CONTRACTOR REPORT

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Design and Development of a Laminated Fresnel Lens for Point Focus PV Systems – Phase II

R. C. Hodge
General Electric Company
Advanced Energy Programs Department
King of Prussia, PA 19406

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Under Contract No. PO62-9975

Abstract

A laminated Glass-plastic lens parquet using injection molded point focus Fresnel lenses is described. This report covers the second phase of a program aimed at investigating the cost effectiveness of a glass-plastic concentrator lens assembly. The first phase dealt with the development of a first generation lens design, the selection of the preferred glass coverplate and glass-to-lens adhesive and initial injection molding lens molding trials. The second phase has dealt with the development of an improved lens design, a full size parquet lamination process, and a second group of injection molding lens molding trials.

FOREWORD

This final report is submitted to Sandia National Laboratories by the General Electric Company. The final report summarizes the findings and work performed in conjunction with the Sandia sponsored program "Design and Development of a Laminated Fresnel Lens for Point Focus PV Systems" Sandia P.O. 62-9975.

The work was performed by the Advanced Energy Programs Department of the General Electric Company under the guidance of Mr. Charles Stillwell of Sandia National Laboratories, Albuquerque. Mr. Ronald C. Hodge served as program manager with key technical support from the following individuals: J. Henkes - lens design development, H. Walters of Fresnel Optics - lens master and control lens fabrication, E. Campagna - lamination process development and G. Puckett - injection molding process engineer.

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Section 1

Introduction

The objectives of this program were to evaluate the cost effectiveness of an injection molded flat point focus Fresnel lens and to investigate the feasibility and cost potential of a laminated glass-plastic lens parquet.

This report documents the results of the program which represents the second phase of an earlier program. Phase I program dealt with the design of a thin 6.65" sq. acrylic Fresnel lens laminated to a 7" sq. 3mm glass superstrate which focused to a 0.61" square spot. During Phase I a series of injection molding trials were conducted in an attempt to duplicate the lens performance commensurate with compression molding. Progress was made with each molding trial; however, it was concluded that a new lens design and series of molding experiments were needed. The results of the Phase I effort are documented in Sandia Report number SAND80-7134.

The Phase II program has attempted to build on the molding and lens design experience from the previous phase and to accomplish the following:

1) develop an improved lens design
2) demonstrate improved performance injection molded lenses
3) develop a parquet laminating process suitable to a variety of parquet sizes, i.e. 3x5, 5x5, 5x6.

Section 2

Summary

Objective. The basic objectives of the program were as follows:

1. Develop a new lens design that has improved transmission efficiency and better injection molding compatibility.

2. Develop a process for fabricating a glass superstrate-plastic lens laminate as shown in Figure 1.

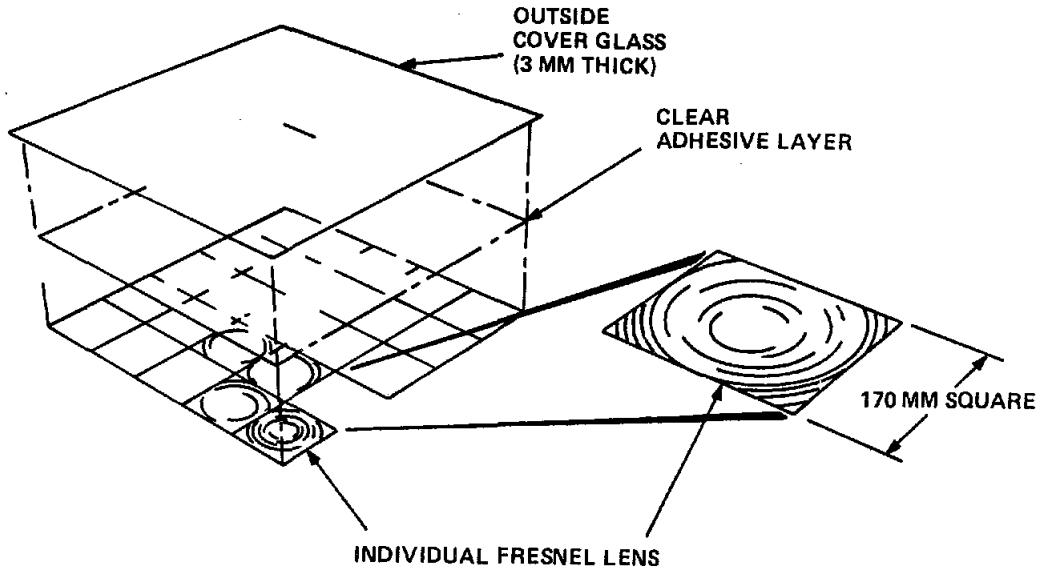


Figure 1. Parquet Lens Concept

The outside cover glass serves as the principal lens mechanical support and provides a durable lens cover. An array (parquet) of indivdually molded square lenses are bonded to the glass with a thin clear adhesive maintaining a specified center-to-lens center spacing within +.010".

Approach. The approach used to develop a better lens design involved an analytical computer analysis coupled with close interaction with lens tool and injection molding manufacturing people. Results from initial injection molding trials in Phase I indicated a problem with inadequate lens facet fill. As a result, engineers involved emphasized the development of

approaches (lens, mold, process) that would improve facet filling.

During the program, two lens designs were developed: one with a .015" wide facets, another with .030" wide facets. The .015" facetted lens had shallower facets, whereas the .030" facetted lens had one half as many facets to fill. Mold inserts for both lens designs were fabricated and used in the injection molding trials.

Sample lenses were tested and used to verify the basic lens design (flux profile, efficiency potential) and to "fine tune" the injection molding process.

The approach used to develop a parquet lamination process was basically a trial and error method evaluating three different techniques. Individual lens-glass specimens were used to evaluate the basic adhesive bond integrity. Larger, 2x2 trial specimens were used to screen the three candidate lamination schemes. Results from both GE and Sandia environmental testing were used to evaluate the laminate bond integrity. Once the preferred lamination technique was selected, a full size laminating fixture was fabricated, and twenty prototype full size 6x5 parquet lenses assembled.

Prototype Parquets. A prototype full size parquet lens assembly is shown in Figure 2.

As part of the program, twenty prototype parquets were made. A high transmission soda lime glass was used as the lens superstrate. The adhesive

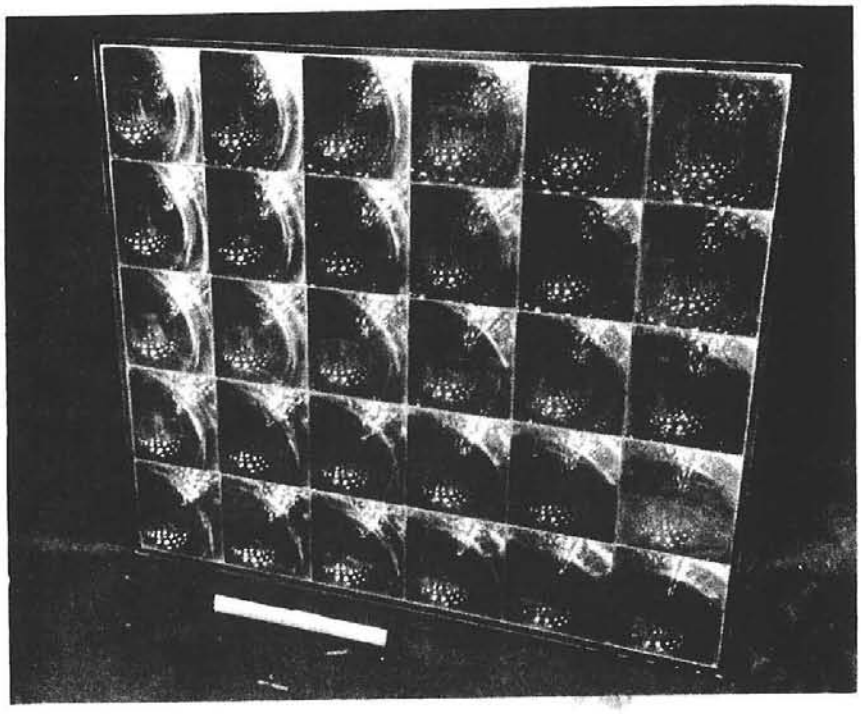


Figure 2. Prototype Parquet Lens

used was GE RTV 534-044. A property sheet for this material is found in Appendix A. The individual Fresnel lenses were molded out of several different acrylic materials. The compression molded control lenses were made with Rohm-Haas V045; whereas a variety of materials were used during the injection molding trials.

The basic design requirements for the full size parquet lens are shown in Table 1.

Table 1. Full Size Parquet Design Requirements

• Overall Size	34.50" ±0.030" x 41.20" ±0.030"
• Lens Center-to-Lens Center Spacing	6.70" ± 0.010"

• Lens Edge-to-Lens Edge Gap	0.050"
• Hail Impact Resistance	1.00" diameter iceballs at 73 ft/sec
• Temperature Cycling	One -30 to 50°C cycle/2 hrs.
• Exposure Temperature Range	-35°C to 65°C
• UV Exposure	< 5% transmission degradation after 30MW/cm^2 for 300 hrs.
• Temperature-Humidity	To Be Determined

A drawing package for the parquet lens is found in Appendix B.

Lens Design. The basic design requirements for the individual Fresnel lenses are shown in Table 2.

Table 2. Individual Fresnel Lens Requirements

Individual Fresnel Lens Size	6.66" +.010" -.020" square
Distance From Lens to Focal Plane (cell)	8.0" "F#1.2"
Illumination Target Size	0.61" diameter spot
Flux Distribution at Focal Plane	Peaks < 2X $I_{ave.}$
Overall Solar Spectrum Lens Efficiency (AM1.5)	> 80%
Lens Thickness	.040"-.080"

The lens efficiency term relates to the percent of solar energy "focused" within the required target area, in our case the target area is a 0.61" diameter spot. Design verification lenses were manufactured using compression molding. These lenses were used as our "control" lenses for comparison with the injection molded lenses.

Table 3 shows a comparison between our Phase I and II lens design.

Table 3. Lens Data

Lens Design	Design Focal Spot Shape	Lens-Only Efficiencies[1]		Lens-Cell Efficiencies[2]		Facet Width in.
		Total Cell Area	Design Spot	Lens	Lens-Cell	
I-Phase I	.61"sq	79.9%	76.3%	80%	12.4%	0.015
III-Phase II	.61"dia.	85.9%	83.2%	87.8%	13.0%	0.015
IV-C-Phase II	.61"dia.	90.0%	88.1%	88.5%	13.3%	0.030

1-Sandia Lens Analyzer

2-Outdoor test using a Sandia designed .81 x .81 Strawman silicon cell masked to .61 in. dia.

Note the change in "focused" spot shape from a 0.61 inch square to a .061 inch diameter spot. In addition note the improvements in both lens-only and lens-cell efficiencies.

Lamination Process Development. The major process requirements associated with the assembly of the laminated parquet were

1) maintain the tight lens center-to-lens center spacing
2) minimize voids/air entrampment in the adhesive layer
3) keep the RTV out of the Fresnel facets
4) ensure a uniform adhesive thickness
5) minimize adhesive waste and assembly labor
6) have the potential for large volume production

The following basic lamination process approaches were investigated:

1. Soft Tool - RTV630 is used to form an individual mold/seal around each lens. Deaerated RTV 534-044 is then poured onto the planar

side of the indivual Fresnel lenses and the glass cover is laid down. The RTV630 does provide an excellent seal to keep the RTV 534-044 from filling the Fresnel facets, but the soft mold is not reuseable and thus not practical.

2. Hard Tooling With Vacuum - Each lens is placed facet side down on a flat aluminum plate. A gasket filled groove is located at the perimeter of each lens position. Vacuum ports are machined into the aluminum plate. Each lens is positioned onto the aluminum plate. A vacuum is applied which draws the lenses down flush and suppresses the gasket. A number of gaskets were tried. Unfortunately, adequate lens edge sealing was not achieved. Parquets made with this approach consistently had slight amounts of the bonding adhesive in their lens facets.

3. Hard Tooling Without Vacuum - This approach uses accurately positioned studs in a flat fixture to position each lens. Molded in to the facet side of each lens is a small .065" diameter indexing hole which mates to the fixture's studs. The bonding adhesive is kept away from the facets by sealing each lens edge with a thin (.002") narrow (.125" wide) transparent tape. Testing at GE and Sandia confirm that the tape does not adversely affect lens transmission efficiency. This approach was subsequently selected as our baseline lamination process.

Lamination Bond Integrity Studies. During the program, GE has sent glass-adhesive-plastic laminate specimens to Sandia for routine temperature

and humidity cycling. To date, the specimens have exhibited various degrees of delamination. This has been a frustrating problem in that the RTV experts at GE-Silicon Products Division maintain that technically our material system of glass-RTV-acrylic should not delaminate under our thermal-humidity conditions.

The delaminations in question range from an early uncured specimen, to random bubbles ranging from 1/16" to 3/8" diameter, to small (0.060 in^2) "void" areas particularly around our molded-in spacer feet. Troubleshooting of the early uncured specimen showed that the cause was a random case of inadequate mixing of RTV534-044 part A and part B. Subsequent specimens and lenses do not indicate any uncured resin.

Troubleshooting of the random bubbles concluded that the bubble development could be due to very small, visually undetectable pockets of entrapped air in the RTV blend. With elevated temperature, these pockets then expand into visible bubbles.

Troubleshooting of the small void areas appear to indicate that the delaminations are primarily due to insufficient primer application particularly around the small lens spacer feet.

The twenty full size parquets were built paying special attention to the above delamination problems. Results to date indicate that, for the most part, the bubble problem has disappeared, but we are still finding small delaminations or tears around the spacer feet, see Figure 3.

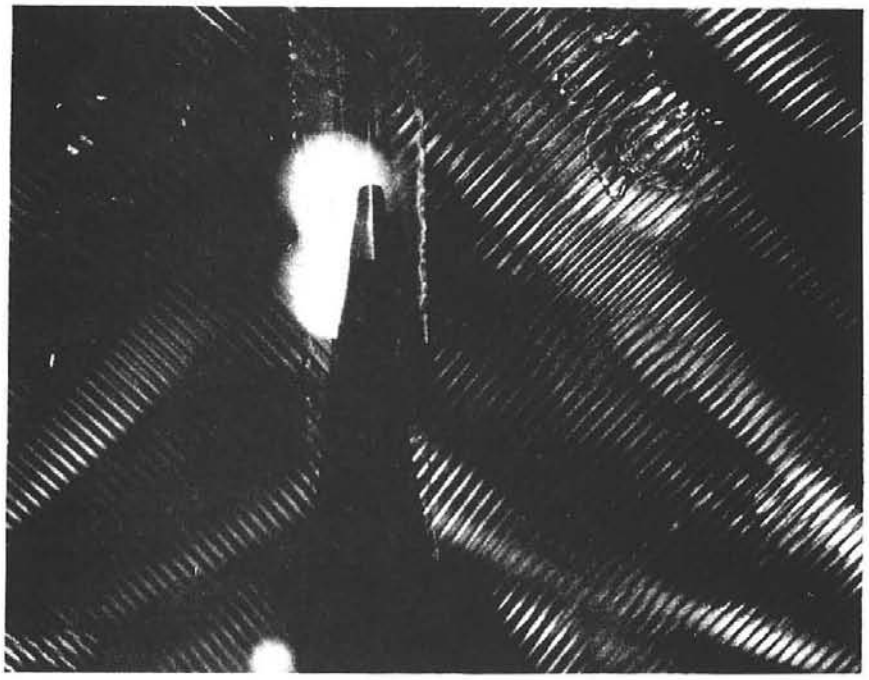


Figure 3. Photograph of Void Areas on Lens

The small voids or tears do not show up on every lens and when they do they always seem to appear after the first few days of temperature cycling. Data todate indicates that the voids do not seem to get any larger. For example, a full size parquet was placed outdoors. After four months of this exposure, the voids had not gotten larger and their number had not increased. In addition, the total area affected by the void condition represented only 0.02% of the total lens area. Whether this condition will continue to exist is something that only time will tell. Several of the prototype lenses will be placed outdoors by Sandia to monitor the delamination over an extended period of time.

Injection Molding Trials. Over 900 6.66 inch square Fresnel lenses were molded using a modified injection molding process. These molding trials were part of a GE funded development effort. Per a GE and Sandia agreement, representative injection molded lenses were delivered to Sandia for

subsequent evaluations. In addition, ten of the twenty prototype parquets were made with the injection molded lenses.

As stated, one of the major problems uncovered during our initial injection molding experiments was inadequate facet filling. As shown in Figure 4, we made significant progress in this area during our second round of molding.

Glass Superstrate. Due to the long lead time and the high cost of low quantity orders for Schott B-270 glass, a search for an alternative glass source was conducted. As a result of this survey, Solakleer (another low iron soda lime glass) was selected. Figure 5 shows the transmission characteristics for these two glasses as compared to regular soda lime glass. Specification sheets may be found in Appendix C.

