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Finance Board Review
Surface Detector Systems

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Fermilab

Surface Detector Performance Requirements

- 3000 km^2 area: for sensitivity above GZK Cutoff
- 1.5 km triangular spacing: for 5-station trigger sensitivity at 10^{19} eV (15 at 10^{20} eV)
- 10 m^2 area: for statistical precision of reconstruction
- WCD for sensitivity to inclined showers
- 1.2 m water depth for μ-em separation for primary composition determination
- 50 photoelectrons per vertical equivalent μ for composition, rise time, time profile determination

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Surface Detector Reference Design & Requirements

- 1600 opaque cylindrical tanks, 3.6 m diameter, 1.2m deep, 1.5 km spacing, covering 3000 km^2 area
- Position accuracy known by GPS
- Environmental resistance: -15°C to 50°C, 160 km/hr wind, 2.5 cm hail, ultraviolet exposure
- Resistant to windblown sand, insects, rodents, cows, persons
- Operational for 20 years without major repairs

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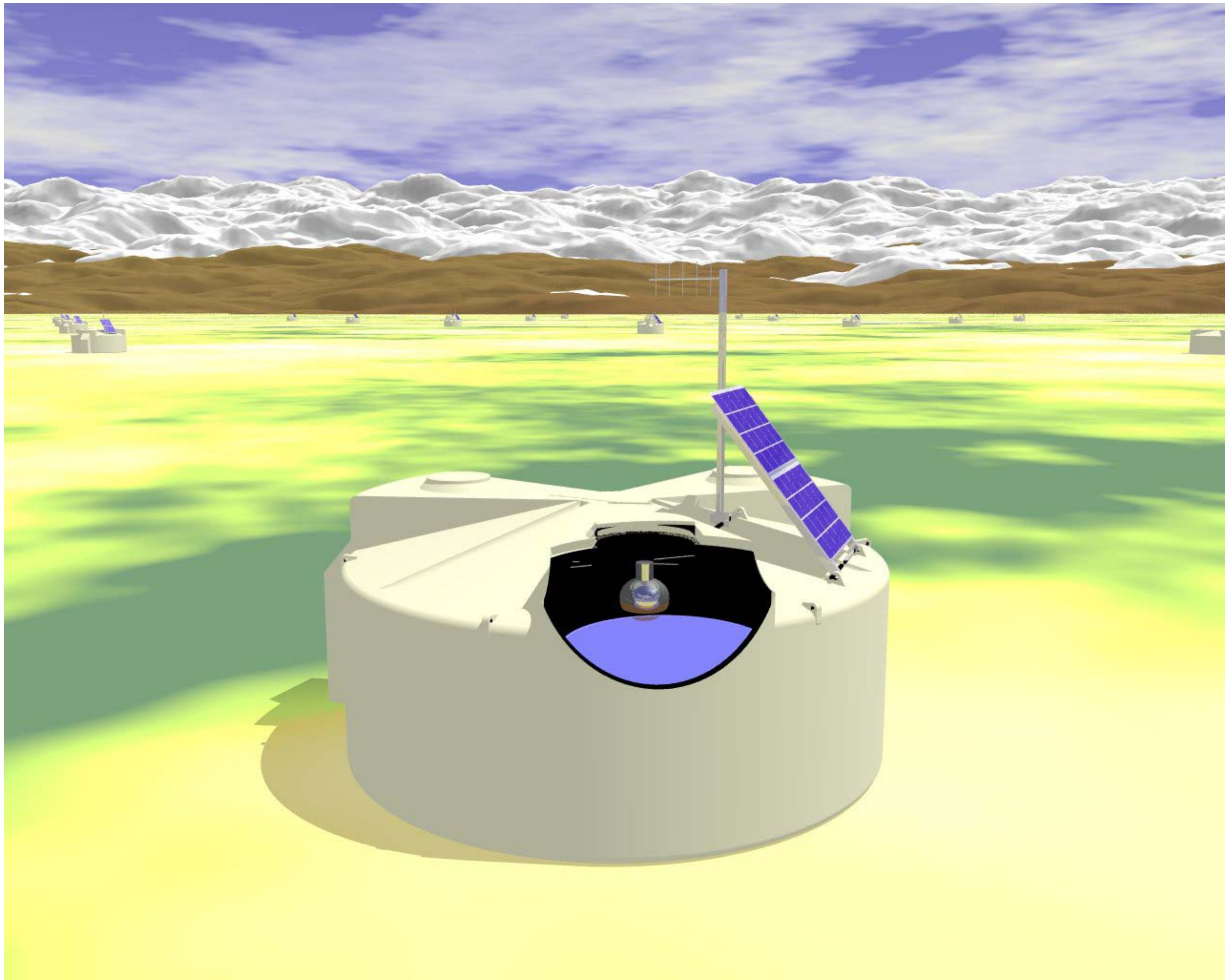
Surface Detector Baseline Design & Requirements

