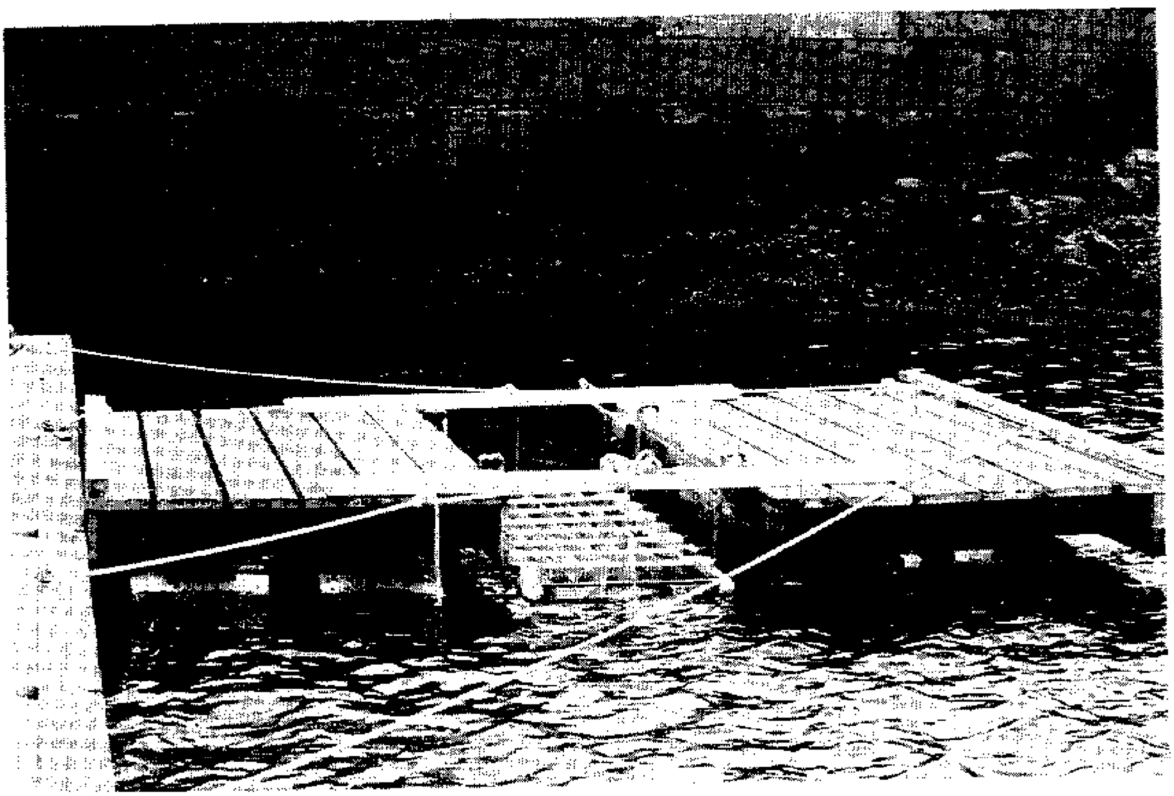
S.P.U.G.S
Self Powered Urchin Growth System

A Feasibility Study of an Independent, In-water Growth Raceway *for Strongylocentrotus droebachiensis* to Enhance Wild Stocks



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Laura Marshall
Seung Suk
Brian Sullivan

Advisor: Dr. Larry Harris

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Abstract

Stock enhancement of the green sea urchin *Strongylocentrotus droebachiensis* has become an area of greatly increased interest due to the currently diminishing wild population, and natural recruitment. While the Japanese have an extensive urchin stock enhancement program, their system is not readily adaptable to use in the Gulf of Maine; in part due to high amounts of labor and resources required. A more cost effective floating raft juvenile grow out system was designed and built using a fiberglass-like material formed into a raceway, to provide a controlled temperature, saline and nutrient filled unit. One of the most important aspects of this design is the ability for it to become independent of land-based power sources, thereby utilizing the limited amount of coastal space found in the northeast.

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Introduction

Sea urchins, members of the Phylum Echinodermata and Class Echinoidea, are common benthic inhabitants of intertidal and subtidal zones throughout the oceans of the world. (Brusca, R.C. and Brusca, G. J. 1990) While regarded as pests by most westerners, excluding the French, the Japanese have long harvested urchins for their roe as a delicacy. (see Fig. 1) Japan remains by far the largest consumer and importer of urchin roe as their local stocks have declined to where the fishery in local waters can not supply the level of demand.(Saito 1992) They have recently adopted techniques such as aquaculture in an attempt to supplement the natural fishery but even this has failed to keep up with demand. (Saito 1992)

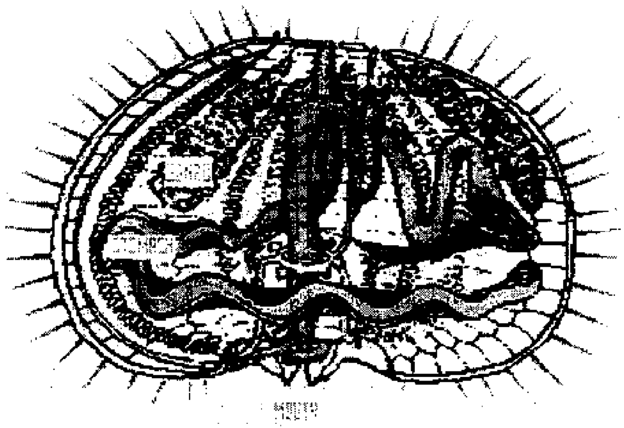

Fig. 1 Sea Urchin Internal Diagram showing the roe or gonad.

During the 1970's, Japanese buyers in search of urchins for their market came to the US Pacific coast along with many other parts of the world such as Chile. On the West Coast of the US, they were able to set up a fishery mainly for the red sea urchin *Strongylocentrotus franciscanus* within a few years and successfully import the roe to Japan. By 1988, the US became the world's largest harvester of urchins mainly from this stock from California waters. (Moody, M., et al 1998) Unregulated and poor harvesting methods led to a decline in these stocks by the late 1980's. Once again, the Japanese buyers went searching for a new supplier of urchins for their market.

This time on the northeast coast of the US and Canada, they found a completely unutilized stock of the green sea urchin *Strongylocentrotus droebachiensis*, a cosmopolitan species already harvested in northern Japan. (Harris, L. 1998) The fishermen in Maine were quick to begin harvesting urchins without regulation to meet this demand. After all, they were considered pests to the lobster fishery and had recently become very abundant in these waters creating barren communities in place of kelp bed communities, a preferred habitat for lobster. Since the late 1960's, increased populations of *S. droebachiensis* had been noted along the eastern coast of Nova Scotia and also in the Gulf of Maine. (Harris, L. et al 1994) The barren areas that resulted from this increase in urchins excluded lobster *Homarus americanus*. (Simoneau, A, et al 1995) There had even been previous discussions on ways to control the populations of urchins via artificial methods. So when the Japanese buyers approached, local fishermen harvesting of urchins began and grew at an exponential rate. Within a few years, the urchin fishery became the second largest fishery in the state of Maine only trailing lobsters. In 1993, harvesting reached a maximum of 43 million pounds in Maine but has declined every year since 1993. (Creaser, T. 1999 pers com) (see Fig. 2)

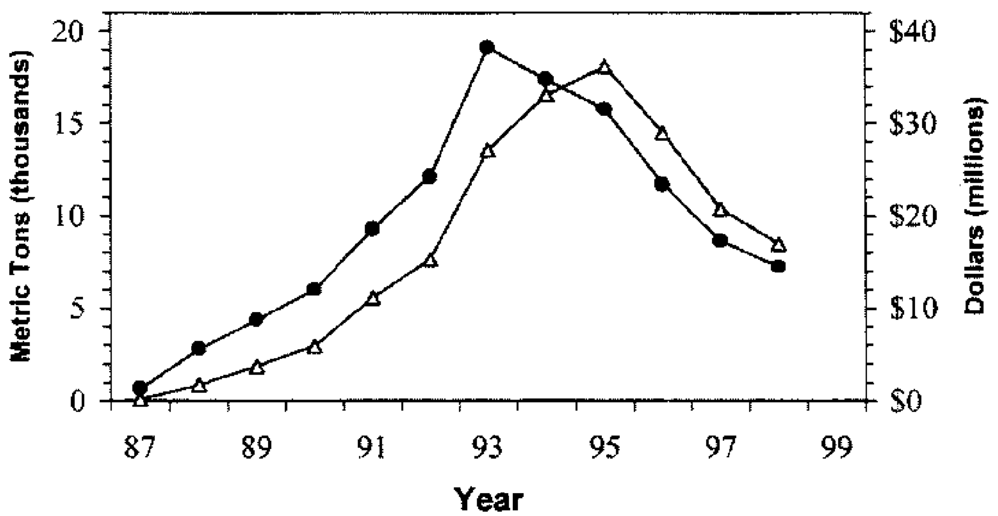

Fig. 2 *S. droebachiensis* harvests and price paid for catch reported to Maine's Dept. of Marine Resources from 1987 through 1999. (courtesy of Ted Creaser)

Similar to the West Coast fishery, poor harvesting techniques and minimal regulations have allowed this Maine fishery to crash. (Williams, C.T. and Harris, L.

1998) Compounding this problem is the fact that recent data on urchin recruitment in the Gulf of Maine shows very little natural recruitment in most areas, and virtually none in the region northeast of Penobscot Bay. (Harris, L. 1998) The decreased population along with a near absence of recruitment of new individuals in many parts of the Gulf of Maine has made a hatchery system for stock enhancement and aquaculture necessary for setting up a sustainable fishery or even maintaining this fishery in the near future. (see Fig. 3) Relying on natural recruitment to catch up and increase the population is a gamble at best. In other recent experiments, it has been shown that areas depleted of urchins and subsequently replaced by algae have very little natural recruitment. (Harris, L. et al 1994) There remains few areas in the Gulf of Maine not dredged or hand picked of urchins which provides little hope for natural recruitment. Our goal was to build a floating raft-based juvenile growout system to produce juveniles at 10mm diameter, at which time they would be ideal for out planting.

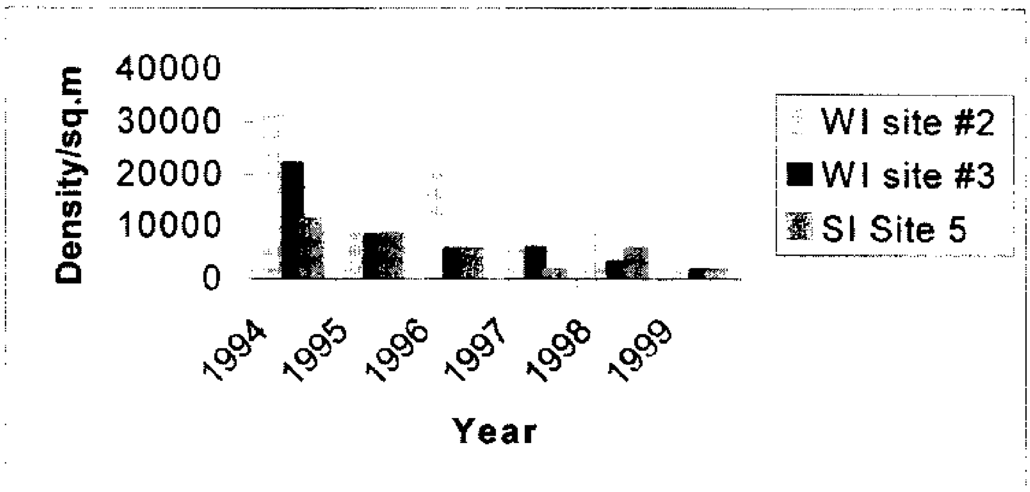

Fig 3. Summary of *S. droebachiensis* recruitment at three stations at the Isles of Shoals from 1994 through 1999. (courtesy of Larry Harris)

Biological and Behavioral Considerations

S. droebachiensis are omnivorous invertebrates that feed on algae and detritus by actively scraping them off of hard surfaces using an apparatus called an Aristotle's lantern located on their ventral surface. (see Fig. 4) Based on earlier experiments, the early juveniles of concern here, feed and grow very nicely on a diet of natural algal film dominated by diatoms, *Navicula sp.*, that cover fiberglass panels left in seawater. The algal film can be supplemented by adding in locally abundant green alga *Ulva lactuca* or brown alga *Laminaria sp.*. We decided on using a fiberglass-like material called Kelwall Sun-Lite HP, manufactured by Keller Industries to make the panels and to also create an easy way to add further nutrients such as *U. lactuca* or commercially available fertilizers to enhance algal growth.

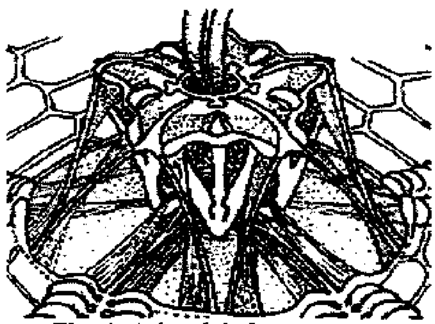

Fig. 4 Aristotle's Lantern

S. droebachiensis prefer vertical surfaces with high water flow and often will actively move in order to find these conditions. Since urchins excrete feces through an anus on their dorsal side it makes sense for them to seek vertical surfaces and high flow areas to prevent a buildup of bacteria that often cause disease. We decided to hang panels vertically in a raceway with a pump providing high velocity flow to provide such conditions. Uninterrupted flow was also desired at the bottom of the raceway to flush waste material out of the tube.

S. droebachiensis has an internal cavity filled with 5 gonads. This roe enlarges during the reproductive season, a time period immediately prior to spawning. In the northwest Atlantic this bulking period lasts from late fall to early spring followed by spawning in late winter or early spring. Since maximizing roe content is desirable, some have suggested selectively limiting the populations to increase food availability for each individual thus maximizing roe content. This is pointless now that urchin stocks have been reduced to such a low level that most urchins in the wild are not limited by food availability.

