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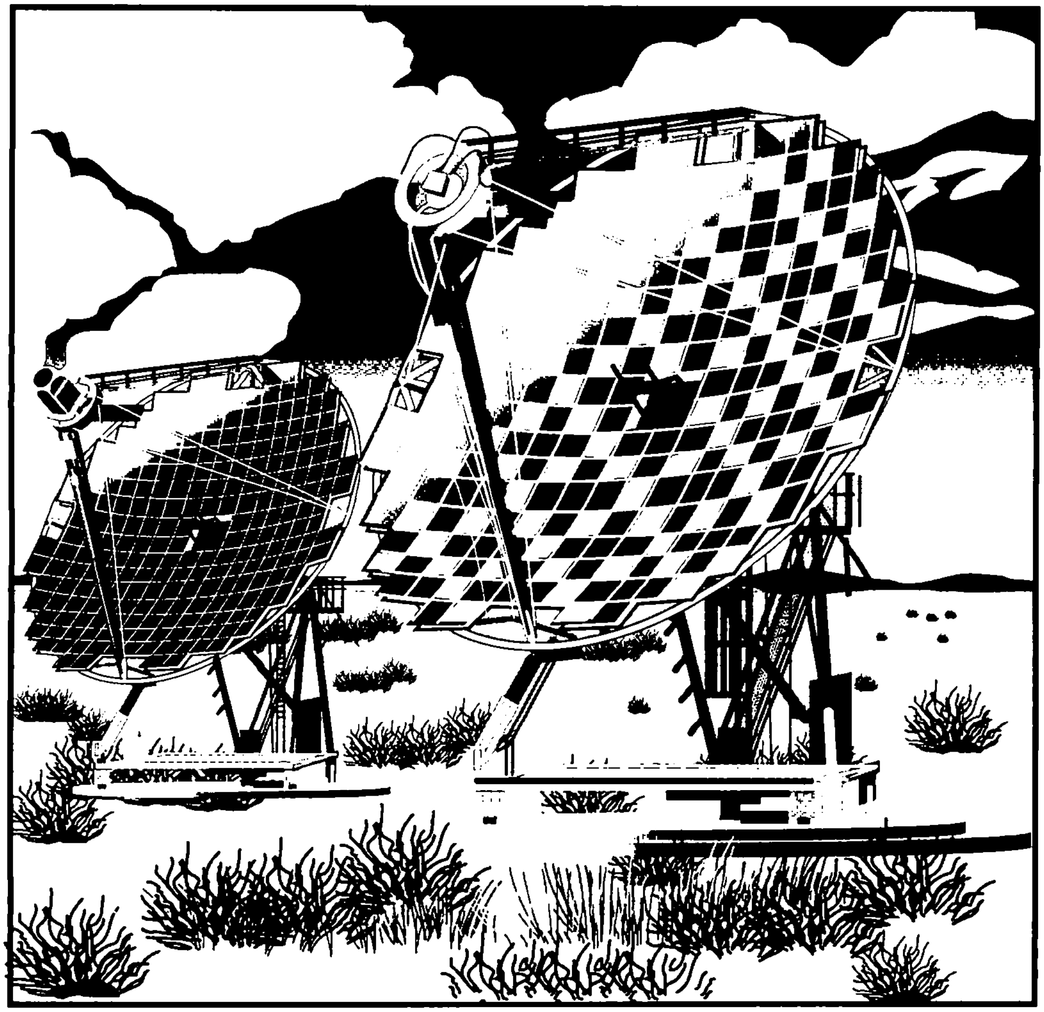
Optical Performance of the TBC-2 Solar Collector Before and After the 1993 Mirror Lustering

Richard M. Houser and John W. Strachan



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OPTICAL PERFORMANCE OF THE TBC-2 SOLAR COLLECTOR BEFORE AND AFTER THE 1993 MIRROR LUSTERING

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Abstract

In 1993, the mirror facets of one of Sandia's point-focusing solar collectors, the Test Bed Concentrator #2 (TBC-2), were reconditioned. The concentrator's optical performance was evaluated before and after this operation. This report summarizes and compares the results of these tests. The tests demonstrated that the concentrator's total power and peak flux were increased while the overall flux distribution in the focal plane remained qualitatively the same.

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The before-and-after focal plane location test indicates that the dish's focal plane did not change significantly and is located 71.8 cm (28.3 in.) toward the vertex from the dish reference plane (see Table 1 and Figure 2).

Table 1. Beam Measurements in Focal Region During Focal Plane Determination Test

Before Lustering Day 20 (1993) at 11:45 AM				After Lustering Day 356 (1993) at 11:45 AM			
Insolation: 0.895 kW/m2				Insolation: 0.996 kW/m2			
Position Relative to Ref. Point (cm)	Relative Power (% of Max.)	Relative Peak Flux (% of Max.)	Beam Diameter (cm)	Position Relative to Ref. Point (cm)	Relative Power (% of Max.)	Relative Peak Flux (% of Max.)	Beam Diameter (cm)
69.1	97.8	89.1	98.4	69.2	97.4	90.8	99.1
69.7	98.5	94.1	94.3	69.8	97.5	94.3	96.4
70.4	98.9	97.5	91.1	70.4	97.8	96.9	93.7
71.1	99.4	99.2	88.6	71.0	99.3	98.7	91.9
71.6	99.4	100.0	87.8	71.5	99.4	100.0	91.9
72.4	99.7	99.2	87.8	72.2	99.6	99.6	91.9
73.1	100.0	97.5	90.2	72.7	99.0	97.8	93.7
73.6	99.9	94.1	93.5	73.0	99.3	96.5	94.6
74.4	99.8	88.7	97.6	73.6	99.1	93.9	97.3
75.0	99.3	84.5	100.0	73.9	98.7	91.7	99.1
74.8	99.7	84.9	100.0	74.2	98.6	90.0	100.0