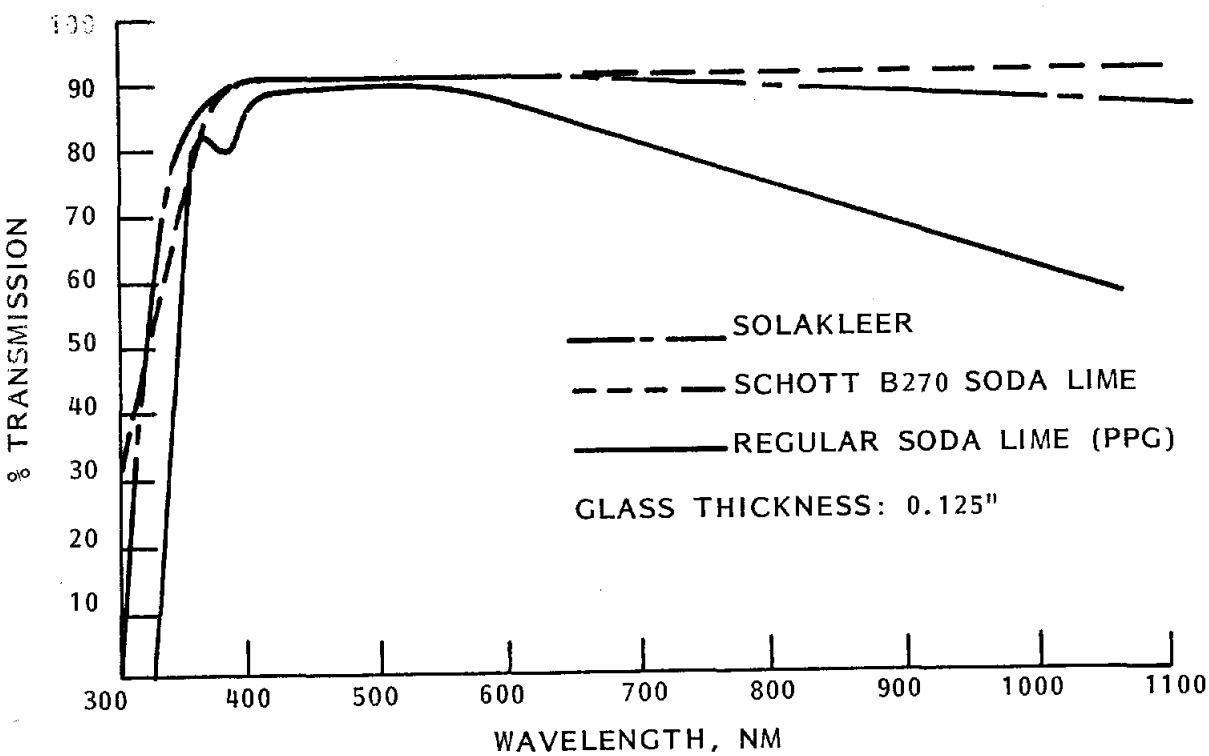
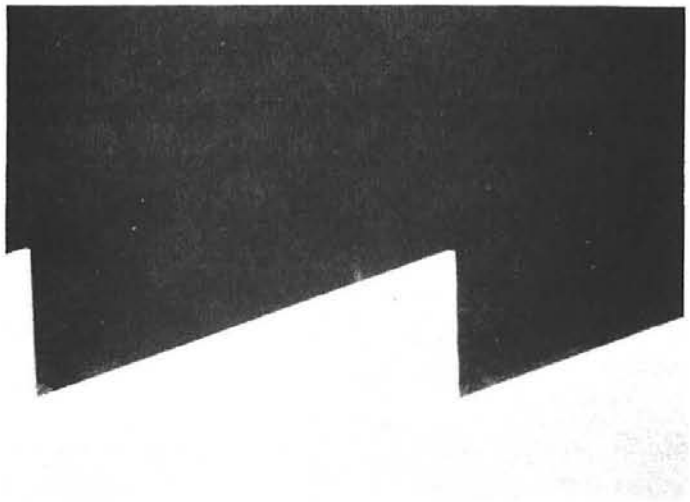
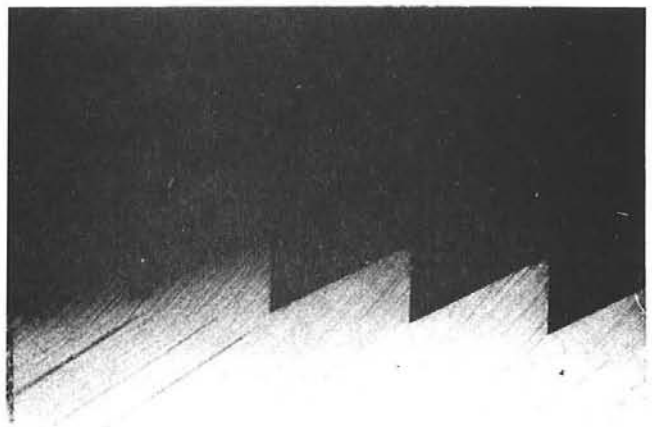


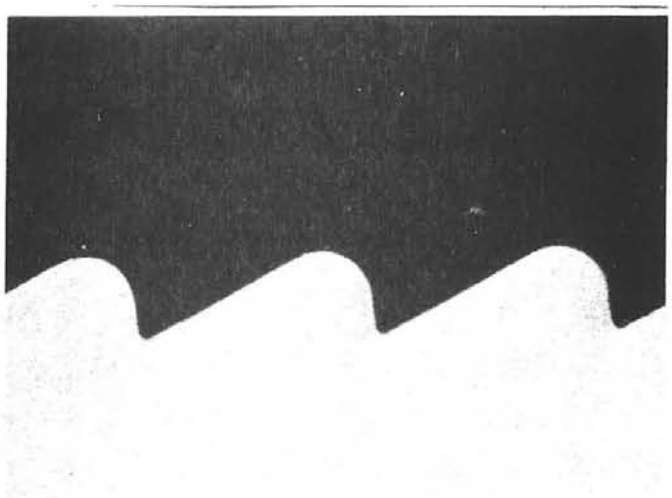
Figure 5. Transmission Characteristics of the Programs's Glass Superstrate



Compression Molded Standard



1981 Molding



1980 Molding

Figure 4. We Have Made Progress in Fresnel Facet Sharpness

Of the twenty prototype parquet lenses, ten were made with Schott glass superstrates and ten with Solakleer glass superstrates.

Section 3

Lens Design

Summary. Soon after the second phase of the program got underway, a meeting was held at Sandia to review the lessons learned from the previous injection molding experiments. At this meeting, the following Fresnel lens design considerations and parameters were discussed:

1. Reduce the number of facets
2. Increase F-number for higher efficiency
3. Constant-depth facets
4. Constant-curve facets

Of the above considerations, reducing the number of facets from our previous design appeared to be the best way to improve lens efficiency. Our earlier injection molding experiments had indicated that we were having difficulty in completely filling the facet tips. By reducing the number of facets, we would reduce the negative effect the inadequately filled facet tips had on lens efficiency.

We decided to design two new lenses, one with 0.030 inch wide facets and another with 0.015 inch wide facets. The 0.030 inch facetted lens would have half as many facets as our Phase I 0.015 inch facetted design, whereas a new 0.015 inch facetted lens could be a thinner lens with half as deep facets as the 0.030 inch facet design. During the lens design effort, several revisions were made to both the 0.015 and 0.030 inch designs in order to optimize their light distribution. Masters of the best designs were fabricated, and proof-of-design lenses made and tested. Outdoor lens testing at Sandia indicated that both lens designs were very similar with lens efficiencies of 88.5% for the 0.030 design and 85.6% for the 0.015 lens design.

Design Development. Two lens designs were developed: 1) an update of our earlier Phase I 0.015 inch facet lens and 2) a new 0.030 inch facet design based on theoretical and real data evaluations of the new 0.015 inch facet lens. In the development of both lens designs, detailed computer analyses were performed by C. Stillwell of Sandia before the masters were cut.

An updated 0.015 inch lens (lens II) design was generated and sent to Sandia for computer analysis. A summary of the Sandia analysis is provided in Table 4.

Table 4. Design Summary Chart
GE Lens II Design (0.015 inch facets)

Facet Design

Width (in)	Tip Radius (in)	Valley Radius (in)	Draft Angle (Deg)	Image Dia. (in)	Lens Eff. %	Concentration	
						Ave.	Peak
.015	.001	.0005	2	.61	77.6	151	217
.015	.0005	.0005	2	.61	80.4	151.3	288

As shown, the effect of going from a .0005 inch facet tip radius to a .001 inch tip radius is fairly significant, i.e. 3.4% efficiency loss. From this analysis, an injection molded lens tip radius design goal of less than or equal to .0006 inch was established. In addition, analysis of the predicted light distribution indicated an improvement from the Phase I lens design.

The first 0.030 inch facet lens design (design III) was sent to Sandia for computer analysis. A summary of this analysis is provided in Table 5.

Table 5. GE Lens III Design
(0.030 inch facets)

Facet Parameters

Tip Radii (in)	Valley Radii (in)	Draft Angle (Deg)	Image Dia. (in)	Lens Eff (%)	Concentration	
					Average	Peak
.001	.0005	2	.61	82.9	151	214
.001	.0005	3	.61	82.18	151.3	213
.001	.0005	4	.61	81.48	151.3	210
.002	.0005	2	.61	80.3	151.3	206
.003	.0005	2	.61	77.3	151.3	198
.003	.0005	2	.81	83.2	85.8	189
.0001	.0001	2	.61	86.7	151	249
.0001	.0001	3	.61	85.9	153.2	249
.0001	.0001	4	.61	85.2	152.3	228
.0001	.0001	2	.81	87	85.8	203

In this analysis, the effects of different facet radii and facet draft angles were evaluated. From this analysis, we concluded that going to a 0.030 inch facet reduces our sensitivity to "rounded" facet tips and that, if needed, we could tolerate going to a four degree draft angle.

Computer analysis at Sandia indicated that Lens III had a slightly smaller intensity profile than desired. It was then decided that revisions to lens III would be made. One revision (IVa) attempted to reduce the "hole" in the intensity profile, and one revision (IVb) attempted to open up the intensity profile a bit.

Sandia evaluation of these revisions indicated that lens IVa had been opened to the desired degree; however, IVb was overcompensated for and was now slightly peaked in the center.

A final touch-up of the 0.030 inch facet design (IVc), that included elements of the IVb modification, was made and sent to Sandia for evaluation. Based on

the Sandia computer analysis data, it was decided that lens IVc would be selected as our best 0.030 inch facet design.

Masters were cut by Fresnel Optics of Rochester, New York, for both lens II and IVc designs. Compression molded proof-of-design lenses for both designs were sent to Sandia for testing. Tables 6 and 7 summarize outdoor test data for lens designs II and IVc respectively. Representative Sandia lens analyzer test data for lens design IVc is provided in Figure 6.

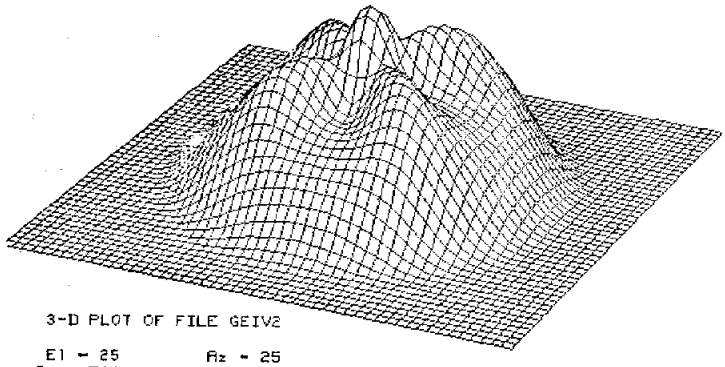
From this test data, it was concluded that we had developed improved lens designs. Inserts made from lens design II and IVc masters were then used in the subsequent injection molding trials.

Table 6. GE Strawman Lens Design II
6.7" x 6.7" Lens Mask
Sandia Strawman Cell .81" sq.
.015" Facet Width

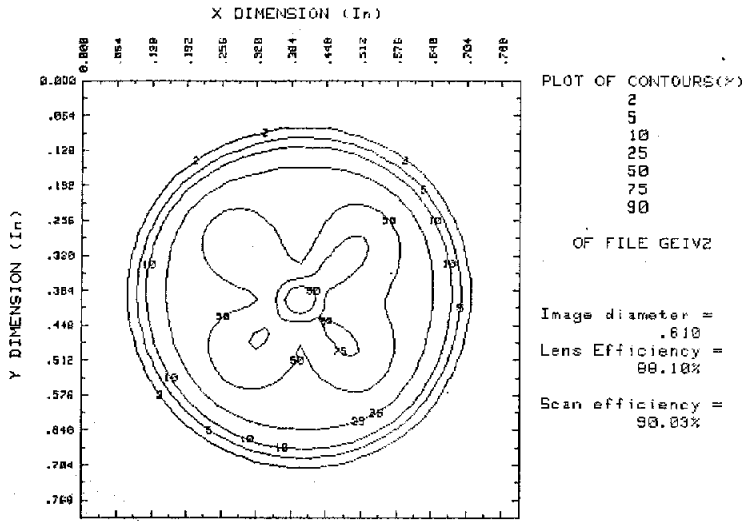
Lens to Cell (in)	DNI Std. Cell (mw/cm^2)	I_{sc} (A)	NI_{sc} (A)	P_{mp} (W)	NP_{mp} (W)	cm	Efficiency Lens (%)	Module (%)	Cell (%)	Cell FF
.61" Dia. Cell Mask (1.8855 cm^2) Cg = 153.6										
Ref	93.4	.05155	.0552						14.06	.798
8.000	92.6	6.893	7.444	3.475	3.753	134.87	87.80	12.96	15.2	.719
7.938	92.9	6.815	7.336	3.538	3.808	132.91	86.53	13.15	15.5	.733
7.875	93.2	6.572	7.052	3.485	3.739	127.76	83.18	12.91	15.8	.750
7.813	92.8	6.044	6.513	3.268	3.522	118.00	76.82	12.16	16.1	.765
7.750	92.7	5.315	5.734	2.924	3.154	103.88	67.63	10.89	16.3	.777
7.688	92.7	4.499	4.853	2.501	2.698	87.93	57.25	9.32	16.3	.780
.81" Dia. Cell Mask (3.3255 cm^2) Cg = 87.115										
Ref	92.1	.0938	.10185						15.4	.813
8.000	92.3	7.008	7.593	3.597	3.897	74.55	85.58	13.46	15.7	.710
7.938	92.6	7.037	7.599	3.694	3.989	74.62	85.65	13.77	16.1	.724
7.875	92.5	7.047	7.618	3.795	4.103	74.80	85.87	14.17	16.5	.74
7.813	93.4	7.085	7.586	3.865	4.138	74.48	85.50	14.29	16.7	.751
7.750	93.1	7.014	7.534	3.874	4.161	73.97	84.91	14.37	16.9	.759
7.688	92.9	6.968	7.500	3.922	4.222	73.65	84.54	14.58	17.2	.773

Table 7. GE Strawman Lens Design IVc
6.7" Square Lens Mask
Sandia Strawman .81" Sq. Cell
Fresnel Optics/GE Lens #1
.030" Facet Width

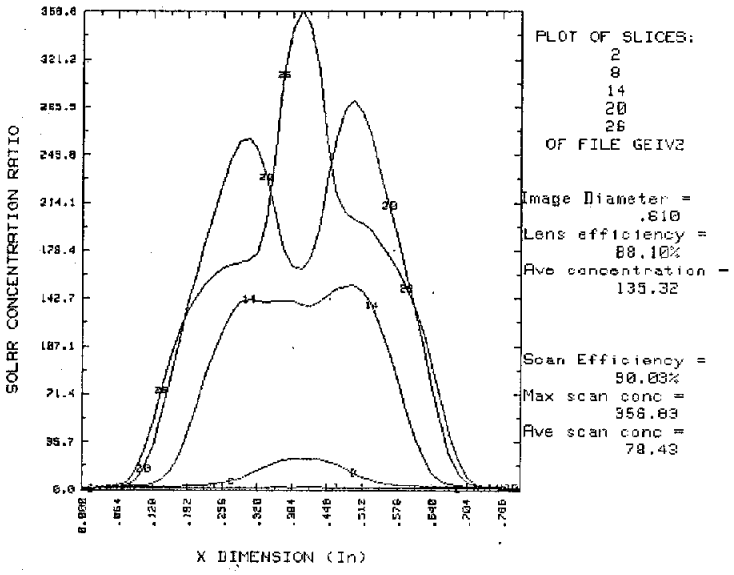
Lens to Cell (in)	DNI Std. Cell (mw/cm^2)	I_{sc} (A)	NI_{sc} (A)	P_{mp} (W)	NP_{mp} (W)	cm	Efficiency Lens (%)	Module (%)	Cell (%)	Cell FF
.61" Dia. Cell Mask (1.8855 cm^2) Cg = 153.6										
Ref	93.4	.05155	.0552						14.06	.798
8.000	92.3	6.995	7.505	3.589	3.851	135.98	88.53	13.30	15.02	.709
7.938	93.5	6.813	7.287	3.575	3.826	132.02	85.95	13.26	15.36	.725
7.875	93.2	6.284	6.743	3.333	3.576	122.16	79.53	13.25	15.72	.743
7.813	93.0	5.640	6.065	3.094	3.327	109.88	71.53	11.49	16.05	.761
7.750	93.1	4.803	5.159	2.678	2.877	93.47	60.85	9.93	16.32	.777
.81" Dia. Cell Mask (3.3245 cm^2) Cg = 87.115										
Ref	92.1	.0938	.10185						15.42	.813
8.000	92.3	7.107	7.700	3.618	3.920	75.60	87.21	13.53	15.59	.703
7.938	91.7	7.095	7.737	3.743	4.082	75.97	87.17	14.09	16.16	.727
7.875	92.2	7.112	7.714	3.830	4.154	75.74	86.94	14.34	16.49	.741
7.813	92.1	7.091	7.699	3.882	4.215	75.60	86.78	14.55	16.77	.753
7.750	92.0	7.044	7.657	3.922	4.263	75.18	86.26	14.72	17.05	.765



3-D PLOT OF FOCUSED FLUX



FOCUSED FLUX PLANAR VIEW



FOCUSED FLUX CROSS SECTION

Figure 6. Representative Sandia Lens Analyzer Output

GE Lens Design IV-c, 7.94" Focal Length

Section 4

Lamination Process Development

Objective. The objective of this phase of the project was to develop a process for fabricating a Fresnel lens parquet. The parquet measures 41.2 x 34.5 inches and contains an array of 6 lenses by 5 lenses with each lens being 6.66 inch square. Figure 7 illustrates the materials used in fabricating the parquet.

