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Alpha Solarco's Photovoltaic Concentrator Development Program

Daniel Anderson, Bruce Bailor, Don Carroll, Ed Schmidt,
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Sandia Contract 40-8941D

ABSTRACT

This report details the work done under Sandia's Photovoltaic Concentrator Development contract, funded jointly by Alpha Solarco and the US Department of Energy. It discusses improvements made to the cell assembly and module design of Alpha Solarco's point-focus, high-concentration photovoltaic module. The goals of this effort were to increase the module efficiency, reduce the manufacturing cost of the cell assembly, and increase product reliability. Redesign of the secondary optical element achieved a 4 percent increase in efficiency due to better cell fill factors and offtrack performance. New, lower cost materials were identified for the secondary optical element, the optical couple between the secondary optical element and the cell, and the cell assembly electrical insulator. Manufacturing process improvements and test equipment are also discussed.

ACKNOWLEDGEMENTS

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0.0 INTRODUCTION

In 1989, Alpha Solarco Inc. developed and installed a nominal 12 kW point-focus array in Pahrump, Nevada to test components of an economical and efficient concentrator array design (Fig. 1).[1,2] The measured power output of the installed array was 9.6 kW, almost 25% below the nominal 12 kW array rating. Upon close inspection it was determined that the low power production of the array was due to problems with module alignment and a material failure of the secondary optical element.

In response to Sandia contract No. 40-8941D, Alpha Solarco redesigned its cell assembly to prevent further failures of the secondary optical elements and modified the manufacturing techniques necessary to produce these cell assemblies for production. This report describes the redesign of the secondary optical element of the installed array at the Pahrump Test Facility as well as other improvements to the cell assembly design, module assembly design, and production methods used to manufacture the cell and module assemblies.

The failed modules of the Nevada array were replaced with redesigned modules and additional modules were installed as a result of this project. The measured power of the modified array improved 56% to 15 kW. In addition to this achievement, this project made significant gains in the areas of concentrator module and cell manufacturing and reliability. First, information was obtained about the effects of high intensity UV radiation on glass material properties. Second, an appropriate material was identified for use as a secondary optical element. Third, a successful means of manufacturing the secondary optical element was developed.

The original Pahrump Test Facility array consisted of 100 modules mounted on a tracking platform. Figure 1 shows the completed photovoltaic system. This array now contains 132 modules connected in four parallel strings with each parallel string of modules consisting of 33 modules in series.

The modules of the installed array consist of three strings of cells in series. Each string contains 8 cells connected in series and is protected by a bypass diode. The typical module in this array has an electrical output of 9.5 amp at 12.6 volt (Fig. 2) at a normal operating cell temperature of 66 °C and an illumination intensity of 912 W/m^2. The module consists of a housing, lens assembly and 24 cell assemblies. The module housing is formed from aluminum with dimensions of 114 x 19.7 x 12 inches (Fig. 3). The lens assembly consists of a primary Fresnel lens mounted on top of the module housing providing each module with an active aperture area of 1.254 m^2.

Each cell assembly (Fig. 4) consists of an SOE (secondary optical element) attached to the surface of the cell. The cell is mounted to a copper heat spreader which, in turn, is both electrically insulated from and mounted to the bottom of the module housing. The typical cell assembly has an electrical output of 13.8 amp at 0.6 volt at an operating temperature of 67 °C and 400 sun illumination (the illumination the cell is exposed to when assembled in a module).

The array, modules and cell assemblies designed, developed and assembled under this contract satisfy the requirements of Sandia's qualification tests for concentrating collectors as outlined in the document "Qualification Tests for Photovoltaic Concentrator Cell Assemblies and Modules" SAND86-2473.

1.0 CELL ASSEMBLY DEVELOPMENT

The objectives of the Cell Assembly Development portion of the Phase I contract was to redesign the cell assembly in order to increase the cell assembly conversion efficiency, reduce the manufacturing cost of the cell assembly, and increase the reliability of the product. These objectives were accomplished through investigations in the following areas.

1) cell soldering
2) solder bond testing
3) secondary optical element design
4) secondary optical element to cell optical coupling
5) anti-reflective coating for the secondary optical element
6) modifying the top contact

As a result of these investigations:

1) A UV resistant glass was identified for use as a refractive material in concentrating systems.
2) A computer model was developed and tested that accurately predicts the electrical performance of concentrating photovoltaic systems with refractive secondary optical elements.
3) A cleaning agent was identified that removes the flux residue responsible for debonding the secondary optical element from the solar cell.
4) An optical adhesive was identified that can survive the humidity freeze test as well as provide a reliable and optically pure bond.
5) An inexpensive and reliable method was developed to prepare the heat spreader for soldering to the back of the cell.
6) The top contact was modified to provide better contact with the cell buss bar thus reducing solder bridging

The heart of the cell assembly (Fig. 4 and Dwg. 1) is the refractive secondary optical element (SOE) coupled with the solar cell. A high level of illumination uniformity is necessary to achieve high efficiency from the solar cell. The secondary optical element provides this uniformity as it redirects the light from the primary lens. The SOE is of BaZn glass with a cross section that resembles a Silo (Dwg. 2). BaZn glass was chosen because its material properties do not change when exposed to UV radiation. The SOE is optically coupled to the cell using an optical adhesive (Sylgard-184, manufactured by Dow Corning).

The solar cell design was optimized by Applied Solar Energy Corporation (ASEC) for 400X concentration. The cell is a square measuring 0.5416" x 0.5416" (13.757 mm x 13.757 mm) with an active area of 1.0609 cm^2 (Dwg. 3). Both the front and back contacts are evaporated and sintered layers of titanium. Palladium and silver are alloyed with an aluminum P+ layer underneath the back contact metals. The front contact is silverplated to 10 μm thick to increase conductivity. The bulk material characteristics of the cell are as follows:

Single crystal float zone (FZ) silicon
P type silicon boron doped
0.17-0.23 ohm-cm resistivity
<100> crystal orientation
Thickness: 0.203 mm

The remainder of the cell assembly consists of a top connect, a top connect insulator made of Danar (a Dixon product), a heat spreader, a Danar heat spreader insulator and two mechanical fasteners along with their insulating washers (Dwg. 4). The top connect (Dwg. 5) and heat spreader both are of copper 110 (this copper-beryllium alloy is 99.9% copper and has an electrical conductivity second to silver). A Danar insulator (Dwg. 6) electrically insulates the negative contact (top connect) from the positive contact (heat spreader). The Danar heat spreader insulator insulates the cell assembly from the module housing to which it is mounted.

The cell assembly is manufactured by first soldering the top connect to the front of the solar cell and then soldering the back of the cell to the heat spreader. The front and back contacts are electrically insulated with adhesive-backed Danar. Next, the SOE is both optically and physically coupled to the solar cell with an optical adhesive. The cell assembly is mounted in the module with the lower piece of Danar. The Danar, having adhesive on both sides, firmly holds the heat spreader to the backplane of the module housing.

1.1 CELL SOLDERING

Alpha Solarco has investigated improvements in the cell/heat spreader solder bond. The objective of the investigation was to reduce the cell assembly manufacturing costs as well as resolve concerns about the stress on the solder bond due to materials of differing coefficients of thermal expansion.

Two soldering methods were examined for higher throughput and greater solder bond reliability. The first method involved applying the solder to the heat spreader first and then soldering the cell to the heat spreader. The second method involved applying the solder to the solar cell first and then soldering the cell to the heat spreader. Both methods were tested by manufacturing cell assemblies. The cell assemblies were characterized by flash testing and then ultrasonic imaging to perform a non-destructive evaluation (NDE) of the cell/heat spreader solder bond. Random samples were subjected to thermal cycling at Sandia National Laboratories and at Alpha Solarco. Neither method was clearly superior in results or ease of manufacture.

In addition to examining the soldering process, Alpha Solarco has explored materials with a thermal expansion more comparable to silicon. Because molybdenum has a coefficient of thermal expansion like silicon, molybdenum was laminated with copper on both sides (so that solder would bond). Six cell assemblies were manufactured with 30 mil copper-molybdenum-copper (CMC) laminates soldered to the heat spreader. These laminates were sent to Sandia for analysis. The cell assemblies underwent thermal cycling and did not fail.

1.2 SOLDER BOND TESTING

Initially, the quality of the solder bond on the solar cell back contact was evaluated with ultrasonic testing. However, the results of ultrasonic testing require personnel capable of interpreting those tests. A new technique using infrared radiation (IR) was evaluated for manufacturing purposes that would simplify the interpretation of the solder bond test. The IR technique passes a short duration, 30 amp current, through the solder bond and monitors the infrared image of the solder bond area. Figure 5 shows a computer generated IR image resulting from this technique. Additional heat is generated in regions where the solder bond is good.

The infrared method of testing solder bonds was evaluated by correlating tests results with those of the ultrasonic tester. Three thousand cell assemblies were sorted into acceptable, unacceptable, and questionable groups using a Xedar infrared tester. These cell assemblies were retested using ultrasound and the results were correlated. Good correlation was found between the NDE (nondestructive evaluation) ultrasound images of solder bonds and Xedar's infrared analysis of the same solder bonds. However, the infrared method was not explored completely and further evaluation is necessary to determine its value in evaluating the reliability of solder bonds.

1.3 SOE IMPROVEMENT AND OPTICAL SYSTEM EVALUATION

Minor changes in the secondary optical element (SOE) reflect significantly in both the cost and efficiency of the module. A great deal of effort went into determining the final design, which consisted of an SOE referred to as "the Silo" and having a shape similar to a farm silo and made of BaZn glass (Dwg. 2).

Initially, modules were made and then tested at Pahrump, Nevada. The glass chosen for use as the SOE was a generic glass similar to BK-7 designated "crystal" in the glass industry and the SOE shape was arrived at using computer modeling. The computer program used was developed by Larry James of James Associates through Sandia funding. Because the glass contained certain elements which absorbed light, these early SOEs failed and a new type of glass, of BaZn composition, was used for subsequent SOE production. The shape went through two major iterations. First it was changed to a shape refered to as "The Haystack" (Fig. 6). This shape was an improvement over the original shape in that it was optically more efficient and had better tolerance to tracking error (see Appendix A for comparison) than the original, but ultimately was rejected because it did not produce as good a uniformity as the original. The final version was a return to a shape which more closely resembled that of the first SOE.

Criteria for the determination of the SOE fall into two categories: Material (the type of glass to be used) and the geometrical shape. Considerations for material choice are: transmission efficiency, index of refraction, cost of the glass mix, environmental factors, manufactureability (machineability of material, manufacturing yield, tooling required), and chemical/physical stability. Considerations in the determination of geometrical shape are: uniformity of light intensity produced, ease of manufacture, high optical efficiency, index of refraction and the ability to focus the maximum available light on to the solar cell, and tolerance to tracking error.

CRYSTAL GLASS FAILURE

Upon arrival at Pahrump, each module was independently tested, i.e. an IV curve was made. These tests indicated that an output of about 12 kWDC could be expected from the test array.

When tested in the POCA (Proof Of Concept Array), the glass quickly degraded upon exposure to the intense illumination received from the module's primary lenses. This led to a search for a replacement, which resulted in the selection of a BaZn glass to replace the failed glass.

The test array was populated with 100 modules, aligned, and brought on track. An IV curve for each series string of 25 was taken. These results indicated an array power of about 9.2 kWDC. Additional IV curves were taken during a 3 day period.

The power continued to decline over this period until it seemed to stabilize after the third day. An examination of the modules showed that the Silos were cracking. The typical fracture was along the major axis of the Silo. An intensive effort was immediately begun to determine the exact cause of the fractures. Samples of the Silos were sent to several glass manufacturers and consultants including the University of Dayton Research Institute (UDRI). When the fractured Silos were returned to Alpha's Cincinnati facility, it was obvious, under fluorescent lighting, that the Silos had turned a pale shade of purple with an intensity roughly correlating with the expected ray paths through the Silos. Upon examination of the Silos under a polarimeter at UDRI, it was seen that the stress patterns corresponded almost exactly with the computer predicted ray trace.

Samples of the Silos that had not seen service showed virtually no stress patterns. In order for the glass to show these permanent stress patterns, Messrs. R. Grant and D. Wolf of UDRI estimated that the glass had to have achieved a temperature of the order of 400 °C. Although no heat transfer model of the Silo exists, it was estimated that the Silo was unlikely to have achieved such a temperature unless the absorption coefficient had increased significantly. To investigate this assumption, a sample of the glass which had been used to determine the transmission and spectral indices, was exposed to an unfiltered ultraviolet light source of approximately 2000 microwatts per cm^2 for 12 hours. The UV source was used because it seemed likely that the higher energy photons were the impetus for the observed color change in the fractured Silos. This guess proved to be correct. The UV exposed sample exhibited the same color change as the Silos that had seen service in the modules. The sample was then retested for transmission. Figure 7 illustrates transmission vs. wavelength before and after UV irradiation. From this curve one can see that the transmission decreased from about 1% to 5% after UV irradiation between the wavelengths of 395 nm to 875 nm. Below 395 nm, there is a rapid decrease in transmission after the UV irradiation. Figure 8 shows the percent difference vs. wavelength for spectral reflectance and transmission of the glass samples. The spectral reflectance is approximately 2.5% greater after UV irradiance than before in the region between 400 nm and 640 nm, while there is a decrease in transmittance of roughly 4% in that same region. The change in spectral reflectance and transmission properties is apparently due to a phenomenon discovered as early as 1825. This phenomenon is known as "solarization".[3] Solarization is a process in which the light energy that is absorbed can bring about a change in the chemical composition of the glass. This in turn affects the physical and optical properties of the glass. Glass constituents such as manganese, iron, titanium, arsenic, antimony, and cerium are thought to play a significant role in promoting solarization. The Silos used in the POCA modules were found to contain a small amount of manganese. It is thought that this small amount of manganese caused the glass to undergo solarization which led to the fracturing of the Silos. Glasses which do not contain the aforementioned elements are apparently incapable of absorbing sufficient energy from solar radiation to undergo solarization. However, it should be noted that only trace amounts of these elements are necessary for the phenomenon to occur.

Armed with the above knowledge, a search for a new glass material was begun. The following is the list of candidates that were considered:

TABLE 1 SOE GLASS INVESTIGATION RESULTS

BK 7	It was recommended for imaging SOEs.	Trace amounts of manganese caused failure under intense sunlight.
B-270	This material has properties similar to BK-7 as well as greater resistance to solarization, according to Schott.[4]	Trace amounts of manganese caused failure under intense sunlight.
F2	It is a leaded glass with high solar transmission and high index of refraction. Preliminary work done by James and Associates indicated that a higher index glass will give better SOE performance.[5]	Quantities of lead increase the cost of production due to environmental regulations.
Pyrex	It is a well known glass in solar and thermal applications.	Poor light transmission characteristics of this glass means that the resulting SOE is optically inefficient.
BaZn	This glass has good optical properties and complete absence of photo-active constituents.	Good light transmission characteristics and an absence of photoactive elements makes this glass a good choice for SOE.

Samples of these glasses were exposed to radiation under an unfiltered UV light and monitored for solarization effects. The BK-7 sample yellowed in 24 hours and a Silo, made from BK-7, that had not been used in a module, exhibited a slight purple tint in the same period. The B-270 sample exhibited a very slight brownish tint after six weeks. Samples of the F2, Pyrex and BaZn type glass showed no visual changes. The glasses which evidenced color changes were naturally rejected from further consideration. Pyrex was also rejected because of low solar transmission. F2 was the ideal technical choice because of its high transmission and high index of refraction. However, there are problems associated with its use owing to the toxicity of lead. Alpha Solarco was unable to locate any glass "hand" shop that regularly works with leaded glass similar to F2. Most of the glass shops contacted indicated that because of environmental, safety, and health concerns, they were unwilling to produce even prototype quantities of a leaded glass. Lancaster Glass, which still regularly produces a high-lead glass, indicated that because of EPA regulations the cost of leaded glasses (currently $3.00 per pound) will rise and may become unavailable in the near future.[6] Such considerations led to the rejection of F2. Therefore, the BaZn glass was selected as the replacement for the crystal glass. An analysis at UDRI indicates that this glass has a high zinc and barium content along with amounts of sodium and potassium that are comparable to that of lead glass mixes. The transmission curves (Fig. 9) for this glass appear very good and indicate no appreciable absorption, especially in the UV. Figure 10 shows the index of refraction as measured for this glass. The results indicate a refractive index similar to the crystal glass used in the earlier POCA modules. The equipment used to make these measurements, gives an uncertainty of about 5% in the measured values.

PRODUCTION

Production of the SOEs entails making the glass (mixing the batch materials), molding, grinding and polishing in order to get the final product. Generally, a change in shape requires changes in tooling and technique along the way in order to optimize quality and to be able to produce units economically. Switching to BaZn glass introduced a new manufacturing challenge, namely how to manufacture SOEs without introducing any significant strain into the glass material.

After switching to the BaZn glass, many Silos made from it were found to have low optical efficiencies, efficiencies ranging from 70% to 90% depending on orientation.. This serious problem was attacked immediately. Careful examination of the Silos after polishing, using polarized light, revealed that distortions - irregular strings, existed in the Silos. It was postulated that these cords or striae might be due to improper mixing of raw batch or maybe due to thermal conditions in the melt. Cords were also seen in some of the haystacks which were received about the same time. The glass manufacturer tried varying temperatures at various stages in the glass production but these changes did not help. There was a possibility that the batch had been contaminated. Several suggestions by Alpha Solarco personnel were implemented for various stages in the glass production in an effort to avoid anything that might possibly cause this problem. Also, an attempt was made to determine at an early stage in the glass production if these strains would result in the final product. To do this, samples were taken from the batch, cooled and examined for cords. The quick cooling itself introduced too much strain to make this test useful. Examination of SOEs from subsequent glass batches revealed no further problems and so it is not known for certain what caused the original problem.

SOE SHAPES

The shape of the SOE was determined by computer modeling. A good shape design attempts to optimize 3 qualities:

- even light distribution over the entire active area of the cell
- tolerance to off-axis tracking
- manufacturability - easily and economically producible

An even flux distribution on the surface of the cell is very important because the cell is designed to operate at an illumination of about 400 suns. Tests of the solar cell have shown that its efficiency begins to degrade at light intensities of approximately 200 suns and to fall off precipitously above 400 suns. The inefficiency due to overilluminating a cell is seen as a degradation in the cell's fill factor. The amount of off axis tracking that the module can tolerate without significantly reducing efficiency is important because this determines the tolerance to which the array tracking system must be held in order to keep the array aligned to the sun (Fig. 11). The design must take into account how difficult molding and machining the part will be because of production cost.

Figure 12 is a computer generated output showing the effect of an SOE. Work done by Dr. Larry James of James Associates indicated that the performance of the SOEs, particularly the off track performance, could be improved by changing the Silo shape from that of the shape originally used in the POCA at Pahrump.[5] Short computer runs using approximately 800 rays were done for various SOE diameters and two aspheric top factors: 1.0 and l.l. As can be seen from Table 2, there is very little difference in the optical efficiency based on the aspheric top factor. However, it would be necessary to use a cell model to determine if the increased chromatic aberrations expected with a top factor of 1.0 would decrease the overall performance. An SOE with a diameter of 0.8 inches appeared to give the best on-track optical efficiency. This diameter was then used in a full 800,000 ray simulation. The plots indicated a very uniform flux distribution for on-track performance and 91.5% of that performance at 0.9 degrees off-track. This shape (Dwg. 7A) is referred to as "the ice cream cone" SOE. Because of the underprediction of the program relative to measurements made by Sandia, the actual off track tolerance could be greater than one degree. An alternate design designated as the "haystack" SOE was also considered. It is shown in Fig. 13 as it would come from the mold. Figure 6 and Drawing 7B show the SOE in its final form.

The computer program incorporating a cell model with the optics program that simulates the SOE was developed by James Associates. Initially, the program produced values that disagreed with experimental results, particularily with regards to peak power, fill factor and short circuit current values. These discrepancies were later resolved under another contract by Dave King and Charles Stillwell of Sandia and Larry James of James Associates. The discrepancies between experimental and predicted values were due to the use of incorrect device parameters in the computer model.[7]

Table 2. 1.1 vs. 1.0 Aspheric Top Factor Comparison

Diameter of SOE (in)	Aspheric Top Factor	Optical Efficiency	Aspheric Top Factor	Optical Efficiency
0.65	1.1	0.8182	1.0	0.8195
0.70	1.1	0.8194	1.0	0.8205
0.75	1.1	0.8202	1.0	0.8212
0.80	1.1	0.8209	1.0	0.8218
0.85	1.1	0.8194	1.0	0.8213
0.90	1.1	0.8129	1.0	0.8177

Manufacturing Considerations

The evaluation of SOE shapes from a manufacturing standpoint was based on short and long-term manufacturing costs. The two shapes considered were the Ice Cream SOE and the Haystack SOE. The factors considered were mold design and manufacture, mold stripping (removal of glass from mold), SOE scrap, mold flash (overflow of glass), and the number of manufacturing operations required. The Ice Cream SOE (Dwg. 7A) design requires advanced mold design and costly manufacturing operations to assure close tolerances required for proper SOE function. The Haystack SOE (Dwg. 7B)is a relatively simple mold design where close tolerances are more easily held. The removal of the Ice Cream SOEs from the mold is also more difficult and a high failure rate upon removal is likely, resulting in slower manufacturing and increased cost. An additional consideration is that the Ice Cream SOE design will have mold flash around the tangent point where the top arc meets the cone. This flash would need to be removed, increasing the risk of damage to the optical surfaces, before any other manufacturing operation could take place. At this time, it appeared that the smaller diameter on the Haystack SOE would have to be machined, but this could be done in the grinding operation and would not result in additional manufacturing operations as with the Ice Cream SOE. In the manufacturing comparison for the SOE shapes it appears that the Haystack SOE design is the most cost-effective.

BaZn Haystack SOE

The Haystack SOE shape was selected and new cavities were made. At about this time, the F2 glass was dropped as a candidate for the previously mentioned reasons. However, the shape is determined by the geometry of the system and on-track performance is not significantly affected by the index of refraction. The index of refraction affects the off-track performance more significantly. A full simulation using BaZn glass was performed (Appendix A) and the on-track performance was found to be similar to that of the F2 glass. The off-track performance was less similar to that of the F2 glass, with the BaZn SOE performing about 2% lower at 0.9° off-track. The flux distributions indicated a slightly less uniform flux profile with the BaZn, which was thought not to significantly reduce the performance. The cell model was still not available at this time so it was not known if this would produce a significant change in the cell performance. The old tooling was modified to accommodate the new cavities, and samples were poured. These sample Haystack SOEs were examined under a polarimeter and high stress regions were found. In addition, the first sample showed poor upper surfaces indicating possible inadequate temperatures in the lehr. New samples were poured and the temperature of the lehr was raised and the dwell time was increased. This resulted in smooth upper surfaces and reduced stress. However, the stress still appeared to be greater than that of the Silos that were used in POCA. New Haystack SOEs were ordered with further increased lehr dwell times. UDRI indicated that to completely relieve the stress, a dwell time on the order of 20 hours would be required. From a cost standpoint, this was unacceptable and a compromise anneal schedule was sought such that stresses were minimized.

The subsequent batch of SOEs received appeared to be well fire-polished and lehred as well as being free of bubbles and inclusions. However, when they were placed in a polarizer, it was obvious that the stress relief had been inadequate. This batch of SOEs had a straight cylindrical shape and was sent to a local glass firm to bevel grind them into the Haystack SOE configuration. After many attempts, the grinding firm concluded that it was very difficult to transform the molded shape into that of the Haystack SOE, because the SOE tended to fracture almost immediately when applied to the grinder. It was the opinion of the grinding firm that the fracturing was inherent in the nature of the glass and that additional stress relief would probably not affect the susceptibility to fracturing. It was then determined that it might be possible to mold the Haystack SOE shape directly without employing a multi-piece tool. The general idea was to enlarge the diameter of the sprue so that it was slightly larger than the diagonal of the active area of the cell. The length of the sprue was increased by cutting the cavity depth so that the appropriate length of the Haystack SOE could be accommodated without excessive modifications of the existing tool and cavities. This approach proved to be practical and new SOEs were made within a week. These new SOEs were of the right size and shape and had been lehred at a higher temperature and for a longer time which reduced the stress considerably. However, the upper surface was not smooth and actually appeared slumped in places. It was unclear whether this resulted from inadequate fire-polishing, a cold tool, or both. A third batch was then made with great pains taken to insure that the tool was adequately heated for each pour and that the fire-polishing was appropriate. These SOEs were then lehred in the same manner as the second batch. Polarimeter examination indicated stress comparable to the second batch. Of the 113 SOEs received, approximately 85 were acceptable with the rest either having bubbles, inclusions, inadequate fire-polishing, or minor cracks that may have resulted from improper handling or undue stress imposed when the sprues were separated from the matrix (Fig.13).

A vertical glass grinder along with a fixture to ensure perpendicularity was used to grind and polish the SOEs. First they were rough-ground with a course belt to approximately the right height. Next, a fine belt was used to take the SOEs to their final size. This two-step process was used to avoid leaving gouges in the bottoms of the SOEs owing to the size of the grit. This problem was experienced in the POCA Silos that were not ground and polished in-house. The Haystack SOEs then received a final polish with a cork belt. The SOEs done in this manner appeared to have vastly improved lower surfaces and were virtually free of the scratches and gouges that had been observed in the POCA Silos. The height tolerance was held to about + /- 0.2 mm. The variations on the POCA Silos were on the order of + /- 0.5 mm. Based on the lens-cell spacing sensitivity studies done at Sandia, this variation should have little effect on the overall performance of the module.

1.4 SOE COUPLING

The optical coupling of the SOE to the solar cell is a crucial part of the cell assembly. Light is lost at the material interface of each element resulting in lower conversion efficiencies for the solar device.

The coupling of the SOE to the solar cell involves two separate steps: cleaning the solar cell and applying the optical adhesive. Cleaning the solar cell involves removing any remaining flux residue that would inhibit the adhesion of the optical material. The optical material provides both the optical and mechanical coupling of the SOE to the solar cell.

To test the optical coupling of Alpha Solarco's cell assemblies, sample cell assemblies were made and sent to Sandia for evaluation. Defects were detected in the optical coupling of the SOE and solar cell. A surface analysis performed at UDRI indicated the presence of flux residue in the areas of debonding. In response to the findings, several experiments were conducted to develop a more effective method of removing the flux residue. The most common solution to this problem utilizes an ultrasonic tank with an appropriate cleaning agent. Several cleaning agents were examined to do this.

One cleaning agent tried: 1,1,1 trichloroethane, is an industry standard degreasing agent. This agent was used only as an interim solution because of the number of Environmental, Safety & Health concerns involving the use and disposal of the liquid. This class of chemicals may not be available within a few years and therefore was rejected as a part of the manufacturing process for these reasons.

Another material, IPA, is a solution with Environmental, Safety & Health concerns similar to 1,1,1 trichlor (including legal liabilities). Also considered was Bioact EC7R. The first five cell assemblies cleaned in the Bioact EC7R did not have bonding defects. Unfortunately, Bioact EC7R has a very low open cup flash point and therefore requires explosion proof motors on the cleaning system. Ultimately, Bioact EC-Ultra was chosen as the cleaning agent for this project. It is essentially EC7R with an open cup flash point of about 150 °C, therefore, it does not require the use of explosion proof motors on the cleaning systems.

Once the cell assembly is cleaned of flux, the SOE must be optically coupled to the solar cell. This is accomplished through the application of Sylgard - 184.

Testing at Sandia has shown that Sylgard-184 can survive the humidity-freeze test. The process was developed to ensure consistent quality of the couple. Sample cell assemblies using Sylgard 527 were submitted to Sandia for evaluation along with room cured Sylgard-184 coupled cell assemblies. The Sylgard-184 was chosen because it could be room cured on an accelerated schedule, it provided good optical quality and satisfactory bonding characteristics.

1.5 AR COATING

Alpha Solarco has investigated the effect of antireflection (AR) coatings on cell assembly performance. The AR coating is applied to the SOE to improve the amount of light transmission through the SOE. AR coating reduces the amount of reflection at the glass/air interface by as much as 4%. The measured optical efficiency of the primary lens was about 85% and the measured optical efficiency of the complete optical system was 82%. This puts the optical efficiency of the SOE-cell couple at about 96.5%.

Three different methods of manufacturing the AR coating have been examined.

1) Vacuum deposition
2) Neutral Solution Processing (NSP)
3) Sol-Gel process

Vacuum deposition is the most costly of the three solutions. This is because most vacuum deposition facilities are small and require fairly long cycle times. RFQ's were sent to several vacuum deposition facilities. Only one written response was received estimating a cost of about $0.25 per Silo in quantities of millions per year.[8] Such prices are low enough to be cost-effective, provided they can be realized and the coatings have suitable durability. This method of AR coating was not pursued further.

Neutral Solution Processing (NSP) promises to be inexpensive. It uses relatively non-toxic chemicals, results in antireflection films effective over a wide range of wavelengths and is effective for light striking the surface at angles considerable off from the perpendicular. This latter characteristic is particularily important for SOEs which have light striking them at large angles of incidence. Neutral Solution Processing (NSP) was developed for use in high energy laser optics and uses a sodium dibasic or similar solution at about 87 °C in two phases to separate and etch the AR coating.[9] Neutral Solution Processing was found to be sensitive to minor changes in the process, such as using deionized water instead of distilled water or variations in the annealing rate. Research on the NSP process has been done by Alexander Maish of Sandia National Laboratories indicating possible gains in transmission on plano-plano coupons of nearly 7%.[10]

Other experimental work was done at Sandia using the NSP on flat coupons of the BaZn glass and on BK7 glass. The results of experiments on BaZn glass reported by Scott Reed of Sandia indicated that the reflectance of the sample decreased but the transmission curve did not show a corresponding increase. When the NSP film was polished away, the reflectance increased and the transmission remained the same. One possible explanation may be that the NSP process decreases the reflectance of a sample by increasing the absorptance and/or scattering within the film.

A BK7 sample was NSP processed for forty hours using the techniques reported by Cook et al (Fig. 14). The reflectance curves taken before and after NSP indicate a decrease in reflectance from about 8.5% to 5.5% at 450 nm and from 8.5% to 7% at 850 nm. The transmission curve after processing showed virtually no changes. After consultation with a member with UDRI, it was discovered that the process is sensitive to minor changes. In fact, it is believed that the slightly higher potassium content in the deionized water preparation may have adversely affected the process. A new NSP solution using distilled water was used and the PVC reactor vessel was lined with polypropylene and the samples were cleaned according to UDRI specifications.

The Sol-Gel AR process was developed at Sandia for application on Pyrex envelopes used in solar thermal applications. A metal alkaloid solution is applied to the glass where it polymerizes and forms a gel. The gel is stabilized into glass by heating to about 500°C. The thickness of the AR coat is determined by etching.[11]

The increased optical efficiency provided by the use of these AR films is only desirable if the overall cost of its use will reduce the dollars per watt cost of the module. At this time the process has not been sufficiently refined to make AR coating cost effective.

1.6 TOP CONNECTION MODIFICATION

Alpha Solarco has improved the mechanism for making electrical contacts to the top of the cell. Previously this was done by adding solder paste to each of the top contacts, placing the top conductors, and heating the assembly to melt the solder. Occasionally, misalignment by as much as 0.060 inch occurred between the top conductors and the metallized area on the cell. This misalignment can cause solder bridging between the top conductor and the buss bar of the solar cell. The ends of the fingers on the top contact were bent down by about 0.01" which provided better contact with the cell buss bar and less solder bridging.

2.0 RECEIVER SECTION AND AS225 MODULE DEVELOPMENT

The objective of the Module Development portion of the Phase I contract was to redesign the module to exceed the qualification criteria outlined in SAND86-2743. These objectives were accomplished through investigations in the following areas.

1) Fresnel lens investigation
2) Fresnel lens installation
3) Thermal analysis
4) Anti-radiation shielding development
5) Adhesive evaluation
6) Module moisture relief
7) Wet Hi-Pot Testing
8) Interconnecting cell assemblies

As a result of these investigations:

1) Anti-radiation shielding was designed to shield the conformal coating from off-axis irradiation.
2) An adhesive was identified that would pass both the pull test and the Hi-Pot qualification tests.
3) The lens/module housing seal was redesigned to prevent the entry of moisture.
4) The number of holes in each module bulkhead was increased to disperse water vapor more quickly by means of convection.

The module assembly consists of a module housing, twenty four cell assemblies, Fresnel lens assembly, three bypass diodes, five module bulkheads and miscellaneous hardware and wiring (Dwg. 8). The electrical circuit of the module consists of three strings of cells connected in series (Dwg. 9). Each string of cells is composed of eight cells connected in series. A bypass diode is connected across each string to prevent reverse voltage bias when a cell in the string fails or is shadowed.

The bypass diode is fastened to an "L" shaped aluminum bracket which in turn is fastened with adhesive coated Danar to the module bottom in the middle of each series string of eight cells. These cell assemblies and bypass diodes are electrically isolated from the module with the Danar dielectric, capable of withstanding 2500 VDC.

The module housing is formed from a single sheet of 0.063 inch aluminum. Five bulkheads, spaced 18 inches apart add strength to the unit and help support the lens parquet (Fig. 3).

2.1 FRESNEL LENS INVESTIGATION

Three approaches to producing the primary (Fresnel) lens were investigated. The first method laminated a flat Fresnel lens material (22 mil) produced by 3M corporation to a clear acrylic substrate. The second method directly cut the Fresnel lens into the acrylic. The third and preferred method involved a compression molded lens for which tooling was designed and purchased. See Drawing 10 for an overview of the module optic system.

Each of these methods was tried and each method had its associated manufacturing and performance problems. The laminating method used a complicated manufacturing process to apply the lens film to the acrylic sheet. The main problem with this method was the uneven feed of the lens film as it came off the roll. This caused misalignment when the film was attached to the supporting acrylic sheet resulting in a skewing of the individual lens elements. The manufacturing yield for this process was typically below 60 percent.

The direct cut method had its own set of manufacturing concerns. First, tool chatter marks degraded the performance of the lens. The cutting process leaves excess material called "flash" that also degrades the performance of the Fresnel lens.

An investigation of cost and efficiency indicated that a compression molded primary Fresnel lens was preferrable to the laminated alternative. The reasons for this are two fold. First, the compression molded lens has no internal optical boundary and thus can have no significant internal light losses, resulting in better optical efficiency. Second, the single piece material will not have the possibility of faults at the lamination interface which is possible using the first approach. Finally, the mold used to manufacture the lens was trapping air during the molding process. The trapped air affected the manufacturing yield of the lenses and was resolved by porting the mold to relieve the air entrapment. Comparing the compression molded technique to the direct cut method, it was determined that the compression molded technique would be cheaper to manufacture; however, it would be less efficient than the direct cut lenses.

Alpha Solarco initially negotiated with Electric Power Research Institute for a unique method to produce tool dies used for compression molded Fresnel lenses. The contract included an economic and performance evaluation on the development of a Fresnel parquet. The first phase of the contract called for a new die duplicating the current EPRI compression molded design. Alternatively, Sandia provided a design for an EDM machined lens mold for a compression molded lens. The focal length of this lens was 11.85 inches to 12.35 inches. The lens developed under Sandia's guidance was ultimately not used because of manufacturing cost and performance reasons. Laminated lenses are currently being purchased from 3M Corporation for use in the module assemblies. Current investigations indicate that moisture causes significant expansion of the acrylic lens resulting in a defocusing of the Fresnel lens.

2.2 FRESNEL LENS INSTALLATION

A precise orientation of the Fresnel imaging lens, the SOE and the cell must be maintained. A unitized module housing was developed that provides adequate rigidity, but the Fresnel lens is still subject to warping because of moisture and temperature differentials. This will cause the illumination pattern to shift creating a blurred image on the PV cell. The initial orientation of the Fresnel imaging lens is dependent on a precise knowledge of the center of the lens. Drawing 11 shows the difference between the optical center of the lensfilm as measured from the edge of each lens by a cordex machine relative to the physical center of each lens as measured from each edge of the lens parquet. A two parquet section was used for the measurements.

Vertical positioning of the parquet is not so critical because the cell tends to increase in efficiency as the lens decreases in efficiency. As a result, the combined lens/cell efficiency remains flat for a lens/cell spacing between 11.85 and 12.35 inches (11.95 inches is the design point). Appendix E shows results of tests done by Sandia showing module (lens/cell) efficiency versus lens/cell distance.

Initially, the alignment of the parquet was effected by slots or guides in the parquet. The parquet was fastened by means of a shoulder pin to the module housing (Dwg. 13). To prevent the intrusion of moisture as well as to facilitate assembly, the design of the lens assembly was modified so that the alignment of the parquet is effected by use of grooves in the parquet being placed over a weldment on the module housing. Drawing 14 shows the details of the Final Design Assembly Method which is an improvement over the initial design.

2.3 SOLAR CELL THERMAL ANALYSIS

Alpha Solarco has examined the effects of high emissivity paint on the normal operating cell temperature (NOCT). Two modules were used in the study: one module was used as a control and the backplane of the other module was painted with high emissivity paint. The objective of painting the module backplane was to increase the radiative heat loss of the backplane thereby lowering the NOCT. The backplanes of both modules were wired with thermocouples and then both modules were mounted on a tracker at Sandia. Temperature readings were taken while the modules were exposed to the sun and no significant differences between the backplane temperatures of the two modules were detected.

The application of high emissivity paint requires four separate operations: cleaning, etching, priming, and painting. A drying operation is required after the etching, priming, and painting steps. Each of these operations adds to the manufacturing time and materials cost of a module.

To aid in the determination of the effectiveness of the high emissivity paint, the modules were examined with an Inframetrics Infrared (IR) system and thermocouples were placed on the module's backplanes. The IR system was used to thermally image the backplanes. On the painted module, the backplane beneath the cell assemblies could clearly be distinguished as quasi-isothermal discs with the temperature decreasing as the radius from the cell centers increased. The IR system showed that there was a variation of a few degrees Centigrade between cell centers which could have been, at least partially, due to slight misalignment. The non-painted module appeared to act as an IR mirror and no useful information could be obtained from it with the IR system. The thermocouple data were used to determine that the paint provided no appreciable gain.[12] This testing has demonstrated that the IR system can provide valuable information of a quality that has not been previously available through other techniques.

High emissivity paint is only cost effective if the cell temperatures are decreased sufficiently to increase the operational efficiency. The high cost of the high emissivity paint does not justify its use in the manufacture of the modules.

2.4 ANTI-RADIATION SHIELDING

Alpha Solarco investigated a more effective anti-radiation device to shield the conformal coating. Severe damage to the conformal coating was caused by misfocussed high intensity light during off-track conditions. Two designs were considered. One design was a reflective cone such that all off-track rays would either strike the inside or outside of the cone and never reach the conformal coating.

The other design used a piece of reflective foil shaped as shown in Drawing 12, Anti-Radiation Shielding, providing entrance apertures for each SOE such that off-track rays could not reach the bottom of the module housing and cause damage to the coating. This design required 12 such shields for each of the 24-cell modules. This design was implemented for reasons of cost and ease of installation.

2.5 ADHESIVE EVALUATION

Alpha Solarco has examined the adhesive used to attach the heat spreader to the module backplane. Previously, a thermal cure adhesive was used that required six hours in a heated room to cure properly. The large size of the module necessitates the use of a very large curing room with significant energy requirements. The cost of this process was enough to warrant an evaluation of pressure sensitive adhesives that cure at room temperature in an attempt to find a replacement adhesive.

The POCA modules had used a thermal-cure adhesive to bond a Kapton film electrical insulator between the heat spreader and the bottom of the module. The thermal cure adhesive required approximately six hours at 60 °C to cure properly. This same adhesive was also used in test modules made under this contract, where Danar film was substituted for Kapton.

Five different adhesives were evaluated for their ability to electrically insulate as well as mechanically bond heat spreaders to aluminum squares. The results of this test is in the Hi-Pot/Pull Test Table below. The five adhesives tested were 7100, R1004, 1751, 5000 and M6366. Samples were prepared with and without a Danar interface(D and N respectively in the first column of the Hi-Pot/Pull Test Table). Most samples failed the Hi-Pot without Danar. Two samples using the 7100 material did pass while the third failed at 1800 VDC. The pull test results were adequate for all candidate materials. Six samples of the 5000 material showed uncured sections even though all samples were left undisturbed for at least seven days. The visual inspection of the samples after the pull tests did not indicate more uniform adhesion than observed in the current adhesive/Danar/adhesive coupling schema. The results are summarized in Table 3.

The replacement of the thermal cure adhesive with a pressure sensitive adhesive is one solution to the negative aspects of the materials requiring curing. To determine if this new technique would significantly affect cell temperature, a submodule with eight cell assemblies was made. Half of these cell assemblies used Danar and the thermal cure adhesive, while the other half used Danar and the pressure sensitive adhesive. The dielectric films were of equal thickness, about 0.025mm, as were the adhesives, about 0.05 mm on each side of the insulator. The submodule's backplane was covered with a high emissivity paint and the submodule was mounted on a tracker at Sandia with the backplane imaged by an Inframetric IR system. There did not appear to be any significant temperature differences in the cell assemblies based on the adhesives.[13] However, upon disassembly, an inspection revealed significant void areas with both types of adhesive. Perhaps, it may be possible to improve the thermal transfer properties of the modules if adhesives can be obtained which will fill the voids created by the surface variability of both the heat spreaders and the bottoms of the modules. A smoother module housing bottom is expected as a result of anticipated module housing tooling changes. The submodule was subjected to the module thermal cycle protocol and re-examined with the IR system upon completion. Again, there did not appear to be any material temperature differences based on the different adhesives.[13] The IR scans did indicate about a 13 °C temperature difference between the backplane directly below the cell areas and that of the backplane along the long axis of the module equidistant from cell assemblies. This may indicate that the backplane is not optimally dissipating the thermal energy. The efficiency might be improved by a redesign of the heat spreader.

TABLE 3 HI-POT/ PULL TEST RESULTS

ADHESIVE SAMPLE	HI POT VDC FOR >=50uAMP	PULL TEST (pounds)	BOTTOM CONNECT PULL AWAY (pounds)
7100 N1	1800		124
7100 N2	3000+		93
7100 N3	3000+		146
7100 D1	3000+		~200
7100 D2	3000+		118
7100 D3	3000+		95
R1004 N1	1500	107	
R1004 N2	750	52	
R1004 N3	1000	64	
R1004 D1	3000+	90	
R1004 D2	3000+	67	
R1004 D3	3000+		73
1751 N1	250		146
1751 N2	250		83<>116
1751 N3	250		<83
1751 D1	3000+		63
1751 D2	3000+		93
1751 D3	3000+		139
5000 N1	1250	~44*	
5000 N2	1500	62*	
5000 N3	2350	53*	
5000 D1	3000	75*	
5000 D2	3000	74*	
5000 D3	3000	95*	
M6366 N1	150	78	
M6366 N2	500		74
M6366 N3	2000	74	
M6366 D1	3000	34	
M6366 D1	3000	32.5	
M6366 N1	3000	23.5	

* Uncured in center

2.6 MODULE MOISTURE RELIEF STUDIES

Alpha Solarco has improved the moisture handling capabilities of the AS-225 module. Previous water spray tests performed at Sandia found that some of the moisture from the test was not able to flow out of the drain valve. Consequently, the water remained in the modules for several days and was not adequately relieved by the two venturi-type air vents.

Two mechanical design modifications were made to address this problem (Dwgs 13,14,15,16). A medium density, UV resistant neoprene gasket material was identified to seal between the Fresnel parquet and the module housing. The other design modification involved increasing the number of air vents in the module bulkheads to allow for greater convection through the module. Modules produced with these modifications were more water resistant than the POCA modules however, some residual water still remained after completion of the water spray tests. The extreme thermal cycling nature of a concentrator module may make it impractical to eliminate the entry of all moisture. The interior of the module, therefore, should be designed to safely withstand a wet condition.

The gasket was tested for both UV resistance and for the mechanical strength of its adhesive. The material was tested for UV resistance by exposing a sample of the material to an in-house UV source for a period of one month. After one month, the surface of the samples developed a slight powder which was easily removed with no significant degradation of the material beneath. Pull tests were made on the irradiated samples to evaluate the adhesive strength and the stretch of the foam material.

Two other methods of sealing the modules were evaluated before selecting neoprene as a gasket material. First, a module was constructed for testing which used Butyl tape to seal the lens to the bezel. This form of caulking was inadequate and was abandoned. The second module was constructed using a combination of Butyl caulking and Acrylic Latex pre-form bead in the sealing area. Testing indicated that a minimum amount of water entered the module. However, the Butyl caulking had a tendency to creep onto the active area of the parquet and was difficult to remove. Because this method seemed incompatible with a high production volume, it was also abandoned.

2.7 WET HI-POT TESTING

Hi-Pot testing consists of measuring the leakage current between the cell assembly heat spreader and the aluminum module housing when these two elements are at a 2500 volt potential relative to each other. In the case of the Wet Hi-Pot Testing the unit to be tested is soaked for 5 days and temperature cycled and then the leakage current is tested in the same manner as in the dry Hi-Pot Testing. Modules are rejected if the leakage current is above 50 microamps. Criteria used for the Hi-Pot testing are detailed in the Sandia Document Qualification Tests for Photovoltaic Concentrator Modules SAND 86-2473.

All module housings are electrically isolated from their internal subassemblies to prevent personal injury from contact during maintainance, repairs or array operation. Each cell assembly heat spreader is isolated from the module housing with a dielectric. Three different methods of electrically insulating cell assemblies and modules were examined:

1) One insulation method utilizes two pieces of Danar as the insulating material. One square piece of Danar (4" x 4" x 0.002") is placed between the heat spreader and the module housing electrically isolating the cell assembly from the module housing. The other piece of Danar (3" x 3" x 0.002"), has a hole in the center of it to accomodate the solar cell. This insulator prevents the top cell contact from touching the heat spreader and creating a short circuit. This is the method of manufacture currently in use. This method was tested and developed in the following manner.