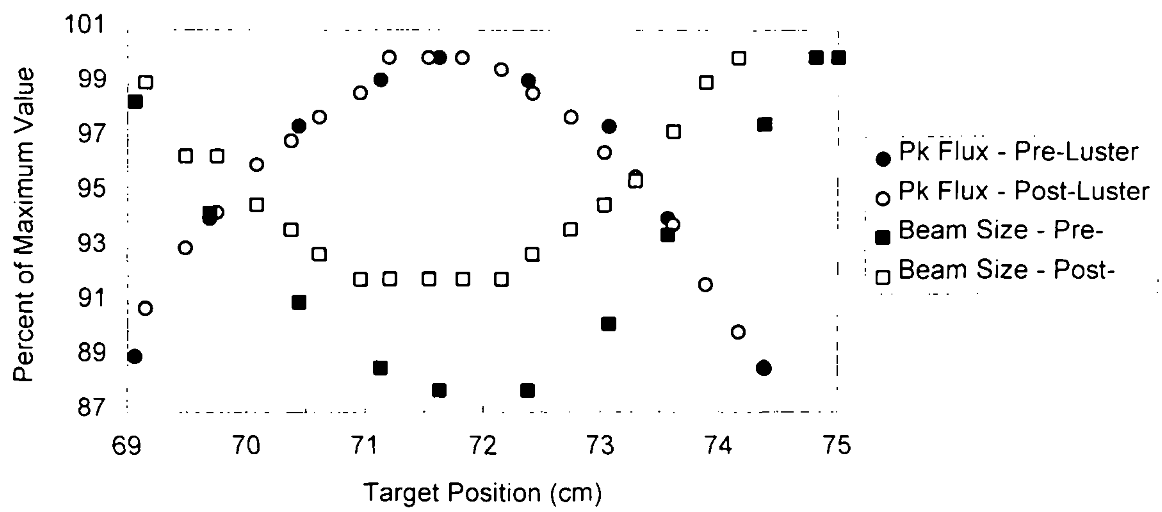

Figure 2. Location of dish's focal plane before and after lustering process

RECEIVER PLANE FLUX DISTRIBUTION TEST

Flux Distribution

Before and after the TBC-2 lustering, the dish's flux distribution at the focal plane and in the region behind it was characterized using the BCS. Flux maps were obtained at the focal plane[1] and at four positions behind it: 8.1 cm (3.2 in.), 15.7 cm (6.2 in.), 23.3 cm (9.2 in.), and 30.9 cm (12.2 in.). Color contour plots of the flux distribution at these five locations are presented in Figures 3 through 7.

A BCS image was acquired of the flux on the target while positioned at each focal plane location. Sensor data from the flux gauges were acquired simultaneously as was an insolation reading from a normal incidence pyroheliometer, or NIP. The target flux measurements were equated to the corresponding image intensity levels in the BCS image to obtain a measure of the peak flux. The image picture levels (pixel levels) were integrated using this peak flux value to estimate the total beam power. The effective beam diameter was obtained using the BCS's image analysis software functions. The TBC-2's peak flux, power, and beam diameter at the selected positions before and after the lustering process are presented in this report.

The flux maps indicate that qualitatively the distribution of flux in the focal region did not change as a result of the lustering process (see Figures 3 through 7). However, the peak flux that the dish is capable of producing did increase. Prior to the lustering of the TBC-2 mirrors, the

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[1] The focal point is located 71.8 cm [28.3 in.] toward the vertex from the reference plane.

peak flux at the focal plane was 16,598 kW/m^2 (Table 2); after lustering and realignment the peak flux measured 17,953 kW/m^2, an increase of approximately 7.5%. Figure 8 shows the peak flux values before and after the lustering process as measured with the BCS and normalized to the average total power measured by CWC (pre-luster calorimetry was performed in May and June 1993 and post-luster calorimetry in November 1993). There is an unexpected drop in the 63.8-cm (25.1-in.) target position following the lustering and realignment. This lower flux level was observed on both postluster test dates (December 22, 1993 and January 3, 1994) and is unexplained at the present.

