2. SURFACE DETECTOR

2.1. Surface Detector System

The main scientific goals of the Auger Observatory as well as the role assigned to the surface array have been described in the introductory chapter to this document (see section 0.3). After a short presentation of the main objectives of the surface detector system, we will concentrate here on the description of the components of the surface detectors (SD): tanks, liners, solar panels and antenna masts, water production and finally assembly and deployment. The surface detector electronics will be described in section 2.2.

2.1.1. Surface Detector Overview

The role of the surface array is to measure the lateral density and time distribution of particles in the shower front at ground level. These shower quantities are correlated with the energy, the direction, and to some extent with the nature of the primary particle. The detector performance in measuring these parameters defines the physics performance of the surface array. The resulting detector parameters have been studied using shower and detector simulations as well as with the experience gained with earlier surface arrays. The conclusions of these studies are detailed in the Auger Design Report [1]. It should be noted that, since the Design Report was written, the physics goals have been enhanced by the prospect of neutrino detection from large zenith angle showers.

The main choices and the basic detector parameter definitions were also already justified in the Design Report. Uniform sky coverage is required for anisotropy studies and the observatory will consist of two sites, both located at about 30° latitude North and South. The size of each array is driven by the goal to collect high statistics above the predicted GZK cut-off. The required limiting aperture requires the instrumentation of an area of 3000 km^2 per site. The spacing of 1.5 km between detection stations is defined by the requirement of full detection efficiency above 10^{19} eV and of a good sampling of the lateral density distributions. The low density of particles (~1/m^2) to be measured with good statistical precision imposes a sampling area of ~10 m^2.

The water Cherenkov detection technique has been selected mainly from cost considerations but also because of its own virtues: the water tank offers a natural way to optimize muon pulse heights with respect to the electromagnetic component. Because of its large lateral cross-section it offers a good sensitivity to large zenith angle showers. The experience from the Haverah Park array, where water Cherenkov detectors of similar area and height were used, backs this choice.

Thus, the surface array will be comprised of 1600 water Cherenkov detectors spaced by 1.5 km on a triangular matrix and instrumenting an area of about 3000 km^2.

Each detector consists of a cylindrical, opaque tank having a diameter of 3.6 m and a water height of 1.2 m. The water is contained in a sealed bag or liner that prevents contamination, provides a barrier against any remaining external light, and diffusely reflects the Cherenkov light emitted in the water. Three large diameter (~20 cm) hemispherical photomultipliers (PMTs) are mounted facing down and look at the water through three sealed windows that are an integral part of the liner. The liner also provides filling ports and an additional sealed window hosting an LED calibration system. The PMTs are enclosed in housings to further protect them from external light. On the outside, the tank has supports for solar panels providing the energy supply and for the communication system and GPS antenna. A battery is contained in a box attached to the tank. See Figure 2.1 for a schematic overview of the Surface Detector (SD).

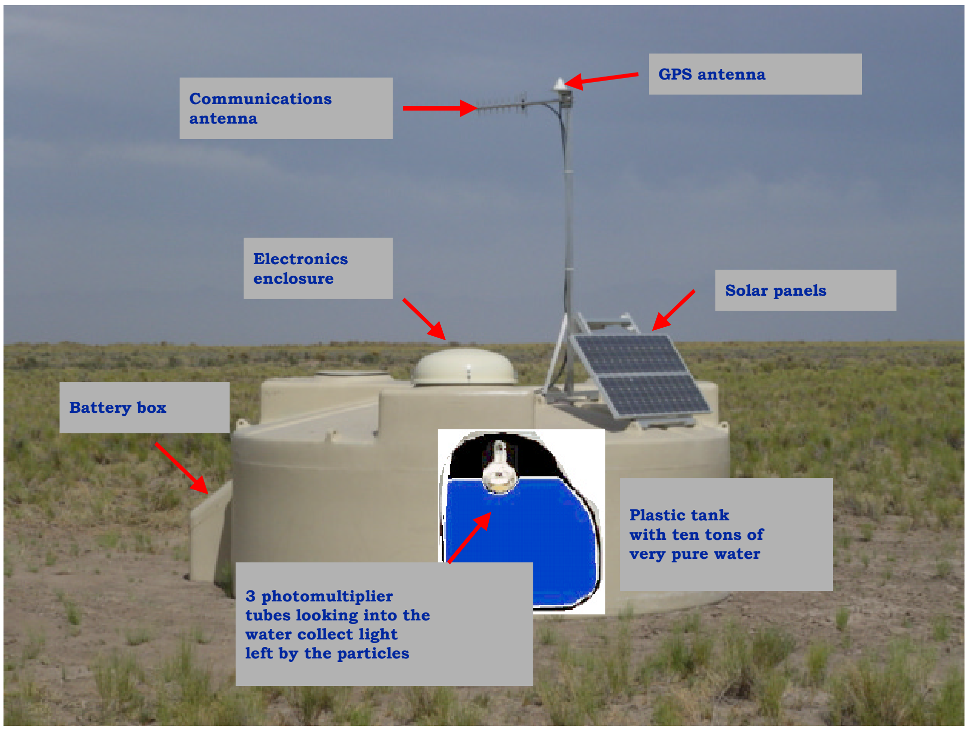


Figure 2.1: A schematic overview of a station of the Surface Detector (SD).

2.1.1.1. Surface Detector Performance Requirements.

2.1.1.1.1. Aperture

The required limiting aperture of the ground array for zenith angles <60º is 7350 km^2-sr per site. The detection efficiency at the trigger level should reach 100% for energies above 3×10^{19} eV.

This aperture is achieved by covering an area of 3000 km^2 per site. The spacing between the detector stations is the result of a compromise between cost considerations and the energy threshold (low enough to insure a good overlap with existing data) as well as a sufficient sampling of the particle density away from the shower core, and of the shower front timing in several places. A minimum of 5 stations triggering at 10^{19} eV fixes the maximum spacing to ~1.5 km. The number of triggered stations for energies > 10^{20} eV is ~15 stations. This adds up to a total number of 1600 detector stations per site.

The surface arrays in both hemispheres will provide data from a nearly uniform celestial exposure. This enables a straightforward search for excess from discrete sources and also a sensitive large-scale anisotropy analysis.

2.1.1.1.2. Energy

The shower energy is obtained by assessing the size of the shower, through the determination of the density at a particular radius of 600 to 1000 m. The measured densities are affected by fluctuations from different origins: statistical fluctuations in the measured density and experimental uncertainties on the shower direction; large physical fluctuations in the shower longitudinal development that lead to shower to shower density fluctuations. Furthermore, the relation between the measured densities and the primary energy is obtained using interaction models and shower simulations. A corresponding systematic uncertainty from model dependence is to be assessed when considering energy measurements. Using the fraction of events that the observatory will detect in the hybrid mode, detailed studies of the shower longitudinal development and cross-calibration will be possible, and we expect to reduce the model dependence of the energy determination by the surface detector alone. The resulting energy resolution is 12% RMS for all events and 10% for events above 10^{20} eV.

It is important to reduce the experimental uncertainty in the measured density as much as possible. At high energy, about 6% of the statistical uncertainty arises from the measurement errors and the rest are from the shower-to-shower fluctuations. The relative error in the particle density measurement at 1000 m from the core should be less than 20%. The muon flux at this distance is of the order of $1/m^2$ at 10^{19} eV. Hence, a minimum sampling surface of 10 m^2 is required.

2.1.1.1.3. Angular resolution

The direction of the primary is inferred from the relative arrival times of the shower front at different surface detectors. A weighted least squares fit is applied to the station triggering times. Fitting the station signal densities to the expected lateral distribution makes refined core location estimation. For the surface array alone, we expect an angular precision of 0.6º for energies $>10^{20}$ eV. This angular accuracy is quoted for the opening angle containing 68% of the reconstructed directions. The angular resolution improves rapidly with zenith angle and energy because of the larger trigger time differences and the greater number of triggered stations.

2.1.1.2. Composition

Heavy primary particles tend to produce more muons and fewer electromagnetic particles than do lighter primaries, when measured at the same total energy. Iron and proton showers may be differentiated using surface detector data alone through the analysis of the ratio of muons to electromagnetic particles, as well as through the arrival time distribution of particles in the shower front. Photons and neutrinos leave very characteristic signatures such as shower front curvature.

The height of the water Cherenkov detector is defined to optimize the muon pulse height. A vertical distance of 1.2 m of water is sufficient to absorb 85% of the incident electromagnetic shower energy at core distances > 100 m, and gives a signal proportional to the energy of the electromagnetic component. Muons passing through the tank generate a signal proportional to their geometric path length inside the detector and rather independent of their zenith angle and position. The number of photoelectrons per PMT corresponding to a vertical muon is in excess of 30 photoelectrons.

Muonic content, rise-time and time profile, are extracted from the measured PMT signal waveforms. This information provides a multivariate handle on the composition of the population of primary cosmic rays. Details of techniques for this type of analysis are still under development.

2.1.1.3. The Surface Detector Reference Design

The surface array general requirements are:

- The array shall consist of approximately 1600 cylindrical, opaque tanks having a diameter of 3.6 m, with a separation of 1.5 km between each one and covering a semi-desert area of 3000 km^2 in a triangular grid.
- The location of each tank shall be determined with sufficient accuracy for shower reconstruction. Differential GPS Systems allow the determination of position and altitude with a precision of less than 1 m.
- Each unit shall support typical semi-desert climates with extreme temperatures varying from –15 ºC to 50 ºC. The surroundings of the tank should be flat and clean to avoid pasture fire and deformations of the tank (or puncture).
- Each unit can be subject to winds with a maximum velocity of 160 km/h; it is waterproof (rains and flooding) and it is impermeable to dust and snow; it is also resistant to the intense solar radiation typical of semi-desert areas. Also, it will have resistance to 2.5-cm diameter hail and will resist wind-blown sand and other particles. It will be resistant to the thermal/ultraviolet diurnal cycle.
- Each unit shall be resistant to strong corroding conditions caused by the salt and some chemical substances that are present in the terrain. Small seismic activity should not deteriorate the detector units.
- Each unit shall have to be robust and to support some load on its top such as the weight of a heavy person, as well as possible aggressive behavior from animals such as insects, rodents, or even cows.
- Each unit of this array must be able, under the above conditions, to maintain itself without functional deterioration, and without major repairs for at least 20 years.

2.1.2. Cherenkov tank assembly

2.1.2.1. Surface Detector Tanks

2.1.2.1.1. Overview

The water Cherenkov detectors require a container to support the water and enclose other detector components, including the photomultipliers (PMTs) and bases, the liner which contains the water and provides both a sealed environment and a highly reflective surface, and other instrumentation and electronics. The tanks are to have a minimum lifetime matching that of the experiment, 20 years. The enclosure must be:

- immune to rain/snow/dew/salt;
- resistant to hail to 2.5 cm diameter at terminal velocity;
- resistant to wind up to 160 km/hr;
- resistant to wind blown sand and debris;
- immune to attacks by insects and animals that might be present.

The container is also used to externally support the electronics, communications antenna, and solar panels.

Tanks made of carbon steel, stainless steel, fiberglass, and polyethylene were considered. Carbon steel presented concerns about corrosion and was not cost-effective. Stainless steel, in order to be cost effective, had to be made with extremely thin walls resulting in marginal structural integrity. In addition, there was considerable concern about chloride stress corrosion cracking in such a thin vessel due to the very salty environment of the Southern Site. Fiberglass was found to be considerably more expensive than polyethylene. Rotationally molded polyethylene was finally selected as the preferred technology.

The water Cherenkov detector is to have a radiator area of 10 m^2 and a depth of 1.2 m. A cylindrical shape for the water volume was selected as the simplest and least expensive to manufacture. The top of the tank is rather complex in order to provide rigidity both for mounting external components such as the solar panels and for people standing on top of the tank and to provide space inside the tank for the photomultiplier assemblies and cabling. The tanks must meet these requirements but not exceed 1.6 m in height so that they can be shipped over the roads two abreast, mounted on their edges, without exceeding the 3.2 m load width limitation for some roads. A desire to make the tanks resistant to .22 caliber bullets was abandoned as impractical. The tank color is selected to blend in with the natural background of the site. Although the tank liner and photomultiplier assemblies are designed for opacity to keep any external light away from the PMTs, we require the tank to be totally opaque in order to provide redundancy.

2.1.2.1.2. The Baseline Design

The Baseline Design for the surface detector tank consists of a rotationally molded (also called rotomolded) tank of high-density polyethylene. Very briefly, the rotational molding process as used to manufacture these tanks consists of seven basic steps:

1) A predetermined amount of light beige powdered polyethylene is deposited inside a stainless steel mold. The inside of the mold has the shape desired for the outside of the tank.

2) The mold is closed.

3) The mold is rotated about two axes simultaneously inside an oven.

4) The beige powdered polyethylene melts and forms a coating on the inside of the mold. Heating and rotation continues until all the powder has been deposited on the surface of the mold.

5) 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.

6) The mold is removed from the oven and cooled while the rotation continues.

7) The mold is opened and the tank removed.

This process produces tanks with a light beige outer layer, matching the environment of the Pampa Amarilla, and an opaque black inner layer guaranteeing that the tank itself will be opaque. Care in the manufacturing process results in a nearly uniform wall thickness of the desired 12.7 mm and minimal warping. Access hatches are cut into the tank after molding. Lugs are molded into the tank for lifting the tank and for supporting the solar panels. These lugs are drilled out after molding.

The 20-year lifetime of the tanks under outdoor conditions is a challenging specification. Unprotected polyethylene deteriorates rapidly due to ultraviolet exposure. Modern polyethylenes contain hindered amine light stabilizers (HALS) that greatly reduce damage due to ultraviolet exposure. In addition, ultraviolet light is absorbed by titanium dioxide found in the beige pigment of the outer layer and by the carbon black pigment of the inner layer. The environmental resistance requirements are easily met by the baseline tank design. The lifetime of 20 years can, however, prove difficult to document. Discussions with consultants and experts in the field yield assurances that this can be done using high quality polyethylene resins, as we are, but obtaining specific lifetime data has not been easy. We continue to seek out more specific evidence and to relate that evidence to specific resins and long term service experiences. The Rotoplas company in Mexico City points out that their water tanks are still in service on rooftops after 17 years, since the founding of the company. Skellerup in New Zealand says they have had tanks in service for 20 years with no difficulty, using Cotene® resins. Tanks made with the Exxon polyethylene resin we are using are in long term service in Saudi Arabia.

The polyethylene resins we use are prepared in two stages before they are used in the rotational molding process. The first stage is the manufacture of the base resin by polymerizing selected alkenes with suitable catalysts. This stage of manufacture also includes the addition of the light stabilizers and anti-oxidants. The character and quality of the resin are determined in this stage. The second stage is “compounding.” The polyethylene resin from the manufacture is melted, the required pigments are extruded into the resin in such a way that they mix very finely with the base polyethylene. Additional additives can be put in at this stage as well. Then the resin is cooled and ground into a powder ready for the molding process. Because of our stringent demands on long lifetime, our material specifications require what amounts to a specific resin prepared by a specific compounding company. As we gain confidence in other resins, they will be added to the specification in an effort to reduce the material cost for future tanks.

2.1.2.1.3. The Engineering Array

The tanks used in the Engineering Array were all made by Alpina in Sao Paulo, Brazil. They were made with Exxon (Canada) resin Escorene® 8661, compounded by the A. Schulman company. Both the resin and the compounder have excellent reputations in the rotational molding industry, and both are expensive. A photograph of a tank deployed in the EA is shown in Figure 2.2.

The tanks made for the EA sometimes had warping problems. The first three tanks were beautiful in that regard, but very few of the next 40 were as good as the first ones. It was not until late in the production that the process seemed to be under control and the tanks again had greatly reduced warping. The manufacturer is continuing to work on the problem. The ability to do datalogging during the manufacturing process to insure reproducible operation of the manufacturing system now exists. We have requested that the company also develop the ability to pressurize the tank during cooling in order keep the tank surface in contact with the mold as long as possible. This gives the manufacturer greater control over the cooling rate and uniformity of cooling over the entire tank. In addition, we have made some small modifications to the tank design to reduce stresses in the tank generated during the cooling process. These include modifications to the top shape and to the design of the solar panel and lifting lugs to reduce stress during the shrinkage that occurs during cooling. We have also added three stiffening ribs to the tank to reduce warping and provide additional stiffness to the tank top. (The stiffening ribs are expected to be particularly helpful to support the weight from several people climbing on the tank top during very hot weather to perform some installation or maintenance task. Calculations indicate the ribs will reduce deflections by half.)

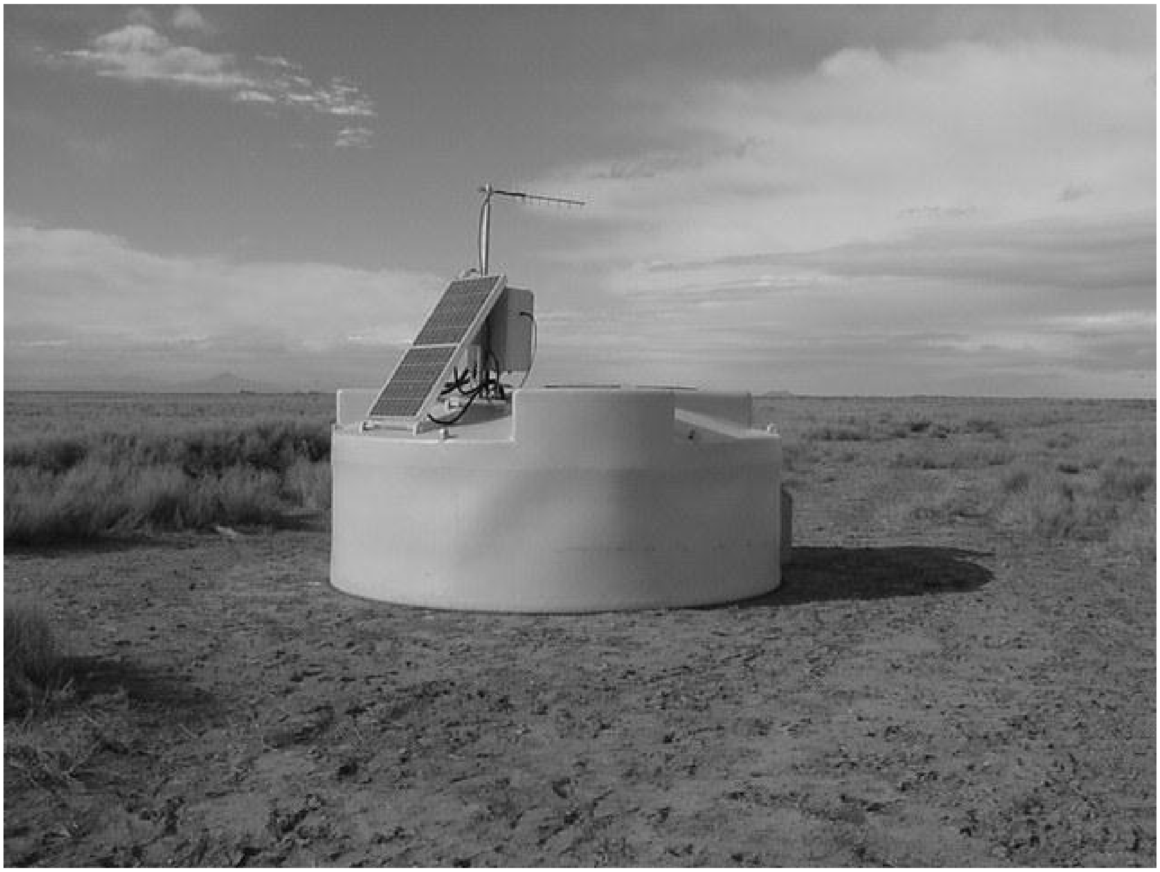


Figure 2.2: A surface detector deployed in the EA. Mounted on top of the tank are the solar panel, electronics enclosure, mast, and antenna.