In out planting juvenile urchins, the Japanese in their semi-wild urchin fishery grow them to 20mm in diameter before out planting. Based on earlier survival experiments on out planting of juveniles of *S. droebachiensis,* we have decided to develop a system raising urchins up to 10mm rather than the standard 20mm which would require more resources and a longer time period. Previous experiments have shown up to 90% survivability rates for 10mm urchins out planted in the winter or early spring. Survivability was far less for these when outplanted during warmer months due to predation. Thus, more juvenile urchins can be grown with the same amount of resources and since this period is not in conflict with natural recruitment periods (e.g. late spring and summer), competition among juvenile urchins is also limited.

Juvenile *S. droebachiensis* grown on a diet of diatom films have been shown to be comparable to those grown in the wild habitat. Once they exceed 10mm in size, growth on this diet is slowed vs. growth on a diet of fleshy algae. This was one of the big reasons why we decided to design our system to accommodate urchins up to 10mm. Utilizing naturally growing algal films for food virtually eliminates food costs and urchins fed on this diet have been shown to have roe in excellent quality in field experiments.

Objectives

The objective of this S.P.U.G.S project was to build a floating raceway system, to be tied up at the Coastal Marine Lab in New Castle. NH. The purpose of the system was to grow juvenile green sea urchins for approximately one year before releasing them to the environment as a means of stock enhancement. This system would allow the urchins to grow to a size large enough to significantly increase their survival rate in the wild.

The system shall have a laminar flow of filtered ocean water through it and will need to be occasionally cleaned out. The urchins will attach themselves to panels suspended in the raceways. The raceway is 10" long, 2" wide, and 1.5" deep. The majority of the system will be constructed with a material that allows natural sunlight to pass through. This light will help foster the diatom film growth needed as a food source for the urchins. Throughout the project, the feasibility of a large scale commercial urchin growth system will be studied, and the results of the project used to help determine future possibilities in this area.

Site location

During manufacture of the basic raceway trough by Keller Inc., S.P.U.G.S. constructed a prototype raceway design in the Jerry Chase Ocean Engineering Laboratory at the University of New Hampshire. This site was used for construction of the prototype and modifications of the manufactured raceway from Keller for several reasons. The first and foremost was for the large space and supply of tools available. The material used for the raceways and panels is delivered in large rolls, which are unwieldy in any thing but a location with a large floor space. The second reason for construction at the laboratory was the central location it provided for easy access for not only the S.P.U.G.S. team but also the advisers and peers that we collaborated with on this project. The laboratory also contains a 60' x 40' test tank that allowed S.P.U.G.S. to conduct the original flotation tests. Once construction was completed the system was transported to the NH Fish and Game docks at the US Coast Guard station in Newcastle NH. (see Fig. 8) This site was selected because of its protected area, availability of shore power from the Coast Guard boathouse, and the close proximity of the UNH Coastal Marine Laboratory where the urchins were being held and cultured. This site also offers a beach landing site that was necessary to launch the floating docks that would form the platform for the raceway. The final attribute of the site is the water flow through the area. The water enters from the far side of the Coast Guard boathouse, and travels in a counter-clockwise gyre through the bay area. This constant flow provides suitable water for urchin growth. The only drawback to the area is the accessibility of the Fish and Game docks on which the platform was attached. Since the docks are traveling with the tidal range, and the boathouse is a fixed pier, there were times when equipment would have to be lowered over twenty feet to the platform.

Design

Prototype Raceway Construction

When we ordered the raceway that was to be manufactured by Keller Inc., we became aware of the development time it would take before it was delivered. This time span was greater than expected, so to fill the time S.P.U.G.S. elected to construct a prototype raceway to become intimately aware of the construction limitations. S.P.U.G.S. designed and built a raceway that was 15" longer and 7" shorter in width than the ordered raceway. This raceway was constructed of the same material, sun-lite HP, and connected in the same manner, with marine epoxy. The main difference between the two raceways was the bracing system to hold the upper side of the raceway apart. Keller Inc. elected to attach bracings along the underside and sides of the raceway, evenly spaced along the length. S.P.U.G.S. chose to attach brass rods spanning the top of the raceway. Both systems have their advantages and disadvantages. The Keller Inc. raceway provided unobstructed access to the interior of the raceway, while the alternative design did not. This design by S.P.U.G.S. provided a platform to support the panels from the interior of the raceway; as well as the ability to vary the raceway width at 5 intervals along the length. The Keller Inc. design required additional modifications to support the panel system. The S.P.U.G.S. design did not incorporate a drain plug for the removal of debris and organic buildup along the bottom of the raceway, an observation that was passed on to Keller Inc., for.their final modifications. The bracing system in the Keller Inc. design proved to be more stable in and out of the water, an important consideration due to the unpredictability of an open water system.

Raceway

For diagrams of raceway and it's components, see figures 5, 6, and 7 contained in the appendix.

For the area to house the juvenile urchins, a raceway was chosen for its lightweight and relative ease of manufacturing. We decided on many characteristics desired for our actual raceway and worked directly with an engineer from Keller Industries on designing the actual tube to be manufactured by Keller. A transparent material was desired to promote the high levels algal growth by letting in lots of light both directly and through backscatter. The actual measurements and dimensions are as follows: Approximately half a cylindrical tube with cones on both ends, tube length of 96' from base of cones and 120' from tip of cones, tube width and cone diameter of 18', cone ends have a 2.5' female PVC fitting, top of tube with opening has a 3' lip, one drain plug bottom of tube near the input. (see Fig. 7) This entire tube would have 5 support bracings placed 24' apart starting at the end of cones and the entire tube would be constructed of ¼' fiberglass-like Kalwall Sun-Lite HP material. The lip all around the top of the tube was meant as a way to attach it to the dock floatations. The drain plug was designed for ease in cleaning. The screw fittings would allow easy attachment of readily available pumps.

Raceway Flotation

The means of supporting the raceway within the water column had two distinct aspects. The first was the construction of a platform for the raceway with two 9' x 4' floating marina docks donated by Brewer's Boat Basin of Jamestown RI These were cut out of a 40' foot original platform, so even flotation along the docks was a problem with the smaller pieces. To counteract this, the high side of each dock was connected to the low side of the other by means of a 2" x 10" x7' pine board, with 4" lag bolts.(see Fig. 6) This connection served several purposes, including stabilization of the platform for topside work, a properly sized channel for the raceway between the docks, and a walkway between the two docks for equal access from both sides of the raceway. Mounted upon these walkways, two 8" open hole, galvanized steel cleats were attached through the walkways and secured into the dock below for securing the platform to the NH Fish and Game floating pier.

To keep the raceway within the channel created between the two docks, a support system was devised that would allow the raceway to float independently of the platform, to minimize movement of the raceway relative to the movement of the platform. Four ½" diameter x 2' length galvanized steel pipes were hung downward from the platform on the sides of the channel. They were attached to the platform by means of two corner elbows and two 2" long couplings of ½" diameter steel pipe to form a U-shaped connection that was then attached to the top of the platform with a 3" round steel flange. (see Fig. 6) The lower side of the 2' steel pipes in the water were also fitted with a 3" round steel flange to prevent the raceway from slipping off the bottom of the supports.(see Fig. 6)

The modifications to the raceway to contain it within the channel consisted of four 2" plate rings on the sides of the raceway, 36" from the ends of the cones attached to 2" x 4" pine wood spacers, bolted to the wall of the raceway. These rings were threaded through the supporting pipes hanging from the platform, to allow movement along two axes. The raceway could travel in the vertical direction along the 2' of the pipe, and the horizontal direction approximately 6" by the rotation of the U-shaped coupling on the top side of the platform.(see Fig. 6) This movement allowed the platform to move with the normal water disturbance, as well as movements induced by researchers on the platform, without affecting the raceway's situation in the water.

The second aspect of flotation for the raceway was to keep the raceway itself positively buoyant, since it is independent of the platform. To accomplish this proved more difficult than expected. It is necessary to have the lip of the raceway sufficiently above the water to prevent surface waves to splash into the raceway, because this would introduce unfiltered water to the organisms. Our first attempt was to attach four 4" diameter x 13" long marine fenders at the four corners of the raceway, underneath the lip.(see Fig. 6) However, this proved to be inadequate to hold the lip above the water level. Next four 8" diameter x 20" long fenders were attached to the bottom of the raceway in pairs at either end, along the centerline of the raceway. This supplied adequate flotation to keep the lip above the surface, but surface waves during a weekend storm were still able to breach the lip. The final flotation added was standard marine Styrofoam used in dock flotation, cut to 18" long x 3" wide x 16" deep, and attached to the lip of the raceway, 8" from the center of the raceway toward the intake end. This placement was necessary due to the weight of the baffle system. This final flotation allowed the raceway to sit properly out of the reach of the waves, and to achieve the goal of independent flotation between the raceway and the platform.

Pump / Flow Rate

The first step in finding a suitable pump was to determine the flow rate. In the beginning of the project, there was little knowledge as to the required flow rate, besides the fact that *S. droebachiensis* prefer higher velocities and demonstrate this by migrating to those areas. The greater the flow provided, the healthier the *S. droebachiensis* will be and the faster they will grow, both of which are extremely beneficial to the goal of this system. (Brusca & Brusca, 1990) (Simoneau et. al., 1995) All flow rates were based on an estimated tube volume of 150 gallons.

The first flow rate was arrived at by deciding to replace the water in the raceway every five minutes. In other words, pump 150 gallons through the raceway every five minutes. This is equal to a pumping rate of 30 gal/min. This value seemed a little high. After taking into consideration other aspects such as cost and feasibility of powering a pump to handle 30 gal/min, as well as pumps readily available to us, it was decided to research the flow rate further.

After looking at pump rates at the UNH Coastal Marine Lab, The New England Aquarium, and the Shoals Marine Lab, replacing the water every hour seemed to be a reasonable value. This produced a pump rate of 2.5 gal/min. This seemed to be a more reasonable and feasible value.

The flow rate of a similar study done at UNH on juvenile sea cucumbers in 1999 was also considered. The water in this system was replaced every four hours. For our raceway, this would require a flow rate of .625 gal/min.

After considering all these values, a pump rate of 5 gal/min was chosen as a target rate for the pump. This was mainly based on the idea of replacing the water every hour. This value was increased to take into account any unforeseen circumstances that could reduce flow into the raceway such as the addition of a second raceway or unconsidered things such as certain head losses or the higher density of seawater. This seemed a reasonable value that was feasible. Increasing the value to 5 gal/min could only help the system by providing *S. droebachiensis* with the higher current that they prefer compared to 2.5 gal/min.

Originally a submersible pump was going to be used to provide this flow. The submersible pump was considered optimal to reduce head created by pumping the water from the ocean, up to a pump that would have to be mounted on the dock, and then back down to the raceway. By using a submersible pump the water could be pumped straight from the filter reservoir (which is in the water) into the raceway, without having to overcome a head. However, as various pumps were considered it became apparent that it would be much easier to find a non submersible pump that would meet our needs. This was especially a consideration since DC pumps were being considered so the system could be run off alternate power sources. Since the static lift of a dock mounted non-submersible pump is still relatively zero, and the suction lift is a maximum of 3 feet, it was decided that the original concerns that would be dealt with were minor.

There were several used pumps available to the S.P.U.G.S group and it was decided to test these before ordering a pump specifically for the system. The pumps were all within the desired flow range and were run off of various power sources including hard wire AC and a DC battery. This way any unconsidered pumping considerations could be observed and the way the system responded to various pumps could be used to find the optimal pump characteristics for the system.

Due to technical problems, the testing of these pumps was never completed. However, a potential pump had been decided upon. Available from Cole and Parmer, pump P-07142-02 pumps 5 gal/min at zero head. It is a small AC powered pump that costs $150. The pump can also be submerged which is a plus since exposure to weather elements will not need to be a concern. It is still suggesting that preliminary testing be completed before the pump is ordered. Also DC pumps should also be considered to allow for ease of alternate power source use.

Filter

The filter system was designed to fulfill several criteria. The most obvious purpose was to keep unwanted objects in the water out of the raceway. Ultimately the only things desired in the raceway are *S. Droebachiensis*, seawater, and diatoms as a food source. It is also important to eliminate other objects and larger particles because of the pump and tubing. Most pumps do not handle solids well and this can cause major problems. The better something is filtered the less likely there will be problems such as clogging and breakdown. While there are benefits to filtering out even smaller objects. the cost of maintenance dictates that this cannot easily be done. Smaller filter mesh is more easily clogged increasing the cost of maintenance.

The theory that simple is better was employed in the design of the filter system. The main component of the filter was an inverted flexible plastic barrel. The major advantage of this system is that the solid walls of the barrel keep the majority of the larger objects that would have to be dealt with out of the filter system. All floating objects including seaweed, styrofoam, leaves, branches, boards, etc simply float by the trash can and don't have to be filtered out by the filter screen. As a result of this system, all water is brought into the filter from several feet below the surface, through the top of the trash can. Having a subsurface intake is also an advantage because the quality of the water is much better even at this small distance below the surface. By using water at least two feet below the surface a more constant temperature and water mixing is obtained. Any floating pollutants from nearby boat traffic or other means are avoided. Most floating algae will not extend down to this depth, so they will not be sucked into the filter and clog it.

The filter was built by obtaining a plastic barrel with a tightly fitting cover. The inner area of the cover was cut out, and a piece of screen, acting as a filter, was then placed over the open barrel and then the cover put in place. In the S.P.U.G.S. project we used a piece of window screen, as this provided a good size for the filter holes. The screen was secured with a rope tied around the barrel and screen to hold it in place. Holes were drilled through the sides of the cover into the lip of the barrel to allow zip ties to secure the top to the barrel. A hole was cut in the side of the barrel to allow the pump intake through. The intake tube sucks water from inside the filter up into the pump that is mounted on the dock. The filter was nailed to the dock to secure it. When the screen needs to be changed the barrel can be rotated up to normal orientation to allow for easy changing. This method also allows for easy experimentation of different size mesh.