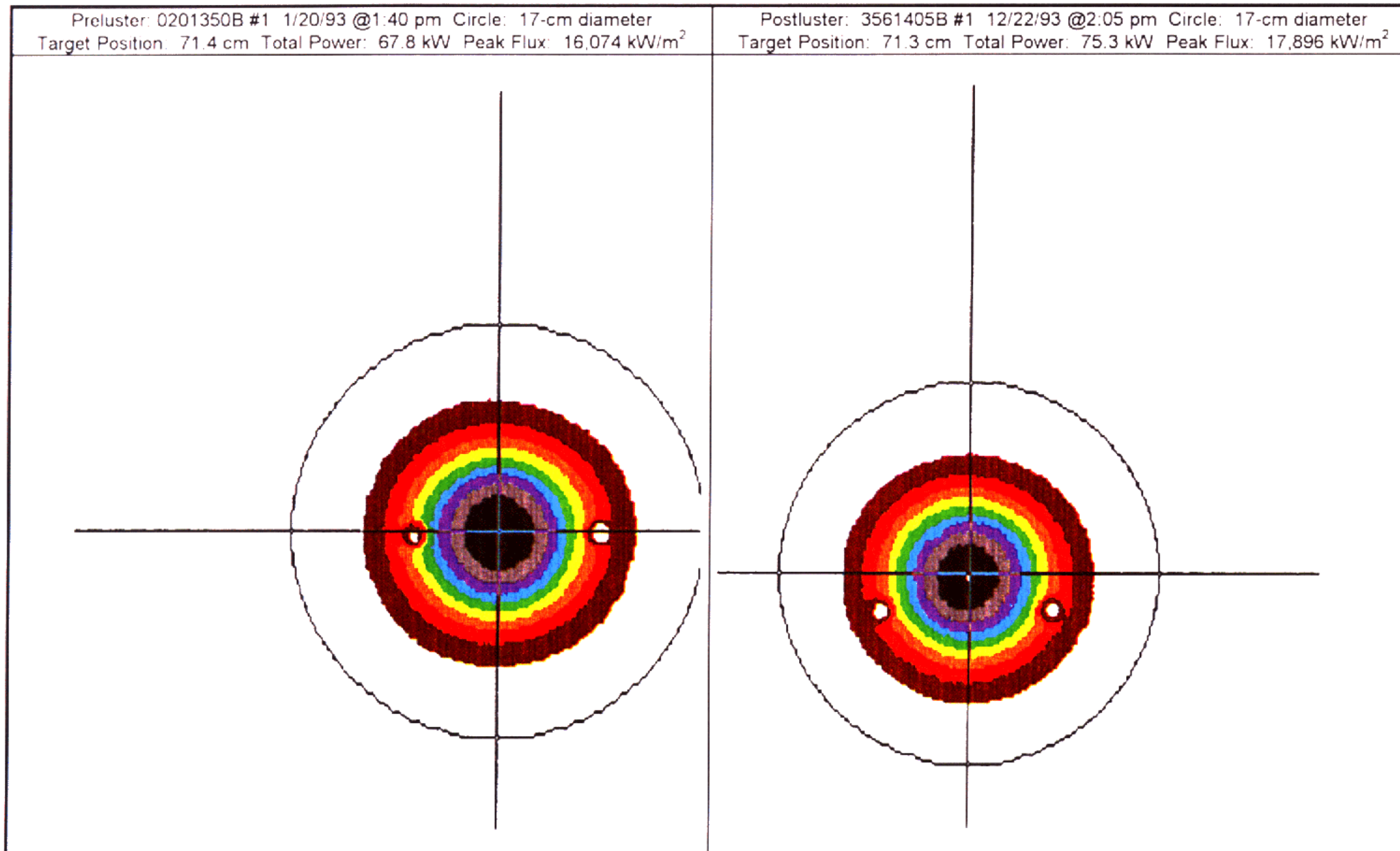

Figure 3. Contour plot of TBC-2 beam at 0.51 cm (0.2 in.) behind focal plane

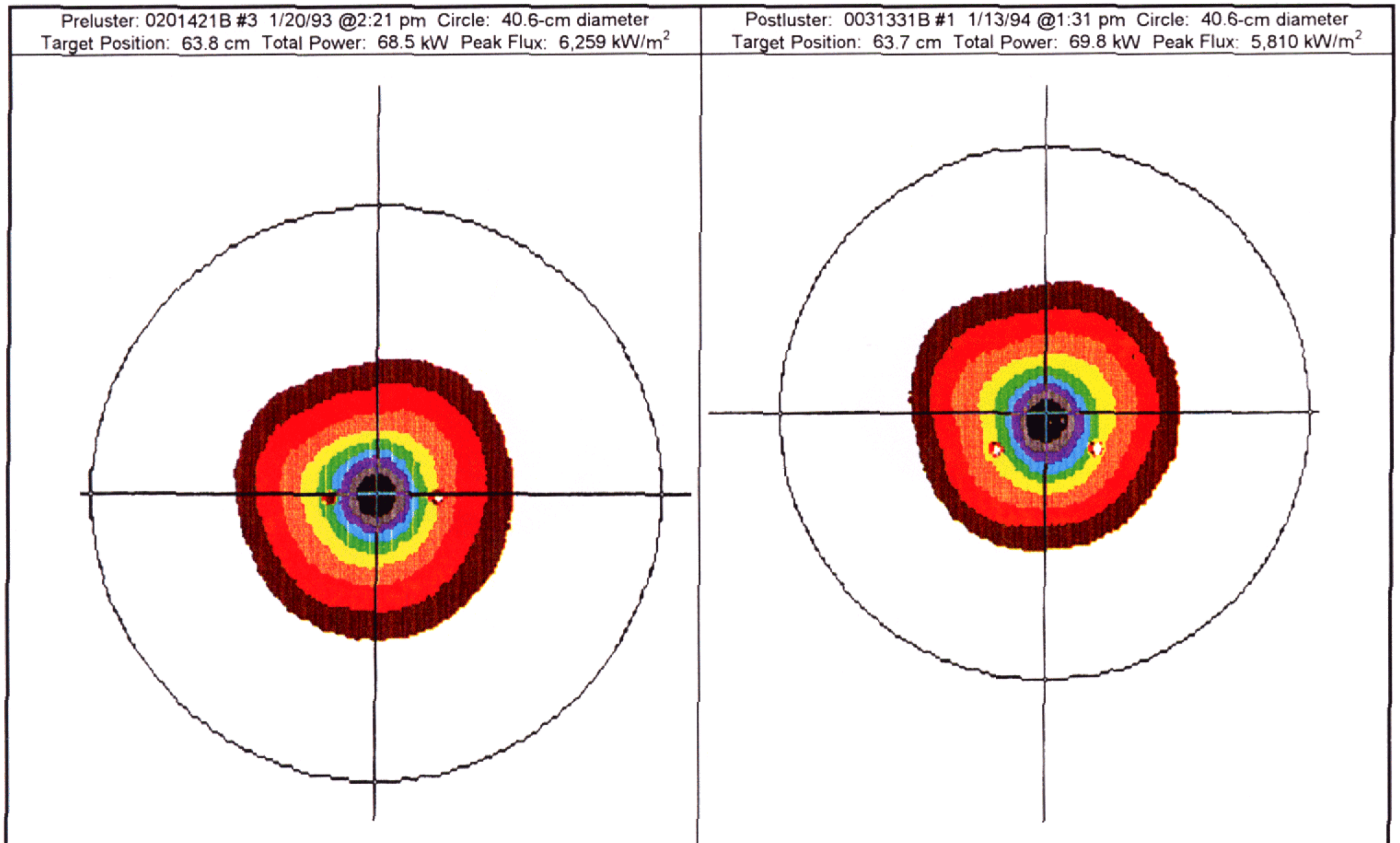

Figure 4. Contour plot of TBC-2 beam at 8.1 cm (3.2 in.) behind focal plane

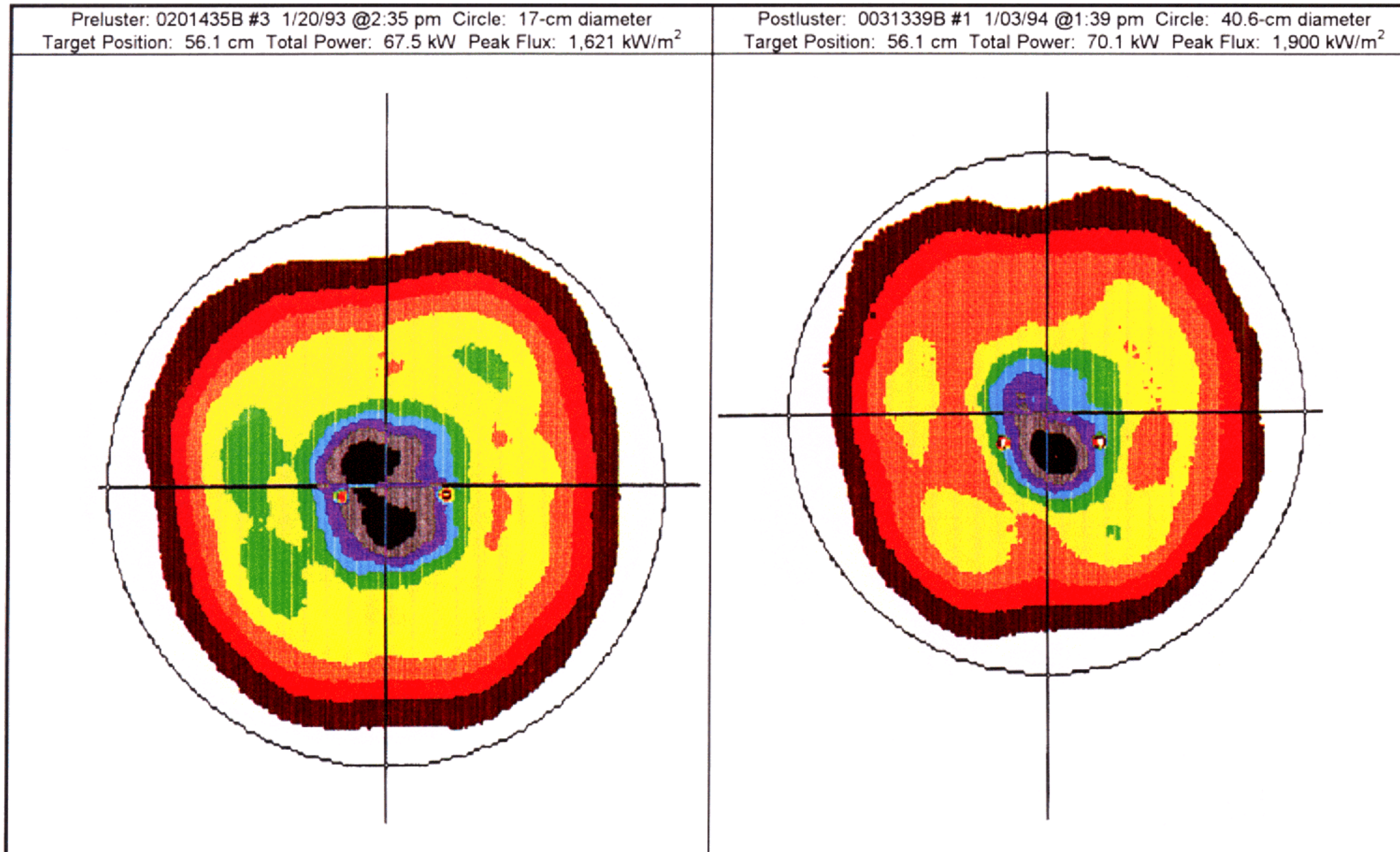

Figure 5. Contour plot of TBC-2 beam at 15.8 cm (6.2 in.) behind focal plane

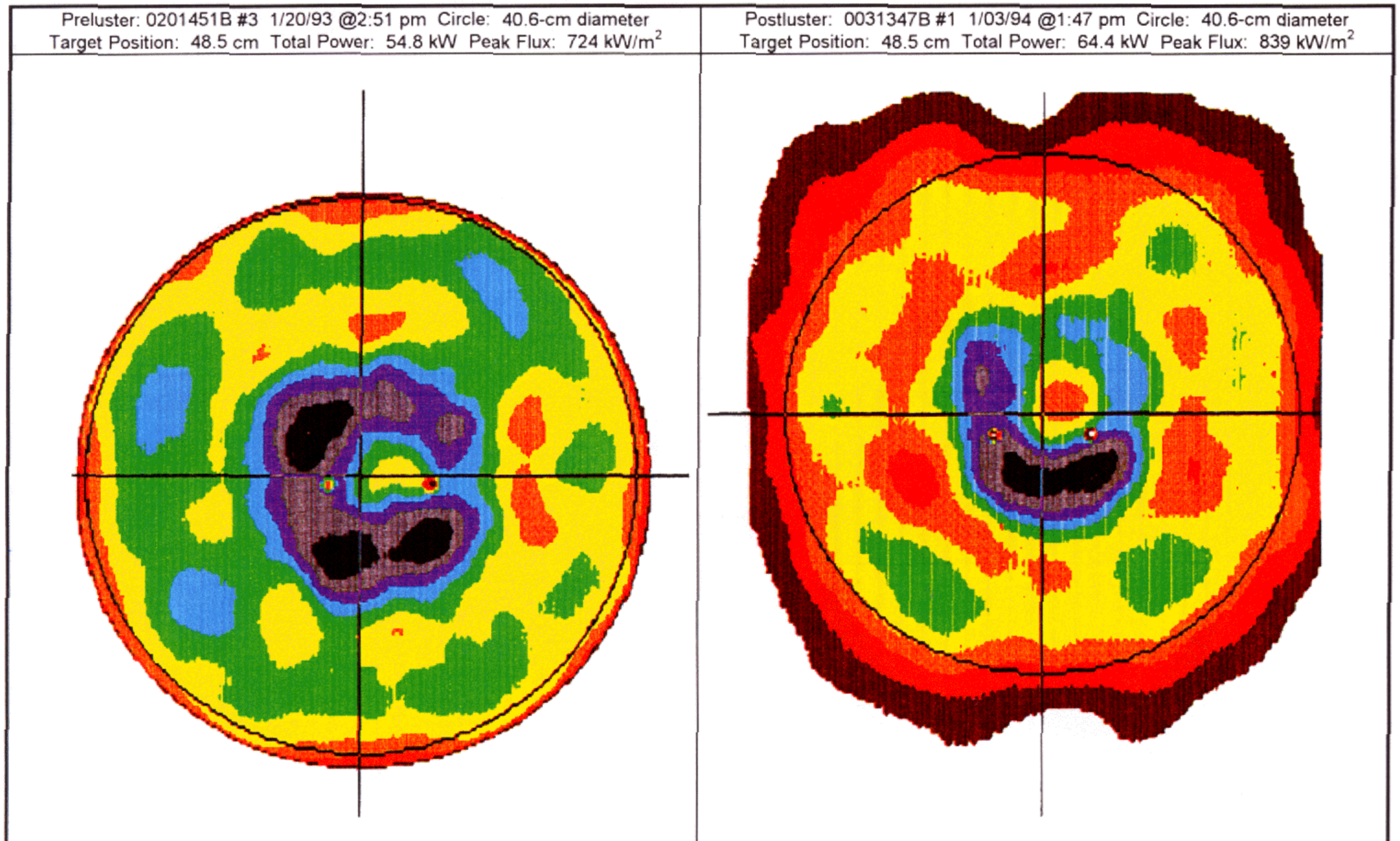

Figure 6. Contour plot of TBC-2 beam at 23.4 cm (9.2 in.) behind focal plane

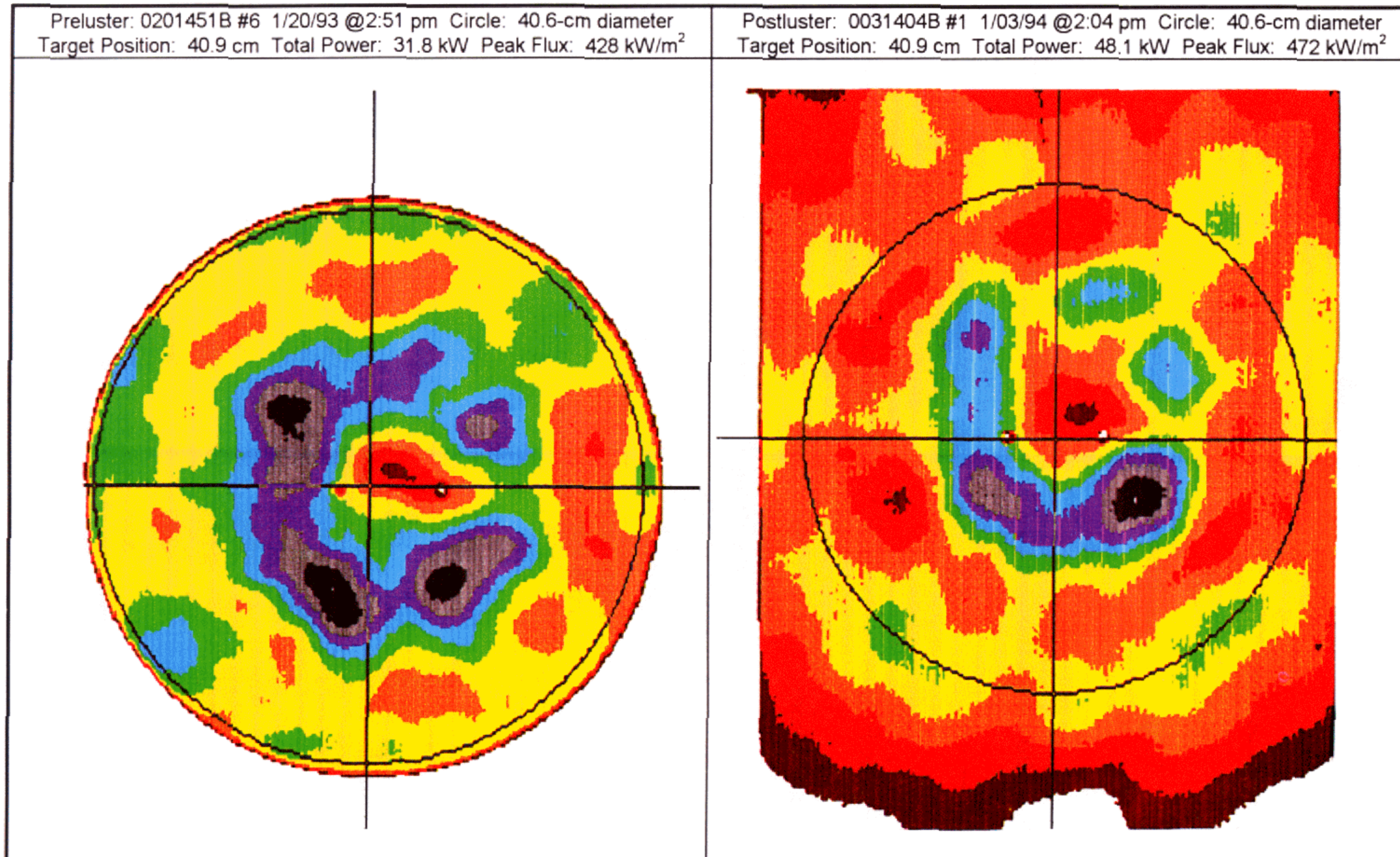

Figure 7. Contour plot of TBC-2 beam at 31.0 cm (12.2 in.) behind focal plane

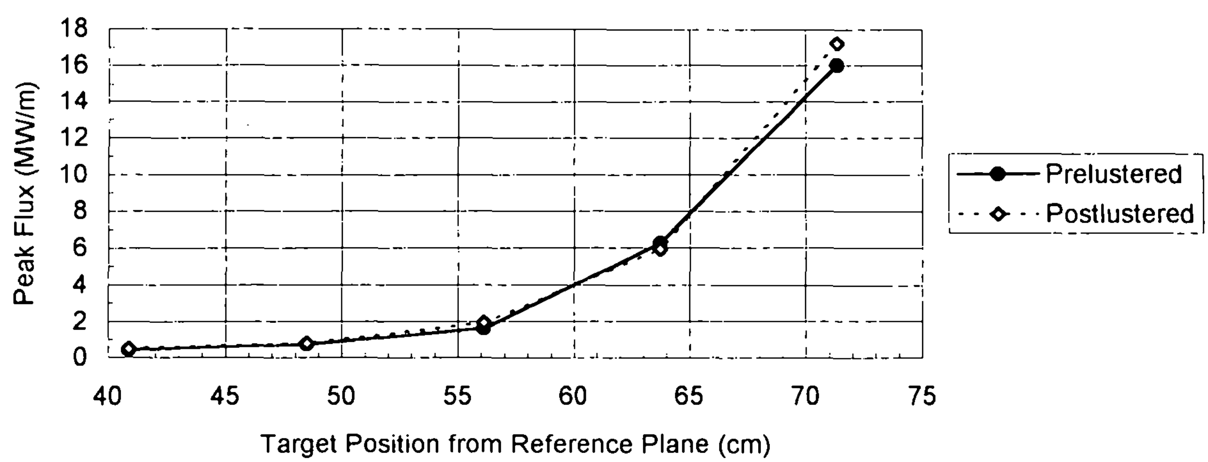

Figure 8. Peak flux measurements before and after lustering process

Table 2. Peak Flux and Total Power Measurements at the Focal Point

Distance from mounting plane (cm)	Distance from focal plane (cm)	Peak flux Normalized to Calorimetry Power (as indicated below) (kW/m^2)	% Change in Peak Flux after Lustering (%)	Total Power Measured with BCS (kW)	% Change in BCS Measured Power after Lustering (%)