Sheets cut from module bottoms were impressed with cell assembly detents (CADs) and adhesive coated danar was placed on the sheets over these detents. Next, the cell assemblies were placed on the Danar after their bottoms were coated with 0.002 inch thick Norwood adhesive. About 50% of these modules failed the Hi-Pot test. Analysis indicated that the CADs were too tall, which meant that the Danar was stretched too much as it made the bend in the detent. The Danar thickness ranged from 0.001 to 0.0003 inches. This agrees with the failure voltage of about 2000 VDC. New sections were cut from the module housings such that they were several inches deep and with relatively flat bottoms. New CADs were then specified having sides of 0.040-0.045 inches tall. Again Danar was applied to one of the sections and it was noted that there was some air entrapment. Hi-Pot testing followed. Still, many units failed the Hi-Pot test. At this point, the CADs were flattened with a hammer to a height of 0.020-0.030 inches. After this, Danar was again applied. All cells then passed the Hi-Pot test showing less that 1 micro-amp leakage at 3000V and air entrapment was subsequently found to be less. The air entrapment resulted from the adhesive insulation material not making uniform and complete contact between the heat spreader and the module housing. This was determined later by removing the cell assemblies from the test specimens and examining the interface surfaces.

2) Another approach examined the use of 3 mil polyethylene laminated to the module housing with the cell assembly bonded directly to the polyethylene. This approach promises to offer a module that will be effective against moisture. Initial pull tests were conducted on heat spreaders bonded directly to the polyethelene with a spray adhesive which, when tested, showed a holding power of 38-50 lbs. After the samples were heat cycled about 180 times (-40 - +60 deg. °C) their holding power fell to 17 lbs.

3) Other commercially available materials were also evaluated as a direct application conformal coating. Most of those dielectrics evaluated met the requirements for the dry Hi-Pot Test but failed significantly when tested under wet conditions.

See the tabulation of Hi-Pot/Pull Test Results in Section 2.5.

2.8 HEAT SPREADER PREPARATION

Five methods of preparing the heat spreader (Dwg. 17) for soldering were examined. The objective of this study was to reduce the cost of the process by reducing the amount of acid cleaning required.

One method of preparation used an abrasive palm sander. Initial results indicated that scratches in the heat spreaders were responsible for nonuniformities in ultrasonic images of some cell assemblies.

Abrasive tumbling was investigated as an alternate method of preparation. This method failed as a manufacturing process because the process relies on a cleaner that contains small quantities of chlorine preventing proper solder adhesion. At one point one dozen heat spreaders were abrasively cleaned and solder silkscreened. Upon the initial melt, it was noted that solder was not adhereing properly to these heat spreaders. Several of these heat spreaders were analyzed at UDRI. The results indicated minute quantities of chlorine present on the heat spreaders. Apparently the abrasive tumbling process uses a "citrus" based cleaner which an analysis showed to contain small quantities of chlorine. This method is promising provided that an appropriate cleaning agent can be identified.

Another cleaning technique was examined wherein the heat spreader was immersed in a 10% HCl solution and then thoroughly rinsed with distilled water and IPA. The acid solution did clean the copper well, however the chlorine was not satisfactorily removed by the rinse.

One method that worked very well involved washing the heat spreader in detergent to remove the mill oil, and then abrasively cleaning it using 1200 grit silicon carbide, 000 steel wool and a fine wire brush. This method was abandoned for a less labor intensive fifth alternative.

The most cost effective and least labor intensive method involves immersing the heat spreader for 30 seconds in an acid solution of the following composition.

17% H_2SO_4
66% H_2O
17% HNO_3

Excellent solder bonds resulted from heat spreaders cleaned in this manner.

3.0 QUALITY ASSURANCE PLAN

A quality control program was developed that defines procedures for the manufacture, inspection, and testing of the product from raw material incoming inspection to the final testing and packaging of the outgoing material. The projected lifetime of the product is 20 years in a field environment. In order to provide a product that meets these specifications, Alpha Solarco has based QA/QC procedures on military specification MIL-Q-9858A and guidelines provided by Sandia. The QA/QC Manual is provided in Appendix D.

4.0 CELL AND MODULE ASSEMBLY PRODUCTION ENGINEERING

4.1 AUTOMATED CELL TESTING

Alpha Solarco has developed an advanced flash tester for the automated testing of cell assemblies. The Cell Assembly Flash Tester (CAFT) measures the electrical performance of a solar cell under both 400X and 1X sun light intensity and is corrected to a standard cell temperature of 25 °C. The results of the test are displayed graphically on a computer. Solar cells are then grouped according to their current output at the maximum power voltage (Vmp) and stored for later use.

This flash tester incorporates a major improvement over other flash testers currently available on the market. The power suppy of the light incorporates a delay line concept that produces a broad light pulse of 3-4 ms duration that allows a complete current and voltage (IV) characteristic to be taken within one pulse of the light. Figure 18 shows a typical IV curve from the Cell Assembly Flash Tester. Figure 19 shows a measurement of the light intensity as a function of time. In addition, the intensity of the light remains constant within 1% during the period of measurement. This improvement increases overall manufacturing throughput as well as increased light stability for the duration of the test.

The CAFT consists of four main pieces of equipment: light source, electronic load, computer/data acquisition system and test fixture. A block diagram of the Cell Assembly Flash Tester is shown in Dwg. 20. A computer/data acquisition system monitors and controls the performance testing from start to completion. The computer sends signals to and receives signals from the light source and electronic load via the data acquisition system. The computer samples the current, voltage and temperature and controls the bias voltage of the solar cell during the electrical performance test. In addition, the computer/data acquisition system is reponsible for triggering the lamp flash and monitoring the charge status of the Xenon lamp. The test process is complete when the bias voltage of the cell is greater than the open circuit voltage (Voc) of the cell.

4.2 ALIGNMENT TECHNIQUES

Procedure to align the cell assembly on the module backplane

Placement of the cell assemblies must be done very accurately to assure alignment of the SOE at the focus of the primary lens. Initially, positioning of the cell assembly was accomplished by use of detents impressed into the bottom of the module housing. (See discussion in section 2.71 - Hi-Pot Testing). This method of alignment was superseded by a technique employing three holes in the heat spreader. See Drawing 17.

Procedure to align the cell on the heat spreader

Alignment of the cell on the heat spreader is important because it can affect the way light is spread over the cell (See section 1.3 - SOE shapes). Once this step is completed, the alignment of the primary and secondary elements is essentially determined, because the placement of the cell assembly onto the backplane does not allow for adjustments. A test was run to determine the accuracy of cell placement on the heat spreader. Drawing 19 is a polar plot of the placement error and Drawing 20 is a histogram displaying the number of cells versus placement error.

The procedure to do the cell alignment involves two steps:
(1) The upper piece of Danar is aligned to the heat spreader making use of the two pins shown in Drawing 4 and Figure 4.
(2) The solar cell, to be soldered to the heat spreader, is then accurately aligned with the hole in the center of the Danar.

4.3 AUTOMATED MODULE TESTING

Alpha Solarco has developed an advanced flash tester for the automated testing of modules. The Module Flash Tester (MFT) measures the electrical performance of a module under 1000 W/m^2 illumination and corrects the results of the test to a standard cell temperature of 25 °C. The results of the test are displayed graphically on a computer. Modules are then grouped according to their current output at the maximum power voltage (Vmp) and stored for later use.

This flash tester incorporates a major improvement over other flash testers currently available on the market. The power suppy of the light incorporates a delay line concept that produces a broad light pulse of 6-8 ms duration that allows a complete current and voltage (IV) characteristic to be taken within one pulse of the light. Figure 2 shows a typical module IV characteristic. Figure 20 shows a measurement of the light intensity of the xenon lamp as a function of time. In addition, the light intensity varies less than 2% during the measurement time period. The increased stability of the light permits an accurate IV curve to be taken within one flash of the lamp while preventing an increase in the temperature of the solar module.

The MFT consists of four main pieces of equipment: light source, electronic load, computer/data acquisition system and test fixture. A block diagram of the Module Flash Tester is shown in Dwg. 21. A computer/data acquisition system monitors and controls the performance testing from start to completion. The computer sends signals to and receives signals from the light source and electronic load via the data acquisition system. The computer samples the current, voltage and temperature and controls the bias voltage of the solar cell during the electrical performance test. In addition, the computer/data acquisition system is reponsible for triggering the lamp flash and monitoring the charge status of the Xenon lamp. The test process is complete when the bias voltage of the cell is greater than the open circuit voltage (Voc) of the cell. Figure 2 shows a typical IV curve from the Module Flash Tester.

5.0 RESULTS

In response to Sandia contract No. 40-8941D, Alpha Solarco has redesigned its cell assembly to prevent further failures of the secondary optical elements and modified the manufacturing techniques necessary to produce these cell assemblies for production. This report has described the redesign of the secondary optical element of the installed array at the Pahrump Test Facility as well as other improvements to the cell assembly design, module assembly design and production methods used to manufacture the cell and module assemblies. Some of the major results determined by these investigations include the following:

1) A UV resistant glass was identified for use as a refractive material in concentrating systems.
2) A computer model was developed and tested that accurately predicts the electrical performance of concentrating photovoltaic systems with refractive secondary optical elements.
3) A cleaning agent was identified that removes the flux residue responsible for debonding the secondary optical element from the solar cell.
4) An optical adhesive was identified that can survive the humidity freeze test as well as provide a reliable and optically pure bond.
5) An inexpensive and reliable method was developed to prepare the heat spreader for soldering to the back of the cell.
6) The top contact was modified to provide better contact with the cell buss bar and reduce solder bridging
8) Anti-radiation shielding was designed to shield the conformal coating from off-axis irradiation.
9) A heat sink adhesive was identified that would pass both the pull test and the Hi-Pot qualification tests.
10) The lens/module housing seal was redesigned to prohibit the entry of moisture.
11) The number of holes in each module bulkhead was increased to disperse water vapor more quickly by means of convection.

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FIGURES

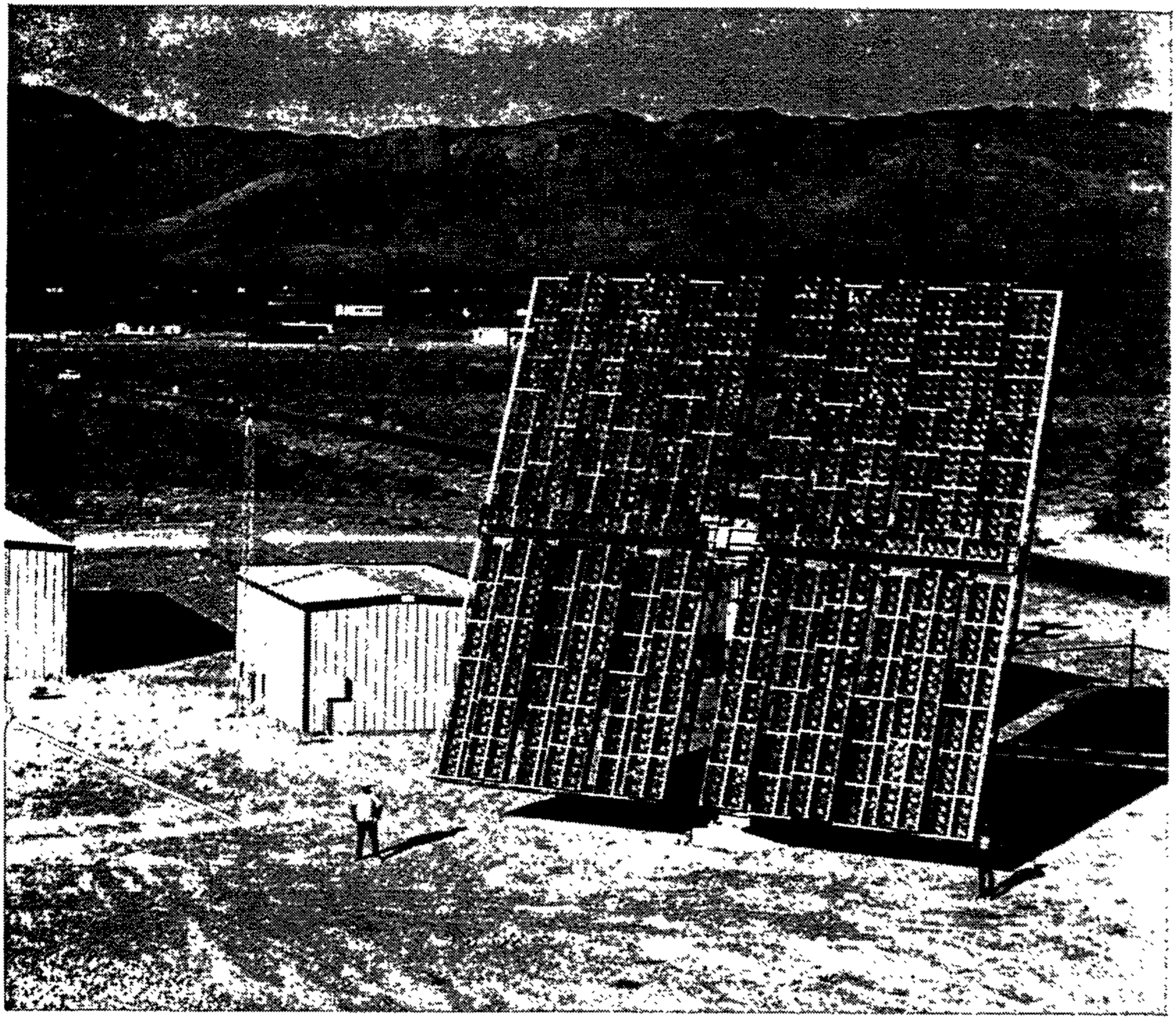


Figure 1. Alpha Solarco's POCA array in Pahrump, Nevada.

Site: P	System: D	Name: D1622
Date: 10-22-93	Module: 16	Misc: 7.7 65.6
Time: 13:10:20		

			Actual	25°C
Irradiance(W/m2)	912.0	Peak Power(Watts)	120.0	166.3
Cell temp(°C)	66.0	I at Peak(Amps)	9.5	10.6
Isc(Amps)	10.2	V at Peak(Volts)	12.6	15.7
Voc(Volts)	15.9	Fill Factor(%)	74.0	

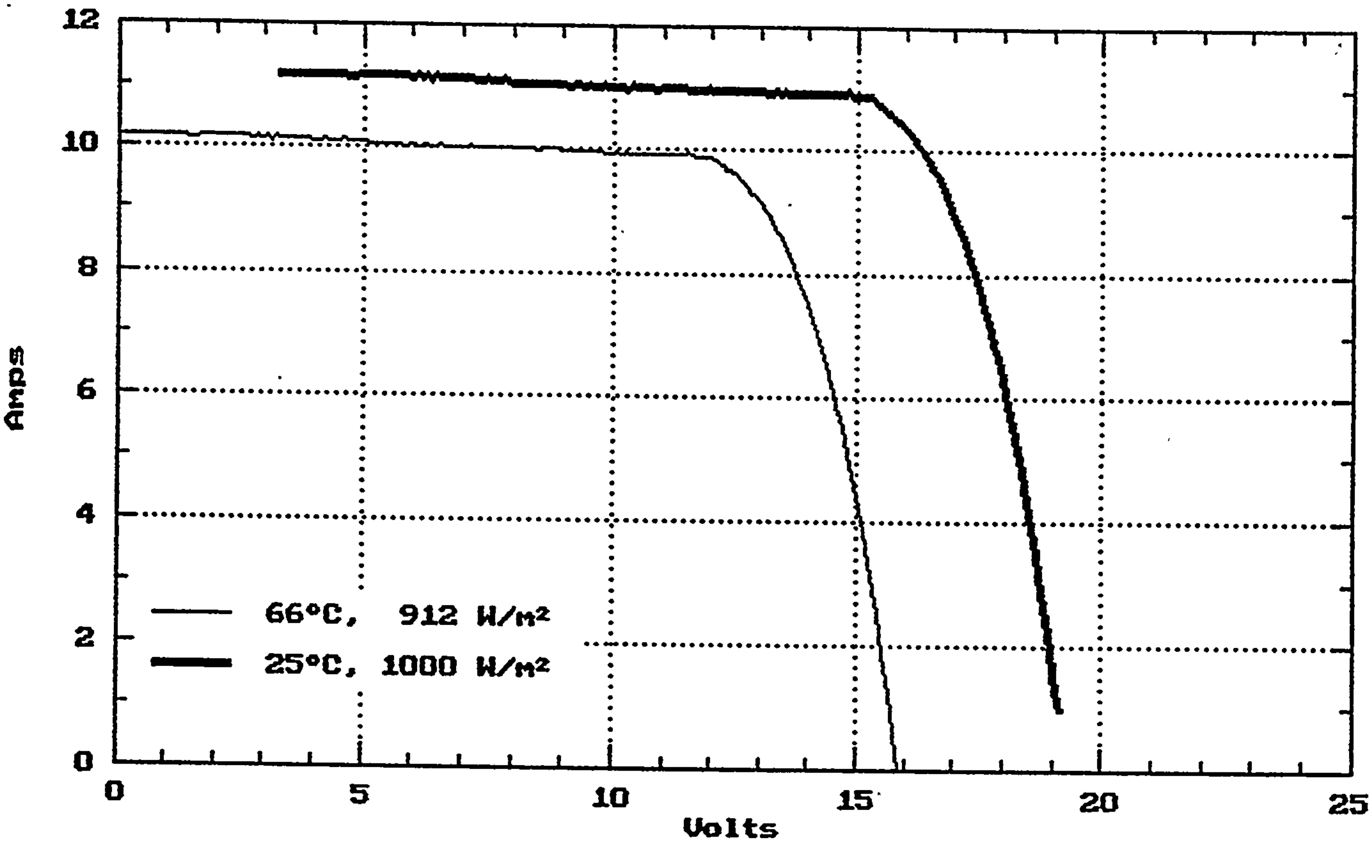


Figure 2. Module IV Characteristic

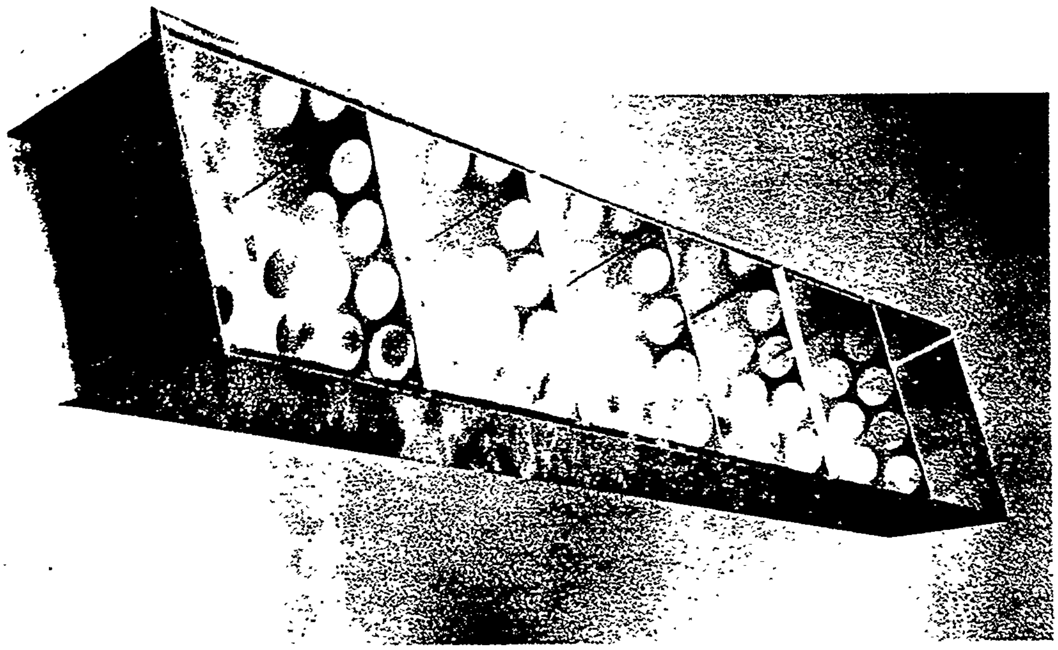


Figure 3. Aluminum Module Housing

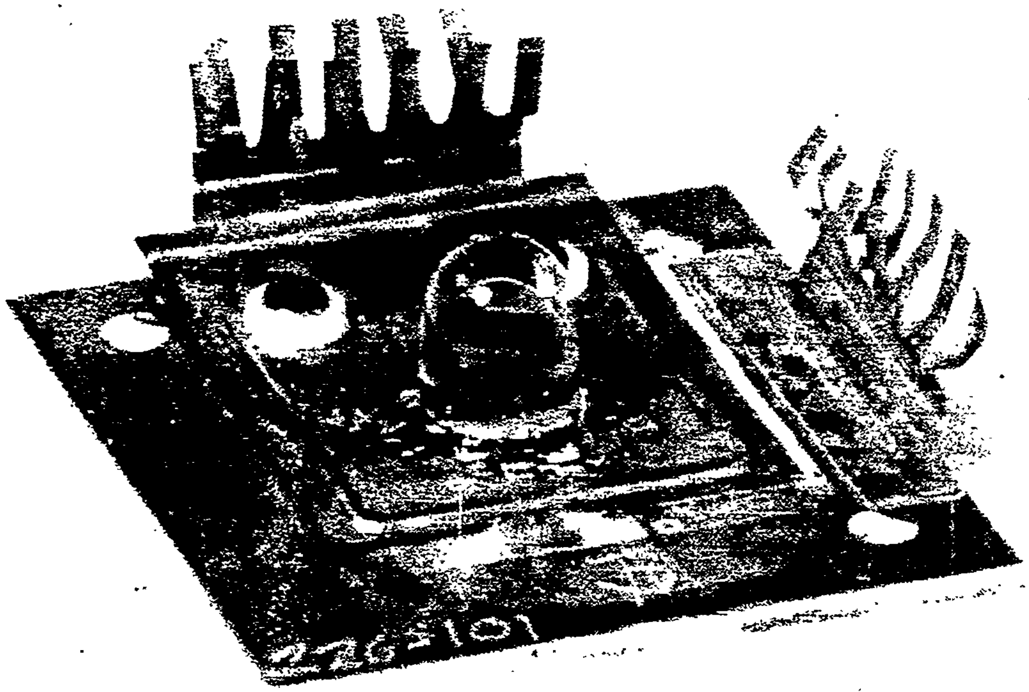


Figure 4. Cell Assembly

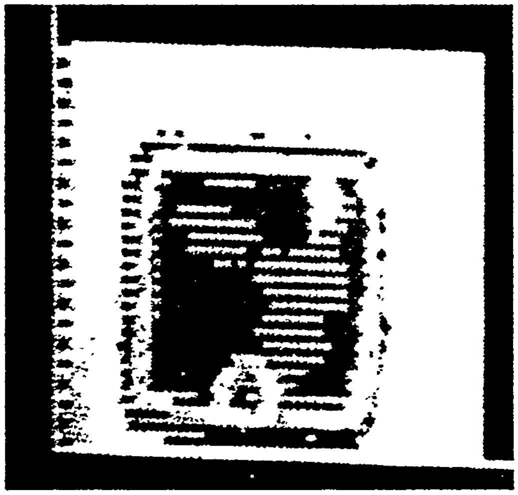


Figure 5. IR Solder Test

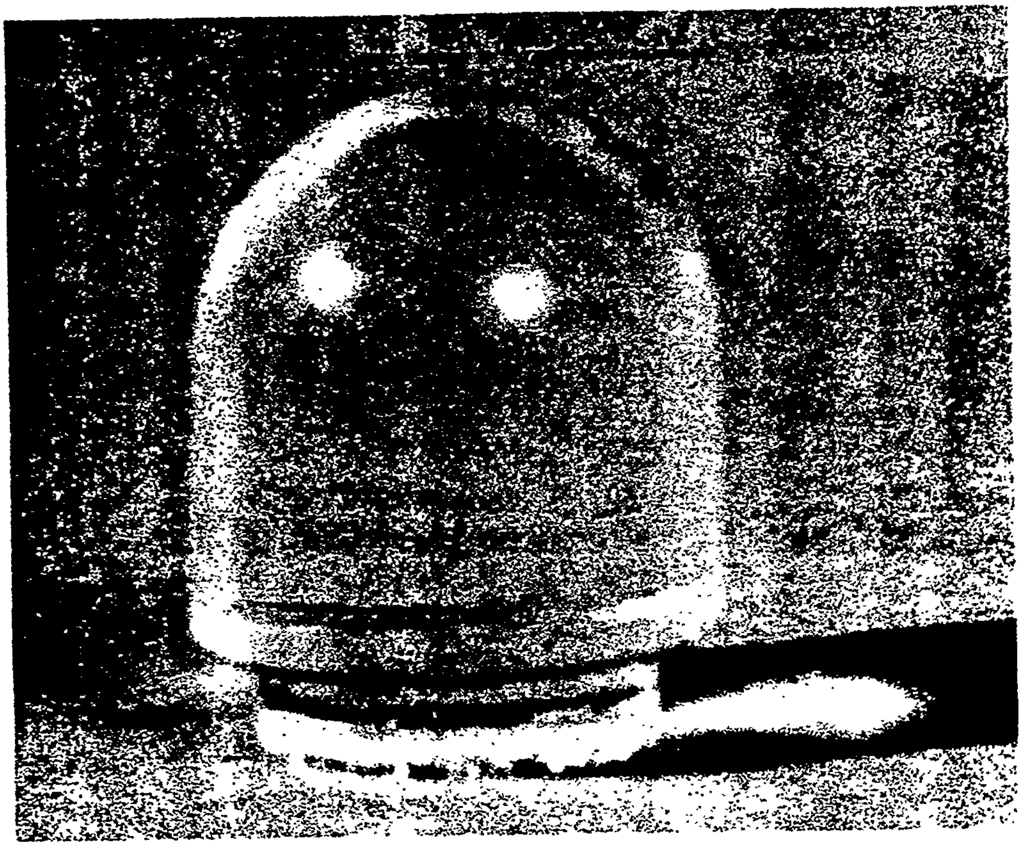


Figure 6. Haystack SOE

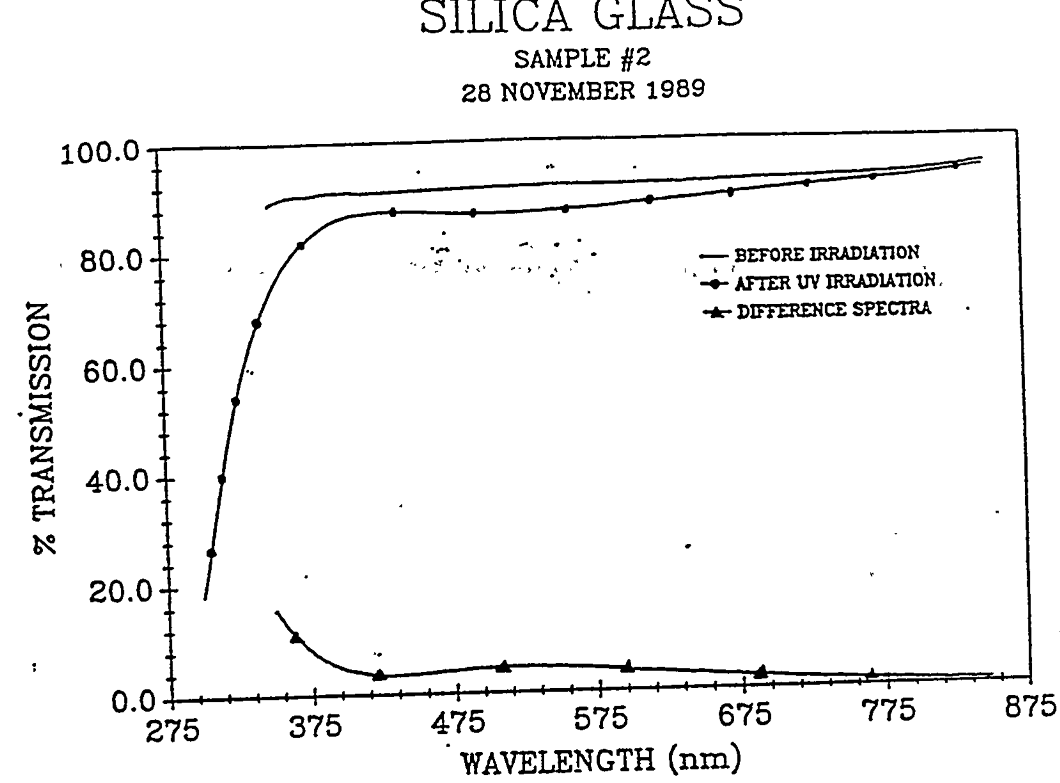


Figure 7. Silica Glass Transmission Curves

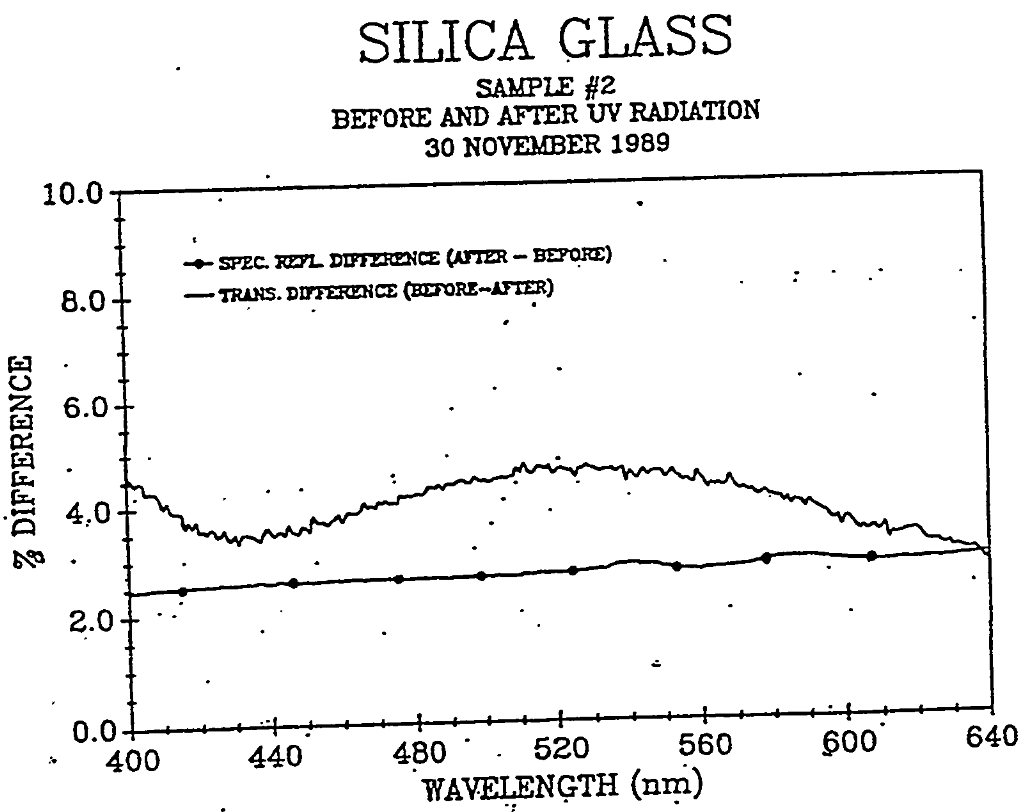


Figure 8. Silica Glass Percent Difference Curves

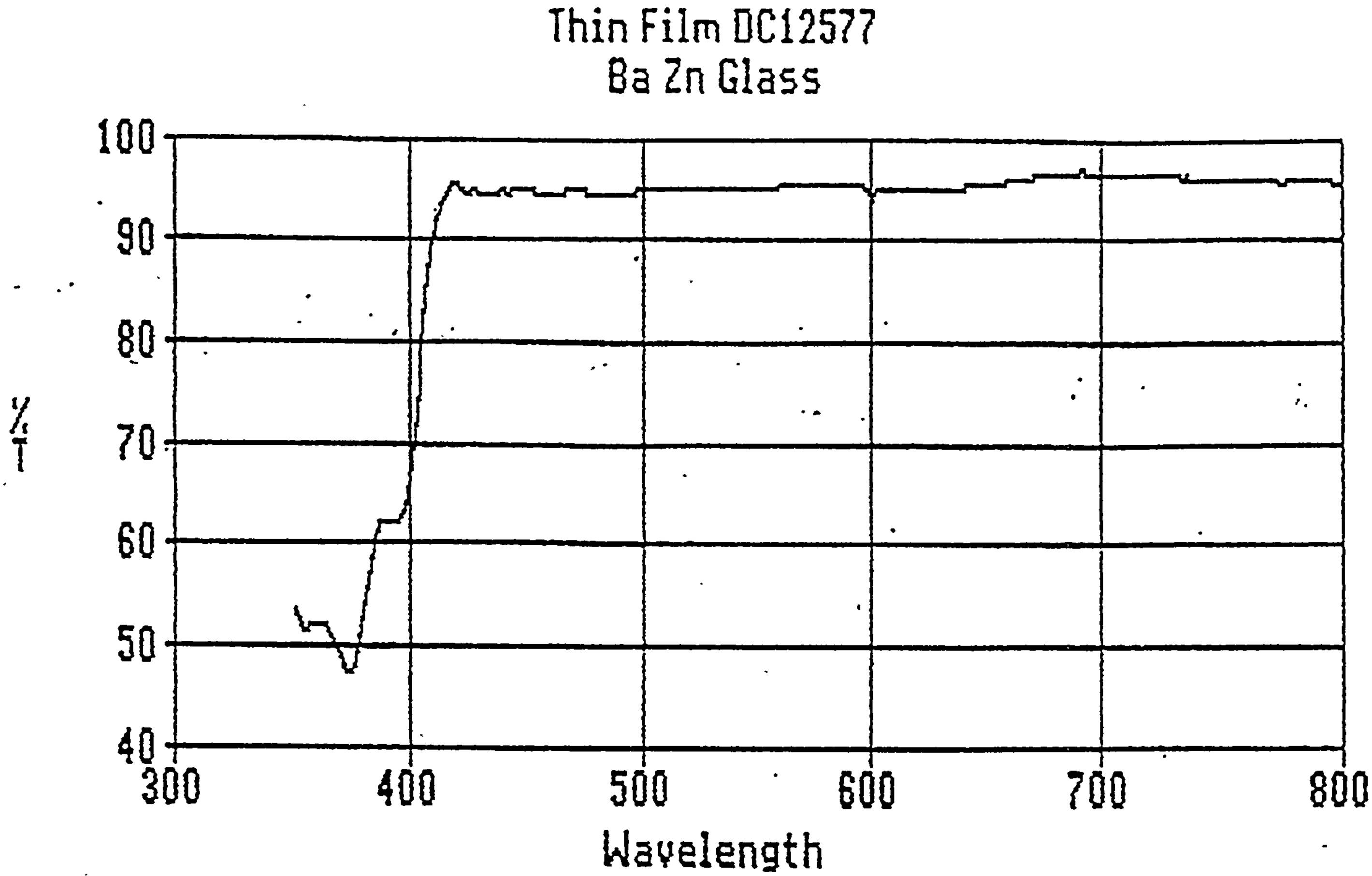
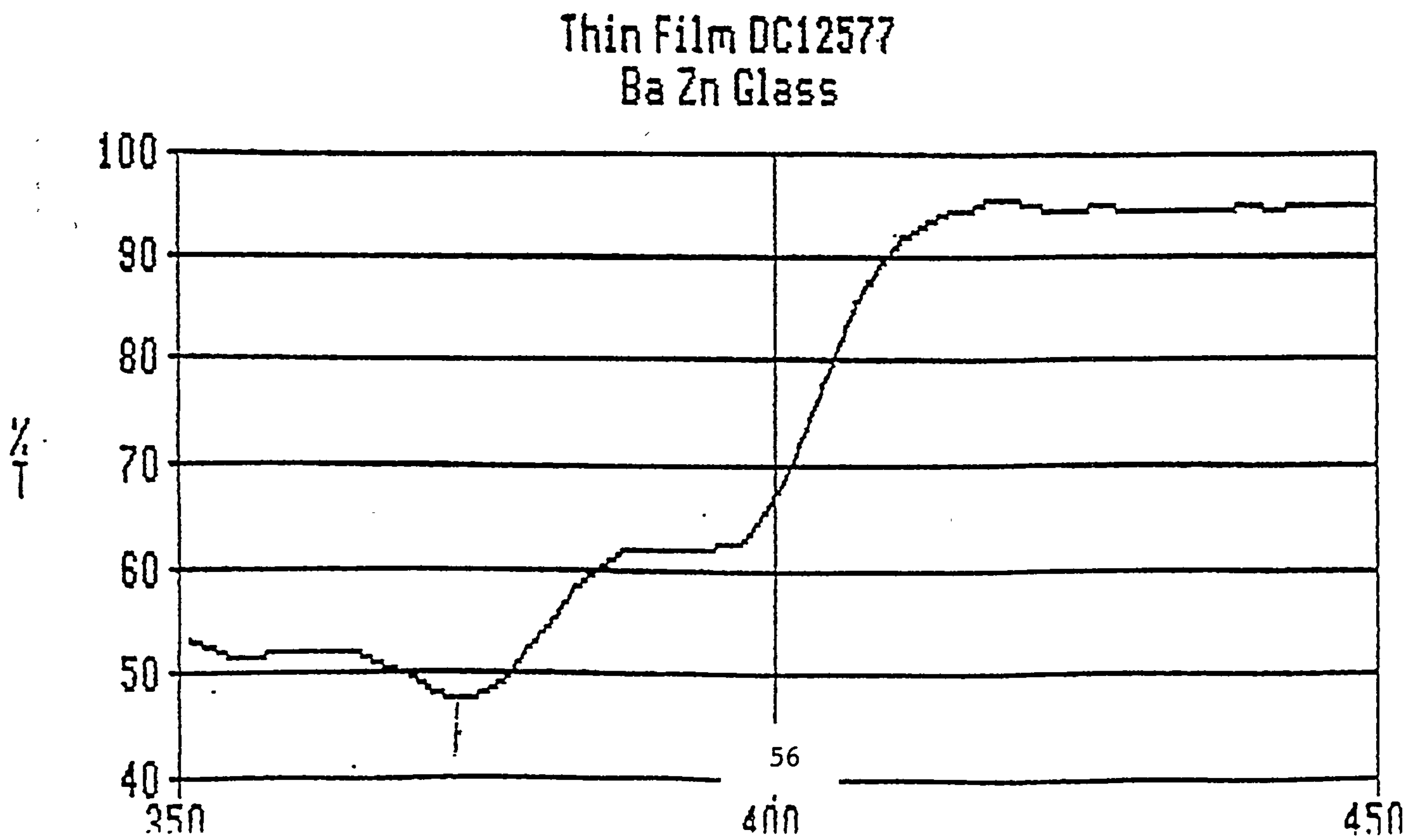
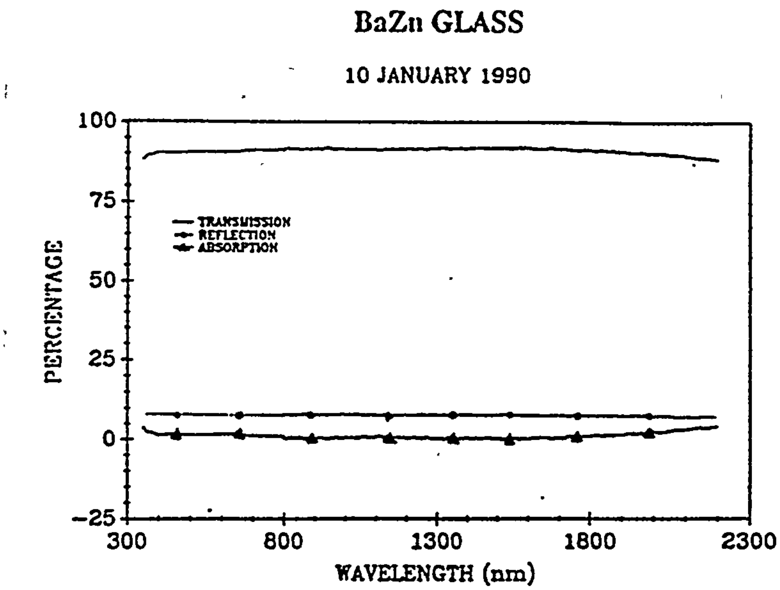


Figure 9. BaZn Glass Transmission Curve





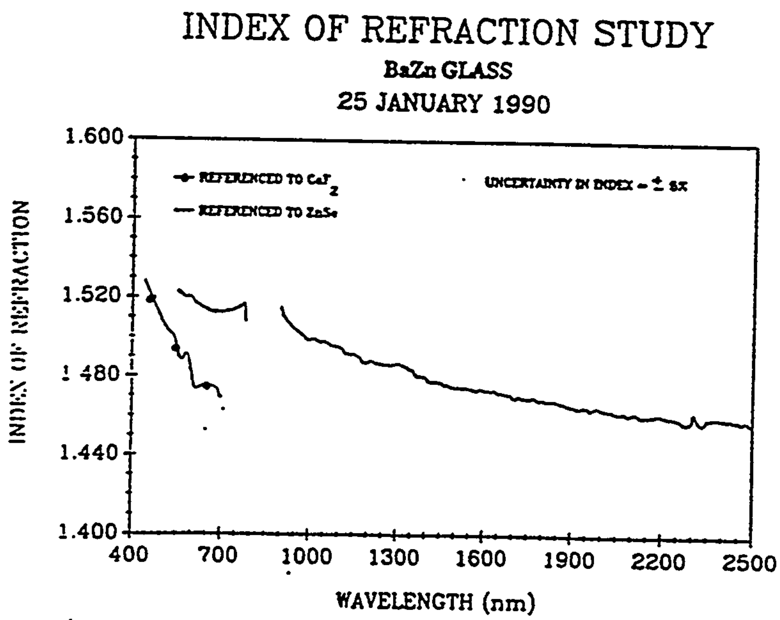


Figure 10. Index of Refraction for BaZn Glass

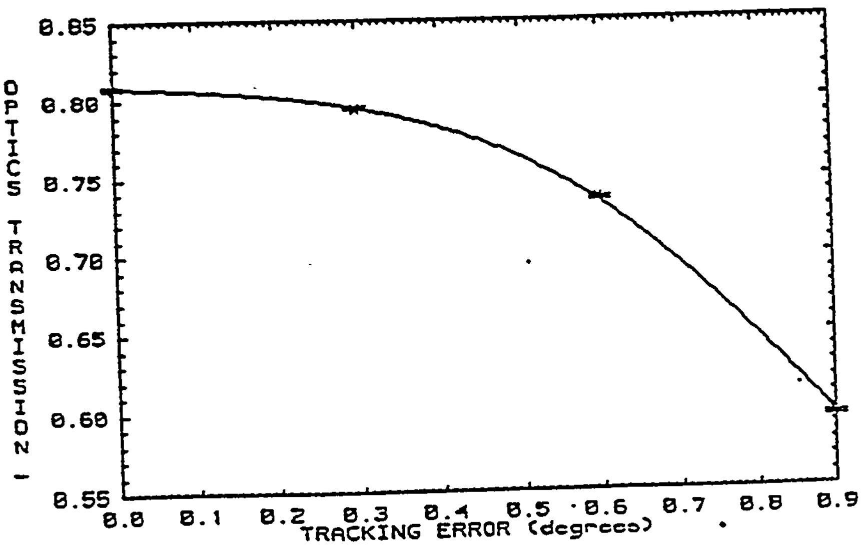


Figure 11. Cell Assembly Off-Track Performance

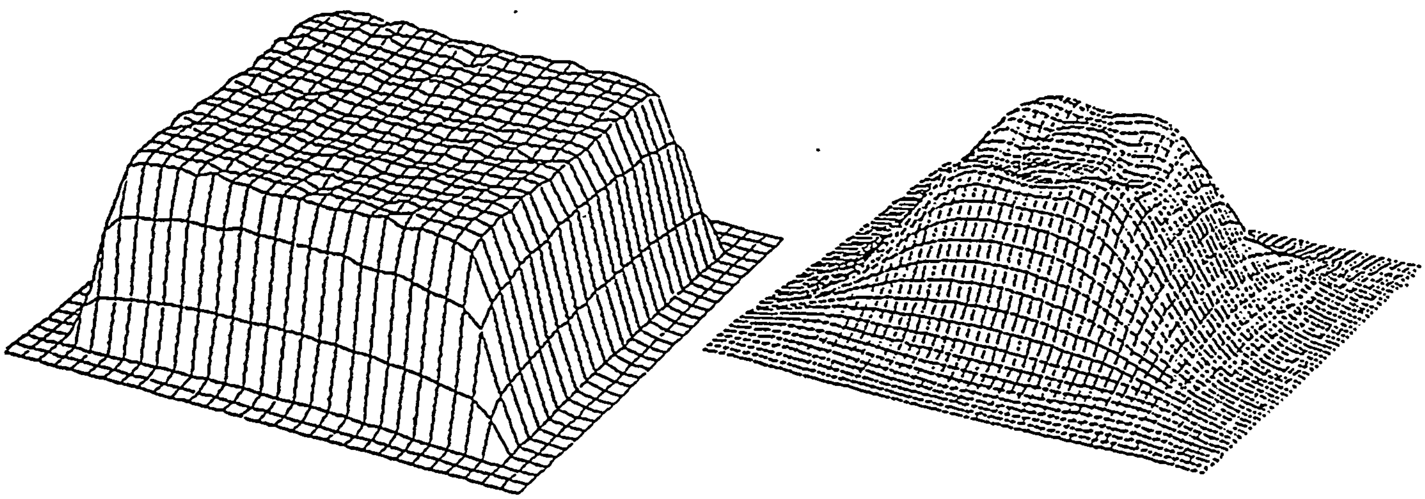


Figure 12. Flux Distribution

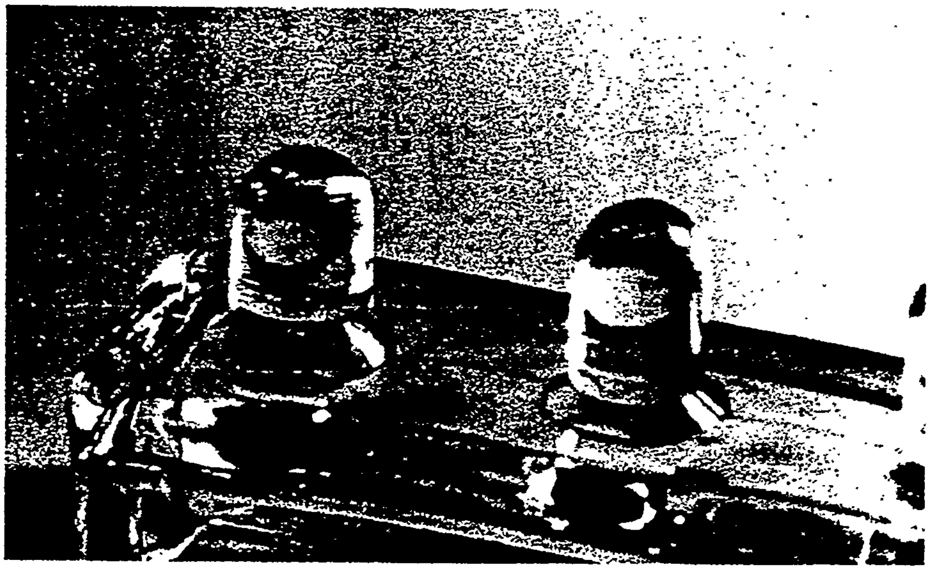


Figure 13. SOE Matrix

Sample: BK7 - SAMPLE 2 - 40 Hour Etch Time
Spectra: Transmission
Date : 11 - March -91