Future renovations to the filter system could include obtaining several container covers and permanently securing screen to each of them. This way when the filter needs to be changed due to clogging and organismal growth, one top can be removed and anther put in place. The used filter can be placed in the sun and after drying can then be brushed off or scrubbed to remove debris, so that it may be reused on a rotating basis.

Baffle System

One of the original design criteria of the S.P.U.G.S. project was to have a laminar flow throughout the system. This flow was desired to provide a smooth, undisturbed flow through the raceway. This provides the *S. droebachiensis* with a constant velocity as well as a constant flow of nutrients and oxygen. The lack of vortices and stagnant flow areas helps to insure a proper constant mixing and turnaround of water in the system. This is important not only for the constant flow of nutrients and oxygen, but to flush out the wastes produced by *S. droebachiensis* as well. A system of baffles was designed to help produce this streamlined flow. Room was left to place the baffles near the inflow, directly after where the water comes through the cone at the beginning of the tube.

The baffle system was composed of half-inch diameter PVC pipes approximately 7.5 inches long. (see Fig. 5) The pipes were bound together to produce a baffle system approximately one foot in diameter. To increase the area of the baffle system to incorporate more of the incoming water through the cone of the raceway, ¾ inch pipe was then added to the existing one-foot diameter system. Adding the larger pipe on the outside not only helped to increase the area of the baffles but helped to channel water towards the outside. The input opening is only 2.5" wide. Therefore the water is flowing mainly in the center of the cone. The larger diameter pipe presents less resistance than the smaller diameter pipe. This increases the flow through the outside pipes, therefore distributing the flow outward. The baffles were supported by two sheets (each two ply and epoxyed together for strength) of the Sun-Light HB plastic/fiberglass material provided by Keller Industries. The sheets were in the shape of the raceway and an opening was cut through each sheet to insert the baffles. The baffles then rested in the sheets, which channeled the water to go through the baffles wetting up a laminar flow.

The sheets created a reservoir of water before the baffles, therefore ensuring that all water pass through the baffles before entering the main part of the raceway.

For future modifications a lighter baffle system is suggested. The current baffle system was quite heavy and weighed down the input side of the raceway. This could be viewed as an advantage in that it caused the side of the tube most susceptible to wave action to float higher in the water. This prevented waves from breaking over the top of the raceway, which contaminates the system with unfiltered water and causes turbulence. However, the baffles caused the raceway to sit unevenly in the water and become less stable. It caused rubbing against the pipes and platform, which not only causes unnecessary wear but hindered the raceway's movement designed to be independent of the platform.

It is also suggested that the system be test run without the baffles. The panels naturally form a baffle like system by channeling the water through the raceway in straight segments. Due to this effect, a separately designed baffle system may not be necessary.

Panels

The developed panel system was one of the more successful aspects of the project. One of the design considerations was a panel system that was easily removed for work with the *S. droebachiensis*, transport and cleaning of the raceway and panels, as well as easy assembly and disassembly. It was important that diatom film could grow on the panels and *S. droebachiensis* could attach themselves to them. The panels needed to go with the flow of the water without causing serious drag forces or inhibiting the laminar flow design. Sufficient panels needed to be provided for sufficient surface area for the desired number of *S. droebachiensis*. However, enough room needed to be left between panels for ease of work with the *S. droebachiensis* attached to them or to reach down to the bottom of the tube for any given reason. The panels also needed to be sturdy enough so that they would stay stable within the system. If the panels moved around within the raceway this would be undesirable as they would interrupt the flow and could possibly knock against each other disturbing the *S. droebachiensis*.

The length of the panels needed to allow the *S. droebachiensis* that were originally placed or fell in the bottom of the raceway to reorient themselves onto the vertical panels. However it was also desirable that panels did not extend to the bottom center of the tube where *S. droebachiensis* waste and any other debris is likely to collect. It would be preferable to have this area open to improve water flow to flush out the waste and so as not to place the urchins in an area of higher concentrated waste which is unhealthy and can lead to disease.

The curved shape of the bottom half of the raceway aided in obtaining this goal. Panel lengths were developed so that the two end panels, which were near the side of the tube, touched the bottom or side of the tube. This way any *S. droebachiensis* on the bottom can climb up and attach themselves to these panels. The inner panels were designed not to touch the bottom to allow this area to stay open.

Four sets of panels were placed in the tube. This number kept the panels small enough that they were easy to deal with, yet still were convenient in that there was not a large number of panels to be dealt with. Each set was composed of six panels, running parallel to each other as well as parallel to the direction of water flow. Each individual panel was made of two pieces of sun-light HB material provided by Keller Industries. This material allowed light to pass through, which is beneficial in providing the *S. droebachiensis* with plenty of natural light. Two pieces were epoxyed together to form each panel since this increased the sturdiness of the panels. Since the material used also seemed to have a natural curvature to it, opposite curvatures were glued together and this produced the necessary straight panels.

Each set of six panels was connected by a pair of dowels placed through holes in the top of the panels. The dual dowel system prevented rotating, as a single dowel would not have. This dowel method kept the panels sturdy both in and out of the water, as well as provided a convenient way to grab onto the panels for transport and placement into and out of the raceway. Small pieces of PVC pipe were slid over the dowels between panels to keep them separated and from banging together. After all panels and spacing PVC was on the dowel pair, stoppers were epoxyed onto the end of the dowels to help keep them in the holding system.

The panels were secured in the raceway by attaching wood blocks and latches to the lip of the raceway where the dowels holding the panels were. The dowels were laid between the wood blocks and the latch was closed, locking the dowel and subsequently the panels in place.

This system allowed easy installation and movement of the panels while providing an optimal place for *S. droebachiensis* to grow. Flow was not disturbed and may have even been improved by producing a channeling effect on the water.

Future Feasibility

One of the main goals of this project was to make recommendations for future feasibility of urchin aquaculture, specifically in terms of a large scale raceway system. The ability to apply this system to a large scale operation was a major concern throughout the design and construction. There are two main ways to build such an operation, the first is a modular system, such as we designed. This permits coupling of the raceways in a series along one main platform, or the addition of smaller platforms each containing a raceway. The fact that the water flowing through the tank is filtered and pumped into the raceway is the key to upscale. It is not necessary to separate the raceways to allow each to get fresh water, since the wastewater output can be controlled. Raceways lined up end to end, each feeding off a common water intake, and separate water outputs, allows a uniform water quality to be maintained. Flexible vinyl tubing was utilized to permit flexibility in the placement of the raceways, to conserve valuable dock space. This modular system prevents any occurrence of disease from spreading from one raceway to another, barring contamination of the main water intake. Separate water intakes for each raceway could be utilized, but it is not cost effective. Since *S. droebachiensis* is a cold-water organism, the surface waters may become too warm for proper growth in the late summer months. Also, in coastal regions, it is possible to have a freshwater influx from spring water runoff. Due to these factors, it is advisable to have the water source from an input below the thermocline, where the water is not only cooler and of constant salinity, but is usually higher in nutrient content. These attributes provide sufficient argument for having the intake in deeper water, so to have each raceway on its own separate intake hose would require many pipes to be run deep. Each raceway would also need to have its own pump, again raising the cost. The possibility of a disease being brought in from a common intake pipe is quite low, so it is our recommendation that a common source be used.

The second way to upscale the system would be to build long raceways, containing many sets of panels. This system introduces many problems however. When the raceways grow in size, proper water flow becomes a problem. To maintain a laminar flow throughout the system, additional baffle systems may be required to redirect the current in the raceway. Larger pumps need to be employed to move the water, and water quality will decline as you move farther from the raceway intake, affecting the urchins located at the far end of the raceway. The long design also raises questions concerning resistance and drag due to the disruption by the panels, as well as the multiple sets of baffles necessary. The effect of drag within the raceway may also require the use of additional pumps to supply the necessary water flow. The most troubling aspect however is the possibility of disease, as well as a mechanical failure in the water system. If a problem occurs within one of the long tubes, many more urchins would be lost, severely impacting the revenues of a commercial operation. For these reasons, a modular system is the most advisable alternative.

To upgrade the system in such a way requires ease of assembly for the system. The most time consuming part of upgrading a system would be to obtain proper flotation for the raceways, since the system would be supplied with the panels already constructed. The manufacturer of the raceways and S.P.U.G.S. have devised a possible way of obtaining positive buoyancy for the raceway upon delivery. If the tube was constructed with a double-wall design along the sides approximately 5" below the lip, an injected foam could provide the necessary flotation for the raceway and its components. This design would allow not only a quick turnaround time for delivery to operational status, but would eliminate many of the possible failures associated with an external flotation system. The ocean is a harsh environment for man-made structures, and eliminating as many exterior and moving parts from the raceway would be beneficial in a long term, commercial setting.

To fully realize the potential of this design requires that an alternative power source be utilized for operation of the pumping systems as this design is optimized for isolated coastal areas. Aspects that we researched included, wind and solar generators as well as propane fueled generators. For true self-sustainability, the propane option can be relegated to a back-up system only, leaving the solar and wind systems as the top contenders. The determination of which system is most effective depends upon the location of the operation. In the northern latitudes where *S. droebachiensis* is found, the usable photoperiod is often reduced to four hours or less. This restriction on time period leaves two options. One is the incorporation of large surface area of the photovoltaic cells, a potentially expensive and bulky system. With the restriction of space that is found upon such a raft system, large areas for photovoltaic cells can be a hindrance. The benefit of the solar system however is the low maintenance and quiet operation. The wind-powered system is potentially very useful. as there is almost always a constant breeze in the coastal regions of the Gulf of Maine where these operations would be implemented. Wind power is not perfect however, as the spinning blades not only pose safety hazards, but demand more maintenance than the solar cells in a marine environment due to the corrosiveness of the seawater, and the moving parts contained within the turbines. The wind system can also be loud and unstable in high winds, and since *S. droebachiensis* spawns in the later part of the winter, there is the possibility of large winter and fall storms that would render the turbines useless. The best possible system for an operation is most likely a hybrid system containing all three power systems. The solar panels provide power in the spring to early summer months, supplemented by the wind turbines during the dark or cloudy periods. In the case of an extended storm which could render both the turbines of the wind system, and the photovoltaic cells of the solar system ineffective, the propane backup could run the pumps through the storm. Set up in this way, a commercial operation could be virtually self-sustaining, independent of land-based power sources.

Research Expansion

There are many aspects of this project which can lead to research areas of great interest. The most pressing question in terms of successful urchin aquaculture is how well the organisms raised in captivity compare to the wild organisms of equal maturity. Such a comparative study is necessary to determine the feasibility of an aquaculture project. Roe weight, color and taste need to be analyzed from a public market standpoint, and the weight, viability and mortality rate need to be analyzed from a scientific background. These two comparative studies would supply much needed information as to both the possibility and profitability of such a system. Comparative studies also need to be done to determine the necessity of a baffle system within the raceway; in terms of roe weight and color, as well as mortality and disease rates during the first year of benthic life.(0.5mm to 10+mm).

Further studies that need to be conducted before such a system is presented to the public is the effect of a natural versus artificial diet. The urchin size that is being dealt within the system we devised (<10mm) cannot sustain itself on macroalgae. It must be fed by means of diatoms and other organic matter that settles upon the panels. In a full-scale system, where urchin density is necessary to maximize, the naturally occurring food supply may not be adequate to support a commercially feasible population, even with the transparent materials used to promote organic growth on the panels. If this is the case, artificial nutrients must be added to supplement the organisms. A study focusing upon the different advantages between feeds should be conducted, incorporating the effects of using sub-surface, or an upper-level water source.

The final experiment which should be conducted pertains to the necessary flow rate to support an urchin population. Most of the research that has been conducted so far in non-finfish aquaculture has been done on filter-feeding organisms.(Stephen C. et al 1998) Such studies do not provide accurate information as to the necessary refresh rate of water in an urchin system. Nutrient levels, salinity and temperature all affect urchin viability. These factors need to be quantified before a full-scale operation is successfully conducted.

Budget

For this project we were granted an allowable budget of $2,000 from the Nation Sea grant Fund. Of this money, $1790.28 was spent on the project. The breakdown is as follows:

Manufactured Raceway: $1100.00

Construction of Prototype: $140.00

Modifications to Raceways: $360.28

Labor (transportation of docks): $95.00

Presentation Materials and Services: $95.00

Total Project Cost: $1790.28

Conclusion

In conclusion, we feel that this system consisting of one raceway, as well as an upscaled larger commercial system is feasible and has potential for the future. However, more modifications, tests, improvements, studies, etc. need to be done to run the system optimally.

The basic form of the raceway with suspended panels is successful, and could be used in an upscaled system, preferable of modular form. Laminar flow considerations through baffles or other means needs to be further developed. Pump and flow considerations need to be further tested and biological tests of growth and health *of S. droebachiensis* need to be done to determine optimal conditions. The filtering system could also be modified. It is suggested that in the future, raceways be made to order containing the necessary floatation components. The buoyancy components can be analyzed to determine the correct amount of floatation necessary to float the top of the raceway at the desired height above the surface. This would simplify the system, save space, and result in easier upscaling to a larger modular system. With further work, the system could be made totally independent of shore by using alternate power sources, or passive flow through the system where a current is present.

The economic market for *S. droebachiensis* in Japan is strong and should remain this way. This provides a constant and reliable demand, especially if a reliable source of premium *S. droebachiensis* were developed here on the East Coast. There is currently support for this type of system in some areas in Maine, however more needs to be developed for this cultivating to take off into a large scale market. It is important to note that this is not aquaculture, in that the organisms are not being directly harvested. It is simply a means of stock enhancement to a declining population as a result of over fishing. This over fishing was a result of the strong market demand. The organisms are released to the environment and grow and reproduce for at least a year, increasing natural stock, before reaching legal harvest size.

In conclusion, we feel that fostering juvenile growth of *S. droebachiensis* using a floating raceway system has potential. With the current rate of fishing and urchin populations, this may inevitably become at least an integral part of the *S. droebachiensis* fishery in Maine and possibly other areas the northern East Coast.