Before Lustering (data file:R93020R)		(Calorimeter Pwr: 70.5 kW)			
71.4	-0.5	16598	⇓	68.0	⇓
63.8	-8.1	6442		68.5	
56.1	-15.8	1693	⇓	67.5	⇓
48.5	-23.4	751		54.8	
40.9	-31.0	474	⇓	31.8	⇓
After Lustering (data file:R94003A)		(Calorimeter Pwr: 77.9 kW)			
71.4	-0.5	17953	8.2	74.7	9.9
63.8	-8.1	6606	2.5	70.2	2.5
56.1	-15.8	2183	28.9	68.1	0.9
48.5	-23.4	900	19.9	62.1	13.3
40.9	-31.0	553	16.5	35.2	10.7

Beam Size

The beam size at TBC-2's focal point appears to be unchanged by the lustering and realignment processes. At its focus, which tests located at 71.8 cm (28.3 in.) from the reference plane, the measured beam diameter was 11.0 ±0.2 cm before and 10.8 ±0.2 cm after the reconditioning of the mirror facets. Beam diameter is defined as the diameter of a circle containing all flux in a beam whose intensity is ≥10% of that beam's peak flux intensity.

Figure 9 provides a graphical view of the preluster and postluster beam diameters measured at the five axial positions in the dish's focal region (see Table 3 for numerical values).