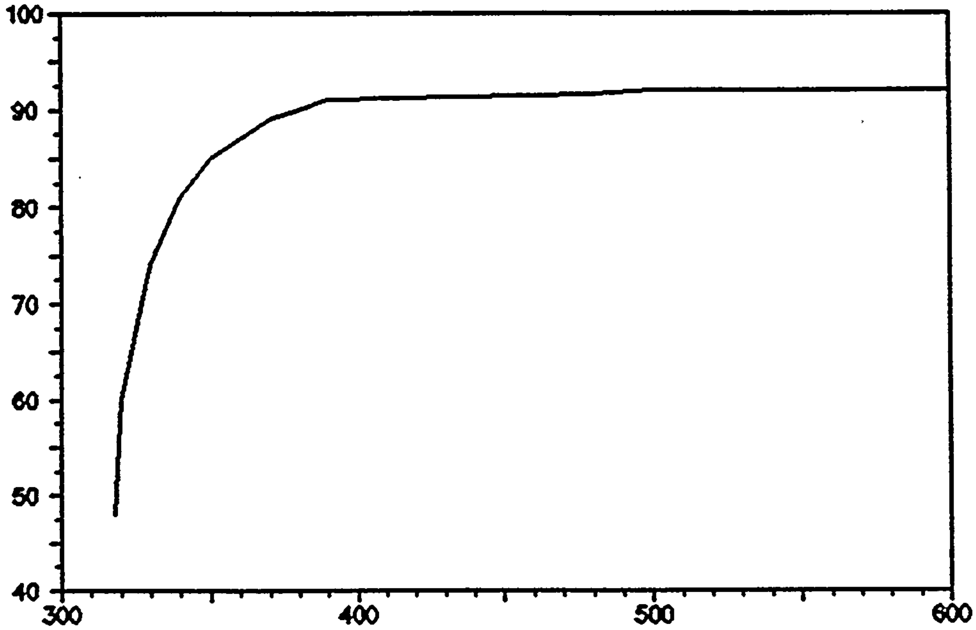


Figure 14. BK-7 Transmission 40 Hour Etch

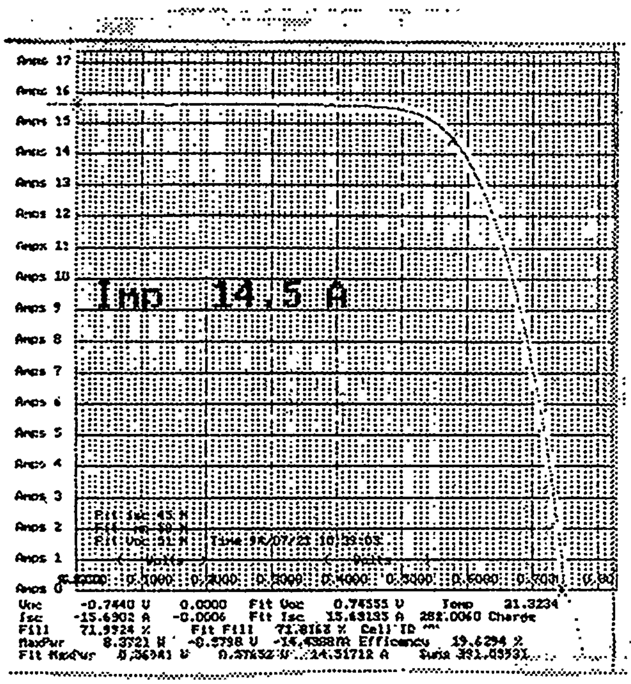


Figure 15. IV Curve from the Alpha Solarco Cell Tester

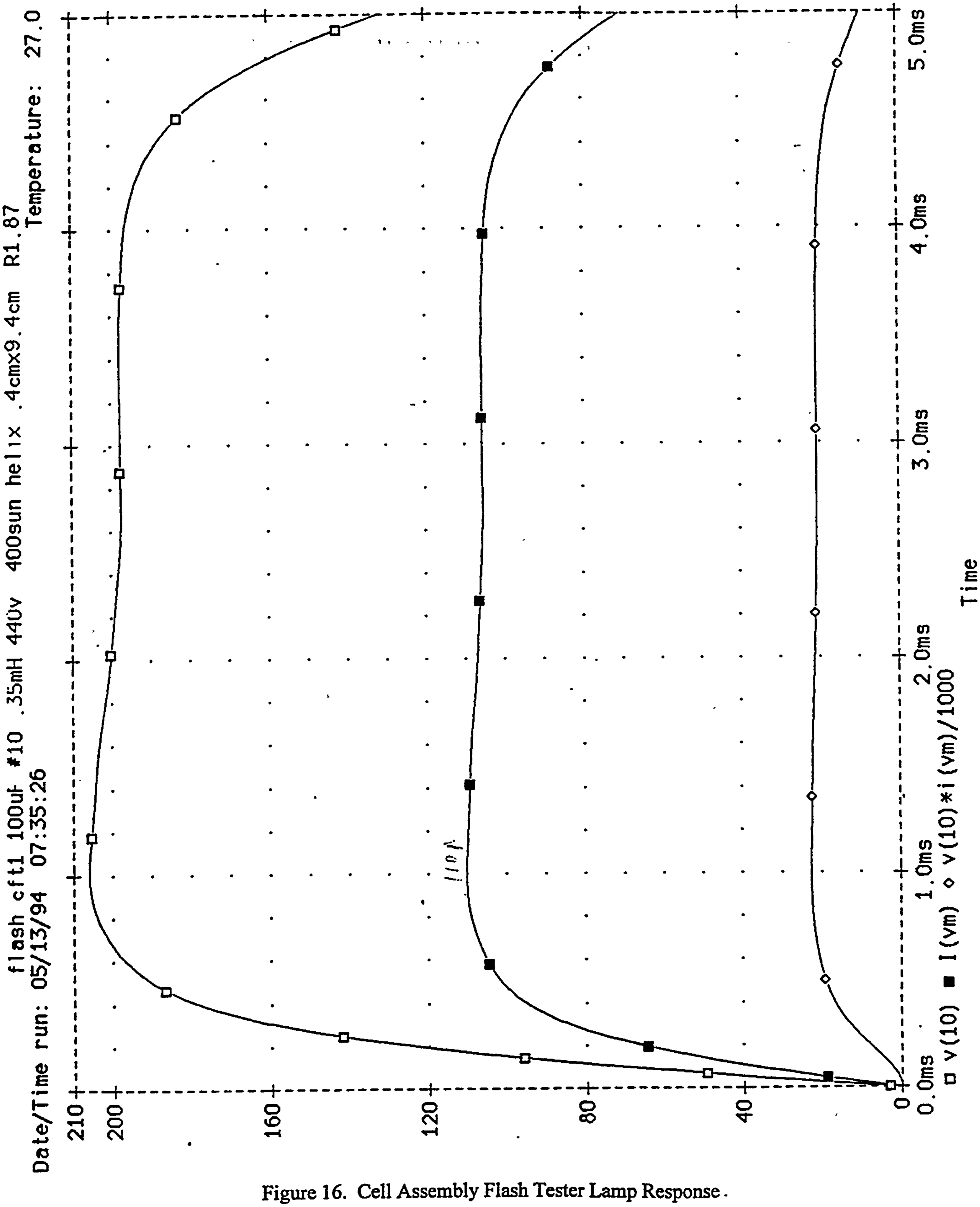


Figure 16. Cell Assembly Flash Tester Lamp Response.

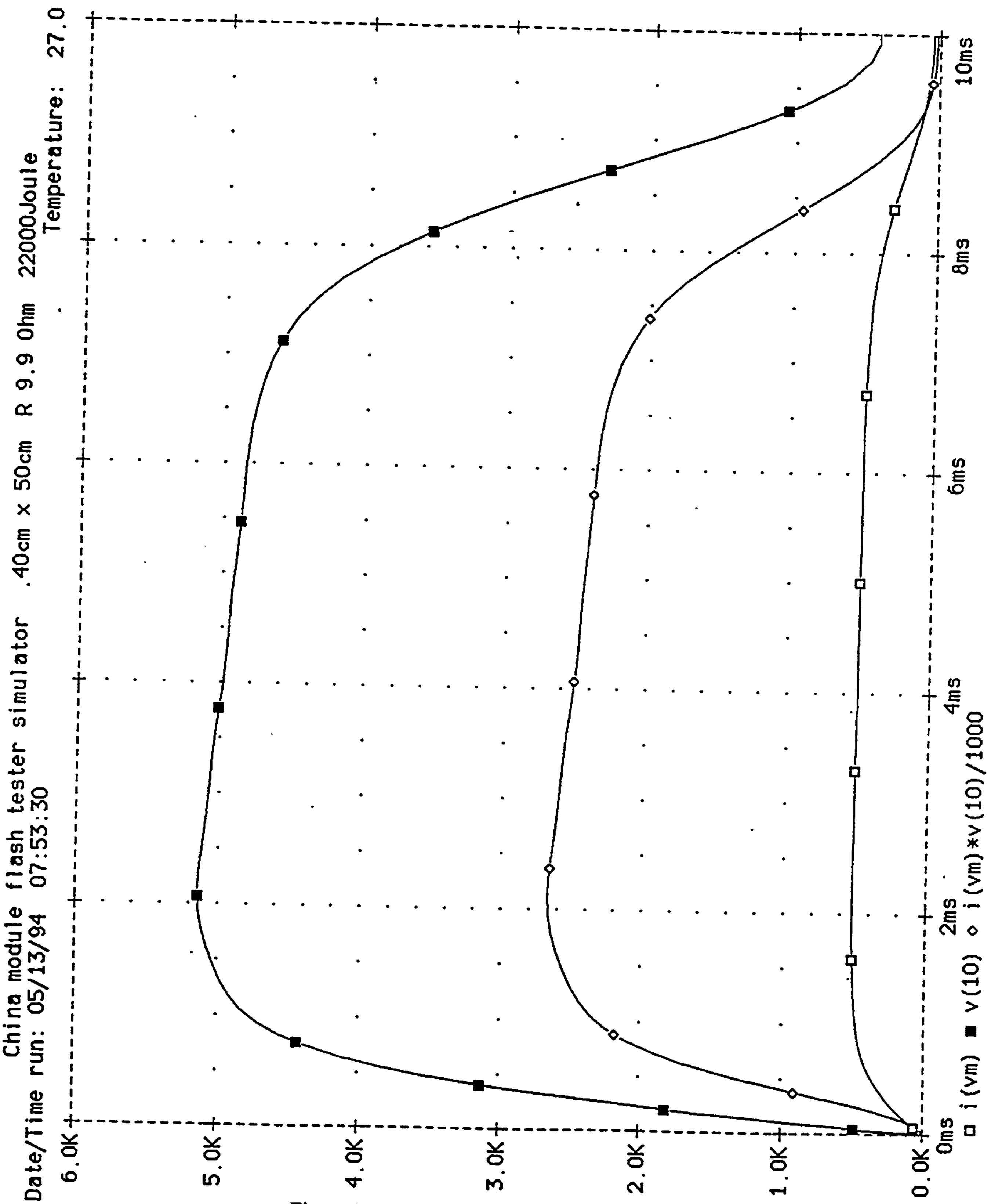
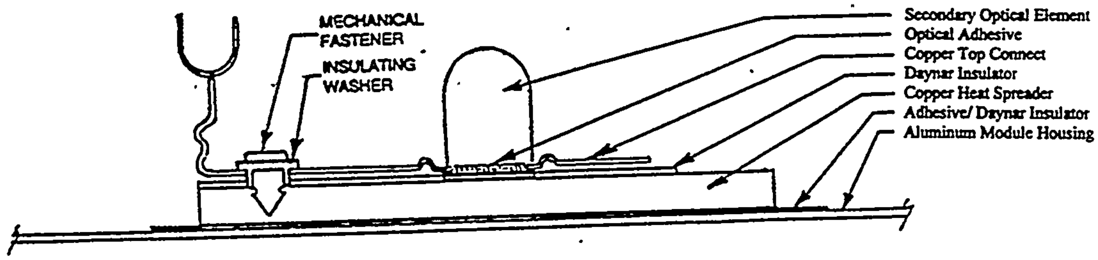
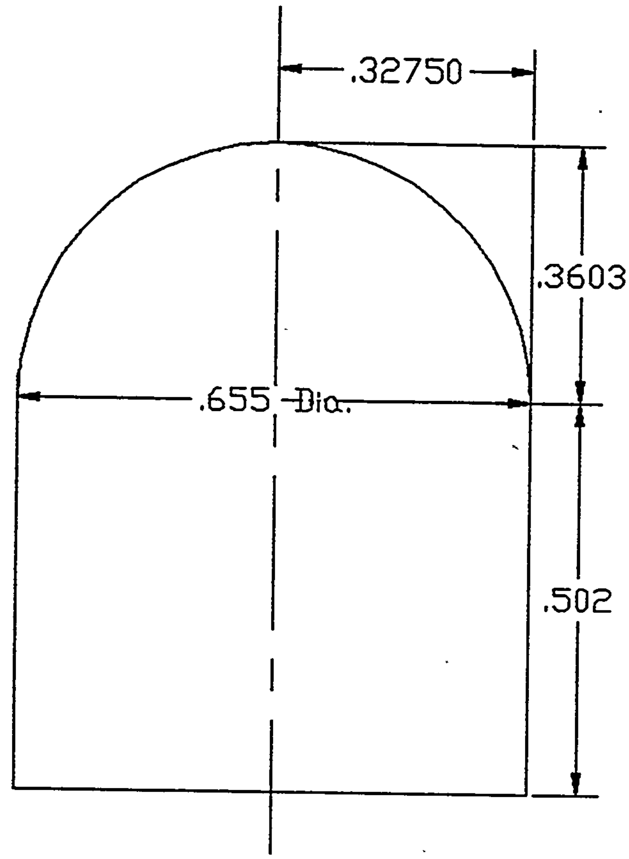


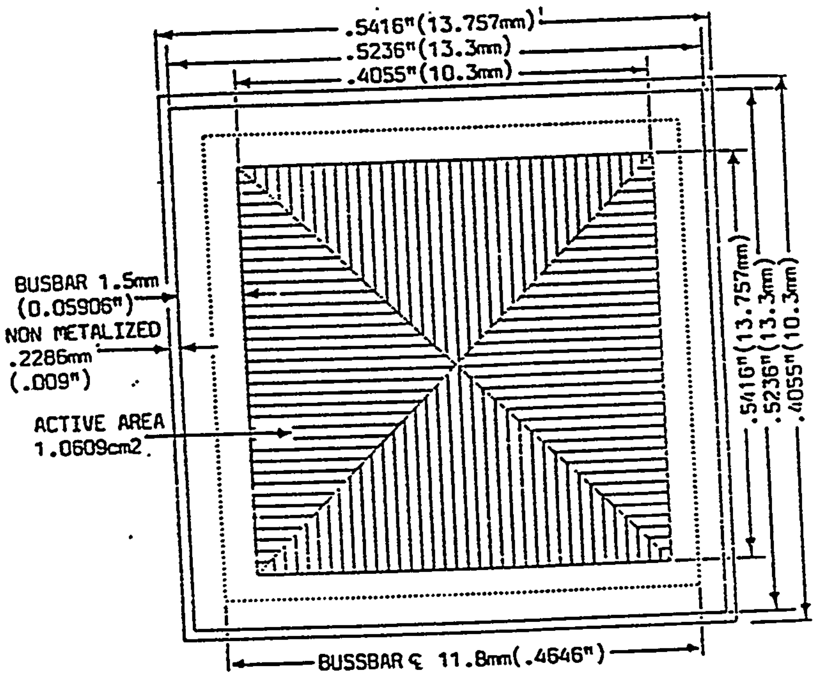
Figure 17. Module Flash Tester Lamp Response



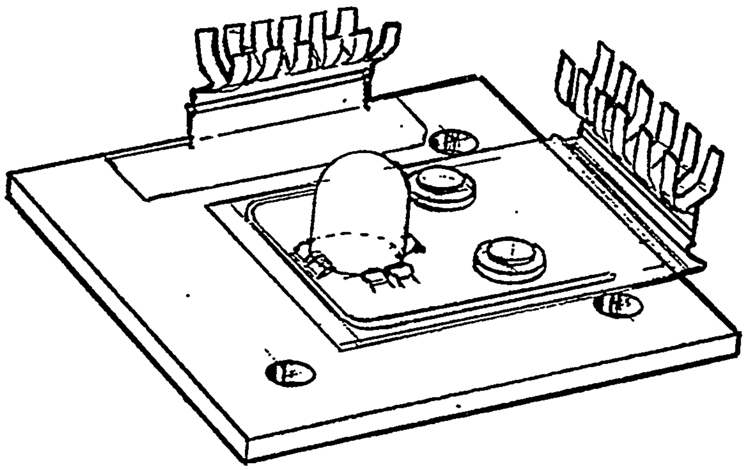
Drawing 1. Cell Assembly Cross Section



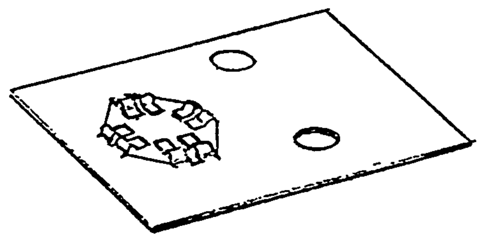
Drawing 2. SOE Silo Drawing Final Design



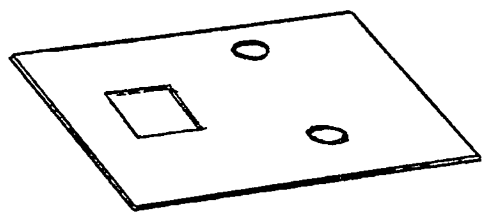
Drawing 3. Solar Cell



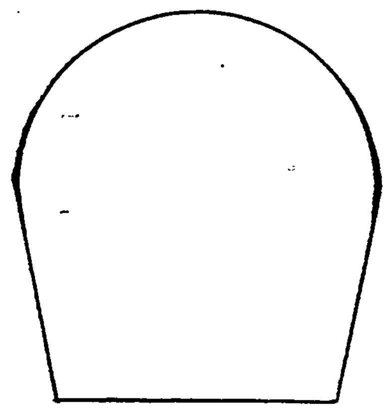
Drawing 4.   Cell Assembly Drawing



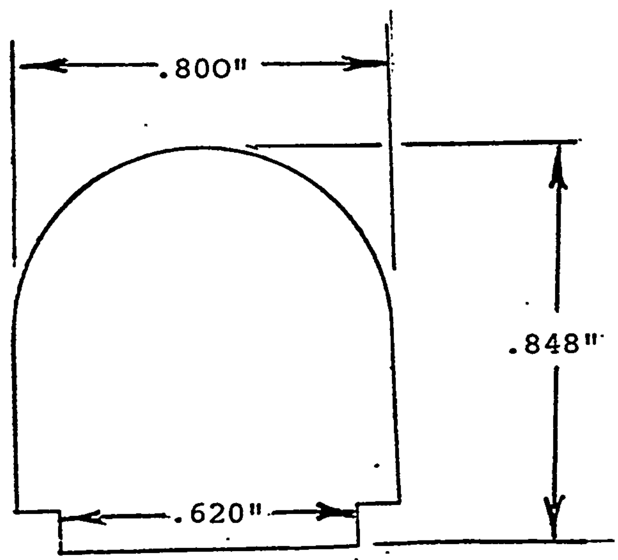
Drawing 5. Top Connect Drawing



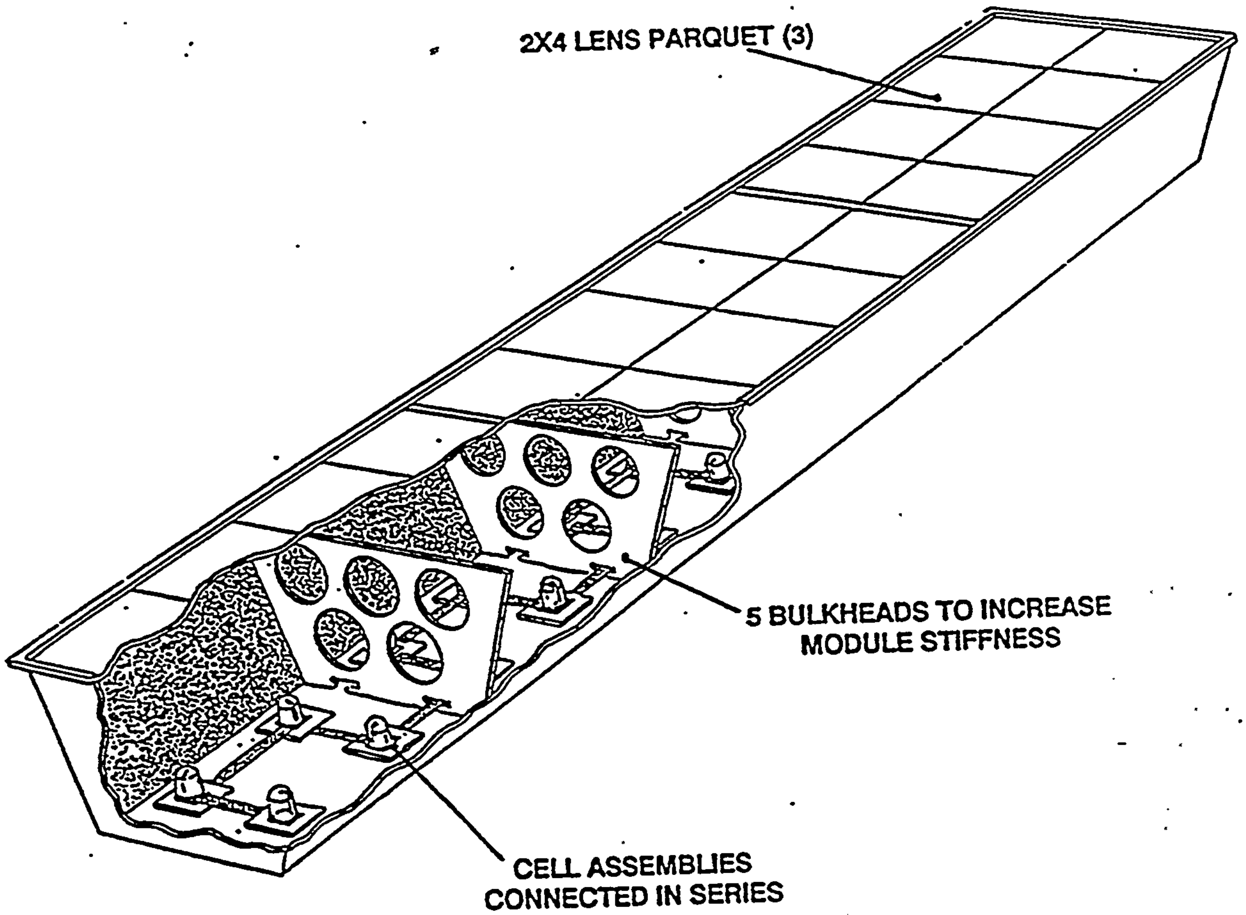
Drawing 6. Danar Top Connect Insulator Drawing



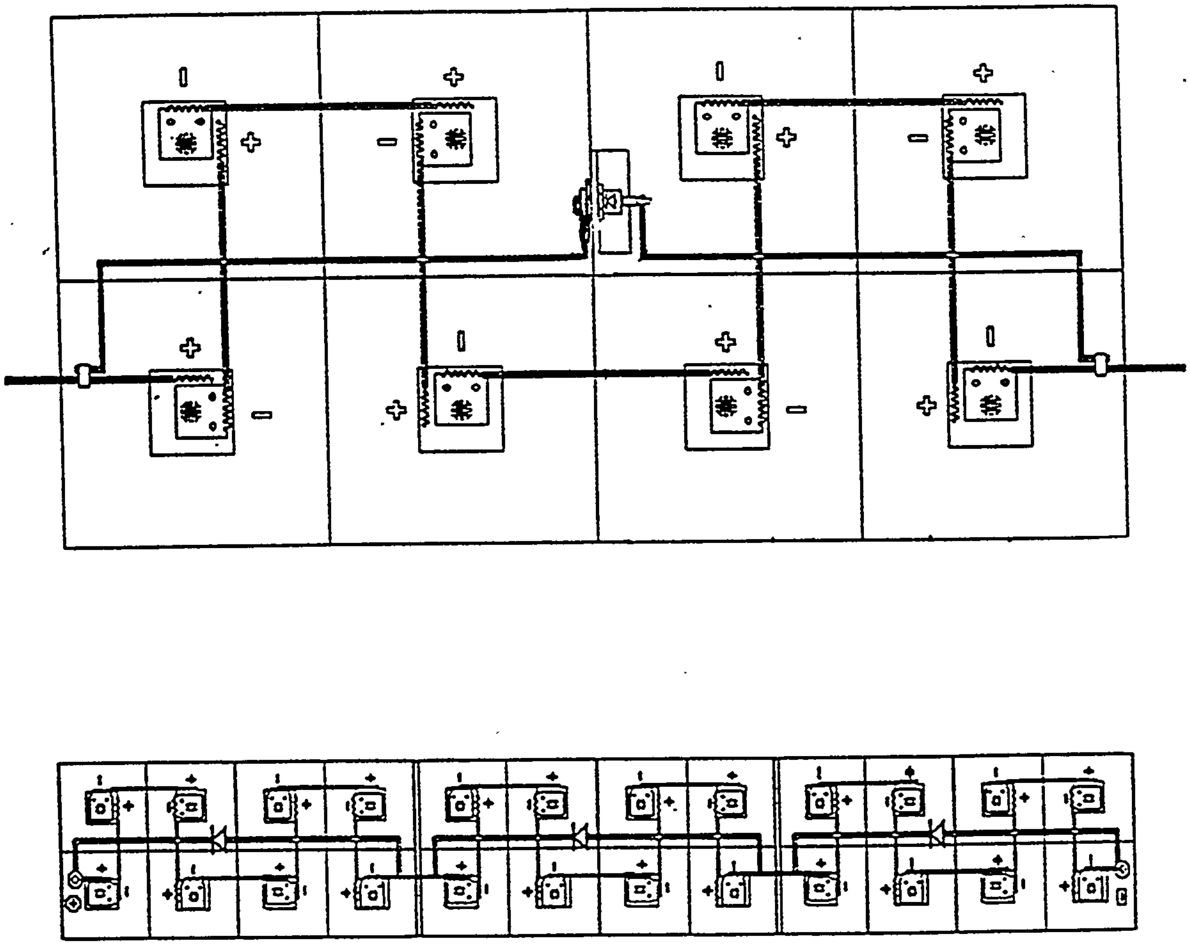
Drawing 7A. SOE Ice Cream Cone



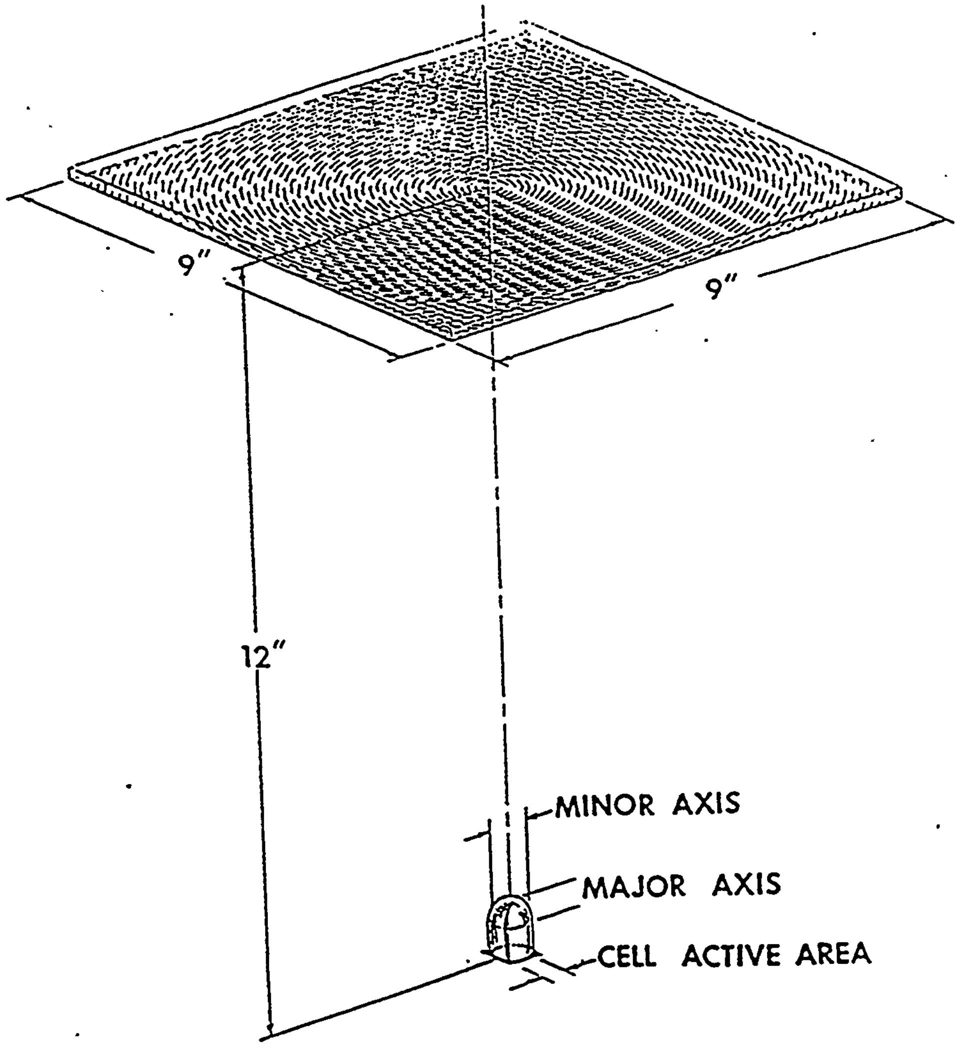
Drawing 7B. Haystack Drawing



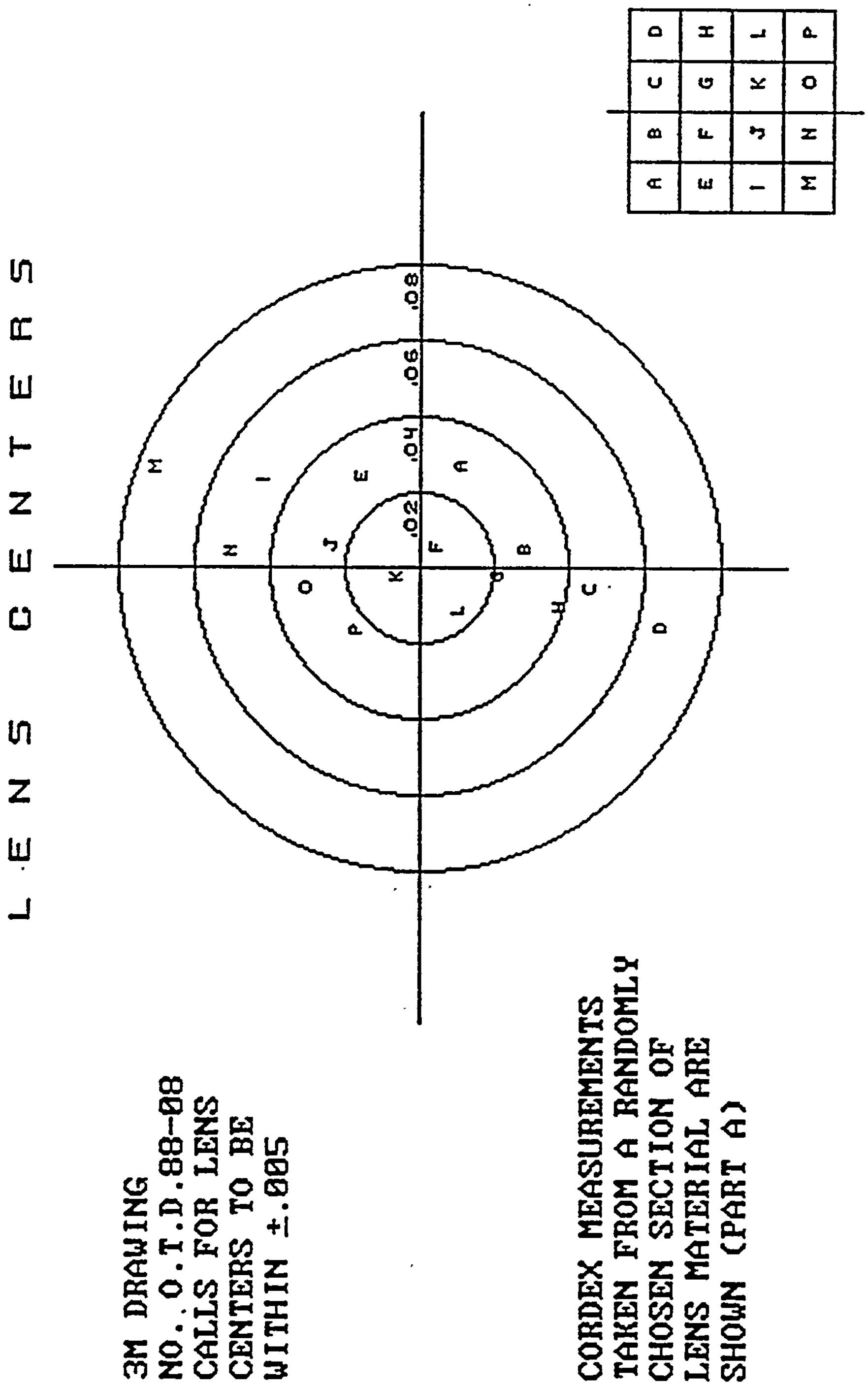
Drawing 8. Module Assembly



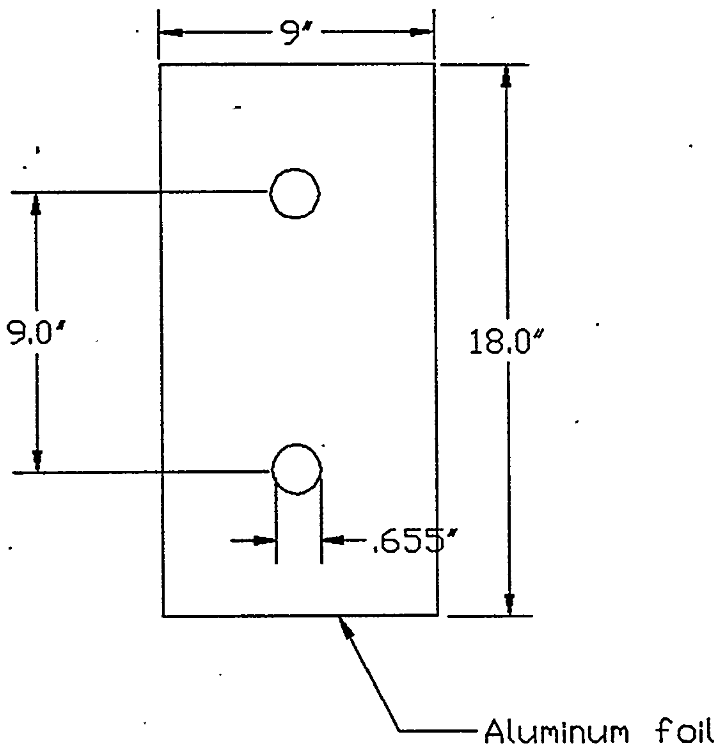
Drawing 9. Cell Assembly Interconections and Module Wiring



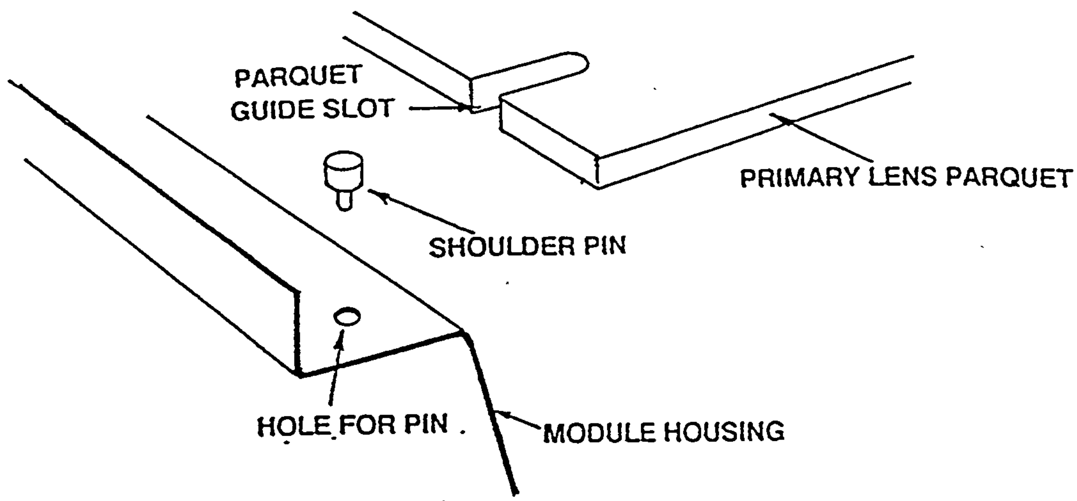
Drawing 10. Optical System Components



Drawing 11. Lens Center Variations

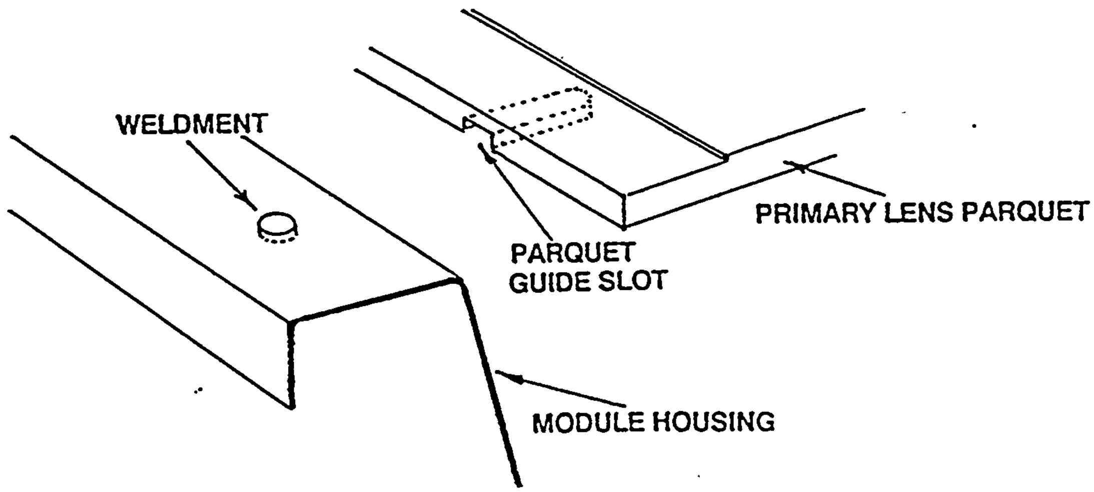


Drawing 12. Anti Radiation Shielding



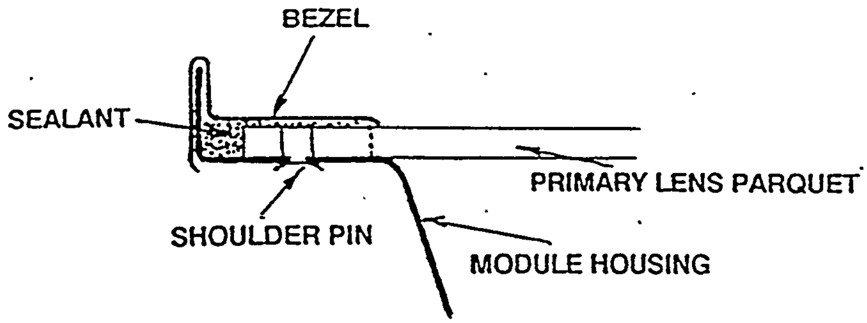
Drawing 13. Module Housing: Precontract Assembly Method

Outer lip of the module housing is turned up. Alignment holes in parquet holding area are to locate primary lens. Shoulder alignment pin is locked in position with swedging. Parquet guide penetrates through the primary lens.



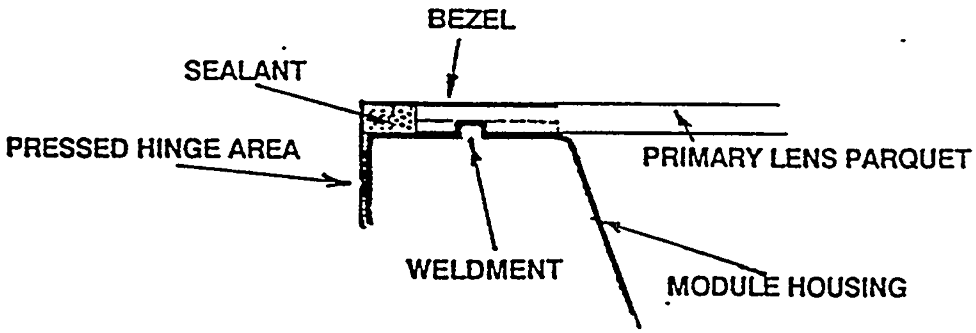
Drawing 14. Module Housing: Final Design Assembly Method

Outer lip of module is turned down. Weldment is drawn into parquet holding area to replace alignment hole and eliminates costly alignment shoulder pins. Parquet guide in compression molded lens does not penetrate full thickness of parquet and eliminates potential leak area.



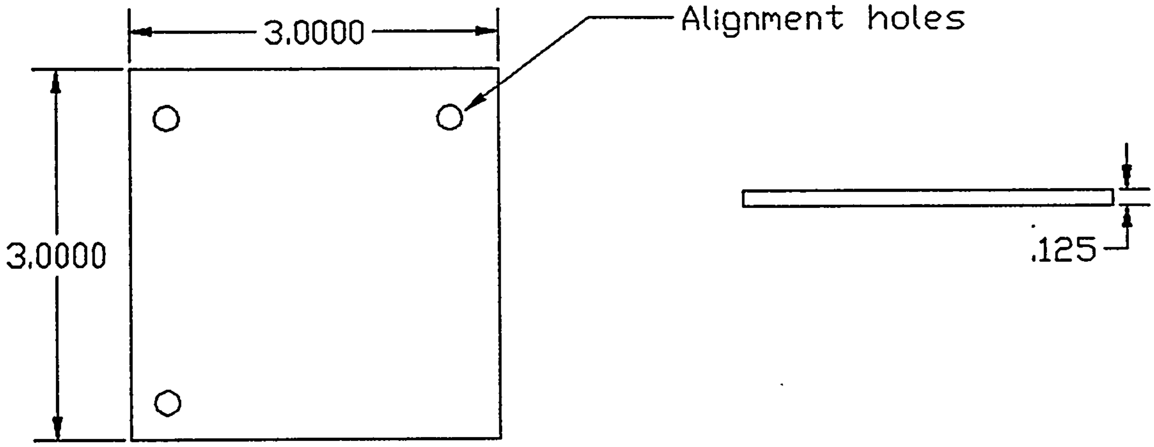
Drawing 15. Module Housing (Precontract)

Bezel is made of .025 aluminum. Sealing compound on top and end of parquet is used to prevent water from entering module. A wall formed by the bezel and the housing acts as a dam which allows water to build-up and leak into module. Bezel is crimped onto housing at nine inch intervals.

