SOLAR-COLLECTOR TEST REPORT

SSEC/TP--12226

DE82 009467

Compiled by
William E. Stoney

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

June 1981

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

Prepared by

✓ Florida Solar Energy Center
→ Testing and Laboratories Division
for

✓ SOUTHERN SOLAR ENERGY CENTER

and

U.S. DEPARTMENT OF ENERGY ✓

under contract DE-AC02-79CS30166

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Cont

SOUTHERN SOLAR ENERGY CENTER

A REGIONAL CENTER OPERATED FOR THE U.S. DEPARTMENT OF ENERGY
61 PERIMETER PARK ATLANTA, GEORGIA 30341 404 458-8765

951 4690
968

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Solar Collector

Test Report

Models: X-29, X-31, & X-32

Brookhaven National Laboratories
Solar Technology Group, Bldg. 701
Upton, New York 11973

T & L

Test Report

80150, 1, 2

Florida Solar Energy Center
Testing and Laboratories Division
300 State Road 401
Cape Canaveral, Florida 32920

Approved: James D. Roland

Test Manager

Date: 12 May 1981

Revision Date: 9 June 1981

TABLE OF CONTENTS

Introduction	1
Summary	2
FSEC Test Results	3
- Collector Description	
- Results	
- Appendix A	
- Appendix B	
- Appendix C	
Letter from FSEC Test Director	.50
Collector Review at Brookhaven (January 13, 1981)	.51
- Agenda	
- List of Attendees	
- Cost Summary	
- Evaluation Questionnaire	
- SSEC Summary	

TEST REPORT CONTENTS

1. Collector Description
 - 1.1 Collector Identification
 - 1.2 Collector Construction
2. Results
 - 2.1 Introduction
 - 2.2 Explanation of Results
 - Efficiency Curve
 - Incident Angle Modifier
 - Data Tabulation
 - 2.3 Computer Printout Key
 - 2.4 Results of Static Tests
 - 2.5 Explanation of Efficiency Curve
 - 2.6 Performance Test Results, English Units

Appendix A

Partial Data, Model X-29

Appendix B

Partial Data, Model X-31

Appendix C

Partial Data, Model X-32

Introduction

This report summarizes activities undertaken by SSEC to evaluate the commercial readiness and potential of an all plastic solar hot water collector under development by Brookhaven Laboratories under contract to the Department of Energy. The Center's activities involved two separate functions. The first was to sponsor the testing of the collector at the Florida Solar Energy Center. The results of these tests are reported in detail in Section 1. Section 1 also includes a letter from the director of the testing and laboratories division of FSEC to Dr. Wilhelm of Brookhaven, providing a correction to part of the original report and summing up his opinions as to the merits of the collector. The second involvement was the participation by Mr. Stoney of SSEC in a review of the collector held at Brookhaven on January 13, 1981. The meeting was called by Brookhaven with the expressed purpose of obtaining an outside evaluation of the collector and recommendations as to further activities needed to bring the collector to commercial readiness. Descriptions of this meeting and SSEC's summary comments are contained in Section B of this report.

Summary

The FSEC tests show that the Brookhaven collector compared favorably with other collectors of its type. While there were some changes noted after the exposure test, in the opinion of the test director these changes were caused by problems peculiar to the prototype construction of the test article.

In the opinion of SSEC, the review panel came to essentially unanimous conclusions. The committee agreed that the Brookhaven design demonstrated that a thin-film plastic absorber could be built to produce performance equal to, or better than the mid-range of conventional copper or aluminum absorbers. It was agreed that thin-film plastic collector production costs could probably be at least half that of currently available collectors. The committee's confidence in the performance and cost potential of the thin-film concept led them to propose that extensive efforts should be made to present their findings to those sections of industry capable of creating commercial products based on the Brookhaven concept.