The inside surface of the first tanks was rough, with a lot of “drooling” of the molten plastic during cooling. The inside surfaces of these tanks were ground smooth. Later tanks have been greatly improved and essentially no grinding has been needed inside the tanks after the first few. Rotoplas, the largest rotational molding company in Mexico, made several tanks in Mexico City but they were all very badly warped, and in addition did not have the uniform wall thickness we require. The company moved the mold to their branch factory in Pilar, Argentina, near Buenos Aires, and began making tanks. Serious efforts by engineers from both Mexico and Argentina resulted in tanks being manufactured with minimal warping. Although the wall thickness is not yet uniform enough to meet out specifications, we are hopeful that the company will produce satisfactory tanks with their next batch of tanks. The Rotoplas company uses an open flame method, whereas the Alpina company uses a closed oven. The open flame method consists of many gas jets playing flames on the outside of the mold as it rotates. The temperature uniformity is controlled by adjusting the intensity and direction of the jets until the desired result is achieved. The closed oven is greatly superior in terms of uniform heating.

In addition to wall thickness variation, Rotoplas had some difficulty filling the lugs during the molding process. These lugs, for lifting and for mounting the solar panels, need to be filled with enough resin that drilling the attachment holes does not open the tank to light leaks. In trying to put enough heat on the lug region, they are “overcooking” the tank top, resulting in a change in the physical properties of the polyethylene. Both control of the manufacturing process and quality control tests of the finished tank will be required to insure high quality tanks for Production. Rotoplas Argentina has staff members that seems to be good at their craft and are willing to work hard to make the tanks properly. We are expecting Rotoplas tanks to become of suitable quality during the Preproduction phase of the Project. The Rotoplas tanks were manufactured too late to be deployed in the Engineering Array, but several are in service performing thermal studies in Malargüe. Rotoplas tanks have, however, been manufactured for the Preproduction and Production arrays. All of the difficulties described above during the Engineering Array experience nave been overcome and the tanks are of satisfactory quality.

Shipping of tanks from Sao Paulo to Malargüe resulted in some damage to the tanks. One was destroyed, and several others have been deformed. For later tanks an elaborate cradle system had been installed on the trucks carrying the tanks to distribute the loads over a larger area of the tanks. The result is that the tanks are greatly improved, although we are still hoping for further improvement to insure shipping damage does not occur even under the most adverse conditions. A removable internal support column has been requested. Shipping tanks in cool weather does not seem to be a problem because the polyethylene becomes much stiffer when cooled. The best shipping fixtures are required in hot weather, when the tanks are the softest. This is the time when we will receive and install most of the tanks, so it is important to plan for the optimum shipping fixtures.

There were problems sealing the hatchcovers onto the tank using the gaskets we have selected. In addition to working with new gasket designs, we are have raised the lip of the hatches to prevent water from accumulating there and draining into the tank. The tanks made in Argentina by Rotoplas already incorporate this feature, and all Preproduction and Production tanks have this feature.

The foundation for each tank has simply been the ground, smoothed and leveled with large rocks removed. The support has proven adequate and no difficulty has yet been seen. Burrowing rodents could undermine the supporting ground and cause the affected tank to collapse. Control of such rodents is required and the expertise and assistance of the local ranchers will be required.

2.1.2.1.4. Procurement Drawings and Specifications

Drawing 5525-ME-360032 Rev. A and Engineering Specification 5525-ES-362182 were used to procure the tanks for the Engineering Array. A new drawing with the modifications already mentioned was prepared for Production, 5520_ME_360224 Rev. A. A new Engineering Specification with tighter the dimensional tolerances (changed from ± 3% to ±1.5%) for the molded dimensions, and with the addition of further quality control tests dimensional measurements, is used.

2.1.2.1.5. Procurement Plan

Although Brazil, Mexico, and Argentina each wish to provide some of the tanks, the only satisfactory tanks we have received for the EA made in Brazil by Alpina. Some of the Alpina tanks, particularly those made well before the end of Engineering Array production, have been flawed by unacceptable warping. Although the tanks are very close to being acceptable, we will continue to work with Alpina to reduce the warping problem.

87 of the 100 Preproduction tanks were provided by Alpina, and the remainder of Preproduction tanks and the beginning of the Production run were made by Rotoplas.

1) Alpina has a carbon steel mold for our tanks. The mold was modified to produce the new Preproduction design and we are making tanks with this modified mold.

2) The Rotoplas stainless steel mold was modified and is producing satisfactory tanks.

3) Formingplast in Argentina has made a carbon steel mold and is beginning to make tanks. If they are fully successful, they will bid for tank production in Argentina.

2.1.2.1.6. Resins

We have been using a proprietary resin from A. Schulman based on Exxon Escorene® 8661 linear resin. It has an excellent reputation for performance, lifetime, and moldability. It is also expensive, resulting in 43% of the total manufacturing cost of the tanks in Brazil. It is the only resin that meets our specifications. The outer 1/3 of the tank is molded with a beige formulation with a UV-15 HALS light stabilizer package. The inner 2/3 is molded with a black formulation consisting of 1% carbon black and a UV-8 HALS package, for an estimated UV-11 result. The UV-n packages, indicating a lifetime of n-thousand hours, is based on testing much thinner specimens and our expected lifetime due to ultraviolet exposure is expected to exceed the 20 year requirement.

2.1.2.1.7. Delivery Plan

Delivery has been by semi-trailer, on a “lowboy.” From Brazil, tanks are delivered eight per load, on edge, two abreast. A cage to support the tanks is necessary, since tie-down straps add loads that distort the tank. A semicircular support base has been mounted on the trailers to distribute the load of the tank weight over a large surface area, approaching half the circumference. A support column inside the tank to support some of the weight of the upper half of the tank is also desirable but these columns have not been built yet. It will be important to observe and document carefully the before-and-after-shipping condition of the tanks to optimize the shipping fixtures so that shipping damage, especially in hot weather, is eliminated.

Rotoplas in Pilar, near Buenos Aires, has a much shorter and faster trip to Malargüe than the trip from Sao Paulo. Therefore the shipping arrangement is much less critical. (Damage is time dependent, since it is cold flow of the material over time that causes the damage.) Rotoplas has a trailer outfitted for shipping the tanks, but it carries fewer tanks. This is still be economical, because round trip times are much less than required for trips from Brazil. Deliveries have been satisfactory.

2.1.2.1.8. Quality Assurance Plan

Data management will be done by the MDB database system used throughout the Project. All quality control data will be entered and the data for each tank will be accessible through the MDB.

The tank manufacturer has the first responsibility for quality of the tank and makes the first measurements of the tank dimensions and wall thickness. The wall thickness is measured ultrasonically, for example, and the data recorded in an Excel® spreadsheet using the standard software and hardware of the ultrasonic measuring device. The manufacturer measures thickness at 122 at locations specified on Auger Project drawings, and in the order specified so that data analysis can become automatic. Auger personnel re-measure both the tank outside dimensions and the thickness for some tanks as a check on this process. Other quality observations, such as for color uniformity, finish of both the inside and outside of the tank, visible blemishes, defects, and damage, is done by the manufacturer and checked by Auger inspectors.

The tests requiring a sample of the material to be cut from the tank limits the testing to the region of the hatches. If a tank is made that has some serious flaw making it unacceptable, it is be cut up and the material properties tested for many positions on the tank. Examination of the cross section of the tank wall provides information about the proper cure of the resin.

Each lot of the resin provided for the manufacture of the tanks is to be tested by the resin compounder before tank production begins for the following properties:

- Density using test ASTM D1505,
- Melt Index using ASTM D1238,
- Mesh Particle Size using ASTM D1921,
- Bulk Density using ASTM D1895.

Samples of the resin are to be supplied to the Project before molding begins so that these tests and others, including ARM Impact Test series, can be performed before the tanks production begins.

We have an Auger inspector present at the factory during some phases of tank manufacture. This has been useful, especially in the early stages of procurement. Random visits during later production have proven adequate once confidence in the manufacturing process was gained.

We require measurements of physical dimensions. This is being done now and data is being taken and recorded in the MDB is required. A way to quantify the warping of each tank was developed using a laser level and electronic level. These dimensional measurements, thickness measurements of some tanks, inspection of the lugs to see if they are properly filled with resin, and visual inspection of the interior and exterior is done as the receiving inspection.

2.1.2.1.9. Spares Inventory

The tank failure rate is unknown although there have been no failures in the Engineering Array. A spares inventory of 1-2% is deemed adequate and it is easily possible to find storage space for this many tanks. As failed tanks are replaced by the spares, we can have more tanks manufactured at any time because the Project owns the molds used in their manufacture. Even if we do not maintain an inventory of resin, it should be possible to obtain more tanks from the manufacturers within about 90 days of ordering them. Keeping resin on hand allows manufacture of replacement tanks to be completed very quickly, since several tanks can be manufactured per day once production begins.

By the time the entire Array is completed the failure rate should be well enough understood that the spares requirements can be reevaluated.

2.1.2.1.10. Organization and Resources

Tanks will be provided by Argentina, Mexico, and Brazil and will be manufactured by the industries located in or with a corporate headquarters in the supplying countries. Administrative resources for the purchase activity within each country will be provided by that respective country. Quality control tests are first done by the manufacturer. Quality control verification tests will be done by the Project at Malargüe and by testing laboratories associated with the Argentine collaboration.

2.1.2.2. Hatch Cover and Electronics Enclosure Assembly

2.1.2.2.1. Overview

The hatchcover assemblies consist of the hatchcovers, the gaskets, a shim (spacer) between the tank and hatchcover, and fastening screws. The hatchcovers are a part of the tank and should meet the same basic requirements of the tanks. That is, they should seal and protect the tank contents for 20 years, keeping out light, water, dirt, and dust. They must be removable easily for access to the tank contents. One of them must have penetrations for the cable feed-throughs. This one, the largest hatchcover, will also be the mounting place for the electronics box. By mounting the electronics directly on the hatchcover and covering the assembly with the electronics box, the cables, connections, and feed-throughs are minimized. The only cables exposed to the outside world are the two antenna cables and the solar power cable coming from the bracket assembly and entering the enclosure.

2.1.2.2.2. Specifications and Requirements

The hatchcovers will be of similar material to the tank itself so that stresses in the attaching screws will be minimized. They must be opaque and have a color similar to the tank on the outside. Retaining fasteners must be corrosion resistant for the life of the project. If at all practical, tamper resistant fasteners shall be used to minimize unauthorized entry into the detector tanks. The system design and the gaskets shall provide protection from the elements for the lifetime of the project, although the gaskets may be considered to be a consumable with a lifetime somewhat smaller than that of the experiment. A five-year minimum lifetime, based on the expected frequency of visits to each detector, is adequate although a longer lifetime is preferred and expected.

The electronics enclosure consists of two parts: the weather enclosure and the rf enclosure. Together they will contain and protect the electronics, cabling, and feed-throughs from the elements and from casual vandalism.

2.1.2.2.3. Baseline Design

Hatchcovers are machined from 12.7-mm high-density polyethylene (HDPE) sheets. A two-layer polyethylene with beige on the outer side and opaque black on the inner side is used. The shape of the hatchcover is a simple disk with 24 equally spaced holes drilled around the outer edge for the attaching screws. Because the two-layer HDPE is a custom-made product, a simpler, all black HDPE was used for the Engineering Array. A drawing of the hatchcover is shown in Figure 2.3.

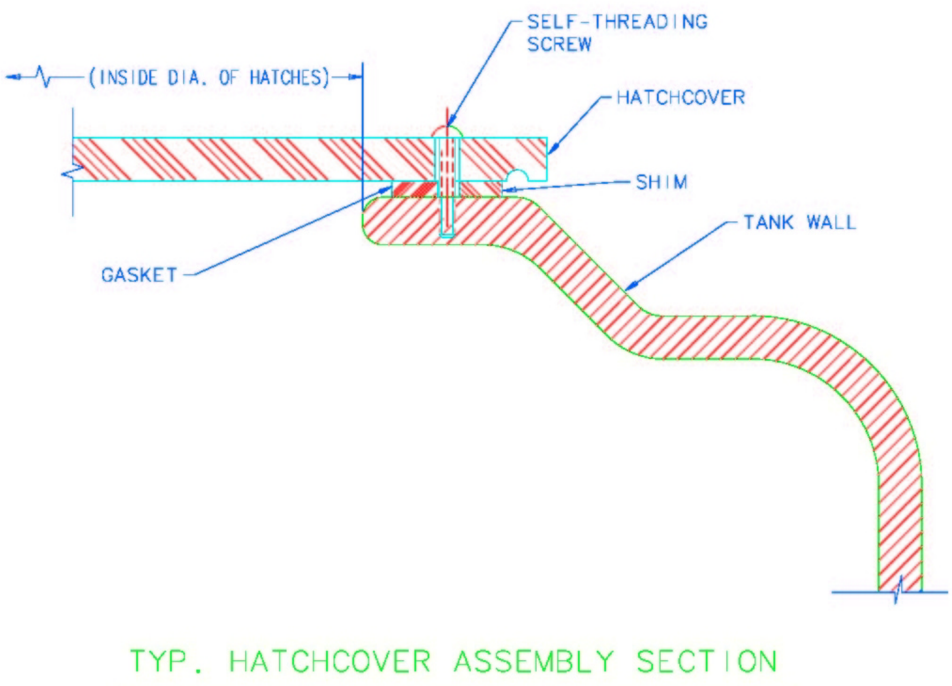


Figure 2.3: Hatchcover assembly drawing.

The gaskets consisted of an o-ring of rectangular cross section, 4.8×12.7 mm^2. Compression set, the property of permanently deforming after a period of time under compression, has been a problem during the Engineering Array. New gaskets, much more resistant to compression set, are used in Production. The gaskets tested are polyurethane foam and have proven satisfactory.

The purpose of the shim is to control the spacing between the tank top and the hatchcover at the location of the gasket. The amount of compression of the gasket is thereby limited, and external forces, such as would be due to tank warping or someone stepping on the hatchcover, are prevented from affecting the gasket. The shims are made from HDPE similar to that used for the tanks and hatchcovers. They have been laser cut for the Engineering Array but they are injection molded for Production. The shims are 3.2

mm thick. The shims and gaskets are mounted to the hatchcover using 3M 9472 acrylic adhesive transfer tape which is particularly good at bonding to low surface energy materials, including polyethylene.

The hatchcovers are attached to the tanks using self threading screws designed for thermoplastics. The screws used in the Engineering Array have been successful. They were #10 Plastite® zinc plated steel with a Phillips pan head. Similar screws, with a pin-in-head Torx head for higher security and made from stainless steel are used for Production to reduce long term corrosion possibilities and enhance security.

The hatchcovers were installed by drilling 24 pilot holes using a drill template around each hatch on the tank. This procedure occurs during tank preparation in the Assembly Building in Malargüe. The gaskets and shims are bonded to the hatchcovers and the hatchcovers can then be screwed to the tank.

The hatchcovers in the Engineering Array were successful except for one notable failing: The gaskets did not maintain a good seal and rainwater entered some of the tanks. There were several reasons for these failures:

1. The gaskets took a compression set too easily and did not provide adequate sealing force.
2. The tanks were warped, so that rainwater accumulated on the top of the tank in a depression at the hatchcover location. Consequently, there was standing water at the gasket that would penetrate even very small leaks.
3. Installation of the gaskets was done with several experimental procedures. Some of these allowed the gasket to be placed incorrectly or to come loose.

The failures in the Engineering Array have been addressed to prevent further failures:

1. New gaskets of polyurethane foam replace the EPDM foam used in the Engineering Array to optimize compression set resistance.
2. The mold for the tank has been redesigned to reduce stresses during cooling which should reduce warping. In addition, a raised lip has been added to the tank around the hatchcover so standing water is not in contact with the gasket.
3. The installation procedure has been optimized for the new gasket.
4. A modification to the hatchcover consisting of an increase in diameter to allow an overhang of the hatchcover and a small groove machined on the underside of the hatchcover to prevent rainwater from getting under the hatchcover are used on the small Production hatchcovers. The large hatchcover is covered by the electronics enclosure dome that provides a similar benefit.

The weather enclosure is a spun-aluminum dome that covers the large hatchcover. This dome provides rain protection, dust protection, and the outer security layer. The dome can be seen in Fig. 2.1. The dome itself is spun from 2.3mm soft aluminum. A foam polyurethane dust gasket is installed inside the lower lip so that it compresses against the large hatchcover. The dome is painted with a beige color to match the color of the tank, and held down using a bracket, J-bolt, and security nuts. The hold-down system can be seen in Fig. 2.4.

Fig. 2.4. The hold-down system for the weather enclosure consists of a bracket riveted to the dome, a J-bolt which engages the large hatchcover, and two jam-nuts and one security nut, which can be opened only with a special tool.