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Appendix

Top View of Raceway

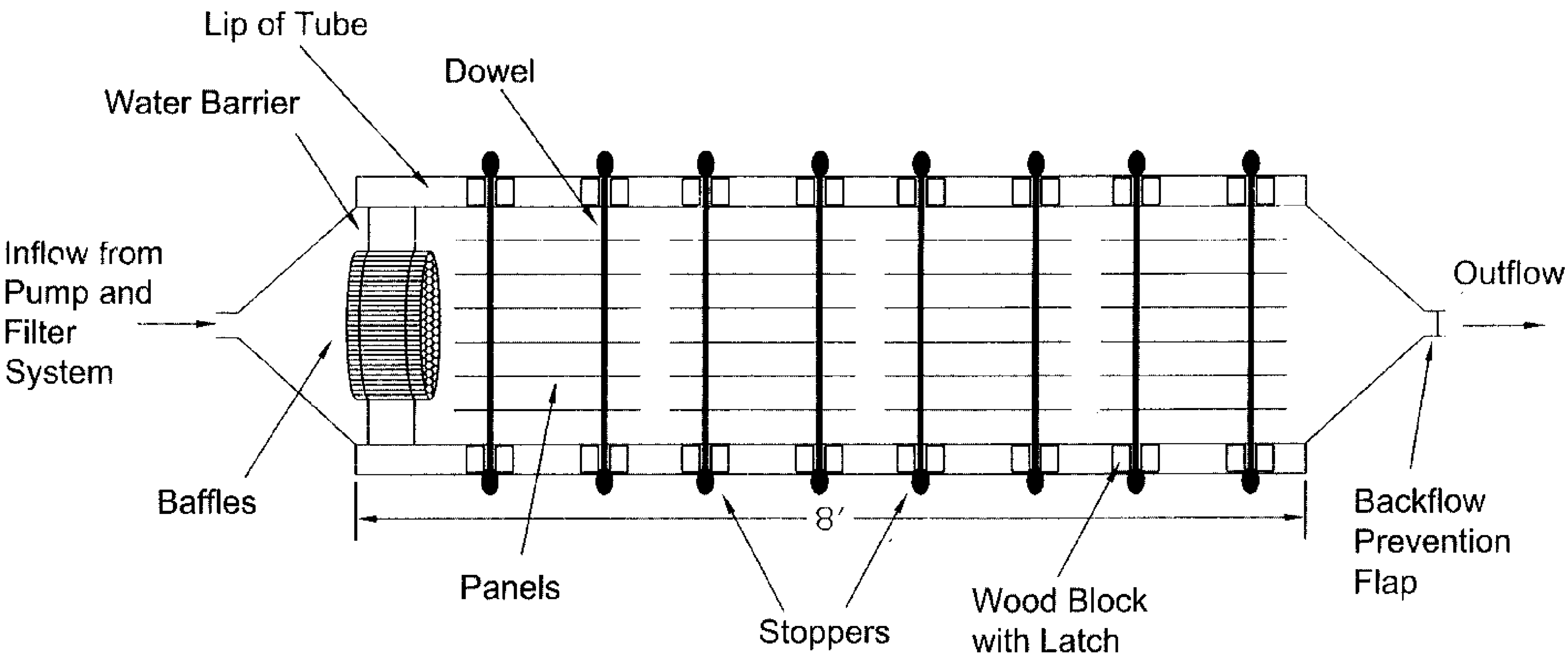


Fig. 5

End View of Raceway

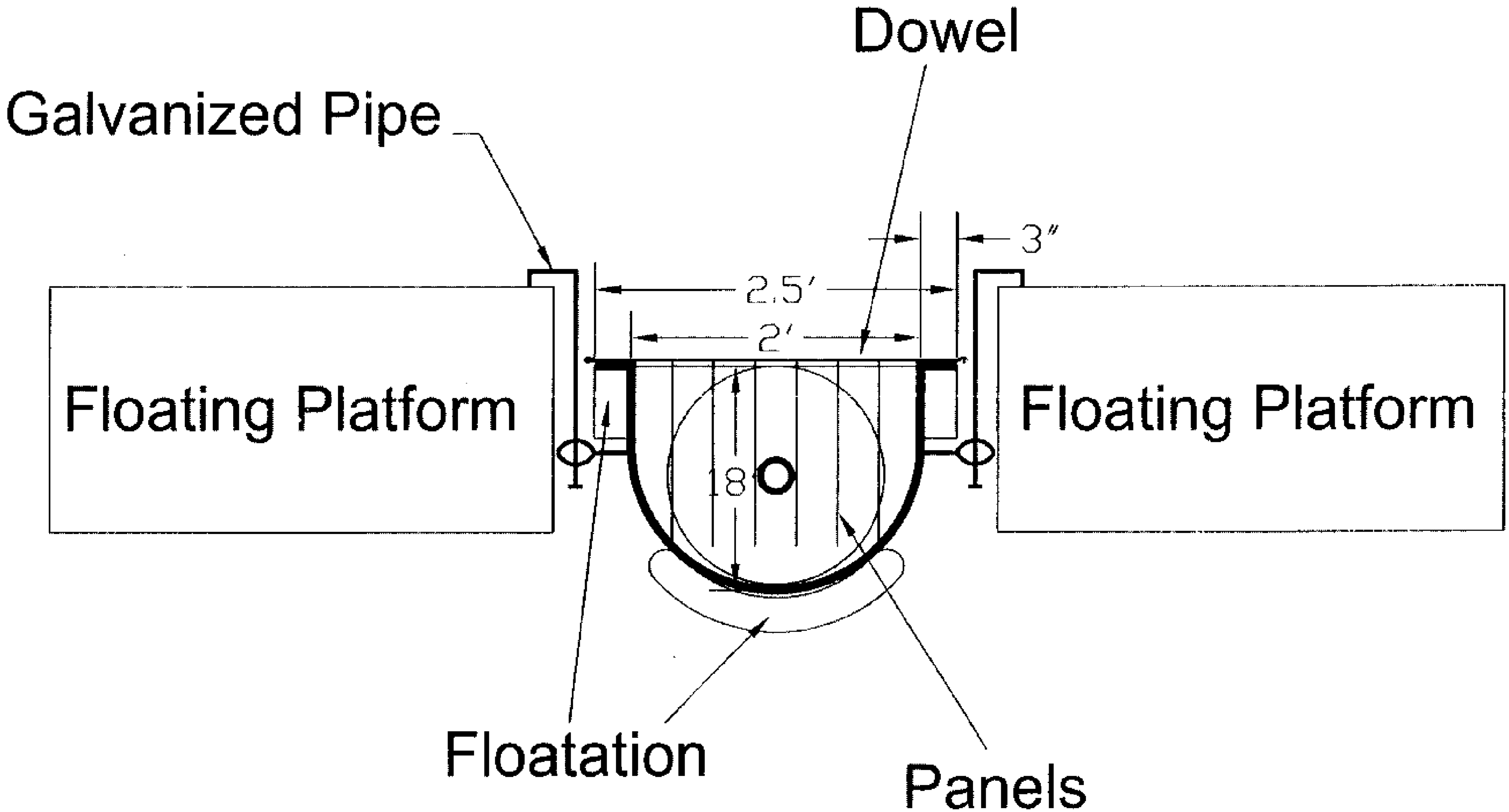
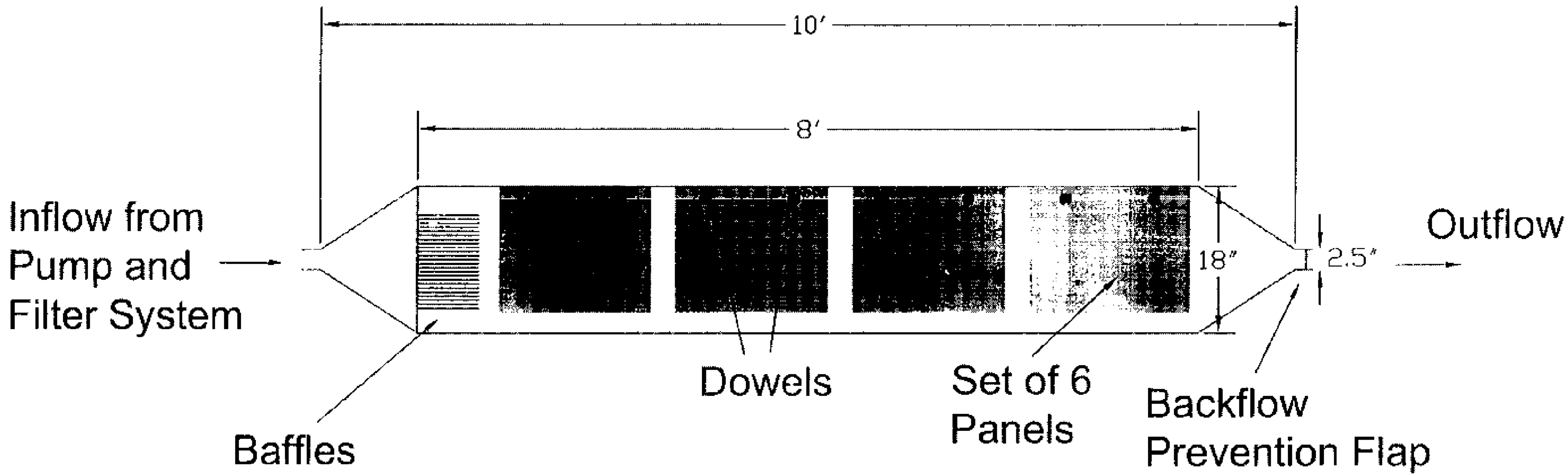