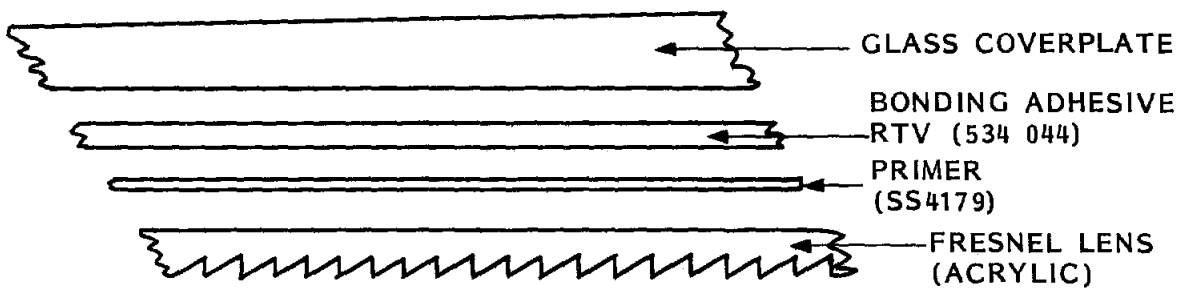


Figure 7. Crossection of Lens Lamination

The material which causes the most difficulty during the fabricating of the parquet is the RTV bonding adhesive (534-044). This RTV is a low viscosity liquid and will readily flow through any minute crevice or opening in its path such as the open facets found along the perimeter of the Fresnel lens. As a

result, a major objective of the lamination process development effort was to identify a process that would prevent the RTV from flowing into the lens facets. In addition, the process had to address the need to accurately control the lens center-to-lens center spacing of 6.700 + .010 inch. In addition, the process also had to minimize the occurrence of voids or air bubbles in the adhesive layer, ensure uniform adhesive thickness, and minimize adhesive waste and assembly labor. Finally, the process needed to be adaptable to potential large production runs.

The following paragraphs describe the various process approaches that were investigated:

Hard Tooling Approach with Vacuum. Figure 8 shows the 2 x 2 (2 lenses by 2 lenses) hard tooling fixture used to test this approach. The picture gives the impression of a 4 x 4 lens arrangement, but the cross in the center of each quadrant is actually a vacuum channel underneath the lens. There are 4 lenses on the fixture. The intent was to prove out the feasibility of this approach before ordering a large 6 x 5 fixture. The main purpose of the fixture is to hold the lenses against a gasket by means of a vacuum under each lens while the adhesive is being applied onto the top surface of the lenses and the one piece glass sheet on top of that. The lenses are held against the gasket so that none of the adhesive can flow onto the facetted side of the Fresnel lenses.

Observation of Figure 8 reveals that the darkened strip around the perimeter of each of the 4 lenses is the gasket material and that the hose arrangement in front of the fixture provides a vacuum in the area directly below each

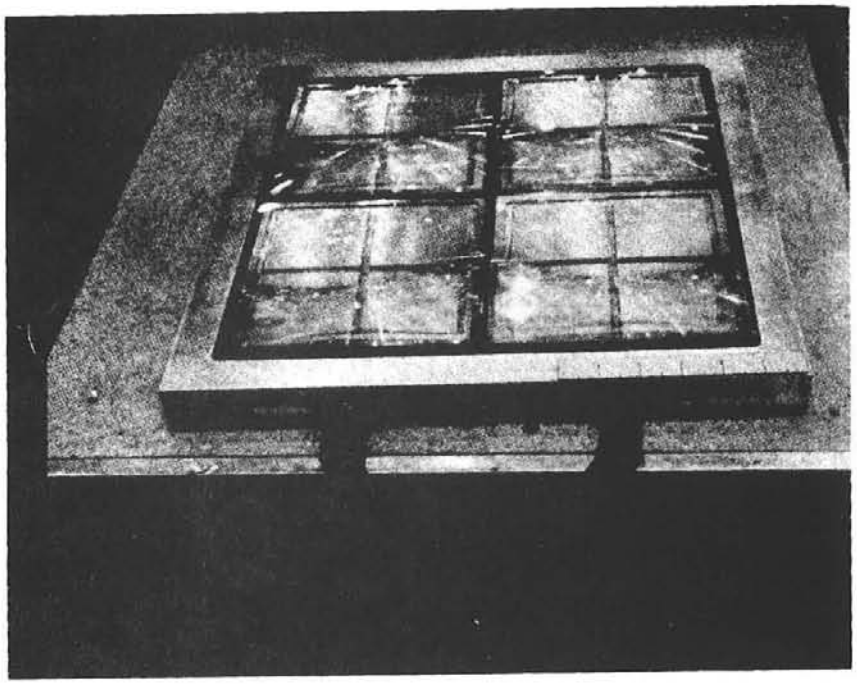


Figure 8. Prototype 2x2 Hard Tooling Test Fixture

individual lens. Prior to pouring the adhesive over the top of the 4 lenses, they are pulled down against the gasket material when the vacuum is activated.

It should be remembered that the facets on the underside of the lenses come out to the 4 sides of each lens. This means that in order to form a complete seal, the gasket material must conform exactly to the shape of the facets. This is difficult to accomplish, since the facets have very sharp features.

This has been the main difficulty encountered with the hard fixture approach. Without this conformity between facet and gasket, the suction action of the vacuum under each of the lenses pulls adhesive through the unprotected facets onto the underside of the lenses, which is supposed to be kept free of adhesive.

In trying to resolve the sealing problem the following approaches were investigated:

- Different gasket materials - Five gasket materials varying in cell structure, smoothness and composition and gaskets made from RTV were tested. The sharp facets made all of these inadequate for a 100% sealed condition.

- Fused lens edges - As a possible aid in providing sealing capacity for the lenses, a hot iron was run along the perimeter of the lenses with the intention of closing up the open ends of the grooves along the lenses' perimeter. This did fuse the material at the end of the grooves. However, it did not solve the problem, since there was a combination of the fusing not being 100% effective and the melted material moving in such a way so as to provide an uneven edge to rest on the gasket material.

- Vasolene - In view of the fact that vasolene improves the sealing capacity of gasket material, it was used to improve the seal. Although it helped considerably, the main difficulty encountered was that the Vasolene contaminated the underside of the lenses and could not be removed without affecting the lenses. Capillary action along the facets allowed the vasolene to lodge into the facets.

- Double faced adhesive tape - To possibly provide an adequate seal, the tape was applied along the perimeter of each lens prior to positioning onto a flat surface. The tape prevented adhesive from flowing to the underside of the lenses. However, the tape held the lenses so tightly against the flat surface that the 2 x 2 parquet could not be released without damage to the glass covering.

- Fill in facets along lenses' edges - RTV 630 molding material was applied along the perimeter of the lenses with the intention of filling in the facets. The outcome was that in addition to not providing a 100% seal, the RTV 630 was so thin that it could not be removed without damaging the lens.

- Fill in .040" space between lenses - Silglaze was used in the space between adjacent lenses with the purpose of sealing the exposed facets at the lenses' edges. It was very difficult to apply the silglaze so that there was complete coverage. As a result, adhesive seeped onto the lenses' underside.

As a result of this study, it was concluded that the vacuum sealing hard tooling approach did not work.

Soft Tooling Approach. A full (5 x 5) soft tooling setup is shown in Figure 9. This particular setup is a 5x5 instead of a 5 x 6. The 5 x 5 mold was available from some earlier work performed in 1980.

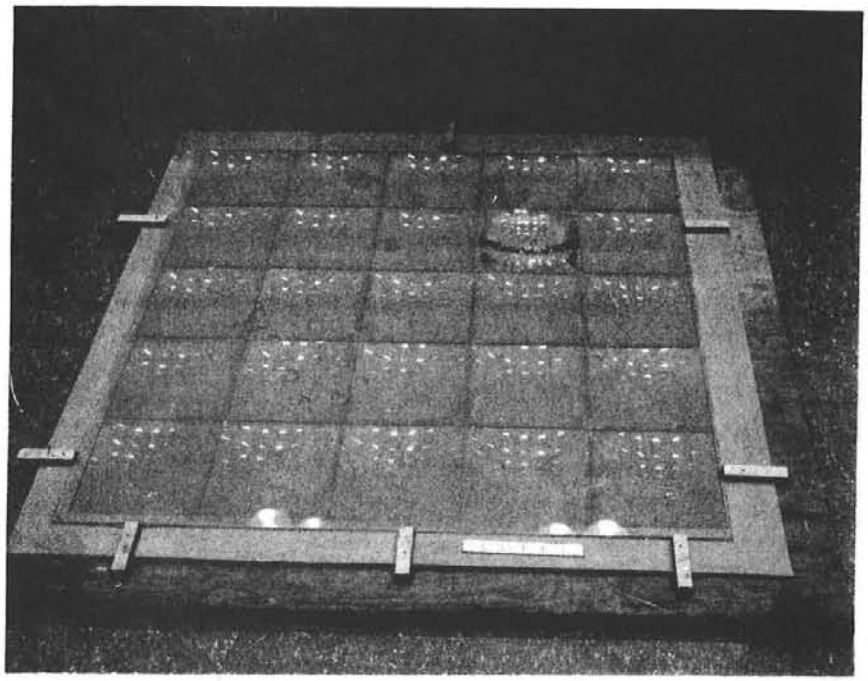


Figure 9. Prototype Soft Tooling Mold

The soft tooling approach involves two steps, as shown in Figure 10. Although Figure 10 shows only one lens, the final setup would involve thirty properly positioned lenses.

The lenses are positioned with the Fresnel side up (Figure 10a). RTV 630 molding compound is poured over all thirty lenses so that the result is a mold conforming exactly to each individual lens, especially in regards to the facets.

With the mold now formed, the assembly is turned upside down as shown in Figure 10b. The bond adhesive is then poured over the lenses and the one-piece glass cover lowered into place. The conforming RTV 630 molding material prevents the bonding adhesive from penetrating the facets.

Tests with a 2 x 2 parquet and an earlier 5 x 5 parquet made in 1980 indicated that the soft tooling approach is workable. However, the following should be considered.

Figure 10a

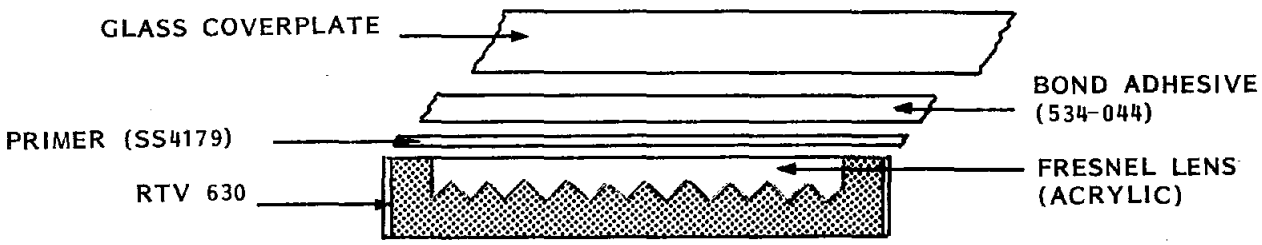


Figure 10. Soft Tooling Approach

Advantage of Soft Tooling

- RTV-630 will provide a complete seal around grooves and sides of lens so that adhesive will not contaminate the Fresnel side of the lenses.

Disadvantages of Soft Tooling

- RTV 630 mold requires 13 lbs. At $12/lb. this amounts to $156.00 for each parquet because the mold cannot be reused.
- Excessive time consumed to set up for making mold as well as positioning lenses and glass sheet.
- A total 18 hour cure time for both the RTV 630 and 534-004 makes it a slow process.
- Each lens must be held flat with double adhesive tape which will make removal difficult as well as possibly contaminate the lenses with adhesive.

Hard Tooling Approach - Without Vacuum (Baseline Process). The final approach investigated, and the baseline lamination approach finally selected, was a modified hard tooling approach that used a clear polyester/acrylic adhesive tape to seal the individual lenses. The key features of this approach are shown in Figure 11.

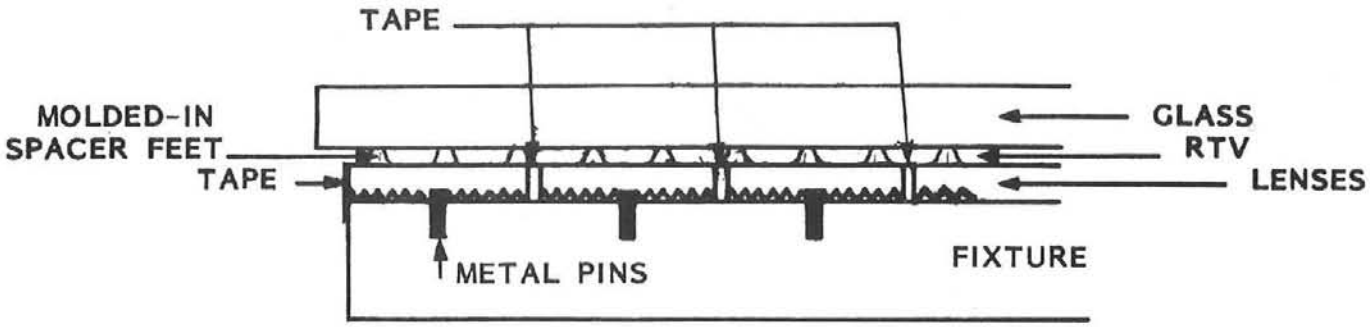


Figure 11. Key Features of the Baseline Lamination Approach

A flat aluminum plate has thirty .062 inch holes drilled in a 6x5 matrix with hole center-to-center spacing of 6.700 + .001 inch. Metal dowel pins are then inserted into each .062 inch hole. The drawing for this fixture is provided in Appendix D. A photograph of the actual program fixture is provided in Figure 12.

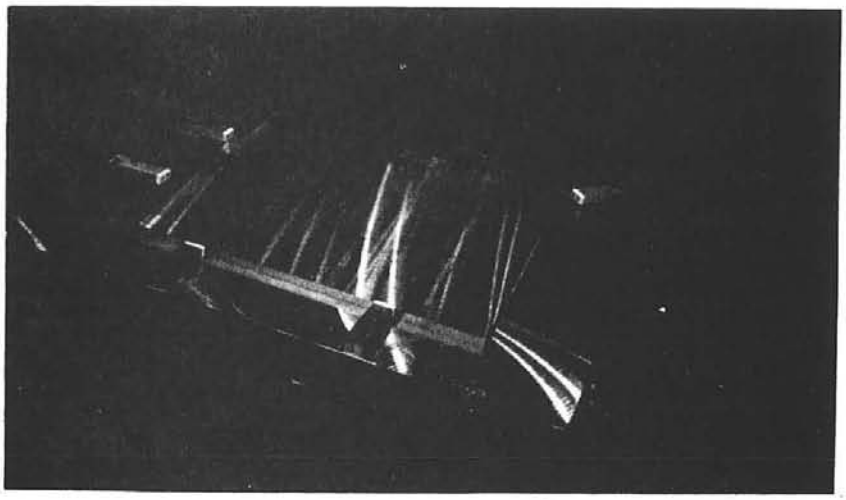


Figure 12. Full Size Parquet Lamination Fixture

Each lens has a corresponding hole molded into its center which mates to the fixture's metal pin. Using this approach, very accurate lens-to-lens center spacing is achieved, as shown in Figure 13.

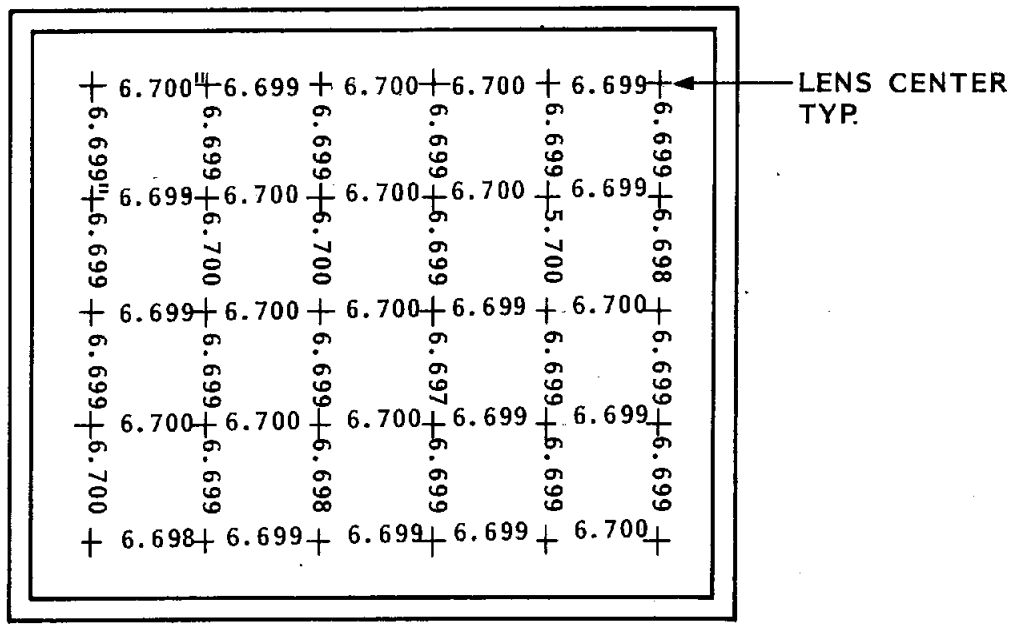


Figure 13. Actual Lens Center-to-Lens Center Spacing

Small spacer feet are also molded into the planar surface of the individual Fresnel lenses. These spacer feet serve to control the bond adhesive thickness. A thin .002 inch 0.125 inch wide UV stabilized polyester tape with an acrylic adhesive backing is then applied over the 0.050 inch gap between each lens and around the parquet perimeter. The acrylic surfaces are then cleaned and primed with GE RTV primer #SS4179. The bond adhesive RTV 534-044 is blended, deaerated and poured over the surface of the lens parquet pattern. The glass is then immediately lowered onto the RTV starting from one edge of the fixture and working to the other edge. Weights are then positioned onto the glass, and the entire assembly is allowed to cure for at least 4 hours.

The perimeter tape is then cut just under the facetted side of the lenses and the entire 6x5 parquet lifted off the machined aluminum fixture. Excess tape and RTV are then cleaned off the glass along the perimeter which completes the parquet assembly.

Prototype Parquet Hardware. As part of the program twenty full size 6x5 parquet lens assemblies were assembled using the baseline lamination process. The drawing package for the parquet assembly is provided in Appendix C. Ten parquets were assembled using 3mm thick Schott B270 glass and ten using 3mm (.118 inch) thick Solakleer glass. Ten of the parquets were assembled using compression molded Fresnel lenses with molded-in spacer feet and center locating indent per GE drawing 47C258398 (see Appendix B). Ten of the parquets were assembled using a sample of the latest injection molded lenses. The injection molded lenses did not have the molded-in center indent or spacer feet. The decision to go to these molded-in lens features was made after the injection mold fabrication task had started. The twenty parquets were delivered to Sandia for subsequent evaluation and testing.