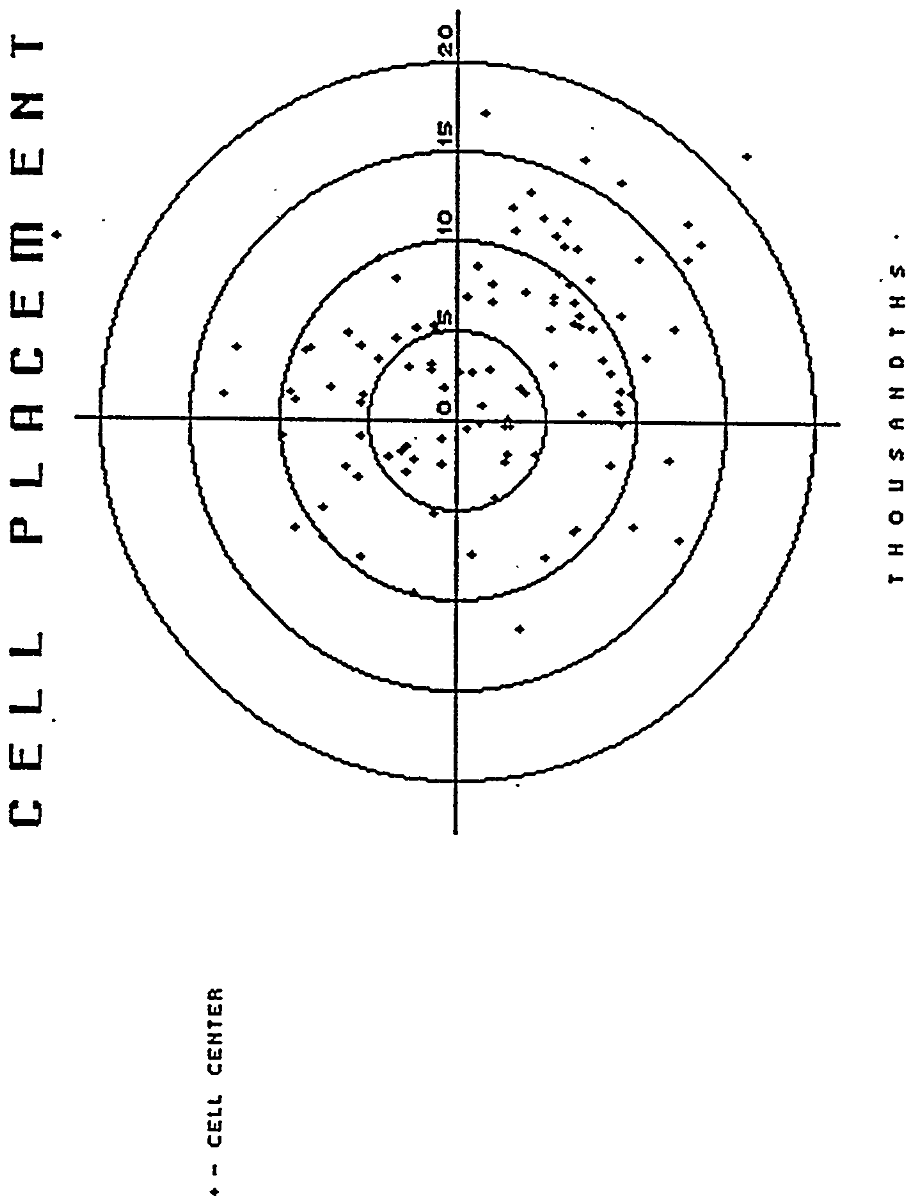


Drawing 16. Module Housing (Final Design)

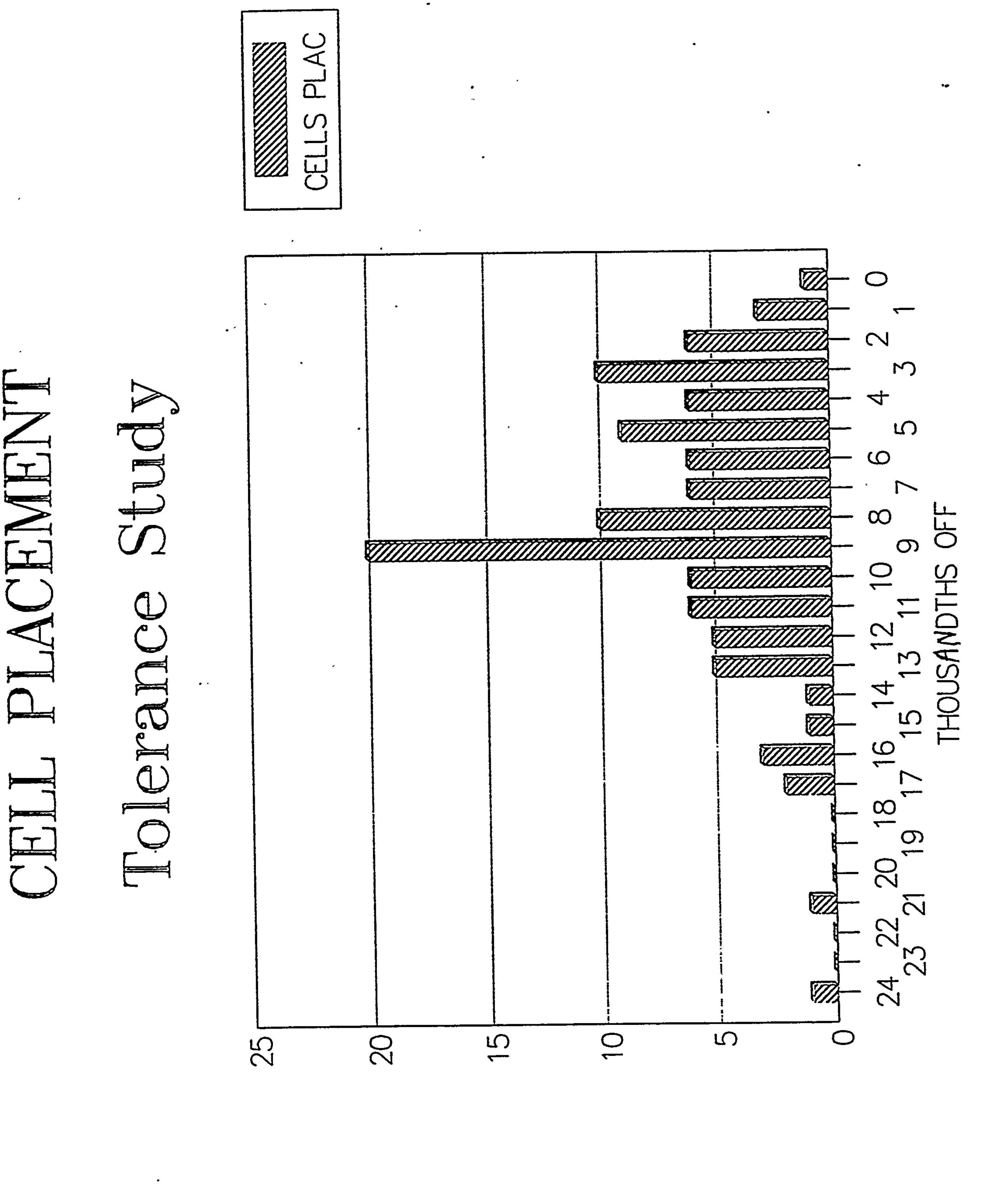
Bezel is made of .015 aluminum, less material lowers cost. New bezel is attached to parquet with leak preventing adhesive along the offset ledge around the entire parquet. Sealant is used only on edge of lens parquet which reduces related costs. A bending area is pressed into the bezel which allows for expansion and contraction of the primary lens. Bezel would be glued to module housing along entire length of bezel which will minimize water entering into the module.



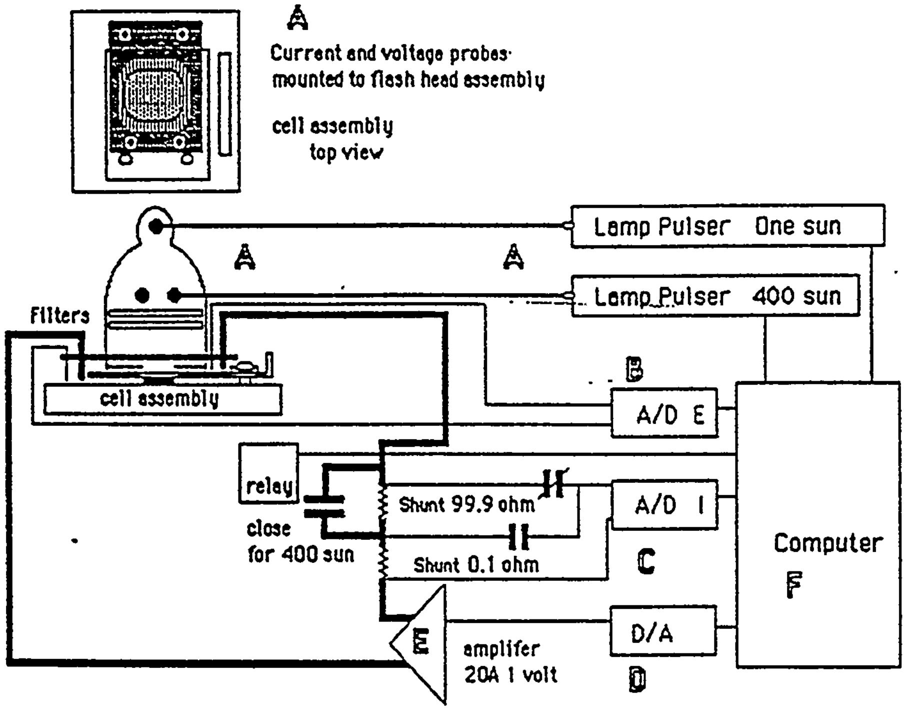
Drawing 17. Heat Spreader



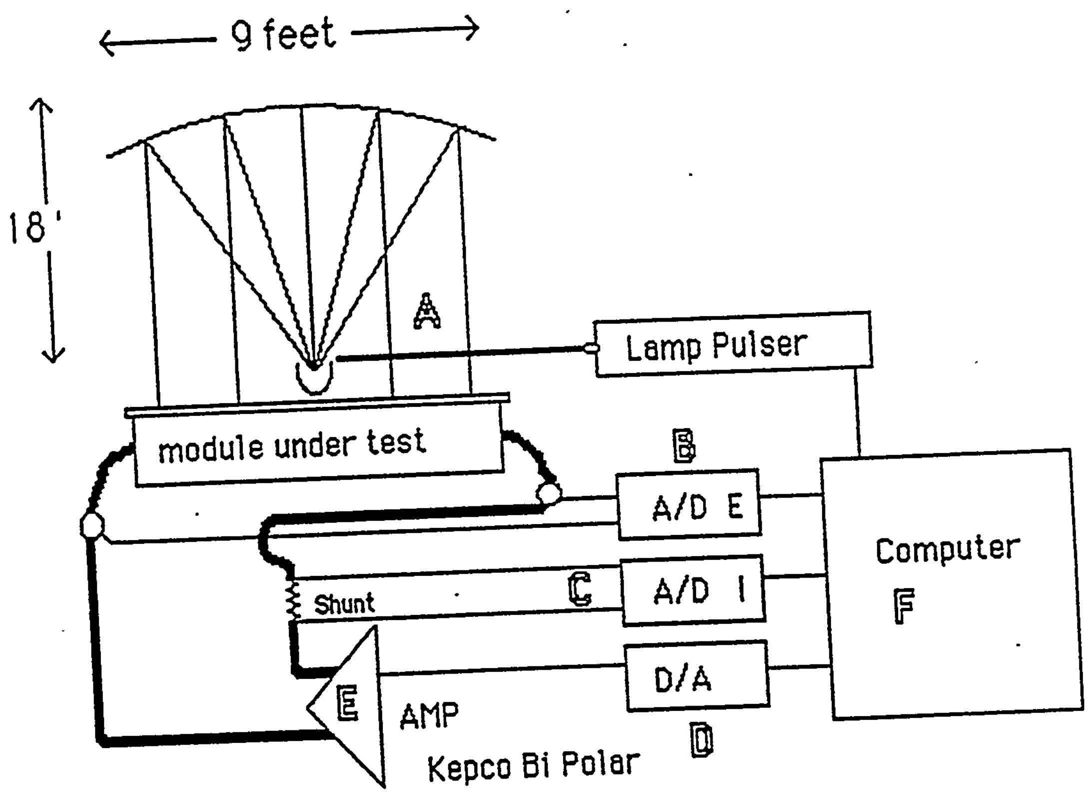
Drawing 18. Cell Placement Variations



Drawing 19. Cell Placement Tolerance



Drawing 20. Cell Assembly Flash Tester Block Diagram



Drawing 21. Module Flash Tester Block Diagram

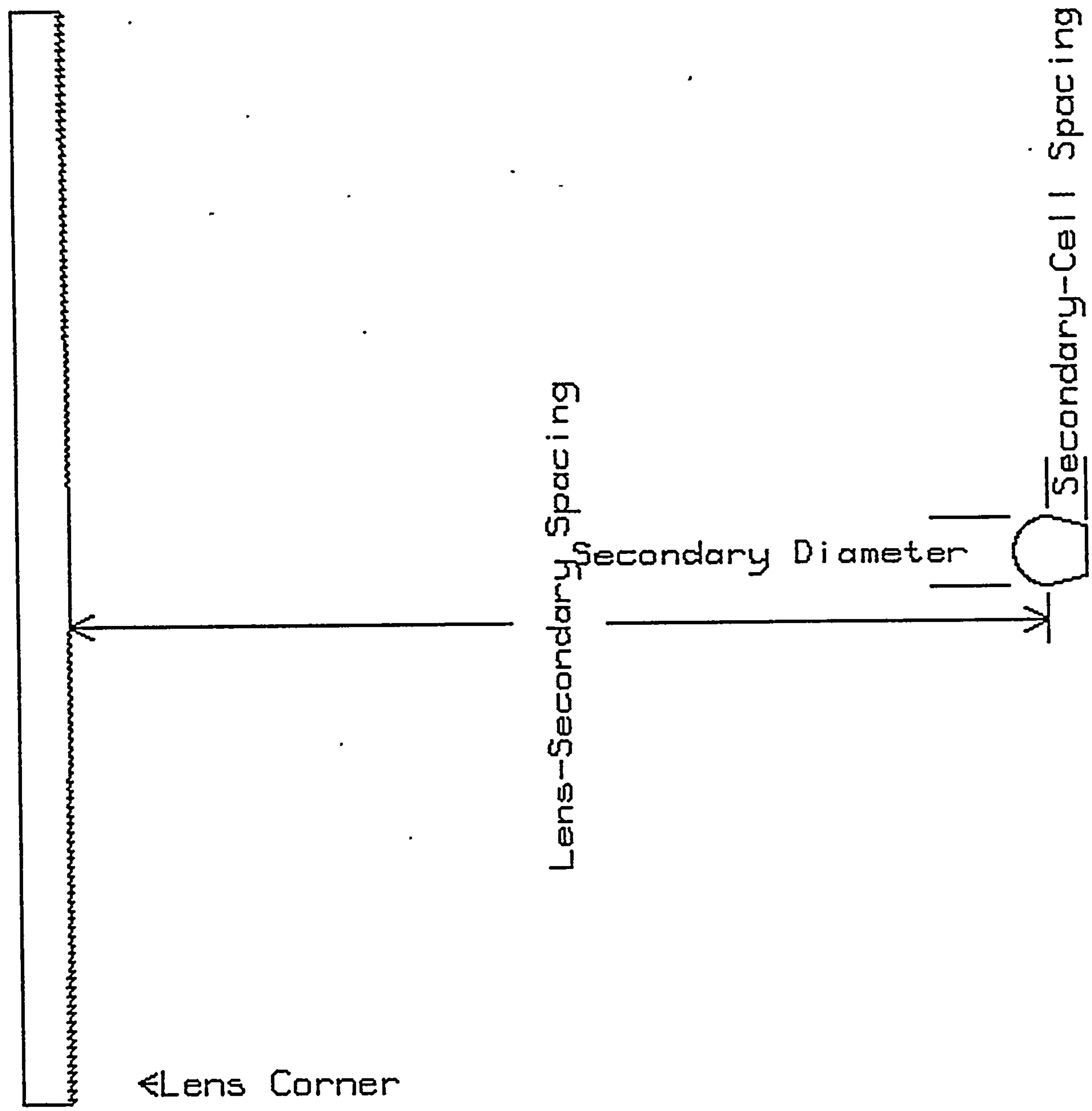
APPENDIX A

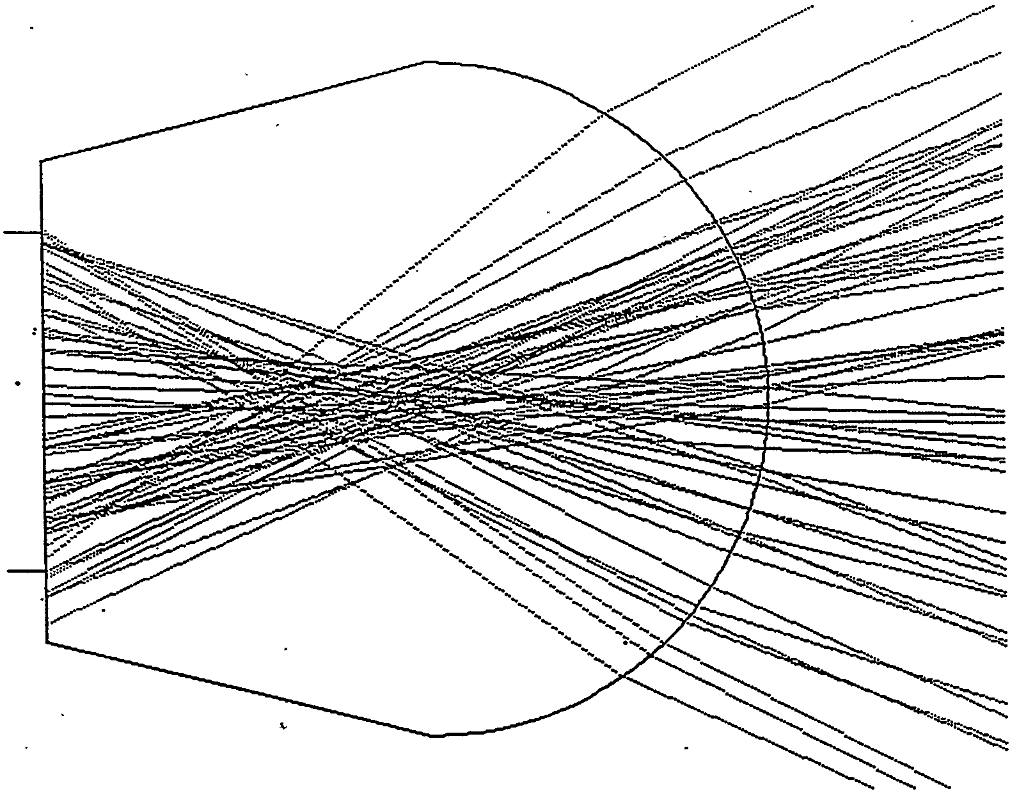
SOE computer model results from James Associates using BaZn glass

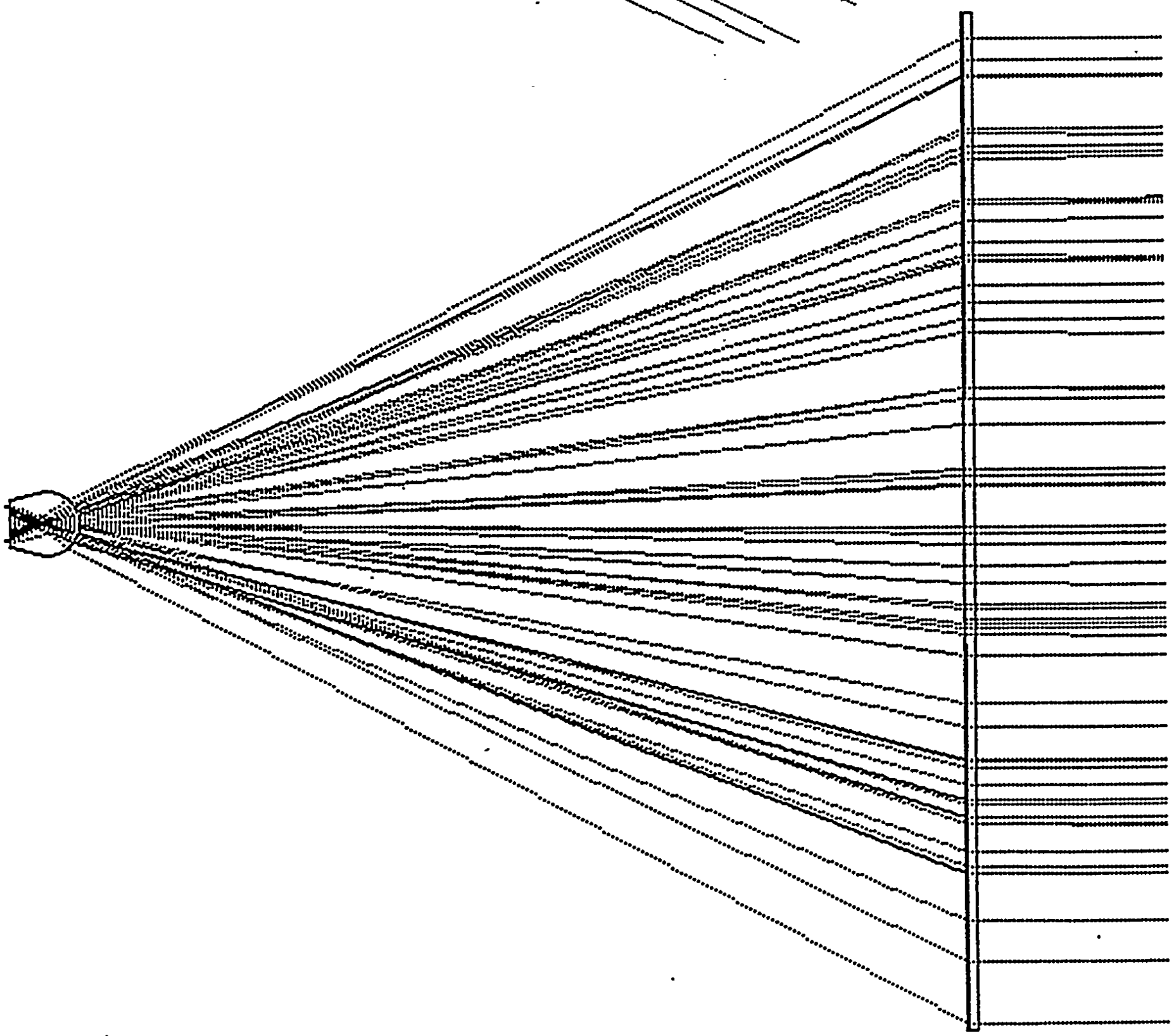
```
SOLAR OPTICS COMPUTER MODEL by James Associates   31 Jan 1990   16:25:15
2D FLAT FRESNEL LENS with FLAT GROOVES, IMAGING SECONDARY

CRY-001

CELL PARAMETERS
 CELL DIAGONAL (- for side) (inches) = .573463599542
 CELL QUANTUM EFFICIENCY FROM BLUESI

LENS DESIGN PARAMETERS (flat Fresnel lens with constant width flat grooves)

16726  DEF FNRef_index(Hv)
16727   RETURN (.0027*Hv+.001364)*Hv+1.475115             !ACRYLIC
 SQUARE LENS DIAGONAL (inches)  = 12.7279220614
 LENS to SECONDARY (inches)  = 11.491
 FACET WIDTH (inches) = .02
 LENS THICKNESS (inches) = .125
 DRAFT ANGLE (degrees) = 0
 RADIUS OF CURVATURE OF FACET TIPS (inches) = .0002
 RADIUS OF CURVATURE OF FACET VALLEYS (inches) = .0002
 DESIGN RAY'S PHOTON ENERGY (eV)  = 2
 AIM POINT OFFSET FROM SECONDARY CENTER (inches)  = 0

IMAGING SECONDARY PARAMETERS
16729  DEF FNSec_absorption(Hv)
16730   RETURN 0                                           !IDEAL GLASS
16732  DEF FNSec_ref_index(Hv)
16733   RETURN (.001820265*Hv+.006119076)*Hv+1.493213          !Crystal
16735  DEF FNAr_ref_index(Hv)
16736   RETURN (.002172*Hv+.004776)*Hv+1.32                 !??? AR Coating
 AR COATING THICKNESS (Angstroms) = 1
 ASPHERICAL FACTOR TOP = 1
 ASPHERICAL FACTOR BOTTOM =-1
 APPROXIMATE LOWER IMAGE DIAMETER (inches) = .538
 DIAMETER OF SECONDARY (inches) = .8

OPERATING CONDITIONS
 CLEAR SUN AIR MASS  = 1.5
 TRACKING ERROR (degrees)  from 0 to .9 step .3
 TRACKING ERROR DIRECTION (degrees from Perp.to flat)  = 0
 X CELL MOUNTING ERROR (inches)  = 0
 Y CELL MOUNTING ERROR (inches)  = 0
 Z CELL MOUNTING ERROR (inches closer to lens)  = 0

 204800 RAYS TO BE TRACED FOR EACH TRACKING ERROR (degrees)
 819200 TOTAL RAYS TO BE TRACED
```

SECONDARY TO CELL SPACING = .457
LENS TO CELL SPACING =11.948
ELLIPSOID MINOR AXIS = .800
UPPER ELLIPSOID MAJOR AXIS= .800

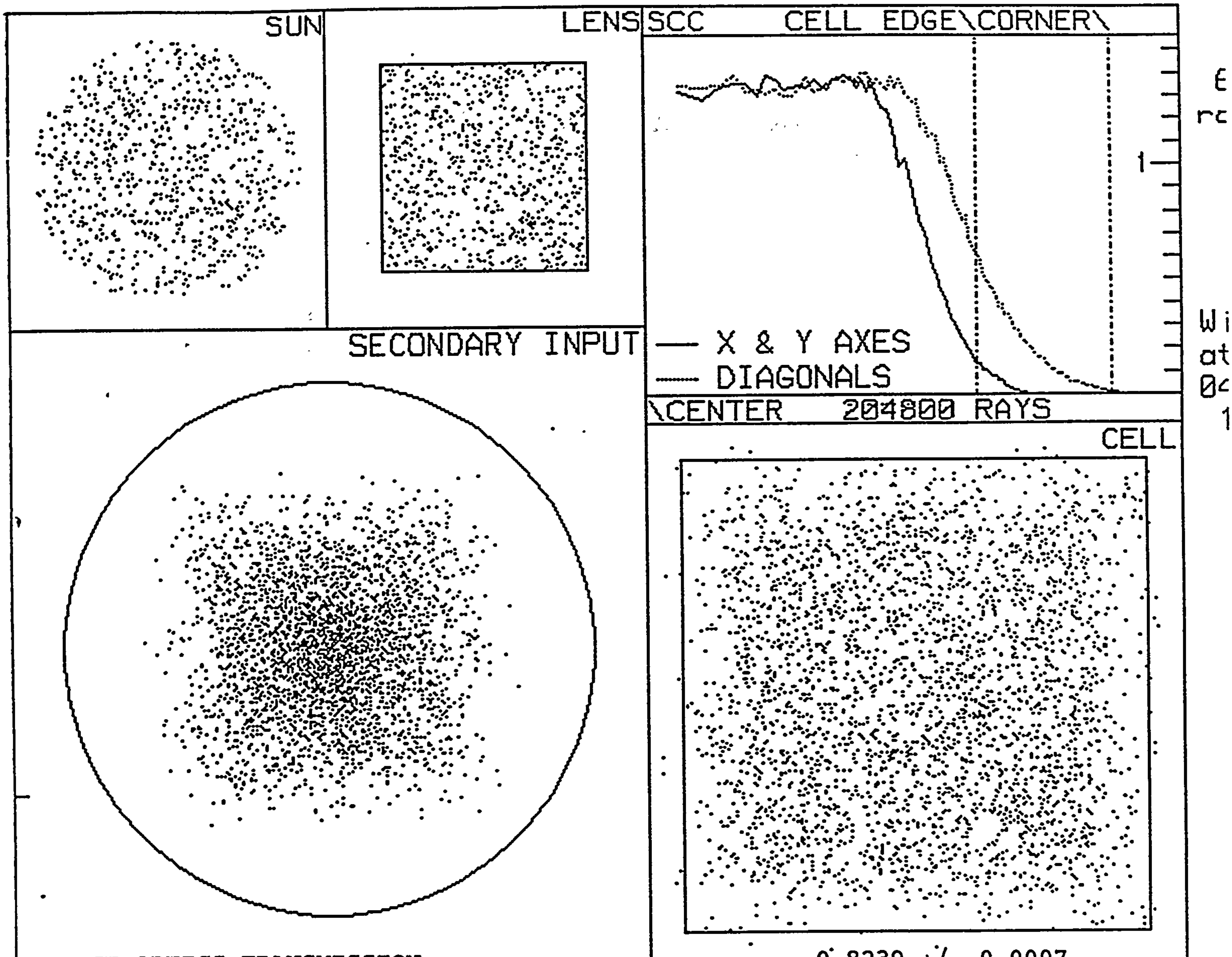
DIAGONAL VIEW OF OPTICS (FACETS AND LENS THICKNESS SHOWN 5 TIMES REAL SCALE)





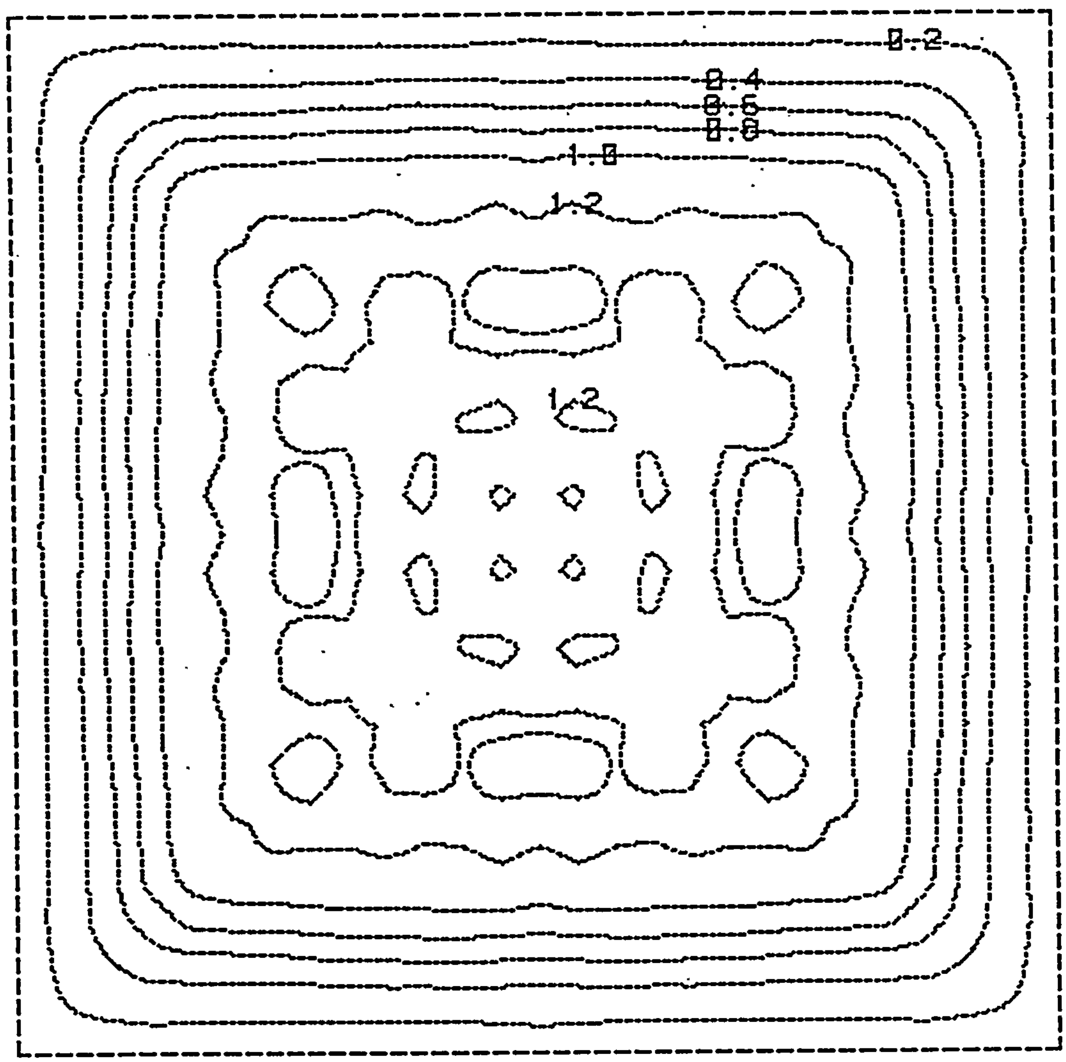


TRACKING ERROR (degrees) = 0

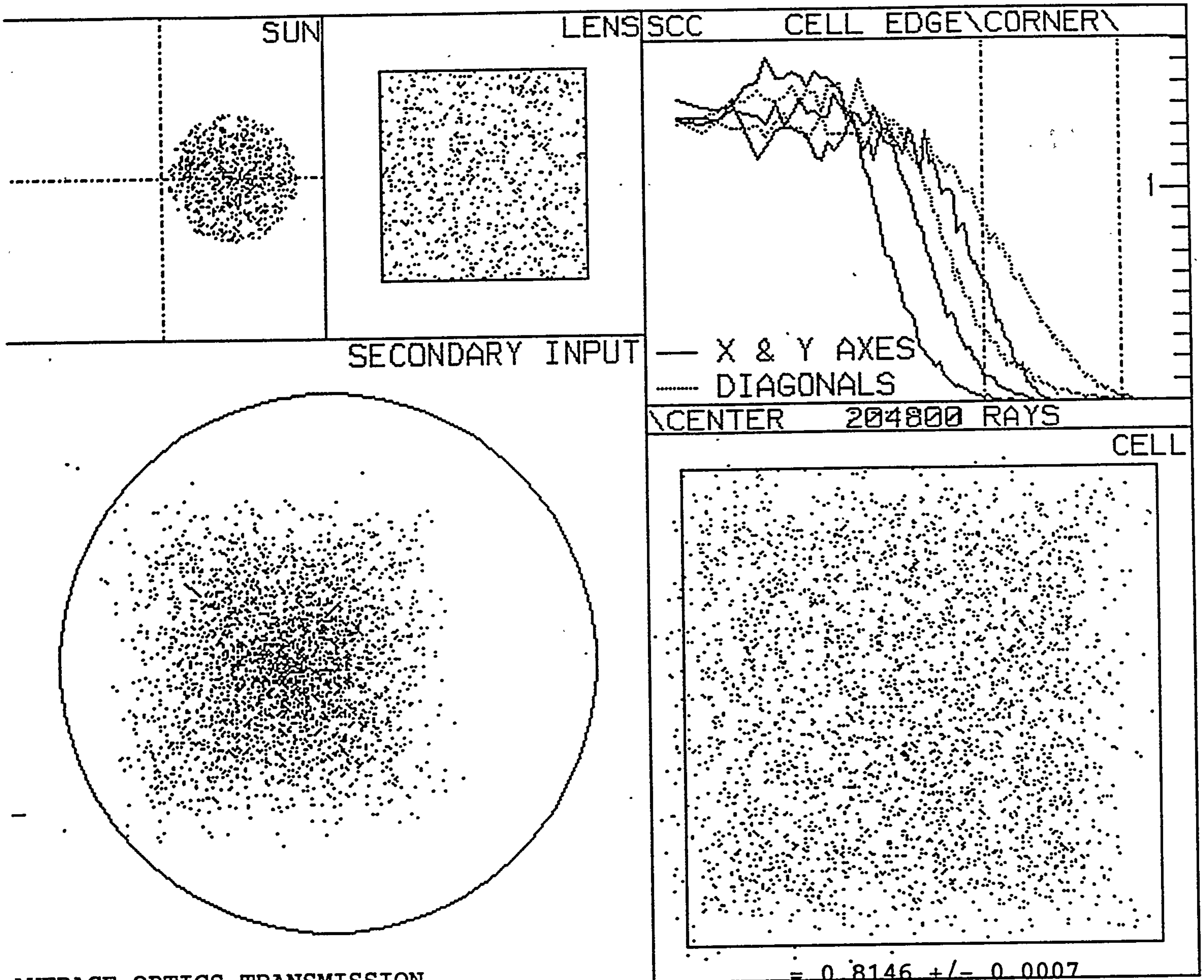


AVERAGE OPTICS TRANSMISSION	= 0.8239 +/- 0.0007
FRACTION OF RAYS LOST BY TIR IN FRESNEL	= 0.0000 +/- 0.0000
FRACTION OF RAYS LOST BY TIR IN SECONDARY	= 0.0000 +/- 0.0000
FRACTION OF RAYS HITTING DRAFT SURFACES	= 0.0201 +/- 0.0004
FRACTION OF RAYS MISSING SECONDARY	= 0.0000 +/- 0.0000
FRACTION OF RAYS MISSING CELL	= 0.0112 +/- 0.0003
FRACTION OF RAYS REFLECTED BY AR	= 0.0441 +/- 0.0006
GEOMETRIC CONCENTRATION RATIO	= 492.6 SUNS
PEAK FLUX CONCENTRATION RATIO	= 597 +/-16 SUNS

CONTOUR PLOT OF CELL'S SHORT CIRCUIT CURRENT FLUX DENSITY
(1.0 corresponds to uniform illumination and 100 % lens transmission)

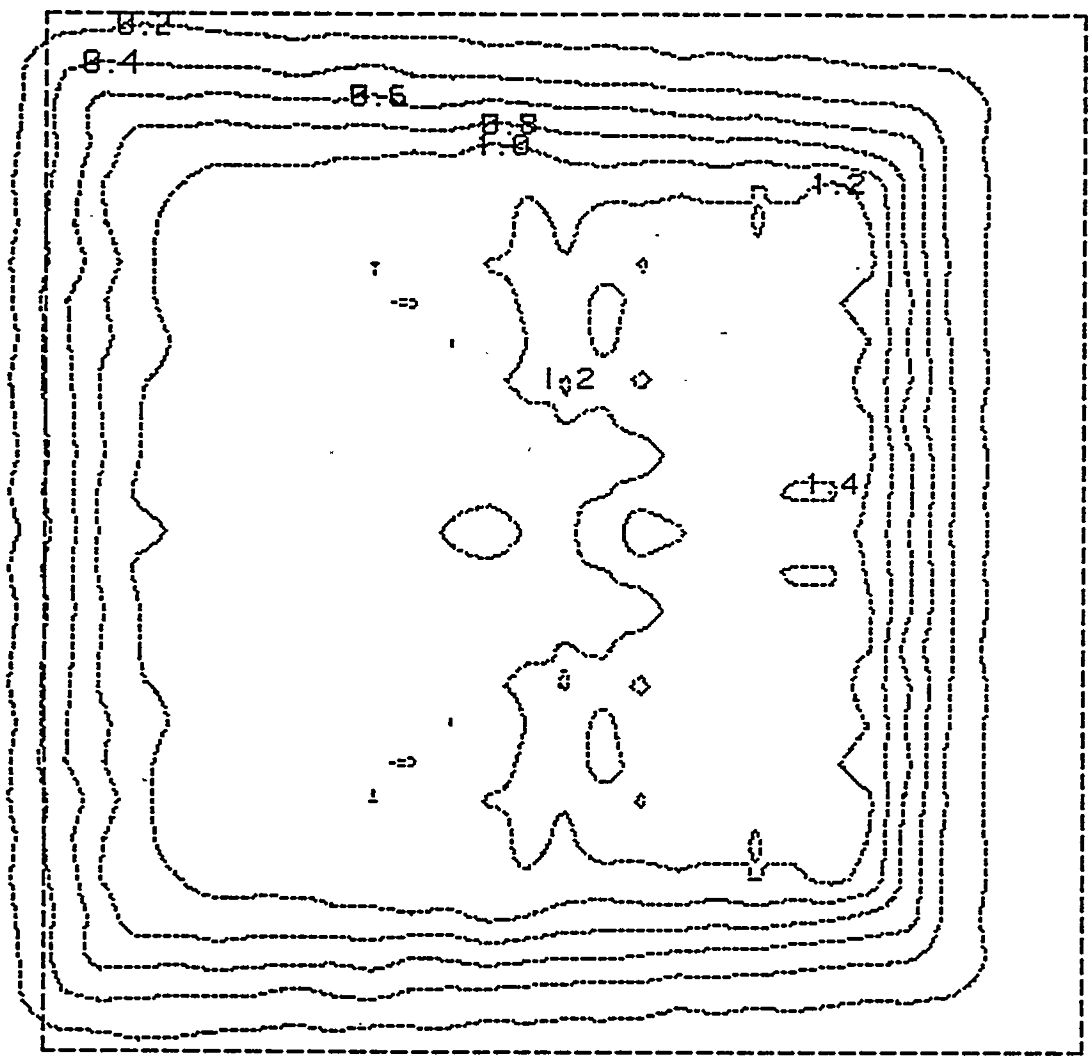


TRACKING ERROR (degrees) = .3

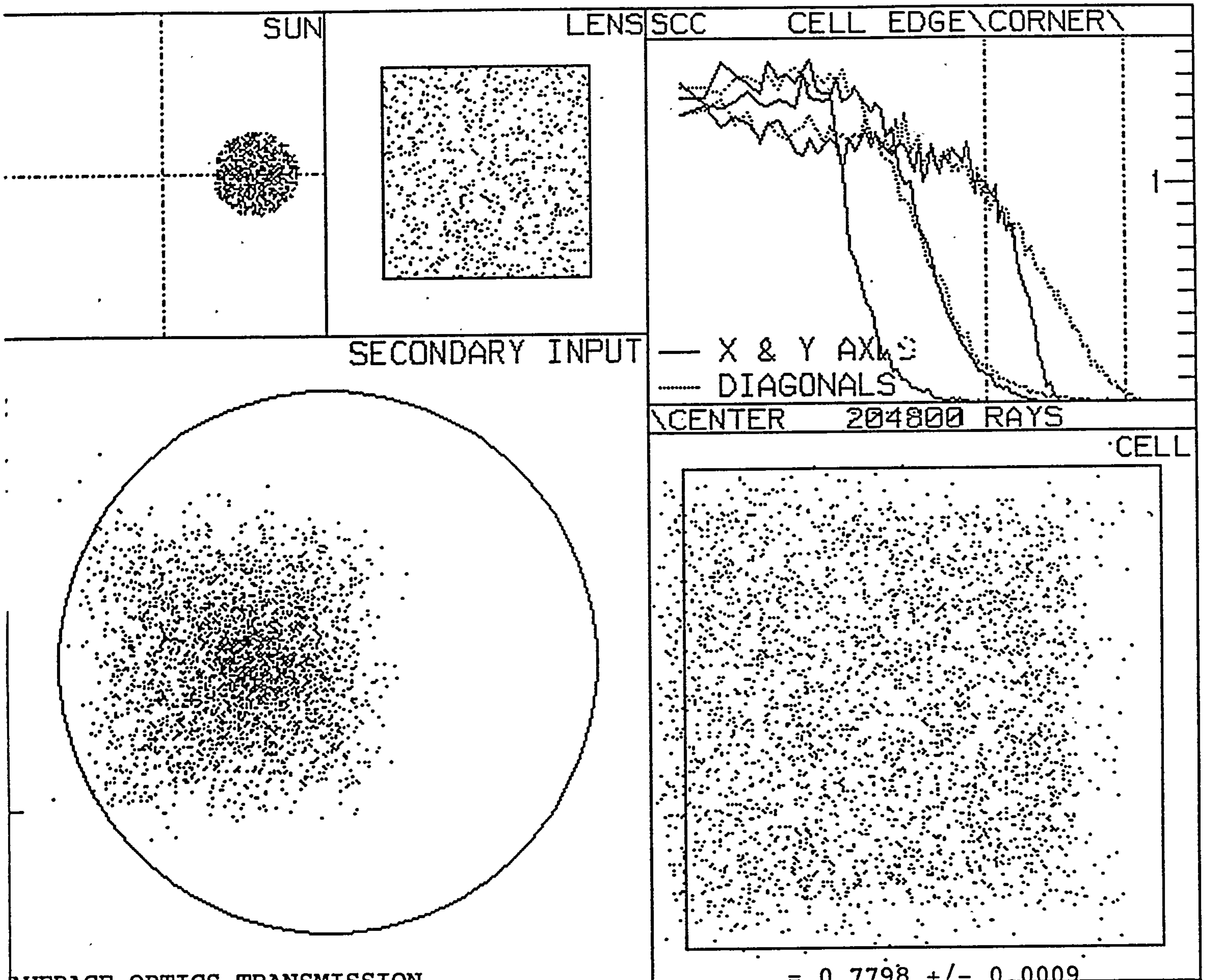


AVERAGE OPTICS TRANSMISSION	= 0.8146 +/- 0.0007
FRACTION OF RAYS LOST BY TIR IN FRESNEL	= 0.0000 +/- 0.0000
FRACTION OF RAYS LOST BY TIR IN SECONDARY	= 0.0000 +/- 0.0000
FRACTION OF RAYS HITTING DRAFT SURFACES	= 0.0194 +/- 0.0004
FRACTION OF RAYS MISSING SECONDARY	= 0.0002 +/- 0.0000
FRACTION OF RAYS MISSING CELL	= 0.0188 +/- 0.0004
FRACTION OF RAYS REFLECTED BY AR	= 0.0483 +/- 0.0007
GEOMETRIC CONCENTRATION RATIO	= 492.6 SUNS
PEAK FLUX CONCENTRATION RATIO	= 666 +/-35 SUNS

CONTOUR PLOT OF CELL'S SHORT CIRCUIT CURRENT FLUX DENSITY
(1.0 corresponds to uniform illumination and 100 % lens transmission)