2.1.2.2.4. Engineering Analysis

The finite element analysis of the tank includes the hatchcovers. The hatchcovers for the purposes of analysis were assumed to be 12.7 mm HDPE, as we are still planning. The stress of a heavy (114 kg) person walking on the top of the tank was considered to be the failure mode for this design. The stresses on the hatchcovers and on the hatchcover bolts (20 were used in the analysis, 24 are used in practice) when subjected to this load are low. The case where the person stands on the tank next to the hatch yields a maximum tensile load in the screws of 166 N. Tests of the pullout strength of the screws in the plastic were performed and pullout occurred at approximately 2200 N.

2.1.2.2.5. Costs and Procurement Plans

a) The Hatchcover

The hatchcovers have been made from 12.7-mm thick sheets of extruded HDPE, with a thin beige outer layer and with the majority of the material black with 1% carbon black loading for opacity and lifetime. The Engineering Array hatchcovers were made by hand using a router. This has proven to be a satisfactory technique for Production hatchcovers as well. Hatchcovers are manufactured in Malargüe.

Hatchcover HDPE raw material in sheets with the desired two layers is manufactured in the USA and shipped to Argentina. The gaskets, shims, adhesive transfer tape, and screws are all manufactured in the USA. Argentina is responsible for machining the hatchcovers and assembling them to the tanks.

b) Gaskets

Gaskets for the hatchcovers for the Engineering Array consist of EPDM foam gaskets in a rectangular cross section 4.8×12.7 mm^2 formed into an o-ring. The gasket manufacturer formed the o-ring by vulcanizing the ends of strip stock together. Production gaskets are purchased as long strips of polyurethane foam with the adhesive transfer tape already applied. The gaskets are cut to length in the Assembly Building and installed on the gaskets using a fixture for precise positioning.

c) Shims

The Engineering Array shims were laser cut from black 3-mm HDPE sheet. Production shims are injection molded in LDPE.

d) Screws

28mm #10 screws for thermoplastics made from 300 series stainless steel with pin-in-head Torx heads are manufactured in the USA at reasonable costs.

e) The Enclosure

The weather enclosure, brackets, and other hold-down fixtures are made in the US by commercial enterprises. The dust gasket is provided in large rolls with an adhesive backing already applied by the came company supplying the hatchcover gaskets.

2.1.2.2.6. Quality Control Issues

The hatchcovers were machined using a template. Errors in machining become obvious during the installation process. They are machined in small quantities so if an error in fabrication is found it can be fed back into the manufacturing process quickly, before many bad parts are produced.

The gaskets were accepted from the manufacturer without inspection. Installation is done by mounting the gaskets in a fixture and attaching them to the hatchcovers. During this process, the technician has to install the gasket in the fixture inch-by-inch and therefore automatically inspects the gasket for obvious flaws and rejects bad gaskets.

The shims were accepted without detailed inspection. One set was found to be out of specification and the entire set was rejected and replaced by the manufacturer.

The weather enclosure domes had some dimensional difficulties when the first examples were shipped from the manufacturer. The early domes were measured on a coordinate measuring machine and production was corrected until the required domes were fabricated.

2.1.2.2.7. Maintenance

Performance of the gaskets is not yet known, but it is anticipated that, when a surface detector is opened for some reason in the field, the gasket will be replaced if needed. No other maintenance procedure is anticipated at this time. It is possible that the weather enclosure paint will need to be recoated after many years, but this is not readily predicted. Chalking or fading, which would make the paint unacceptable in other, commercial uses, is not a problem here and a loss of the paint itself (and its infrared absorption properties) would be the only cause for repainting.

2.1.2.2.8. Spares Inventory

A 2% spares inventory for hatchcovers and shims seems appropriate. It is most important to have an excess of the large hatchcover because that one has the electronics feed-throughs and may have to be replaced for more reasons than hatchcover failure, including feedthrough failure.

The gaskets should be considered a consumable. The large gasket will be replaced more often than the small ones because that hatch is likely to be opened more often to check on the electronics. Experience will determine what the spares inventory should be. A guess at 20% is a minimum for startup. No lifetime is known for the gaskets (it is too long to have been discovered so far) so determining the ultimate number of replacements is not possible. It is not at all likely to be a problem, based on the experiences of Preproduction and Production

The domes should have a very low failure rate. A 2% spares inventory may be satisfactory.

2.1.2.2.9. Electronics Enclosure

The enclosure for the local station electronics was designed with multiple goals:

1. Environmental protection of the electronics
2. RFI mitigation
3. Ease of electronics assembly
4. Ease of field maintenance
5. Modularity to match the electronics modularity

As the local station electronics was delivered in three separate packages (radio, tank power control board (TPCB), and main local station computer board (unified board)), a three electronic box solution was settled on. The radio box is a UK commercial product and the radios are delivered in their environmental box. The unified board demanded a large box to suit the single large motherboard and the TPCB needed a box of approximately the dimensions of the radio box.

Commercially available boxes were judged to be too expensive for the TPCB and completely unreasonable for the relatively large unified board. Joe de la Cova at the University of Minnesota, School of Physics and Astronomy Instrument Shop produced a custom box design. The boxes would be custom extrusions made of aluminum with stamped metal endplates. L-brackets would be used to clamp the three boxes together and a flange, rubber grommet, spacer, and special screw to hold in thermoplastics would mount the assembly onto the hatch cover.

There are six primary parts to the electronics enclosure:

1. Unified board box (custom extrusion)
2. uTPCB boards box (custom extrusion)
3. Radio box (delivered from the Leeds engineering group)
4. Connection L-brackets (custom extrusion)
5. Unified board panels (custom metal stamping with silk screen)
6. uTPCB boards panels (custom metal stamping with silk screen)

The extrusion material is 6063-T3 aluminum extruded by the Magnode Corporation of Ohio, USA. The size of the unified board extrusion limited us to a handful of extrusion plants in the USA (in fact, to less than a dozen worldwide). Only Magnode was able (and willing) to work on this size custom extrusion and the small batch size.

The coating on the extrusions is a high-phosphorous (measured at 10-13% by weight), electroless nickel plating of about 20 μm in thickness. This plating is sufficient for permanent installation in a marine environment. Pioneer Metal Plating Corporation in Wisconsin, USA, did the plating. Pioneer was the lowest bidder.

Panels are mechanically punched and silk-screened by the Stremel Corporation of Minnesota, USA on 0.035" (0.88mm) thick 304 stainless sheets. This process is a standard, easily transferable technology and we chose to work with a local company with which we had had good prior dealings.

Extrusion history:

1. Extruded at Magnode
2. Holes drilled, deburring, parts wash
3. Sample inspection
4. Bulk packaging
5. Shipped to Pioneer Plating
6. Degreasing, acid bath
7. Plating
8. Sample inspection
9. Individual packaging
10. Shipment to Malargue

Quality control checks were in broad accord with ISO-9001/2 standards. All of the vendors are ISO-9000 qualified, and parts checks on delivery yielded no flawed parts. Parts that had been internally flagged at Magnode were discarded/recycled by Magnode. Parts flagged at Pioneer were examined by Minnesota staff and found to be marginal (no egregious problems) and were recycled locally.

Since all parts were produced in a single batch, adequate spares were also built for the lifetime of the Auger South array.

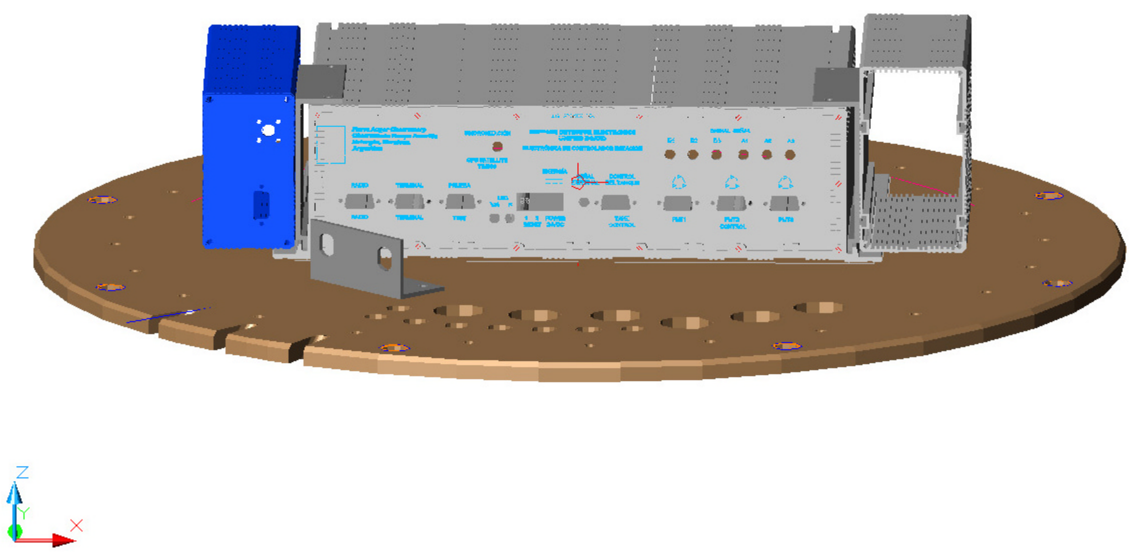


Figure 2.5: Front view of CAD model electronics enclosure. From left to right, (blue) radio box from the Leeds Engineering group, unified board box, (in front) radio and GPS cable strain-relief panel, and (open) micro-TPCB box.

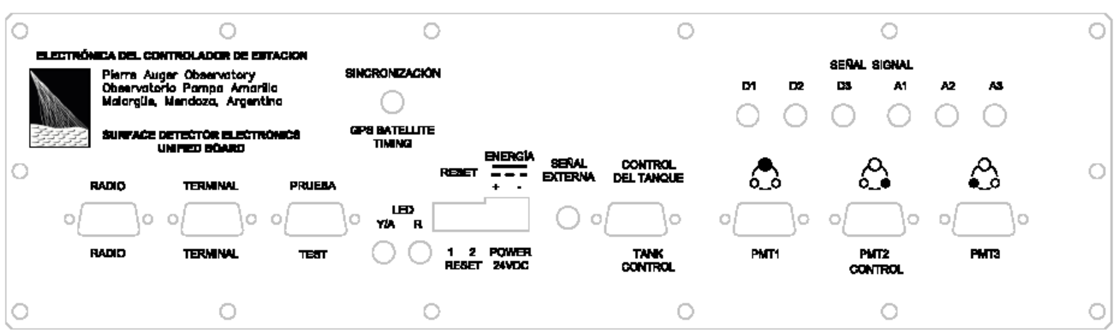


Figure 2.6: Unified box front panel silk-screen (in English and Spanish).

The assembled configuration of radio box, unified board box, and uTPCB box on top of the hatchcover can be seen in figure 2.5. The front panel for the unified board box appears in figure 2.6. The text is silk-screened onto the front panel in English and Spanish. The assembly procedure for the electronics enclosures on top of the hatchcover has been detailed in an assembly manual for the SDE fabrication facility, but some details appear below. Figure 2.7 shows the mechanical detail of the radio box to L-bracket to the unified board box assembly. UTPCB assembly works the same way.

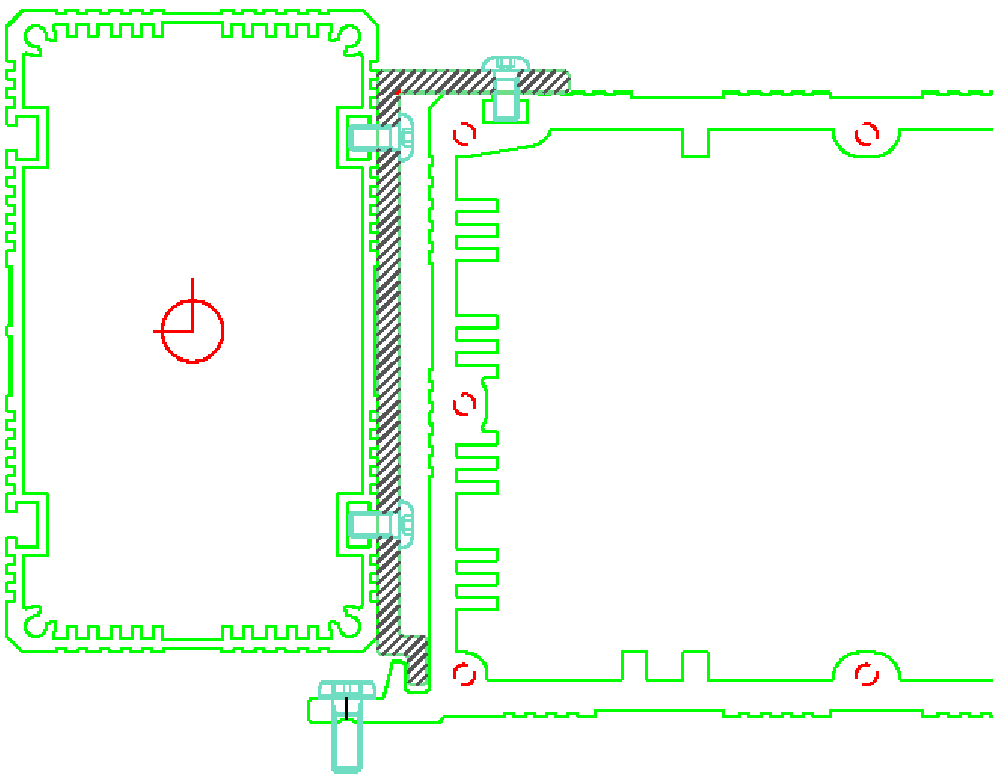


Figure 2.7: Detail of the L-bracket mounting scheme for attaching the radio and micro-TPCB boxes.

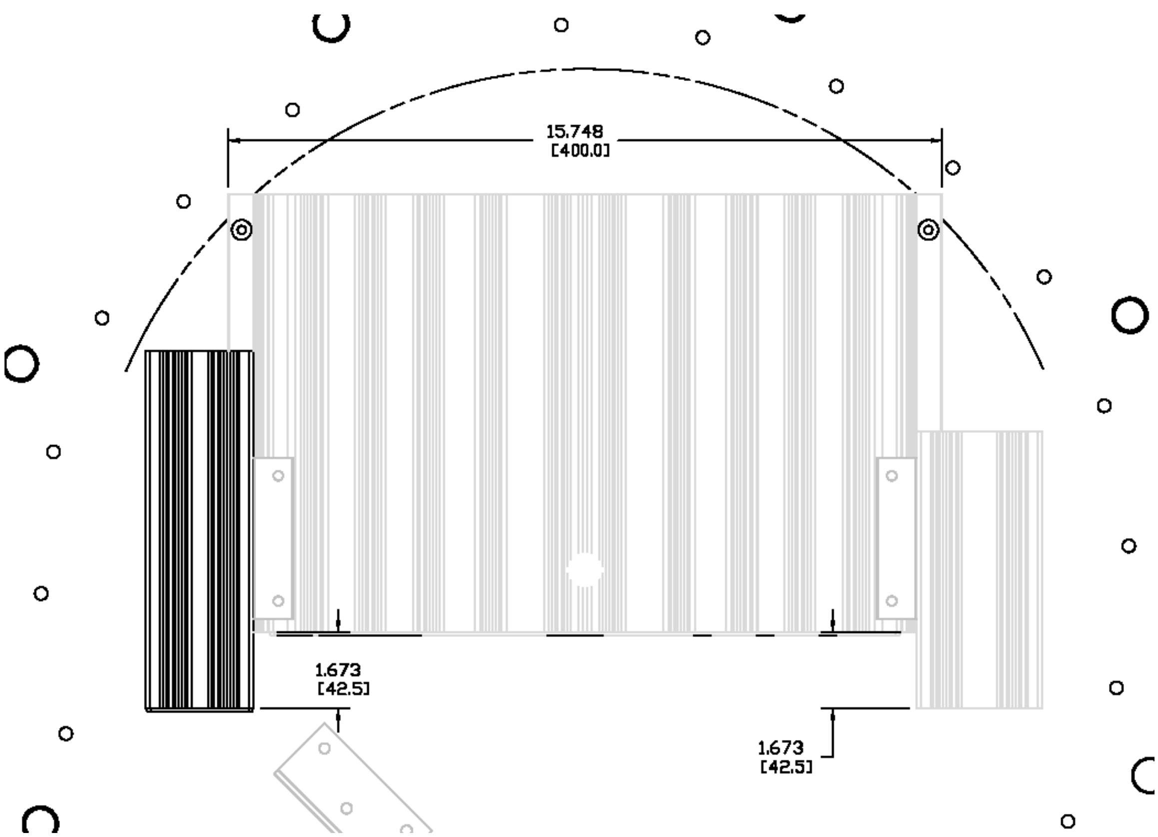


Figure 2.8: Drawing of enclosure top, showing positioning on the hatch-cover, and location of smallest spacing between dome and electronics enclosure (at solid-dashed line) of over 2 cm.

In figure 2.8, a top view of the complete assembly shows how the round hatchcover and near-spherical section dome constrain the construction. Closest approach to the assembly is at the top, back corners of the unified board box. That spacing is about 1” (2.54cm). The vertical screws going into the hatchcover are custom Plastite trilobular screws designed to hold in the thermoplastic. These screws pass through captured grommets that provide “slop” for a non-flat hatchcover.

The custom extrusions were a significant engineering design item and the associated documentation, plans, and analyses are all available on CD-ROM from the University of Minnesota, R&D Machine Shop. One of the thirty subsidiary plots from the design effort is seen in figure 5.