Lamination Transmission Evaluations. The spectral transmittance and optical performance of the glass-RTV-acrylic lens lamination were evaluated.

The spectral transmittance was measured at Sandia under the direction of David King. The transmittance results are shown in Figure 14.

For comparison, the transmittance characteristics of 0.148 inch thick plexiglass is as provided. From this data, the transmittance for the laminate and plexiglas specimens was calculated to be .8895 and .9176 respectively over a .25 to 1.09 AM1.5 solar spectrum range.

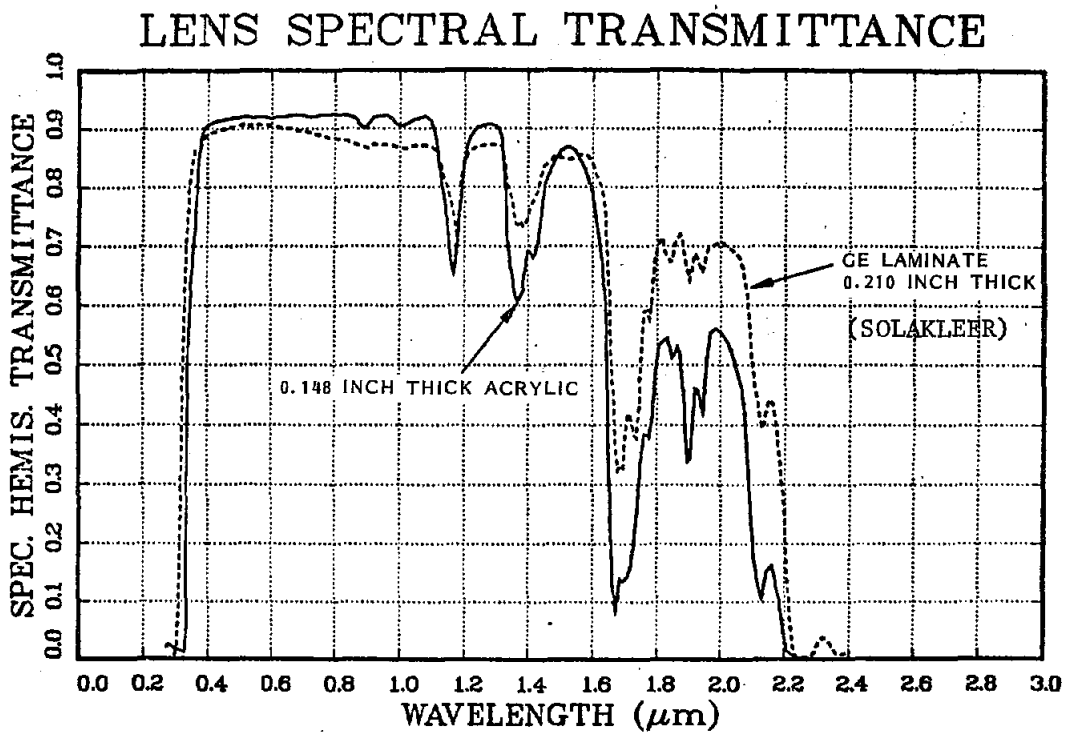


Figure 14. Laminate Spectral Transmission

The effective optical performance of the laminate was determined via outdoor testing at GE using an Applied Solar Energy Corporation 2.35 x 2.35 cm silicon concentrator cell. Individual 7 inch square glass-RTV-compression molded GE Lens IV-c lens laminates were prepared using both Schott B270 and Solakleer glass superstrates. The results of this testing are provided in Figure 15.

The plotted data represents averages of over 38 individual lens-cell test runs. As shown, data points are provided comparing Schott, Solakleer and varying degrees of cleanliness. The plastic lens only is a thin 0.070 inch compression molded control.

The module efficiency is the resulting single lens laminate-cell efficiency adjusted to a 28°C cell temperature. Assuming a 18.5% cell efficiency at 28°C and 70X concentration, the effective lens laminate optical efficiency

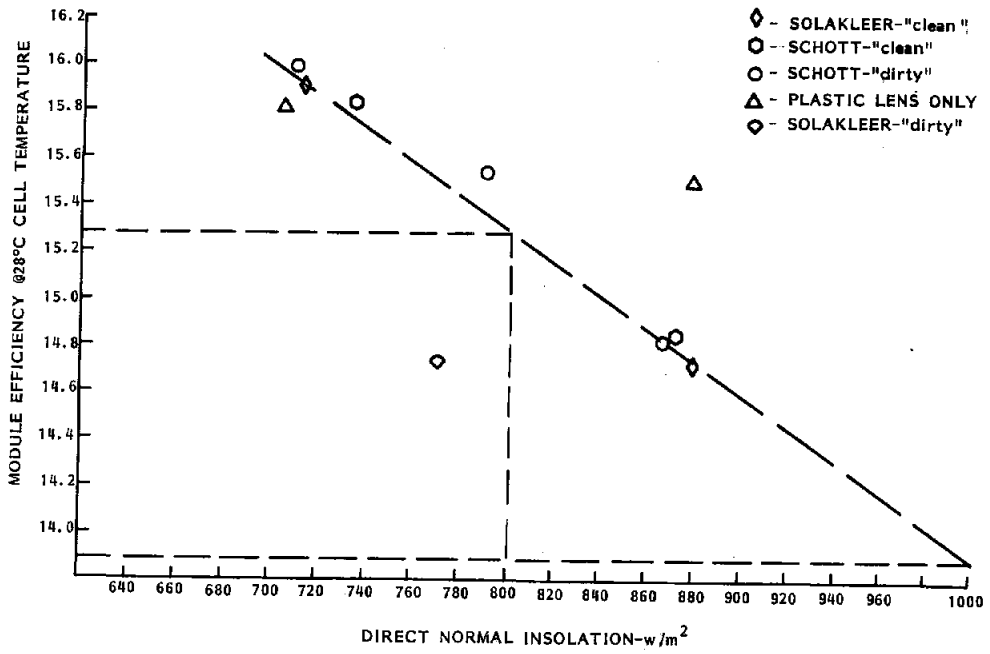


Figure 15. Laminated Lens-Cell Efficiency Data

is approximately 82.7%. Of interest is the relatively insignificent impact of "clean" versus "dirty" lenses and Schott versus Solakleer. The "dirty" lenses were not excessively dirty, but did have random finger prints on the glass and small RTV chips in some of the facets. We wanted to evaluate how critical it was to keep the lens-laminate "clean."

Section 5

Bond Integrity Studies

Summary. Throughout the lamination process development effort, glass-adhesive-plastic laminate specimens have been periodically subjected to temperature and humidity cycling. Various degrees of delamination have been found. As stated in the summary of this report, this has been a frustrating problem in that, technically, the material "experts" at GE-Silicone Products Department felt that our material system of glass-RTV 534-044 and primed acrylic should not delaminate under the thermal-humidity conditions in question.

In an attempt to identify the cause and a suitable fix, GE has analyzed the potential relative humidity environment, surveyed existing temperature and humidity cycling procedures, and conducted an in-house delamination-process study.

Relative Humidity Environmental Analysis. A survey of current relative humidity test requirements for other solar hardware development programs has shown a wide range of relative humidity/temperature specifications. For example, JPL specifies an 85% r.h. at 30°C test condition for its 11-meter dish collector program and an 85% r.h. at 85°C for its Block V flat plate PV module test.

In order to define the test requirements for the laminated Fresnel lens parquet, a survey of the relative humidity and temperature combination profiles was made for locations along the Atlantic Coast and the Gulf of Mexico. Based on the TMY weather data, Miami and Fort Worth have the worst

temperature/relative humidity combinations and these profiles are presented in

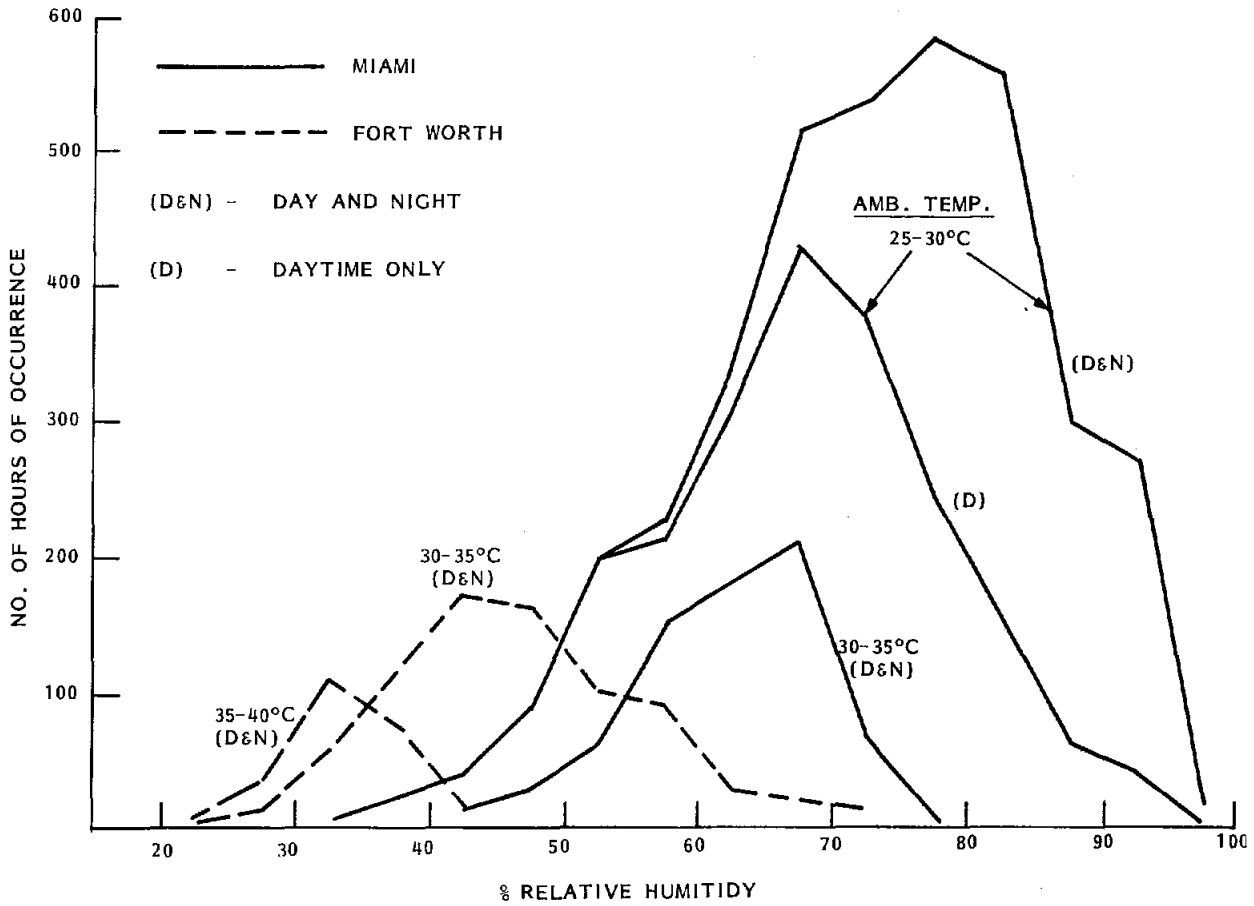


Figure 16. Ambient Temperature-Relative Humidity Occurrence Profile

It can be seen that the high humidity (75% at 25-30°C hours in Miami) occur mostly during the night. As the ambient temperature increases during the day (30-35°C), the relative humidity decreases significantly due to the increase in water-vapor capacity of the air with increasing temperature.

If the point-focus Fresnel module design, which uses a laminated parquet, incorporates a breather/filter, the worst environmental humidity-temperature combinations the parquet will see are those shown in Figure 16. As the module becomes operational during the day, the air inside the module housing is

heated and will leave the module housing in order to maintain equal pressure with the ambient. Assuming that no water vapor escapes through the breather filter, the relative humidity as a function of increasing inside air temperature will follow the constant water vapor lines on the psychrometric chart shown in Figure 17.

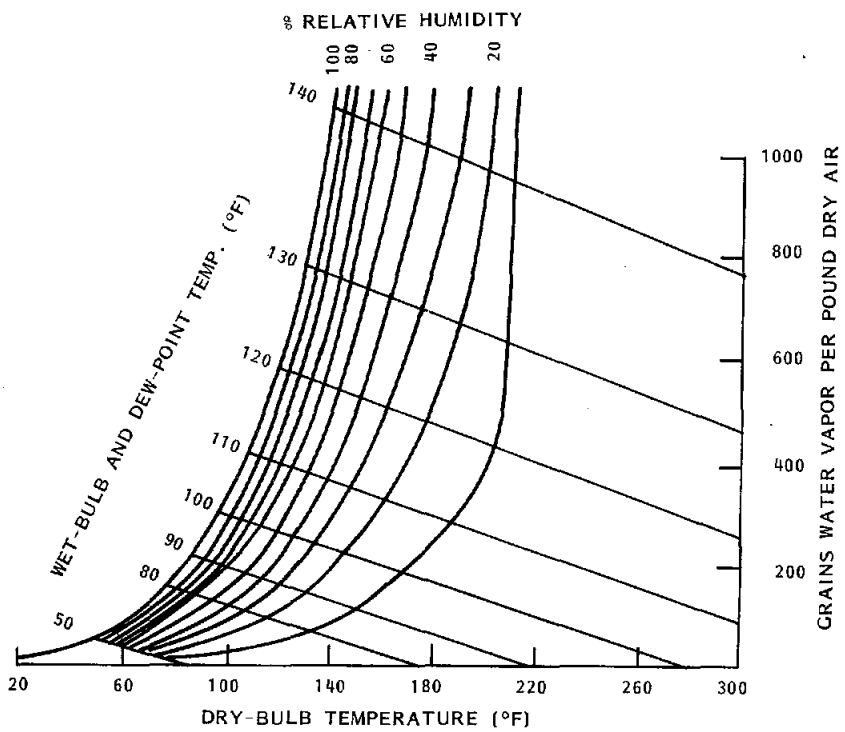


Figure 17. Psychometric Chart for Air at Barometric Pressure 29.92 In. Hq.

The mechanism for parquet delamination is probably the absorption of moisture by the acrylic lens which results in swelling and consequently pulling away from the adhesive. The major force behind the moisture migration and penetration is constituted by the vapor pressure imposed on the lens. Current accelerated environmental tests subject the laminate to vapor pressures/relative humidities-temperature combinations that are higher than

those that might ever be experienced.

Temperature-Humidity Cycling Procedures. In an attempt to identify how the glass and plastic industry evaluates bond integrity versus temperature and humidity cycling, a review of ASTM Standards and contacts to various industry sources were made.

An extensive review of the ASTM Standards identified the following documents as having possible relevance to the problem:

1.	ASTM D 618:	Conditioning Plastics and Electrical Insulating Materials for Testing
2.	ASTM D 759:	Conducting Physical Property Tests on Plastics at Subnormal and Supernormal Temperatures
3.	ASTM D 3045:	Heat Aging of Plastics Without Load
4.	ASTM D 1151:	Effect of Moisture and Temperature on Adhesive Bonds

Items 1. through 4. were carefully examined with particular emphasis on 4. However, this documnent was applicable only to adhesive bonds subjected to continuous exposure. Furthermore, Note 1 in the document states, "The condition under which the exposed specimens are tested will depend upon the nature of the adhesive, the adherence, and the strength property being investigated. This will be prescribed by the material specifications or by written agreement between the manufacturer and purchaser of the adhesive."

Following the review of the available ASME literature, the Staff Manager (Jane Turner) of ASTM Committee E44 (Solar Energy Conversion) was contacted at ASTM Headquarters in Philadelphia. Ms. Turner also reviewed the literature,

including most recent proposed changes, and could find nothing applicable to temperature/humidity cycling.

At Ms. Turner's suggestion, Dr. Howard Swift, Libby-Owens-Ford Glass Company, and a long-time member of ASTM Committee C14.08 (Flat Glass) was contacted. Dr. Swift was sympathetic and stated that the glass industry recognizes the problem since the use of silicone bonded flat glass is increasing. However, ASTM Committee C14.08 has not specifically addressed the problem.

Mr. David Nerrow of GE-Silicon Products Department made the following comments:

1. Any temperature excursion causes large expansion/contraction in adhesive and therefore requires careful thermal analysis of entire system.

2. RTV Adhesive 534-044 is an excellent choice.

3. The loss of adhesion in only small areas suggests that bonding system and technique are good, but perhaps cleaning methods, primer and bond application techniques should be more carefully controlled.

A contact with Rohm and Haas resulted in obtaining a copy of a brochure, "Thermal and Humidity Differential Bonding - PL72f," which states that changes in humidity and temperature may produce slight dimensional changes. However, these changes are not instantaneous, but require several days for equilibrium

to occur. Therefore climatic changes are rarely stable long enough for Plexiglas (acrylic) to equilibrate at a given humidity.

As a result of our survey, we concluded that no standard temperature/humidity cycling test exists for evaluating the subject parquet bond. Further work is needed to formulate appropriate temperature/humidity cycling test specifications for a laminated Fresnel parquet.

Delamination Studies. During an October 1981 review with Sandia, the results of a Sandia conducted thermal/humidity cycling test were discussed. A summary of the findings was that random bubbles ranging from 1/16 inch to 3/8 inch in diameter and delamination lines particularly around the spacer tabs/feet was observed in all five test specimens.

The bubble development was felt to be due to very small, visually undectable, pockets of entrapped air in the 534-044 blend that were incompletely removed in the deaerating operation. With the exposure to elevated temperature these pockets then expanded into the visible, various-sized bubbles. The delaminations were felt to be due to inadequate primer application. For the RTV adhesive system to work with acrylic a thin, uniform primer coat is essential. All delaminations seem to start at the acrylic interface. Several of the test specimens that were peeled apart clearly show that portions of the acrylic lens surface never had any primer.

In an attempt to resolve the delamination problem, GE conducted an in-house delamination study. A listing of the various process conditions evaluated is provided in Table 8.