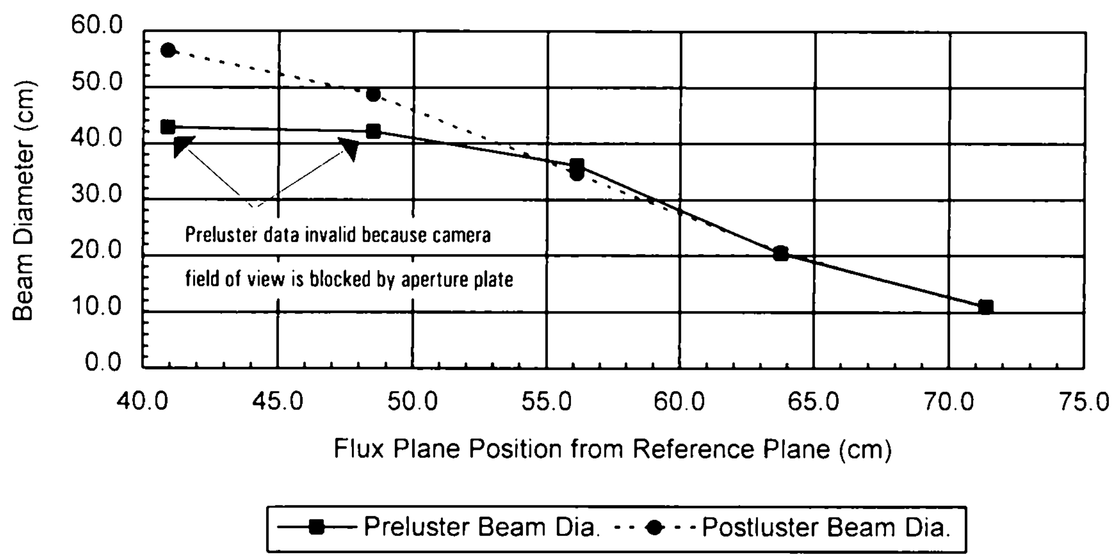

Figure 9. Beam diameter before and after lustering process

Table 3. TBC-2 Beam Diameter		
BCS Target Position from Reference Plane (cm)	Preluster Beam Diameter (cm)—file: R093020R.WK1	Postluster Beam Diameter (cm)—file: R093020R.WK1
71.4	11.0	10.8
63.8	20.3	20.6
56.1	36.1	34.6
48.5	data invalid	48.7
40.9	data invalid	56.5

In the preluster test, the beam's diameter and power measurements were not accurate in the region 22.8 cm (9 in.) behind the focus (and beyond). An accurate measurement was prevented by the presence of the dish's aperture plate, which limited the BCS camera's field of view for the beam data obtained at the 22.8- and 30.4-cm (9- and 12-in.) positions behind the focus.[2] For the postluster test, the aperture plate was removed.

[2] During the preluster beam characterization the TBC-2 was equipped as usual with its aperture plate. This is a water-cooled flux shield that is typically mounted on the vertex side of the dish's mounting ring and provides a means of shielding the receiver or dish-test subject from the dish's intense beam of

Beam Power

Although excellent for characterizing collector flux distributions, the BCS is not particularly well-suited for making accurate beam power measurements. At Sandia, CWC is currently the preferred measurement, and calorimetry measurements of the TBC-2's total beam power were made in the same time frame as the preluster and postluster beam characterizations. The preluster and postluster calorimetry, performed in near-solar-noon conditions and subsequently normalized to an insolation level of 1,000 W/m^2, yielded total power values of 70.5 ± 1 and 77.9 ± 1 kW, respectively. Error analysis established the measurement accuracy at 1.5%. By contrast, the BCS accuracy is 6 to 10%. For this reason, the beam power measurements cited here are those made by calorimetry. For comparison purposes, Table 4 lists the TBC-2 power measurements made at or close to the focal plane obtained with both the BCS and the CWC.