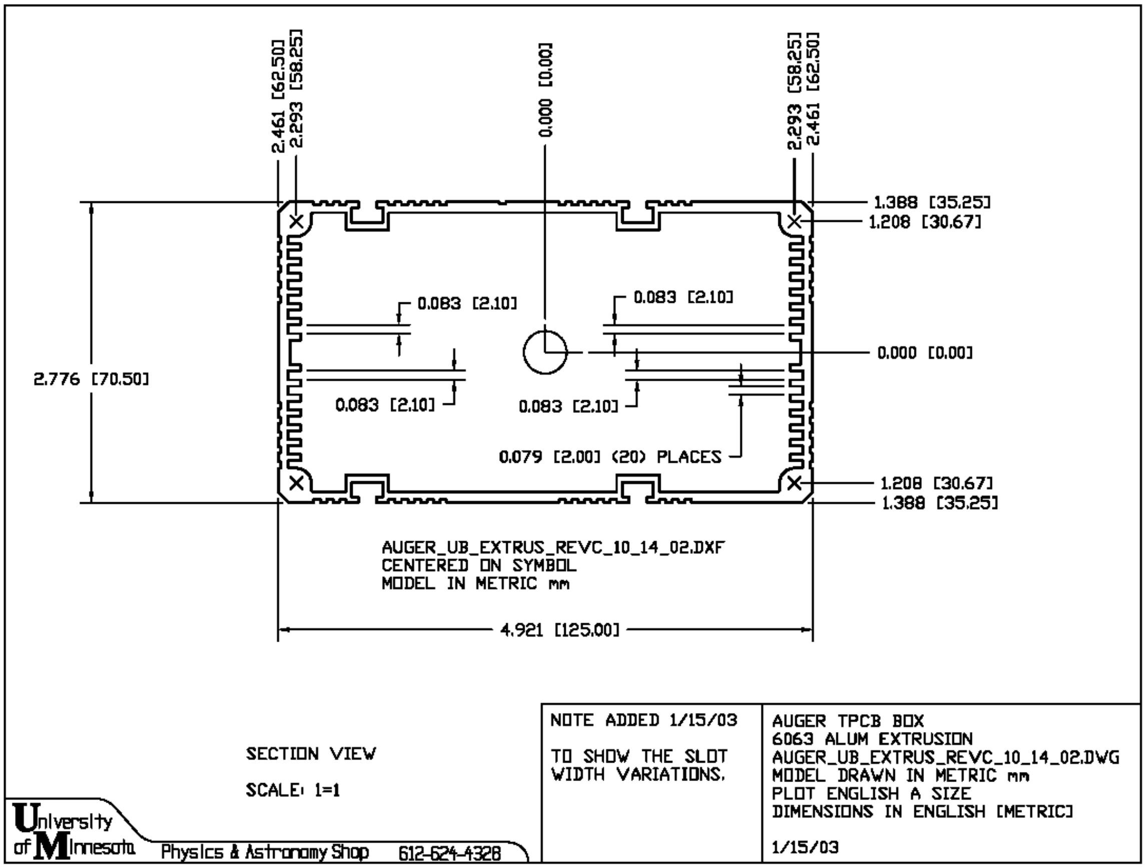


Figure 2.9: Pierre Auger Observatory TPCB extrusion print

2.1.3. Water Tank Liners

2.1.3.1. Background, Overview, and Goals

Tank liners are right circular cylinders made of a flexible plastic material conforming approximately to the inside surface of the tanks. The liners fulfill three functions: They (1) enclose the water volume, preventing loss of water or contamination and providing a barrier against any light that enters the closed tank (2) diffusively reflect light traversing the water, and (3) they provide for access to the interior of the tank and PMTs without exposing the water to the environment.

Tank liners will contain the detector water volume within rotomolded polyethylene tanks. The liners must minimize any external contamination from entering the water volume and not contaminate the pure water themselves. Furthermore, the inner surface of the liners must be a diffusely reflective material in the range of wavelengths produced by the cosmic ray showers. Dupont Tyvek® fibrous polyolefin sheet has been found to meet these requirements. Several fitments, (six fill ports and three dome window/flanges assemblies) must be hermetically sealed to the liner. The window/flange assemblies allow for the mounting of the photo-detector assemblies and allow them to monitor the tank. The fill ports allow for filling and venting the tank, as well as providing for an LED flasher to be used for calibration and initial testing.

Although the rotomolded tanks will provide a first defense against contamination from external light sources (including ultra-violet), it is necessary that the liners be completely opaque to act as a secondary protection against small amounts of light leaking through the tank hatch seals or other light leaks through the tank. It is thus necessary that the seals be completely opaque against single-photon level light transmission. For this purpose, opaque shall be defined to mean 0% light transmission for light of wavelengths between 300 and 700 nm, as measured by counting single-photon detection rates through the liner.

The water tanks containing the liners will operate outdoors. Although the mass of water will moderate temperature fluctuations, the temperature range to which the liner is exposed is approximately –10 to +40 degrees Celsius. It is possible that up to 10 cm of ice will form at the upper surface or sides of the water volume inside the liner. The liner must be sufficiently strong and flexible that it is not damaged by such ice formation. The requirements for strength and flexibility are also demanded by the fact that seismic activity may cause waves up to 15cm high to form on the surface of the water.

The outside of the tank liner may be exposed to water which has either condensed in the tank between the tank wall and the liner or which has diffused through the liner material itself. This water may include salts from blowing dust in the area, and may be biologically active. The liner must not be damaged by this exposure.

Tank liners produced following the assembly techniques and specifications developed by the Project and outlined in this document have been extensively tested in a prototype array deployed in Malargue and have been found to meet these requirements. All pre-production and production tank liners produced for the project are being produced following the specifications and techniques documented below.

The production tank liners for the project are being assembled and tested at a facility at UTN Mendoza designed and built especially to meet the requirements of the project. It is critical that an adequate quality control and quality assurance plan be in place during liner assembly. Towards that end, an extensive list of procedure documentation and QC/QA records has been developed by the project and is included below. The facility has been certified to meet the requirements of the project as listed below, and the record keeping and materials handling specifications have been certified to meet the requirements of ISO 9001:2000.

2.1.3.2. Lamination

The tank liners are produced from a custom plastic lamination to specifications produced by the Project. The main requirements were strength, opacity to external light, diffuse reflectivity of inner surface, sealability, and minimal extractables from the lamination material which might contaminate the water volume enclosed.

The lamination is composed of an opaque three-layer co-extruded low-density polyethylene film bonded to a layer of Tyvek 1025 BL by a layer of Titanium-dioxide colored low-density polyethylene. The three-layer co-extruded film consists of a low density/carbon black blend formulated to be opaque to single photons, sandwiched between layers of cleat low-density polyethylene to prevent the carbon black from migrating into the water volume. Tyvek 1025-BL was chosen as the reflective layer due to its strength and excellent diffuse reflectivity in the near ultraviolet. Tyvek grade 1025 BL is an untreated polyolefin non-woven material, which minimizes the chemicals available to leach into the water volume. It is the thinnest grade of “biological grade” Tyvek commercially available, which simplifies the bonding processes used in manufacturing liners.

The full lamination manufacturing specifications for the lamination can be found in the document “Request for Proposals for Production of Laminate Film”. The specific formulation of the film can be found in 2.1.3.6.5.

The Auger lamination is not produced in a “clean room” environment. The extruders, lamination machines and slitting machines are all cleaned prior to production of the Auger lamination, and hair restraints and gloves are worn during all handling of the film. Polyolefin film has a strong tendency to pick up an electrostatic charge when unrolled or pulled over a surface, and even in a very clean assembly environment would collect significant dust during the hours involved in liner assembly. The method for controlling contamination of the liners centers on minimizing food sources by eliminating hair and skin contact with the lamination and working in a reasonably clean environment. Low levels of biological activity have been measured over several years use in the field in the engineering array and pre-production liners.

2.1.3.3. Liner Assembly Specifications

The liners are assembled by heat-sealing strips of polyolefin film together according to the drawing CSU-Auger-WTL-8.1 entitled "Auger Surface Detector Array - Water Tank Liner." Production liner assembly is done at two sites: Liner tops are manufactured at Colorado State University. Fully-assembled liner tops, with six polyethylene fill ports and three window flanges pre-attached as shown in drawing CSU-Auger-WTL-8.1A entitled "Auger Surface Detector Array - Water Tank Liner Top Assembly”, are shipped to the final assembly site at UTN Mendoza. The liner bottoms and sides are manufactured at the Mendoza site according to the attached drawings CSU-Auger-WTL-8.1B entitled "Auger Surface Detector Array - Water Tank Liner Bottom" and CSU-Auger-WTL-8.1C entitled "Auger Surface Detector Array - Water Tank Liner Side", and the final assembly and testing of the liners occurs there as well.

The seals are made with impulse heat seal machines custom-designed and manufactured by Colorado State University. The machines are controlled by a Packworld model RES-440 impulse heat seal control module, and are pneumatically actuated by the heat seal control module. Three seal machines are used for liner sub-assembly production and final assembly: A 660mm bar sealer, a 200mm bar sealer, and a 40mm bar sealer. A chilled water unit is used to maintain the temperature of the seal bar at 10 degrees Celsius. One chiller is used to supply all the seal machines

Due to variability in the absolute seal temperature of the control modules, it was necessary to determine empirically the range of allowable seal settings to be used for each of the liner seams. These settings are listed in 2.1.3.6, in Seal Machine Settings. A variation of plus or minus five degrees Celsius is allowed to the settings as determined to be necessary by the local supervisor to maintain seal quality without requiring retesting of the seals. The precise settings used for each seal process for each liner are documented as part of the quality control record for the liners, along with a sample of each seal.

A liner bottom is made by sealing three strips of laminate 1250mm wide by 3730mm long together into a rectangle approximately 3730mm long by 3700mm wide. Each of the two long joints requires 6 seals of the 660-mm heat seal bar. The pieces of lamination are aligned side-by-side before sealing, and they must overlap by 25mm along their long axis. The bottom sub-assembly circle is cut out of the assembled rectangle of lamination and alignment witness marks are made on the black side of the lamination. Film samples from each of the three strips are retained (the section retained should be the portion on which the lamination lot number was written), as well as the required weld samples for the QC/QA record.

A liner top is made by first manufacturing a liner bottom. The positions of the three window flanges and the 6 fill ports are marked out on the circle of film using templates, and the openings required are cut away. The flanges and fill ports are then sealed to the liner top using a circular heat seal machine, which allows for sealing the fitment (flange or fill port) to the liner top with a single seal. The fitments are positioned on the liner top according to the drawing CSU-Auger-WTL-8.1A entitled "Auger Surface Detector Array - Water Tank Liner Top Assembly." Film samples from each of the three strips are retained, as well as the required weld samples for the QC/QA record.

Liner sides are made by sealing two long, narrow pieces of laminate called “tape strips” (50mm wide by 11,550mm long) to a large (1250mm wide by 11,550mm long) strip of lamination. Each of the two joints requires 19 seals of the 660-mm heat seal. The tape strips are pre-cut to the correct width, and they are pre-marked with lines 190.5mm apart, which are used later to align the liner side with the witness marks on the liner top and bottom during assembly. Next, the long strip is sealed into a hoop 3638mm in diameter; this requires two seals of the 660mm heat seal. The completed assembly is shown in drawing CSU-Auger-WTL-8.1C entitled "Auger Surface Detector Array - Water Tank Liner Side.”

The final liner assembly is a three-step process: First, the top and bottom are attached to the side using the short 40mm heat seal bar with the "40mm tack Seal" settings from 2.1.3.6. This step requires 60 seals around the circumference, and care must be taken to align the witness marks on the separate components to ensure satisfactory relative positioning. Before starting the tacking step, the overlap seal in the side is aligned between the two overlap welds in the top, as shown in drawing CSU-Auger-WTL-8.1 entitled "Auger Surface Detector Array - Water Tank Liner." Similarly, the bottom is aligned with its overlap welds parallel to those in the top**.** Next the two components are sealed together with the 200 mm sealing bar. This step also requires 60 seals. A total of 10 locations on the liner (5 on the top/side seal, 5 on the bottom/side seal) require assembly of extra layers of material, due to overlapping of laminate sheets at those points. These points are called "triple points", and an extra seal step with the 40mm tack sealer is required at these points to insure a watertight seal

2.1.3.4. Liner Testing and Repair

All liners must be tested for leaks and flaws, and any flaws repaired, before packing and shipping to the site.

First, the liner is inflated to a pressure of 20 millibar over atmospheric pressure and observed not to fail by rupturing. Next, the all the seals, both tape and lap, are tested using a soap and water solution, looking for visible signs of bubbling. In addition, seals between all flanges and fittings and the liner top are carefully checked with the soap bubble solution. Any sign of bubbling shall be grounds for repairing the liner. Finally, the liner is examined in a darkened room with test lights covering the window ports illuminating the interior of the liner. Any visible translucencies in the liner indicate a potential leak in the liner, and require repair according to the repair procedure outlined below. Any translucencies found are tested with the soap solution to determine if they are in fact an air leak.

The testing procedures described above were tested to determine that they are sensitive to leaks of a magnitude which could cause a leak of more than 10% of the detector volume in 20 years. These tests are documented in the paper entitled “Liner Test Procedure Qualification Procedures”. The tests consisted in making holes of known diameter in a small test bladder made of lamination and measuring the leak rate through these holes. We then looked for the holes using the test methods described above. All the test methods were highly successful in finding leaks of interesting size.

A record is kept of all leaks or translucencies found in the liner during testing along with a record of the repairs made to the liner.

Liners may be repaired by one of two methods: Leaks found at a seam due to failure to sufficiently overlap seal sections are repaired by re-sealing at the controller settings appropriate for that seal section. Leaks found due to holes in the laminate are repaired by applying a patch, consisting of a piece of laminate sealed to the liner using the 40mm tack sealer using the "Repair Patch Seal" setting from 2.1.3.6.

Any liner requiring more than five repairs shall be considered excessively flawed, and may be rejected.

2.1.3.5. Quality Control/Quality Assurance Documentation and Manufacturing Facilities

2.1.3.5.1. Initial Setup and General Operating Conditions

All liner components will be shipped to the manufacturer in wrapped plastic packages (with a small opening to allow or air pressure equalization), which should not be opened until the components are inside the clean assembly area. All assembly shall occur in a Class 100,000 (ISO Class 8) clean assembly area. All contact of liner materials with uncovered skin shall be avoided. All workers handling liner materials shall wear hair restraint, gloves, and protective outer garments to avoid contamination of the liner materials.

All materials that come in contact with liners or liner components shall be approved by the Project before use. This includes wipes, chemical cleaners such as alcohol, and any cleaners used to clean surfaces used to support liners. A record of all approved materials for contact or use with the liners shall be kept as part of the quality control record.

All work surfaces used in liner production shall be cleaned at the beginning of each work shift or every 4 hours, whichever is more frequent.

2.1.3.5.2. Initial Setup and Calibration of Seal Machines

All seals are required to meet the strength requirements listed in Table 1 ("Seal Strength Requirement Table") below. These requirements will be used to determine the settings indicated in the seal setting table.

Testing of tensile strength of the joint at failure will be done using an Instron (or similar) stress-strain measuring device capable of producing a written chart of the measured stress-strain curve for the joint. A 25mm wide sample of the weld to be tested shall be placed in sheer in the measurement device, and the strain applied at a rate of 25mm per minute. Due to variations in the laminate material, failure will often occur in the material away from the joint under test. Tests where failure occurs away from the joint shall be considered valid and the joint passing specification as long as this failure occurs above the value specified in Table 1. Failures of the lamination below the required strength of the joint shall be considered void and a re-test required. The large variations in the thickness of the Tyvek layer of the material (which are due to the nature of the Tyvek itself and are allowed within the lamination specification) make calculation of the stress in the material difficult to calculate, so the maximum total force at separation of the joint or the rupture of the Tyvek layer, not the stress in the material itself, shall be considered the relevant number for this specification. A minimum of 10 samples of each seal shall be tested, and records of the stress-strain curves measured shall become part of the quality control documentation of the project.

Re-testing of seal strengths for standard seals shall be conducted upon completion of each 100 liners to ensure that the seal settings are still valid. Results of this testing shall become part of the quality control documentation of the project.

No deviation from the seal setting table will be permitted without a full battery of seal strength testing to certify the seals meet the requirements of Table 1.

Seal Type	**Required Strength**
Standard Tape Seal	>50 N/cm
Type A Triple Point	>35 N/cm
Type B Triple Point	>35 N/cm
Standard Lap Seal	>50 N/cm

Table 1 Seal Strength Requirements

2.1.3.5.3. Operational Calibration of Seal Machines

At the beginning of each work shift or every 4 hours, whichever is more frequent, the seal machines shall be auto-calibrated to the correct temperature as measured with a thermocouple. Careful visual inspection of the seals throughout the process of assembling liners and components is critical, both to ensure that the seals are continuous and to notice any variations in seal width or color which might call for re-calibration of the seal machine or an increase or decrease in seal temperature within the allowed range.

2.1.3.5.4. QC/QA Records to be Maintained during Production

The attached quality assurance travelers (or similar versions containing at least the information on each of these forms) will be maintained for each liner (and liner component) produced. All the indicated information must be recorded for each liner during manufacturing, and this record (along with the seal samples mentioned above) must be delivered to the Project along with the liner. In addition to the information on the traveler, samples of many materials used in manufacture are also required, as outlined below:

2.1.3.5.4.1. Bottom Manufacture

Quality assurance records for the bottom include: a 50mm X 100mm sample of lamination from each of the three pieces of lamination used for the bottom (this sample should be marked with the lamination lot number) weld samples 100mm long from each of the two lap welds; the names of the operators who made the seals; the date and time the bottom was made; and the welding machine settings used. The bottom will be assigned a number following the component numbering convention (below), and that number will be written on the black side of the lamination with indelible ink.

2.1.3.5.4.2. Side Manufacture

Quality assurance records for the side include: a 50mm X 100mm sample of lamination used for the side (this sample should be marked with the lamination lot number); a 100mm long sample of the tape used; weld samples 100mm long from each of the two lap welds; the names of the operators who made the seals; the date and time the side was made; and the welding machine settings used. The side will be assigned a number following the component numbering convention (below), and that number will be written on the black side of the lamination with indelible ink.

2.1.3.5.4.3. Liner Final Assembly

Quality assurance records for final assembly include weld samples (on samples of the appropriate lamination type) of both the tack weld and the 200mm seal. These samples will be made at the beginning and the end of the final liner assembly step for each liner. Also included in the QA records are the names of the operators who made the seals, the date and time the liner was assembled, and the welding machine settings used. The liner is assigned a number following the component numbering convention (below), and it should be confirmed that this number is written on the top clearly and legibly.

2.1.3.5.5. Liner Handling, Packaging, and Shipping

Following assembly and testing the operators will empty the liner of air, place seal plugs and caps on the fill ports, roll the liner into a bundle approximately 3750mm by 500mm by 30mm, and seal it in a polyethylene film bag for storage and shipping. Care must be taken to ensure that the fill port and flange seals do not fall at the folds of the roll. The liner number will be written on the outside of the protective shipping bag. The liner will not be folded other than this rolling, and will be shipped to Malargue in this fashion, ready for installation in a detector tank.

Liners must not leave the clean assembly/testing area until they are enclosed in their protective bag.

Liners should not be stacked more than 5 high, to prevent excessive weight on the liners.

The protective bag should not be removed from the liner until it is ready for use.

Standing on, walking on, folding, or other rough handling of the liners must be avoided. (The only routine exception to this rule occurs during LED installation when the liner is inside a tank.)