Table 8. Delamination Test Matrix

Exp. Run No.	Variable	Primer Application Method	Drying Time, Min.	Blending		Time Before Mating, Min.
				Ratios A:B	Method	
1.	Primer Application	Wiping-L	15	25:1	A(E-15 Min.) +B+E	3
2.	Primer Application	Wiping-H	15	25:1	"	3
3.	Primer Application	Spray-L	15	25:1	"	3
4.	Primer Application	Spray-H	15	25:1	"	3
5.	Primer Drying	Wiping or Spray Depending	30	25:1	"	3
6.	Primer Drying	On #1-4 Results	30	25:1	"	3
7.	Joining Time	Wiping or Spray	15 or 30	25:1	"	3
8.	Joining Time	Wiping or Spray	15 or 30	25:1	"	5
9.	Joining Time	Wiping or Spray	15 or 30	25:1	"	10
10.	Blending	Wiping or Spray	15 or 30	19:1	Automatic Mix Equipment	3
11.	Blending & Joining Time	Wiping or Spray	15 or 30	19:1	"	5
12.	Blending & Joining Time	Wiping or Spray	15 or 30	19:1	"	10

Notes

A = Part A of GE 534-044
B = Part B of GE 534-044
E = Evacuation
H = Heavy Film
L = Light Film

The experimental runs detailed in Table 8 involved the preparation of 1x1 lens-laminate test specimens. Each experimental run was intended to evaluate the affects of variations in the primer application technique, primer drying time, exposure time before mating the adherends, and the blending ratio and technique. After completion of the cure (5 days at RT), each specimen was subjected to the thermal cycling as shown in Figure 18 until the appearance of some condition of failure, interpreted as appearance of delamination or bubbles or crazing lines not observed in the original condition. The maximum period for this exposure was 10 days.

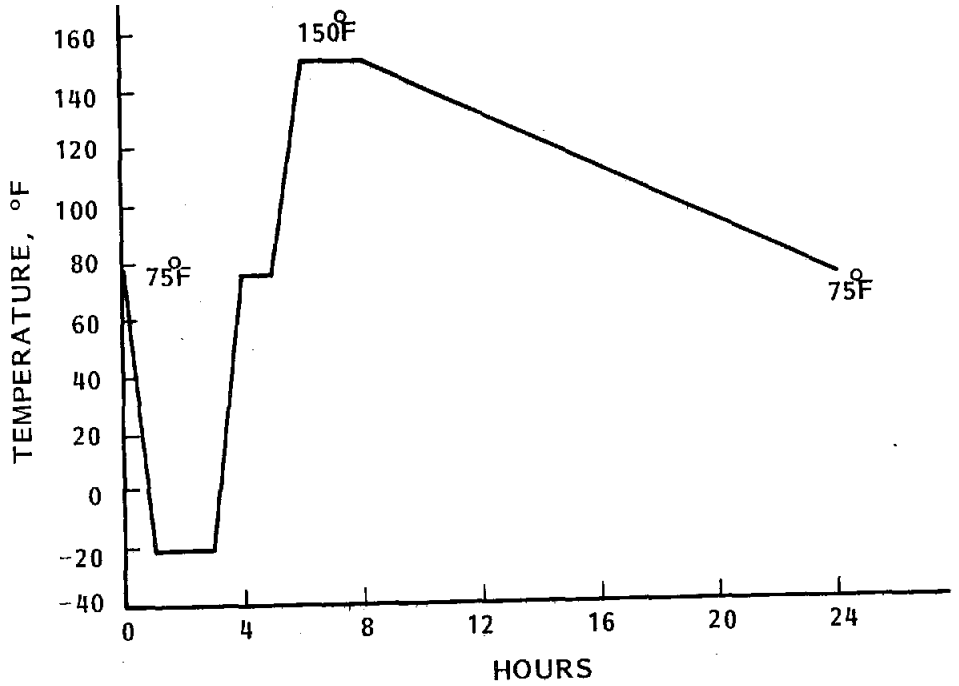
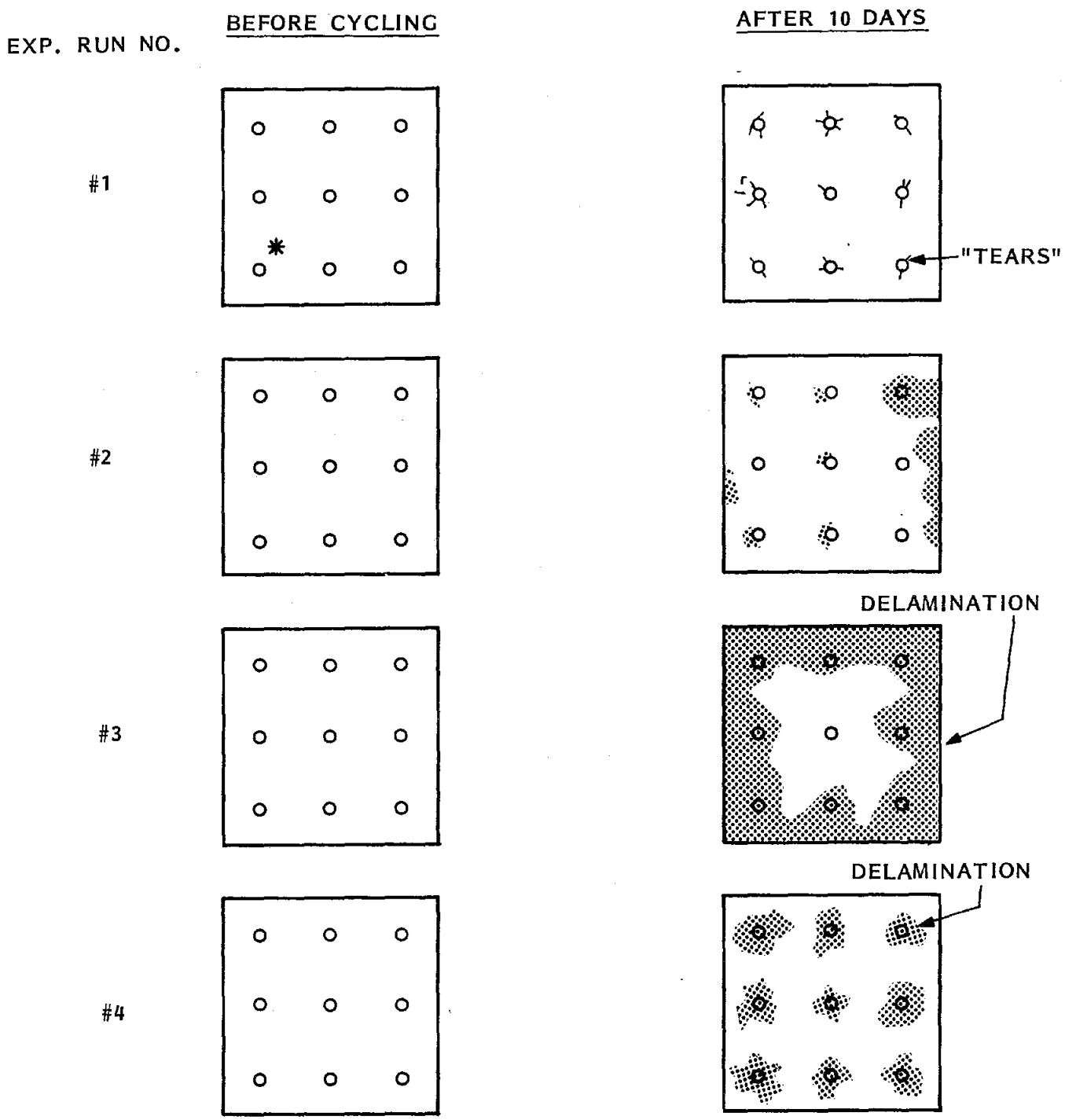


Figure 18. Daily Thermal Cycle for Delamination Study

Results for experimental (Exp.) run numbers 1 through 6 and 9 and 10 are presented in Figures 19 through 21. A review of these results produced the following conclusions:

1. Primer application is critical. A wiped, heavy film works the best.
2. The delaminations or tears show up after the first day of cycling.
3. The delaminations seemed to always start at the spacer feet locations.
4. The test specimen without spacer feet did not exhibit any delaminations after four days of cycling. Apparently the spacer feet contribute to an excessive stress build-up in the RTV adhesive bond.

Full Size Parquet Delamination. Several full size 6x5 parquets were assembled and placed outdoors. After a three month exposure minor delaminations were observed. Figure 22 shows the locations and frequency of these delaminations



✱ SPACER FEET NOT TO SCALE

Figure 19. Temperature Cycling Results - Exp. Run No's 1, 2, 3, 4

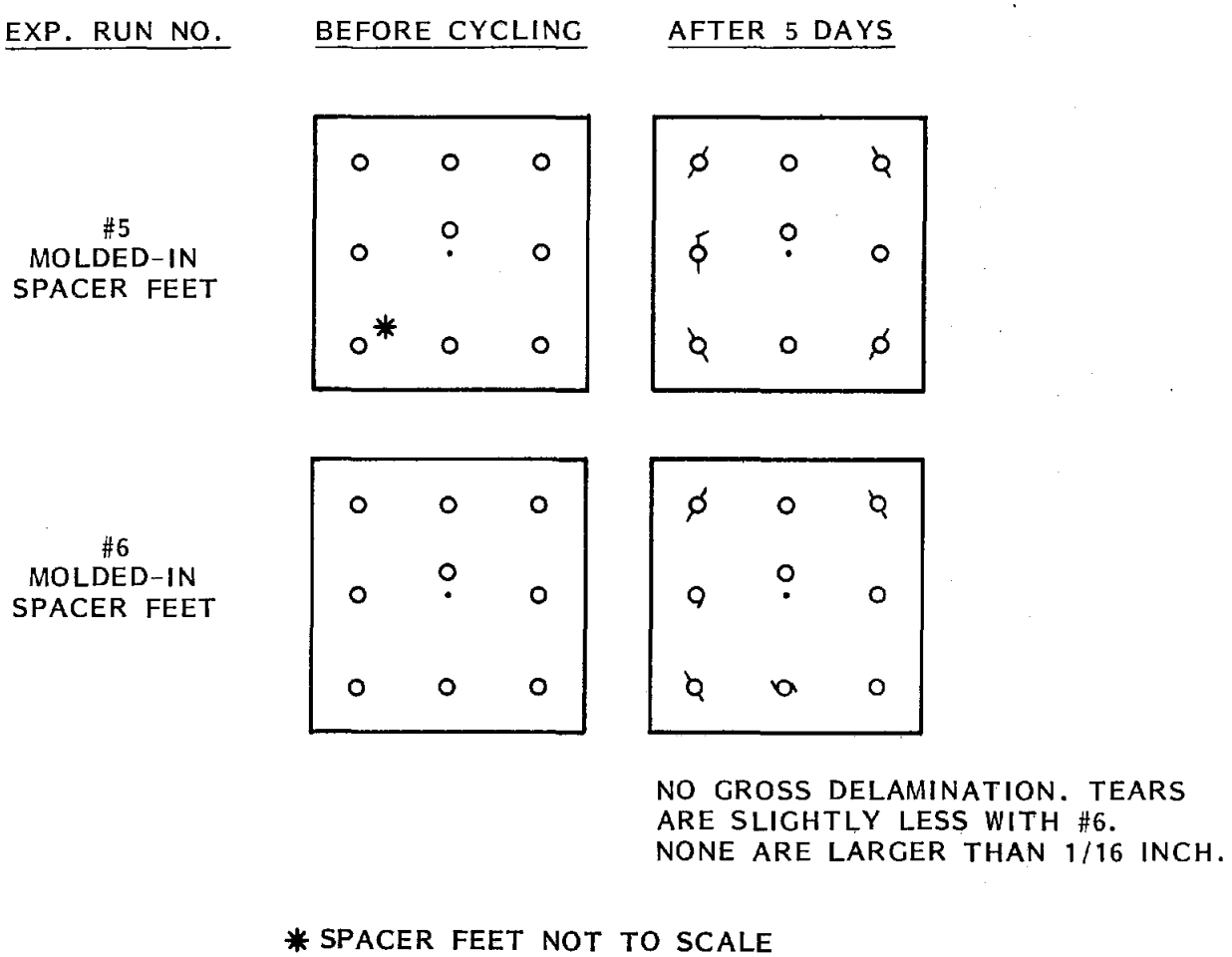


Figure 20. Temperature Cycling Results - Exp. Run No's 5, 6

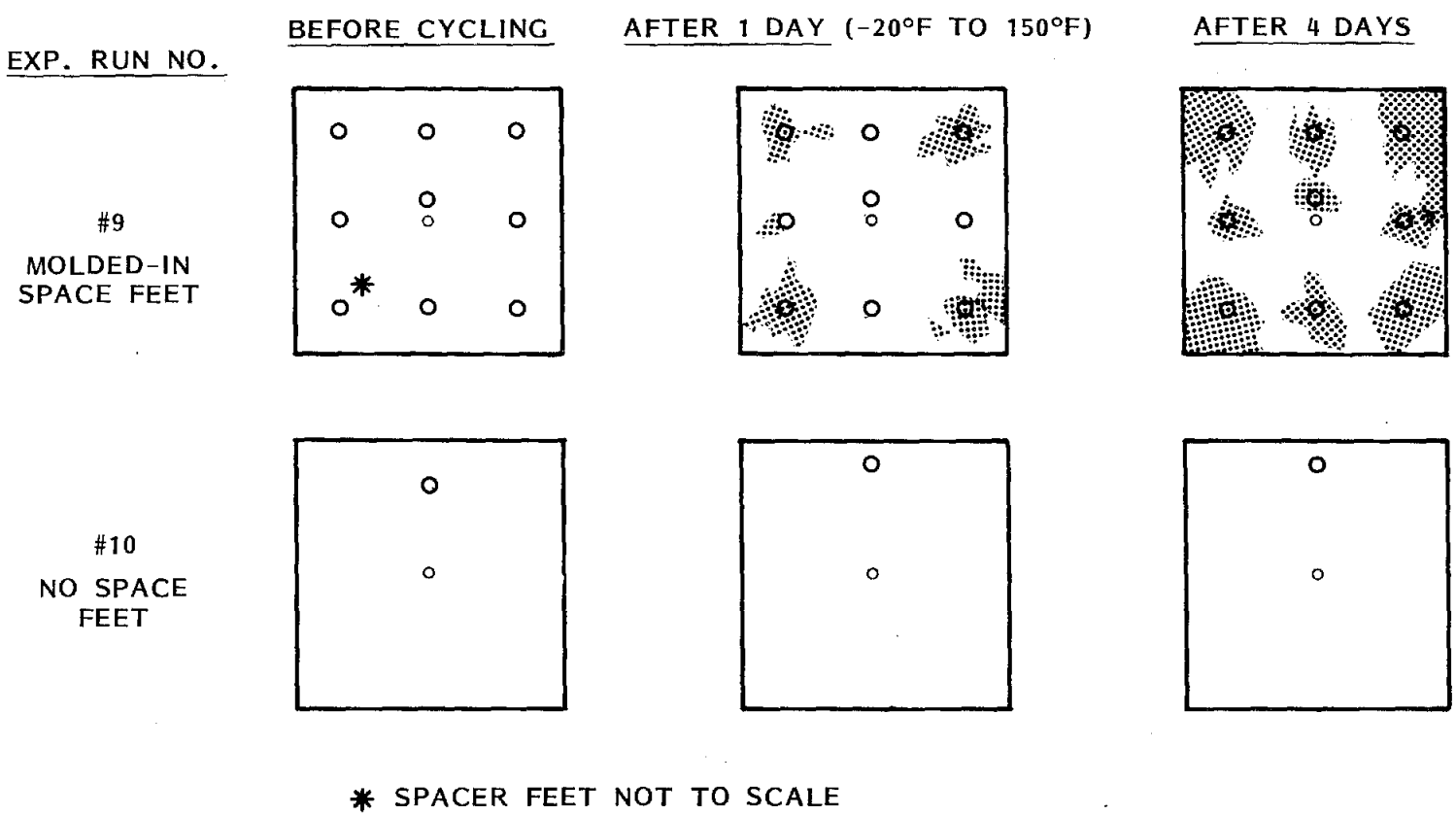


Figure 21. Temperature Cycle Results - Exp. Run No's 9, 10

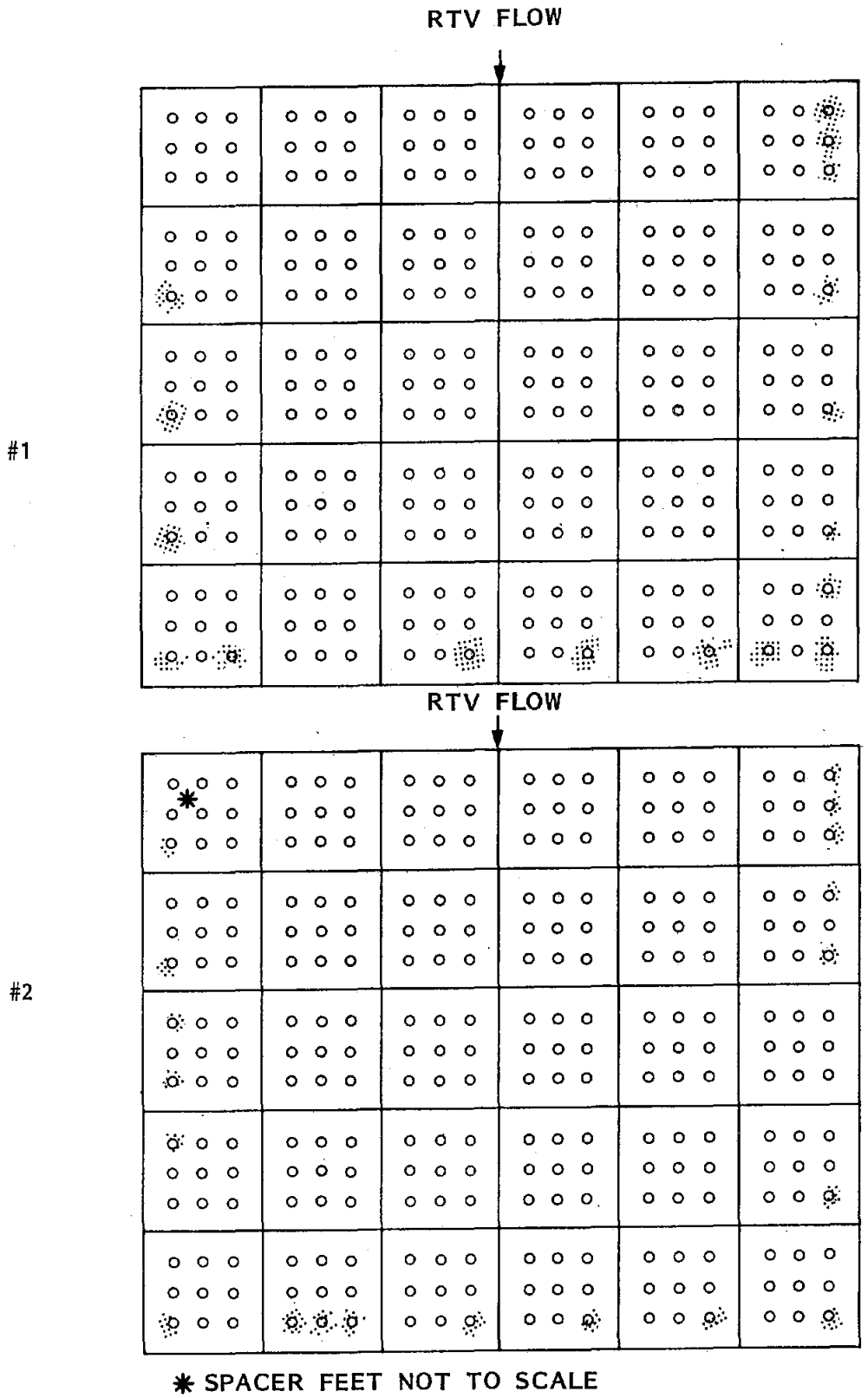


Figure 22. Representative Full Size Parquet Delaminations

for two representative parquets. From a study of these Figures the following conclusions were reached:

1. The total delamination area represents only .09% of each parquet's total area.

2. The delaminations are always located at the spacer feet and only along the outer parquet edge.

3. The specific location and frequency of the delaminations varies from parquet to parquet.

4. The parquet edge where the RTV was first poured has a significantly lower occurrence of delamination than the opposite edge.