1. COLLECTOR DESCRIPTION

1.1 Collector Identification

Manufacturer and Address: Brookhaven National Laboratories
Solar Technology Group, Bldg. 701
Upton, New York 11973

Collector Model Number: X-32

1.2 Collector Construction

Overall Dimensions:

Length: 2.238 m

Width: 0.811 m

Depth: 0.984 m

Overall Front Area: (length x width) 1.816 square meters

Height of outlet above inlet when collector tilt is 90^0 : 2.238 m

Glazing:

Material: Dupont Tedlar

Thickness: 0.91 cm

Transmittance*: Not Given

No. of Cover Plates: one

Transparent Frontal Dimensions:

Length: 2.188 m

Width: 0.760 m

Area: 1.663 m

Absorber:

Material: Two sheets of Tefzel Aluminum laminated together with integral fluid passages.

Length: 2.442 m

Width: 0.760 m

Area: 1.857 sq. m

Absorber coating: 99% pure nickel foil with selective surface deposits on top and high temperature silicon adhesive below

Absorptivity*: Not Given

Emissivity*: Not Given

INSULATION:

TYPE: Polyisocyanurate

DIMENSIONS: 3.81 cm. thick

K-FACTOR*: 0.02 Watts/M.DEG.C (.14 BTU/HR. SQ. Ft. DEG.F/IN)

HEAT TRANSFER FLUID:

MATERIALS: Water

DENSITY: 977.81 KG/CUBIC Meters at 70DEG.C

SPECIFIC HEAT: 4189.6 J/KG DEG.C. at 70DEG.C

COLLECTOR WEIGHT: 10.0 KG.

COLLECTOR WEIGHT/AREA: 5.51 KG/SQ.M

COLLECTOR FLUID CAPACITY: 0.6 Liters

COLLECTOR FLUID CAPACITY/AREA: 0.33 Liters/sq.m.

NORMAL OPERATING TEMPERATURE RANGE: Not Given

MANUFACTURERS RECOMMENDED FLUID FLOW RATE: 1.9 Liter/Min. (0.5 GMP)

MANUFACTUREERS RECOMMENDED MAXIMUM OPERATING PRESSURE:

0. Kilopascals (0.PSIG) - Not Pressure Tested

2.0 RESULTS

2.1 Introduction

Three prototype solar collectors, from Brookhaven Laboratories, were submitted for testing. All three have essentially the same design except for slight variations in size. The collectors were given the following file numbers: 80150, 80151 and 80152, corresponding to Brookhaven Model Numbers X-29, X-31 and X-32.

On November 9, 1980 the three Brookhaven Laboratories prototype solar collectors were partially tested for thermal performance. Five data points with fluid inlet temperature slightly above ambient and four data points at approximately 12° above were taken. At this point Brookhaven requested that model numbers X-29 and X-31 be returned to Brookhaven for additional testing. Model X-32 was modified by adding more insulation. It remained at FSEC and underwent thermal performance test and an incident angle modifier test.

Results of the thermal performance test on model X-32 is presented in the body of this report in graphical and tabular form. The first graph shows the efficiency plot in both the International System of Units (SI) and English Units. The second graph presents the incident angle modifier test. Finally, the tabulated test data is presented. The English Unit tabulated data is shown in section 2.6.

The partial tests conducted on models X-29, X-31 and X-32 are included in appendices C, D and E respectively.

2.2 Explanation of Results

The Brookhaven model X-32 solar collector was tested for incident angle modifier and thermal performance. Results of the incident angle modifier test, conducted on 12 April 1981, are presented in graphical form. The initial performance test was conducted on 25 November 1980.

On 29 November 1980, the collector was placed on an exposure rack for a period of 46 days. During this period there were at least thirty days on which the total daily insolation level was greater than 4730 watt-hours per square meter (1500 Btu/ft²) and at least one day on which there was a four-hour period with a minimum insolation level of 946 watts per square meter (300 Btu/hr-ft²). During the exposure test the collector rack was adjusted to keep the angle between the incoming solar radiation and a normal to the collector surface less than five degrees at solar noon. On three of the last ten days of exposure the collector was sprayed with water to simulate rain. No thermal shock/cold fill test or static pressure leakage test were conducted on this collector.