2.1.3.5.6. Facilities provided by UTN Mendoza for Liner Manufacture

The following supplies, equipment, and facilities are used for liner assembly:

Materials Storage Room: A clean storage area is required for holding laminate and liner components until they are used. The liner components must be stored in the full-length rolled configuration as received from CSU, without any folding or bending. Space is required for storing up to 75 rolls of laminate (400mm by 1250mm, 100 kg/roll) on end and up to 1000 liner tops. The storage area must be approved by a representative of the Project before use. These materials may be kept in their shipping containers until ready for use.

Clean Assembly Room: A controlled-environment, clean assembly room (Class 100,000) large enough for liner assembly shall be provided by the liner assembly institute/vendor. All personnel operating in this assembly area shall follow project hygiene requirements, including wearing hair/beard restraints, and long-sleeve lab jackets.

Laminate Cutting Table: A rectangular cutting table 3800mm long by 1250mm wide with a support at one end for the 100kg rolls of laminate shall be provided in the clean assembly room.

Table for 660mm Seal Bar: A rectangular seal table 6m long by 1.25m wide and a steel support structure capable of supporting the 660mm bar sealer. The tabletop is smooth and free of features capable of damaging the laminate.

Two Round Assembly Tables: Circular assembly tables, 4 meters in diameter and approximately 800 mm tall capable of supporting a 200 kg load, are positioned in the clean assembly room. The tabletops are smooth and free of features capable of damaging the liner laminate. The top shall be cleaned and coated so as to prevent contamination of the liner film with dust or grease.

Dark testing area: A dark testing area is required for the light-leak test of the liner. This area is sufficiently dark that there are no light sources visible to the human eye after a 5-minute dark acclimatization period.

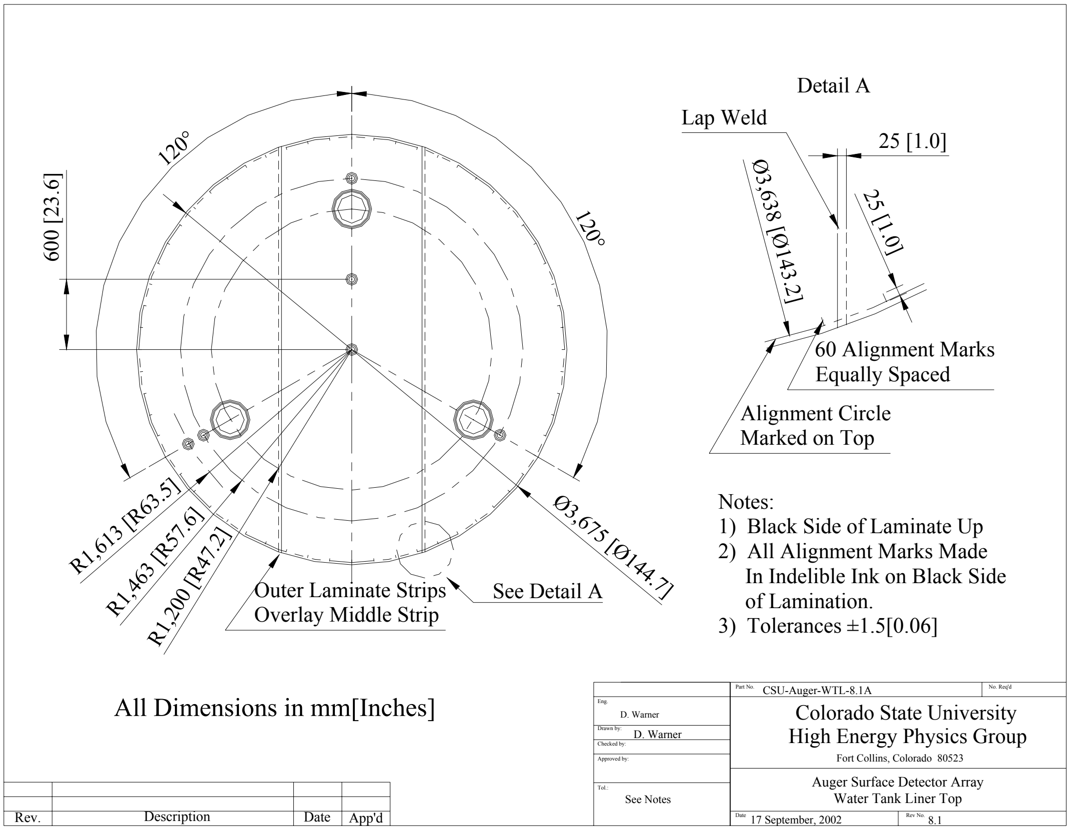
Clean post-assembly storage area: A clean storage area is required for holding liners until they are shipped. The liners are stored in the full-length rolled configuration in protective bags as described above, without any folding or bending.

Filtered liner inflation air supply: A filtered air supply must be provided for inflating liners as required for testing. This supply must provide at least 2000 L/minute of filtered air. The air is to be filtered through a HEPA-type filter, 99.97% efficiency for 0.3 micron particles.

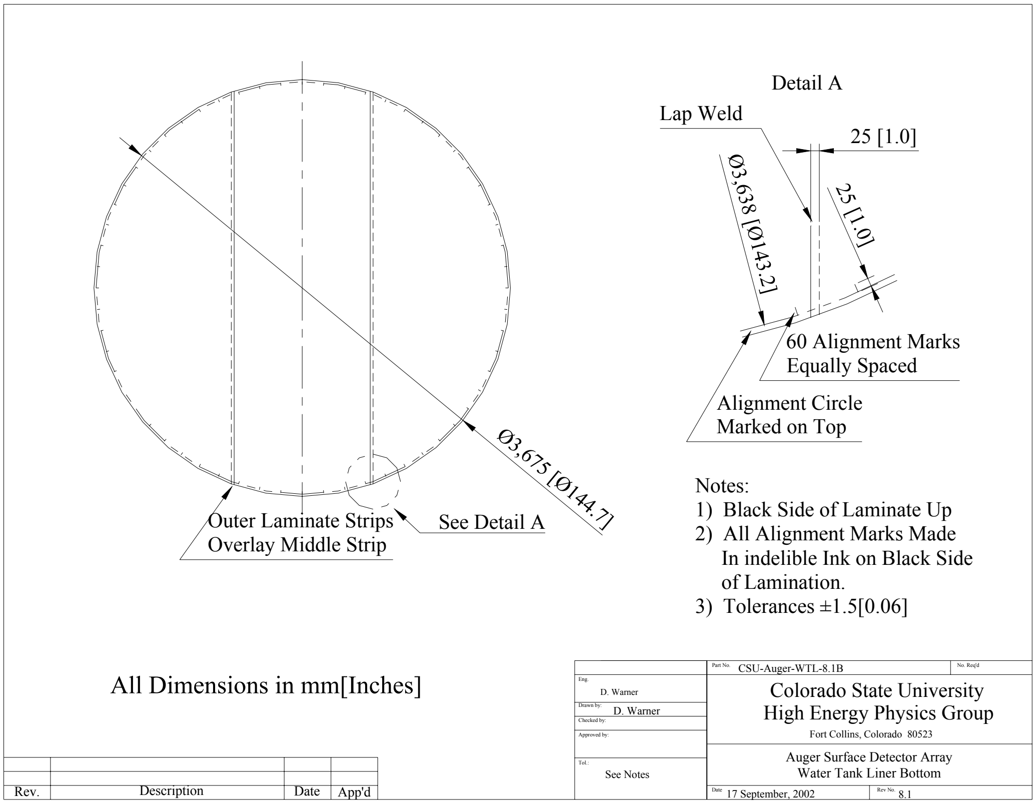
2.1.3.6. Drawings and Materials Specifications

2.1.3.6.1. Water Tank Liner

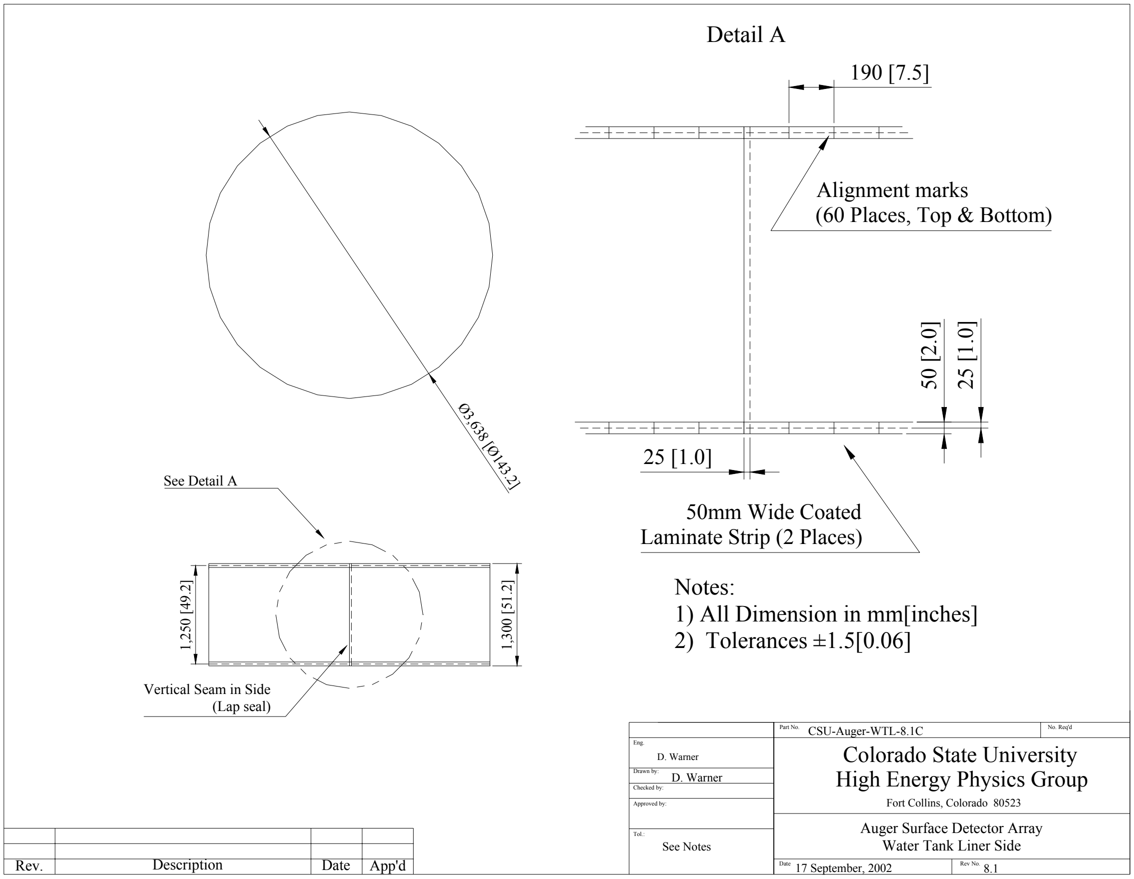
2.1.3.6.2. Water Tank Liner Top Assembly



2.1.3.6.3. Water Tank Liner Bottom



2.1.3.6.4. Water Tank Liner Side



2.1.3.6.5. Laminate Film Specification

MATERIAL CONSTRUCTIONS:

The lamination shall be produced according to the following material specification:

Substrate A: Dupont Tyvek® 1025 BL,
5.6 mils (0.0056") thick, per Dupont Tyvek® thickness specifications

Bonded to (heat laminated to indestructible bond, or fiber tear)

Substrate B: Low density polyethylene coextruded film, 70% white LDPE/30% clear LDPE
1.1 mils thick, +/- 10% tolerance,
Dow 722 LDPE blended with white color concentrate, Ampacet 11171,
Approximately 15% to an opacity of 65%, in core and clear 722 towards the black film.

Bonded to (heat laminated to indestructible bond)

Substrate C: Black polyethylene coextruded film,
7.0 mils thick, +/- 10% tolerance

Composed of the following layers:

Layer 1:	98% Dow 1146 metallocene PE 2% Ampacet PA	1.5 mils thick
Layer 2	45% Mobil NJA661h-LLDPE 45% Mobil LDPE, 1.0 Melt Index, .921 density 10% Black concentrate, hot compounded	4.5 mils thick
Layer 3	98% Dow 1146 mPE 2% Ampacet PA	1.0 mils thick

Each layer to vary no more than 10% around target thickness.

Black concentrate to have a dispersion specification of less than 2 particles per square meter between 0.010" and 0.020", no particles greater than 0.020", and a light transmission maximum of 0%.

White concentrate to have a dispersion specification of less than 2 particles per square meter between 0.010" and 0.020", no particles greater than 0.020", and a light opacity of 65%.

All materials to be FDA approved in accordance with 22 CFR 177.1520 paragraph 3.1 b for conditions of use D, E, F, and G described in section 176.170, table 2 for up to 150 degrees Fahrenheit.

SLITTING SPECIFICATIONS:

Laminate to be slit to a width of 49 ¼" +/- 1/8", on 3" cores, at a total weight of 200 pounds per roll (approximately 1000 feet per roll). Slitting to be done in a clean environment, free of dirt, dust, and oil. Rolls to be handled with gloved hands and hair restraint to be worn during all handling of lamination.

2.1.3.6.6. Liner Numbering Scheme

All liners and liner components are identified by a serial number, consisting of a one-letter prefix and a 4-digit identification number (See below for numbering details). Each component has its identifying number written on it on the black side in indelible ink, while the completed liner is identified by a white tag attached to the liner top and covered with a clear plastic window. The four-digit liner number is attached to the liner top as part of the top manufacturing process.

Components manufactured in Argentina will have identification numbers starting with 5000, to prevent overlap with components made in the USA. Since all the tops are manufactured in the USA, and the top number and liner number are the same, all the liners, even those manufactured in Argentina, will have serial numbers starting with 1000.

Numbers should be assigned sequentially, starting from the lowest unused number in the appropriate classification. For example, the first Argentine side made should be assigned the number S (for side) 5000, the next S5001, etc.

Serial number conventions

Component	Letter Suffix
Top	T
Side	S
Bottom	B
Complete liner	L

Identification Number Scheme

4-digit number	Manufacturing Info
0000 - 0999	Pre-production liner
1000 - 4999	Component made at CSU
5000 – 9999	Component made in Argentina

For example, a production side made in Argentina might have number S5001.

2.1.3.7. Dome assembly and PMT enclosure

2.1.3.7.1. System requirements

Performance requirements:

The PMT enclosures serve four main functions: (a) they complete the hermetic seal of the tank liner, (b) they allow the PMT to collect Cherenkov light from the water detector volume, (c) they provide an access port through which the liner can be filled, and (d) they provide for a cover to shield the PMT from external light and to protect it from the external environment.

Our performance requirements for these functions are as follows:

- Hermetic seal: A PMT assembly, when inflated to 0.5 PSI over ambient air pressure, shall have no observable bubbles through any portion of the kit or its seals around the flange, window, or fill port when submerged in water for a period of 2 minutes. (For EA assemblies, the flange and PMT window were attached to a 61-cm by 61-cm square of liner material to facilitate testing of the kit seals. A temporary protective plastic sheet was sealed to the top side of the kit to allow the inflation test and to protect the concave side of the window during handling. These squares were then welded onto the tops of the EA liners. For pre-production and beyond, flanges with PMT windows will be welded directly onto the liner top, eliminating the 61-cm square of liner material and its associated welds.)
- Light collection efficiency: The test specification shall consider the Cherenkov light collected by a vertical-going muon transiting a de-ionized water volume. A PMT placed viewing a detector volume through a PMT assembly window (and

optical coupling material, if used) shall collect at least 85% of the light collected by the same PMT placed directly in contact with the water.

- The fill port shall provide a seal for the liner both before and after filling the liner (See hermetic seal requirement above). The fill port shall allow for attachment of a fitting capable of filling the liner within 1 hour. The fill port seal shall be able to be broken and remade repeatedly. Two additional fill ports will be welded onto the liner to allow for calibration LED mounting.
- The PMT cover, or fez, shall provide an environmental seal for the PMT and PMT base electronics. The seal is not designed to be hermetic, but rather will protect the PMT and electronics from dust, dirt, and large quantities of water. The relative humidity of the environment inside the enclosure should be assumed to be 100%.
- The fez, fill port, and flange (and associated seals) shall be sufficiently opaque so that a PMT enclosed in a PMT enclosure shall have an increase to the single photon background noise of no greater that 200 Hz due to light leaks when exposed to typical laboratory light levels.

Reliability Requirements:

The PMT housing assemblies are required to function for the entire expected 20-year lifetime of the Auger surface detector. All components must be designed and manufactured for maximum reliability and stability. Several potential failure modes have been identified, and performance specifications developed to avoid these problems.

- Optical performance: The light collection efficiency of the window and any optical coupling compounds used shall not degrade so as to decrease light collection efficiency by 10% during the life of the experiment. This includes losses due to both decrease in transmission of window materials and mechanical problems with optical coupling systems.
- Seals: All seals shall be tested to insure that they will not fall below minimum design specifications throughout the life of the detector. This includes testing at environmental extremes such as humidity, high and low temperature, freezing of the detector water volume, and contact with de-ionized water.
- Component stability: Samples of all plastics shall be tested to ensure that the expectation for long-term stability is not degraded during molding processes. In particular, crystallization levels and melt index tests shall be conducted for representative samples of all molded components. All sealants, o-rings, and adhesives shall be specified and tested to insure their reliability for the expected lifetime of the project.

2.1.3.7.2. Current System Design and Testing Status

1) General System Design:

A full PMT assembly ("Kit") consists of 4 major components; see Figure 2.10 and Figure 2.11. A plastic flange is sealed to a two-foot-square piece of liner laminate. (For post-EA liners, the flange with PMT window is sealed directly to the top of the liner.) The flange is sealed to a window, which is shaped to conform to the PMT face. A plastic enclosure cover, the fez, seals with a silicone o-ring, or with an RTV, to the flange. Finally, a plastic fill port is sealed to the laminate square, and the fill port is sealed with a threaded cap (The fill port in Figure 2.11 is clear. The fill ports for production will be opaque.). Each of these components and its associated seals is discussed below.

Figure 2.10: Photograph of PMT assembly components for an EA liner.

2) Flange:

The flange is injection-molded from Low Density Polyethylene (LDPE). The Engineering Array (EA) and pre-production used mold blanks with several features requiring post-mold machining. For production we will probably not need the machined features and so plan to mold a finished part. The prototype flange also has a hexagonal region for sealing to the liner laminate allowing for linear seals. The hexagonal seal region will be replaced by a circular seal region during production.