Fig. 6

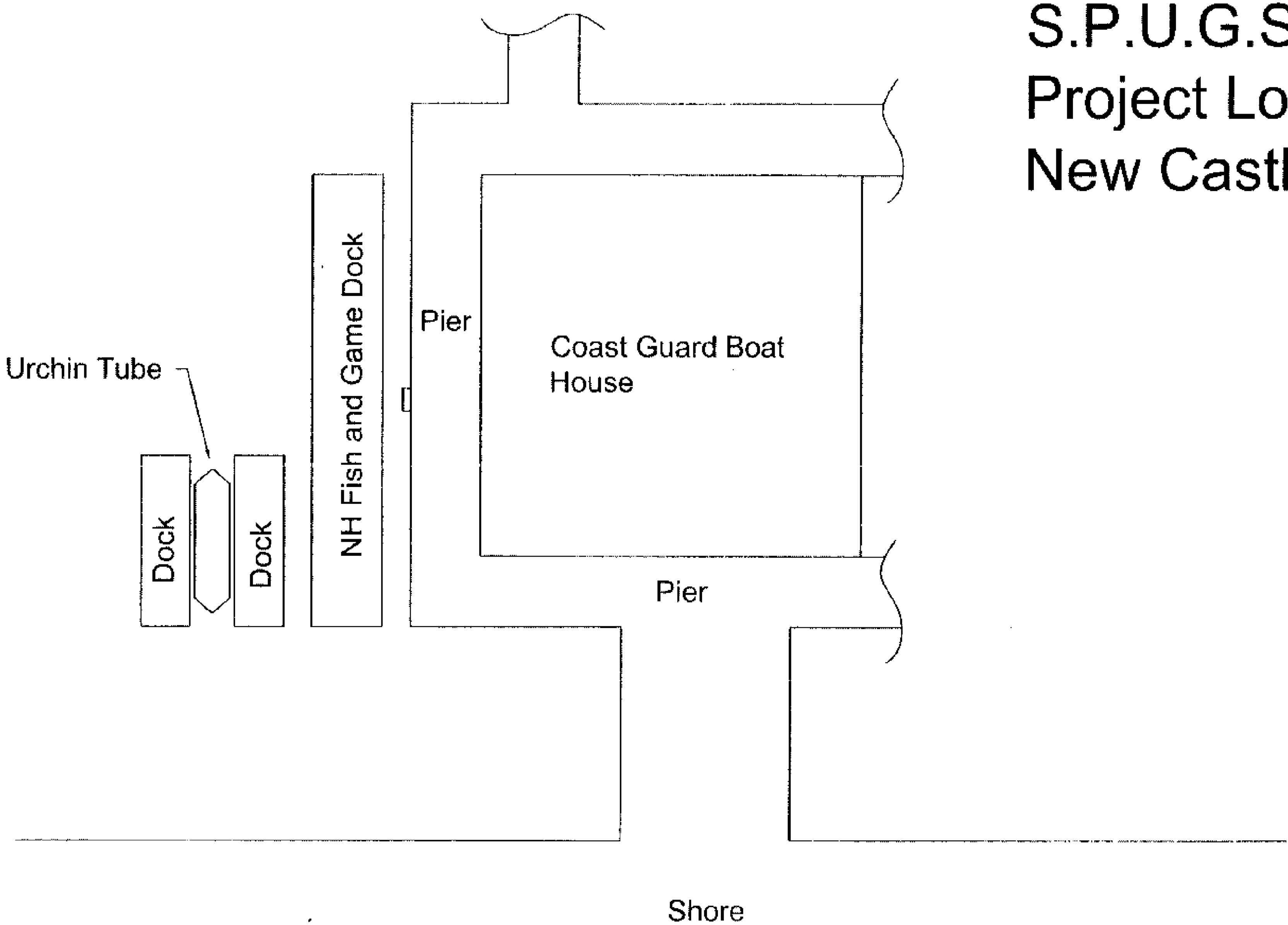
Sideview of Raceway

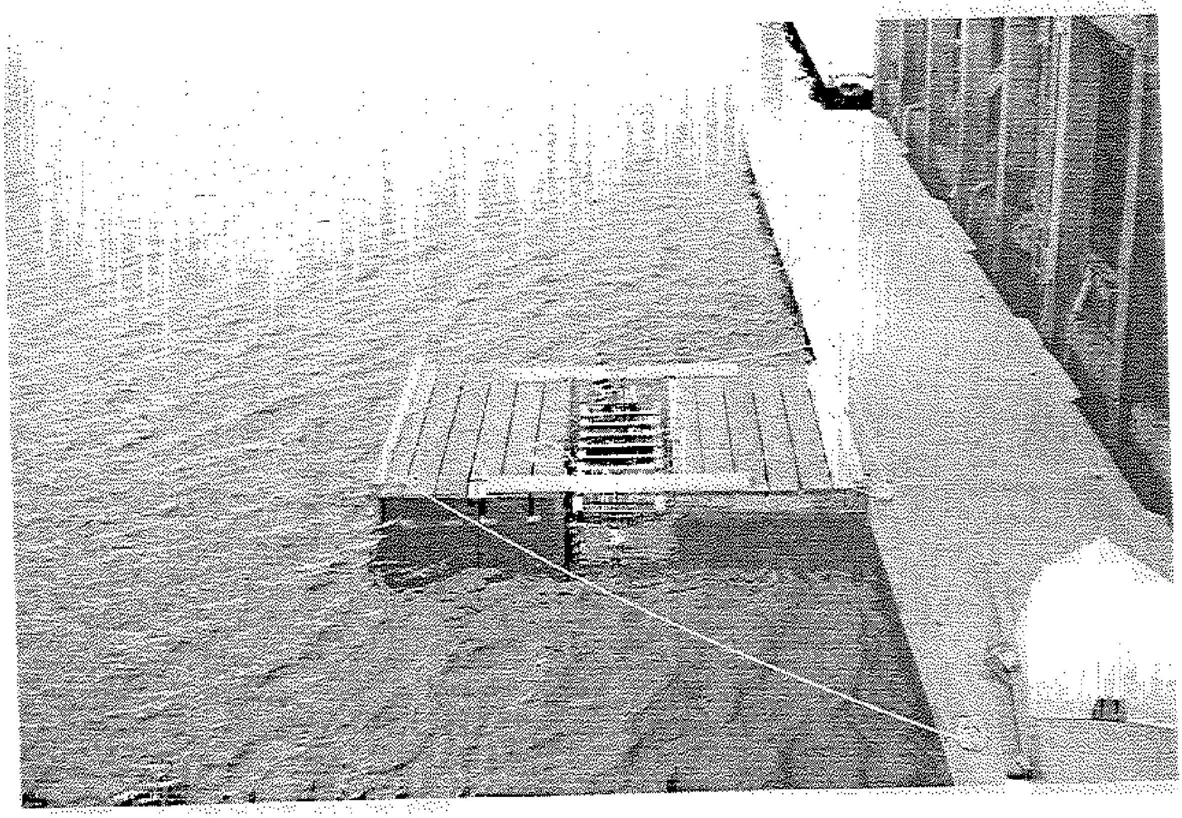


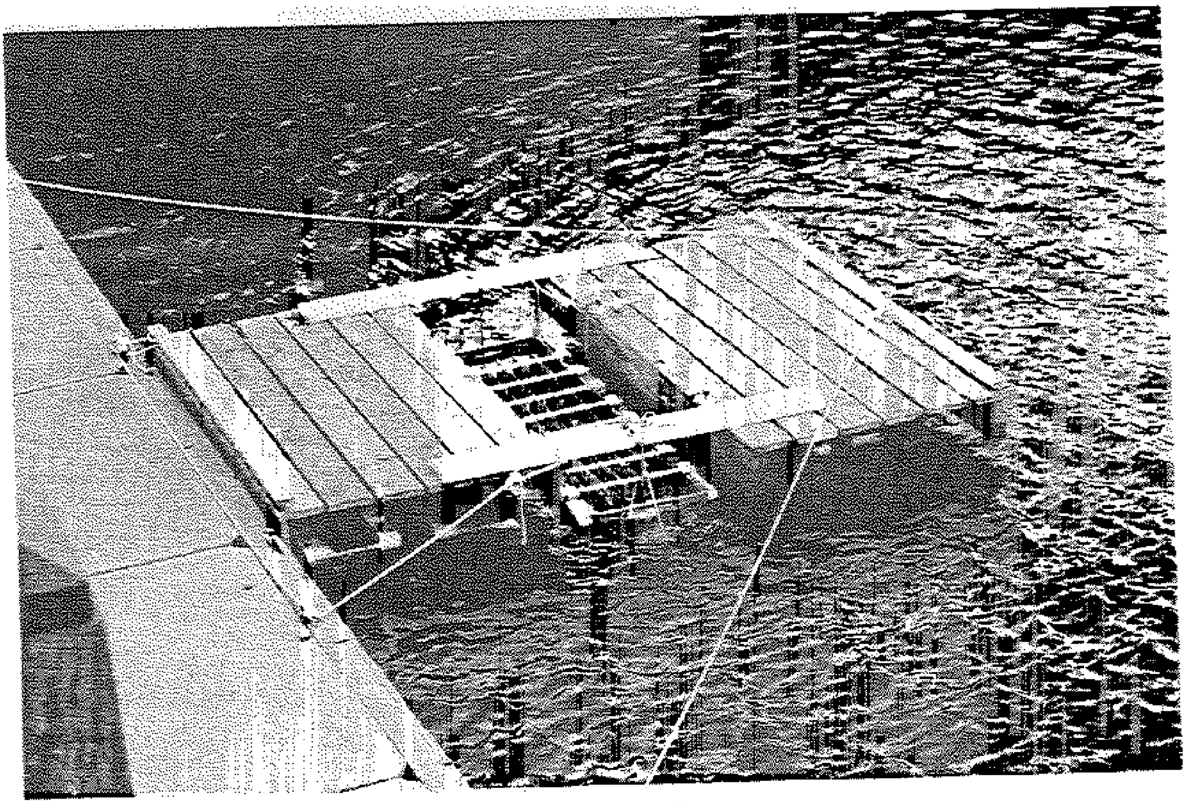
Estimated Volume of Tank = 150 gallons

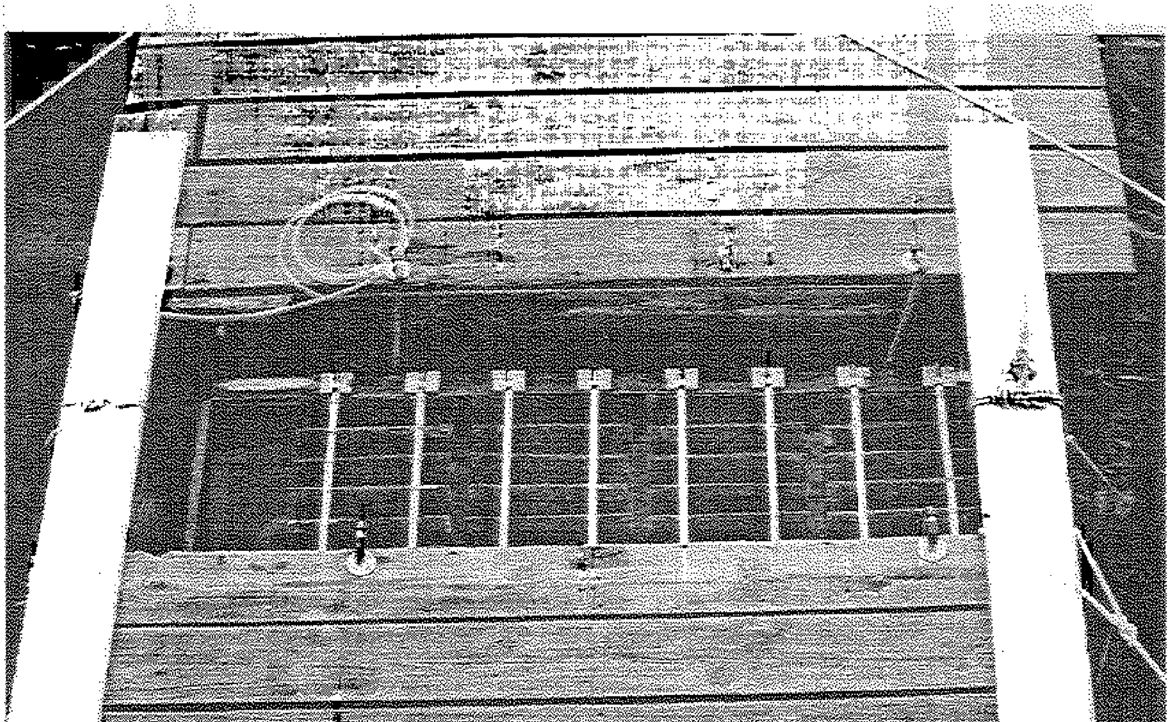
Fig. 7

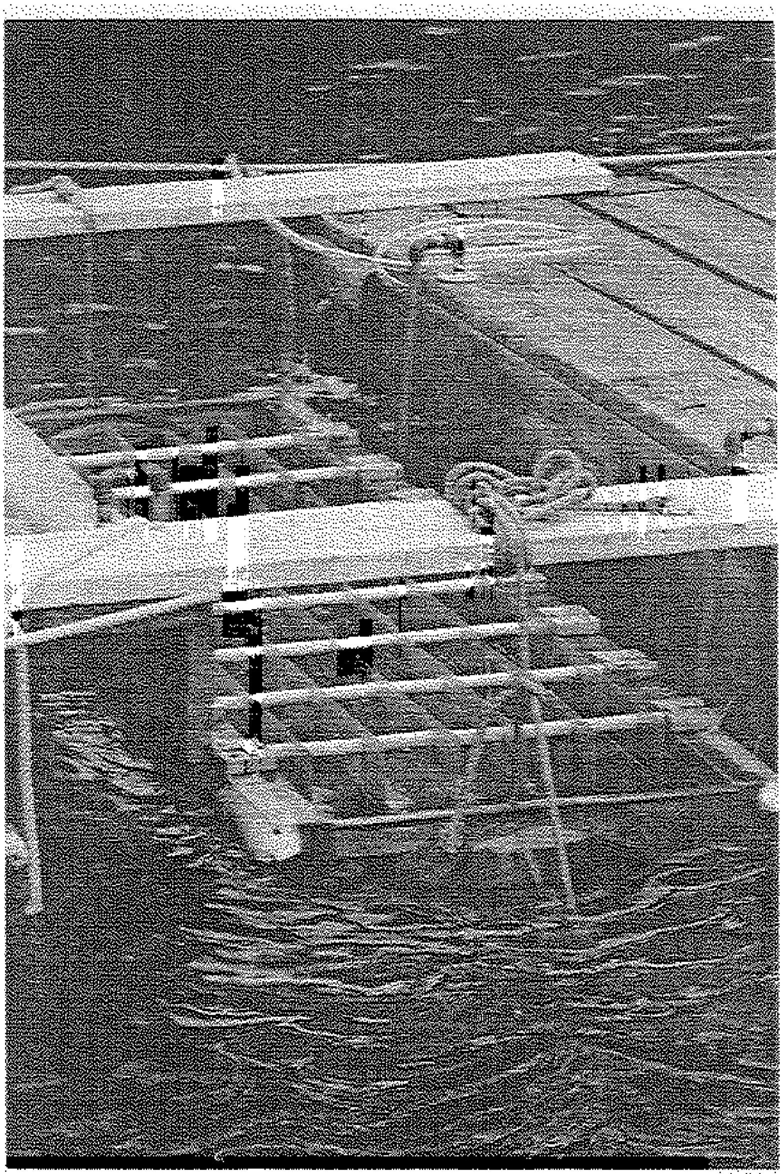
S.P.U.G.S.
Project Location
New Castle, NH