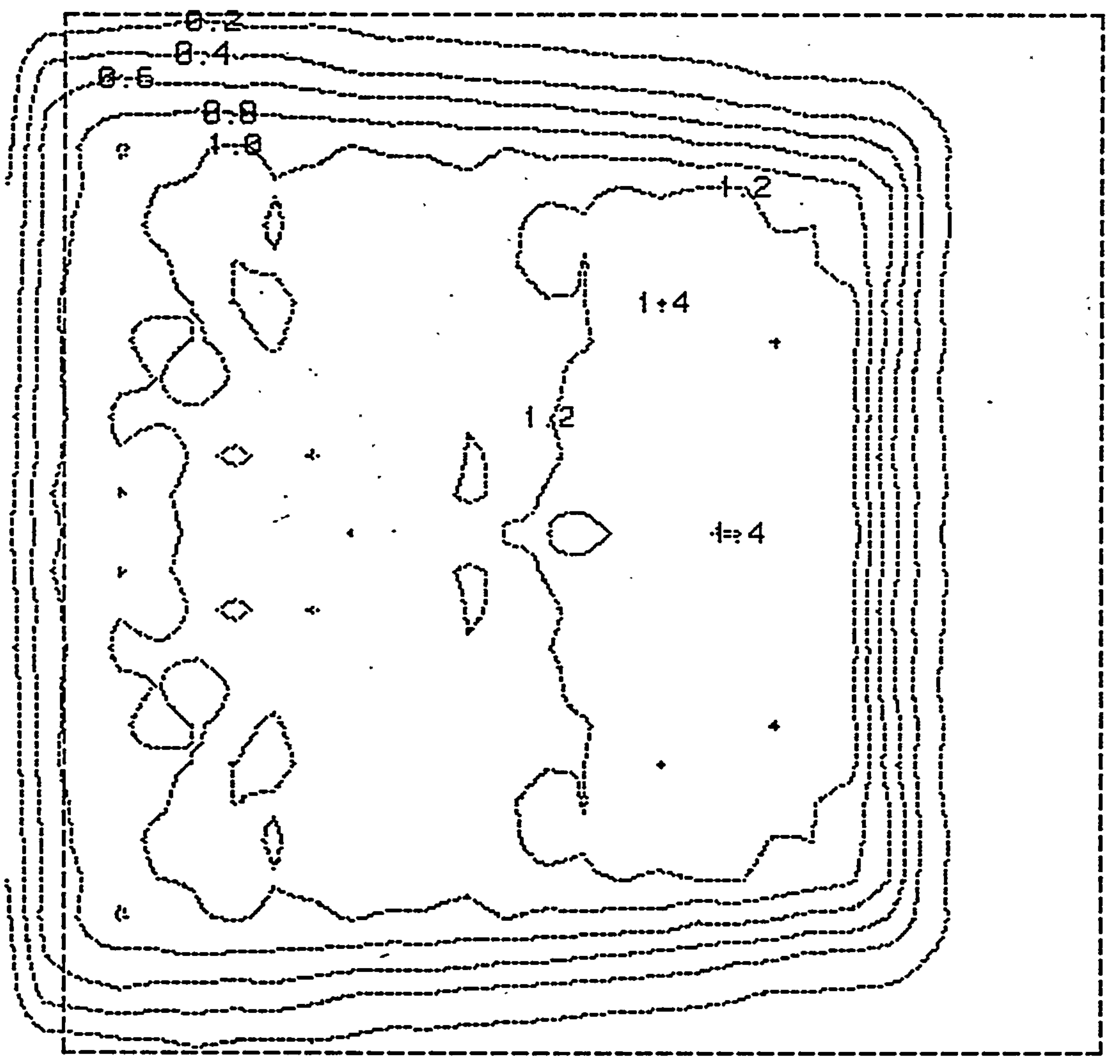


TRACKING ERROR (degrees) = .6

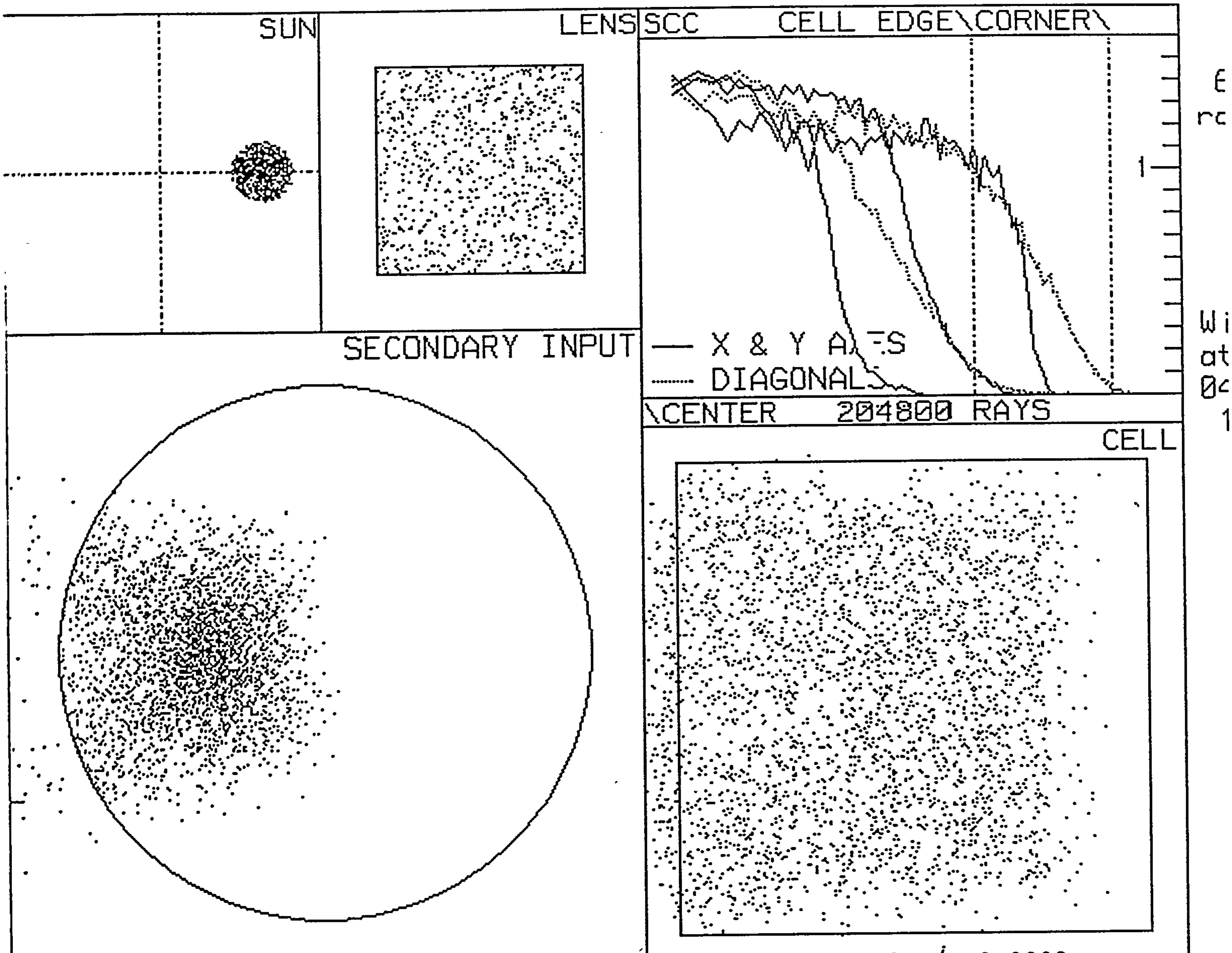


AVERAGE OPTICS TRANSMISSION = 0.7798 +/- 0.0009
FRACTION OF RAYS LOST BY TIR IN FRESNEL = 0.0000 +/- 0.0000
FRACTION OF RAYS LOST BY TIR IN SECONDARY = 0.0000 +/- 0.0000
FRACTION OF RAYS HITTING DRAFT SURFACES = 0.0199 +/- 0.0004
FRACTION OF RAYS MISSING SECONDARY = 0.0026 +/- 0.0002
FRACTION OF RAYS MISSING CELL = 0.0428 +/- 0.0006
FRACTION OF RAYS REFLECTED BY AR = 0.0634 +/- 0.0008
GEOMETRIC CONCENTRATION RATIO = 492.6 SUNS
PEAK FLUX CONCENTRATION RATIO = 662 +/-35 SUNS

CONTOUR PLOT OF CELL'S SHORT CIRCUIT CURRENT FLUX DENSITY
(1.0 corresponds to uniform illumination and 100 % lens transmission)

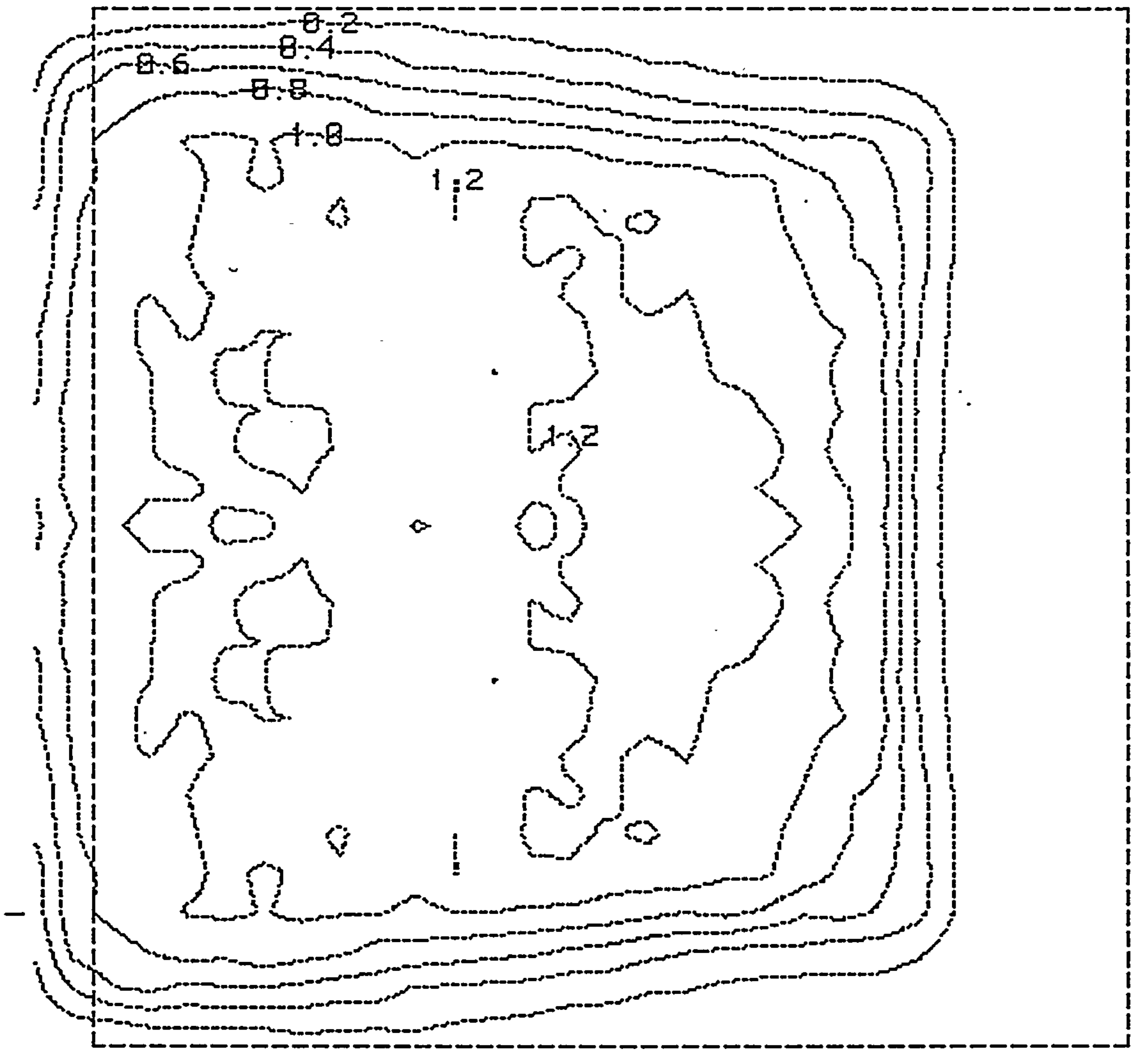


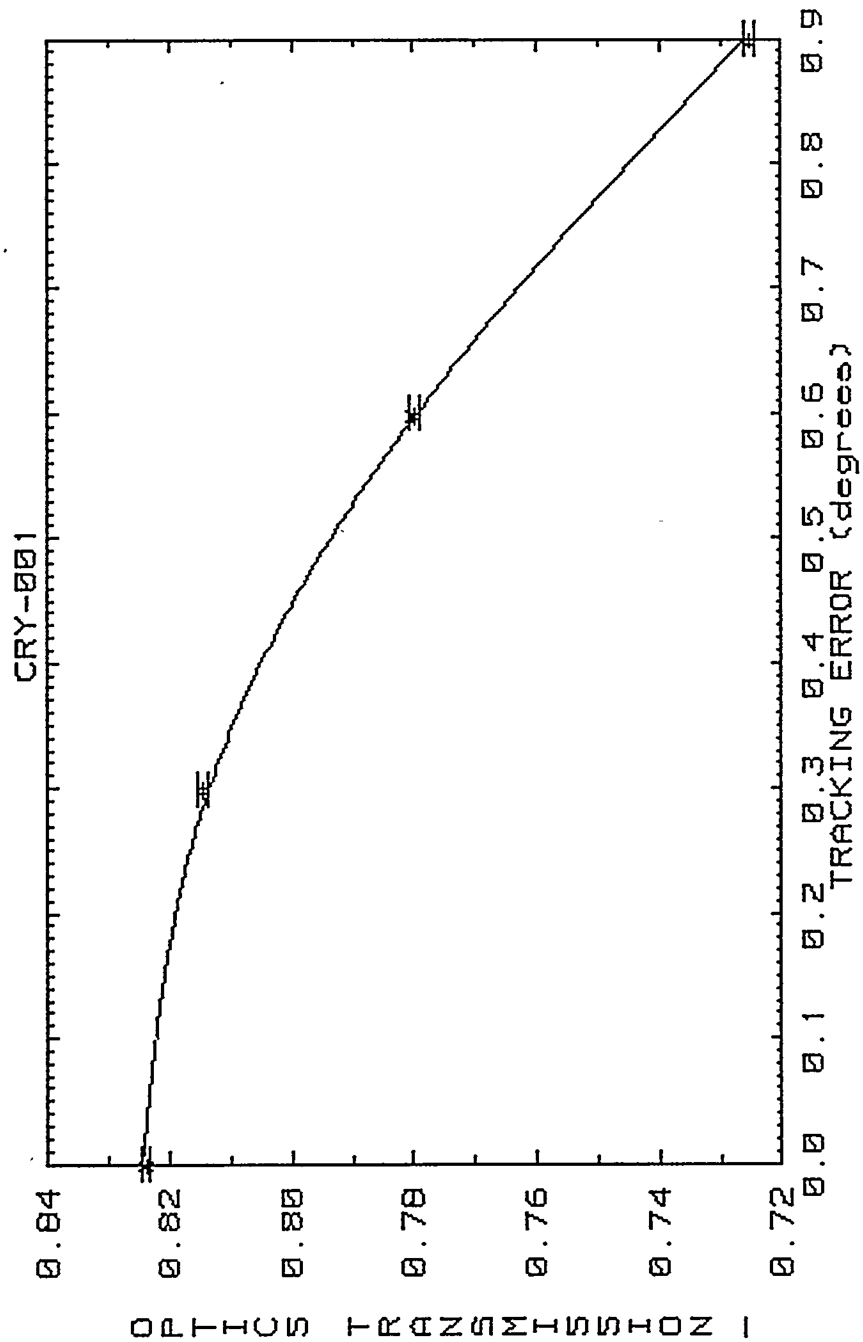
TRACKING ERROR (degrees) = .9

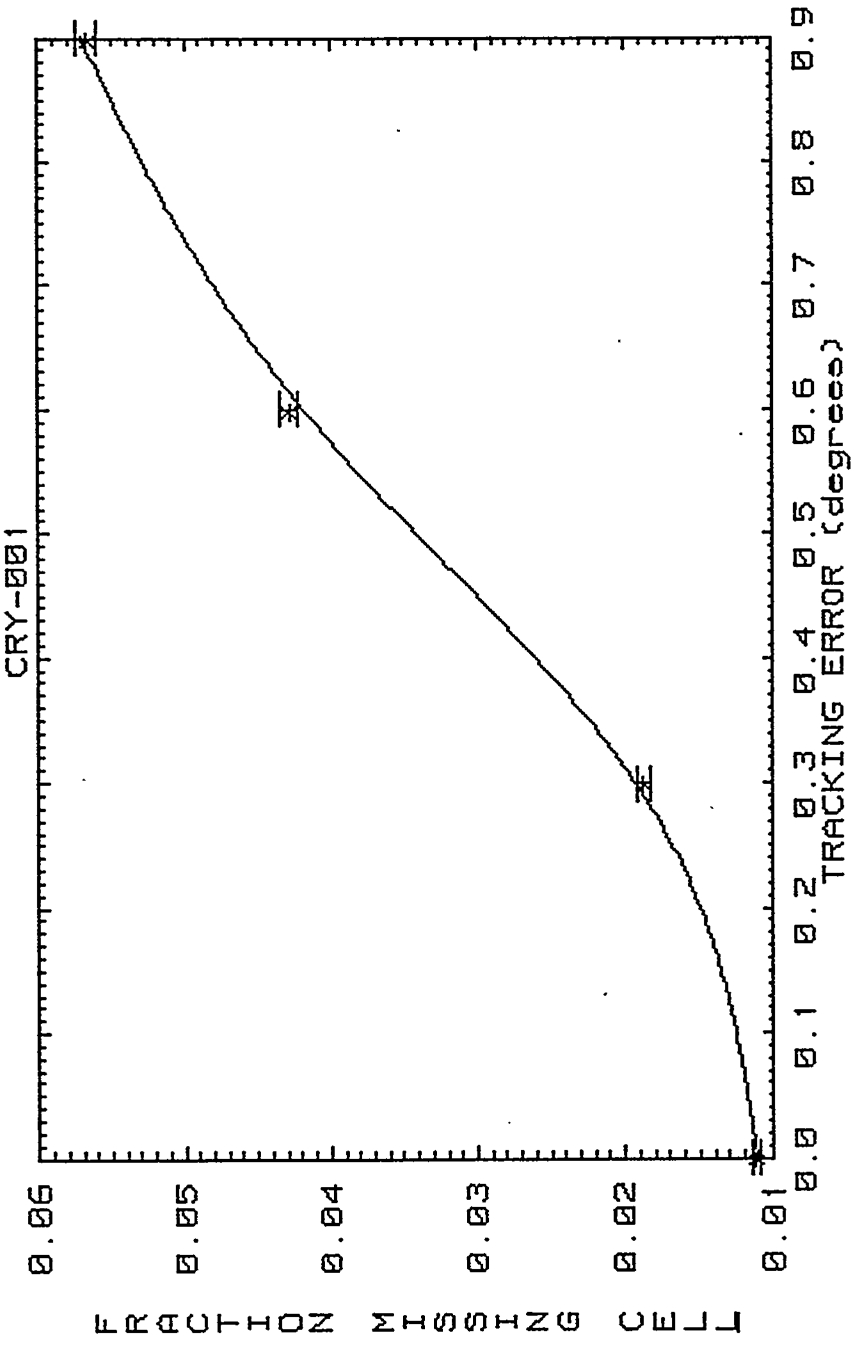


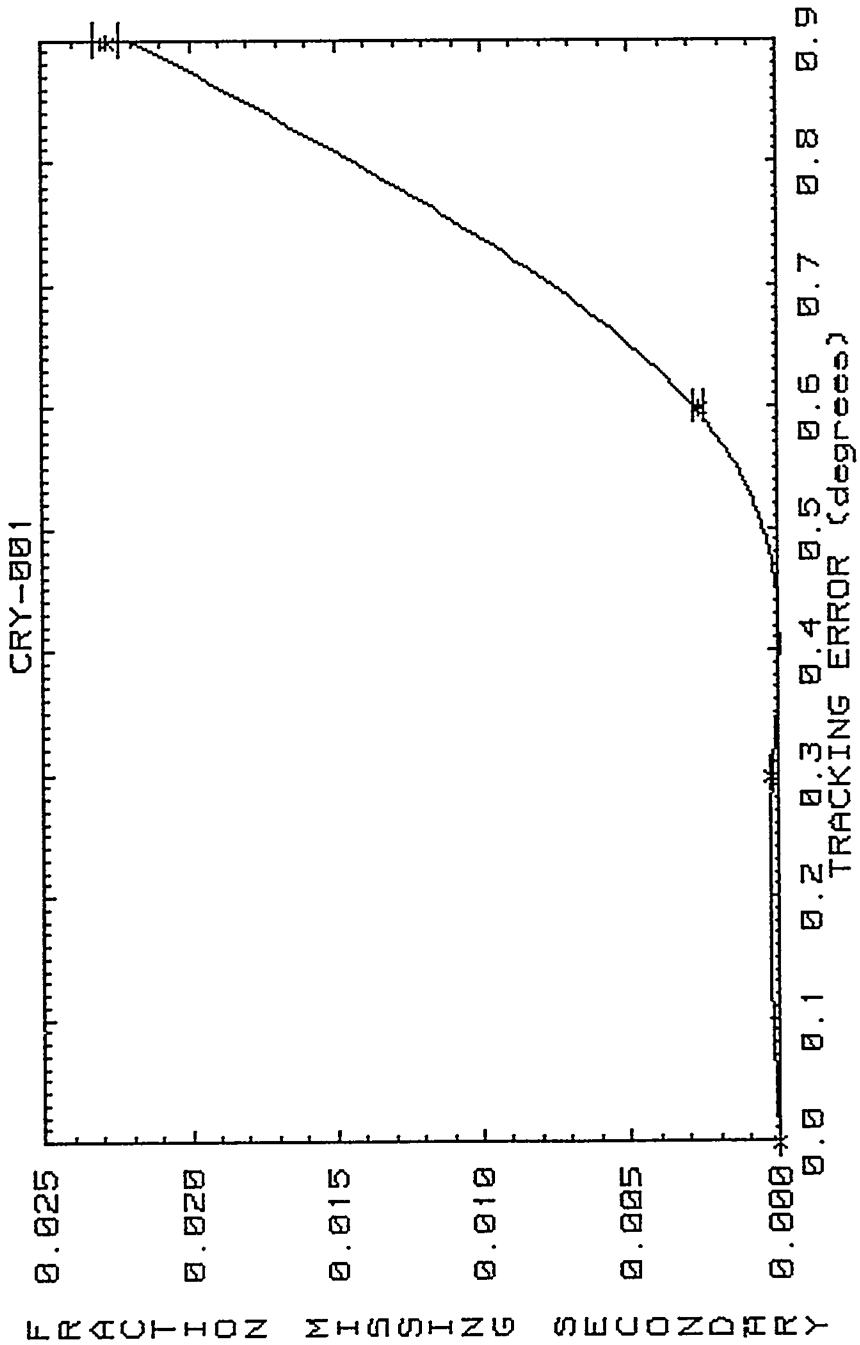
AVERAGE OPTICS TRANSMISSION	= 0.7252 +/- 0.0009
FRACTION OF RAYS LOST BY TIR IN FRESNEL	= 0.0000 +/- 0.0000
FRACTION OF RAYS LOST BY TIR IN SECONDARY	= 0.0000 +/- 0.0000
FRACTION OF RAYS HITTING DRAFT SURFACES	= 0.0205 +/- 0.0004
FRACTION OF RAYS MISSING SECONDARY	= 0.0228 +/- 0.0005
FRACTION OF RAYS MISSING CELL	= 0.0567 +/- 0.0007
FRACTION OF RAYS REFLECTED BY AR	= 0.0933 +/- 0.0009
GEOMETRIC CONCENTRATION RATIO	= 492.6 SUNS
PEAK FLUX CONCENTRATION RATIO	= 605 +/-33 SUNS

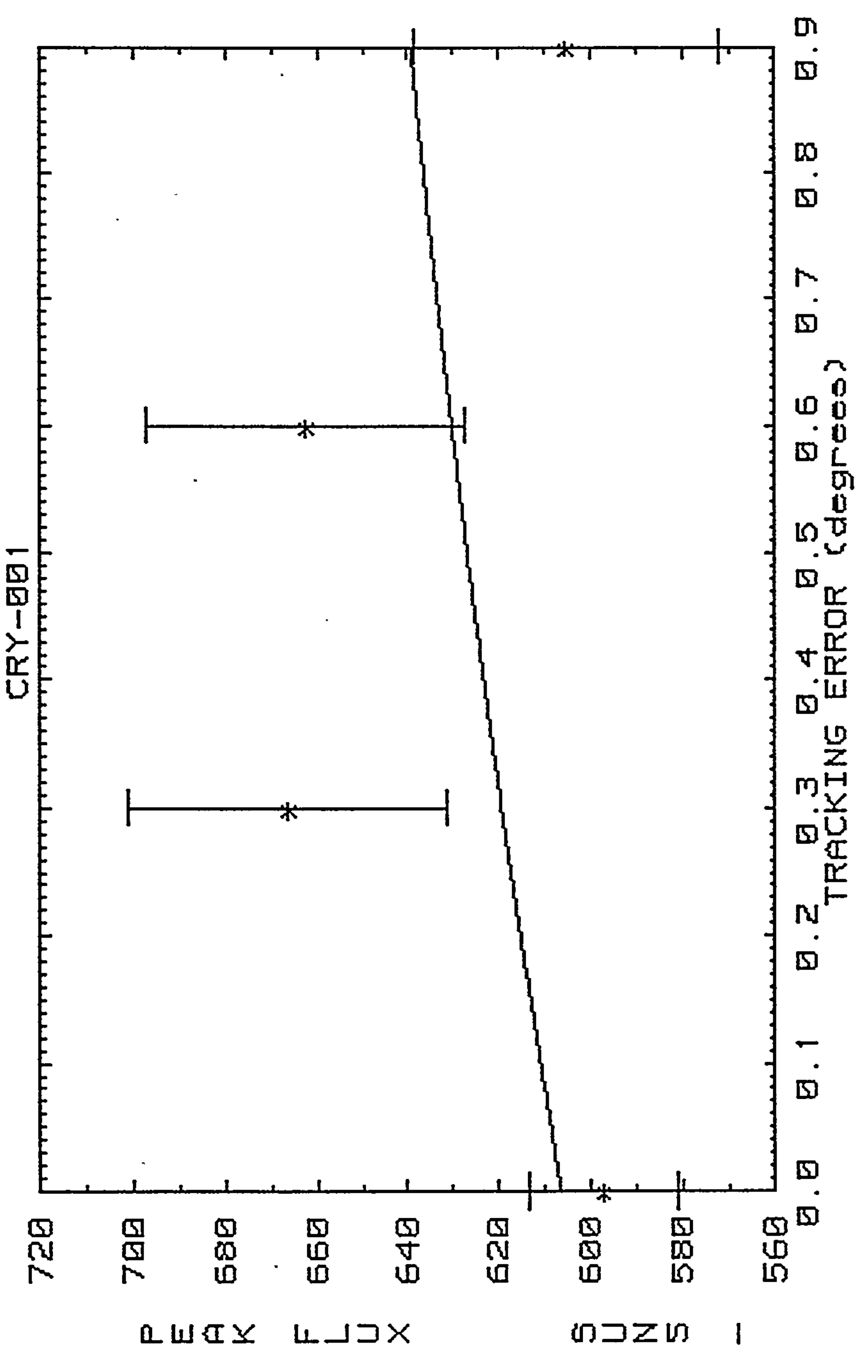
CONTOUR PLOT OF CELL'S SHORT CIRCUIT CURRENT FLUX DENSITY
(1.0 corresponds to uniform illumination and 100 % lens transmission)




CRY-001
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
TRACKING ERROR (degrees)

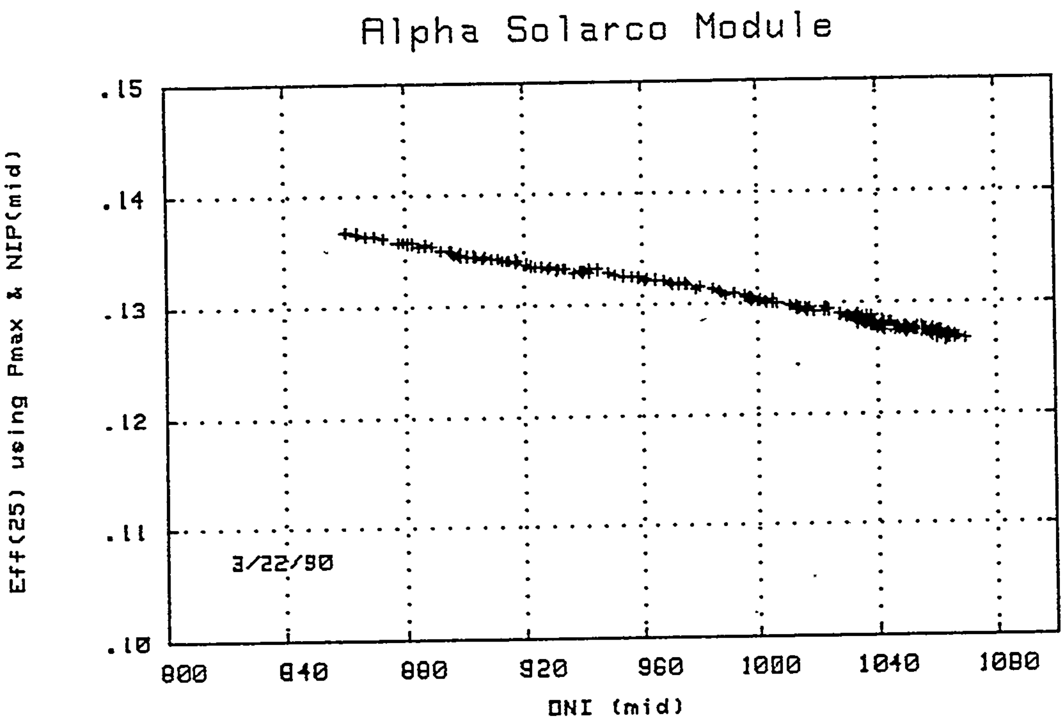

CRY-ØØ1
TRACKING ERROR (degrees)
FRACTION MISSING CELL
Ø.Ø1
Ø.Ø2
Ø.Ø3
Ø.Ø4
Ø.Ø5
Ø.Ø6
Ø.Ø
Ø.1
Ø.2
Ø.3
Ø.4
Ø.5
Ø.6
Ø.7
Ø.8
Ø.9

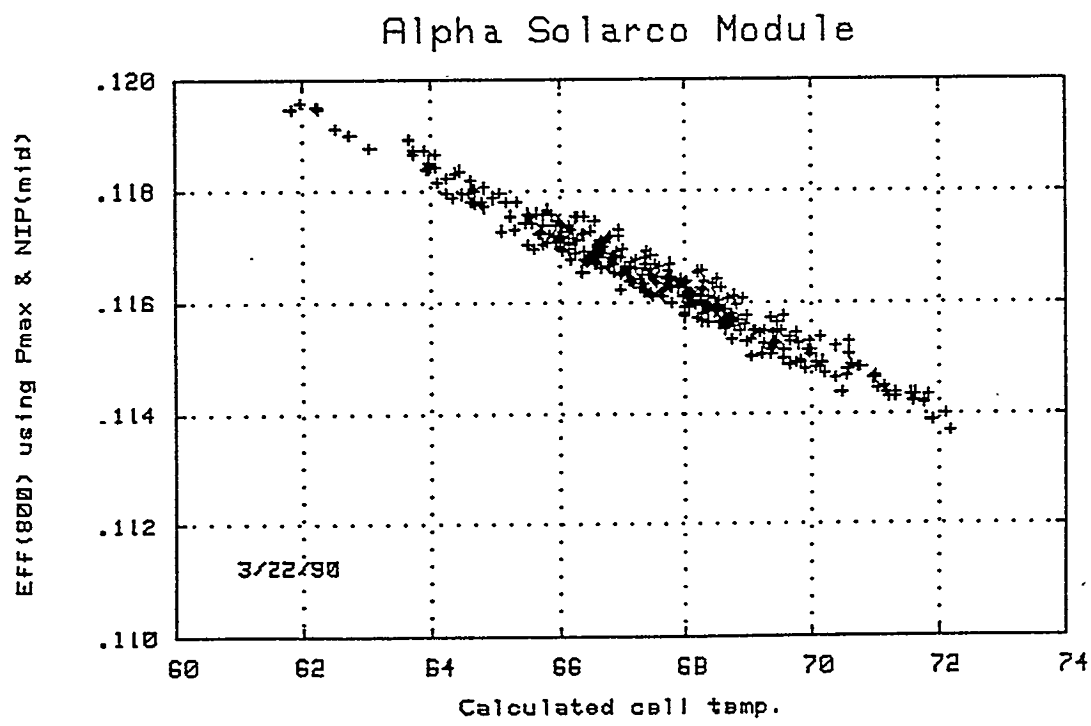

CRY-001
FRACTION MISSING SECONDARY
0.000
0.005
0.010
0.015
0.020
0.025
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
TRACKING ERROR (degrees)


CRY-001
TRACKING ERROR (degrees)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PEAK FLUX - SUNS
560
580
600
620
640
660
680
700
720

APPENDIX B

Module Performance Measurements Performed at Sandia National Laboratories





$$\eta\ (\%) = 19.736 - 0.054\ Tc(^{\circ}C) - 0.005\ DNI\ (W/m^2)$$

****

MULTIPLE LINEAR REGRESSION ON DATA SET:
ALS900322Z

****

--where: Dependent variable = Eff. using Pmax & NIP\mid
Independent variable(s) = Calculated cell temp.
DNI (mid)

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIATION
Calculated	351	6.7534451E+01	3.8087444E+00	1.9516005E+00	2.8897851E+00
DNI (mid)	351	1.0189288E+03	2.9027692E+03	5.3877353E+01	5.2876467E+00
Eff. using	351	1.0594941E-01	7.2899794E-06	2.6999962E-03	2.5483825E+30

CORRELATION MATRIX

Confidence coefficient (e.g., 90,95,99) = ?

	DNI (mid)	Eff. using Pmax & NIP(mid)
Calculated	-.0917038	-.3061522
DNI (mid)		-.9166006

R-SQUARED = .993710239016
STANDARD ERROR OF ESTIMATE = .000214745772063

AOV

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	350	.00255		
REGRESSION	2	.00254	.00127	27490.01
Calculated	1	.00024	.00024	5185.85
DNI (mid)	1	.00230	.00230	49794.17
RESIDUAL	348	.00002	0.00000	

VARIABLE	REGRESSION COEFFICIENTS STD. FORMAT	E-FORMAT	STANDARD ERROR REG. COEFFICIENT	T-VALUE

Confidence coefficient (e.g., 90,95,99) = ?

VARIABLE	REGRESSION COEFFICIENTS STD. FORMAT	E-FORMAT	STANDARD ERROR REG. COEFFICIENT	T-VALUE
'CONSTANT'	.19136	.191363139919E+00	.00047	405.49
Calculated	-.00054	-.544422414600E-03	.00001	-92.17
DNI (mid)	-.00005	-.477427491483E-04	0.00000	-223.15

$$\eta(\%) = 19.136 - .054\, T_c(°C) - .005\, DNI\,(W/m^2)$$

Confidence coefficient (e.g., 90,95,99) = ?

****
****

--where: Dependent variable = Eff. using Pmax & Ref.(mid)
Independent variable(s) = DNI (mid)
Calculated cell temp.

IENT VARIABLE TION	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFFIC OF VARIA
DNI (mid) E+00	351	1.0189288E+03	2.9027692E+03	5.3877353E+01	5.2876467
Calculated E+00	351	6.7534451E+01	3.8087444E+00	1.9516005E+00	2.8897851
Eff. using E+00	351	1.1022337E-01	1.7362487E-05	4.1668318E-03	3.7803523

CORRELATION MATRIX

	Calculated cell temp.	Eff. using Pmax & Ref.(mid)
DNI (mid)	-.0917038	-.9219299

Confidence coefficient (e.g., 90,95,99) = ?

*
Calculated -.0958529

R-SQUARED = .88277384406
STANDARD ERROR OF ESTIMATE = .00143074629723

AOV

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	350	.00608		
REGRESSION	2	.00536	.00268	1310.31
DNI (mid)	1	.00517	.00517	2523.19
Calculated	1	.00020	.00020	97.43
RESIDUAL	348	.00071	0.00000	

VARIABLE ALUE	REGRESSION COEFFICIENTS STD. FORMAT	E-FORMAT	STANDARD ERROR REG. COEFFICIENT	T-V
'CONSTANT' .92	.21042	.210421459110E+00	.00314	66
DNI (mid) .92	-.00007	-.725916056917E-04	0.0000C	-50
Calculated .87	-.00039	-.388430073010E-03	.00004	-9

Confidence coefficient (e.g., 90,95,99) = ? 95% LIMITS

LOWER	UPPER
.20458	.21627
-.00008	-.00007
.0046	-.00032

ALS900322Z

Selected degree of regression = 1
R-SQUARED = .0937291713763
STANDARD ERROR OF ESTIMATE = .0025740291452

AOV

SOURCE E	DF	SUM OF SQUARES	MEAN SQUARE	F-VA[illegible]
TOTAL	350	2.551493E-03		
REGRESSION	1	2.391493E-04	2.391493E-04	3.609460E+0[illegible]
X^1	1	2.391493E-04	2.391493E-04	3.609460E+0[illegible]
RESIDUAL	349	2.312343E-03	6.625626E-06	

VARIABLE	REGRESSION COEFFICIENTS	STANDARD ERROR REG. COEFFICIENT	T-VALUE
'CONSTANT'	1.345540E-01	4.763154E-03	2.824892E+01
X^1	-4.235548E-04	7.049990E-05	-6.007878E+00

Confidence coefficient (e.g., 90,95,99) = ?

*

	COEFFICIENT	95 % CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
'CONSTANT'	1.3455395E-01	1.2518378E-01	1.4392412E-01
X^1	-4.2355482E-04	-5.6224360E-04	-2.8486604E-04

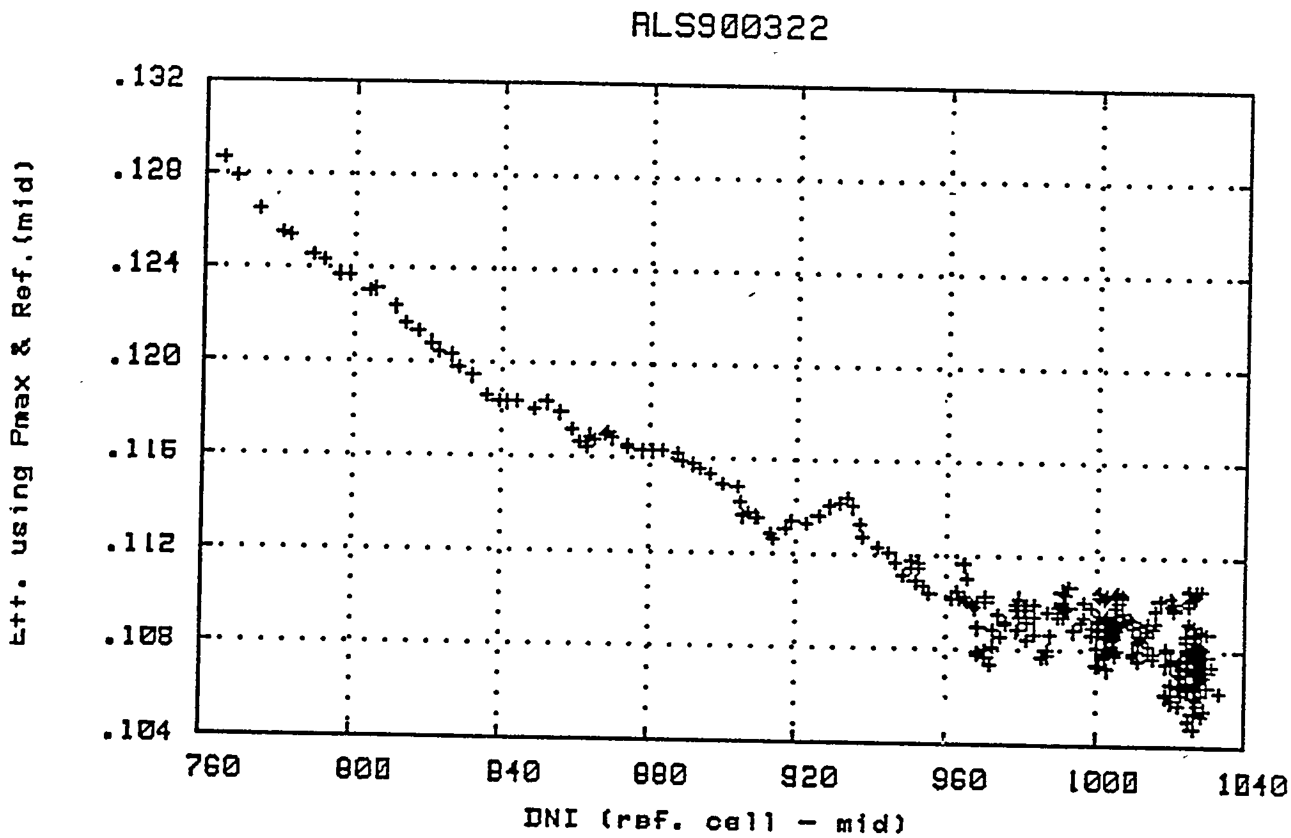
Eff = C + x'(CALCULATED TEMP)

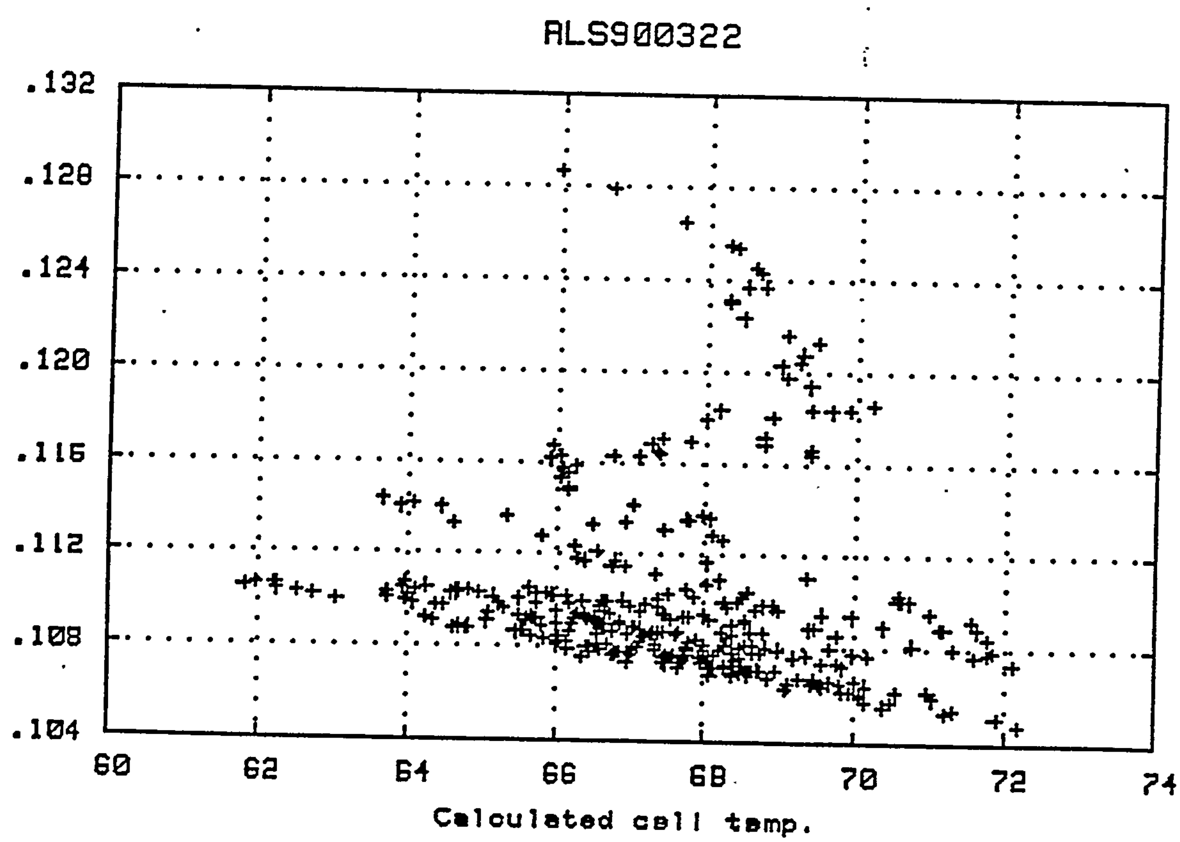
Pause...