Our testing of this component so far has involved investigating the molding parameters needed to insure a part consistently within dimensional tolerances and without voids, sinks, or other molding flaws. Future tests will include melt index and scanning differential calorimetry testing of molded samples to test for plastic integrity. We will also make dimensional and quality checks on components made with the production mold.

This component has been developed by CSU in conjunction with a local injection mold vendor [2], and in conjunction with the vendors responsible for heat seals to the flange, dome and film [3].

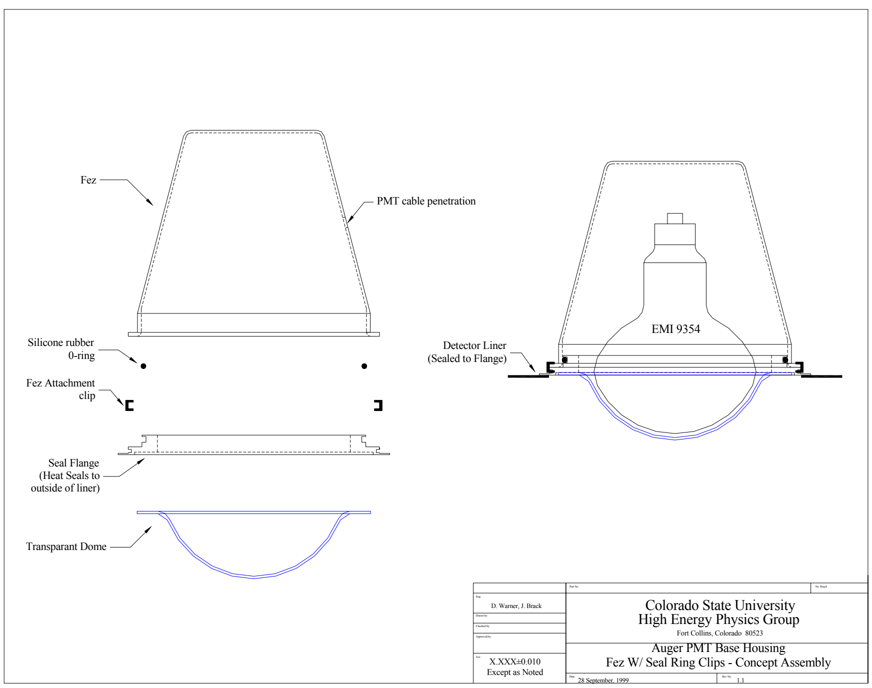


Figure 2.11: PMT assembly drawing showing the o-ring option for fez-flange seal.

3) Flange-liner seal:

The flange is heat sealed to the liner laminate. Currently this seal is made with 6 linear seals each approximately 20-cm long around the hexagonal flange lip. Our specification for these seals is that they achieve at least 50% of the yield strength of the liner laminate itself. The laminate yield strength is dominated by the approximately 0.013-cm thick Tyvek® layer, whose strength varies considerably between small samples due to variations in thickness. We have measured an average value of approximately 60 N per linear cm of laminate, setting a strength requirement of 30 N per linear cm of seal. Measurements of flange/laminate seals failed in all cases in the film, not at the seal, thus meeting the requirement.

The seals for the EA were checked for leaks during the assembly testing process by inflating the kit with the protective plastic cover, submerging it, and looking for bubbles. No failures have been detected in more than 150 assemblies tested during prototyping, thus qualifying the production procedure. We will test initial products for pre-production and then spot check as pre-production continues.

The flange/liner seal was developed in conjunction with a California vendor [3] specializing in developing heat seal equipment for the medical industry.

4) Dome:

The dome windows are vacuum-formed from plastic materials transparent in the near-UV. There are currently two materials under consideration for the windows: (1) metalocene- catalyzed linear low density polyethylene (m-LLDPE) film ("floppy") domes and (2) ultraviolet-transmitting acrylic ("hard") domes. The windows are custom-fit to specified shape of the front face of the PMTs. Development and testing of the domes has mostly involved investigating the transparency of the candidate material, researching the long-term loss of transmission of the materials, ensuring dimensional stability of molded parts, and looking for stresses molded into the domes during forming. Tests run on samples of both candidate materials show good light transmission throughout the wavelength region of interest (see Figure 2.12), although the UVT acrylic is slightly better. This approximately-10% relative transmission difference between the hard dome and the soft dome is also seen in tests in the small water tank at CSU using vertical cosmic-ray muons. Long-term yellowing of the potential dome material is typically due to exposure to UV light. The operating environment of the domes is such that this will not be a problem. There is a great deal of information available about the change in transmission of acrylic with time, both with UV exposure (the tanning industry) and without UV exposure (scintillator lightpipes, etc.). Less information is available about m-LLDPE film. We are conducting exposure tests of film in direct sunlight, as well as temperature cycling tests for both materials at CSU. The tests are ongoing, but so far the results look promising for both materials. Tests conducted on film exposed in this fashion for 10 months show no reduction in their transmission (See Figure 2.12).

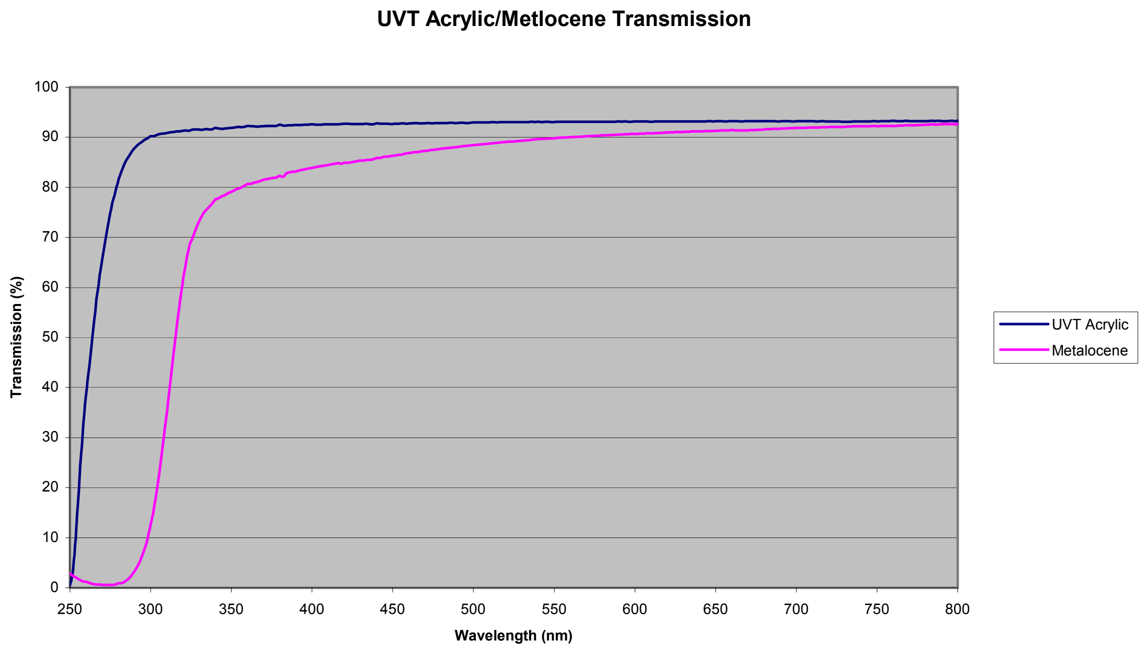


Figure 2.12: Transmission spectra for hard dome and floppy dome materials. The soft dome transmits slightly worse at lower wavelengths resulting in above 10% loss of light from vertical muons in a water tank compared to the hard dome.

Figure 2.13: Transmission spectra of unexposed metalocene low-density polyethylene film.

The most critical design decision recently taken has been the selection between acrylic hard domes and film floppy domes. Both meet our basic requirements for window performance. The acrylic domes are well understood with regard to aging, and offer robust protection to the PMTs against freezing and other problems. Their difficulties include a more complicated assembly process, rigidity that may increase difficulties in handling & packing, greater difficulty in quality control and assurance, and a greater cost. The film domes are inexpensive to purchase, easy to assemble in a controlled fashion, and more resilient to rough handling and storage due to their flexibility. The difficulties with film domes include less-well-understood aging and concerns with regard to their behavior when the detector water volume freezes.

We have provisionally selected film domes for production assemblies. Both will be tested in the Engineering Array, and we will continue to tests in the lab, particularly to attempt to improve our understanding of the behavior of the film domes in freezing water. Recent (June and July 2001) freezing tests at CSU with a second optical coupling RTV(see below) indicate that the soft dome option may well be able withstand freezing events expected at the Southern Site. Tests also indicate that the simple addition of a small (61-cm by 61-cm) square of insulation in top of the liner around the PMT greatly reduces the chances of damage due to freezing – even in extremes of cold. We will also work to improve the assembly techniques used for acrylic domes to improve our quality control of the operation.

5) Dome-flange seal

The hard and floppy domes utilize different dome flange seal techniques. For acrylic domes, the seal is made using 3M DP-8005, a low-surface-energy bonding agent recently made available for commercial use. For the polyethylene film domes, the joint is a heat seal between the film and the flange. Tensile tests have been made for both joints in sheer, and for the acrylic dome joint in peel, as well. The heat seal tests for the film dome have never failed at the seal, the dome material itself yielding first at approximately 20 pounds per linear inch. Tests of 0.32-cm LDPE flange material epoxied to 0.32-cm acrylic dome material failed with the LDPE (200 pounds per inch of seal). Again, for 5 samples tested there were no failures in the joint adhesion (although the acrylic broke in the middle of the seal of one sample). Our attempts to measure the acrylic-ldpe seal in peel were complicated by flexure of the acrylic under the off-axis load, which results in a combination of sheer and peel on the seal. These tests were conducted with mechanical weights loading a 6.45 cm^2 joint between 0.32-cm thick LDPE and acrylic samples. The sample joints did not fail under a load of greater than 40 inch-pounds.

We also tested the strength and quality of seal of both joints by sealing the back of a flange and inflating the dome to 5 PSI overpressure. The domes were left inflated for 1 week. Neither the LDPE film dome nor the acrylic dome lost more than 0.5 PSI during this test.

Finally, samples of DP-8005 seals between LDPE and acrylic sheets have been immersed in de-ionized water and subjected to 150 cycles of freeze-thaw-heat to 40 degrees Celsius. These joints still exceed the sheer strength of the LDPE strip.

6) Fill port

Fill Ports for the Engineering Array were 3.28-cm diameter screw cap ports injection molded from High Density Polyethylene (HDPE) and heat-sealed to the kit laminate. These fill ports were a commercially available part.

Our experience with the EA has shown that the liners can be filled in 45 minutes through the existing fill ports, which meets the requirement for fill speed. In order to make a better seal, a plastic plug which makes an o-ring seal to the fill port bore has produced and tested (See Figure 2.14). Since we were not able to find a commercially available opaque version of the fill port, an injection mold has been produced to make hot-compounded black LDPE fill ports.

7) Fill Port-Liner Seal

The fill port is heat-sealed to the kit laminate. Tests conducted on EA parts show a seal rupture strength greater than the laminate strength. The plan for the final fill port calls for a heat seal to the laminate using the same technique as used in the EA.

Figure 2.14: Engineering Array Fill Port, with new seal plug and cap.

8) Fez

The fez is a truncated cone of opaque ABS plastic. Fezzes for the Engineering Array were vacuum formed; we plan to injection mold the fezzes for production to reduce cost and improve dimensional stability.

Tests conducted on the fez to date include opacity testing and insuring components can be produced within dimensional tolerance.

The fezzes were designed and developed by CU and CSU, working with a local vacuum-form molding company [4]. Preliminary injection mold cost estimates have been provided by the same company producing the mold for the flange.

Currently, the fezzes are modified after molding to allow for cable penetration. Finalizing design of the cable penetration will allow us to include these penetrations in the molding process.

9) Fez-Flange Seal

The fez-flange seal is not intended to be a hermetic seal, but rather to prevent water, dust and other contaminants from entering the enclosure and also to provide a light-tight seal.

In the Engineering Array, the planned seal was to be provided by compressing a silicone o-ring between the fez and the flange (see Figure 2.). The o-ring compresses less than 10% of its diameter, and is specified not to take a set in 20 years. The fez is held onto the flange by means of a plastic u-channel. This seal has the benefit of being relatively easily opened and resealed, which may be important during electronics installation and testing. The o-rings are expensive, however, and the flange design is complicated by the need for o-ring and clip grooves, which greatly increase the cost of the flange mold. At the review of the PMT assemblies at CSU in April 2001 it was tentatively decided to replace the o-ring/clip seal by simply attaching the fez to the flange with silicone RTV in the full array. We will realize cost savings if we can eliminate the o-ring and flange clip attachment method for the fez, as well as simplification of the installation process. We will learn the likely frequency of access to the enclosure required by the electronics people during Engineering Array operation. If frequent access will not be required, we will change to a semi-permanent RTV seal for the fez. We will test this idea in a few tanks in the Engineering Array.

In practice no tanks in the EA yet (as of July 2001) have any fez-flange seal at all. All fezzes have simply been placed on the flange, without o-rings or RTV sealant, to facilitate access to the PMTs.

10) PMT-Dome Optical Coupling

Tests conducted at CSU and Fermilab, as well as in the Engineering Array, show a loss of ~40-50% of light collection efficiency for a PMT not optically coupled to an acrylic dome compared to a PMT face directly in the water. Similar tests for a film dome show a loss of 35%-50% for an uncoupled PMT (with much greater variation from PMT to PMT since the optical seal of an uncoupled floppy dome depends on just how the PMT is placed in the window). Most of this light can be recovered by optically coupling the PMT face to the inside of the dome window. A coupled hard dome collects virtually 100% of the light collected by a PMT with its face directly in the water, while, as discussed above, a coupled floppy dome collects about 10% less light.

For approximately the first 20 tanks of the EA we have used GE RTV 6136A-D1, a clear silicone adhesive RTV as the optical coupling material. Optical transmission spectra show this material has excellent light transmission to wavelengths below 300 nm. In addition to making the optical seal, the RTV mechanically stabilizes the PMT, removing the requirement for weights or alignment fixtures to position the PMT in the housing. The RTV also prevents migration of water through the film dome, a concern for either air or oil coupled PMT-film joints. Freezing tests at CSU with floppy domes and the GE RTV resulted in failures of the optical coupling: the GE RTV would un-couple from the dome if the ice on the tank attained a thickness greater than a about 5 cm. So an alternate RTV was found, Wacker Silgel 612. The Wacker RTV has been successfully used in the Antares experiment.

The Wacker RTV also has good optical properties, and is significantly stronger. A floppy dome coupled to the PMT with the Wacker RTV has survived about 10 freeze cycles on a small water tank with 5-10 cm of ice, and one cycle where we let the ice form so as to completely enclose the PMT. Freezing tests continue at CSU, and we are encouraged by these recent (June and July 2001) results with the Wacker RTV. And as mentioned above, a square of insulation on the top of the liner around the PMT greatly reduces chances for damage due to freezing.

2.1.3.7.3. Conclusion

The PMT housing assembly design is in an advanced state of development. Prototypes of all major components have been produced, and are under test at CSU and in the Engineering Array. No high-risk problems of the design remain unresolved at this time.

Four decisions remain before proceeding to the pre-production phase of the project: Selection between the three PMT candidates, between the transparent dome options, the method of sealing the fill ports, and the attachment of the fez to the flange. All of these questions are being investigated, and decisions are planned for the fall of 2001.

We have received cost estimates or quotes for all major components from vendors, and are working closely with these vendors to minimize the costs of the system. We hope to begin the formal solicitation of quotes for all major components following the system design review.

2.1.4. Solar Panel Brackets and Antenna Mast

2.1.4.1. Overview

The solar power system brackets must support the solar panels used to power the surface detector station. In addition, the bracket assembly baseline design now includes the mast that supports the communications antenna, and GPS antenna. The electronics enclosure, which was mounted on the brackets for the Engineering Array, is no longer a part of the brackets but will be installed on the large hatchcover during Production.

The brackets have the following requirements:

- They must last 20 years in service in the Malargüe site, and in particular they must withstand environmental corrosion;
- They must withstand 160 km/h winds and 25 mm hailstones;
- They must support the solar panels in a manner which will not cause the panels to be damaged;
- They must be reasonably tamper-resistant.

2.1.4.2. Solar Panel Brackets Baseline Design

The brackets have been designed and built in two different but similar technologies: aluminum Unistrut® with stainless steel or zinc plated bolts and aluminum 38-mm square tubing with aluminum rivets. Both systems have been installed in the Engineering Array successfully and are performing in a satisfactory manner. Four different models of solar panel were installed in the Engineering Array in order to qualify several for possible use, and the Unistrut® brackets were used with two types and the square tubing system with three. The square tubing technology is selected as the baseline design over the Unistrut® technology for the following reasons:

- The Unistrut® technology mixes plated steel with aluminum, a concern for electrochemical corrosion. The square tubing is assembled with aluminum rivets, with only minimal bolting in a few critical locations, and then stainless steel bolts are used.
- Theft of solar panels by casual vandals with Unistrut® is possible using a wrench. Theft of solar panels mounted with the square tubing system requires that the rivets be drilled out or broken off.
- The cost of the square tubing seems to be marginally lower than the Unistrut® system.

The bracket assembly mounts onto lugs molded into the top of the tank for this purpose.

2.1.4.3. The Engineering Array Experience

The first (approximately half of the total) brackets installed were of the Unistrut® design. There are few machined parts and the assembly involves cutting the Unistrut® to length and bolting the system together. The panels are riveted to the Unistrut® uprights. The final assembly of the brackets to the solar panels, including drilling for the rivets to mount the panels themselves, and preparation for mounting to the tanks is done with less than one man-hour of labor.

The remaining brackets were of the square tubing design. A mast structure was added to the original design to support the antennas. Preparation of the bracket involves cutting the aluminum extrusions to length. The rivet holes for the solar panels are drilled and the panels riveted to the extrusions. Then the square tubing is drilled and riveted instead of being bolted as in the Unistrut® system. For the small number of systems for the Engineering Array, drill templates were manufactured and used with battery operated hand drills to drill all the parts for riveting. The drilling was time-consuming, adding about 1 – 1 ½ man-hour per assembly. However, in Production, this is done in Buenos Aires in a factory setting, using CNC drilling instead of templates. Costs for the drilling will be modest under these circumstances. Assembly of the brackets once the holes have been prepared is much faster with rivets than with bolts, taking only a few minutes per assembly. A few sets of holes are not drilled in the factory but must be reserved for a "field fit" to individual tanks which might have some warping and hence variation of the mounting lug provisions. Field fitting of the mast was necessary to make it vertical. This required custom drilling of two sets of six holes for each detector. (The vertical specification may be more cosmetic than real: The communications antenna will work well with a 10° tilt but the visual appearance is poor.)