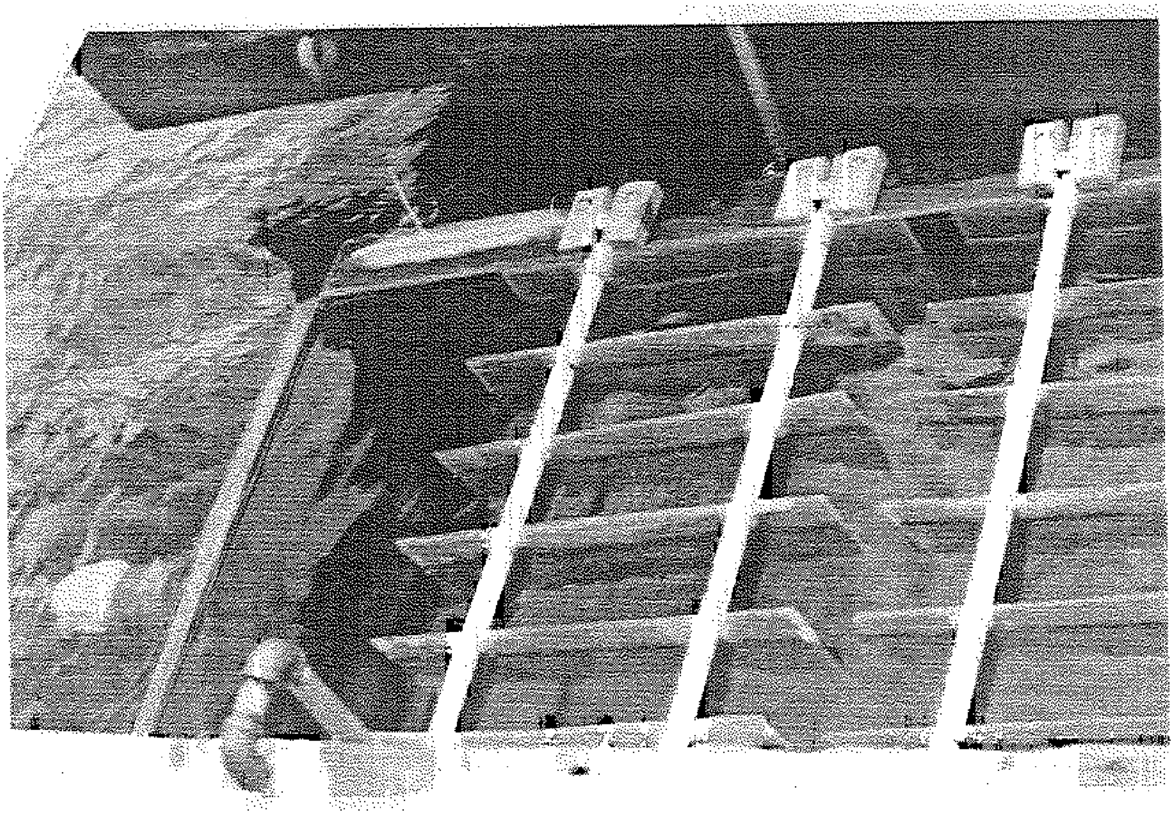


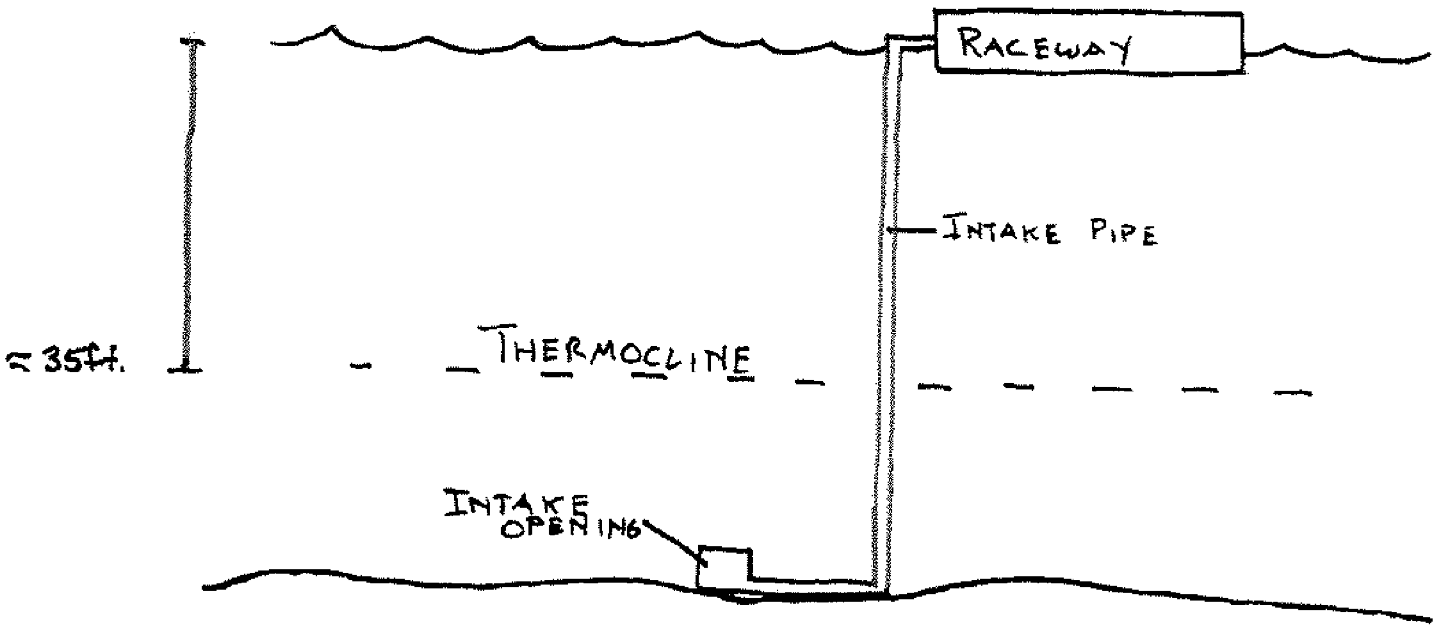











RACEWAY
INTAKE PIPE
≈ 35ft.
THERMOCLINE
INTAKE OPENING

Sun-Lite HP SOLAR GLAZING MOLECULARLY ENG

KALWALL® Sun-Lite HP Solar Glazing for low and medium temperature solar heat collectors.

Features:

- Engineered to excel under extreme Moisture, Heat, and U.V. exposure conditions;
- High solar transmission, low infrared transmission;
- Shatterproof, high impact resistance;
- Light weight;
- Easily handled, cut with hand tools, nailable;
- Low expansion coefficient;
- Low cost.

Experience has shown that plastics and plastic based resins fabricated into glazing sheets, panels, or films for covers on solar collectors of all types have been quite satisfactory for long-term use in lower temperature solar applications, that is, when the covers are exposed to temperatures regularly approaching 160°F., under relatively low humidity conditions.

However, many materials, including acrylics, polycarbonates, and fiberglass reinforced polyesters, have failed to maintain high solar transmission with the combined effects of higher temperatures, more extreme moisture, and sunlight. Such exposures include solar greenhouses, solar attics and furnaces, Trombe walls, site, or factory-built air heaters and water heaters.

Solar collector covers are exposed to a solar environment which, due to the extreme cycling of heat, moisture, and ultra violet rays, causes deterioration due to molecular change. The result is an unacceptable loss of solar transmission, usually accompanied by visual whitening, and/or yellowing. Due to the development of the Solar Industry since the late '60's and early '70's, many polymer based systems have been improved to provide more satisfactory service under certain specific conditions, i.e. tougher and more ultra violet resisting coatings on thermoplastics and fiberglass materials, added chemicals to provide more moisture resistance. However, none of these attempts has provided a truly new generation of solar collector cover material which is fully satisfactory for the low and medium temperature exposures, up to the range of 212°F., under severe moisture conditions. This would include the covers for hydronic collectors in most of the Continental United States. While the collector absorber plate in a medium temperature hydronic collector may reach temperatures approaching 300°F. in stagnation, the state-of-the-art collector glazing will seldom reach 212°F. in a single glazed unit and 257°F. for the inner glazing in double glazed collectors. (These temperatures have been repeatedly verified based on work done by the National Bureau of Standards.)

Kalwall Corporation, has been, and continues to be, a pioneer in the development of high performance, lightweight glazings for the Solar Industry. It recognized that the need for a non-glass alternative providing lightweight, shatter resistance, and ease of handling was very large indeed! Fabricators, architects, and to some extent consumers, have become disenchanted with non-glass alternatives due to apparent degradation of virtually all of the existing plastic based materials under many solar exposures. Kalwall, based upon its long years of experience and successful development of Sun-Lite Premium and Premium II, has now finished development on an entirely new solar glazing material *molecularly engineered* to perform in this highly demanding glazing exposure. This new system is called Sun-Lite® HP, and is engineered to resist the terrific accelerated aging processes applied to solar glazing materials. An absolutely fresh approach to molecular structuring was required in the development of Kalwall's new Sun-Lite® HP.

The comparisons between the new Sun-Lite® HP and existing solar glazing alternatives is dramatic.

MILLIONS OF SQUARE FEET of previous Sun-Lite grades have been installed over the past twelve years throughout the world. Because [illegible] Components is a *solar* company, rather than a [illegible]*tics* company, we have maintained surveillance on hundreds of applications, under varying conditions.

MOIST HEAT RESISTANCE
Loss of transmission due to moisture permeation is fatal to most polymer materials unless molecularly structured to resist moisture. Tests of materials under full soak as well as soak/dry cycling @140°F., 160°F., and 212°F. show few materials survive the elevated temperatures and 100% relative humidity conditions common to flat plate collector condensation cycling, even in solar greenhouses!

THERMAL STABILITY
Unless engineered for heat exposure, poly[illegible] break down over time. Combinations of internal microcracking, delamination of reinforcing fibers from the resin, and surface chipping will occur. 3,000 hours will roughly equate to 3-10 years exposure depending upon collector design and climate. Tests prove the molecular integrity built into the Sun-Lite® HP system.

ULTRA VIOLET RESISTANCE
U.V. stabilizer technology is well known, but the best additives are expensive and often degrade other properties. Sun-Lite® HP's chemistry provides the best of both worlds, even without a weatherable surface laminate others rely upon exclusi[illegible] Exposure of samples under artificial and n[illegible] conditions all show Sun-Lite® HP's unusual stability.

Other polymer based materials rely on surface films or coatings for U.V. protection. Sun-Lite® HP's surface and internal resin matrix have been completely U.V. stabilized for maximum service life.

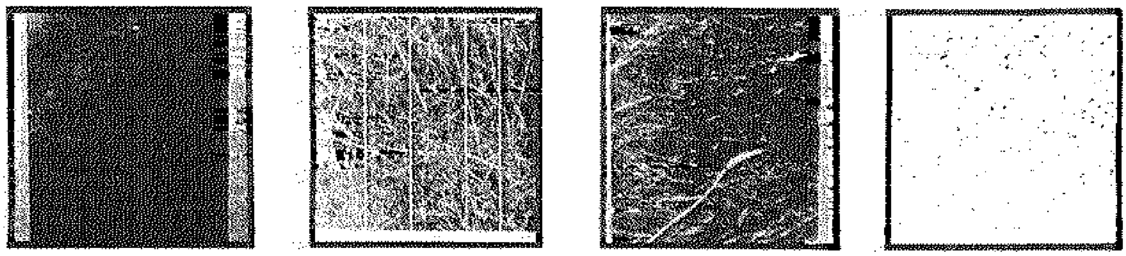
EERED TO PERFORM UNDER SEVERE EXPOSURE.

HANDS ON REAL WORLD EXPERIENCE shows ASHRAE 93-77, ASTM, and NBS mini-collector tests to be too short to predict long-term lazing performance under these drastically varying conditions. Therefore, we have created an appropriately severe testing series to separate best from the rest. Sun-Lite® HP is the highest performing polymer based glazing for low and medium exposure we know of in this world!

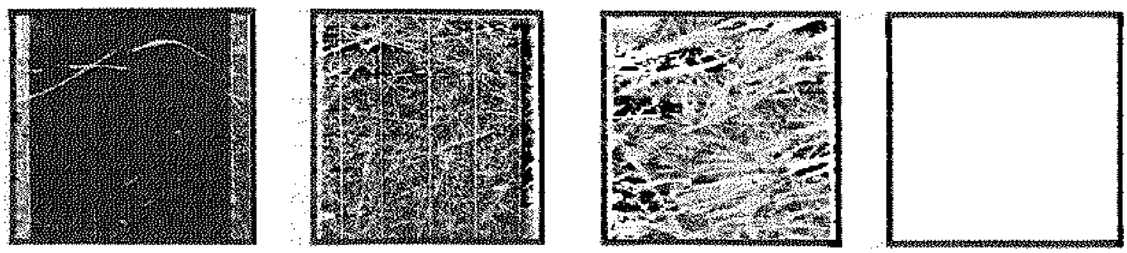
...-Lite® HP is not suitable for all designs, however, i.e. high temperature hydronic collectors or collectors designed for lengthy stagnation in hot climates. For these special designs, we encourage your thorough testing. *(For all passive applications, and state-of-the-art flat plate designs with controlled stagnation and low to medium operation conditions, Sun-Lite® HP will outperform all other polymer glazings!)*

Sun-Lite® HP	Filon Solar E®	Lasco Crystalite®	Filon 556

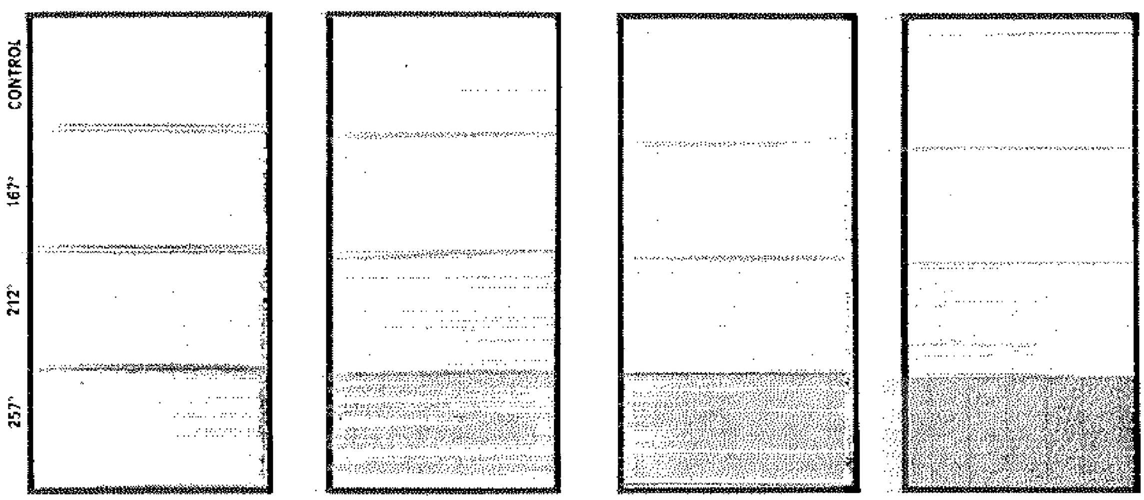
Water soak @ 160°F. for 24 hours: no change in Sun-Lite® HP, while others begin degradation and transmission loss due to fiber whitening.

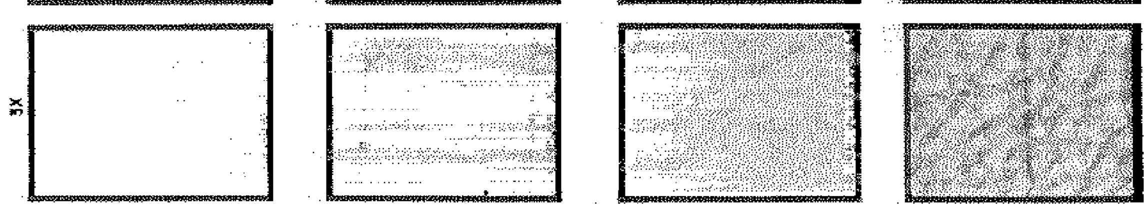


Water soak @ 212°F. for 24 hours: superior molecular linkage in Sun-Lite® HP resists absorption; others fail. Test coupons mounted on black background.