A second thermal performance test was conducted on 4 and 13 April 1981. The performance equations in SI units are as follows:

INITIAL TEST	$\eta = 68.8 - 590.9 \text{ DT/I}$
	$\eta = 68.2 - 518.2 \text{ DT/I} - 1041.5 (\text{DT/I})^2$
RETEST	$\eta = 71.6 - 678.6 \text{ DT/I}$
	$\eta = 70.5 - 559.8 \text{ DT/I} - 1713.4 (\text{DT/I})^2$

After all the tests had been completed, the collector was carefully inspected. The inspection revealed some evidence of deterioration resulting from the exposure test. See Section 2.4.4 for inspection results.

THERMAL PERFORMANCE BROOKHAVEN 152 X-32

$$K_{ta} = 1.0 - 0.10 [1/\cos(\text{INCI}) - 1]$$

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

27-APR-81

MANUFACTURER: BROOKHAVEN 152 FINAL

MODEL: X-32

GROSS AREA = 1.816 SQ M

J:80152.RE1

ST	DATE	SOLAR TIME START END	TA (C)	TI (C)	TE (C)	FLOW L/MIN	AVE IN W/SQ M	TOTAL IN J/SQ M	(TE-TI) (C)	DEL T C-MIN	EFFIC %	(TI-TA)/I (C-SQ M)/W
4	4/ 4/81	15:19 15:24	25.5	28.2	37.3	1.88	942.0	282602.	9.03	45.1	68.8	0.0029
4	4/ 4/81	15:29 15:34	25.4	28.2	37.1	1.88	930.7	279195.	8.89	44.4	68.6	0.0031
06	4/13/81	11:24 11:29	25.4	27.5	36.4	1.88	929.1	278716.	8.95	44.7	69.0	0.0022
02	4/13/81	11:34 11:39	25.6	27.2	36.3	1.88	930.5	279139.	9.11	45.6	70.1	0.0017
04	4/13/81	12:37 12:42	25.8	48.0	55.5	1.87	940.3	282096.	7.51	37.5	56.7	0.0235
05	4/13/81	12:42 12:47	25.8	48.0	55.4	1.87	939.6	281881.	7.44	37.2	56.1	0.0236
07	4/13/81	12:52 12:57	25.9	48.0	55.6	1.87	951.1	285341.	7.62	38.1	56.8	0.0233
09	4/13/81	13: 2 13: 7	25.9	48.0	55.7	1.87	957.1	287124.	7.68	38.4	56.8	0.0231
00	4/13/81	13:41 13:46	26.2	73.9	79.4	1.88	977.7	293309.	5.42	27.1	39.1	0.0489
01	4/13/81	13:46 13:51	26.1	73.8	79.3	1.87	978.5	293547.	5.50	27.5	39.3	0.0487
02	4/13/81	13:51 13:56	26.0	73.9	79.4	1.85	978.7	293597.	5.49	27.4	39.0	0.0490
03	4/13/81	14:11 14:16	25.9	73.9	79.3	1.87	980.3	294096.	5.44	27.2	38.8	0.0490
04	4/13/81	14:47 14:52	25.8	89.4	93.0	1.86	964.5	289340.	3.57	17.8	25.6	0.0660
00	4/13/81	14:52 14:57	25.7	89.6	93.1	1.84	959.3	287785.	3.41	17.1	24.3	0.0667
01	4/13/81	14:57 15: 2	25.3	89.7	93.4	1.85	953.6	286075.	3.67	18.4	26.6	0.0675
02	4/13/81	15: 2 15: 7	25.6	89.8	93.2	1.86	948.4	284517.	3.41	17.1	25.0	0.0677

THE FIRST ORDER EFFICIENCY CURVE IS: EFFICIENCY = 71.6 -678.6 (TI-TA)/I
 THE UNITS ON (TI-TA)/I ARE (C-SQ M)/W.