A torsional oscillation of the solar panels using the Unistrut® system in the wind was observed using Solarex® and Kyocera® solar panels, with a peak-to-peak amplitude estimated at up to 5 mm by eye, not with much precision. No damage was apparent, and the displacement is within the tolerances specified for the panels, but we are concerned with very long-term effects. An analysis has been performed, and it found the low frequency modes of the system. An improved bracket system is under design to raise the frequency of the lowest modes. However, if compact tanels are used, this is not necessary. Note that this oscillation was observed with Solarex® and Kyocera® panels, but not with the much more compact Siemens® panels. Isofoton® panels are used in Production and they are almost identical to the Siemens panels. The oscillation is not a concern. No oscillations have been observed in Production systems.

2.1.4.4. Cost and Procurement Plan

The preparation of the square tubing for assembly required the drilling of a lot of #11 holes for the rivets. There are approximately 110 rivets per installation. These holes were drilled using drill templates and hand drills or using the mating part (that was drilled using a drill template) as a drill guide. Manufacture is proceeding using CNC techniques with no difficulty.

The aluminum extrusions are made in Argentina. Rivets are provided by the USA.

Argentina is responsible for the bracket and mast assemblies.

2.1.4.5. Quality Assurance Issues from the Engineering Array

The Engineering Array bracket assembly was assembled by Auger physicists in Malargüe. Therefore, one must recognize this as a rather limited experience with limited application to factory assembly. The most important concern for quality control was the tolerance on the lengths cut and the position of holes drilled. The metal extrusions arrived and were received without more than cursory inspection. (Standard extrusion tolerances are acceptable, and no special tolerances were called out.) Manufactured parts also were received with no more than cursory inspection. No parts were ever rejected because of flaws or out-of-tolerance conditions that caused difficulty in assembly. Sample parts were checked for length and found to be well within acceptable tolerances. At assembly, the parts were determined to fit correctly in each case. In Production, with premade and partially assembled brackets being delivered from Buenos Aires, the experience has been highly successful. Parts fit has not been a problem, and assembly has not been difficult.

2.1.5. Solar Power System

2.1.5.1. Overview

The electronics for the surface detectors will be powered by solar photovoltaic systems at each detector. The power system will satisfy the requirement for at least 10 W continuous average power. A 24-V system has been selected for efficient power conversion for the electronics. Because solar power systems are in extensive use worldwide for many applications, reliable, cost-effective components are readily available. Therefore detector system requirements can be met by careful selection of components from those already available.

The solar power system will consist of two solar panels in series connected to two lead-acid storage batteries through a charging controller circuit. (Connecting cables and a battery box, which houses the batteries and the regulator, are also required.) Insolation data are limited for the area of the Southern Auger Site. However, using the data available for three years for Rama Caida, near San Rafael, not far from the edge of the Southern Site, an analysis was performed to determine suitable sizes for the solar panels and batteries. This analysis found that, with 80 ampere-hour (Ah) batteries, 50 Wp panels (Wp is a unit expressed in watts for solar panel output with a standard solar irradiation applied) would fail to provide around the clock power 0.14% of the time during the worst year. With 100 Ah batteries, the 50 Wp panels would meet the load requirements at all times. We have selected 100 Ah batteries and 55-60 Wp panels. Degradation of their capacities to 80 Ah and 40 Wp, respectively, during long term operation would still result in power being available 97.8% of the time. (Note: The 55 Wp panels are warranted by the manufacturer to have no less than 40 Wp at the end of 25 years.)

2.1.5.2. Specifications and Requirements

2.1.5.2.1. Solar Panels

Solar panels must survive 25 mm hail and 160 km/h winds. Torsion displacement in a corner of 0.02 times the diagonal of the panel, with the other corners fixed (this is ~1.2 degrees) must not damage the panels. These requirements can be met by requiring that the panels satisfy IEC1215, a test standard for "Crystalline Silicon Photovoltaic Modules for Terrestrial Applications" of The International Electrotechnical Commission. The solar panels of the major manufacturers meet this standard (or equivalent standards such as IEEE 1262).

A power output rating when new of 55-60 Wp with a warranty limiting degraded output after 20 years to be no less than 40 Wp is required. (While a warranty is not necessarily needed for the operation of the Project, it indicates that the manufacturer is committed to making a product that they expect to last at least 20 years.)

2.1.5.2.2. Batteries

Batteries shall be of the Absorbed Glass Mat Valve Regulated Lead Acid (AGM VRLA) type. They shall be 12 volts with at least 100 ampere-hour (Ah) capacity at the 20- or 24-hour discharge rate. They must be shippable without hazardous material restrictions.

2.1.5.2.3. Charge Controller

The charge controller shall be of the pulse width modulated (PWM) type, series design for 24-volt systems with a charge current up to 4 amperes. It shall incorporate temperature compensation. It shall be conformal coated or potted for corrosion resistance and exposed metal components shall be suitably treated or coated to provide corrosion resistance. It shall be approved for use in Class 1, Division 2, Group B hazardous locations. It shall have a failure rate of no more than 0.2% over 5 years. A lifetime of 20 years should be reasonably expected. Transient overvoltage protection shall be by silicon avalanche transient voltage suppressor devices.

2.1.5.3. Baseline Design and the Engineering Array Experience

The baseline design for the solar power system consists of

- two solar panels rated at 55-60 Wp connected in series to provide a voltage suitable for charging two 12-volt batteries in series. A change for production allows the use of 53 Wp batteries with a tighter output tolerance, resulting in no less power than the standard 55 Wp panels.
- two Absorbed Glass Mat, Valve Regulated Lead Acid (AGM VRLA) 12 volt, 100 Ah batteries. A change for Production allows the use of Moura 105Ah selectively permeable membrane lead acid batteries
- a charge controller, with a series connected PWM design and documented high reliability; the brand/model Morningstar Sunsaver® SS10L-24V has been selected;

- cables;
- a power control circuit to allow the controlled shut down and restart of the entire array in the event of prolonged darkness resulting in a low state of battery charge; it will be discussed in the section on Surface Detector Electronics;
- a battery box to contain the batteries and the charge controller. A photograph of a battery box installed on a Production surface detector station is shown in Figure 2..

Figure 2.15: Surface detector station for the Engineering Array showing the battery box in place.

2.1.5.3.1. Solar Panels

There were four models of solar panel installed in the Engineering Array:

1. Solarex® SX-60U, 60 Wp output rating;
2. Kyocera® KC-60, 60 Wp output rating;
3. Siemens® SM55, 55 Wp output rating;
4. Unisolar® US64, 64 Wp output rating.

The four types were installed in order to test models from leading companies in the industry. The Unisolar®, from a smaller company, was included mostly because of its unusual design: it is made of stainless steel covered by plastic, as opposed to tempered glass. The Unisolar® is therefore bulletproof, in that a few bullet holes will not have much effect on the power output. However, the panels are also substantially larger than the others, and this large size causes some concern about wind loading of the brackets and tank mounting structure under extreme wind conditions. Therefore the Unisolar® panel design is not considered to be part of the baseline design panel set, even though no failures have been observed.

There has been one solar panel damaged in the Engineering Array and one in Production and vandalism is suspected, but not with certainty. No other solar panel failures have occurred. We consider the Solarex®, Kyocera®, and Siemens® panels to be suitable and qualified for the baseline solar power system. After the Engineering Array, Spain joined the Pierre Auger Observatory and offered to provide Isofoton I-53 solar panels. These are very similar to the Siemens SM55 panels. The Isofoton panels were tested in Preproduction and proved to be satisfactory. They are the choice for Production as well.

2.1.5.3.2. Charge Controllers

The charge controller controls application of current from the panels to the batteries, charging them to a full charge and maintaining the charge at the highest level possible. All of the controllers installed in the Engineering Array are Morningstar Sunsaver® SS10L-24V. This had previously been selected as the baseline because it meets our specifications at a highly cost effective price. In particular:

1. It has been engineered to have a predicted, long lifetime and predictable, low failure rate;
2. It has been engineered to survive in difficult environments;
3. It is of a type (series connected pulse width modulated) that should optimize battery performance and lifetime.

This controller has been developed by the Morningstar company in conjunction with Sandia National Laboratories and the development of this series of charge controllers has been described in some detail [5]. The five year failure rate quoted is less than 0.2%, and the wearout lifetime is expected to exceed 15 years. However, the wearout lifetime is determined by factors including the operating temperature and thermal cycling. We will maintain a lower operating temperature than used in the Morningstar/Sandia analysis by installing the controllers in the battery box, which is insulated to stay cool, and by operating at 1/3 of the rated current. We therefore expect to extend the lifetime somewhat and do not anticipate replacing many before the 20-year operating life of the Project has been completed.

There have been no failures of controllers in normal use. One controller was connected using the “load” output terminals. This output failed and it is believed the output terminals were shorted together during installation of the electronics. Since the load output provides no useful function for us, with the possible benefit of optimum transient voltage spike suppression, we have been successfully connecting the load directly to the batteries. (We may return to using the load output with proper fusing in the future.)

The controller is of the pulse width modulated type and operates by applying pulses of current of varying width to the batteries as the batteries state-of-charge, as measured by the battery voltage and temperature, varies. This is claimed to be the best method of charging for maintaining battery efficiency and lifetime. There have been no observations of electronic interference from the PWM operation in the Engineering Array or Production.

2.1.5.3.3. Batteries

We have installed 12 volt 100 ampere-hour AGM VRLA batteries in the Engineering Array. There were two models but all were made by Exide Yuasa® in Taiwan and purchased in Argentina. They appear to be satisfactory, although we are not able to assess their expected lifetime based on our short experience. Batteries and battery manufacturers acquire a reputation among the users that is difficult to trace experimentally. From the distributors of different brands of batteries, for example, one can learn which batteries have been reliable and which have proven troublesome. Variations in battery quality often depend on trace elements in the plates that cause important effects in battery operation and lifetime. Manufacturing quality control, something very hard to specify, becomes extremely important. After investigating battery reputation with distributors, we learned of the Concord SunXtender® series of batteries which meet our specifications, appear to have a long expected lifetime, and can be purchased in the United States at an advantageous price. We anticipate purchasing these batteries if the price remains competitive but we do not rule out other, similar batteries in the future.

Batteries made by Moura in Brazil have been purchased for Preproduction and for Production. These are a new type of lead acid battery designed for solar power applications. They have a selectively permeable membrane and are not expected require maintenance. They are provided by Brazil at about half the cost of the Concord batteries. The reduced cost and availability from Brazil resulted in the choice of these batteries over others. There has been no problem observed in Preproduction or Production installation of these batteries.

2.1.5.4. Procurement

2.1.5.4.1. Solar Panels

The solar panels are Isofoton I-53 panels provided by Spain. They have been procured through competitive bid and have considerable cost advantages over their competitors.

2.1.5.4.2. Charge Controllers

The Morningstar® SS10L-24V are ordered by competitive bid from various distributors. They will remain in the factory packaging until ready for installation unless external package damage is observed. The United States is providing the charge controllers.

2.1.5.4.3. Batteries

Delivery of batteries for Production is made challenging by the fact that one does not want the batteries to sit around unused without being charged. A plan is required to charge any batteries delivered but not installed before the battery has self-discharged to about half of its capacity. The Moura batteries are ordered and delivered shortly before they are needed. Brazil makes these arrangements and the batteries are delivered several times per year during Production.

2.1.5.5. Installation

2.1.5.5.1. Solar Panels

Installation has been rather straightforward in the Engineering Array: Solar panels are riveted to the bracket assembly before deployment, and the bracket assembly installed on the tanks during Assembly and taken out into the field when the tanks are deployed in a collapsed configuration. The panels and mast are raised and locked in place by a single screw.

2.1.5.5.2. Charge Controllers

Installation of the charge controllers in the EA was done by mounting the controller to the insulation inside the battery box and connecting the cable wiring harness to the terminals. This was done in the field at the time the cabling and other electronics systems were being installed. (It could also be done at the same time as the tank is first delivered to the field.) In Production the controller is mounted to a 12.7mm thick plate of polyethylene. The plate with the controller is placed in the battery box during deployment.

2.1.5.5.3. Batteries

The battery box is installed before the tank is filled with water because it is necessary to put the tongue of the box under the tank as our "security lock." It is easiest to install the battery box at the time the tank itself is delivered to the field. Any time between the installation of the battery box and the need to connect the power is acceptable for battery installation. It is most convenient to install the batteries when the tank is deployed or when the water or electronics are deployed, if these are done at separate times..

2.1.5.6. Maintenance and Operations

The failure rate and failure modes of the solar panels, charge controllers and the batteries are unknown. Solar power system parameters will be recorded and analyzed using the central data acquisition system. Failures will be treated on an individual basis. Monitoring software for the solar power system will have to be developed in order to make this monitoring routine for operating personnel. The lifetime of batteries is expected to be 5 years. The batteries will be monitored along with the rest of the solar power system. The condition of the batteries can be easily determined from the data (voltages, currents, and temperatures) that are being monitored and the weak batteries can therefore be identified weeks or even months before complete failure occurs. Batteries can then be scheduled for replacement by the routine maintenance process. This will be part of the normal operation of the Observatory.

2.1.5.7. Spares Inventory

Spares for the solar panels and controllers will be determined by the experience with the EA and Preproduction. A long-term budget for 10% spares may be prudent through the life of the experiment. Keeping 1-2% spares on hand may prove sufficient.

Batteries will be a consumable item. The real lifetime is difficult to predict because it depends on the temperature and on the cycle characteristics. Therefore we will not be sure of the operating costs until a more precise lifetime for the battery can be established. Prudent planning would call for budgeting for a five-year lifetime for the batteries. After the first set of batteries begins failing we will be able to refine these plans.

2.1.5.8. Ground array tank thermal modeling and insulation

Both the northern and southern Auger Observatory sites are between 35 and 40 degrees latitude at elevations of 1300 to 1400 m, in regions where freezing is common in winter. Placing large water Cherenkov detectors in such regions naturally has some associated risk. Insulation costs for 1600 tanks are significant and are related to insulation thickness, so evaluation of the required amount of insulation for the given climate is necessary.

A simple finite-element heat transfer code has been developed to model heat loss from the tank as a function of outside temperature. Using local weather data records over previous decades as input, predictions can be made of tank water temperature as a function of time for a given insulation configuration. The predictions have been compared to data gathered from two prototype Cherenkov tanks placed at the northern site in Fillmore, Utah, and to a test tank in Delta, Utah. The prototype tanks were equipped with data loggers collecting data from temperature probes at three levels in the tanks over a period of several years. Additional data were logged from probes on the outer surface of the tanks, in the ground under and surrounding the tanks, and from a solar irradiance detector. These data were used in the model to include the effects of ground temperature profile and solar induced convective currents which cause mixing in the tanks, inhibiting temperature stratification and delaying the temperature inversion associated with freezing.

Analysis of the data acquired from the Utah test has been completed [6,7]. In general, the conclusions are that the model predictions replicate tank temperature data over several years of running with an accuracy of near 1 degree C (see Figure 2.). When the local weather data bases are used (50-year data base in Utah; 4-year data base in Malargüe), it is found that to avoid freezing in all but the most extreme winter conditions, a layer of 2 cm insulation is sufficient at the southern site (see also 8), and 5 cm at the northern site. With no insulation, freeze-thaw cycles are expected to occur nearly every winter at either site.

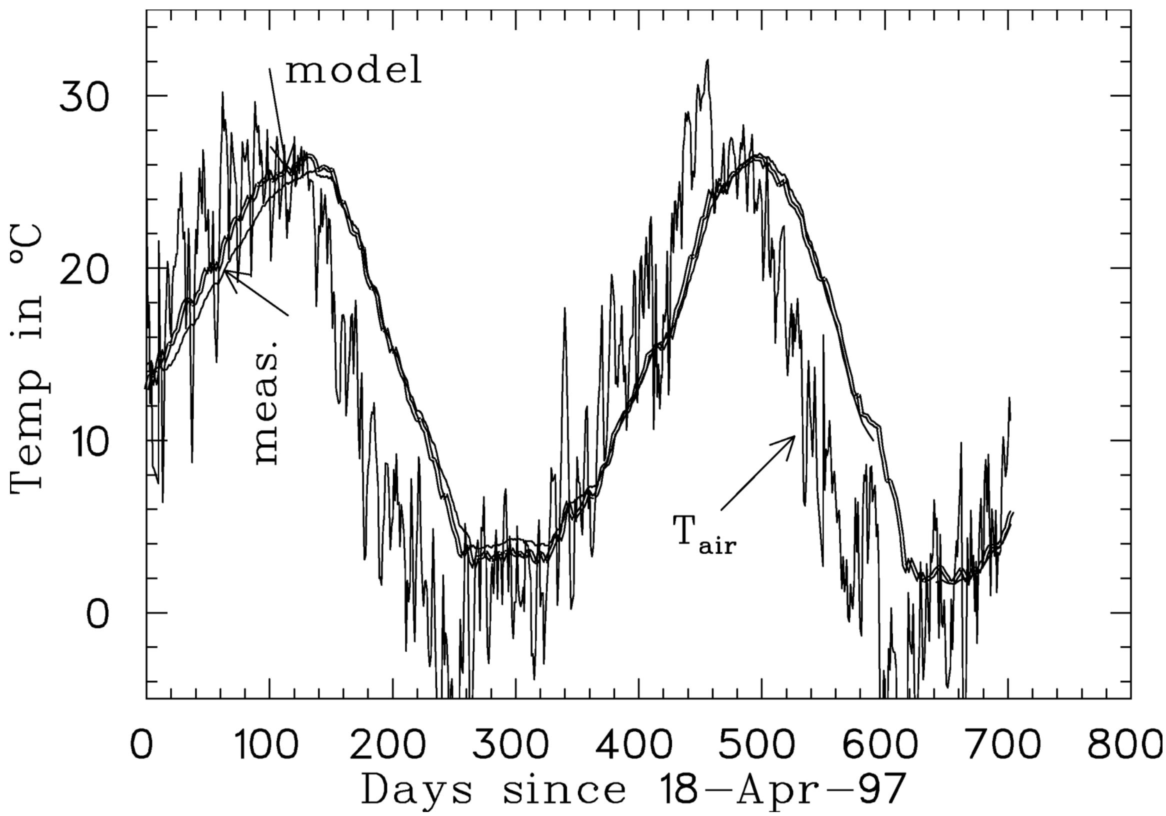


Figure 2.16: The temperature predicted by the model (double line), the measured tank temperature by a single probe in the tank (thin line) and the daily average air temperatures at the Delta site (jagged, oscillating line). Note the lack of measured tank data between Dec 1998 and Jan 1999 (days 600-640).