In summary, we have experienced minor delamination at some of the outer edge spacer feet locations. The total area involved is very minor. The question of whether or not the delamination will progress to a point where serious lens performance degradation exists is still open. Extended outdoor exposure is needed to answer this question adequately.

Section 6

Injection Molding Lens Development

Summary. The first phase of the GE funded injection molded Fresnel lens development project took place in 1980. In phase one Fresnel lenses were molded using conventional injection molding techniques. Unfortunately, acceptable lenses were not achieved. The principal molded lens deficiencies were inadequate facet tip sharpness and nonuniform facet fill.

In 1981 a second phase of molding trials were conducted that built-on the experience gained during the first phase of molding trials.

At the beginning of the Phase II project, the following objectives were established:

1. Achieve a one minute part-to-art cycle time
2. Have facet tips with radius of 0.0006" or less.
3. Have lenses flat to + 0.03".
4. Demonstrate molded lens concentration efficiencies of 80% (95% of compression molded lens efficiency).

The first two objectives were met. However, the lens flatness and lens efficiency objectives were not.

Molded Lens Evaluations. Nine variations of molding parameters were evaluated. At least nine samples of each variation were tested. To facilitate the testing of the 89 samples, their performance was compared to that of a compression molded control under the same conditions where the compression molded control was considered to perform at 100% efficiency. The injection molded samples were then rated as a percentage of the performance of the compression molded control lens.

The lens test set-up is shown in Figure 23. A fixed target distance of 7.875 inches was used with a limiting aperture of .61 inch square, masking a .8 inch square photovoltaic cell. Voltage was read across a 1.5 ohm resistor placed in parallel with the cell. Light concentration was virtually proportional to voltage.

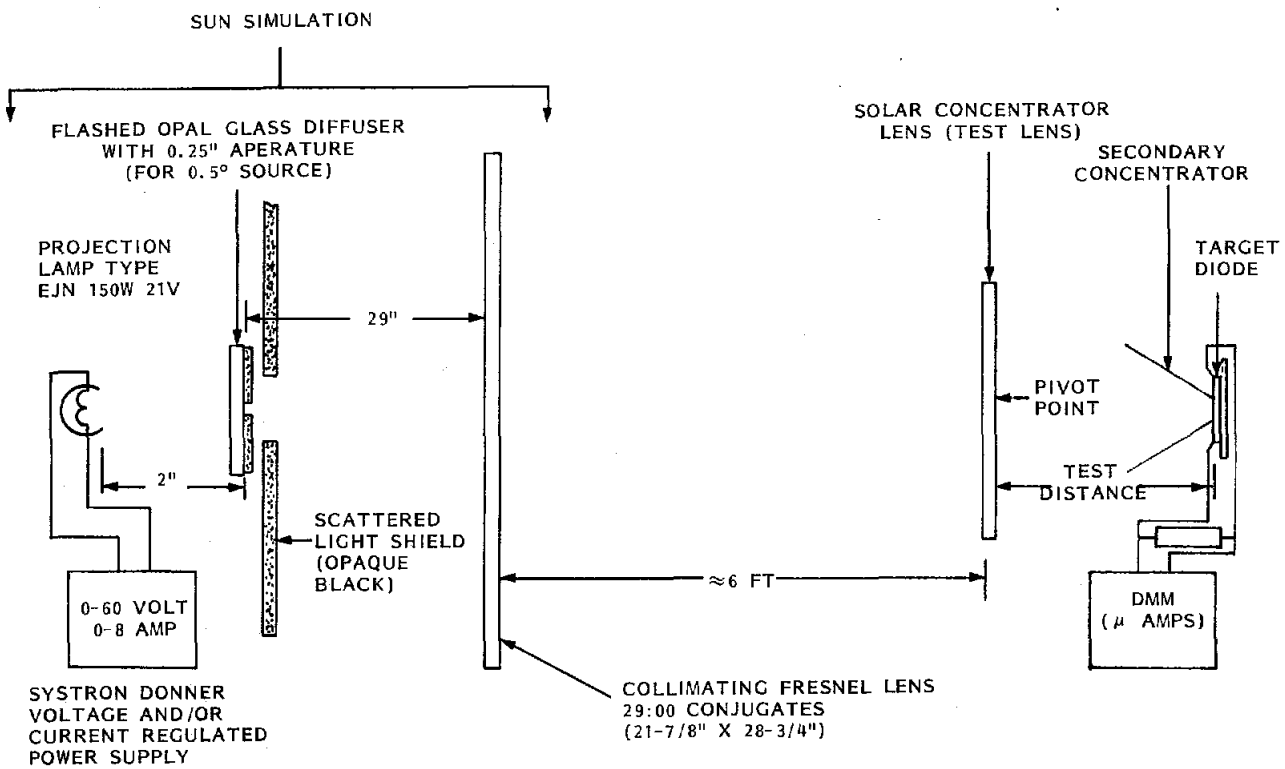


Figure 23. Injection Molded Lens Test Set-up

The solar angle of $.5^{0}$ was simulated with a large Fresnel lens and appropriate light source. No compensation was made for nonuniformity of illumination by the Fresnel collimator, due to the small central portion of the Fresnel utilized and because the same position in the collimation beam was used for all test samples. Since comparative data was sought, duplication of

the sun's terrestrial solar spectrum was not deemed necessary. However, a highly regulated power supply was necessary to supply power for the tungsten light source. Relative lens efficiency results are provided in Table 9.

Table 9. Relative Efficiency of Injection Molded Lenses

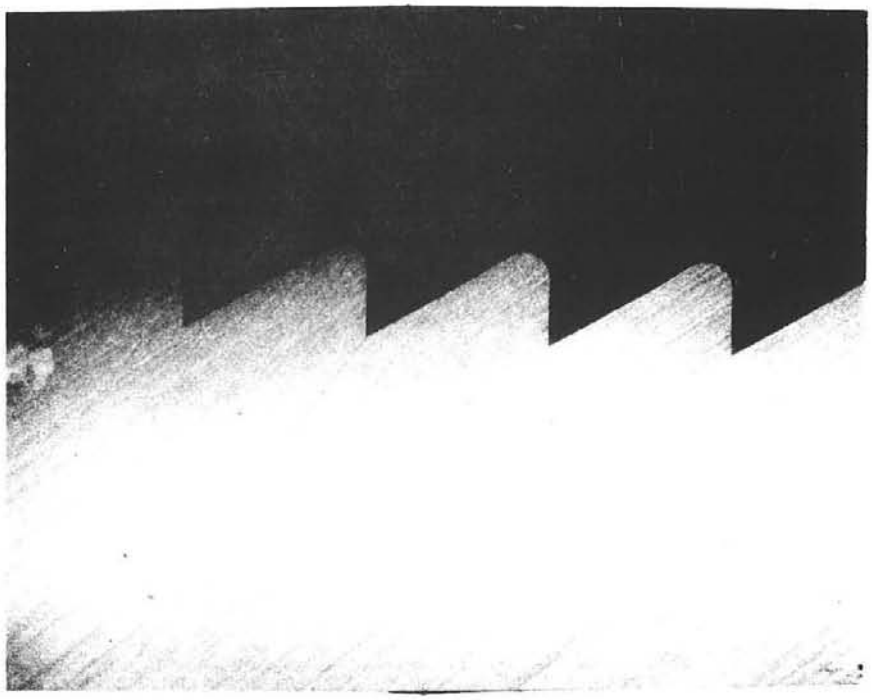
Code	Material	Lens Efficiency*
106-1	V052	85.5
106-2	V052	84.1
106-3	V052	76.8
106-4	V052	83.4
106-5	V052	87.1
106-6	V052	86.5
106-7	V052	88.3
106-8	V052	87.1
106-9	V052	86.8
VS-7	VS	86.5

*Compared to Compression Molded Lens Equal to 100%.

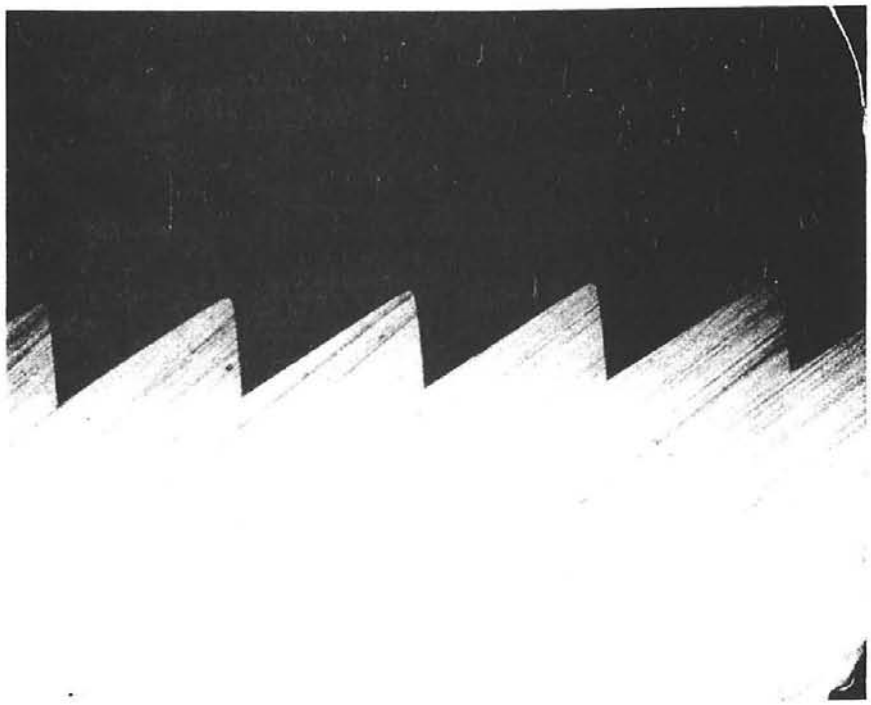
The loss in efficiency compared to the compression molded control is due to more than one particular physical feature of the injection molded lenses.

A visual inspection of the flux distribution in the target area gives an indicator whether the lens will or will not prove efficient. A compression molded lens produces a very sharply defined image with high contrast to the surrounding area. Due to chromatic dispersion, a saturated red circle with an inscribed blue clover leaf trimmed with green is the normal pattern.

The injection molded samples had many different characteristics. Scatter due to moisture in the molding material desaturated the color image and also reduced the contrast (scattered light out of the target area). The image pattern may sometimes be distorted, usually due to lens warp. In addition it was found that some of the facet tips were rounded. An example of this is provided in Figure 23 where facet detail of samples taken from the lowest



Group I



Group II

Figure 23 Processing Conditions Impacted Facet Sharpness

efficiency group (group I) and highest efficiency group (Group II) are shown.

In some cases, the image looked quite acceptable, compared to a compression molded sample, but when tested could be found to have efficiencies on the low side. The reverse is also evident at times with poorer appearing images giving higher efficiencies than normally would have been predicted.

Outdoor Lens Testing. Samples from the various molding runs were tested outdoors at GE. A summary of the test results is provided in Table 10. As shown, calculated injection molded lens efficiencies varied from 68 to 75%. Our goal of an 80% efficient lens was not achieved; however, significant improvement from 1980 to 1981 was demonstrated.

Table 10. Summary of Injection Molded Lens Outdoor Testing

Lens Group	Normalized Lens-Cell Efficiency	Calculated Lens Efficiency[1]	GE Molded Lens Vs Control Lens
VS-Run 7	.133	.72	.867
Run 7-1	.124	.68	.819
Run 7-8	.126	.68	.819
VS-Run 7	.132	.72	.867
Run 3	.126	.68	.819
Run 7-5	.125	.68	.819
End of Year Run '81	.138	.75	.904
1980 Run	.110	.60	.723
Compression Molded Lens (Control)	.152	.83	1.00

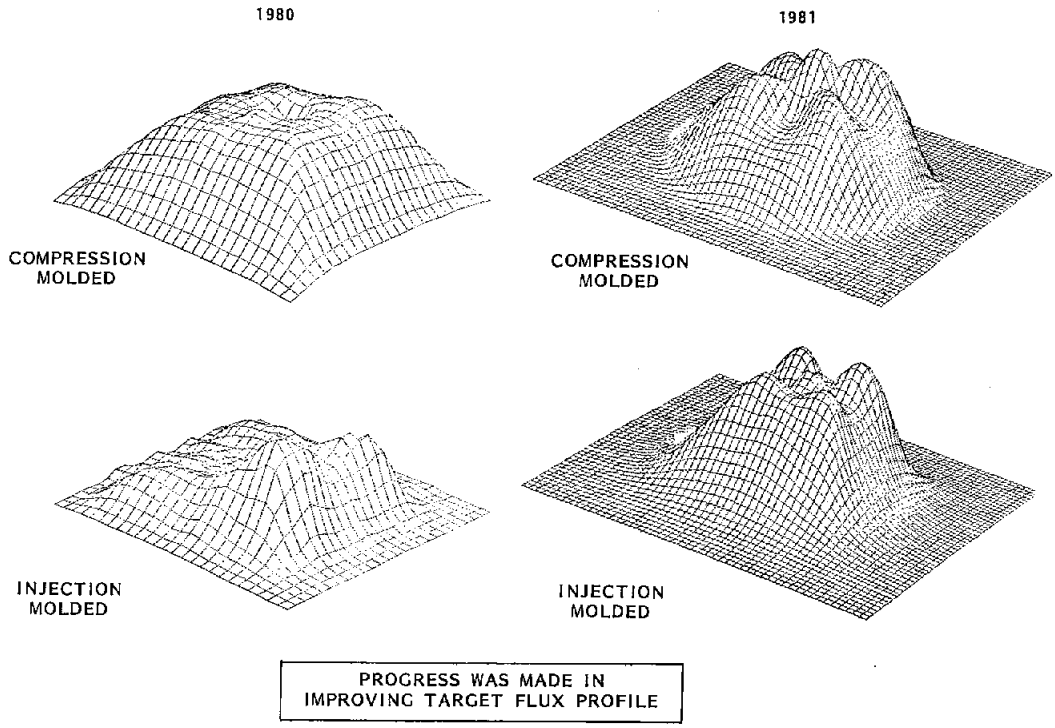
1. Normalized lens-cell efficiency : assumed cell efficiency (.184).

Phase I vs. Phase II Results. A comparison between Phase I and Phase II injection molded lenses is provided in Figure 24. As shown, a significant improvement was achieved in improved focused flux uniformity. A respectable improvement was also achieved in net module (lens-cell) efficiency.

Phase II Lenses with a Secondary. The performance difference between an injection molded lens and a compression molded lens can be reduced by using a simple reflective cone secondary. Actual test data for such a case is shown in Table 11.

Table 11. Injection Molded Lens Performance With a Secondary

Lens	Ratio of GE Molded Lens Efficiency to Compression Molded Control			
	No Secondary		With Secondary	
106-7-3	.907		.982	
106-7-1	.899		.980	
106-7-2	.897		.978	
106-7-4	.889	.891	.974	.975
106-7-9	.885		.970	
106-7-8	.874		.966	



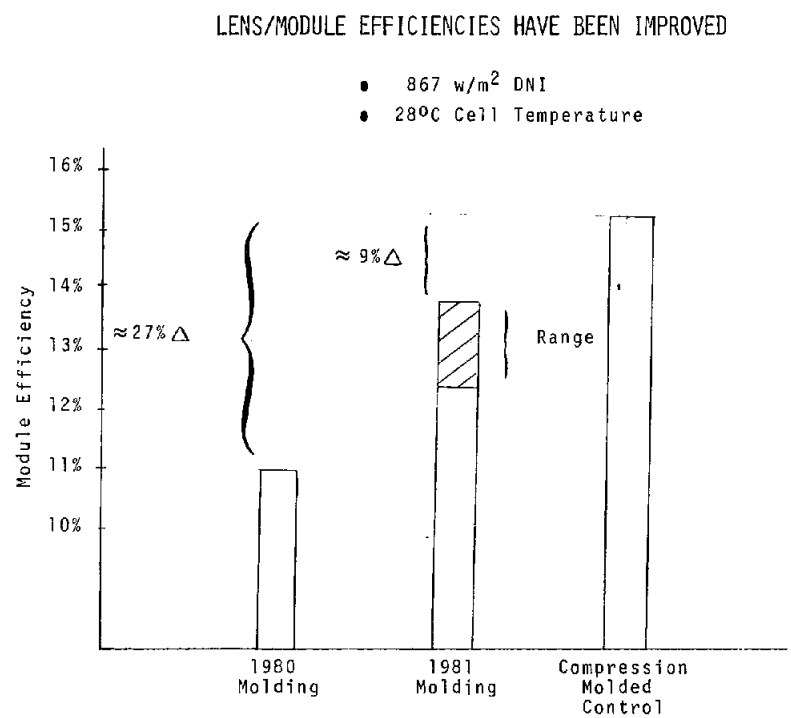


Figure 24. Injection Molded Lens Improvements

Key Results and Conclusions

Summary. The main objectives of the program were to:

1. Develop an improved point focus Fresnel lens
2. Develop a lamination process capable of assembling large parquet laminated Fresnel lenses.
3. Continue the development of an acceptable injection molded point focus Fresnel lens (GE funded effort)

Key Results. Key results regarding each of these objectives follows.