THE SECOND ORDER EFFICIENCY CURVE IS: EFFICIENCY = 70.5 -559.8 DT/I -1713.4 (DT/I)²
 THE UNITS ON DT/I ARE (C-SQ M)/W. DT=TI-TA

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

27-APR-81

FACTURER: BROOKHAVEN 152 FINAL
80152.RE1

MODEL: X-32

GROSS AREA = 1.816 SQ M

TEST	TILT DEG	AZIM DEG	INCI DEG	MASS KG/SEC	SPEC HEAT J/(KG C)	IN P KN/SQ M	WIND M/S	WIND DIR	DIF IN W/SQ M	% DIFF INSOL	TI-TA (C)
4	45.	-72.	8.	0.0312	4177.9	219.9	3.6	111.	200.9	21.3	2.8
6	45.	-73.	10.	0.0312	4177.9	220.6	3.1	112.	204.0	21.9	2.8
20	45.	62.	31.	0.0311	4178.0	227.9	2.3	91.	850.0	91.5	2.0
22	45.	62.	33.	0.0311	4178.0	228.5	1.8	96.	852.6	91.6	1.6
24	45.	-62.	29.	0.0308	4181.1	226.8	2.2	102.	859.7	91.4	22.1
25	45.	-62.	28.	0.0308	4181.1	226.8	2.5	100.	858.4	91.4	22.2
27	45.	-63.	26.	0.0308	4181.1	226.3	2.3	106.	868.2	91.3	22.1
29	45.	-63.	24.	0.0307	4181.1	225.7	2.3	101.	872.8	91.2	22.1
30	45.	-66.	15.	0.0305	4194.0	227.4	2.0	117.	890.6	91.1	47.8
31	45.	-66.	14.	0.0303	4193.9	226.8	1.9	112.	891.4	91.1	47.6
32	45.	-67.	13.	0.0301	4194.1	226.3	1.9	98.	891.4	91.1	48.0
36	45.	-68.	8.	0.0303	4194.0	225.1	1.9	95.	892.9	91.1	48.0
39	45.	-72.	1.	0.0299	4206.5	224.8	1.7	108.	878.6	91.1	63.6
40	45.	-73.	1.	0.0295	4206.6	224.5	1.8	111.	873.9	91.1	64.0
41	45.	-74.	2.	0.0298	4206.8	225.2	1.5	91.	868.8	91.1	64.4
42	45.	-74.	3.	0.0300	4206.8	224.7	2.0	98.	864.0	91.1	64.2