Table 4. TBC-2 Power Measurements

	Preluster Beam Power	Postluster Beam Power
Beam Characterization (71.4 cm from reference plane)	68 ± 5 kW	75 ± 6 kW
Calorimetry (72.2 cm from reference plane)	70.5 ± 1 kW	77.9 ± 1 kW

Power Intercept

The lustering process increased the total dish power (from 70.5 ± 1to 77.9 ± 1 kW). Figure 10 provides power intercept curves that were obtained at two focal plane locations (71.4 and 63.8 cm (28.1 and 25.1 in.) from the dish reference plane) before and after the mirror reconditioning. Table 5 gives the data from which the curve was drawn. The power values were obtained from the BCS images or flux maps. The absolute accuracy of these beam power values is ± 8 to 10%, but the relative accuracy (i.e., the accuracy of one power value relative to the next) is ± 2 to 4%[3].

Beam Profile Analysis

The overall flux distribution in the TBC-2 beam does not appear to have been altered by the mirror lustering process. As another means of exploring this property, the beam profiles (a beam profile is essentially a cross section of the beam) of the TBC-2 before and after the lustering process were examined. Figure 11 compares the beam profiles at two focal plane locations

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collected solar energy. The shield consists of a fixed, large circular aperture plate having a 40-cm (16-in.) diameter hole (through which the flux may pass), and a rectangular plate that can slide across the aperture to block the flux from reaching the receiver or whatever test apparatus is mounted in the focal region. During the postluster test this aperture plate was absent. Because the aperture plate is normally positioned between the BCS target and the BCS camera, the camera's view of the target is constrained by the 40-cm (16-in.) hole in the aperture plate. At a point around 17.7 or 20.4 cm (7 or 8 in.) behind the focal point, the dish's collected solar beam becomes wider than the 40-cm (16-in.) diameter, and that flux is not in the BCS camera's view. Thus, for the 22.8- and 30.4-cm (9- and 12-in.) positions behind the focal point, the preluster test was unable to measure flux outside the 40-cm (16-in.) inner circle of the flux target.

[3] The largest contributor to BCS measurement uncertainty is the calibration accuracy of the flux gauges. Relative power measurements (i.e., the power associated with individual picture elements in a BCS image) are obtained by image analysis without employing the flux gauges; their accuracy is unaffected by flux gauge inaccuracies.