- **Tank contains a closed liner with a highly reflective inner surface (Tyvek®), three windows and three 20 cm photomultipliers.**
- **Solar power will provide 10 W.**
- **Brackets on the tank will support the solar panels and antenna mast.**
- **Three hatches provide access to tank interior over the three PMTs.**
- **Electronics enclosure mounted on one hatchcover.**

The Surface Detector



Surface Detector Tanks Technologies Considered

- Carbon Steel was subject to corrosion, not cost effective.
- Stainless steel was expensive, very thin (to keep cost down) and concern remained about chloride stress corrosion cracking.
- Fiberglass tanks were found to be too expensive; some concern about opacity remains.
- Rotationally molded high density polyethylene was selected for cost, corrosion resistance, strength, design flexibility.

Surface Detector Tank Design Features

- Rotationally Molded high density polyethylene
- Beige exterior, opaque black inner layer
- 3.6 m diameter × 1.6 m high (1.2 m water depth)
- Complex top design for rigidity with small vertical height and for mounting and lifting lugs
- Maximum height of 1.6 m allowed for truck shipment two abreast
- Hatch openings over each of three PMTs

Surface Detector Tank in the Field before Water Filling

Tanks Arriving in Malargue

Unloading Tanks in Malargue

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Tank Engineering Analysis

- Finite element analysis (FEA) was performed for different tank designs to determine stress levels.
- Stresses were calculated with a heavy (114 kg) person standing on various parts of the tank.
- 160 km/hr wind loading on solar panels was analyzed.
- FEA was done on the hatchcover mounting to determine stresses in the mounting screws. Predicted forces are <7.5% of measured pullout forces.