2.3 Computer Printout Key

TEST	Number assigned to the data for a particular test
DATE	Date on which the test was performed
SOLAR TIME	Solar time at the start and finish of the test
TA	Ambient air temperature ($^{\circ}\text{C}$ or $^{\circ}\text{F}$)
TI	Temperature of the transfer fluid at the collector inlet ($^{\circ}\text{C}$ or $^{\circ}\text{F}$)
TE	Temperature of the transfer fluid at the collector exit ($^{\circ}\text{C}$ or $^{\circ}\text{F}$)
FLOW	Volumetric flow rate of the transfer fluid (liters/minute or gallons/minute)
AVE IN	Average instantaneous insolation (watts/square meter or Btu/hour-square foot)
TOTAL IN	Total (integrated) insolation in the plane of the collector during the test period (joules/square meter or Btu/square foot)
DEL T	Total (integrated) temperature rise across the collector during the test period (degree centigrade minutes or degree fahrenheit minutes)
EFFIC	Calculated collector efficiency for the test period (percent)
(TI-TA)/I	Value calculated for the abscissa of the efficiency graph I = average instantaneous insolation. ($^{\circ}\text{C}$ - square meter/watt or $^{\circ}\text{F}$ - hour - square foot/Btu).
TILT	Angle which the collector was tilted from the horizontal (degrees)
AZIM	Collector azimuth angle (degrees from due south; east positive)
INCI	Angle between the incoming radiation and a normal to the collector surface (degrees)
MASS	Mass flow rate of the transfer fluid (kilograms/second or pounds mass/minute).
SPEC HEAT	Specific heat of the transfer fluid (joules/kilogram - $^{\circ}\text{C}$ or Btu/pound mass - $^{\circ}\text{F}$)
IN P	Gage pressure at the collector inlet (kiloNewtons/square meter or pounds/square inch)
WIND	Wind speed (meters/second or miles/hour)
WIND DIR	Wind direction (degrees east from north)
DIF IN	Diffuse instantaneous insolation (watts/square meter or Btu/hour-square foot)
% DIFF INSOL	Percent of the incoming radiation that was diffuse
TI-TA	Temperature difference between the inlet fluid temperature and ambient air ($^{\circ}\text{C}$ or $^{\circ}\text{F}$)

Note: Stars indicate that no data was taken on the indicated parameter during that test

2.4 Results of Static Tests

2.4.1 Pressure Test Not Performed

Date of Test:

Static Test Pressure:

Duration of Test:

2.4.2 Pressure Drop Test Not Performed

Date of Test:

Inlet Temperature:

Flow Rate:

Inlet Pressure:

Pressure Drop:

2.4.3 Exposure Test

Start Date: 29 November 1980-

Completion Date: 14 January 1981

No. of Days of Exposure: 46

No. of Days of Exposure when insolation exceeded
4730 watts/m² (1500 Btu/ft²): 30

Pressure Relief Setting: 0.0 kPa (0.0 psig)

Spray Tests:

Dates:	2 January 1981	8 January 1981	10 January 1981
--------	----------------	----------------	-----------------

Insolation:	1069 Watts/m ² (399 Btu/hr-ft ²)	1090 watts/m ² (346 Btu/hr-ft ²)	1040 watt/m ² (330 Btu/hr-ft ²)
-------------	---	---	--

Thermal Shock/Cold Fill Test: Not Performed

Date:

Air Temperature:

Insolation:

Inlet Water Temperature:

Test Duration:

Flow Rate:

Static Pressure Leakage Tests: Not Performed

Date:

Pressure:

Fluid:

Duration:

2.4.4 Inspection Results:

Cover Plate: The cover stretched and became distorted during exposure. Moisture appeared on the inner surface of the cover after each spray test.

Absorber Plate: See below*

Absorptive Coating: No evidence of deterioration

Collector Enclosure: No evidence of deterioration

Insulation: No evidence of deterioration

Gaskets, caulking and sealants: Foil tape around the outside peeled and separated from the collector.

Absorber Plate: Creases appeared in the absorber surface along the long axis of the collector. The creases appeared as upward projections of the absorber surface, were up to twelve in number, and were immediately above the absorber fusion lines. The crease lines, in some cases, ran nearly the entire length of the collector and in other cases ran only short distances along the fusion lines. The creases are a separation of the absorber surface/foil laminate from the plastic layer and in some cases, a further separation of the absorber surface from the aluminum foil backing. These separations are apparently a failure of the adhesive along the absorber fusion lines.

