pressure Relief

Pressure relief is provided though one or more of the auxiliary nozzles. Currently the energy plane head auxiliary nozzle is used and the port has a tee to allow gas flow/pressure relief function to coexist with the drift cathode high voltage cable feedthrough. The auxiliary nozzles are designed to vent the pressure vessel to the recovery cylinder under 1 minute or less; this is desired since there are electrical feedthroughs, which, though pressure rated to 24 bar, have brittle alumina insulators; these have some possibility of failing catastrophically which would result in a fast with a fast loss of xenon, in approx 10 min. The auxiliary port will have a fast acting pressure signal actuated high flow capacity pressure relief valve or burst disk on the auxiliary port which vent to the recovery cylinder. Proper activation should vent the vessel in approx. 1 minute, limiting loss of xenon through the broken feedthrough to no more than 10% of total. Reaction force is considerable, approx 10 kN. The nozzle will require a rigid brace clamping it to the floor of the support frame, since the outside shielding disallows the addition of bracing gussets between the nozzle and the head shell.

Apart from this, it is required to have a passive relief valve as well, this will also vent to the evacuated recovery cylinder. This valve is of a smaller 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. Sizing for fire, using API methodology a 1 cm dia. vent line is required. Reaction force for this condition is very small.

The vessel and detector are mounted on a movable seismically isolated platform, and they connect to the recovery cylinder which is too large to share space on the seismic platform, which must be mounted to the LSC hall floor. There can be relative motion of up to 100 mm between the platform and the

LSC hall, so the connection to the recovery cylinder, will be by a pressure rated flexible couplings. The piping ends of the recovery cylinder also need to be rigidly braced to the LSC hall floor.

1.7 Assembly

The central cylindrical vessel will be bolted through the shielding floor to the seismic platform below. Footings will be welded to the vessel wall, as is standard practice. The heads will be attached to carriages that slide on precision rails bolted the shielding floor. These are shown in the shielding section of this report. These carriages will attach to the heads by threading some of the flange clearance holes to a 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.

1.8 Vessel Construction

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 presence of the internal flanges will require some care in design. We believe currently that the internal flanges can be machined integral to the flanges and the shells welded adjacent, however it may turn out that the internal flange will need to be welded on as a separate ring, after the main flange is welded. the manufacturer will likely need to run tests to see what works best.

The vessel will be welded using the gas tungsten arc (GTAW) process. particular care will be take to avoid use of thoriated tunsten electrodes, (and guns used with such). There is concern that welding methods characterized by high cooling rates, such as electron beam or laser welding can cause the formation of a martensite, a brittle phase which can crack, so these methods are disallowed.

To assure that the high dimensional tolerances are achieved, particular care in the construction sequence will be made, in particular, several stress relieving treatments will be required, some or all of them a full solution anneal (driving all carbides back into solid solution). This is the only method for obtaining 100% stress relief and requires a heat soak at 1050-1120C with slow cooldown. Details will be worked out with the manufacturer, and specified in the User Design Specification (see below)

1.9 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 licenced professional Engineers.
- 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.
- 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. The draft User Design Specification is given in the Appendix. Preliminary Calculations are also included in the Appendix.