The Last EA Tank Being Load Tested

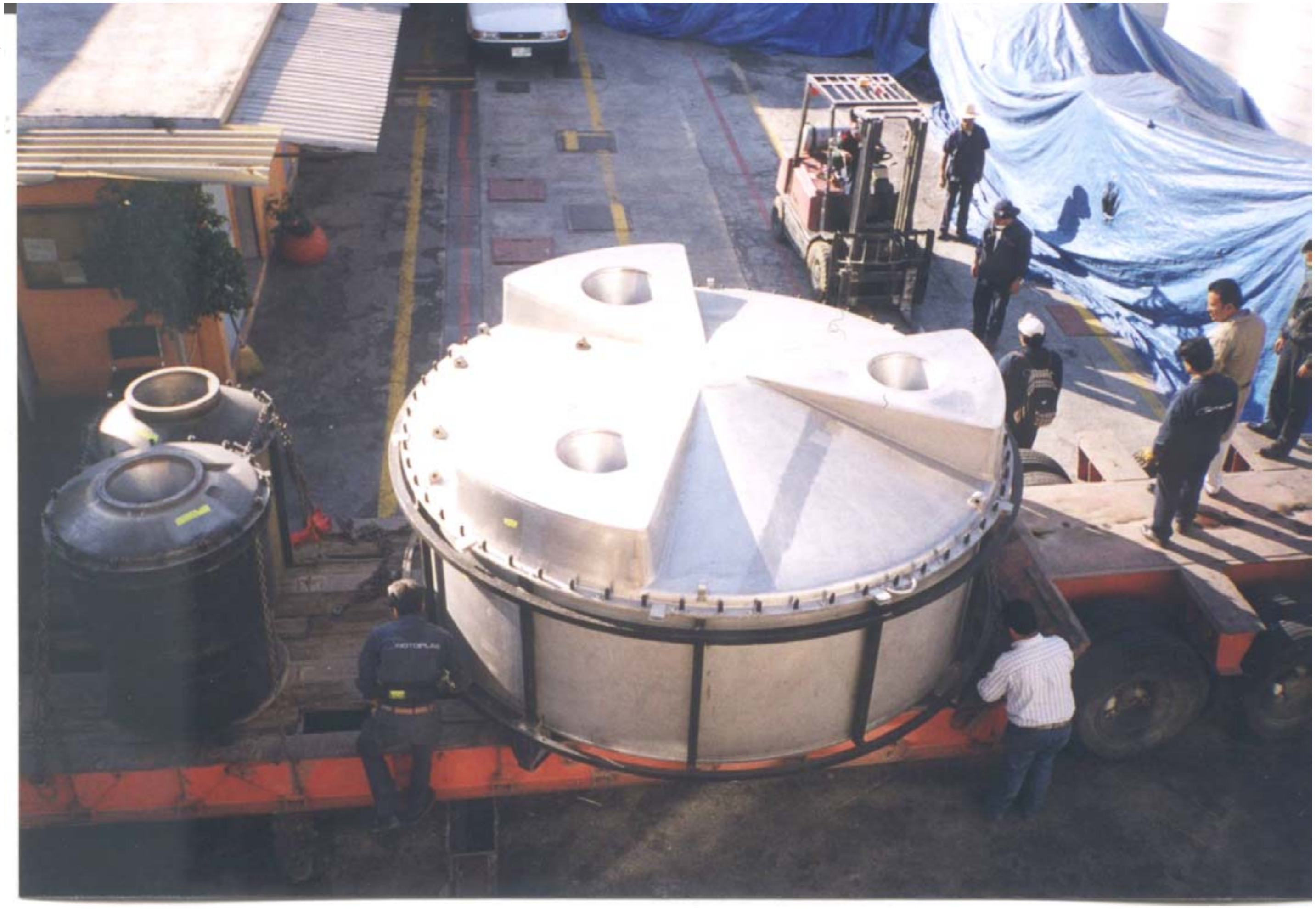
Our Rotational Molding Process

- A predetermined amount of beige HDPE powder is placed in a stainless steel mold. The inside of the mold has the shape of the outer surface of our tank.
- The mold is closed.
- The mold is rotated about two axes simultaneously inside an oven and heated.
- The beige powder melts and coats the inside of the mold. Heat and rotation continue until all the beige powder has been deposited.

Our Rotational Molding Process

- The rotation is briefly stopped and a predetermined amount of black powdered polyethylene is put inside the mold. The mold is immediately re-closed and the rotation in the oven continues until all of this powder has been deposited on the surface.
- The mold is removed from the oven and cooled while rotation continues.
- The mold is opened and the tank removed.
- Hatches are cut and lugs drilled.

Tank Mold in Mexico City



Molding Machine Being Assembled in Mexico

Polyethylene Resins

- The base polyethylene resins are manufactured by polymerizing alkenes with suitable catalysts. Light stabilizers and anti-oxidants are added at this point.
- The base resin is "compounded" by adding pigments to the melted resin along with more additives. The resin is pelletized and ground.
- The quality of the final resin is determined by both steps, done by different companies. Our resin is of the highest quality (and cost) because of our demand for stiffness and a 20 year lifetime.