Exact specifications and requirements for insulation are unspecified. The consensus of opinion in the collaboration is that some freezing is acceptable, but there is at present no field experience to support this opinion. The current baseline design for the southern site is the zero-insulation configuration, and tanks have been deployed without insulation. Several centimeters of ice have been observed on EA tanks this winter (2001), as predicted by the model. No damage has been observed. While it has been shown that a thin layer of ice is not a problem for observing the Cherenkov light [9], questions remain concerning possible level of damage caused by the freeze-thaw cycles, where it might occur in the tanks, and whether it can be prevented with a minimal insulation configuration. Of particular concern are the repeated expansion stresses on liner material seams, the RTV joints joining the PMTs to the floppy domes, and the liner material itself.

Full insulation of Southern Hemisphere tanks is likely not necessary and is probably financially unfeasible. Several partial insulation configurations are under investigation as outlined in the paragraphs below. As experience is gained with the EA tanks, insulation requirements will be more apparent.

In early July 2001, two identical tanks outside the assembly building in Malargüe were equipped with temperature sensors and data loggers. One tank has a 5 cm layer of Styrofoam inside the tank covering the upper surface of the liner. The other is in the normal zero-insulation configuration. The foam layer is expected to significantly increase the thermal time constant of the insulated tank and prevent freezing. The cost is approximately $80 per tank.

Tests have been performed in which a piece of liner laminate with a flange and dome installed, was placed in a small test water tank, covered with a 60-cm square, 5-cm thick layer of closed cell polyurethane foam. A hole was cut in the foam to accommodate the installed PMT enclosure. The test tank was placed in a freezer. As the tank froze, water directly under the foam and dome did not freeze. No damage to the dome was observed. A similar piece of foam could be placed over each fez during the tank assembly procedure or in the field on deployed tanks. This minimal insulation configuration would minimize freezing near the domes, which are the most susceptible regions of the liners. The cost is on the order of $10 per tank.

For reasons unrelated to freezing, a new liner laminate is being tested. This laminate has a clear metalocene layer on the inside, covering the fibrous Tyvek® and facilitating the welding of bag seams. It is hoped that an additional benefit of this material will be to keep ice from sticking to the laminate and thus eliminate the stresses on laminate and liner seams from freeze-thaw cycles.

2.1.6. Water[i]

2.1.6.1. Water quality specification

Each surface detector contains 12000 liters of ultra-pure water. The high water purity is required in order to:

- have a maximum attenuation length for UV Cherenkov light
- guarantee stability of the water during the 20 years of operation of the detectors

For these reasons, the detector's water should be deionized and completely free of microorganisms and nutrients. After consulting different water plant manufacturers it was established that a best achievable water quality requires a water treatment that gives an output water of resistivity above 15 MOhm-cm.

The production rate of the water plant has to be high enough to ensure that it can provide water to the detectors at the same rate as they are deployed. This requirement corresponds to up to 36000 liters per day (to fill 90 detector tanks per month).

2.1.6.2. Water production

The pure water required for the surface detectors is produced at the water plant installed by IPA Argentina S.A. at the Central Campus in Malargüe.

Ground water is provided by a well at 80 m depth and pumped to a cistern with 60 m^3 capacity, where it is chlorinated and stored. The water plant is fed from this cistern. Since 2003, the cistern has been filled with a mixture of water from the well and city water from Malargüe. As the city water is of considerably better quality than the water from the well, this change allowed to increase production rate and reduce efluents.

[i] 2_1_SD_011005-waterIA040219.doc

The water purification follows three stages: pre-processing, reverse osmosis and continuous deionization.

a) Pre-processing:

- Prefiltering, to eliminate particles greater than 40 µm
- Softening, to eliminate Ca++, Mg++ and Fe ions, with a resin bed for strong cationic exchange, with regeneration by sodium chloride
- Addition of antiscale solution, to avoid deposit of silicates on the membranes
- Addition of chlorine reducer to eliminate active chlorine contents
- Microfiltering with two pairs of polypropylene microfilters to eliminate particles greater than 5 µm.
- Ultraviolet disinfection with a 254-nm UV unit (64 W power), to eliminate microorganisms from the water.

b) Reverse osmosis:

A high-pressure centrifugal pump pressurizes the water and pumps it to the reverse osmosis unit, consisting of two modules in parallel, with 4 membranes each. Maximum input flow is 3600 l/h, with a maximum output of 2300 l/h. The output water resistivity is ~100 k -cm.

An ultraviolet source of 185 nm eliminates microbiological residues and guarantees that TOC (total organic carbon) is kept at low levels.

c) Continuous Electrodeionization (EDI):

To achieve the required final water quality (resistivity above 15 Mohm-cm), the product of the reverse osmosis process is fed to an EDI unit, which consists of a set of membranes with cationic and anionic transfer. The production capacity of this unit is between 1360 and 2840 l/h.

The water produced by the water plant is stored in a $50m^3$ storage tank. A recirculation system, which also permits quality improvement through a mixed resin bed and UV treatment (254 nm, 151 W), can recirculate up to 5.5 m^3/h. The pumping system of this recirculation is also used to fill the transport tank.

The water plant is fully automated. A PLC monitors the relevant production parameters. A series of instruments allow to monitor the working parameters of the water plant: redox potential at the entrance of the reverse osmosis membranes (to detect excess of chorine), pressure gauges, flux gauges, resistivity meters at the output of the osmosis process and of the EDI.

The present configuration of the water plant allows a production of 36000 liters per day. An upgrade to increase the water production is not required. However, a new storage tank with a capacity of 32.000 liters might be required to store the water produced during weekends.

2.1.6.3. Water testing and handling

The two more relevant parameters that give information about water quality are its resistivity and biological activity. Resistivity can be measured continuously at the output of the water plant and in the storage tank with the instruments incorporated at the water plant. Resistivity of the water in the transport tank and in the detectors can be determined with a handheld conductivity meter.

Resistivity should be measured at every step in water deployment: in the storage tank, in the transport tank, before filling the detector and after filling. Due to a series of technical problems during the EA phase, water of different quality was used in the EA tanks, ranging from 1 to 9 Mohm-cm. Although the water resistivity degrades during transportation, probably due to absorption of carbon dioxide, tanks in the production phase are filled with water of 8-10 Mohm-cm.

To determine the biological activity, samples have to be taken in a sterile container and sent to a biochemist in San Rafael to do the corresponding analysis. Periodically, water samples from the storage tank, the transport tank and the detectors have to be taken and analyzed. In the EA phase, water samples taken from the storage tank in February and April 2001 showed a good bacteriological quality, with only aerobe mesophylls in low concentration and negative values for total coliforms, faecal coliforms, coliforms in Koser citrate as well as for yeasts and fungi in Agar Saboreaud medium.

In April 2001 three detector tanks were sampled: one that was filled with water in February and the other two filled in April. The results obtained were similar to those of the storage tank water, i.e., some aerobe mesophylls were found in all detectors, but in the February filled detector the number of colony forming bacteria per ml was larger. The bacteria were identified as Serratia.

The evolution in the number of bacterial colonies will be followed. According to previous studies (GAP-96-036), the number of bacteria is expected to grow during some time, reach a plateau and decay afterwards.

The periodicity of water sampling for bacteriological monitoring varies with deployment stage, but samples are typically taken from the two detectors filled first after a larger deployment stop. Also, water from the transport tanks is monitored after longer stops. At a continuous deployment rate, two detectors are sampled at the beginning of each month. The evolution of bacteria is followed in some selected tanks, taking samples every 6 months. This periodicity will be changed to once a year after some time.

The bacteriological data obtained up to now shows a decreasing tendency in the presence of aerobial bacteria. Some isolated tanks showed contamination with low quantities of coliform bacteria, which might be originated by contamination during data taking or during sample transportation. In all these cases, they showed a strong decay after a short time.

2.1.7. Assembly and Deployment[ii]

Assembly of the surface detectors takes place at the Central Campus Assembly Building and consists of preparing the tanks and adding all the additional components required to make them ready for deployment. Deployment consists of transportation of the assembled units to their field locations; delivery of water; filling with water; installation of battery boxes, batteries and antennas; connection of cables ; and performance of field tests.

2.1.7.1. Detector Assembly

The major assembly activities consist of preparing the tanks and of installation of liners, PMTs, electronics, and light calibration sources, as well as solar panel brackets with solar panels and masts. Part of the assembly procedure is a complete system test of all the electronics and balancing of the PMTs using the calibration sources. PMT response is measured without water in the tank and therefore it does not fully reflect the operating conditions.

The assembly of the surface detectors that takes place in the Assembly Building consists of the following steps:

- Clean the inside and outside surface of the tank.
- Perform tank quality control measurements as required as part of the receiving inspection. (See Surface Detector Tanks, Section 2.1.2.1.)
- Install hatch covers.
- Install solar panel and antenna brackets.
- Install the vent and drain systems.
- Install and inflate the liner.
- Install PMT assemblies.
- Install electronics and all internal wiring.
- Perform a system test.

During pre-production nine technicians were trained under the supervision of the different Task Groups involved, in order to rely on local manpower for most of the assembly activities. Up to eight detectors (the capacity of the assembly building) can be assembled simultaneously, resulting in improved efficiency for the steps indicated above.

All assembly procedures are detailed in written documents for guidance of the personnel. As these activities proceed, serial numbers, measurements, and other information related to installed components are entered into the Surface Detector database, called Mdb.

During the Engineering Array phase, the assembly steps that took place before deployment were cleaning and preparation of the tank, installation of the drain and vent,

[ii] 2_1_SD_011005-assemblydeploymentIA040219.doc

preparation and installation of the hatchcover assemblies, installation of the liner, and mounting of the brackets. PMT and electronics installation was done in the field, as well as the installation of solar panels. Installation of the PMT assemblies in the field instead of in the Assembly Building, using a two-component transparent silicone rubber compound for optical coupling between the photocathode and the liner windows, required extreme care to prevent dust from being incorporated into the compound. Low temperatures made the process even more challenging.

Even though conditions were somewhat different than for Production deployment, the Engineering Array contributed to the understanding of the assembly and deployment processes in detail.

From Preproduction onwards, installation of PMTs and solar panels was done in the Asembly Building, thus reducing largely the activity in the field. Working in the controlled environment of the Assembly Building significantly facilitates Production assembly activities.

Electronics is still being installed in the field, although a test of PMTs and LED flashers is carried out in the Assembly Building prior to deployment.

It has been verified that a team of 6 technicians can fully prepare and assemble detectors at a rate of 4 detectors per working day.

2.1.8. Detector Deployment

Detector deployment involves survey and site preparation, delivery of the detector units to their prepared locations, delivery and installation of water and the rest of the components required to making an operating station. The main challenge for deployment is the handling of heavy loads (tanks and water) on difficult and variable road conditions. Access to detector locations is affected by seasonal and daily weather conditions.

All deployment procedures are detailed in written documents for training and guidance of the personnel. As these activities proceed, serial numbers, measurements, and other information related to installation of components are entered into the Surface Detector Mdb database.

2.1.8.2.1. The Engineering Array

The Engineering Array was located in an area with a tendency to be particularly wet because the water table is located close to the surface. Both high winds and low temperatures were present and provided further experience on the challenges of deployment throughout the year, including the most difficult seasons. For example, it was learned that low temperatures actually facilitated access to very wet areas by allowing vehicles to move on frozen surfaces.

The experience from the Engineering Array results in a deployment plan divided into a summer season, where a large number of stations can be deployed, followed by a winter period of installation at a reduced rate. During the winter deployment season, deployment would concentrate in areas of easier access.

Important lessons learned concerned the difficulties of operating in the wet season with conventional vehicles, even 4-wheel drive ones. All vehicles are provided with rescuing equipment for stuck vehicles and emergency equipment.. The deployment activity must be carefully planned and synchronized with preparation and assembly activities so that the complete operation takes maximum advantage of the good deployment days.

2.1.8.2.2. Site preparation

Prior to deployment, the ground for the surface detector locations is prepared following written procedures. The following steps are indicated:

- A contracted surveyor team marks the location where each detector is to be deployed, with two stakes oriented north-south at a distance of roughly 10 meters from each other. . The surveyor provides the Project with information on the positioning of both stakes (including altitude) with centimetric precision, as well as information on accessibility, ground, vegetation, access conditions, etc.
- A circular area of 6-m radius is cleared completely of vegetation. At locations with pampas grass (cortadera) and/or heavy bushes, the circular cleared area is increased to 10-m radius in order to reduce the seasonal fire hazard. The removed vegetation is left at a distance exceeding 50 m to the East of the tanks to avoid being blown back to the cleared region. This activity is planned to minimize the ecological impact of the work. Local environmental regulations and procedures are observed.

A central circular area of 2.5-m radius is prepared with the following requirements:

- It is cleared of stones, roots and other sharp objects.
- Irregularities bigger than 1.5 cm in height are flattened or removed.
- If bigger objects are removed, the ground is compacted back to a smooth surface.
- A bed of 10-cm height is prepared with material sifted through a mesh of 1 cm × 1 cm.
- The area has a global deviation from horizontality of at most 1º to avoid overloading the walls of the detector tank and to provide a uniform water depth and PMT height.
- Local irregularities are not greater than 3 cm.
- A report on soil type, water level and vegetation is prepared, including comments on accessibility and problems encountered.

2.1.8.2.3. Deployment

The deployment procedure starts with loading assembled tanks and transporting them to an intermediate station at the site. Tank transport to the intermediate station is done with flatbed tractor-trailer trucks. A flatbed truck which meets the local transportation regulations can transport 4 tanks per trip. Flatbed trucks can be rented on an hourly basis in Malargüe city. Intermediate stations are selected to be approximately equidistant from the four deployment locations and in an area where the truck transporting the tanks can easily maneuver. An escorting vehicle carries other components for deployment.

Loading at the Assembly Building can be done with a forklift truck; unloading and further transportation at the site requires a truck capable of carrying a single tank and equipped with a hydraulic crane. Such trucks are commonly used for transporting bricks, drywall, roofing materials and other construction supplies.

The remaining steps for deployment are:

- **Tank positioning**. This comprises transporting the tank from the intermediate station to its final location. While unloading the tank at its position, it is oriented such that the solar panel will face North (5° tolerance) as determined with a compass
- **Install battery box and batteries**. At unloading time, the battery box is placed at the south (10 degrees tolerance) side of the tank and secured in place by a tongue attached to the bottom of the battery box extending under the tank. The two batteries are simply placed inside the box, side by side. A charge regulator is also installed within the battery box.
- **Cabling**. Power cables are connected to the batteries, regulator and TPCB.
- **Water delivery**. Water is delivered and installed in the detector as discussed in the following section.
- **Install communication mast and antennas**. The communications antenna kit and the GPS antenna are mounted to the mast, which is part of the solar panel bracket assembly. This task is usually carried out by the water delivery team during water filling of the tanks.
- **Installation of electronics kit**: the electronics kit is installed by an SDE deployment team. The electronics for the detector station is tested.

2.1.8.2.4. Water delivery

The water delivery is described in written procedures. Water is delivered to each detector tank (12000 liters) in one filling, with a single hose connection, in an effort to prevent contamination by bacteria and/or potential nutrients.

A water delivery "kit" is composed of two 12500-liter tanks, one mounted at the back of a truck and one mounted on a trailer. Both tanks have independent electrically powered pumps, gasoline power generators to operate the pumps, hoses, connections and accessories. The trailer is pulled by the truck on easy access roads and tracks. To access the more difficult areas, the trailer or the truck are pulled by a frontloader tractor. The tractor is also used to even out irregular roads (sand dunes) and to compact the ground in wet areas.

The transport tank system has the following characteristics:

- A 0.2 μm bacteriological filter is connected to the air inlet-outlet of the tank to filter the air that is sucked into the transport tank while pumping water out. In the

EA phase a coarser filter was used while the details of the underpressure protection system were worked out.

- The transport tank used for the Engineering Array water delivery was made of fiberglass-reinforced polyester resin with food-grade protective coatings on the inside. The maximum allowable working differential pressure of the tank is 100 cm of water. The second transport tank, mounted on the truck, was made of stainless steel, providing a higher water quality and ensuring a better cleanliness condition.
- A pressure relief valve is installed at the manway to avoid damage to the tank by overpressure during filling.
- There is a transparent plastic window on the tank for direct visual inspection.
- A 50-mm hose and associated valves are installed to transfer the water from the transport tank to the detector. The end of the hose is connected to a bayonet that has a valve to regulate water flow and a freely rotating cap that can be screwed to the liner opening. During transportation, the bayonet is protected with a stainless steel scabbard, which can be screwed to the bayonet with an airtight seal. The end of the bayonet has a small stainless disc to dissipate the water stream, thus preventing localized high water pressure on the liner which might damage it or displace it from the correct position.
- An electrically driven stainless steel centrifugal pump, with a capacity of 120-300 l/min, is installed to transfer the water.
- All accessories in contact with water are stainless steel with a sanitary finish to prevent corrosion and formation of bacterial colonies.

To fill the transport tank, the recirculation system of the water plant is used. This allows a flow of 12500 liters in 50 minutes. To fill the detector tanks, hatch covers are removed after cleaning the detector tank surface, one liner cap is opened and the bayonet, after being rinsed adequately, is introduced into the liner, screwed to the liner opening and the pump is turned on. For air release, a second liner port is opened. The filling of the detector takes approximately 45 minutes. The height of the water column is determined by measuring the height of the tank and subtracting the height of the water level, measured from the top of the tank (and subtracting the thickness of the tank walls). This gives a precision of 1-2 cm. The level is measured at different hatch openings to avoid systematic errors due to any possible tank tilt. The water conductivity is tested with a handheld conductivity meter before filling the liner has begun. After filling, any remaining air is pumped out of the liners with a vacuum cleaner.

After longer stops (typically, 5-6 days), the transport tanks as well as all accessories are cleaned and disinfected, filters are checked and replaced as required. Cleaning is done with detergent, bleach and a very thorough rinse.

Detailed information about each detector filling, including the date, which transport tank was used, the water resistivity and water level, is entered to the Mdb database.

References

[1] Pierre Auger Project Design Report, Nov. 1999.

[2] Soft Touch Mfg. Loveland, CO.

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