Improved Lens Design Development. Several design variations have been developed. After close interaction with Sandia, two lens designs were selected. Lens design II retains the initial lens design 0.015 inch facet width, but with an improved focused flux profile and efficiency. Lens design IVc has 0.030 inch facets and is slightly more efficient than design II.

Masters for both lens designs were cut and proof-of-design lenses were compression molded. GE and Sandia outdoor testing indicate that the transmission efficiency goal of 80% was achieved.

Lamination Process Development. A variety of lamination techniques were investigated. After a series of prototype lamination trials, an approach was selected that utilized molded-in lens features to help control lens centering as well as adhesive thickness. A clear tape is used to keep the liquid RTV adhesive out of the lens facets. Twenty prototype full size parquets were assembled using the selected approach.

Development of Injection Molded Point Focus Fresnel Lenses.

A state-of-the-art precision injection mold was designed and fabricated. Using electro formed Fresnel inserts, over 1000 lenses were molded under a variety of processing conditions. Resulting lens efficiencies varied with each set of processing conditions. Unfortunately, our efficiency goal of 80% was not achieved. However, significant improvements were made in facet tip sharpness (filling) and focused flux profile uniformity.

Conclusions. The following summarizes our major program conclusions:

1. The selected liquid adhesive system is a labor intensive approach. Care must be exercised in mixing and dearating the adhesive's two component parts, priming the acrylic lenses and in controlling the adhesive thickness, especially around the perimeter of the lens parquet pattern. A reliable delamination free bond has not been demonstrated using the GE RTV 534-044 adhesive. This adhesive approach is currently unacceptable for this application. Removing the need for the spacer feet might help.

2. A laminated lens exhibits a negligible performance loss as compared to a solid acrylic lens.

3. Several attractive glass types are available.

4. Injection molding definitely offers the potential for significant individual lens price reductions e.g. from $9 to $.80 each for a 6.66 inch square x 0.070 inch thick lens. Its main drawback is its size limitation. Injection molding a full size 41.5 x 34.5 inch parquet requires a very large machine. The capital cost of the machine and mold are significantly higher than for a compression molded full size parquet.

5. Production costs estimates for 6x5 laminated parquet lens options are as follows:

	Existing RTV Adhesive Approach	Potential Thin Film Adhesive & Lens Approach
Labor	$107.00 (5 hrs ea)	14.30 (40 min ea)
Adhesive	8.50 (2.40 lbs ea @ $3.50/lb)	.92 (1.16 lbs ea @ $.80/lb.)
Lens	24.00 ($.80 ea)	11.70 (9.8 ft^2 @ $1.20/$ft^2$)
Glass	8.70	8.70
	$148.20	$35.62

For these estimates production volumes of at least 10000 lenses per year are assumed. For comparative purposes the estimate cost of a solid acrylic 6x5 parquet lens is approximately $60 each.

6. The outstanding durability, cleanability and low cost potential make the quest for a viable glass-laminate lens worthwhile.

APPENDIX A

GE RTV 534-044 PROPERTY SHEET

Table 3-3. Properties of GE Experimental Pottant 534-044

534-044 Experimental Photovoltaic Pottant

Product Description

GE 534-044, experimental photovoltaic pottant is a two-component, low viscosity, low modulus, RTV silicone rubber. After the addition of the curing agent, 534-044 may be cured at room temperature or with mild heat to a flexible rubber. Good adhesion to many substrates is achieved without a primer.

Product Data

Typical Uncured Properties

Color 534-044A	Clear, Colorless
534-044B	Clear, Pale Yellow
Viscosity, cps	900 - 1500

Typical Cured Properties (72 hrs. at 25°C and 50% R.H.)

Catalyst Level	5%	4%	2%
Work Time @ 25°C, min.	15	30	60
Tack Free @ 25°C, hrs.	1	1.25	2
Cure Time @ 25°C, hrs.	4	4	6

Color	Clear, Colorless
Refractive Index	1.4075
Specific Gravity	0.98
Durometer, Shore A	21
Dielectric Strength, v/mil	500
Dielectric Constant, 1 k Hz	2.89
Dissipation Factor, 1 k Hz	.002

Any review, recommendation, or statement, made on behalf of Silicone Products Department of General Electric Company relating to any engineering design, architectural drawing, product formulation, end-use specification, or similar document is limited to the knowledge of product properties as determined by laboratory testing of material produced by Silicone Products Department. Any comments or suggestions relating to any subject other than such product properties are offered only to call to the attention of the engineer, architect, formulator, end-user, or other person, considerations which may be relevant in his independent evaluation and determination of the appropriateness of such design, drawing, specification, document or formula. Silicone Products Department expressly disclaims any liability for any damage, harm, injury, cost or expense to any person resulting, directly or indirectly, from that person's, or any other person's, reliance on any such review, recommendation, statement, comment or suggestion.

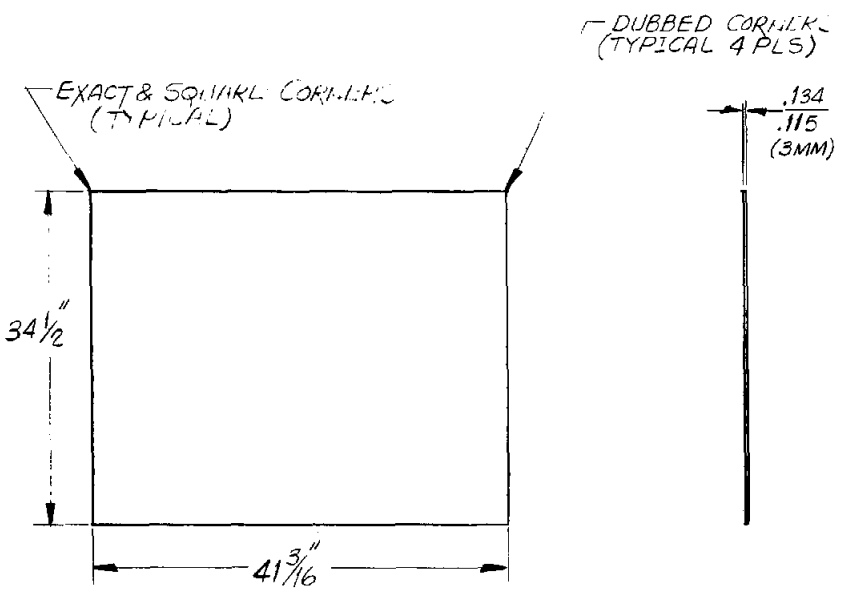
APPENDIX B

PARQUET LENS DRAWINGS

SIZE		SHEET	REV
B	47B258442	1 OF 1	

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED



NOTES:

1. DRAWING TERMS & TOL. PER ANSI-Y14.5.
2. EDGES WILL BE TREATED SO THAT YOU HAVE A CONDITION FOR SAFE HANDLING.
3. THE MATERIAL SHALL BE ANNEALED, CLEAR GLASS HAVING A TOTAL SOLAR TRANSMITTANCE OF AT LEAST 86% AT A.M. 2.0 FOR A NOMINAL THICKNESS OF 0.118" (3mm).
4. VARIATION IN THICKNESS OF THE GLASS SHALL BE NO GREATER THAN 0.005"/FT (0.42 mm/m) MEASURED EVERY SIX (6) INCHES.(15.2cm)
5. NOMINAL VALUES FOR MODULUS OF ELASTICITY AND MODULUS OF RUPTURE SHALL BE AT LEAST 10×10^6 PSI (69×10^3MPa) AND 6×10^3 PSI (41MPa), RESPECTIVELY.
6. CONFORMANCE WITH SECTION 3.3.2, EXCEPT THE REQUIREMENT FOR STONES WHICH SHALL BE AS STIPULATED IN SECTION 3.3.3, OF FEDERAL SPECIFICATION DD-G-451d SHALL BE USED TO DETERMINE THE ACCEPTABILITY OF DEFECTS.
7. USE QUALITY ASSURANCE PROVISIONS (SECTION 4) OF FEDERAL SPECIFICATION DD-G-451d SHALL ALSO APPLY. COMPLETION OF THE REQUIRED INSPECTION DESCRIBED IN SECTION 4 MAY BE PERFORMED BY EITHER THE MANUFACTURER OR THE SUPPLIER.
8. PACKAGING FOR THE GLASS PANELS SHALL PROVIDE ADEQUATE PROTECTION AGAINST DAMAGE DURING SHIPMENT, AND AGAINST WEATHERING AND DAMAGE DURING PROLONGED PERIODS OF STORAGE.

P1

SUFFIX	NEXT ASSY	USED ON
P1	47D258399	APFC

APPLICATION

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON:
FRACTIONS ± 1/16 DECIMALS ± ANGLES ±
ALL SURFACES ~✓
MATL- SEE NOTES

SIGNATURES	DAY	MO	YR
DRAWN	15	7	81
CHECKED	15	7	81
~~ISSUED~~	26	8	81
ENGRG	26	8	81
MFG			
MATLS			

GENERAL ELECTRIC
AEP DEPT LOC PHILA., PA

PANEL, GLASS

SIZE	CODE IDENT NO.	
B	23991	47B258442
SCALE 1/10		SHEET 1 OF 1

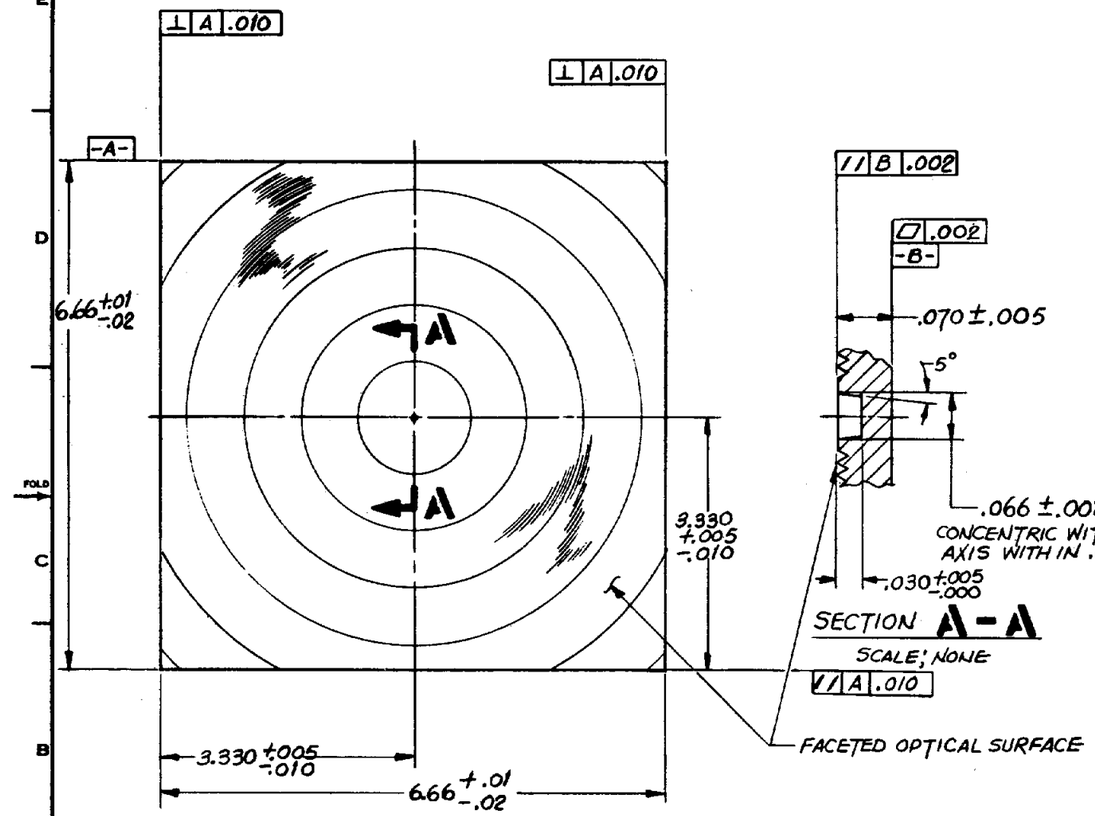
DIST TO IR&D C67

PN 902-F (11-75) PRINTED IN U.S.A.

B-1 / 2

SIZE C | 47C258398 | REV 3

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	1	REVISED SECTION A-A; DELETED SECT. B-B; ADDED 'P2' (SHEET-2)	8/12/81	RSH
	2	.030 DIM. WAS .015; TOL. ON .062 DIA WAS ±.001; ADDED 5° TAPER TO .062 Ø HOLE	9-3-81 9-8-81	RSH ERC
	3	IN IC3, .066 DIA WAS .062 DIA; ADDED DETAIL - 'C' ON SHEET-2	10-13-81	RSH ERC



NOTES;
1. DWG TERMS & TOL PER ANSI-Y14.5.
2. FRESNEL FACET DEFINITION PER SPEC. Later.
3. LENS DESIGN REQUIREMENTS PER SPEC. Later.

REVISION STATUS TABULATION

1	3	REV	REV STATUS OF SHEETS
2	1	SH	

P1
P2 SEE SHT-2

P1, P2	47D258399	APFC
SUFFIX	NEXT ASSY	USED ON
APPLICATION		

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES—
TOLERANCES ON:
2-PLACE DECIMALS ±.01
3-PLACE DECIMALS ±
ANGLES ± 1°
FRACTIONS ±
ALL SURF ✓

MATERIAL— P1 & P2: CLEAR ACRYLIC (SPECIFIC TYPE TO BE DETERMINED BY LENS MANUFACTURER)

SIGNATURES	DAY	MO	YR
DRAWN	4	5	81
CHECKED	20	5	81
ISSUED			
ENGRG	26	5	81
MFG	12	8	81
MATLS			

GENERAL ELECTRIC
AEP DEPT LOC PHILA., PA.

FRESNEL LENS

SIZE	CODE IDENT NO.	
C	23991	47C258398
SCALE 1/1 & NOTED		SHEET 1 OF 2

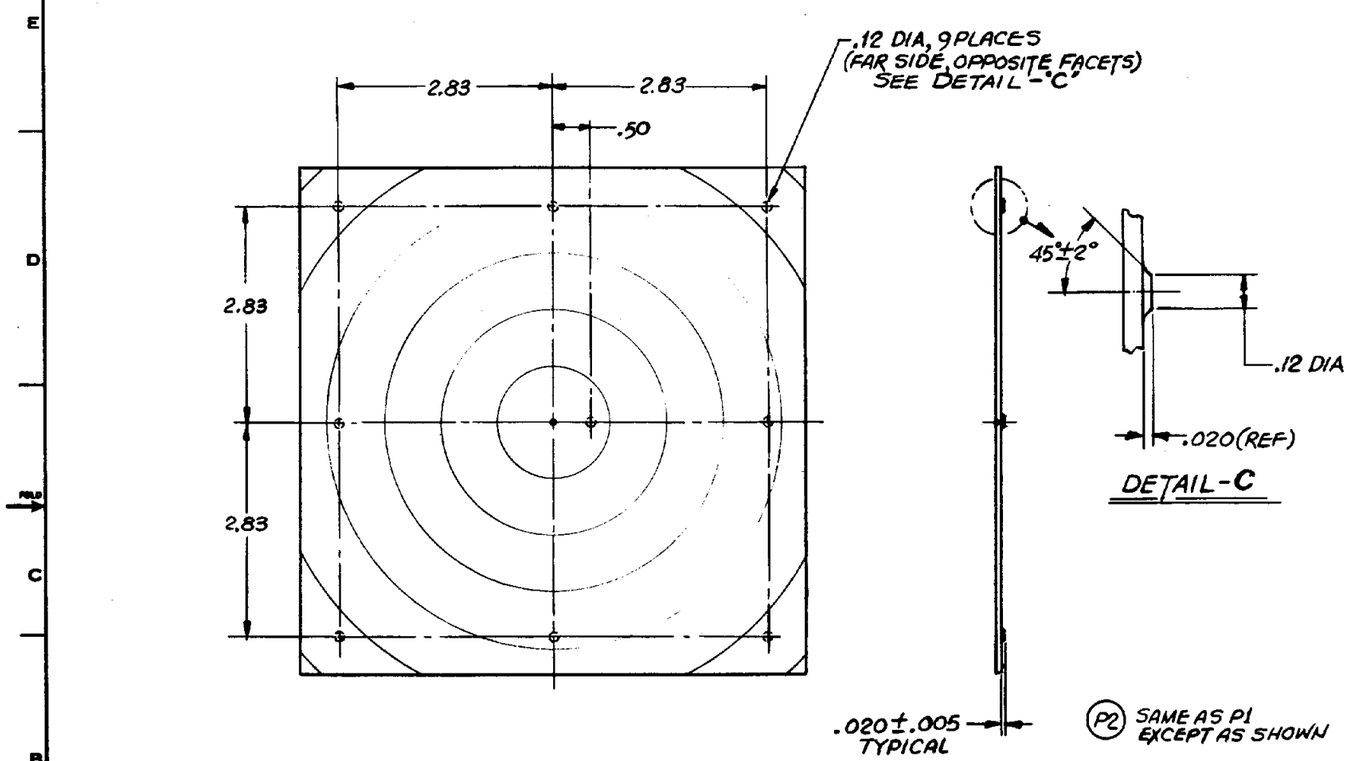
DIST TO TR&D C67

PRINTED IN U.S.A.