Engineering Array Tanks

- The Engineering Array tanks were made by Alpina in Sao Paulo, Brazil. They use a closed oven for best temperature uniformity and control.
- Some tanks were warped more than we want. The molding process was tuned to reduce warping.
- Tank color, dimensions, interior and exterior finish, and wall thickness are satisfactory.
- We have modified the tank design to reduce warping further.
- Rotoplas made tanks, not quite as good, too late for EA. Now in use for thermal tests.

Polyethylene Resins

- EA Tanks used Exxon (Canada) Escorene 8661 base resin compounded by A. Schulman Co. Good but expensive.
- We are testing Exxon XLO-370, a new stiffer resin. It's so new price and delivery are unknown.
- We are also testing Cotene resins from Courtenay in New Zealand. Inexpensive, could save significantly if it proves satisfactory.
- Lifetime is difficult to verify. We must be convinced before switching.

Modifications to Tank and Mold Design for Preproduction

- The origin of the angle of flat top sections of the tank top moved to reduce stress during cooling.
- Lug design modified to reduce cooling stress.
- Stiffening ribs added to tank top conical regions to reduce loaded top deflection in hot weather.
- A raised lip was added around each hatch to stiffen area, thicken area for hatchcover mounting screws, and reduce rainwater entry.

Raised Lip around Hatches

Tank Shipment

- Tank shipment is by truck, two abreast, on edge.
- Some tanks, strapped down tightly, were damaged by creep during shipping from Brazil.
- Fixturing on the truck is required to reduce stresses and deformation during hot weather.
- Shipment from Brazil takes longer, so requires better fixtures, than shipment within Argentina.
- Good fixtures are in place now but they will be improved by internal tank supports.

Tank Quality Assurance

- Quality control data will be entered into the Traveler database.
- The Traveler is our data management tool for QA.
- The tank manufacturer has first responsibility for quality and makes the first measurements of tank dimensions, including ultrasonic measurements of wall thickness, and other quality observations.
- Manufacturers' data is spot checked by Auger inspectors.

Tank Quality Control Tests

- ARM Cold Impact Test will be done by Auger on a sample from each tank, a test of tank strength.
- A sample of material from the tank will be reground and the melt index measured. This test is sensitive to “overcooking”.
- Flexural modulus of a sample from each tank will be measured. This is a test for proper cooling after tank molding
- Each batch of resin is tested extensively by the resin compounder and certified before use.