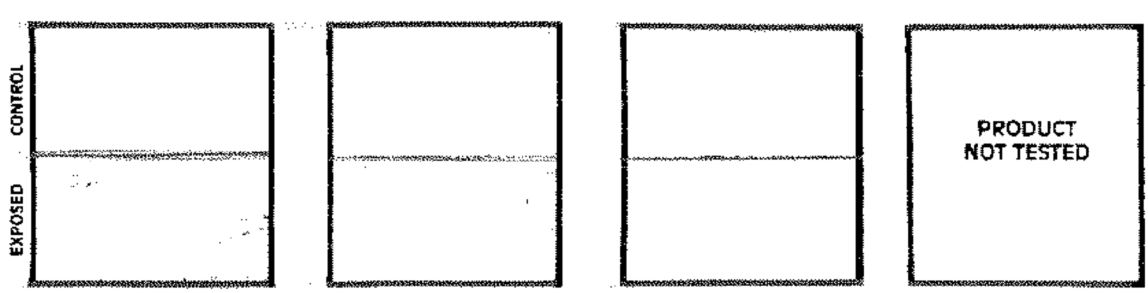


.000 hours exposure to dry heat @ 167°F., 212°F., and 257°F. Lower photo is 3 x close-up of 257°F. exposure clearly demonstrating Sun-Lite® HP molecular superiority. Test coupons mounted on white background.





Specimens exposed via EMMAQUA®, QUV Weatherometer, Fadometer, as ...ll as natural weathering, ... show Sun-Lite® HP's superiority.

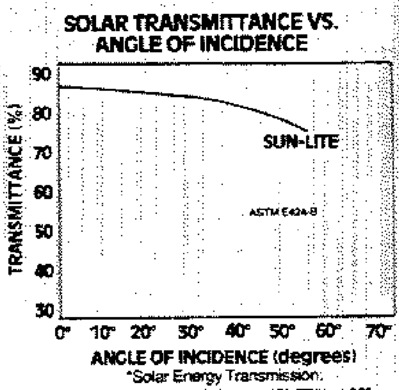


NOTE: All tests conducted on production material. Competitive materials purchased in the open market. Test coupons available for inspection at the laboratory upon written request.

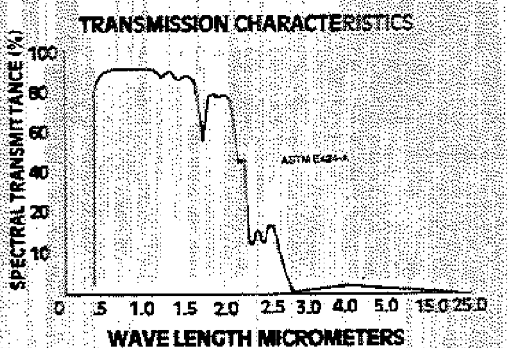
TECHNICAL SUMMARY

Transmission characteristics after aging will vary depending upon actual exposure conditions. In properly designed and maintained solar devices, Sun-Lite® HP is expected to retain in excess of 90% of its original transmission over a 15-20 year lifetime. No other polymer based material can compare to Sun-Lite® HP!

AVERAGE PHYSICAL PROPERTIES	METHOD	UNITS	.040 SUN-LITE H.P.
Solar Energy Transmittance	E424 Method B	%	86%
Heat Transmittance	5-50 Microns	%	less than 5%
Index of Refraction	D542	Ratio	1.55
Tensile Strength	D638	PSI	10,000
Flexural Strength	D790	PSI	17,150
Flexural Modulus	D790	PSI x 10^6	1.0
Shear Strength	D732	PSI	12,800
Izod Impact	D256	Ft. lb./In.	4.89
Water Absorption	D570	% by wt.	0.60
Thermal Expansion	D696	(In./In./°F) x 10^{-5}	1.36
Thermal Conductivity, k	C177	BTU/hr-ft.^{2} °F/in. thickness	0.713
Specific Heat	C-351	BTU/lb.-°F	0.318
Specific Gravity	D792	Ratio	1.324
Weight	ASTM D3841	Oz./Ft.^{2}	2.8-4.7
Thickness	ASTM D3841	Inches	.025/.040/.060
Burn Rate	D635	In./Min.	<2.5



*Solar Energy Transmission: 86% at 0°, 83% at 30°, 80% at 45°, 75% at 60°



Transverse Load Deflection: Sun-Lite® HP deflects less than 1.0" with a 180 P.S.F. load by ASTM D-1502-60. Sun-Lite® HP must be properly installed and fastened – see Installation Suggestions.

Thermal Shock: after repeated cycles of thermal shock (350°F. to 32°F.) no harmful effects were observed.

Impact Resistance: as with many fiberglass reinforced materials, impact strength is not expected to decrease with age. Sun-Lite® HP has an initial impact strength over 28 foot lbs. for a .040" thickness.

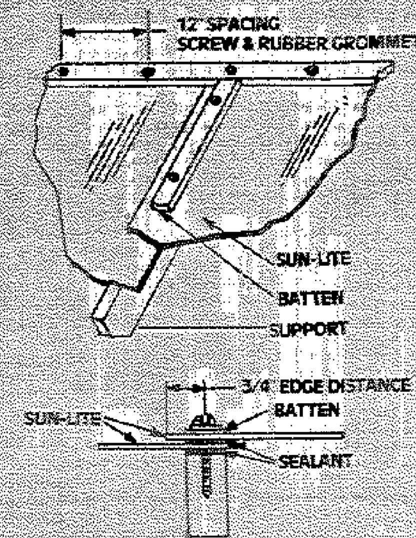
Combustibility Characteristics: ignition temperature above 650°F. and a burn rate well under 2.5" per minute give this material unique combustibility characteristics among fiberglass reinforced materials as well as being an approved plastic glazing material under Major Model Building Codes (CC-2).

SUN-LITE® HP INSTALLATION SUGGESTIONS

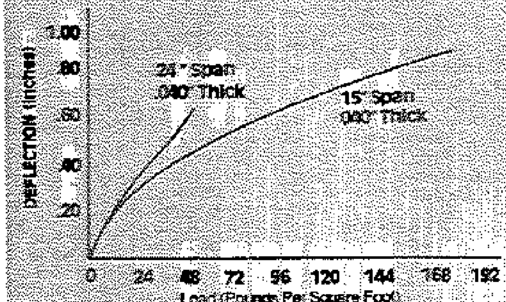
Provision should be made to be sure the Sun-Lite® HP will carry the design load, remain weathertight, accommodate thermal expansion and be aesthetically acceptable. Load capacity is determined by sheet thickness and rafter, purlin, girt or stud s port spacing. Suggested spans are shown in Tε 1. Suggested minimum roof pitch is 2": 12". When overlapping Sun-Lite® HP sheets, a minimum of 1½" lap on sides and ends is suggested. This overlap will allow fastening two sheets with a single fastener and maintain the proper edge distance to prevent the fastener tear-out.

TABLE 1

Sun-Lite® HP Thickness	Suggested Span
.025	24"
.040	24"
.060	30"



TRANSVERSE LOAD DEFLECTION

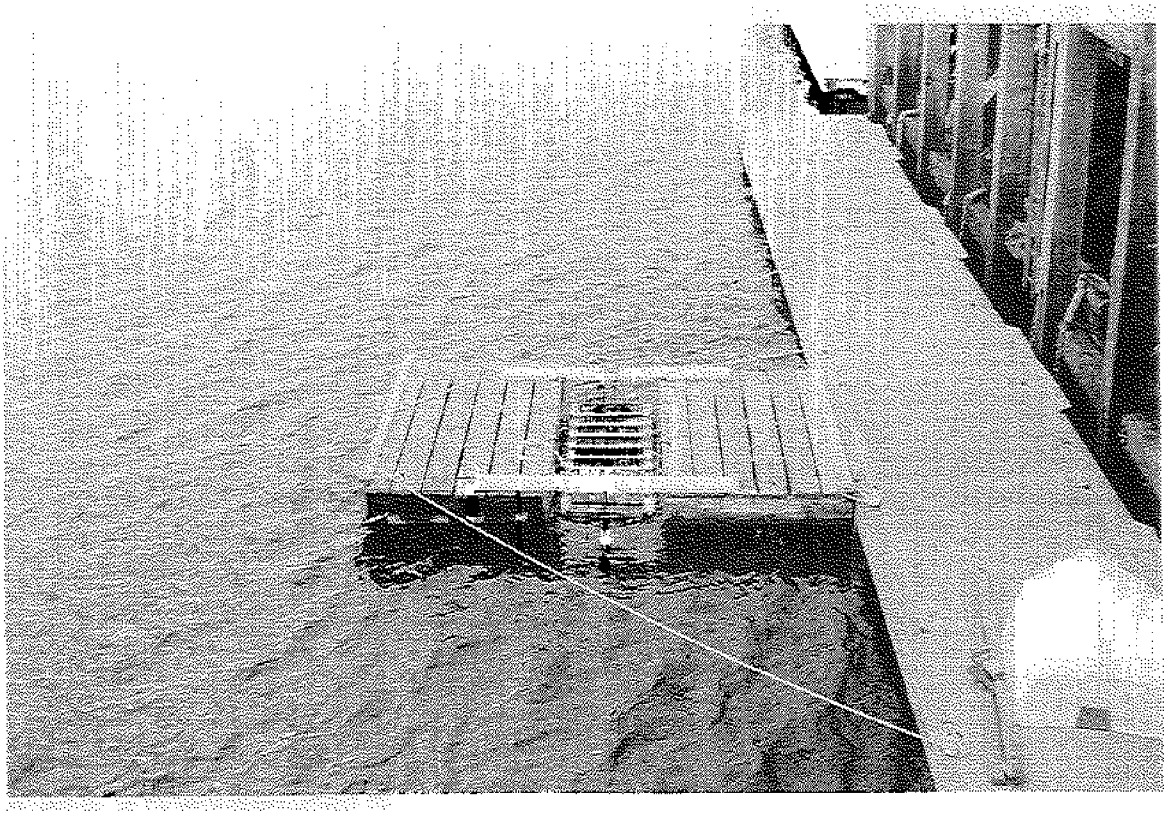


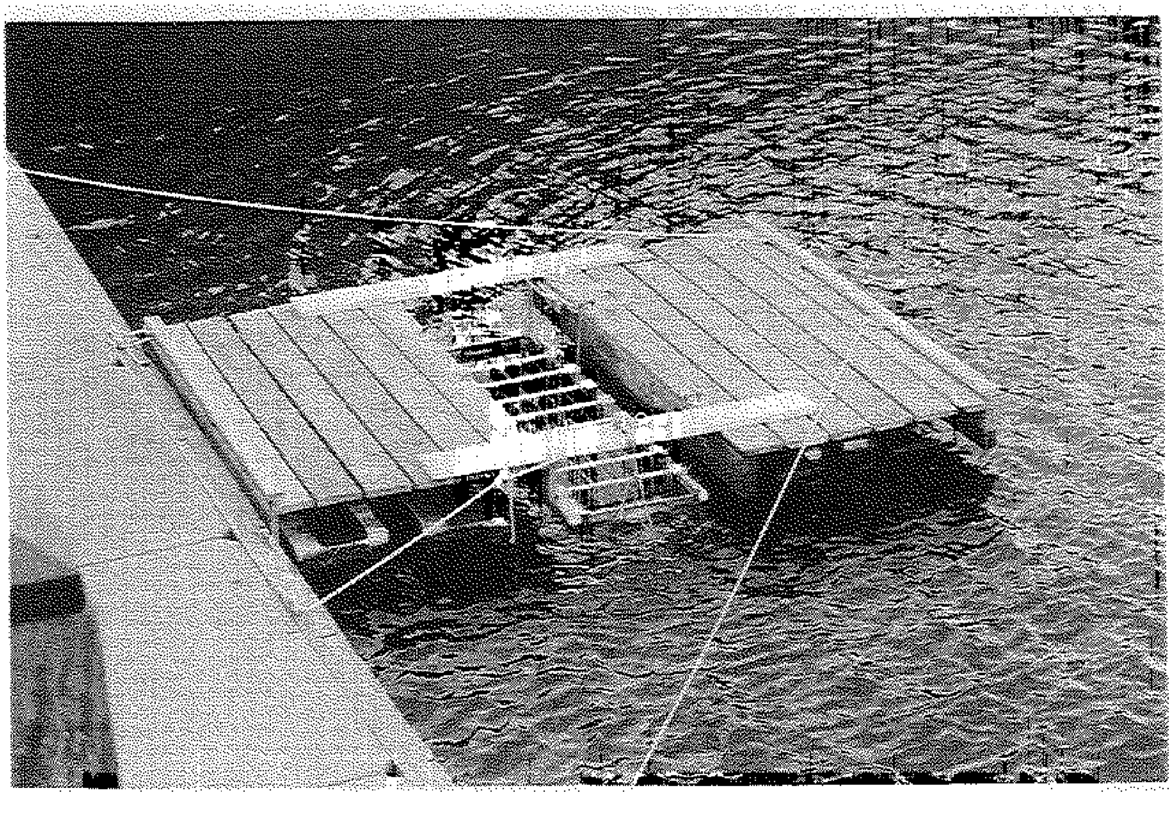
Sun-Lite® HP is available in .025", .040", and .060" thicknesses; 24", 36", 48", and 49½", and 60" widths; 10', 25', 50' and 1500' lengths.