SIZE C | 47C258398 | REV I

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED



UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES—
TOLERANCES ON:
2-PLACE DECIMALS ±
3-PLACE DECIMALS ±
ANGLES ±
FRACTIONS ±
ALL SURF. ✓
MATERIAL—

SIGNATURES	DAY	MO	YR
DRAWN	12	8	81
CHECKED	12	8	81
ISSUED RELEASED	12	8	81
ENGRG			
MFG E R Compagna	12	8	81
MATLS			

GENERAL ELECTRIC
AEP DEPT LOC. PHILA. PA.

FRESNEL LENS

SIZE	CODE IDENT NO.	
C	23991	47C258398

SCALE 1/1 SHEET 2

47C258398 REV I SIZE C

DIST TO TR&D C67

PN-000-7 (11-74) PRINTED IN U.S.A.

REVISIONS				
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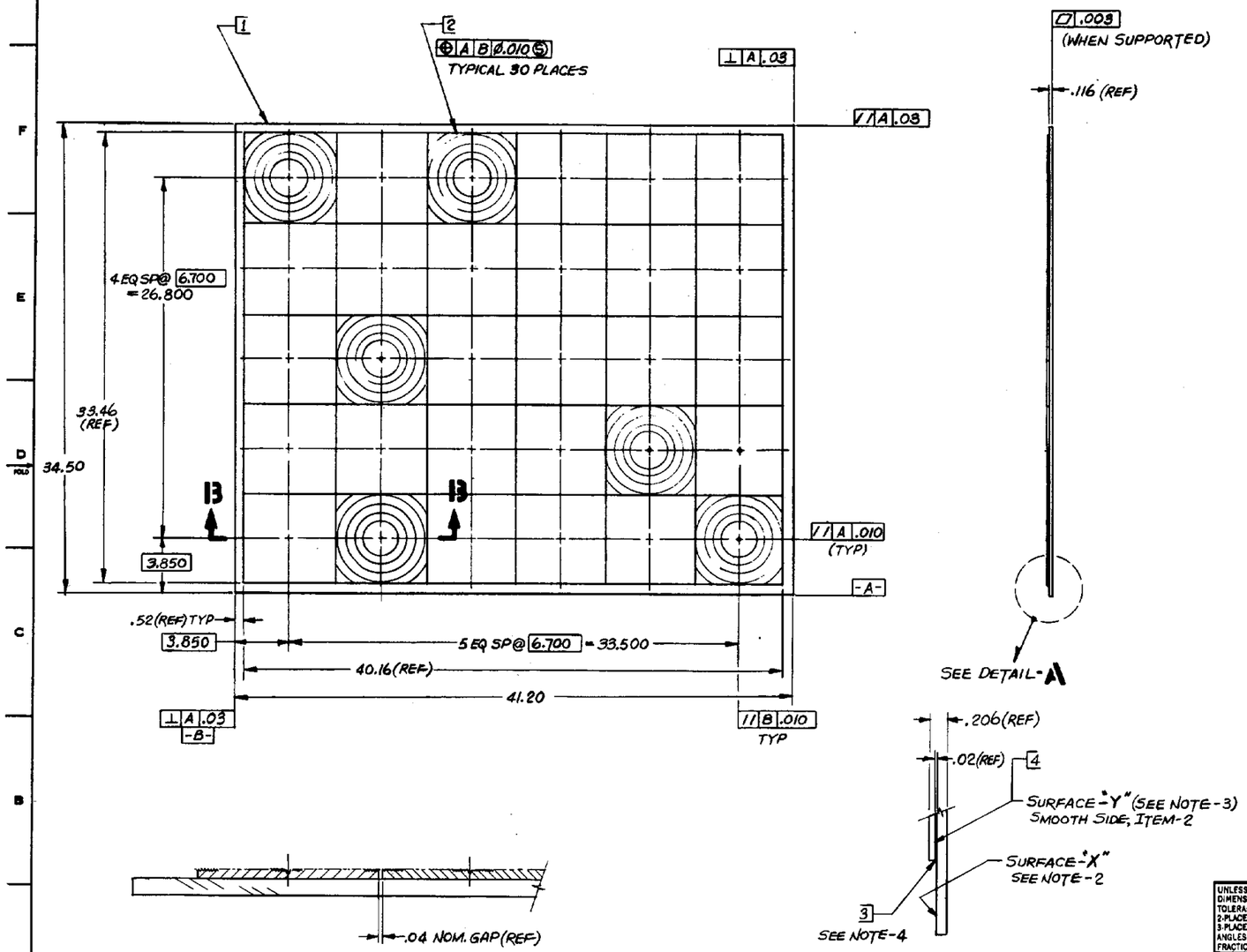


NOTES

1. DRAWING TERMS & TOLERANCES PER ANSI-Y14.5 .
2. OPTICAL SURFACE OF ITEM-2 MUST COINCIDE WITH SURFACE-"X" WITHIN ±[illegible] (Gates)
3. PRIME SMOOTH SURFACE, ITEM-2, (SURFACE-"Y") WITH ITEM-4.
4. ATTACH ITEM-2 TO ITEM-1, USING ITEM-3; NO ADHESIVE PERMITTED ON OPTICAL SURFACES.

(61)

SEE SEPARATE P/L

G1	47D258288	APFC
SUFFIX	NEXT ASSY	USED ON
APPLICATION		

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES— TOLERANCES ON: 2-PLACE DECIMALS ±.02 3-PLACE DECIMALS ±.010 ALL SURF. ANGLES ± FRACTIONS ± MATERIAL— SEE F/D

SIGNATURES	DAY	MO	YR
DRAWN	6	5	81
CHECKED	20	5	81
ENGR			
MFG			
MATLS			

GENERAL ELECTRIC
AEP DEPT LOC. PHILA., PA.

FRESNEL LENS PARQUET ASM (6×5 LENS)

SIZE	CODE IDENT NO.	
D	23991	47D258399
SCALE 1/4 & NOTED		SHEET 1 OF 1

47D258399 REV 1

IR&D C67

PRINTED IN U.S.A. 5-80

APPENDIX C

SPECIFICATION SHEETS FOR PROGRAM'S GLASS SUPERSTRATES

Type of glass	B 270
Colour	clear
Signal recognition	not influenced
Application	Ophthalmic glass for all types of corrective lenses

Code Number: **D 0092**

Optical Properties

Refractive indices at 20 °C	n (g)	1,5341
	n (F')	1,5298
	n (e)	1,5252
	n (d)	1,5231
	n (D)	1,5230
	n (C')	1,5208
Abbe value	ν (e)	58,3
Transmission values in % at 2.0 mm thickness	τ_v (D_{65}–10°)	92
	τ (λ = 313 nm)	56
	τ (λ = 350 nm)	89
	τ (SIR)	89
Chromaticity coordinates	x (D_{65}–10°)	0,314
	y (D_{65}–10°)	0,332
Signal recognition Q-values as per DIN 58 216	Q (red)	1,0
	Q (yellow)	1,0
	Q (green)	1,0
	Q (stop light)	1,0
Stress-optical coefficient in $1.02 \cdot 10^{-12}$ m²/N	C (λ = 555 nm)	2.70

Thermal Properties

Viscosities and corresponding temperatures		
Poise	°C	
$10^{14,5}$	505	Strain point
10^{13}	533	Annealing point
$10^{7,6}$	708	Softening point
10^{6}	806	Forming temperatures
10^{5}	891	
10^{4}	1006	
Tg	521	Transformation point
$93,3 \cdot 10^{-7}$/K		Mean linear thermal coefficient of expansion at 20–300 °C

Chemical Properties

Water resistance DIN 12 111	Test results
Na_2O-donation in µg/g glass	143
Hydrolytical class	3

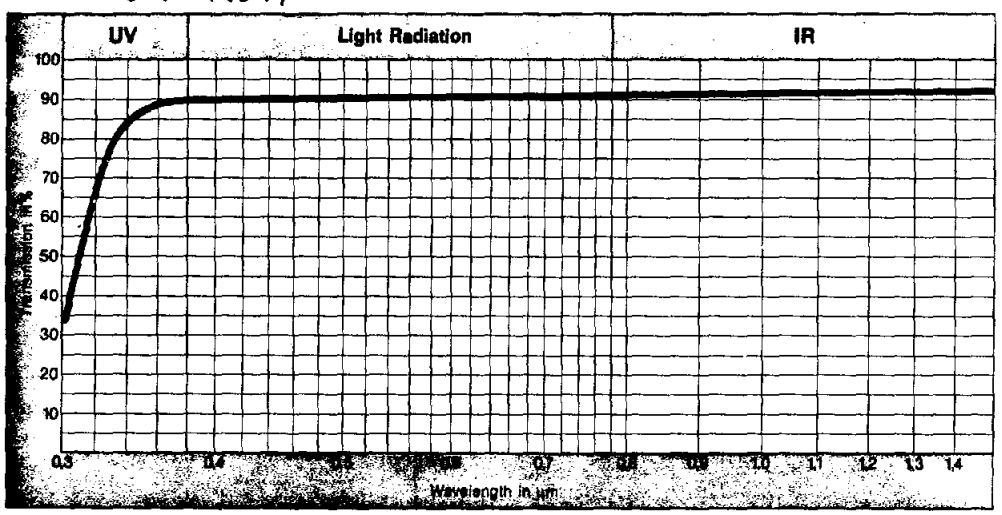
Mechanical Properties

Density in g/cm³ at 23 °C	2,55

Fuseability

with Schott near segments	yes

.9mm- 17mm thick
63.9" x 78.74"



DEUTSCHE SPEZIALGLAS AG · Postfach 80 · D-3223 Delligsen 2 · Telephone: (05187) 75061 · Telex: 092950 desagg d

SOLAKLEER™

Optically flat, virtually color-free solar glass, cut to size and available in thicknesses from 1mm to 5.5mm... produced on a continuous basis to satisfy industry needs

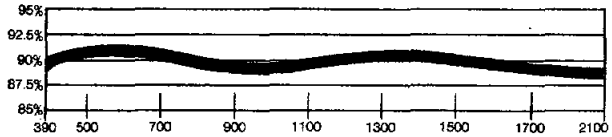
GGI's SOLAKLEER™ is manufactured at the Jeannette Sheet Glass plant in Jeannette, Pennsylvania, which is recognized for the production of highest quality sheet glass. The Jeannette manufacturing process produces glass with exceptional lack of "color"—the dull green cast caused by impurities such as iron. Further refinements in the process have produced a low-iron glass that allows a considerable increase in solar energy transmittance. SOLAKLEER has excellent transparency and an optically flat surface. It is manufactured in a broad range of thicknesses from micro-thin 1mm to 5.5mm, in sheet sizes up to 84"x 96" and is produced on a continuing basis.

Applications

Typical applications for SOLAKLEER include sunlight focusing mirrors, passive solar energy windows for commercial and residential buildings, photovoltaic cells and flat plate collectors.

Green color indicates iron content of various types of glass compared with SOLAKLEER, which has an iron content of .057% and is virtually color free.

Spectral Transmittance (1.0 mm SOLAKLEER)



The TSET specifications shown were measured in the range of 390-1722 nanometers (millimicrons) by Beckman Spectrophotometer equipment in accordance with testing procedure ASTM E 424-71.

Physical Properties

Nominal Thickness	Maximum Size	Weight per Sq. Ft.	TSET*
1mm (.038"-.042")	Cut to your specs	.507	91.3%
2.5mm (.090")	60" x 84"	1.183	90.5%
1/8"	84" x 96"	1.625	90.1%
5/32"	84" x 96"	1.976	89.5%
3/16"	84" x 96"	2.509	88.8%
13/64"	84" x 96"	2.762	88.5%

*Data provided by Battelle Pacific Northwest Laboratories, Richland, Washington.

SOLAKLEER can be tempered upon request. All tempered glass will conform to Federal Specification DDG-451D and to safety spec. ANSI Z97.1-1975.

For additional information and technical data, please contact: David Balik, Mgr., Marketing and Industrial Sales, General Glass International Corp.

SOLAKLEER™ Specifications

Total Solar Energy Transmittance:	1mm-91.3% 2.3mm-90.5% 3.1mm-90.1% 4mm-89.5% 5mm-88.8% 5.5mm-88.5%
Iron Content:	0.057%
Flatness:	Reflective dispersion across the entire mirror area for 3.1mm glass is better than 2.5 Milliradians.
Index of refraction:	1.52
Density:	2.48 gr/cm³
Coefficient of Linear Expansion (@ 0-300°C):	86.6×10^{-7}
Strain Point:	492°C
Annealing Point:	534°C
Windload:	Refer to ANSIA 134-1-1970 or AAMA Spec. 302-7-1971
Weather Resistance:	Excellent

Specifications are subject to change without notice.

SOLAKLEER™

GGI
General Glass
INTERNATIONAL CORP.
270 North Avenue, New Rochelle, NY 10801
Telephone: (914) 235-5900
TWX: 710-563 0636 — Balikglas NROH
Telex: 99 6520 — Balikglas NROH
Cable: Balikglas — New Rochelle

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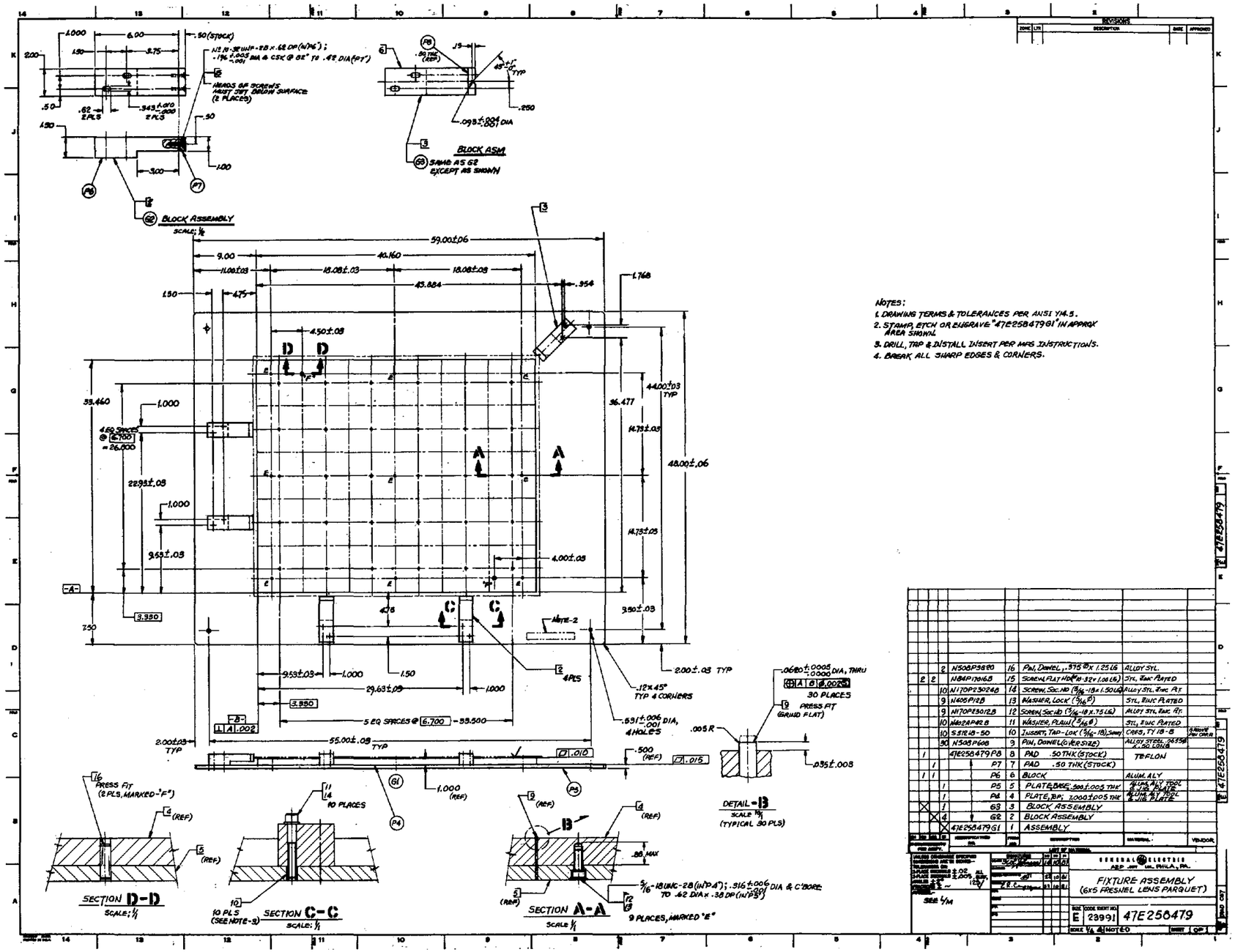
APPENDIX D

BASELINE LAMINATION PROCESS FIXTURE DRAWING



		2	N508P3880	16	PIN, DOWEL, .375 Ø x 1.25 LG	ALLOY STL.		
	2	2	N84P170168	15	SCREW, FLAT HD (#10-32 x 1.06 LG)	STL. ZINC PLATED		
		10	N170P250248	14	SCREW, SOC. HD (3/16-18 x 1.50 LG)	ALLOY STL. ZINC PLT.		
		9	N405P128	13	WASHER, LOCK (3/16 Ø)	STL. ZINC PLATED		
		9	N170P250128	12	SCREW, SOC. HD (3/16-18 X .75 LG)	ALLOY STL. ZINC PLT.		
		10	N402AP428	11	WASHER, PLAIN (5/16 Ø)	STL. ZINC PLATED		
		10	S512B-50	10	INSERT, TAP-LOK (3/16-18), SHORT	CRES, TY 18-8	SUPPLIED BY OWNR	
		30	N508P608	9	PIN, DOWEL (OVERSIZE)	ALLOY STEEL 26338 X .50 LONG		
	1		47E258479P8	8	PAD .50 THK (STOCK)	TEFLON		
			P7	7	PAD .50 THK (STOCK)			
	1	1	P6	6	BLOCK	ALUM. ALY		
		1	P5	5	PLATE, BASE .500 ±.005 THK	ALUM. ALY TOOL & JIG PLATE		
		1	P4	4	PLATE, BASE .1000 ±.005 THK	ALUM. ALY TOOL & JIG PLATE		
			G3	3	BLOCK ASSEMBLY			
	4		G2	2	BLOCK ASSEMBLY			
			47E258479G1	1	ASSEMBLY			

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