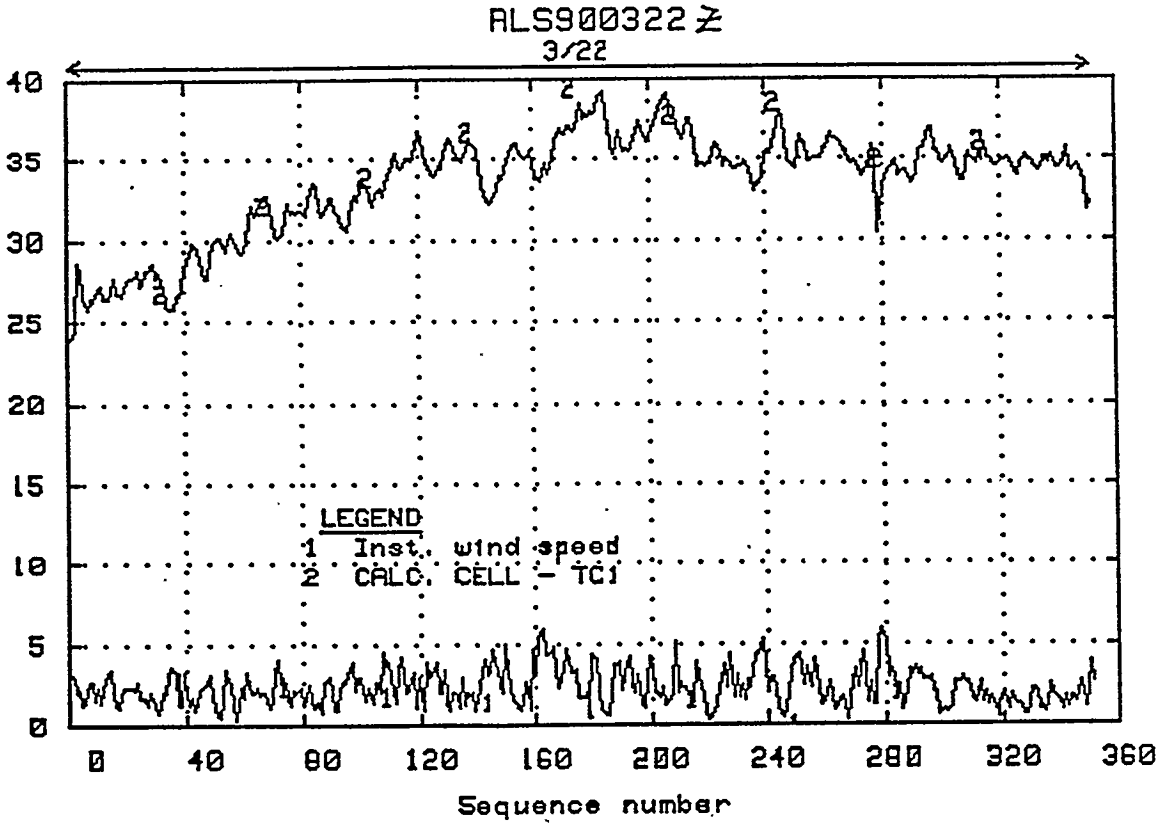
mand e Quit Quit Quit Quit Continue Continue Continue Contin[illegible]

User 1 Caps Co[illegible]

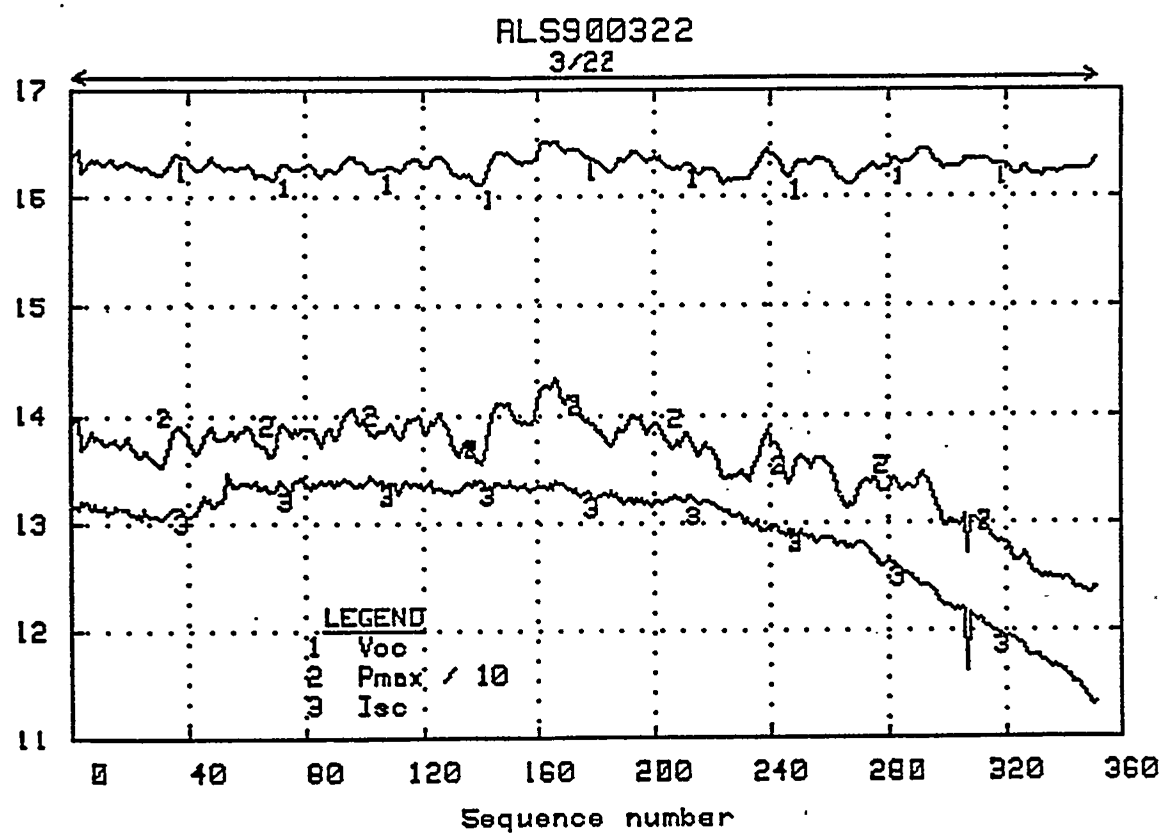
*


ALS900322
Eff. using Pmax & Ref. (mid)
.132
.128
.124
.120
.116
.112
.108
.104
760
800
840
880
920
960
1000
1040
DNI (ref. cell - mid)

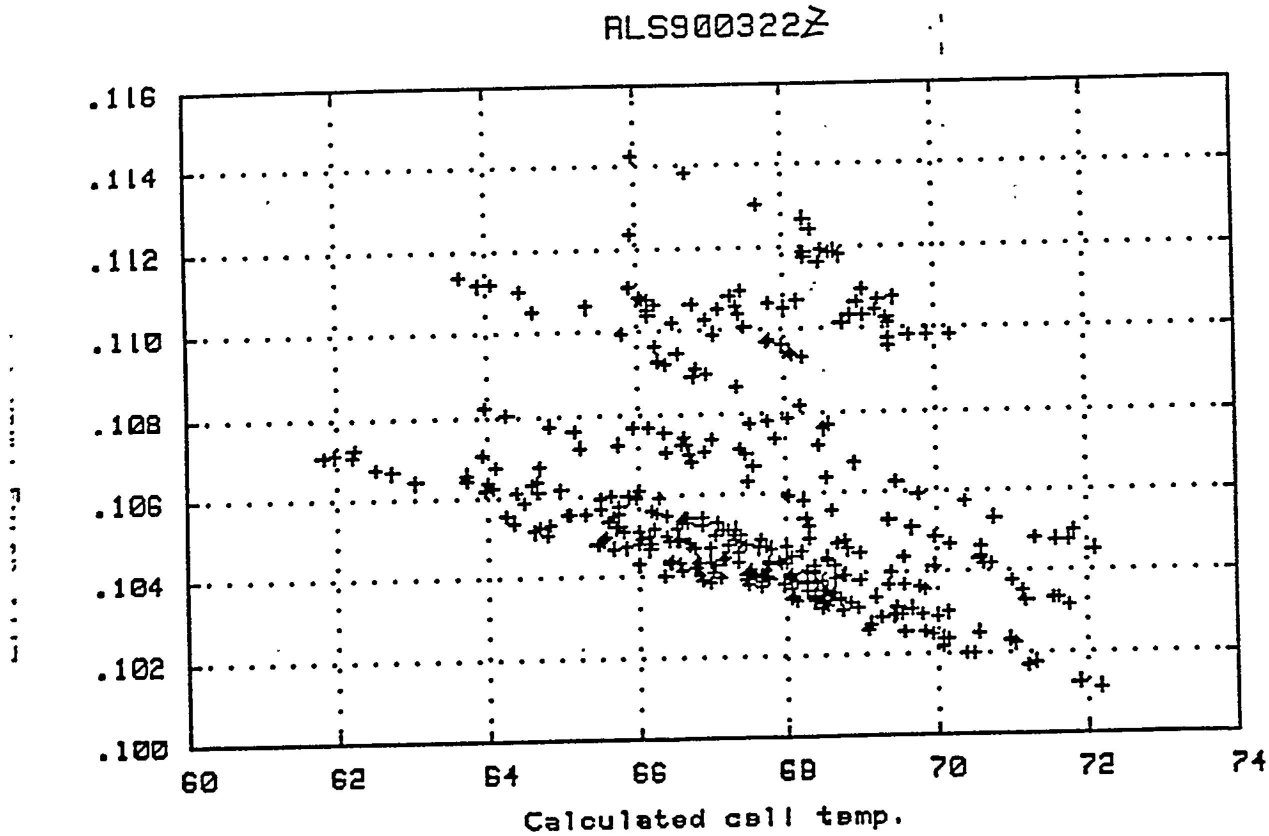

ALS900322
.132
.128
.124
.120
.116
.112
.108
.104
60
62
64
66
68
70
72
74
Calculated cell temp.

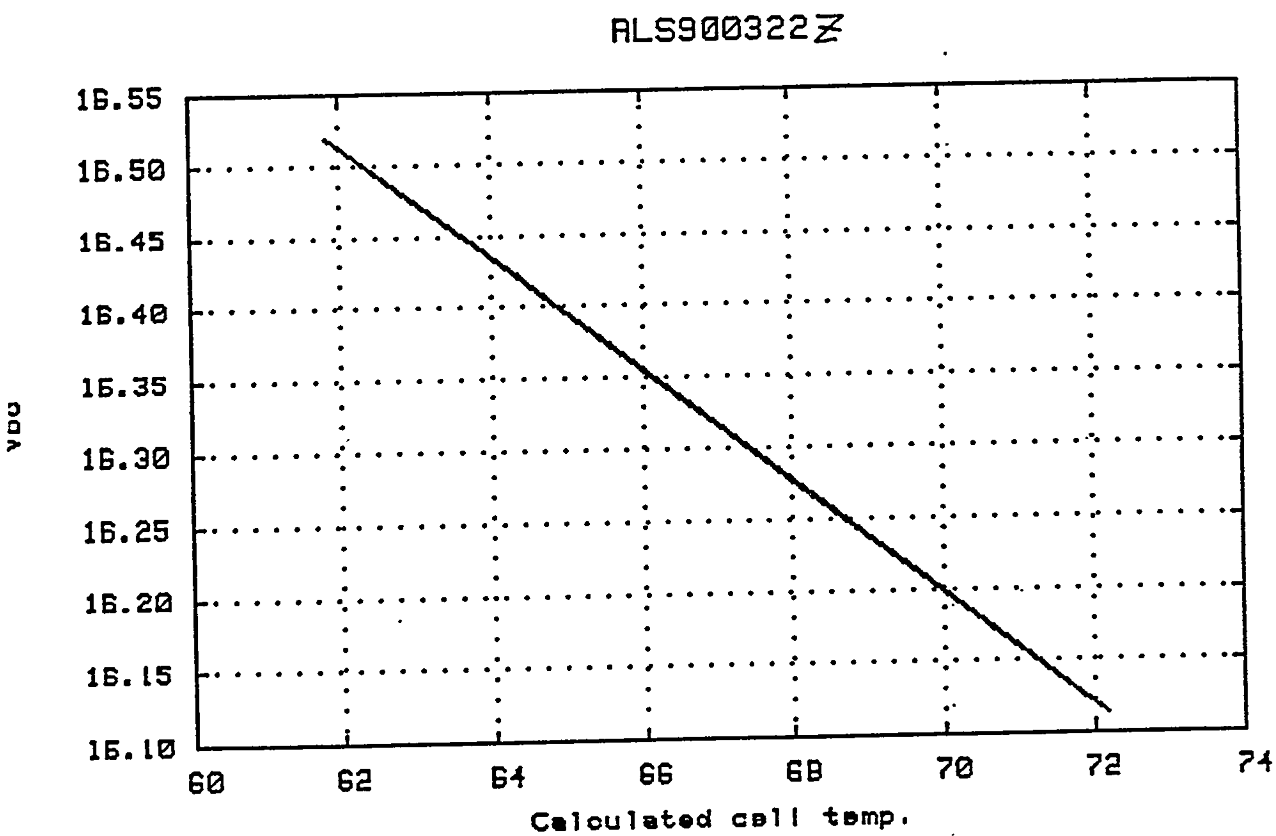


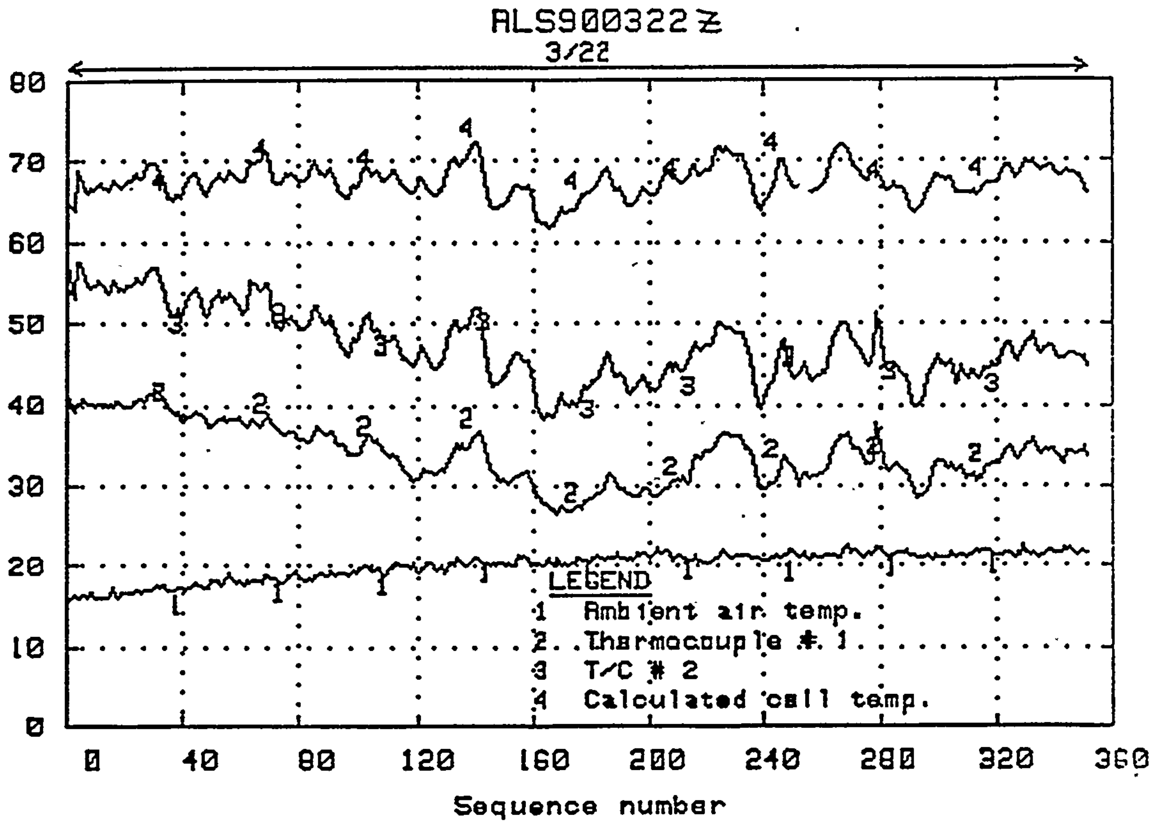
ALS900322
3/22
40
35
30
25
20
15
10
5
0
LEGEND
1 Inst. wind speed
2 CALC. CELL - TC1
0
40
80
120
160
200
240
280
320
360
Sequence number

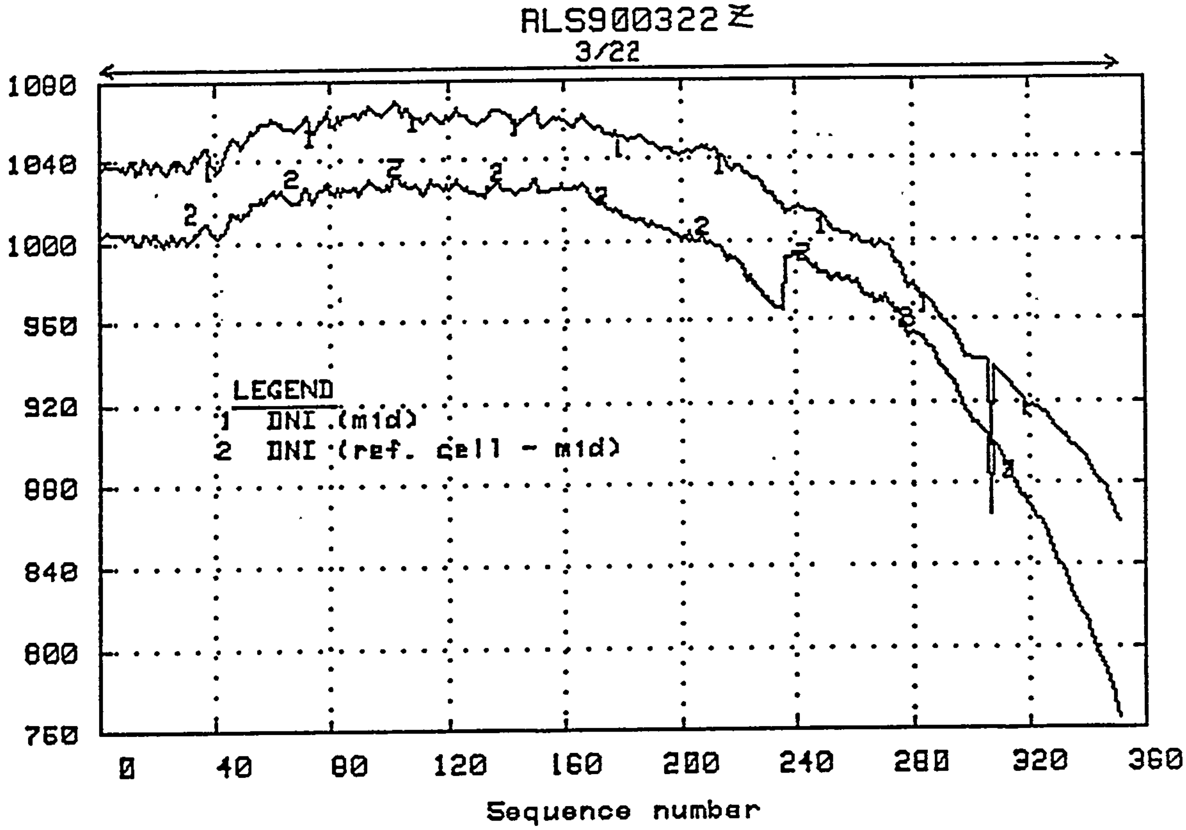


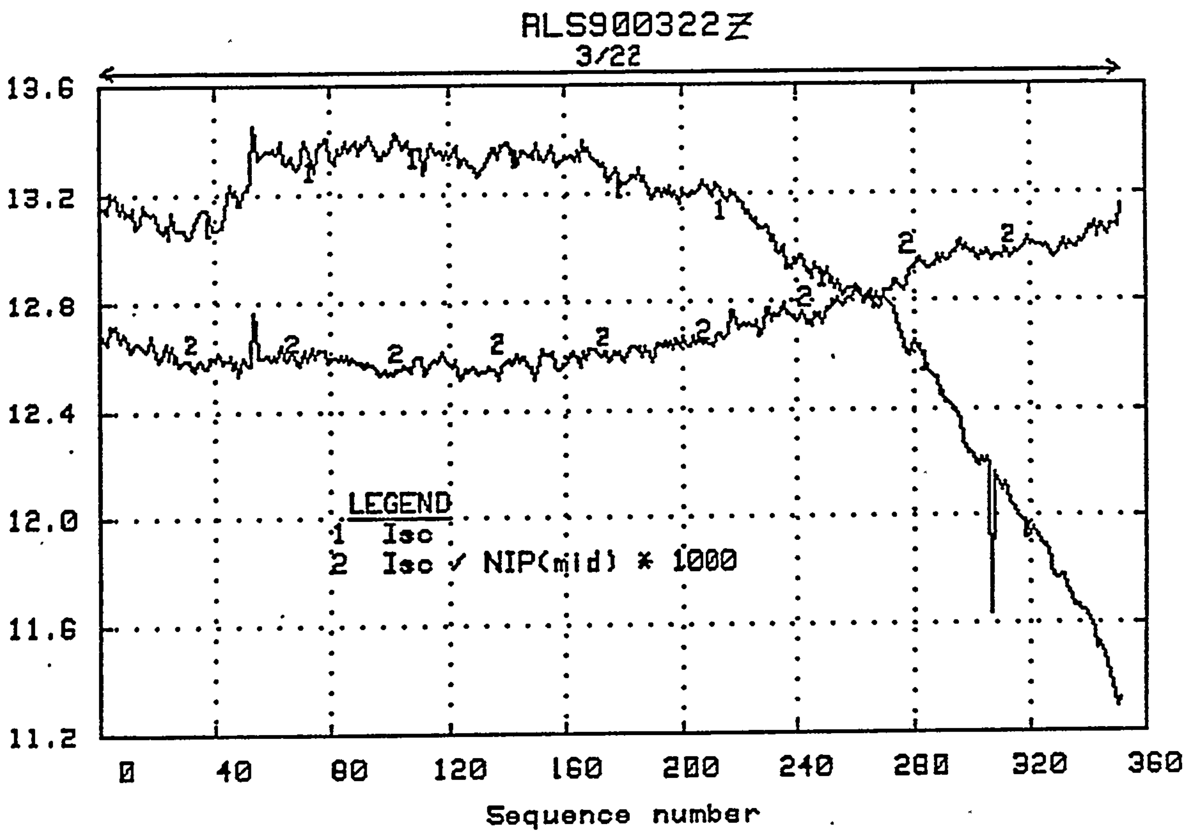
ALS900322
3/22
17
16
15
14
13
12
11
LEGEND
1 Voc
2 Pmax / 10
3 Isc
0
40
80
120
160
200
240
280
320
360
Sequence number

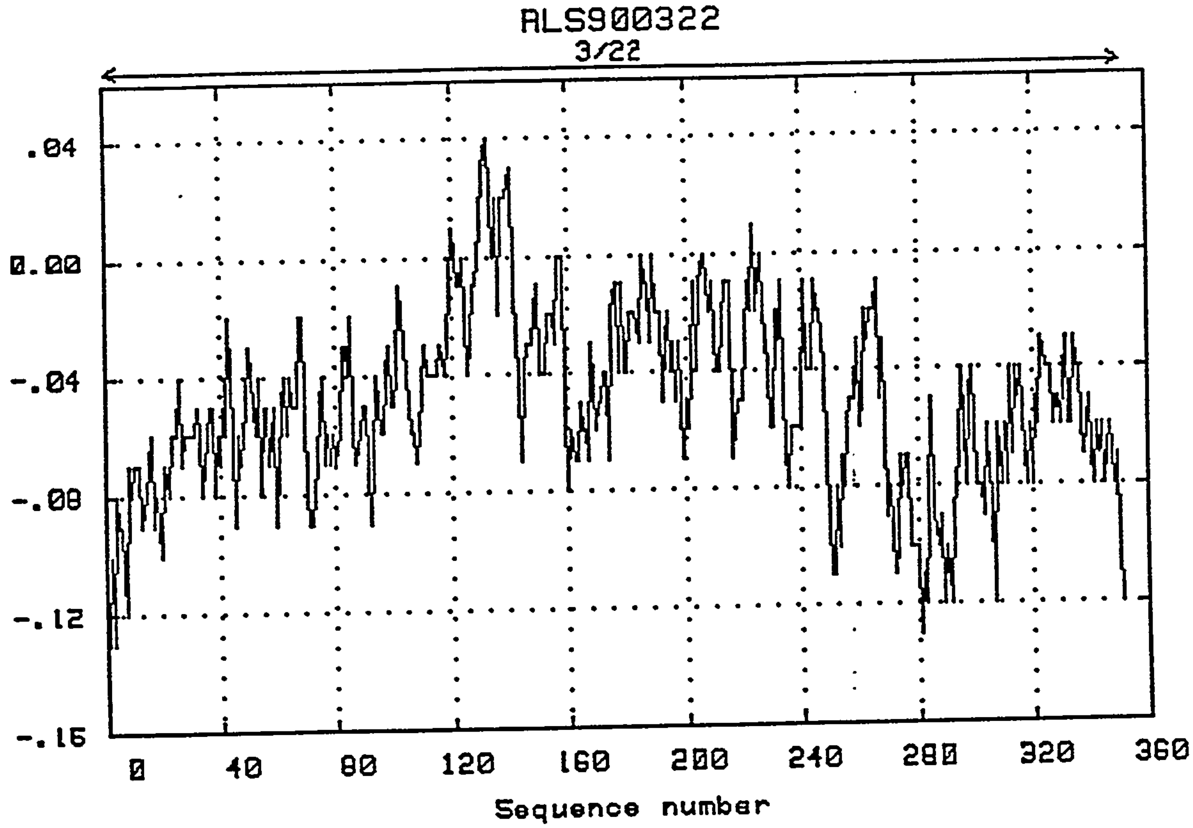

ALS900322Z
.116
.114
.112
.110
.108
.106
.104
.102
.100
60
62
64
66
68
70
72
74
Calculated cell temp.


ALS900322Z
VDC
16.55
16.50
16.45
16.40
16.35
16.30
16.25
16.20
16.15
16.10
60
62
64
66
68
70
72
74
Calculated cell temp.

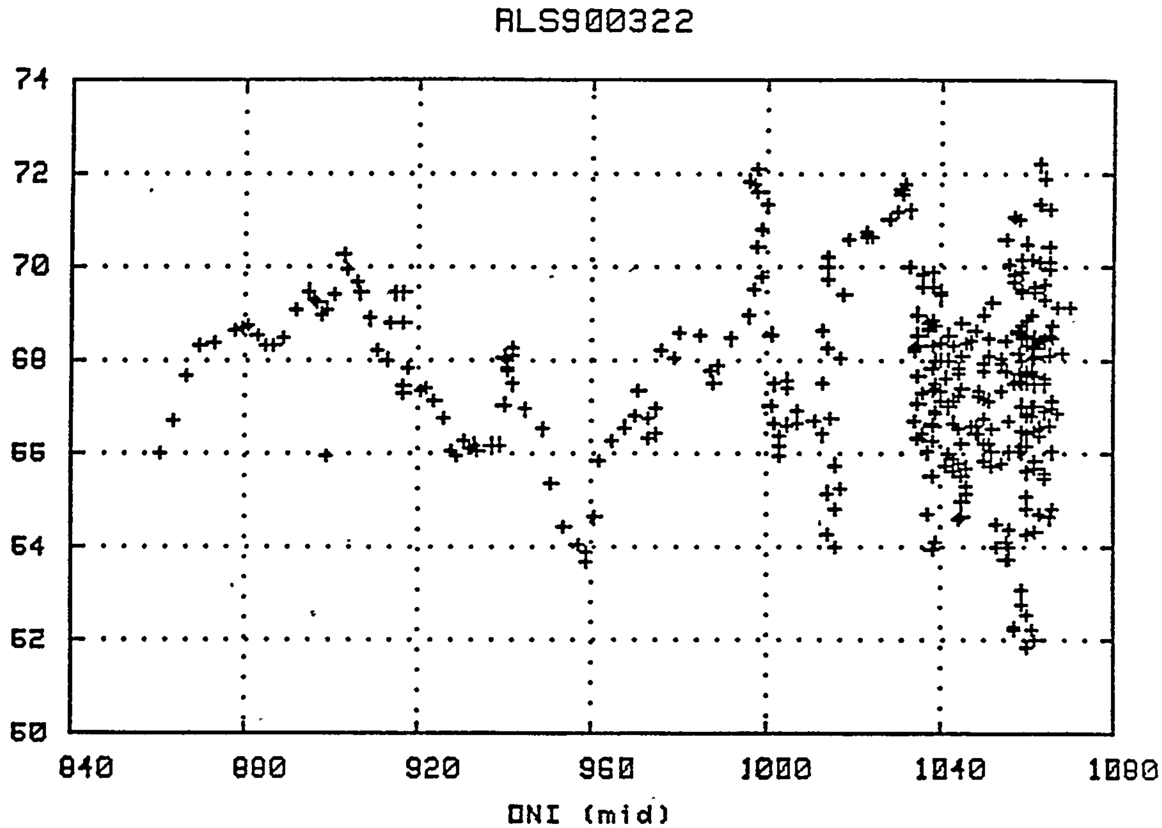

ALS900322Z
3/22
80
70
60
50
40
30
20
10
0
0
40
80
120
160
200
240
280
320
360
Sequence number
LEGEND
1 Ambient air temp.
2 Thermocouple # 1
3 T/C # 2
4 Calculated cell temp.

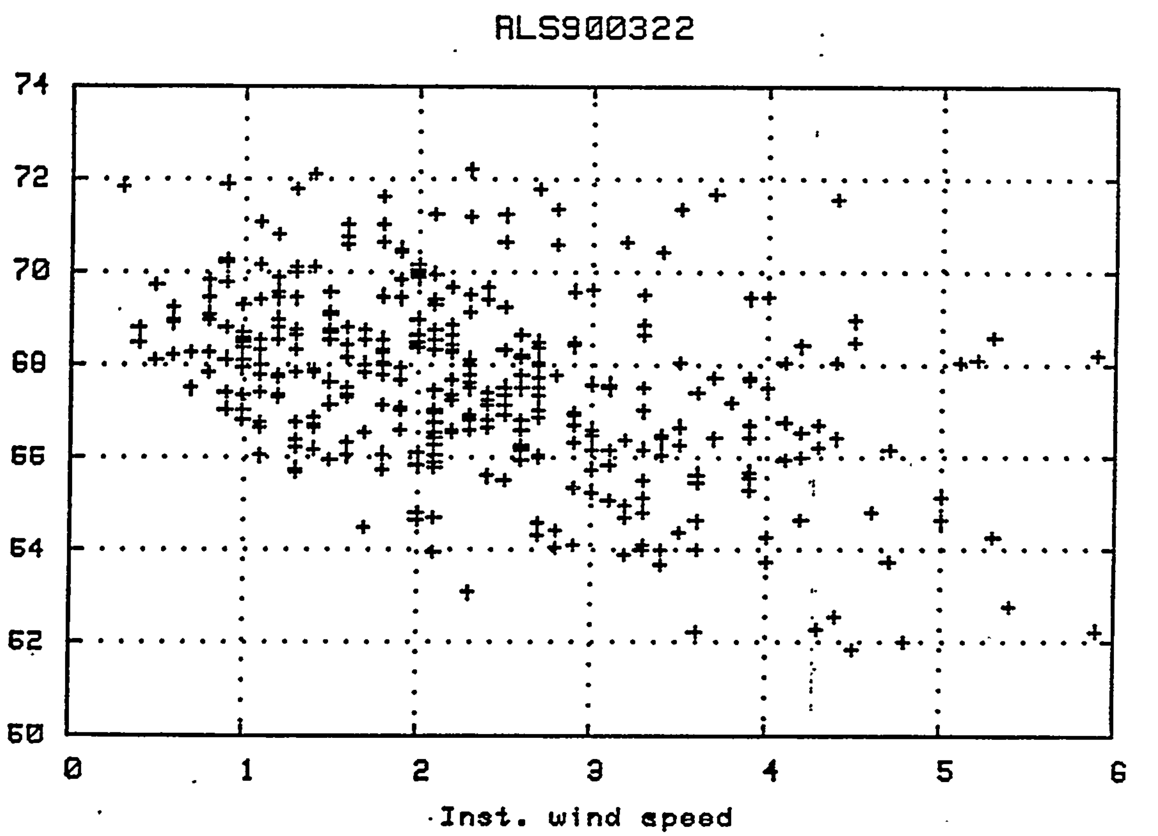

RLS900322Z
3/22
1080
1040
1000
960
920
880
840
800
760
0
40
80
120
160
200
240
280
320
360
Sequence number
LEGEND
1 DNI (mid)
2 DNI (ref. cell - mid)


RLS900322Z
3/22
13.6
13.2
12.8
12.4
12.0
11.6
11.2
0
40
80
120
160
200
240
280
320
360
Sequence number
LEGEND
1 Isc
2 Isc / NIP(mid) * 1000



RLS900322
3/22
.04
0.00
-.04
-.08
-.12
-.16
0
40
80
120
160
200
240
280
320
360
Sequence number


ALS900322
74
72
70
68
66
64
62
60
840
880
920
960
1000
1040
1080
DNI (mid)


ALS900322
74
72
70
68
66
64
62
60
0
1
2
3
4
5
6
Inst. wind speed

ORDER STATISTICS

VARIABLE	MAXIMUM	MINIMUM	RANGE	MIDRANGE
DNI (mid)	1070.00000	861.00000	209.00000	965.50000
THI (mid)	991.00000	351.00000	640.00000	671.00000
TNI (mid)	1155.00000	956.00000	199.00000	1055.50000
DNI (ref.	1033.00000	765.00000	268.00000	899.00000
Track erro	9.00000	5.94000	3.06000	7.47000
Track erro	.04000	-.13000	.17000	-.04500
Ambient ai	22.50000	15.90000	6.60000	19.20000
Dew point	-4.60000	-8.80000	4.20000	-6.70000
Relative h	24.00000	12.00000	12.00000	18.00000
Inst. wind	5.90000	.30000	5.60000	3.10000
Voc	16.51900	16.11400	.40500	16.31650
Isc	13.45418	11.29604	2.15813	12.37511
Pmax	143.26561	123.46747	19.79814	133.36654
Vmp	12.44010	11.78110	.65900	12.11060
Imp	11.67023	9.96024	1.70999	10.81523
Fill facto	.67179	.62799	.04380	.64989
Thermocoup	42.13600	26.74800	15.38800	34.44200
T/C # 2	57.49600	38.28700	19.20900	47.89150
Avr. temp.	50.68850	34.28025	16.40825	42.48438
Calculated	72.17374	61.82542	10.34832	66.99958
(Avr.temp-	.03309	.01284	.02025	.02297
PASTF test	1162.00000	1162.00000	0.00000	1162.00000
Test item	1.26000	1.26000	0.00000	1.26000
Eff. using	.11426	.10113	.01313	.10769

VARIABLE	VARIANCE	STANDARD DEV.	COEF OF SKEWNESS	COEF OF KURTOSIS

ALS900322

1.	Sequence number	2.	Test date
3.	Solar time	4.	DNI (mid)
5.	THI (mid)	6.	TNI (mid)
7.	DNI (ref. cell - mid)	8.	Track error Az. (mid)
9.	Track error El. (mid)	10.	Ambient air temp.
11.	Dew point temp.	12.	Relative humidity
13.	Inst. wind speed	14.	Voc
15.	Isc	16.	Pmax
17.	Vmp	18.	Imp
19.	Fill factor	20.	Thermocouple # 1
21.	T/C # 2	22.	Avr. temp.
23.	Calculated cell temp.	24.	(Avr.temp-Air temp)/NIP(en d)
25.	PASTF test confg. number	26.	Test item aperture area
27.	Eff. using Pmax & NIP(mid)	28.	Eff. using Pmax & Ref.(mid)
29.	Eff. using Pmax & POA(mid)	30.	10*NIP/Ref + 30
31.	Isc / NIP(mid) * 1000	32.	DNI / 10
33.	Voc / 10	34.	Fill factor * 10
35.	Pmax / 10	36.	Eff * 100
37.	CALC. CELL - TC1	38.	

351 observations

APPENDIX C

Off track performance of Haystack and Silo SOEs

Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185

August 22, 1991

Mr. Edward Schmidt
Alpha Solarco
11534 Gondola Dr.
Cincinnati, OH 45241

Dear Ed,

We have completed tests on the new tall version Silo and the Haystack version secondary optical element in our lens/cell tester. Some preliminary test results were reported in my letter to you dated July 29, 1991. The results presented here include offtrack, lens/cell spacing, and temperature tests of the two configurations of secondary optical element mentioned above. In summary, the results confirm prior tests, i.e., the Haystack design has excellent optical efficiencies (81 to 82% peak optical efficiency vs. 69 to 72% for the tall new Silo) but poorer fill factor (.65 to .67 vs. .69 to .72 for the tall new Silo). The result is the Haystack has a slight edge on overall lens/cell efficiency (12 to 12.5%) compared with the new tall Silo (11 to 11.4%). However, we know there is probably some optical loss in the tall Silo, since even if it was perfectly aligned, James' optical code predicts some illumination of the cell buss due to the larger image size. It is probable that one of the shorter versions of the new Silo design would have a better design-point lens/cell efficiency than the tall new Silo and possibly more than the Haystack design.

Attached are some summary data sheets and plots. If you want, I will get you a copy of the full set of data sheets from all tests. First is offtrack data on the new tall Silo for three runs in July and August. Plots adjusted in offtrack angle to align the peak values show similar curves, with a lens/cell efficiency of 95% of the peak value occurring at an offtrack angle of a little over ±0.5°, about ±0.6° to ±0.7°. Peak values are 11 to 11.4% for lens/cell efficiencies. The lens-to-cell spacing study for the new tall Silo design shows the peak efficiencies, either optical or lens/cell, occurs at a longer lens-to-cell spacing than the design; 12.25" vs. 11.95". The temperature test showed the expected drop in Voc and fill factor with increasing temperature, leading to a lower cell and lens/cell efficiency. Lens/cell efficiency drops from 11.46% to 10.8% over 20°C; a drop of 0.033% per °C.

The Haystack results are similar. The Haystack offtrack tests show it has a slightly wider view angle, about ±0.8°. Peak lens/cell efficiencies are higher; 11.9 to 12.6%. The lens-to-cell spacing study also shows the peak to be at a longer lens-to-cell spacing; 12.15" vs. 11.95", although the increase in output is slight. The results of the temperature test for the Haystack secondary are also included. Efficiency drops from 12.92% to 11.96% over 30°C, a drop of 0.032% per °C.

A comparison of the lens/cell efficiencies of the two approaches is also graphed showing the slightly higher efficiency and wider acceptance angle of the Haystack design.

As discussed in the last letter, the optical and lens/cell efficiencies predicted by James' code do not match the values measured on the tall new Silo very well. The optical efficiency was predicted to go from 79% ontrack to 58% at one degree offtrack, but we measured a change from 69% to 70% down to 60% to 63% at one degree offtrack. The cell performance was fairly level at about 16%, as predicted, (16.2% to 16.5%). The differences may be due to misalignment of the Silo on the cell which causes illumination of the buss, or it may be due to reflection effects off the top of the Silo.

However, the values predicted by James' code do match the Haystack values fairly closely. The optical efficiency drops from 80.5% to 68% from ontrack to 1° offtrack in James' computations (assuming a 2% absorption), and we measured a drop from 82% to 72%. Cell performance was predicted to go from 15.5% to 16% at one degree offtrack, whereas we measured a change from 14.5 to 15%. The lens/cell efficiency was predicted to go from 12.5% to 11%, and we measured 12.5% to 11.4% in one test and 11.86% to about 11% in the other test.

To better understand the discrepancy in the new Silo data from James' predictions, we need to fabricate a new cell assembly with a shorter new Silo. The tall version tested was the tallest of four sizes you proposed to test. We are in the process of getting one-sun data on six cell assemblies you sent us which can be used for this purpose.

At this point, the Haystack secondary design has shown the best performance, but I think the new Silo design can provide comparable results if a shorter secondary is used.

Sincerely,

Alex Maish

Alexander B. Maish
Photovoltaic Technology
and Research Div. 6224

Copy to:

D. L. King, 6224
D. E. Hasti, 6224
C. B. Stillwell, 6224

Offtrack Test for Alpha Solarco "New" Silo, Tallest Configuration

5-Jul-91

Offtrack Test Results

Reported Offtrack Angle		-1.50	-1.25	-1.00	-0.75	-0.50	-0.25	0.00 (scan)	0.25	0.50	0.75	1.00	1.25	1.50
Estimated Offtrack Angle	-1.50	-1.25	-1.00	-0.75	-0.50	-0.25	0.00	0.25	0.50	0.75	1.00	1.25	1.50	
Optical Efficiency (%)		56.28	64.92	69.19	70.44	71.72	72.40	71.95	69.68	64.16	51.59	29.82	16.47	
Lens/Cell Effic. (%)		8.83	10.16	10.87	11.11	11.29	11.39	11.35	11.00	10.21	8.36	4.96	2.68	
Cell Effic. (%)		15.69	15.65	15.71	15.77	15.74	15.73	15.77	15.78	15.90	16.18	16.63	16.27	
Isc (Norm.) (A)		9.704	11.238	11.978	12.193	12.414	12.533	12.462	12.056	11.106	8.931	5.156	2.850	
Fill Factor		0.7014	0.6944	0.6954	0.6979	0.6964	0.6957	0.6972	0.6994	0.7070	0.7232	0.7555	0.7563	
Voc (V)		0.6779	0.6807	0.6817	0.6828	0.6826	0.6831	0.6834	0.6819	0.6796	0.6756	0.6652	0.6485	
Heat Sink Temp (C)		63.70	64.70	65.10	65.10	65.40	65.10	65.00	65.40	65.80	65.00	63.20	63.70	

Offtrack Test for Alpha Solarco "New" Silo, Tallest Configuration

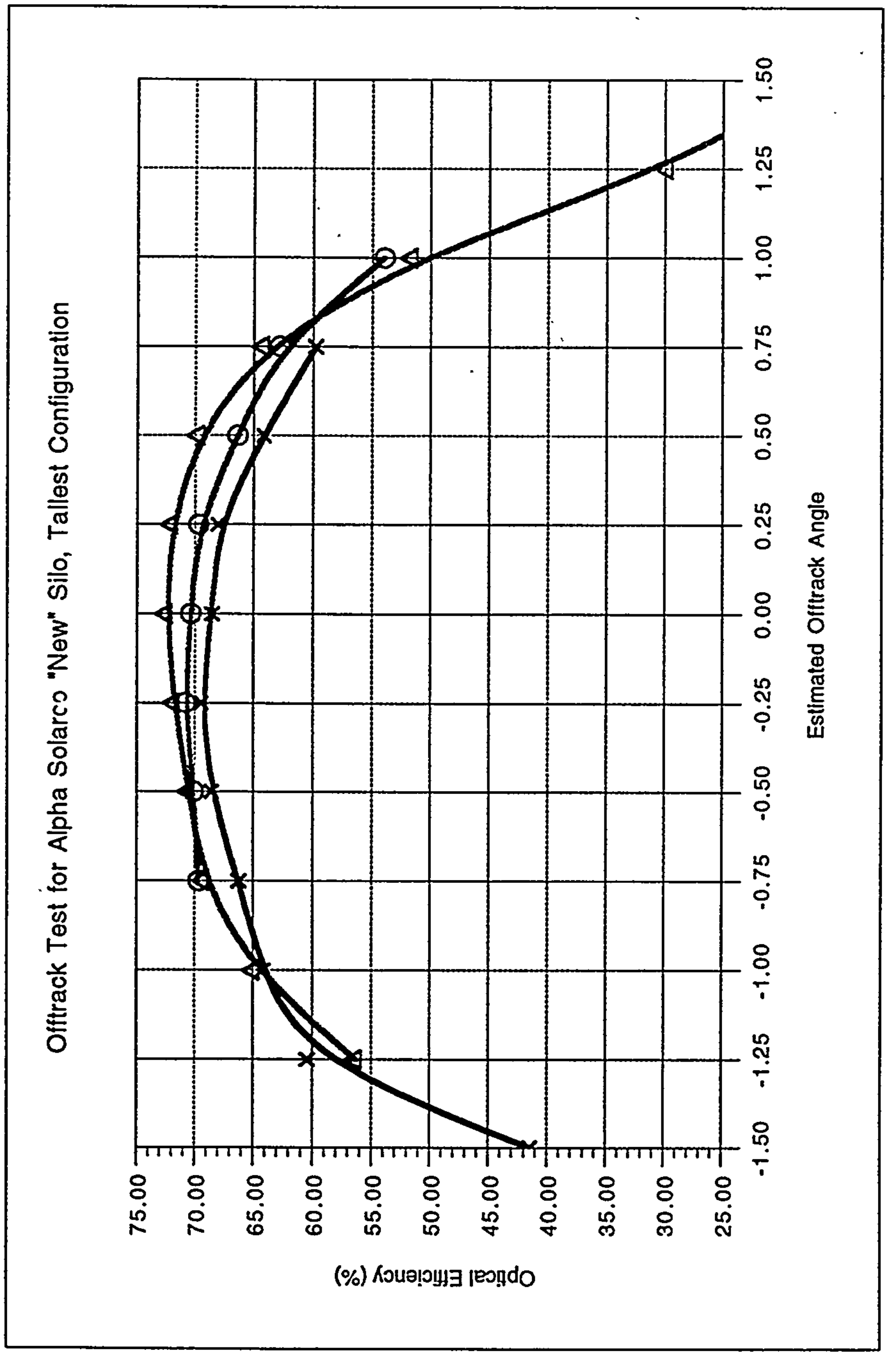
5-Aug-91 Cell 196-55 1-sun 76-68

Reported Offtrack Angle	-1.50	-1.25	-1.00	-0.75	-0.50	-0.25	0.00 (scan)	0.25	0.50	0.75	1.00	1.25	1.50
Estimated Offtrack Angle		-1.50	-1.25	-1.00	-0.75	-0.50	-0.25	0.00	0.25	0.50	0.75	1.00	1.25
Optical Efficiency (%)						69.60	70.06	70.77	70.33	69.66	66.34	62.81	53.94
Lens/Cell Effic. (%)						11.25	11.45	11.55	11.53	11.37	10.60	9.89	8.31
Cell Effic. (%)						16.17	16.34	16.32	16.39	16.32	15.98	15.75	15.41
Isc (Norm.) (A)						11.970	12.23	12.350		12.165	11.570	10.960	9.420
Fill Factor						0.7105	0.71	0.7121		0.7141	0.7022	0.6945	0.6819
Voc (V)						0.6811	0.69	0.6862		0.6849	0.6809	0.6789	0.6762
Heat Sink Temp (C)						65.90	64.00	63.80	63.80	64.30	65.20	64.90	63.80