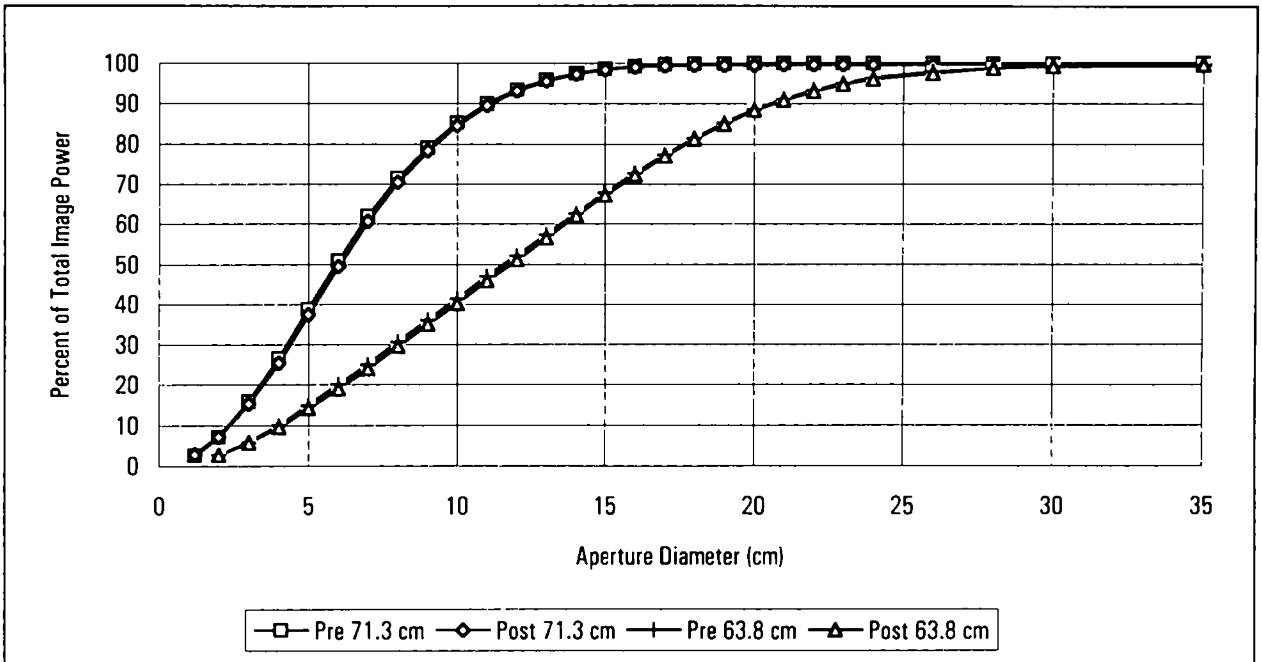

Figure 10. TBC-2 power intercept curve

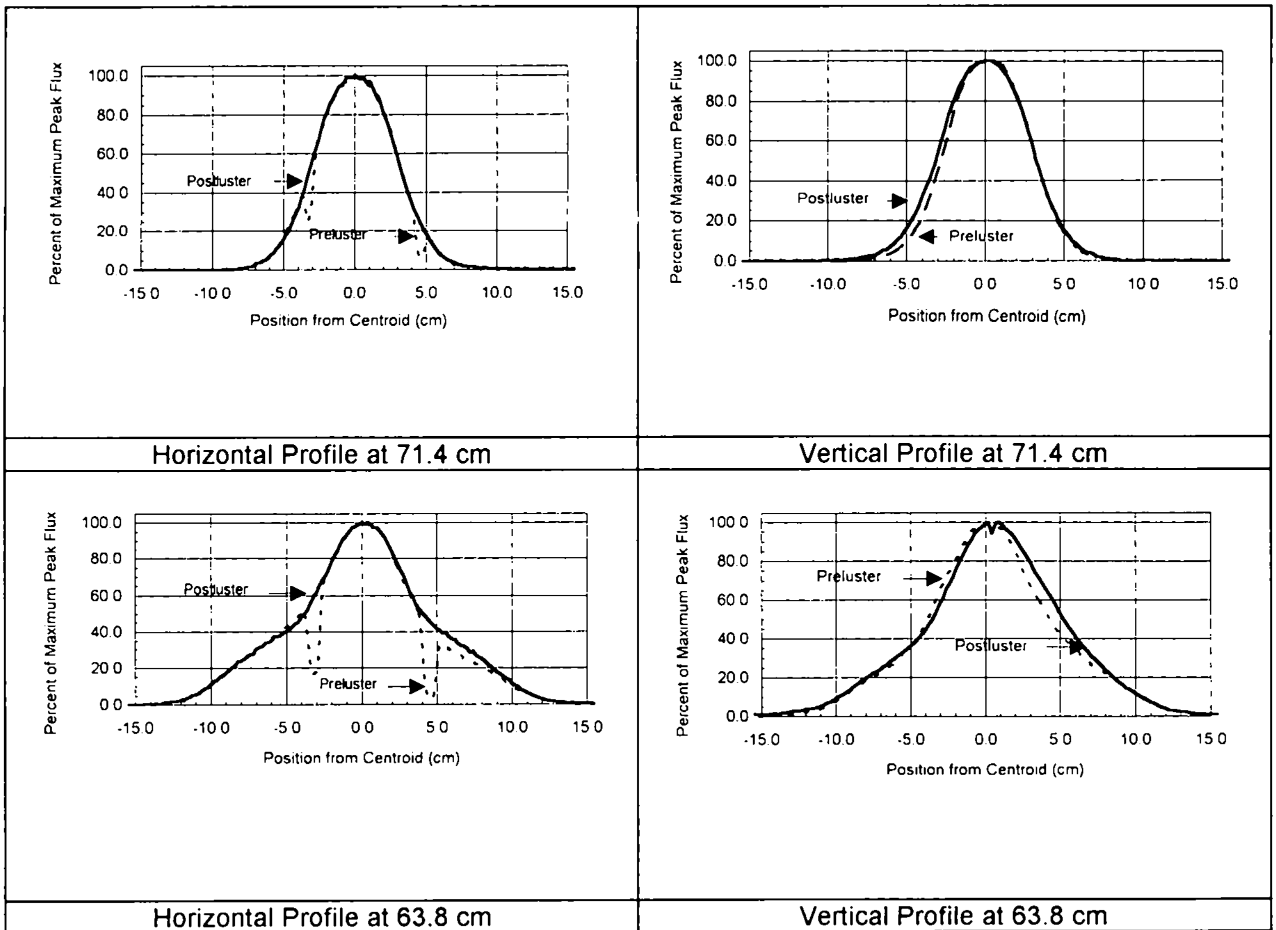

Figure 11. Profile plots of TBC-2 beams before and after lustering process

Table 5. BCS Image Power Data for Power Intercept Curve									
	Average Power (%)					Average Power (%)			
Aperture Diameter (cm)	71.4 cm from Reference Plane		63.8 cm from Reference Plane		Aperture Diameter (cm)	71.4 cm from Reference Plane		63.8 cm from Reference Plane	
	Before	After	Before	After		Before	After	Before	After
1.20	2.6	2.8			16.00	99.3	99.0	72.6	72.2
2.00	7.2	7.2	2.7	2.7	17.00	99.7	99.4	77.2	77.0
3.00	15.8	15.3	5.7	5.7	18.00	99.8	99.5	81.4	81.2
4.00	26.5	25.4	9.9	9.5	19.00	99.9	99.6	85.2	84.9
5.00	38.7	37.5	14.8	14.2	20.00	100.0	99.6	88.4	88.3
6.00	50.9	49.4	20.0	19.0	21.00	100.0	99.7	91.1	90.9
7.00	61.9	60.6	25.0	24.0	22.00	100.0	99.7	93.3	93.1
8.00	71.4	70.5	30.7	29.6	23.00	100.0	99.7	95.0	94.9
9.00	79.1	78.3	36.0	35.1	24.00	100.0	99.7	96.3	96.1
10.00	85.1	84.5	41.3	40.1	26.00	100.0	99.8	98.0	97.5
11.00	89.9	89.5	46.9	45.8	28.00	100.0	99.8	98.8	98.8
12.00	93.3	93.0	52.1	51.1	30.00	100.0	99.8	99.2	99.3
13.00	95.9	95.5	57.4	56.5	35.00	100.0	99.8	99.5	99.7
14.00	97.5	97.3	62.5	62.1	40.00	100.0	99.8	99.6	99.8
15.00	98.7	98.4	67.8	67.2					

before and after the mirror improvement process. No significant change in the TBC-2 beam is apparent.

CONCLUSION

The optical tests performed indicate that as a result of the mirror reconditioning and realignment process the location of the TBC-2's focal point did not change, but the dish's total power and peak flux capabilities did increase. The relative distribution of the flux in the collected beam appeared to remain qualitatively the same. The experimentally determined location of the dish's focal point remained at 71.8 cm (28.3 in.) toward the dish's vertex measured from the dish's receiver mounting plane. The normalized, overall power of the dish increased from 70.5 kW to 77.9 kW (± 1.1 kW), a change of 10.5%. The peak flux in the beam, measured at the focal point, increased from 16,598 kW/m^2 to 17,953 kW/m^2 (± 1,400 kW), a change of 8.2%. The diameter of the flux beam at the focal plane of the dish may have decreased slightly from 11.0 cm (± .2 cm) to 10.8 cm (± .2 cm). The relative flux distribution in the concentrated beam remained qualitatively unchanged.

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