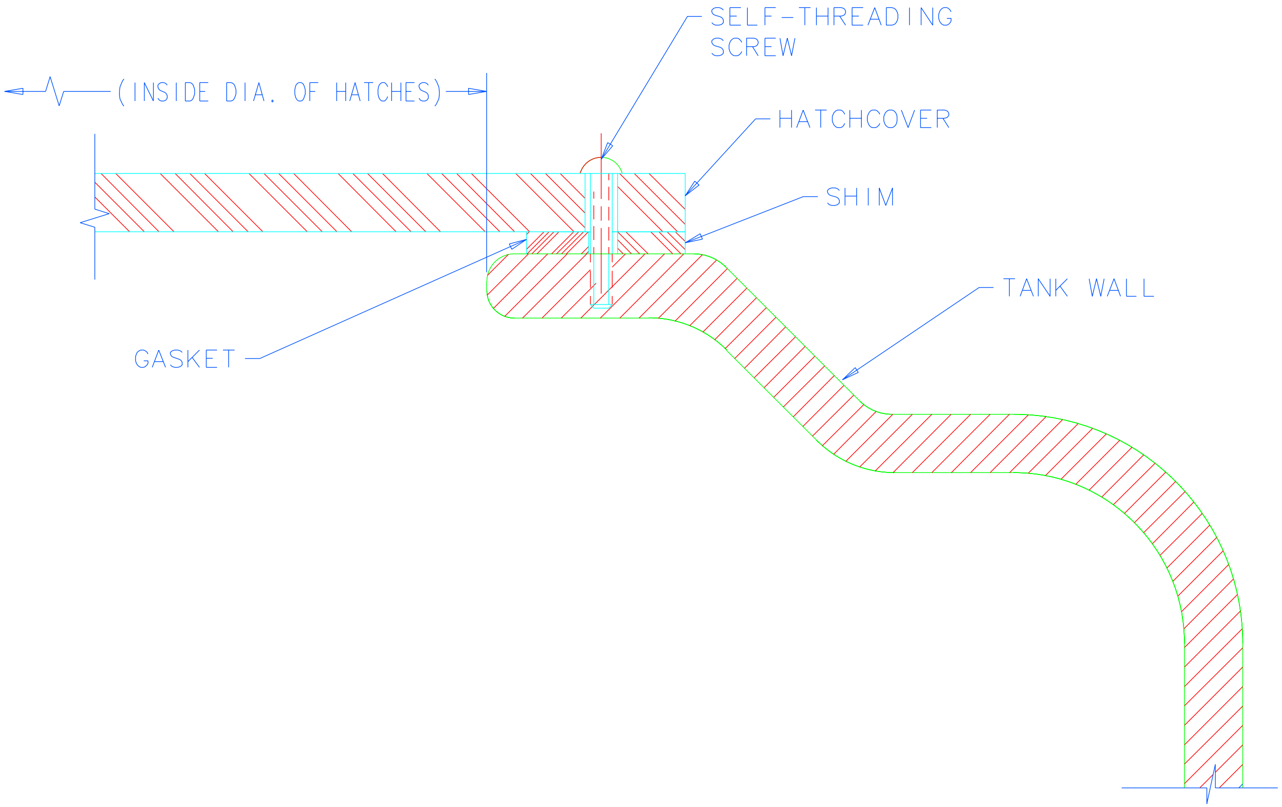
Tank Procurement Plan

- Alpina Brazil is now modifying their (carbon steel) mold for Preproduction.
- When first Alpina tanks are satisfactory, Rotoplas will modify their stainless mold in Mexico.
- Alpina will begin construction of a stainless mold while continuing to produce tanks with the carbon steel mold.
- We expect Rotoplas and Alpina to each produce half the Preproduction tanks.
- Argentina, Mexico, Brazil will each provide 1/3 of the tanks for the Production phase.

Hatchcovers

- **Tank hatches are covered with polyethylene plates similar to the tank material itself.**
- **Hatchcovers are machined from HDPE sheets. For the EA, they were all black, but two layer beige-black is available for Production.**
- **They are attached to the tank with 24 self-threading screws designed for thermoplastics.**
- **Sealing is by an EPDM rubber foam gasket.**
- **Spacing is controlled by shims.**

Hatchcover Assembly



TYP. HATCHCOVER ASSEMBLY SECTION

Engineering Array Hatchcover Experience

- **The Problem: The gaskets took a compression set, allowing water to leak into some detector tanks.**
- **The Solution: New gaskets of different materials (e.g., silicone) and different shapes are now being tested for reduced compression set.**
- **The Problem: Installation of gaskets done with several experimental procedures. Some of them resulted in incorrectly placed or loose gaskets.**
- **The Solution: Optimized procedures for the new gaskets selected will be applied.**

Engineering Array Hatchcover Experience

- The Problem: Warping of the tank top resulting in a depression at the hatch that collected rainwater and made any leakage more severe.
- The Solution: A raised lip will be molded around the hatch areas. Other tank features were redesigned to reduce warping.
- In addition, a "rain hat" design feature of the hatchcover can be installed to eliminate any rainwater problem.