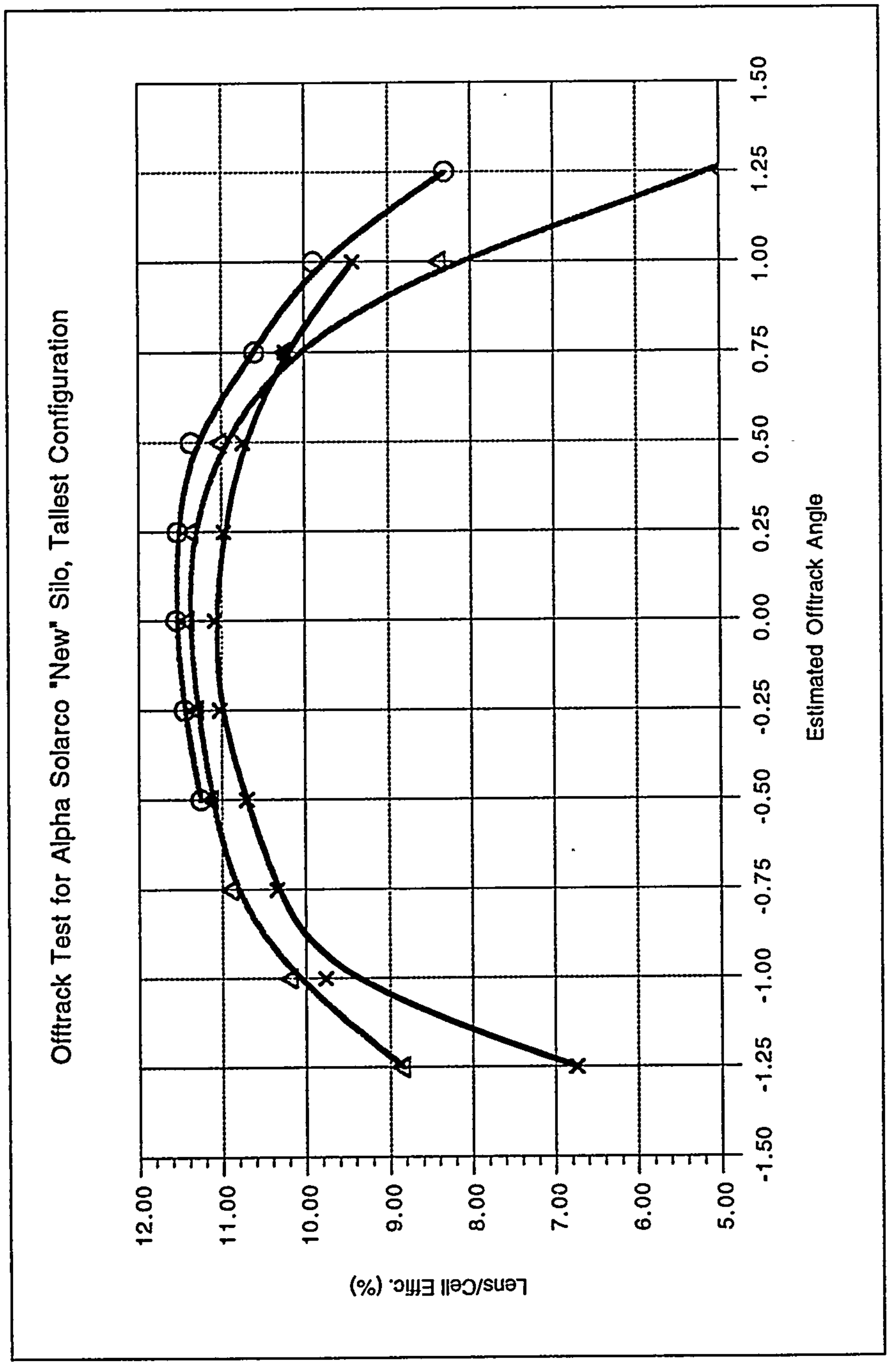
Offtrack Test for Alpha Solarco "New" Silo, Tallest Configuration

6-Aug-91 Cell 196-55 1-sun 76-68

Reported Offtrack Angle	-1.50	-1.25	-1.00	-0.75	-0.50	-0.25	0.00 (scan)	0.25	0.50	0.75	1.00	1.25	1.50
Estimated Offtrack Angle			-1.50	-1.25	-1.00	-0.75	-0.50	-0.25	0.00	0.25	0.50	0.75	1.00
Optical Efficiency (%)				41.46	60.41	64.18	66.21	68.54	69.40	68.49	68.00	64.14	59.73
Lens/Cell Effic. (%)				6.74	9.76	10.34	10.70	11.02	11.08	10.97	10.74	10.23	9.42
Cell Effic. (%)				16.25	16.15	16.10	16.16	16.07	15.97	16.01	15.79	15.94	15.77
Isc (Norm.) (A)				7.07	10.30	10.945	11.29	11.690	11.84	11.682	11.597	10.939	10.187
Fill Factor				0.74	0.73	0.7232	0.7265	0.7209	0.7184	0.7183	0.7143	0.7224	0.7166
Voc (V)				0.67	0.68	0.6823	0.6816	0.6831	0.6811	0.6831	0.6772	0.6762	0.6741
Heat Sink Temp (C)				61.60	63.90	62.40	62.60	62.30	63.20	62.30	65.70	65.40	65.70



Offtrack Test for Alpha Solarco "New" Silo, Tallest Configuration
Optical Efficiency (%)
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
Estimated Offtrack Angle
-1.50
-1.25
-1.00
-0.75
-0.50
-0.25
0.00
0.25
0.50
0.75
1.00
1.25
1.50


Offtrack Test for Alpha Solarco "New" Silo, Tallest Configuration
Lens/Cell Effic. (%)
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
-1.50
-1.25
-1.00
-0.75
-0.50
-0.25
0.00
0.25
0.50
0.75
1.00
1.25
1.50
Estimated Offtrack Angle

Lens/Cell Spacing Test for Alpha Solarco "New" Silo, Tallest Configuration

3-Jul-91

Lens/Cell Spacing Test Results

Lens/Cell Spacing	11.65	11.75	11.85	11.95	12.05	12.15	12.25	12.35	12.45	12.55	11.95 (pre)	11.95 (pre)	11.95 (pre)
Optical Efficiency (%)	69.07	71.83	73.10	74.15	74.88	75.56	75.86	76.12	75.48	73.61	74.78	74.48	74.42
Lens/Cell Effic. (%)	10.40	10.90	11.14	11.21	11.31	11.39	11.45	11.36	11.15	10.71	11.27	11.20	11.15
Cell Effic. (%)	15.06	15.17	15.24	15.12	15.11	15.07	15.09	14.92	14.77	14.55	15.07	15.04	14.98
Isc (Norm.) (A)	11.638	12.116	12.330	12.514	12.623	12.739	12.789	12.827	12.725	12.409	12.587	12.563	12.533
Fill Factor	0.6930	0.6937	0.6947	0.6914	0.6906	0.6896	0.6895	0.6843	0.6798	0.6718	0.6910	0.6906	0.6892
Voc (V)	0.6738	0.6780	0.6798	0.6778	0.6780	0.6774	0.6783	0.6759	0.6798	0.6713	0.6761	0.6752	0.6741
Heat Sink Temp (C)	66.60	63.00	62.50	63.60	63.60	63.90	63.60	65.10	65.70	66.40	64.90	65.30	66.00

Lens/Cell Spacing Test for Alpha Solarco "New" Silo, Tallest Configuration

5-Aug-91 Cell #196-5 1-sun 76-68

Lens/Cell Spacing Test Results

Lens/Cell Spacing	11.65	11.75	11.85	11.95	12.05	12.15	12.25	12.35	12.45	12.55
Optical Efficiency (%)		67.07	69.17	70.33	71.40	72.57	72.79	72.70		
Lens/Cell Effic. (%)		10.99	11.21	11.53	11.61	11.76	11.86	11.76		
Cell Effic. (%)		16.39	16.20	16.39	16.26	16.20	16.29	16.17		
Isc (Norm.) (A)		11.700	11.970	12.272	12.466	12.676	12.693	12.679		
Fill Factor		0.7171	0.7161	0.7157	0.7128	0.7106	0.7118	0.7077		
Voc (V)		0.6841	0.6835	0.6859	0.6831	0.6832	0.6857	0.6848		
Heat Sink Temp (C)		64.30	64.70	63.80	65.60	65.60	64.00	64.40		

7.0.0 PROCUREMENT CONTROL.

7.1.0 Specifications of Deliverables (MANUAL 0090-M).
Alpha Solarco's purchasing agents are responsible for procurement of components, sub-components, and services. Detailed material requisitions (0090-F) and purchase orders (0091-F) are used through the operation, giving proper specifications, and attributes to the materials and services ordered from the vendors. Technical meetings and visits are scheduled periodically to avoid any misunderstandings.

7.2.0 Qualifications of Suppliers.
The purchasing agent(s) responsibility is to determine the vendor's capability to provide quality products, materials or services on time. Verifying these qualifications is done via official channels, or through Alpha Solarco's professional network. A number of procurement documents are used by Alpha Solarco's procurement agents.

7.3.0 Testing of Deliverables.
All received materials and parts are tested within a 10 day max. time period. The shipments are checked for completeness, correctness and breakage.

8.0.0 MATERIALS/INVENTORY CONTROL.

8.1.0 Storage (INVENTORY MANUAL 0110-M).
The received materials are entered in the receiving log (0100-L) and in the inventory list (0110-L), and are stored in the storage area for future use. Any materials that are unsatisfactory will be rejected and returned to the vendor. The transaction is recorded and accounted.

8.2.0 Identification of Materials.
Tags (0110-F) are used in Alpha Solarco's manufacturing operations to identify all parts and materials in the inventory. The I. D. number is used to keep track of the materials and parts in the production cycle.

8.3.0 Disposal.
All items not meeting Alpha Solarco's specs are returned to the vendor, or are disposed of properly.

8.4.0 Shipping (MANUAL 0100-M).
Special shipping instructions are provided to the carrier, transporting components and sub-systems to the installation site.

9.0.0 TESTING CONTROL.

9.1.0 Calibration (MANUAL 0120-M)
Alpha Solarco has established calibration procedures for its test and measurement equipment. All calibrations are done in a controlled environment.

9.1.1 Standards.
NTIS standards are applied in all in-house test and measurement procedures. Outside sources, like Sandia and SERI are used in special cases.

9.1.2 Re-calibration of Instruments.
The test and measurement equipment on Alpha Solarco's premises undergoes a scheduled periodic calibration checks and re-calibration. Calibration tags (0120-F) with the date and initials of the person performing the calibration procedures, are attached to the instruments.

9.1.3 Maintenance (MANUAL 0040-M).
Alpha Solarco has an established schedule for periodic maintenance of all instruments and equipment on its premises. The instruments are checked on regular basis in order to make sure that they operate properly.

9.1.4 Disposal of Faulty Instruments.
Equipment which is not possible to calibrate is discarded. The inventory list is updated after each such incident.

9.1.5 Electrical Standards Authority.
DOE/AL Order XA57 is the authority for resolving all unresolved issues in this area.

9.2.0 Testing Environment.
Special care is taken to ensure the cleanliness of the environment where tests are performed.

9.3.0 Sampling.
100% of the produced items by Alpha Solarco undergo vigorous testing procedures. The QC manager will decide on sampling rate, if it is to be lower than 100%.

10.0.0 QUALITY RECORDS CONTROL.

10.1.0 Quality Records (MANUAL 0130-M).
A number of Quality records are kept at Alpha Solarco. Design records, drawings, design changes, inspection and test procedures, hardware identification numbers and job travelers are kept in storage permanently, or shorter time period. Alpha Solarco maintains two types of Quality Records mainly, permanent records and temporary records.

10.2.0 Permanent Records.
These are kept indefinitely, and include: designs, drawings, calculations, proposals, design changes, Inspection and test procedures, data and results, hardware identification numbers, job travelers, data of material traceability, failure reports and analysis, rework reports, procurement records, certificates reviews, inspections and audits. , etc.

10.3.0 Non-permanent Records.
Some data, not considered for permanent storage, include: raw quality data on "trouble-free" tests and procedures etc.

10.4.0 Storage.
Hard copies of quality records are indexed, filed and stored in file cabinets and storage boxes. Computer disk records are on file whenever appropriate.

10.5.0 Availability and Security of Records.
All Alpha Solarco quality and other records are readily available for inspection by any government official. These are kept in security areas, where they are safe from fire and theft.

10.6.0 Uses of the Records.
These records are often used for comparative studies, design verification and changes etc. activities.

11.0.0 CUSTOMER RELATIONS.

Alpha Solarco has a large network of customers both in the USA and abroad. A wide array of interactions with the customers are undertaken each day on technical and administrative levels. Professional etiquette and common sense guidelines (EMPLOYEE MANUAL 0140-M) are used in dealing with all customers. The degree and level of interaction are determined by Alpha Solarco's management on case by case basis.

12.0.0 MARKETING PLAN.

Alpha Solarco uses a wide spectrum of marketing approaches. These are designed specifically for each customer. The best and most professional techniques are used in all cases.

13.0.0 QUALITY AUDITS.

13.1.0 Audits (MANUAL 0150-M).
Alpha Solarco conducts periodic internal, and is always prepare for external, audits.

13.2.0 Internal Audits.
Alpha Solarco has established a check list covering the activities of each project. A competent technical staff conducts the audit, and report the results to the QC manager. The report details the procedures in used and lists the problems encountered.

13.3.0 External Audits. Alpha Solarco has established plans for external audits, from technical people non-related to the company. The results are again reported to the QC manager.

APPENDIX E

The Effect of Lens/Cell Spacing on Cell Assembly Output

Sandia National Laboratories

Albuquerque, New Mexico 87185

March 30, 1993

Mr. Don Carroll
Alpha Solarco
11534 Gondoloa Dr.
Cincinnati, OH 45241

Dear Don,

Enclosed is some preliminary data taken on the VAN-8 cell assembly using your 0.65" SOE. The data is fairly consistent with data taken in July 1991, although the optical efficiency is down by 2-3% from then. We are using a different lens, a laminated lens from your production line, and the cell operating temperature was set lower (using active cooling) than in 1991, 50°C vs 65°C. The performance trends are similar in that the optimum lens/cell spacing is longer than the design, probably due to slight variations in the lens from design due to manufacturing limitations. The resulting lens/cell efficiency is fairly flat over a wide range of lens/cell spacing, and the performance does not seem to be hurt by the non-optimal spacing.

We are continuing our investigations, and plan to measure primary lens efficiency. We hope to compare the production lens to a direct cut lens.

Sincerely,

Alexander B. Maish
Photovoltaic Technology
Department 6213

Lens/Cell Spacing Test for Alpha Solarco 0.65" Diameter Secondary
3/23/93 Cell Assembly VAN-8 Lens 3M-3

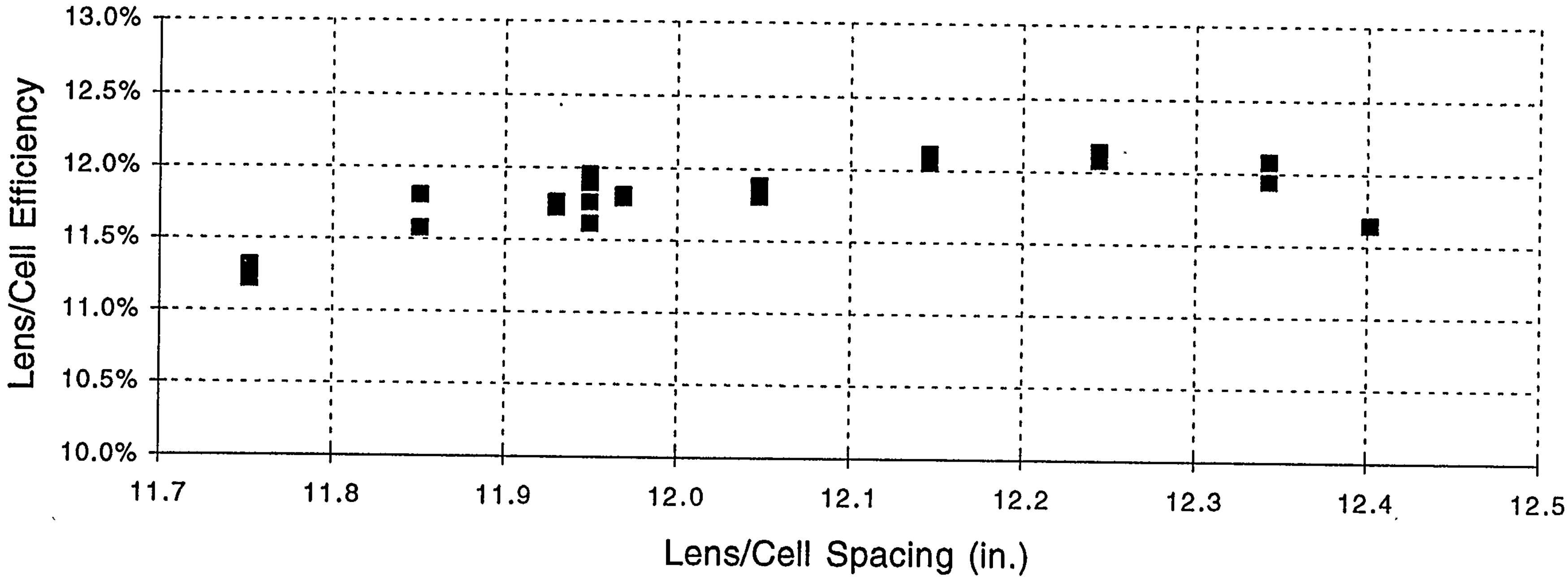
Lens/Cell Spacing Test Results

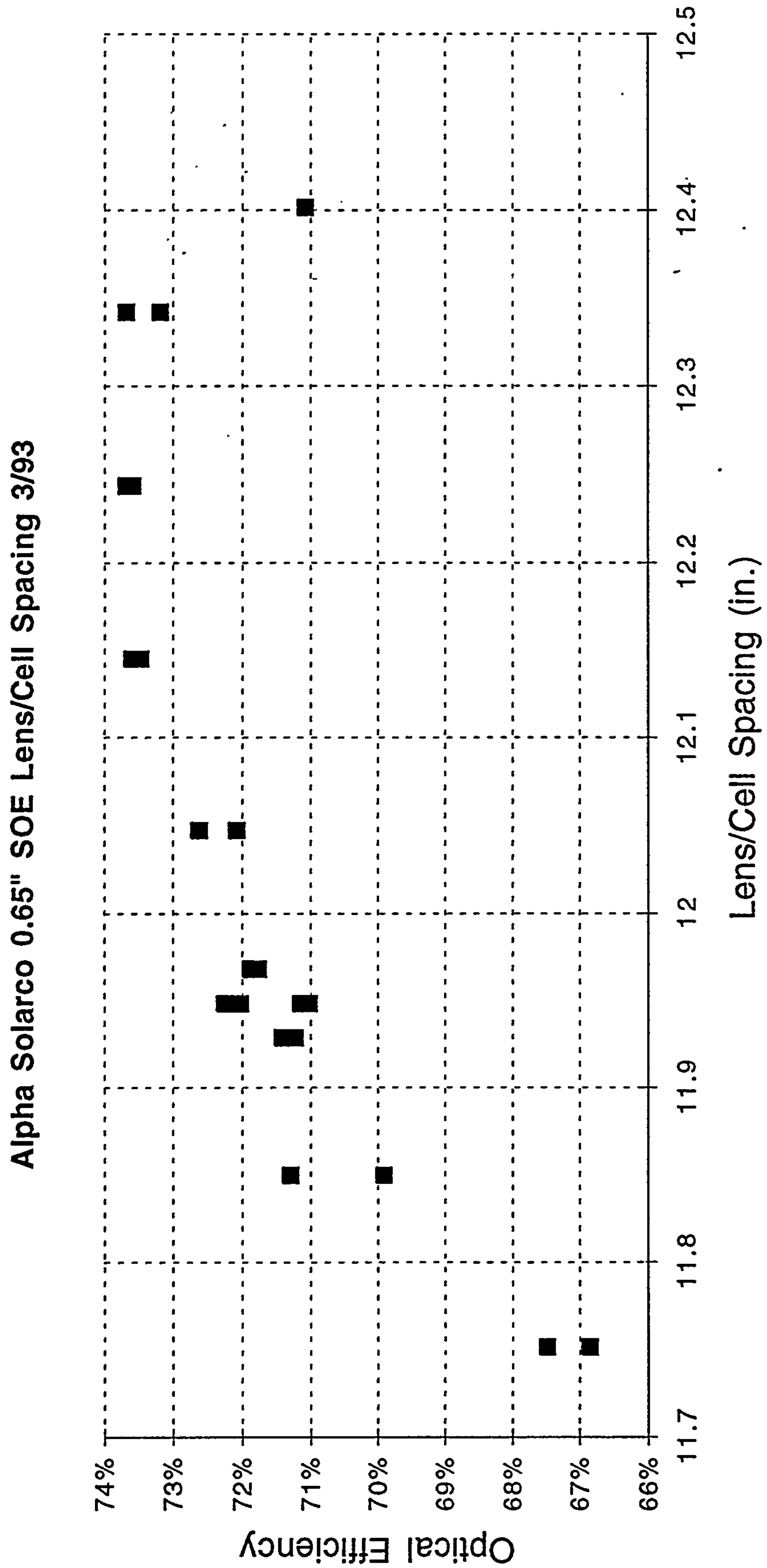
Lens/Cell Spacing (mm)	298.5	298.5	301	301	303	303	303.5	303.5	303.5	303.5	303.5	303.5
Lens/Cell Spacing (in)	11.75	11.75	11.85	11.85	11.93	11.93	11.95	11.95	11.95	11.95	11.95	11.95
Scan No	24	23	22	21	6	5	20	19	10	9	2	1
Optical Efficiency (%)	67.47%	66.84%	69.90%	71.28%	71.22%	71.40%	72.08%	72.24%	72.01%	72.09%	71.13%	71.01%
Cell Efficiency (%)	16.77%	16.78%	16.55%	16.55%	16.46%	16.47%	16.58%	16.45%	16.55%	16.49%	16.53%	16.35%
Lens/Cell Effic. (%)	11.31%	11.21%	11.57%	11.80%	11.72%	11.76%	11.95%	11.89%	11.92%	11.89%	11.76%	11.61%
Isc (Norm.) (A)	11.446	11.339	11.858	12.093	12.081	12.113	12.227	12.254	12.216	12.229	12.066	12.047
Fill Factor	73.85%	73.92%	72.91%	72.81%	72.38%	72.37%	72.82%	72.48%	72.77%	72.64%	72.64%	72.40%
Voc (V)												
Heat Sink Temp (C)	49.7	49.8	49.8	50.1	49.8	49.7	49.1	50.4	49.6	51	49.3	52.6
Lens/Cell Spacing (in)	11.8	11.8	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9
Lens/Cell Effic. (%)	11.3%	11.2%	11.6%	11.8%	11.7%	11.8%	12.0%	11.9%	11.9%	11.9%	11.8%	11.6%

AS L/C 0.65 SOE 3/93

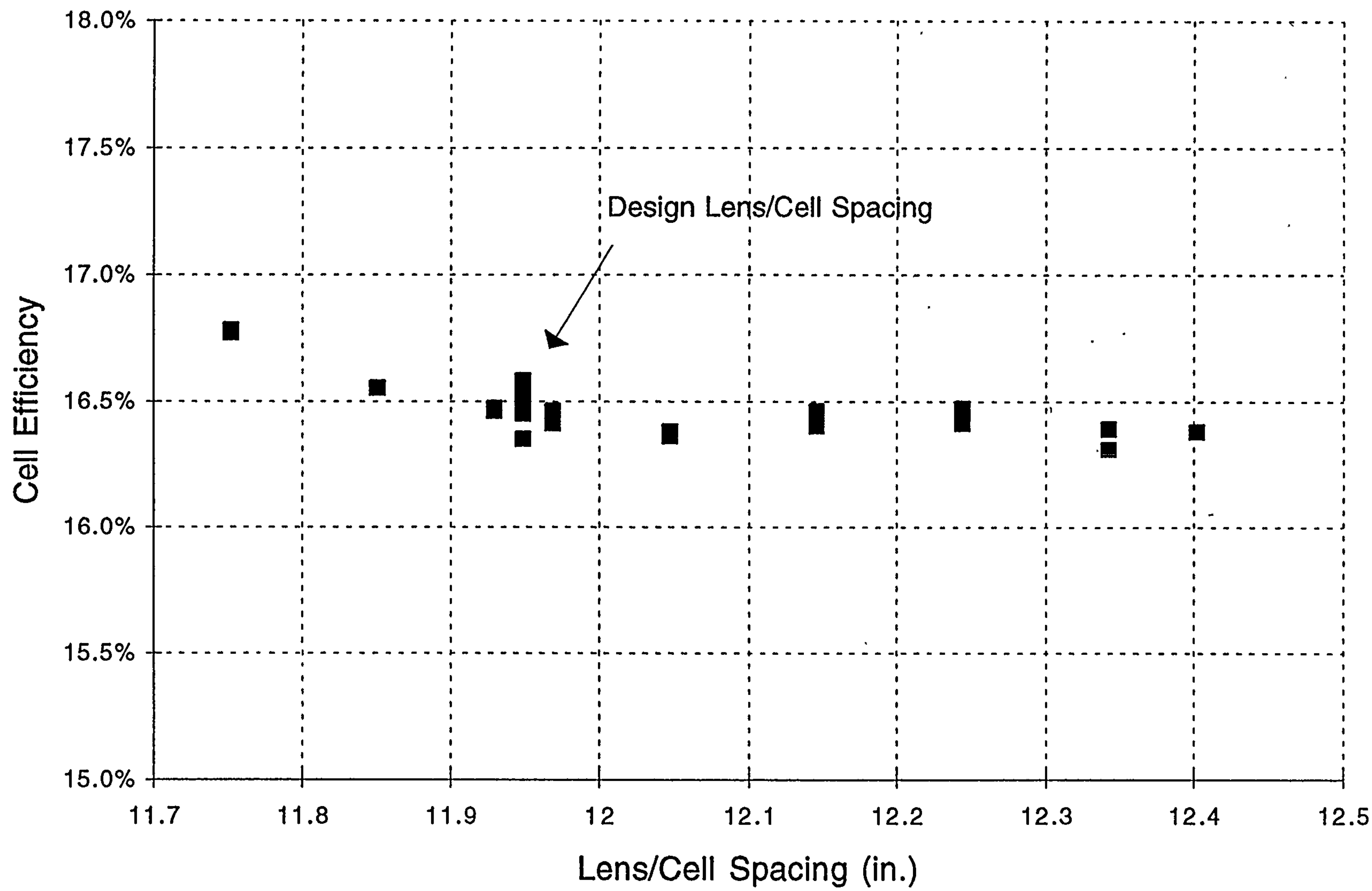
304	304	306	306	308.5	308.5	311	311	313.5	313.5	315
11.97	11.97	12.05	12.05	12.15	12.15	12.24	12.24	12.34	12.34	12.40
4	3	8	7	12	11	14	13	16	15	17
71.86%	71.75%	72.61%	72.06%	73.59%	73.46%	73.68%	73.59%	73.68%	73.19%	71.07%
16.41%	16.46%	16.36%	16.38%	16.46%	16.40%	16.47%	16.41%	16.39%	16.31%	16.38%
11.79%	11.81%	11.88%	11.80%	12.11%	12.05%	12.14%	12.08%	12.08%	11.94%	11.64%
12.19	12.171	12.318	12.224	12.484	12.461	12.5	12.484	12.5	12.416	12.057
72.18%	72.46%	71.95%	72.16%	72.32%	72.27%	72.31%	72.25%	72.00%	71.80%	72.19%
49.6	50.1	49.7	50.5	49.5	50.9	49.2	50.2	49.5	50.1	50.1
12.0	12.0	12.0	12.0	12.1	12.1	12.2	12.2	12.3	12.3	12.4
11.8%	11.8%	11.9%	11.8%	12.1%	12.1%	12.1%	12.1%	12.1%	11.9%	11.6%

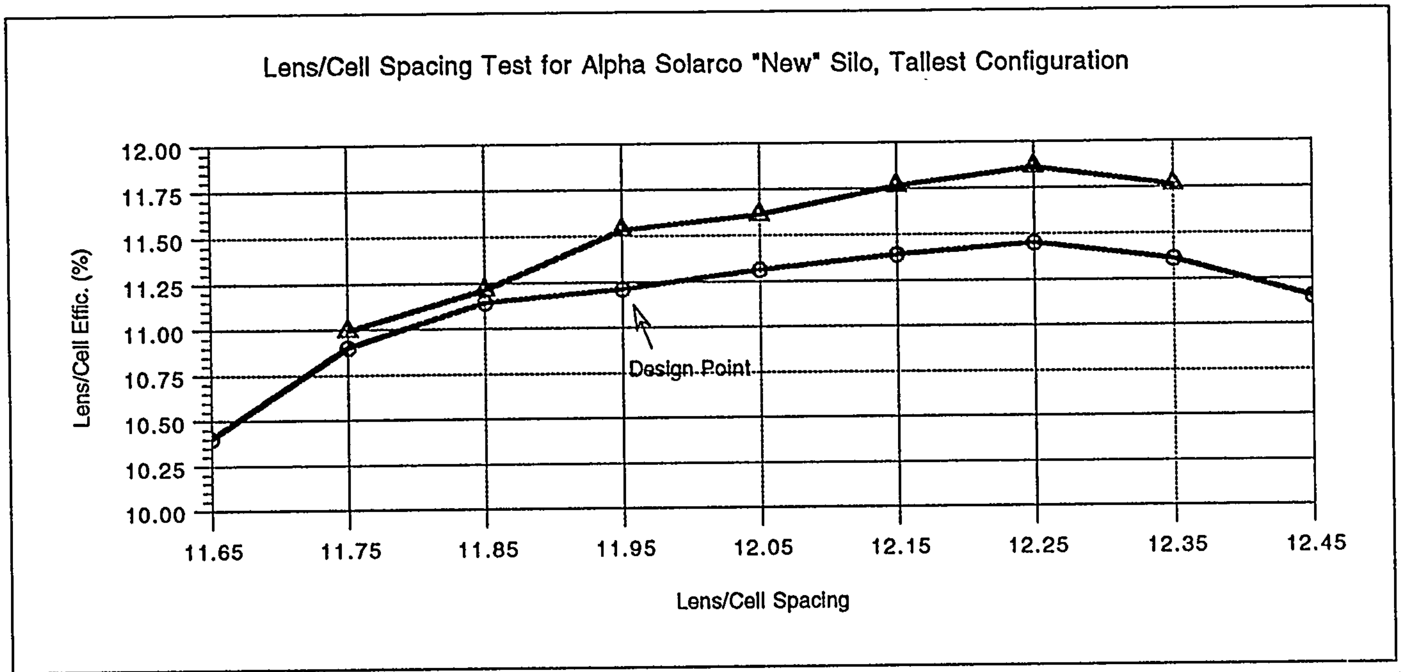
Alpha Solarco 0.65" SOE Lens/Cell Spacing 3/93

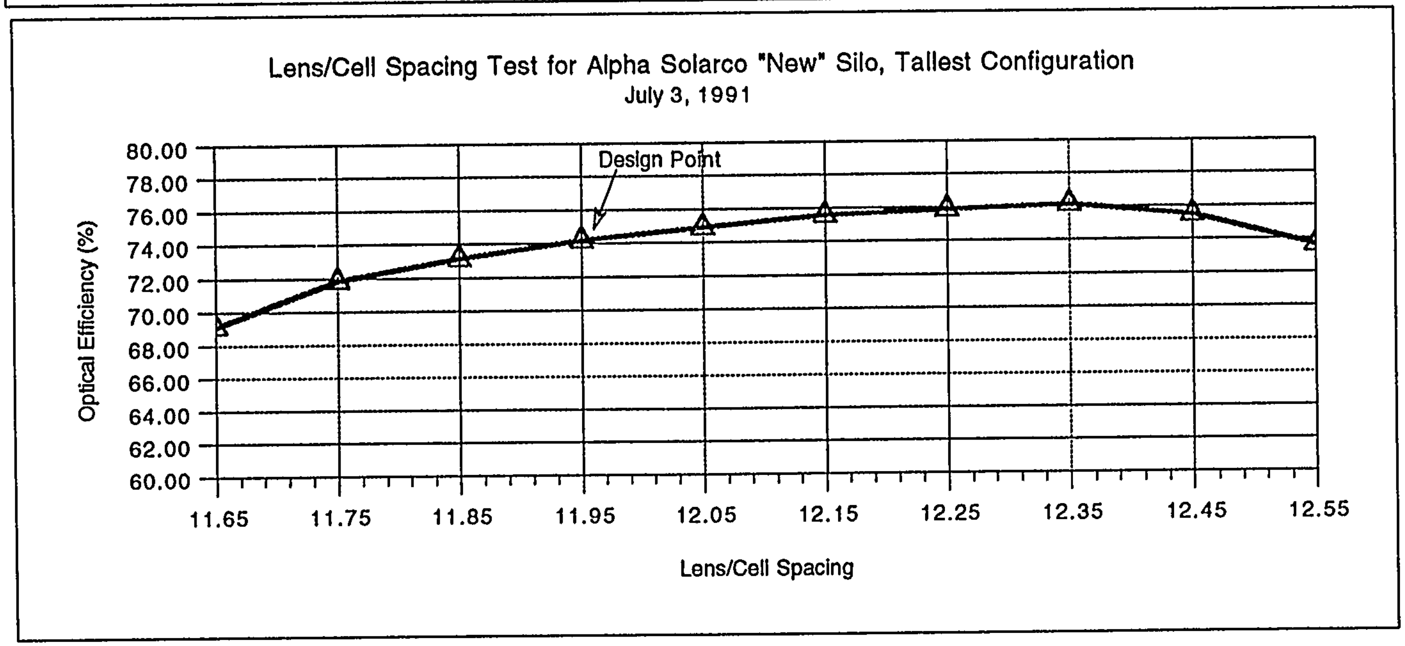



Alpha Solarco 0.65" SOE Lens/Cell Spacing 3/93
Optical Efficiency
74%
73%
72%
71%
70%
69%
68%
67%
66%
11.7
11.8
11.9
12
12.1
12.2
12.3
12.4
12.5
Lens/Cell Spacing (in.)

Alpha Solarco 0.65" SOE Lens/Cell Spacing Test 3/93




Lens/Cell Spacing Test for Alpha Solarco "New" Silo, Tallest Configuration
Lens/Cell Effic. (%)
12.00
11.75
11.50
11.25
11.00
10.75
10.50
10.25
10.00
Design Point
11.65
11.75
11.85
11.95
12.05
12.15
12.25
12.35
12.45
Lens/Cell Spacing

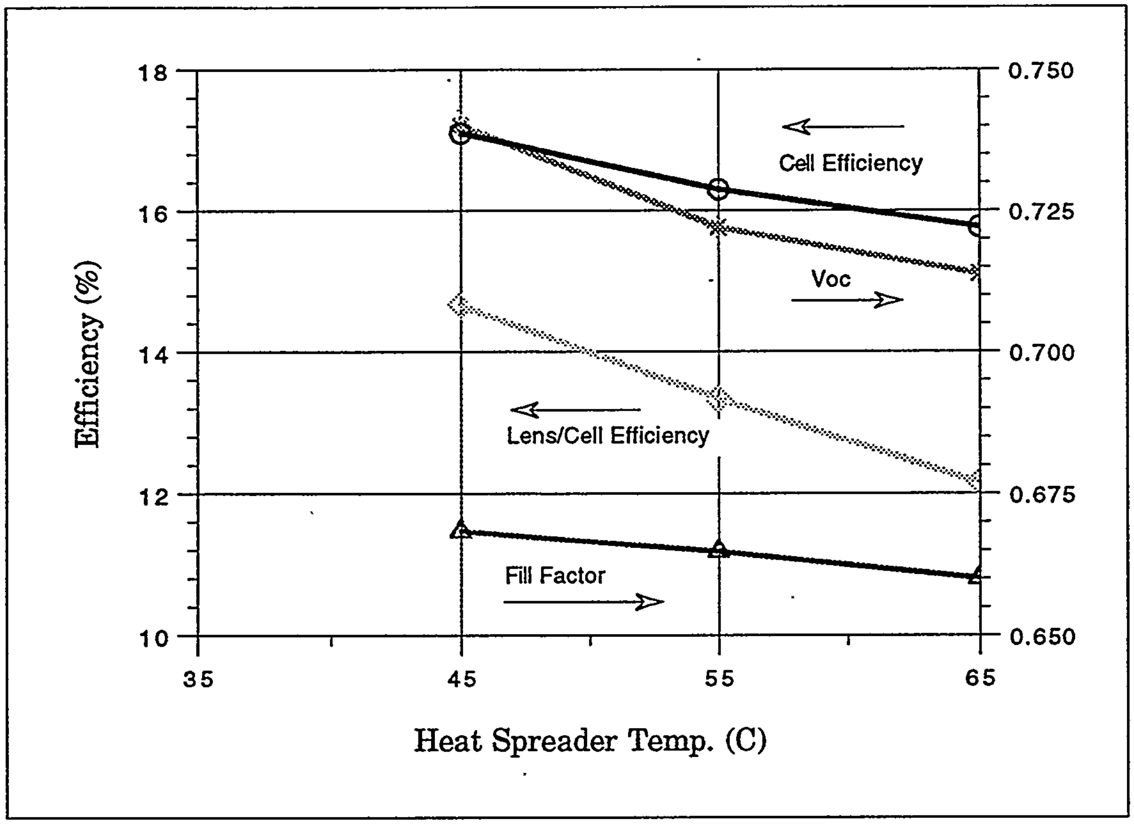

Lens/Cell Spacing Test for Alpha Solarco "New" Silo, Tallest Configuration
July 3, 1991
Optical Efficiency (%)
80.00
78.00
76.00
74.00
72.00
70.00
68.00
66.00
64.00
62.00
60.00
Design Point
11.65
11.75
11.85
11.95
12.05
12.15
12.25
12.35
12.45
12.55
Lens/Cell Spacing

Temperature Test for Alpha Solarco New Tall Silo

6-Aug-91 1-sun used 76-68 Cell 196-55

Heat Spreader Temperature Variation Test

Heat Sink Temperature (C)	35	35	45	55	65
Optical Efficiency (%)			67.03	68.63	68.49
Lens/Cell Effic. (%)			11.46	11.18	10.80
Cell Effic. (%)			17.10	16.30	15.77
Isc (Norm.) (A)			11.43	11.71	11.68
Fill Factor			0.7401	0.7220	0.7137
Voc (V)			0.7081	0.6916	0.6769
Heat Sink Temp (C)			47.0	57.5	66.5



Offtrack Test for Alpha Solarco Haystack Secondary

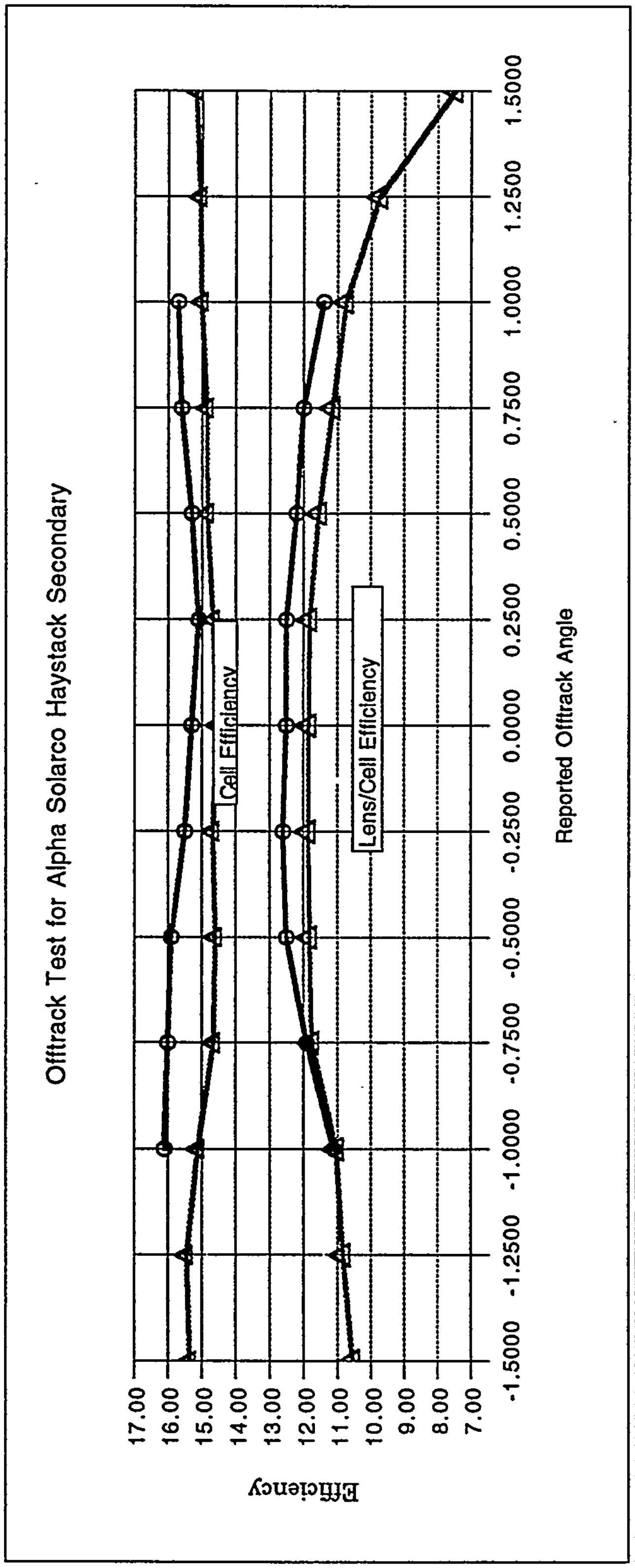
19-Apr-90 Cell Assembly 120 or 98-5

Offtrack Test Results													
Reported Offtrack Angle	-1.50	-1.25	-1.00	-0.75	-0.50	-0.25	0.00 (scan)	0.25	0.50	0.75	1.00	1.25	1.50
Estimated Offtrack Angle													
Optical Efficiency (%)			68.90	74.10	78.60	81.10	82.00	82.20	79.80	76.70	72.60		
Lens/Cell Effic. (%)			11.10	11.90	12.50	12.60	12.50	12.50	12.20	12.00	11.40		
Cell Effic. (%)			16.10	16.00	15.90	15.50	15.30	15.10	15.30	15.60	15.70		
Isc (Norm.) (A)													
Fill Factor			0.69	0.69	0.68	0.67	0.67	0.67	0.66	0.67	0.68		
Voc (V)													
Heat Sink Temp (C)			40 ?										