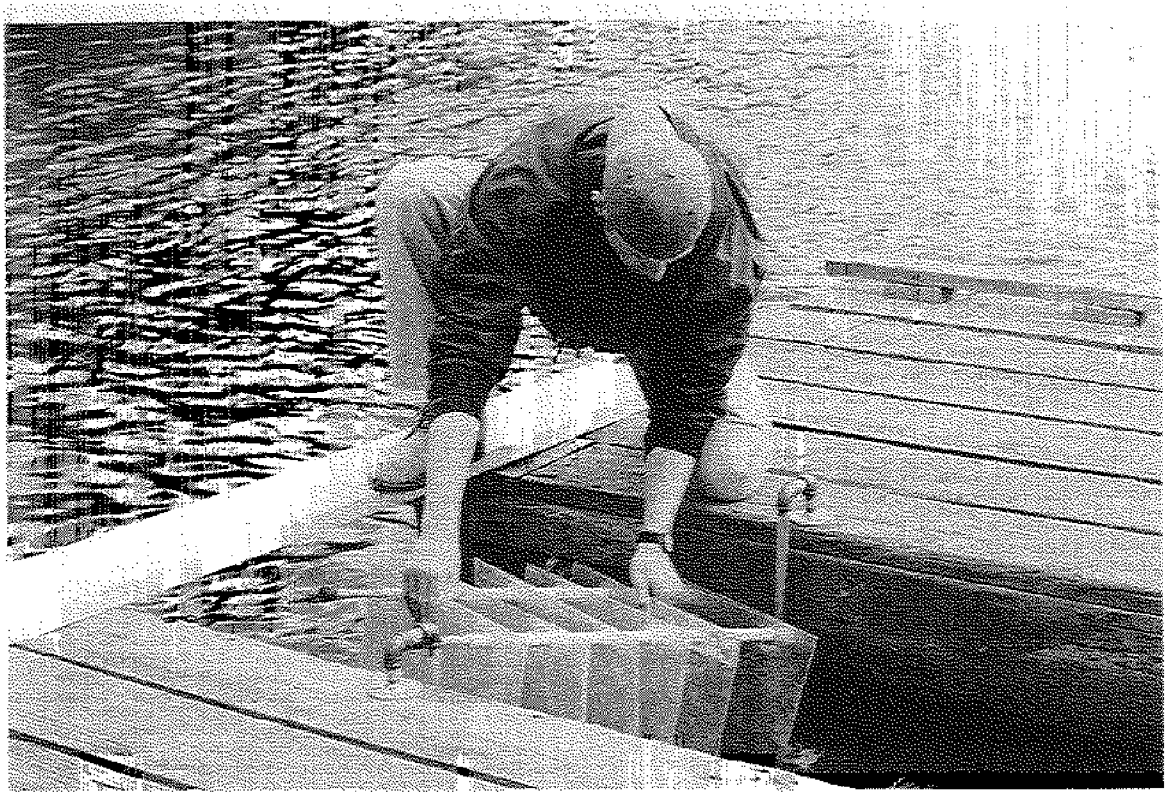
NOTE: All data presented is the most recent available at the time of printing, and is subject to change without notice.

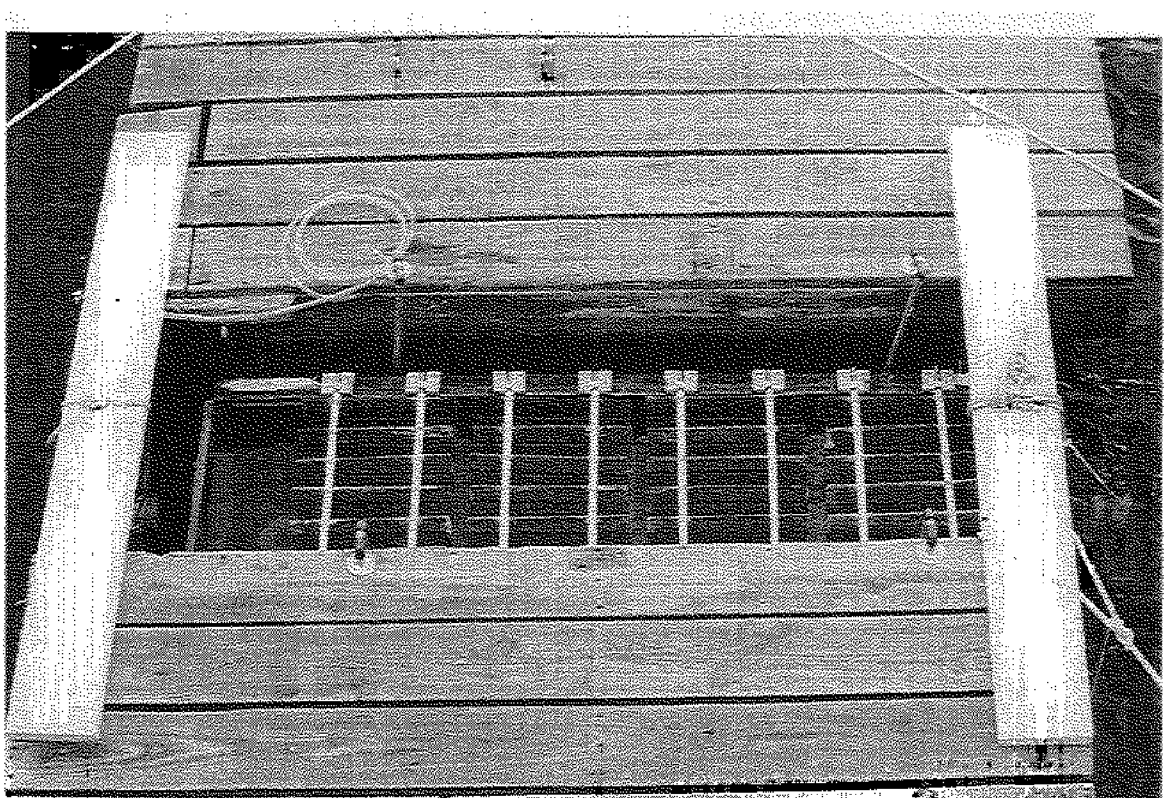
The information in this brochure is accurate to the best of our knowledge, but no warranty is expressed or implied. Furthermore, the information is intended for the use of non-professional designers, applicators, or those who do not purchase or specify these products in the normal course business.

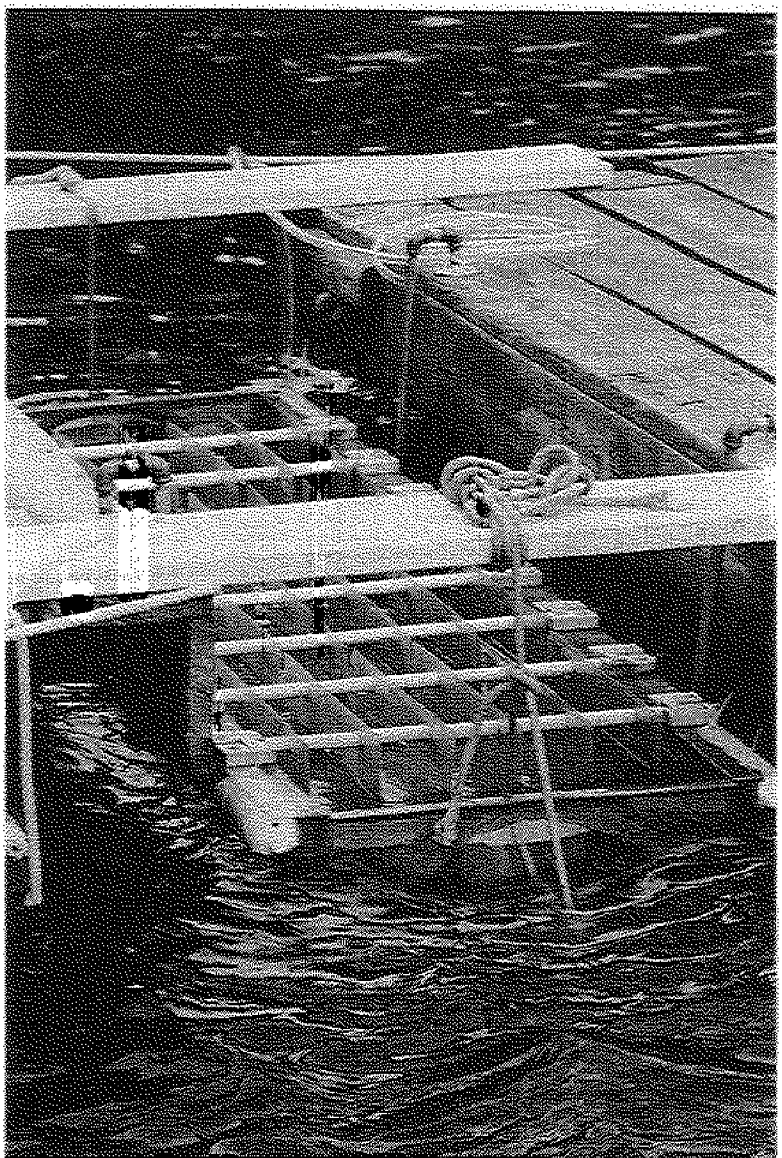
SOLAR COMPONENTS CORPORATION P.O. Box 237, Manchester, New Hampshire 03105
Phone 603-668-8186

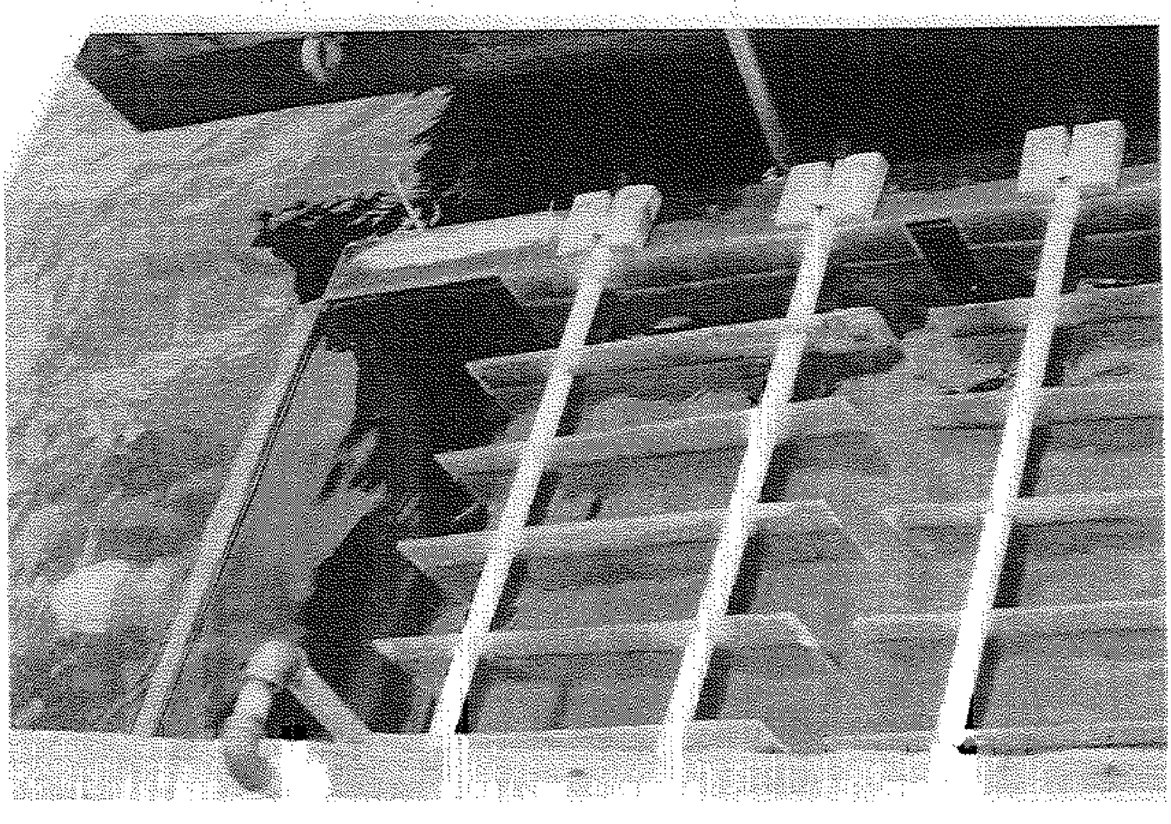


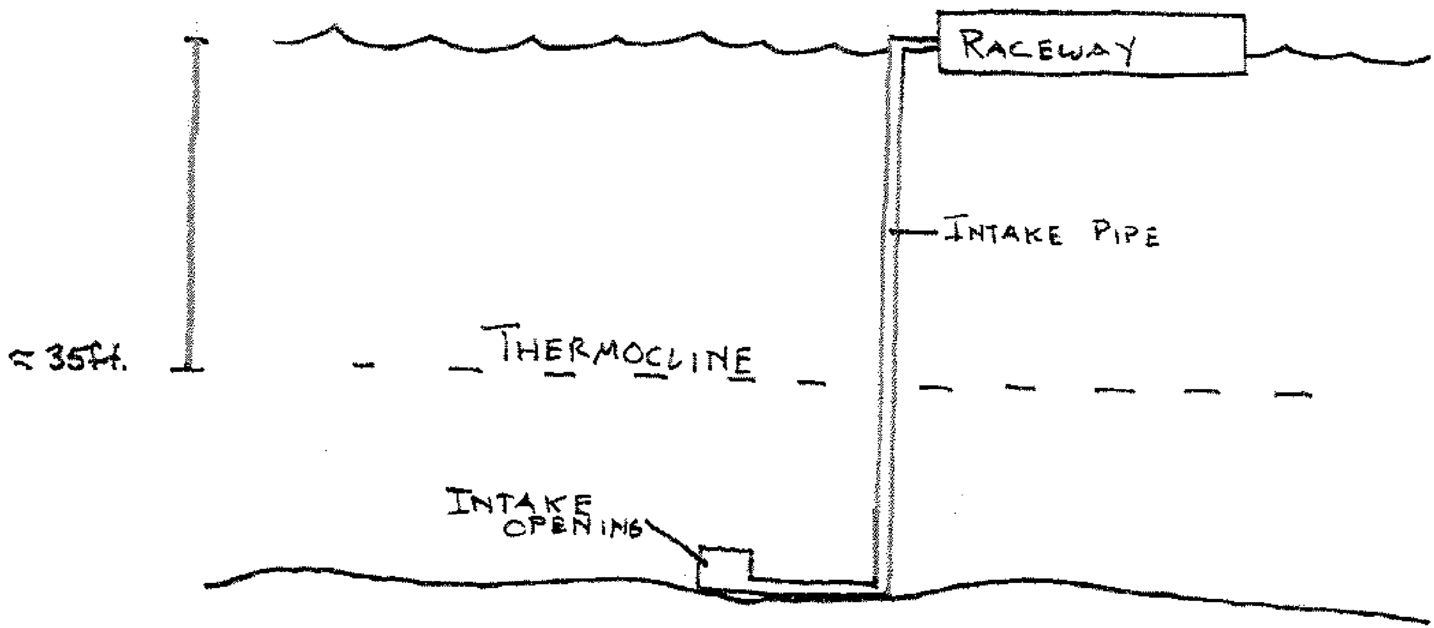












RACEWAY
INTAKE PIPE
≈ 35ft.
THERMOCLINE
INTAKE
OPENING