Tank Liner Assembly Overview

- The water is contained in an opaque, polyethylene liner with a Tyvek® inner surface. Materials are chosen to have no biological activity or plasticizers to leach into the water.
- Flange and window assemblies are welded into the top of the liner for PMT attachment.
- Once filled with pure water, the liner is sealed and the water purity protected, even if a PMT is changed, for example.
- The Tyvek® provides a highly reflective, diffusive surface for light collection.

Inflated Liner under Test

Tank Liner Assembly

- A laminate of polyethylenes, metallocene-polyethylenes, and Tyvek® 1025BL was developed for inertness and sealing ability.
- Engineering Array liners were made by IHEP, China. Quality was marginal.
- Liner manufacturing developed by Colorado State Univ. has stronger seals and better quality because of improved sealing techniques.
- Quality control development by U. of Miss. and CSU assures better quality liners are made.

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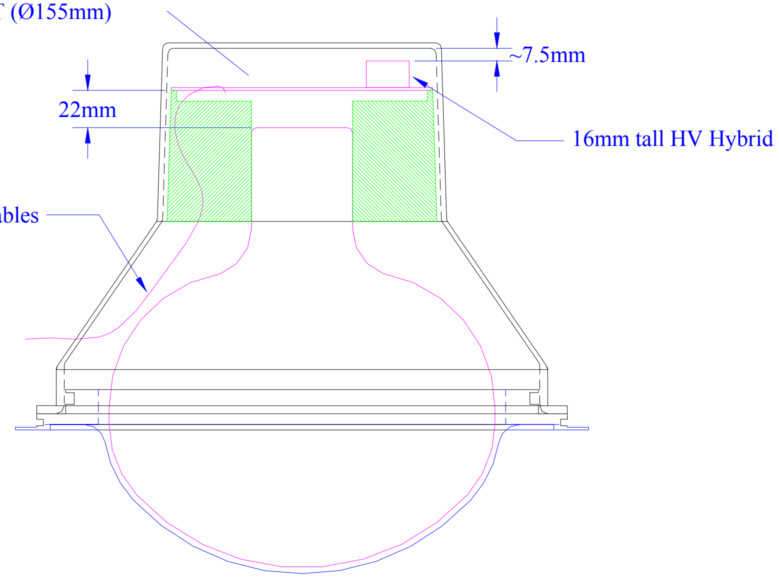
Tank Liner Assembly

- Liners are being made at Colorado State U, USA; and at companies CAC, in Mendoza, Argentina, and Blueridge Films, Virginia, USA, for Preproduction. Liner top (with PMT flange and other parts) and bottom all to be made at CSU.
- Quality testing done at manufacturer and liners arrive at Malargue rolled up and ready for insertion into the tanks at the Assembly Building.
- Liners in the tanks are unrolled, inflated (with a vacuum cleaner), and PMT assemblies are installed and tested.

Photomultiplier Dome Window and Enclosure Assembly

- Seals the liner
- Provides a transparent window for Cherenkov light to reach the PMT: .025" metallocene-polyethylene, heat sealed in place.
- Encloses and protects the PMT from dust and water and shields it from external light.
- Flanges welded to floppy dome, laminate material with an impulse welding machine.
- RTV Silicone rubber optical coupling used between window and PMT: Wacker Silgel 612, used successfully on Antares experiment.

Photomultiplier Dome Window and Enclosure Assembly



Bracket Assembly

- A bracket assembly was developed to support the solar panels and the antenna mast.
- Aluminum Unistrut® and riveted square aluminum tubing systems were tested in the EA.
- Both systems will withstand 160 km/hr winds and the elements for 20 years.
- The riveted tubing was selected as being slightly more corrosion resistant, cost effective and secure against casual theft.

Unistrut® Bracket and Mast Assembly

Solar Power System

- Surface detectors require 10 W power source.
- A 24 volt system was selected for efficient power conversion for electronics.
- Analysis of the insolation in the area allowed the correct sizing of the solar panels and batteries for lowest cost with failure to meet load of less than 1% of the time when new and less than 3% of the time after 20 years.
- Solar power is a successful industrial product, so we don't have to invent it.