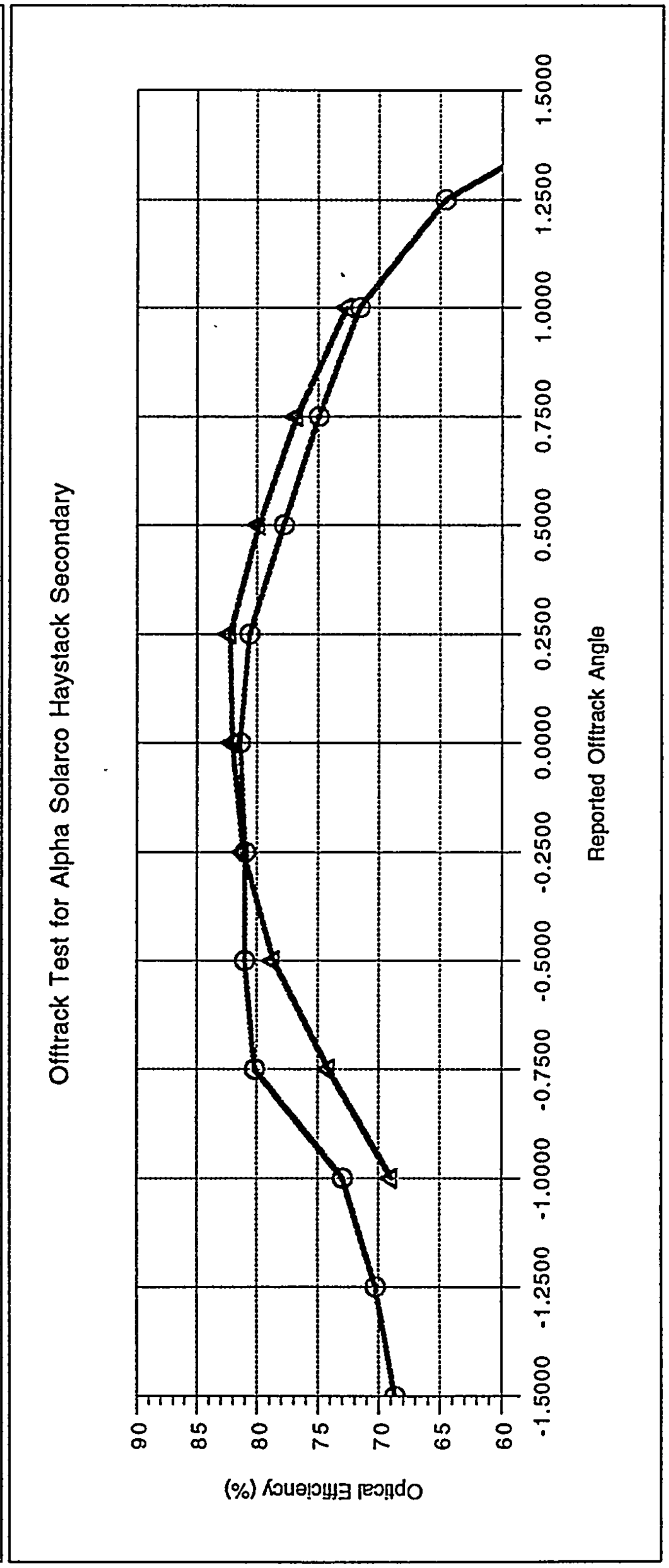
Offtrack Test for Alpha Solarco Haystack Secondary

7-Aug-91 1-sun 76-68 Cell assembly 76-195

Offtrack Test Results													
Reported Offtrack Angle	-1.50	-1.25	-1.00	-0.75	-0.50	-0.25	0.00	0.25	0.50	0.75	1.00	1.25	1.50
Estimated Offtrack Angle													
Optical Efficiency (%)	68.65	70.21	72.92	80.17	81.00	80.96	81.38	80.60	77.78	74.93	71.57	64.55	49.19
Lens/Cell Effic. (%)	10.54	10.83	11.02	11.75	11.82	11.86	11.84	11.82	11.54	11.13	10.73	9.72	7.46
Cell Effic. (%)	15.35	15.43	15.11	14.65	14.59	14.66	14.54	14.67	14.84	14.85	15.00	15.05	15.17
Isc (Norm.) (A)	11.709	11.974	12.444	13.688	13.820	13.808	13.888	13.761	13.273	12.787	12.207	11.00	8.38
Fill Factor	0.6924	0.6955	0.6817	0.6610	0.6561	0.6606	0.6550	0.6613	0.6691	0.6702	0.6768	0.68	0.69
Voc (V)	0.6790	0.6797	0.6792	0.6792	0.6812	0.6798	0.6803	0.6796	0.6794	0.6788	0.6790	0.68	0.67
Heat Sink Temp (C)	63.40	63.40	63.90	64.90	64.30	64.80	64.30	64.50	64.30	64.70	63.90	63.70	61.90



Offtrack Test for Alpha Solarco Haystack Secondary
Efficiency
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
-1.5000
-1.2500
-1.0000
-0.7500
-0.5000
-0.2500
0.0000
0.2500
0.5000
0.7500
1.0000
1.2500
1.5000
Reported Offtrack Angle
Cell Efficiency
Lens/Cell Efficiency



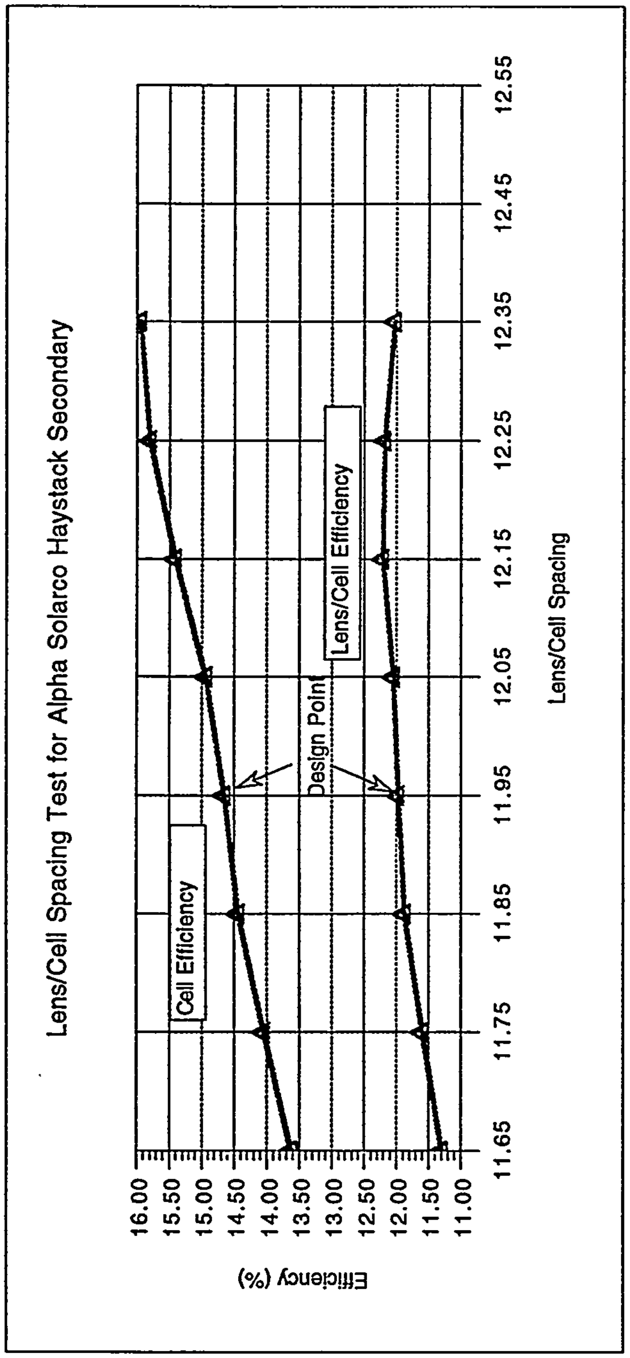
Offtrack Test for Alpha Solarco Haystack Secondary
Optical Efficiency (%)
90
85
80
75
70
65
60
-1.5000
-1.2500
-1.0000
-0.7500
-0.5000
-0.2500
0.0000
0.2500
0.5000
0.7500
1.0000
1.2500
1.5000
Reported Offtrack Angle

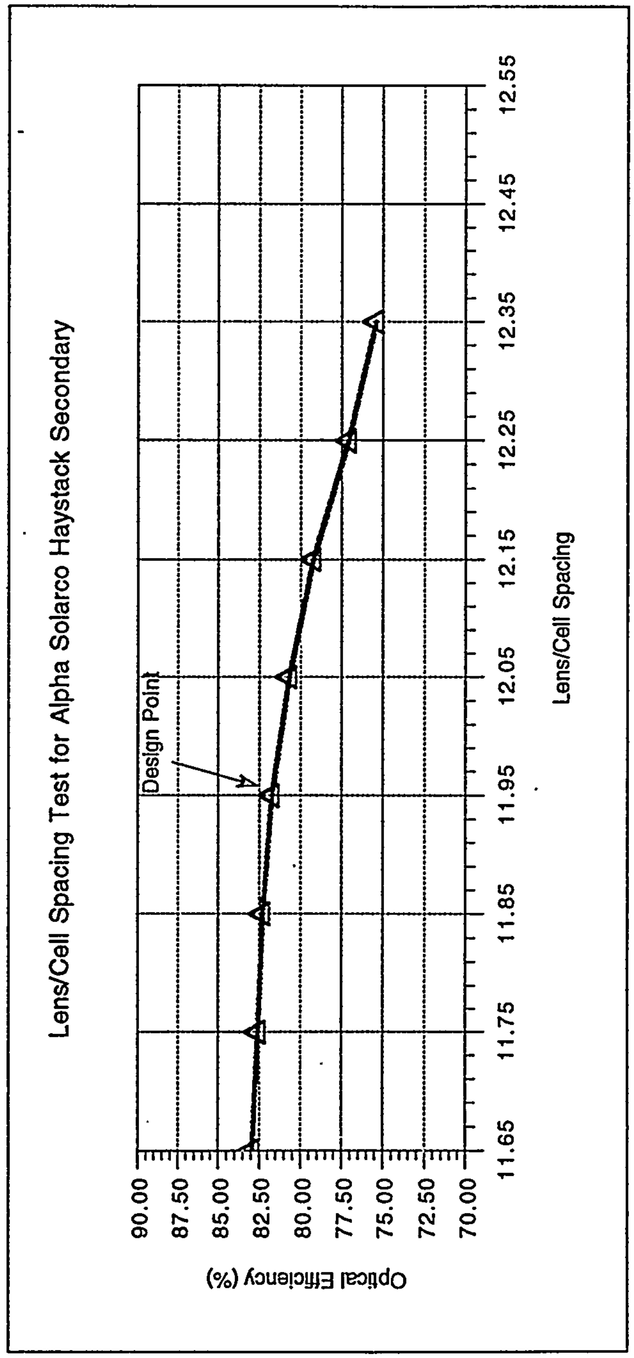
Lens/Cell Spacing Test for Alpha Solarco Haystack Secondary

7-Aug-91 Cell Assembly 76-195

Lens/Cell Spacing Test Results

Lens/Cell Spacing	11.65	11.75	11.85	11.95	12.05	12.15	12.25	12.35	12.45	12.55
Optical Efficiency (%)	82.91	82.54	82.24	81.70	80.64	79.20	77.06	75.39		
Lens/Cell Effic. (%)	11.29	11.59	11.87	11.96	12.04	12.20	12.17	12.02		
Cell Effic. (%)	13.62	14.04	14.43	14.64	14.93	15.40	15.79	15.94		
Isc (Norm.) (A)	14.157	14.070	14.027	13.935	13.753	13.507	13.142	12.857		
Fill Factor	0.6163	0.6330	0.6487	0.6591	0.6726	0.6887	0.7051	0.7129		
Voc (V)	0.6772	0.6797	0.6817	0.6806	0.6800	0.6853	0.6861	0.6852		
Heat Sink Temp (C)	64.60	63.60	62.90	64.30	64.20	61.70	61.70	62.00		


Lens/Cell Spacing Test for Alpha Solarco Haystack Secondary
Efficiency (%)
16.00
15.50
15.00
14.50
14.00
13.50
13.00
12.50
12.00
11.50
11.00
11.65
11.75
11.85
11.95
12.05
12.15
12.25
12.35
12.45
12.55
Lens/Cell Spacing
Cell Efficiency
Lens/Cell Efficiency
Design Point

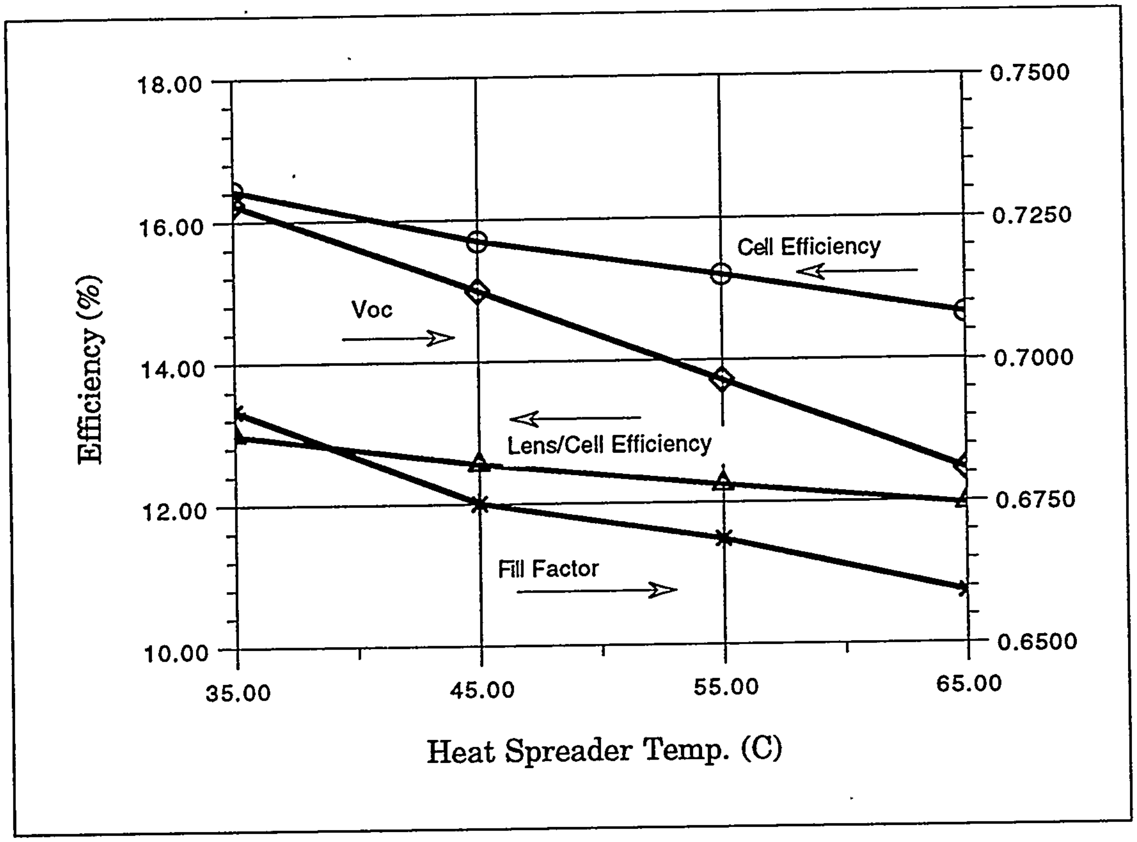

Lens/Cell Spacing Test for Alpha Solarco Haystack Secondary
Optical Efficiency (%)
90.00
87.50
85.00
82.50
80.00
77.50
75.00
72.50
70.00
11.65
11.75
11.85
11.95
12.05
12.15
12.25
12.35
12.45
12.55
Lens/Cell Spacing
Design Point

Temperature Test for Alpha Solarco Haystack Silo

7-Aug-91 1-sun used 76-68 Cell Assembly 76-195

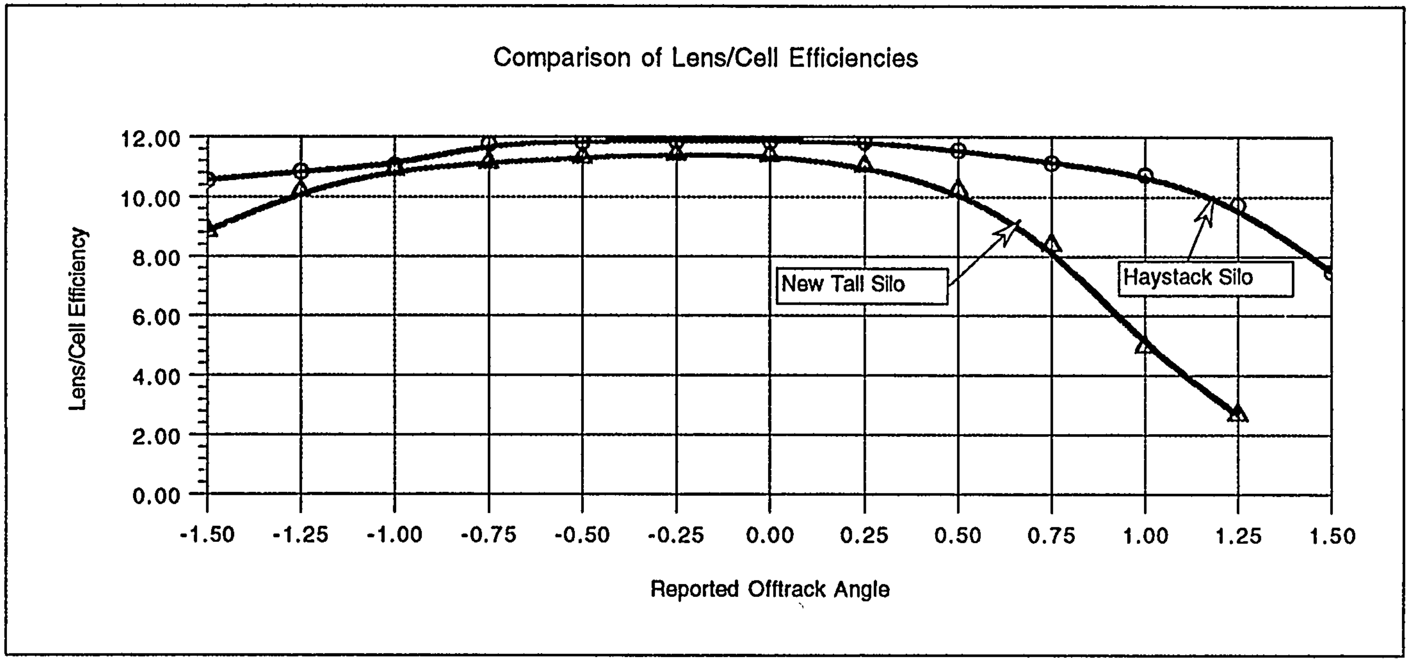
Heat Spreader Temperature Variation Test

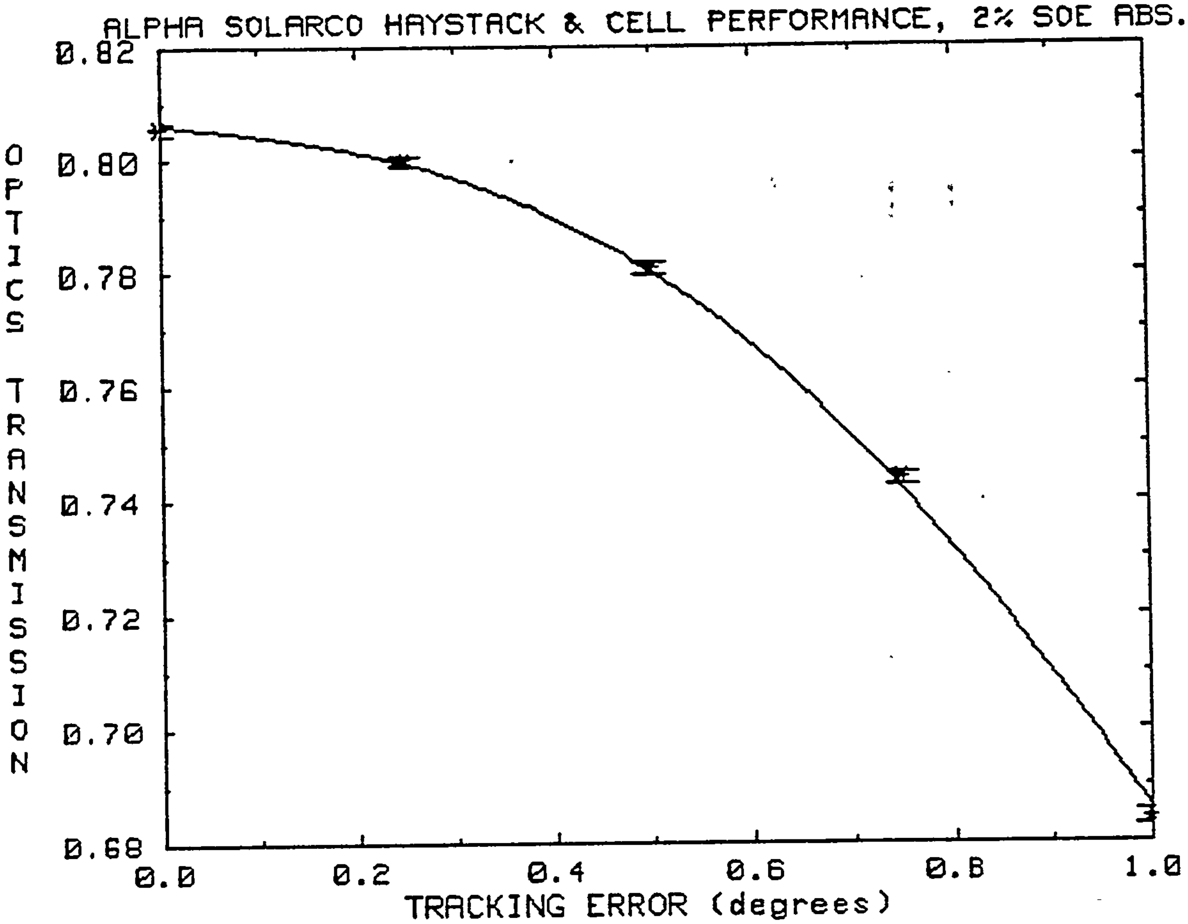
Heat Sink Temperature (C)	35.00	35.00	45.00	55.00	65.00
Optical Efficiency (%)	79.26	78.97	79.95	80.55	81.70
Lens/Cell Effic. (%)	12.92	12.97	12.55	12.24	11.96
Cell Effic. (%)	16.30	16.43	15.69	15.19	14.64
Isc (Norm.) (A)	13.50	13.47	13.65	13.81	13.94
Fill Factor	0.6882	0.6915	0.6750	0.6685	0.6591
Voc (V)	0.7257	0.7280	0.7124	0.6964	0.6806
Heat Sink Temp (C)	36.40	35.10	44.40	54.30	64.30

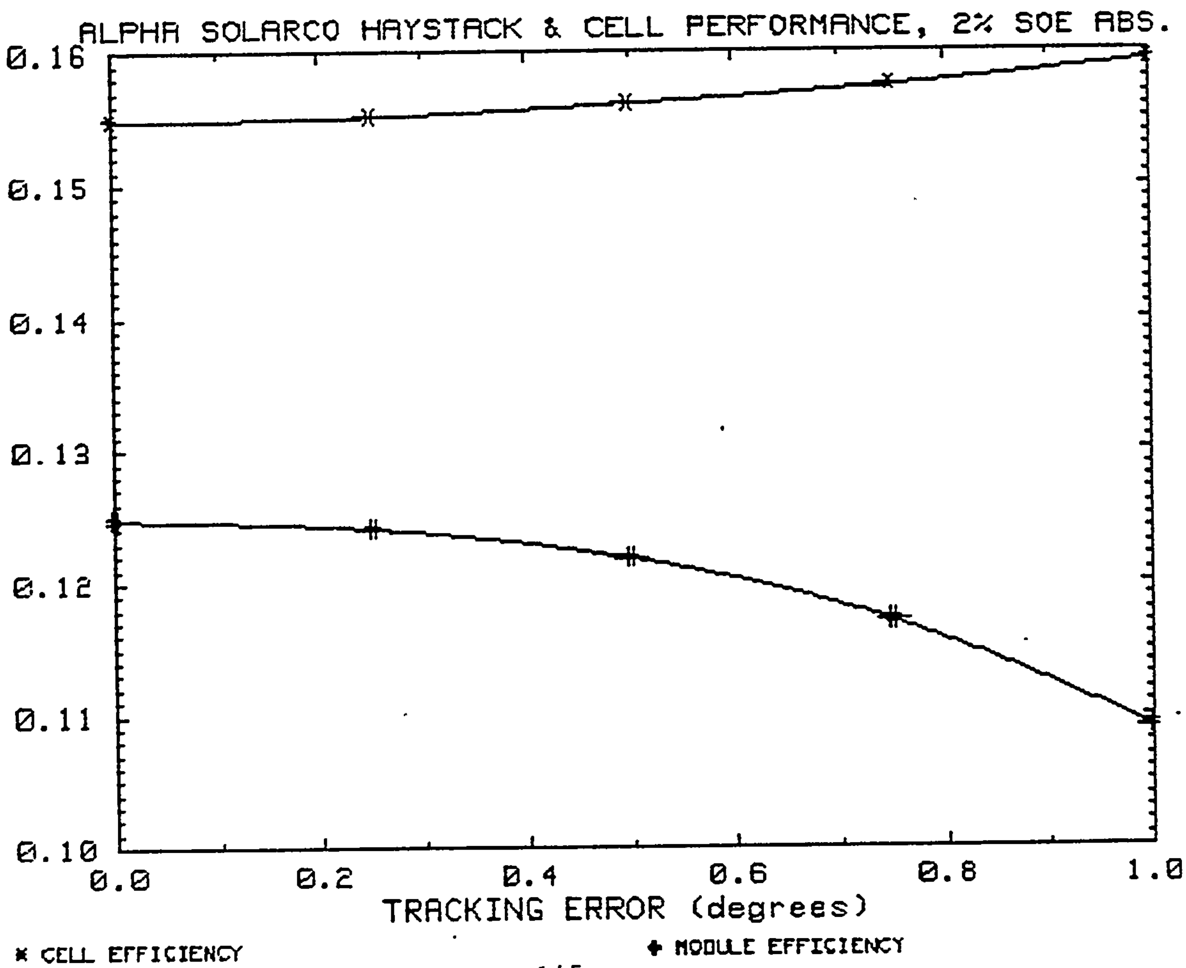


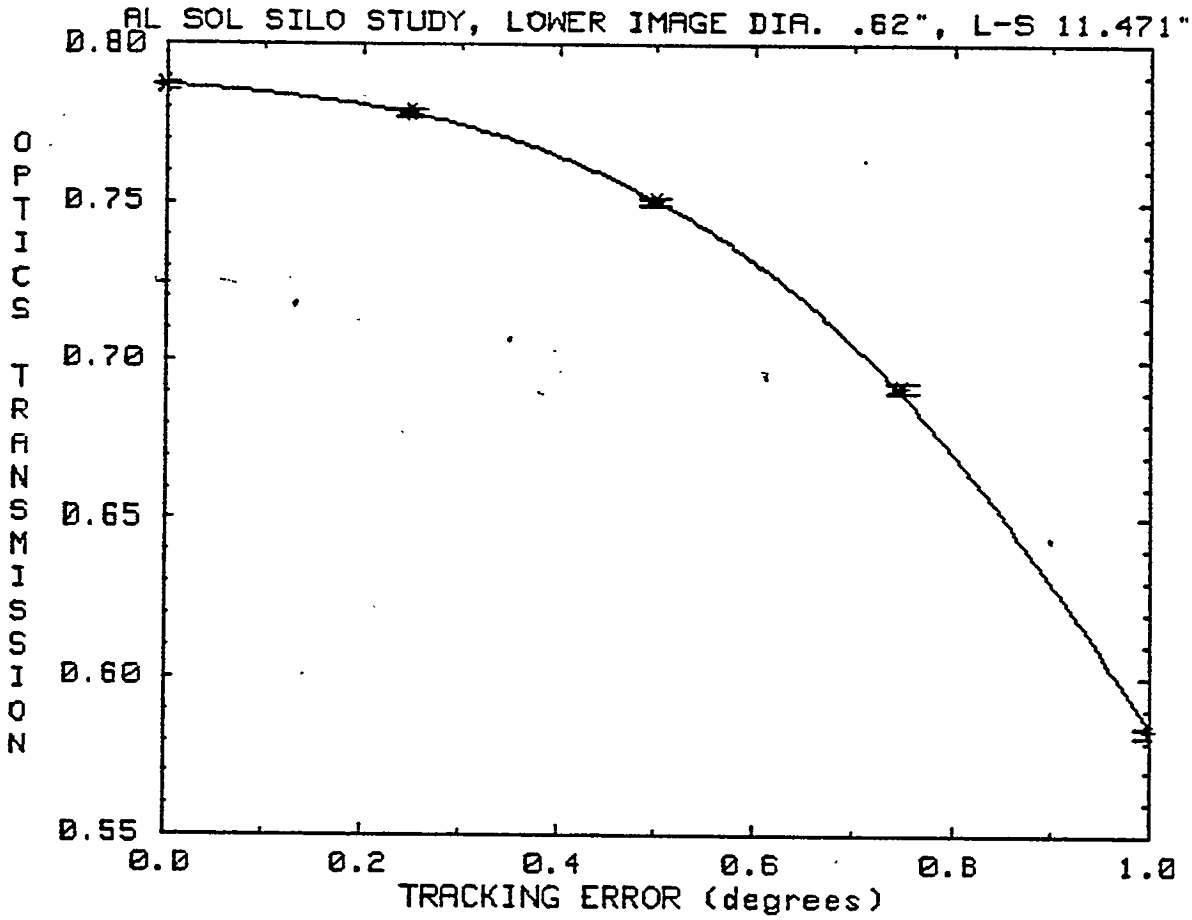
Comparison of Lens/Cell Efficiencies

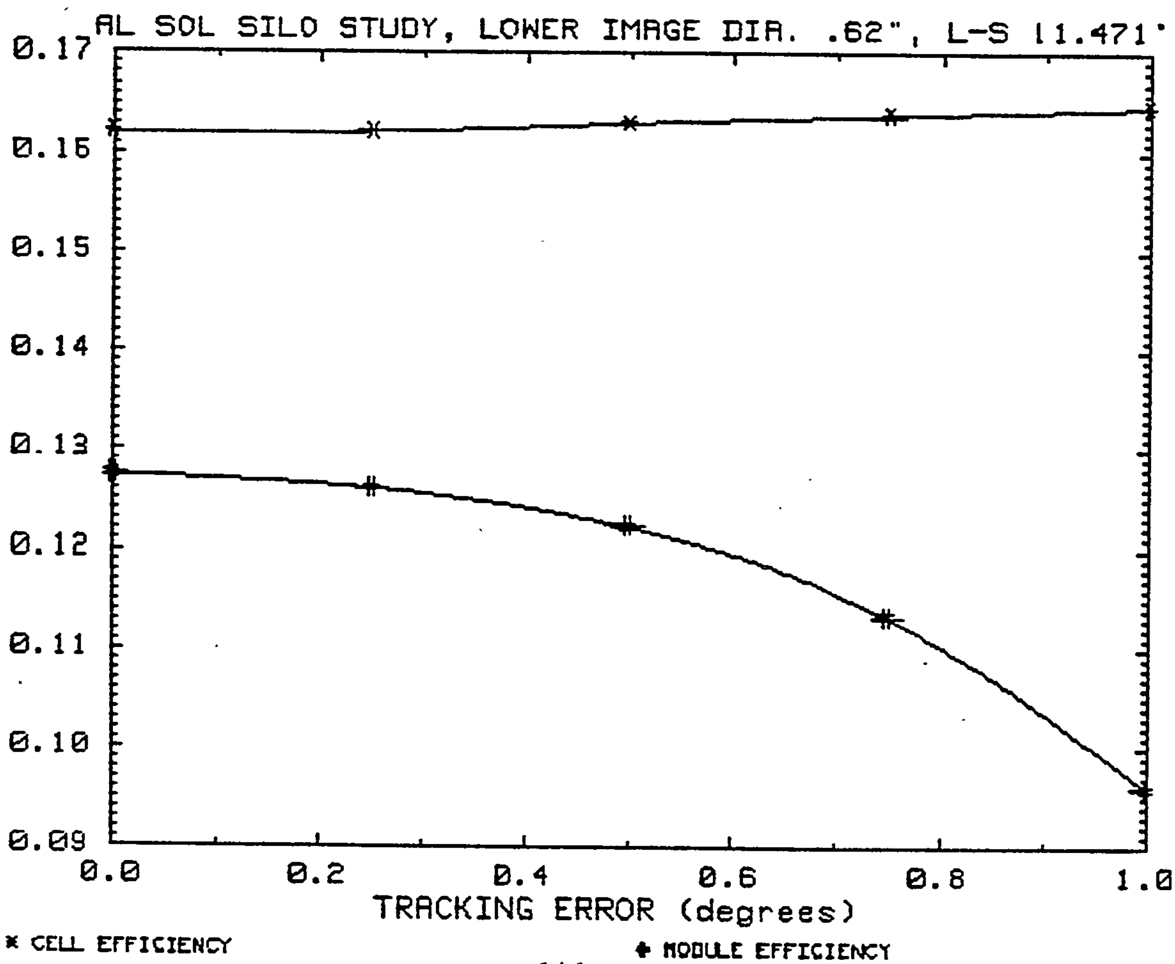
Reported Offtrack Angle	-1.50	-1.25	-1.00	-0.75	-0.50	-0.25	0.00 (scan)	0.25	0.50	0.75	1.00	1.25	1.50
Estimated Offtrack Angle													
Optical Efficiency (%)	56.28	64.92	69.19	70.44	71.72	72.40	71.95	69.68	64.16	51.59	29.82	16.47	
New Silo Lens/Cell Effic. (%)	8.83	10.16	10.87	11.11	11.29	11.39	11.35	11.00	10.21	8.36	4.96	2.68	
Haystack Lens/Cell Effic. (%)	10.54	10.83	11.02	11.75	11.82	11.86	11.84	11.82	11.54	11.13	10.73	9.72	7.46




ALPHA SOLARCO HAYSTACK & CELL PERFORMANCE, 2% SOE ABS.
OPTICS TRANSMISSION
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0.68
0.0
0.2
0.4
0.6
0.8
1.0
TRACKING ERROR (degrees)


ALPHA SOLARCO HAYSTACK & CELL PERFORMANCE, 2% SOE ABS.
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.0
0.2
0.4
0.6
0.8
1.0
TRACKING ERROR (degrees)
* CELL EFFICIENCY
+ MODULE EFFICIENCY


AL SOL SILO STUDY, LOWER IMAGE DIA. .62", L-S 11.471"
OPTICS TRANSMISSION
0.80
0.75
0.70
0.65
0.60
0.55
0.0
0.2
0.4
0.6
0.8
1.0
TRACKING ERROR (degrees)


AL SOL SILO STUDY, LOWER IMAGE DIA. .62", L-S 11.471"
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.0
0.2
0.4
0.6
0.8
1.0
TRACKING ERROR (degrees)
* CELL EFFICIENCY
+ MODULE EFFICIENCY

APPENDIX D

Quality Assurance - Quality Control Manual

QUALITY ASSURANCE/QUALITY CONTROL MANUAL

FOR

THE DESIGN, PRODUCTION AND INSTALLATION

OF

PHOTOVOLTAIC CONCENTRATOR SYSTEMS

Alpha Solarco, Inc.
Cincinnati, OH
USA

Table of Contents

1.0.0 ORGANIZATION.

1.1.0 Structure.

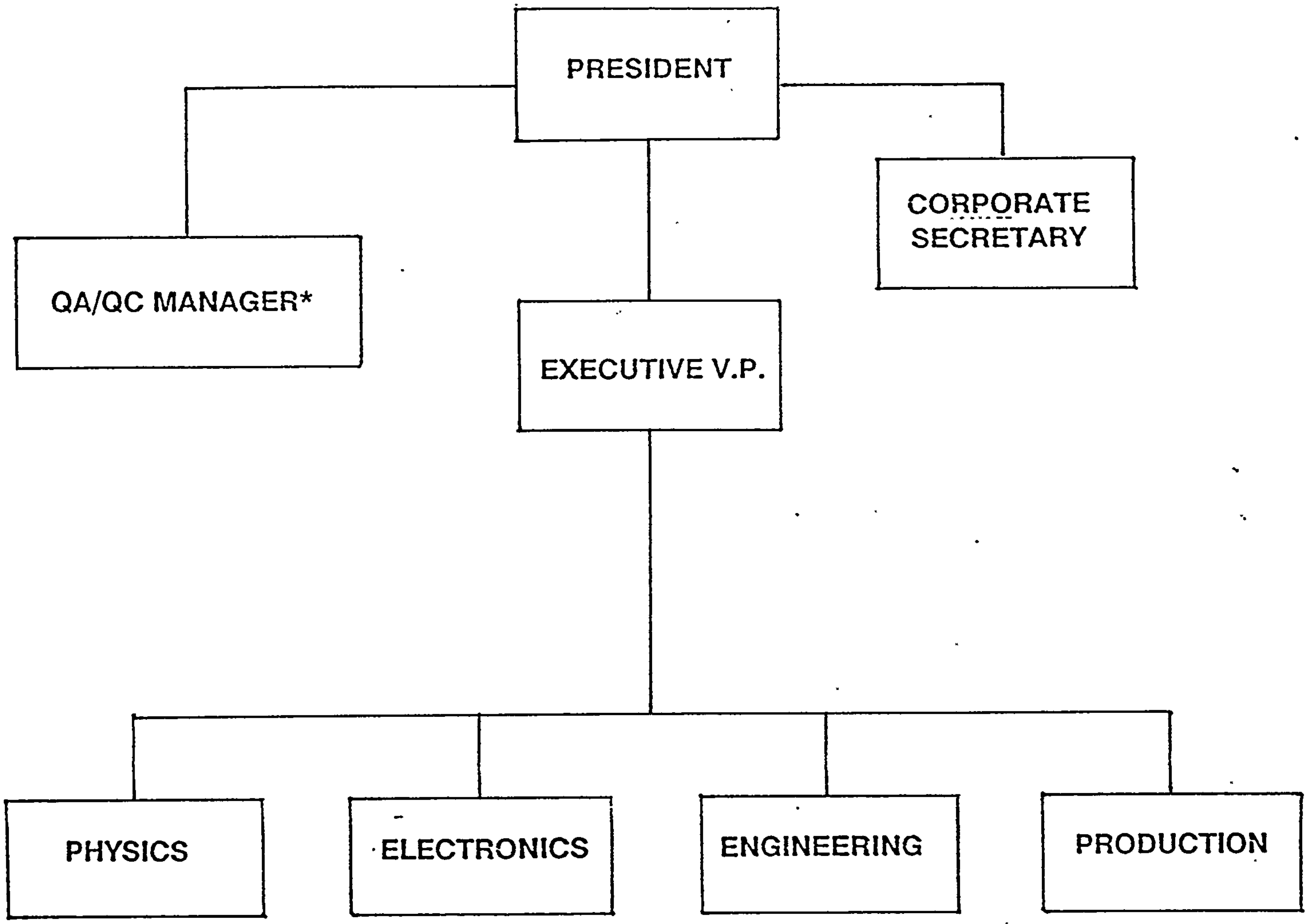
A complex QA/QC structure has been installed in Alpha Solarco's national and international operations. In general terms each project -- for both internal and sub-contractor work -- has a Project Manager, who is ultimately responsible for the overall organization, operation and quality control. He reports directly to the President of the company.

A QC manager is designated by the Project manager. It is the responsibility of the QC manager to develop and enforce the relevant QA programs, with the full support of the corporate management.

Job descriptions of all the people in the organization are on file at Alpha's corporate office. These describe the responsibilities and rights of each employee. The job description of the QA manager -- often someone who also occupies other positions in the company's operations -- include their responsibilities to upper management, and the design, production, testing and purchasing staffs.

1.2.0 Delegation of Responsibilities.

A contingency plan for delegation of authority in case of absence of key personnel is designed. It is in full force during these critical times.



*Each project has its own QA/QC Manager appointed by the Project Manager.

Fig. 1. Alpha Solarco organizational structure in relation to its QA/QC organization.

2.0.0 HARDWARE DESIGN.

2.1.0 Concurrent Engineering.
The company involves all its human resources, customers, consultants, sub-contractors and associates in the decision making processes, affecting the production processes. Special attention is paid to steps which affect the design and quality of the final product.

2.2.0 Performance Requirements.
Before initiating any production activities the engineering staff and the management of Alpha Solarco, the customer, all sub-contractors and associates hold meetings and tele-conferences in order to reach an agreement about the steps to be taken during the design and production phases. We realize the importance of this first step in avoiding post-design changes and providing a low cost quality product.

2.3.0 Critical Design and Production Specifications.
Alpha Solarco's goal, in the initial stages of every project, is to come up with an "optimum" design by specifying steps and tolerances, which are achievable in production mode. The importance of QC during the production process is emphasized, and an optimum number of QC steps are introduced in the production cycle specifications.

2.4.0 System Design.
In completing the design of the PV systems Alpha Solarco relies heavily on the experience of our staff and associate organizations -- Sandia, SERI, several universities etc. This helps us to maintain the performance, durability and the safety requirements of the product within the specified tolerance limits.

2.5.0 Documentation.
All Alpha Solarco's design and process documentation is kept on magnetic disk, and/or hard copy material -- note books, reports, memos, travelers, blue prints etc. These records are readily available for inspection.

2.6.0 Design Reviews.
The design, production and testing personnel have a ready access to all documentation. It is reviewed periodically during the design and production processes in order to assure the correctness of the documentation. Contingency plans and alternative solutions are planned in order to avoid shortage of specialized materials and parts, change of specs etc.

2.7.0 Testing Process Design.

Every Alpha Solarco product undergoes extensive testing procedures (PRODUCT TESTING MANUAL 0010-M) during all stages of design, production and final test. The testing program is coordinated with all participants in the project and is executed accordingly. Every test step has an objective, procedure and a safe/fail criteria. The tests are executed with the best possible product quality in mind.

2.8.0 Literature Used in Design Work.

Together with the standard reference standards, and other tools, Alpha Solarco's engineers and managers use extensive technical magazines, books and reports, such as NTIS publications.

3.0.0 DESIGN QUALIFICATION. (MANUAL 0020-M)

3.1.0 Sub-components and Components.
Alpha Solarco uses an extensive cross check system, assuring self-consistency of the design parameters and the corresponding process steps. The selection of materials and components is made only after a thorough review of all design and process steps. Theoretical and experimental studies are done on regular basis in order to assure the selection of the proper materials and components.

3.2.0 Component Prototypes.
Component prototypes are built on regular basis in Alpha Solarco's lab. These are indispensable for verifying theoretical models, and for checking complex components, which don't lend them themselves to theoretical modeling.

3.3.0 System Design Qualifications.
Alpha Solarco uses a series of tests for the qualification of its PV systems. For example a full scale model of our concentrator system is installed in Nevada, and is in continuous testing mode. The collected data is used for new design and production of similar systems.

3.4.0 System Design for Installation Specifications.
Alpha Solarco and its associates use their extensive experience in the design and installation of small and large PV systems to design and install new systems in different areas of the US and abroad.

3.5.0 Test Procedures and Pass/Fail Criteria.
All in-process QC and final test procedures are designed around a fail/pass criteria. The necessary test procedures are followed in order to obtain the results needed for making a proper decision.

3.6.0 Plans for Failed Tests.
Alpha Solarco follows a special procedure for failed tests, using several alternatives, such as: new design using the same components, or new design using an entirely new concept, etc.

3.7.0 Sequence of Tests.
Different approaches and sequences are used for the different types of components and systems manufactured by Alpha Solarco. These vary from component to component and from project to project.

4.0.0 PRODUCTION QUALIFICATION.

4.1.0 Process Qualification (MANUAL 0030-M).
All processes designed and implemented by Alpha Solarco are first reviewed by Alpha's engineering and management staff. The assistance of outside parties, such as Sandia and SERI, is sought in most cases to ensure an adequate concept and process parameters design. Each process step, along with the process parameters and variables, are described clearly and in detail in Alpha's documents. The results are submitted for approval.

4.2.0 Pass/Fail Criteria.
All in-process QC and final test procedures are designed around a pass/fail criteria. The necessary test procedures are followed through the design, manufacturing and testing processes in order to obtain the results needed for making a proper decision.

4.3.0 Plans for Failed Tests.
Alpha Solarco follows a special procedure for failed tests, using several alternatives, such as: new design using the same components, or new design using an entirely new concept, etc.

4.4.0 Plans after Successful Process Testing.
After process testing and verification the finished products - cells, receiver assemblies, modules etc. undergo extensive bench and field tests. These tests (PROCESS TEST FORM 0030-F) are performed at Alpha's plants, Sandia or in the field. The tests vary from product to product and from project to project. The procedures for the tests are contained in Alpha's documentation.

4.4.1 Further Action.
Upon successful testing, the process is transferred into production mode. Extensive design and planning activities are undertaken by Alpha's engineering and outside consulting personnel. Any design changes are coordinated with Sandia staff.

4.4.2 Plans if Qualification Tests Fail.
Upon test failure Alpha's staff is alerted and Sandia is informed. Testing is discontinued until a new design, or test parameters, are developed and approved. The failed process or parts are redesigned, reworked, or discarded.

5.0.0 PRODUCTION CONTROL.

5.1.0 Training/Retraining (MANUAL 0060-M).
Alpha Solarco's personnel are trained in the area of testing and test evaluation. A Training/Retraining program has been developed for each testing category.

5.2.0 Testing Hardware.
Alpha Solarco has established a criteria, based on scientific data and its own experience, for acceptance of the product. A series of tests are performed to assess the acceptability of the manufactured parts and components.

5.3.0 Process Control.
In-process control and process verification approaches are used in Alpha's manufacturing operations in order to assure the quality of the product. Several levels of identification and removal of the defect-causing conditions are outlined and observed.

5.4.0 Continuous Testing.
The product and process testing is a continuous process, and is performed diligently throughout the design and manufacturing cycles by Alpha's staff.

5.5.0 Hardware Identification. All hardware manufactured by Alpha Solarco and the associated process steps are identified and coded (MANUFACTURING OPERATING PROCEDURE MOP 0050-XXXXXX-M). A flow chart (0050-XXXXXX-F) of the manufacturing process is on hand, and traveler (0051-F) is used by the manufacturing crew to keep a smooth transition of the parts and systems from step to step through the entire production cycle.

5.6.0 Plan for Failed Test.
Upon test failure Alpha's staff is alerted to the situation. Sandia is informed in some cases. Testing is discontinued until a new design, or test parameters, are developed and approved. The failed process or parts are redesigned, reworked, or discarded.

5.7.0 Maintenance Plan (MANUAL 0040-M).
All Alpha Solarco's testing and manufacturing equipment is on a maintenance schedule (0040-L). The wear and tear of the equipment is checked and recorded (0040-F). The data is used for PM scheduling and replacement of parts.

5.8.0 Start-Up and Shutdown.
Alpha Solarco uses standard methods of start-up and shutdown of its manufacturing operations. These are corrected for the specific use and maximum efficiency.

6.0.0 INSTALLATION CONTROL.

6.1.0 Installation Plan (MANUAL 0070-M).
A thorough Plan is developed for each Alpha Solarco installation. It is coordinated with the customer, DOE, DOD etc. appropriate parties. The packaging and transportation quality are checked and reported.

6.2.0 Testing.
Following the installation of the system Alpha Solarco's staff measures the amount of energy produced by the modules and the system, and calculates the overall efficiency. A visual inspection of the structure, modules, drive mechanisms and tracking controls, safety sensors etc. are performed. Wake-up and stow tests are performed as well. All defects, and their causes, are eliminated. A record (0070-L) of the activities are maintained throughout the testing.

6.3.0 Certification.
A certificate (0070-F) of acceptability of performance is issued as soon as all tests are passed, and no malfunction is detected. The certificate details all system components' performance characteristics and limitations. Warranty conditions are also stated.

6.4.0 Training of the Customer's Stuff (MANUAL 0060-M)
Alpha Solarco has outlined a specialized customer training program, used for instructing of the customers' technical staff in the operating and maintenance procedures.

6.5.0 Turnover. A date for turning the responsibility for operation and maintenance of the system to the customer is set at the earliest possible time. Alpha's continuing responsibilities are clearly defined during that time.

6.6.0 User's Manual (0080-XXXXXX-M).
Alpha Solarco has outlined a User's Manual, describing the normal start-up, operation, shutdown and troubleshooting of the system. It includes a parts list, diagrams, drawings, photographs and other tools needed by the customer.

Distribution:

MS-0899
Technical Library
Org. 13414 (5)

MS-0619
Print Media
Org. 12615

MS-0100
Document Processing for DOW/OSTI (2)

MS-9018
Central Technical Files
Org. 8523-2

MS-0752
M. L. Tatro
Org. 6219

MS-0752
A. B. Maish (5)
Org. 6219

MS-0753
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Org. 6218

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Alpha Solarco, Inc.
510 East University Drive
Phoenix, AZ 85004

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Topanga Canyon, CA 90290

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