Solar Power System Baseline Design

- Two solar panels of 55-60 Wp in series
- Two 12 volt, 100 Ah Valve Regulated Lead Acid Absorbed Glass Mat (VRLA AGM) batteries
- A charge controller, series connected PWM design of documented high reliability
- Cables
- Power controller for tank and array shutdown during prolonged periods of darkness.
- Battery box to contain, protect, and keep cool the batteries and charge controller.

Solar Panels

- Four Models were tested in the EA: Solarex SX-60U, Kyocera KC-60, Siemens SM55, and Unisolar US64.
- The Unisolar is so large we are concerned about wind loading.
- All other panels appear satisfactory. One was broken; vandalism is suspected.
- Preproduction panels will be Isofoton I53, from Spain. They are almost identical to the Siemens SM55.

Charge Controllers

- A series connected, pulse width modulated charge controller optimizes battery performance and lifetime.
- One has been selected, the Morningstar Sunsaver SS10-24V. Cost has been very low.
- We expect a five year failure rate of less than 0.2% and a lifetime in excess of 15 years.
- No electronic interference from these controllers has been observed.

Batteries

- VRLA AGM batteries are specified: They optimize lifetime in deep discharge conditions.
- No maintenance required during battery lifetime
- Batteries acquire a reputation with the people buying and selling them. Concorde SunXtender® has a good reputation for quality. They are available in the US at a good price. A lifetime of 7-8 years is expected.
- Concorde claims a 1% per month self-discharge rate, which makes managing delivery and installation easier than others with higher rates.

Battery Box

- The battery box is rotationally molded polyethylene.
- The top is retained by security head screws threaded into brass inserts.
- The bottom of the box is welded to a polyethylene sheet that is captured under the tank for security.
- The box is lined with 50 mm polystyrene foam insulation.
- Cows have damaged many cables. A new box will be built with better cable protection.

Battery Box at a Detector Station

Water Requirements

- Water must be sufficiently clear to produce 50 photoelectrons (PE's) per vertical equivalent muon in our detectors.
- When filled, detectors produce 150 PE's.
- The challenge is not initial clarity but stability.
- Haverah Park obtained excellent long term stability without special water purification: They used wellwater from a magnesium limestone borehole delivered through fire department hosepipe.

Water Requirements

- Our approach is to provide water as pure as practical to minimize growth of microorganisms, and to avoid materials that could leach contaminants into the water.
- Consultants provided an analysis of cost vs. water purity. There were no abrupt increases in capital or operating cost with increasing purity.
- We selected the “high end” plant to produce ultrapure water with normal industrial technology.
- Test of stability will be detector performance.

Water Requirements

- 15-18 MΩ-cm resistivity
- <10 ppb Total Organic Carbon (TOC)
- hardness <1 ppm as $CaCO_3$
- Plant uses particle filtration, water softening, reverse osmosis, and electrodeionization stages.
- TOC removal by 185 nm UV exposure followed by deionization.
- Microorganism control by 254 nm UV exposure.
- Storage tank with recirculating loop with 254 nm UV and particle filtration.

Assembly Activities

- Receive and prepare tanks
  - Clean outside and inside
    - *Pressure washer*
    - *vacuum cleaners*
  - Inspect and measure a sample of tanks
    - *wall thickness*
    - *gross dimensions of tanks*
    - *lug dimensions*
    - *warping*
  - Drill screw holes for hatchcover screws using a drill guide and hand drill
  - Drill and install tubing for drain and vent

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Assembly Activities

- Insert Liner, inflate, and place in position
- Install PMT's, PMT enclosures (Fezes)
  - Pull dome assembly through hatch
  - RTV PMT to window
  - RTV PMT enclosure to flange
  - Return assembly to interior of tank
- Install solar panel bracket parts
- Connect electronics and check out
- Install travel bumpers
- Install hatchcovers