2.5 Explanation of Efficiency Curve

The test data is presented in tabular form and as an efficiency curve. The efficiency curve is based on the following equation:

$$\eta = F_R(\tau\alpha)_e - F_R U_L \frac{(T_i - T_a)}{I}$$

where:

- η = collector efficiency
- F_R = heat removal factor
- $(\tau\alpha)_e$ = effective transmissivity-absorptivity product
- U_L = over-all heat loss coefficient
- T_i = transfer fluid temperature at the collector inlet
- T_a = ambient air temperature
- I = instantaneous level of solar radiation

The standard form of the equation of a straight line is:

$$Y = b + mX$$

where:

- b = Y axis intercept
- m = slope

From these two equations it can be seen that a straight line should result if a plot of efficiency versus the quantity $\frac{T_i - T_a}{I}$ is made and if the slope and intercept functions can be assumed constant. It then becomes apparent that the slope of the line is a function of the over-all heat loss coefficient and the Y axis intercept is a function of the transmissivity of the cover plate(s) and the absorptivity of the absorber plate(s). In reality, however, U_L is not constant under the test conditions since it varies with the temperature of the collector and ambient weather conditions. Therefore a second order curve is used to describe the thermal performance of the collector. That is:

$$Y = c + bX + aX^2$$

The intercept is still related to $(\tau\alpha)_e$ and the slope at any point on the curve is proportional to the heat loss rate for that value of $\frac{T_i - T_a}{I}$.

2.6 Performance Test Results, English Units

Following is a repetition of the thermal performance curve. Although identical to the previous graphs (see Section 2.1) in content, this graph and computer printout is presented in English units.

THERMAL PERFORMANCE BROOKHAVEN 152 X-32

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

27-APR-81

MANUFACTURER: BROOKHAVEN 152 FINAL

MODEL: X-32

GROSS AREA = 19.55 SQ FT

01:80152.RE1

TEST	DATE	SOLAR TIME START END	TA (F)	TI (F)	TE (F)	FLOW GPM	AVE IN B/H-FT2	TOTAL IN BTU/SQ FT	(TE-TI) (F)	DEL T F-MIN	EFF %	(TI-TA)/I (F-H-FT2)/B
4	4/ 4/81	15:19 15:24	77.9	82.8	99.1	0.497	298.8	24.9	16.25	81.3	68.8	0.017
6	4/ 4/81	15:29 15:34	77.6	82.8	98.8	0.498	295.2	24.6	16.00	80.0	68.6	0.017
20	4/13/81	11:24 11:29	77.8	81.4	97.5	0.496	294.7	24.6	16.10	80.5	69.0	0.012
22	4/13/81	11:34 11:39	78.0	81.0	97.4	0.496	295.2	24.6	16.40	82.0	70.1	0.010
24	4/13/81	12:37 12:42	78.5	118.3	131.8	0.495	298.3	24.9	13.51	67.5	56.7	0.134
25	4/13/81	12:42 12:47	78.4	118.3	131.7	0.494	298.1	24.8	13.39	67.0	56.1	0.134
27	4/13/81	12:52 12:57	78.6	118.4	132.1	0.494	301.7	25.1	13.72	68.6	56.8	0.132
29	4/13/81	13: 2 13: 7	78.6	118.4	132.2	0.494	303.6	25.3	13.82	69.1	56.8	0.131
30	4/13/81	13:41 13:46	79.1	165.1	174.9	0.497	310.1	25.8	9.76	48.8	39.1	0.277
31	4/13/81	13:46 13:51	79.0	164.8	174.7	0.493	310.4	25.9	9.91	49.5	39.3	0.276
32	4/13/81	13:51 13:56	78.8	165.1	175.0	0.490	310.4	25.9	9.88	49.4	39.0	0.278
36	4/13/81	14:11 14:16	78.6	165.0	174.8	0.493	311.0	25.9	9.79	49.0	38.8	0.278
39	4/13/81	14:47 14:52	78.4	192.9	199.3	0.491	305.9	25.5	6.42	32.1	25.6	0.374
40	4/13/81	14:52 14:57	78.2	193.4	199.5	0.485	304.3	25.4	6.14	30.7	24.3	0.378
41	4/13/81	14:57 15: 2	77.6	193.5	200.1	0.489	302.5	25.2	6.61	33.1	26.6	0.383
42	4/13/81	15: 2 15: 7	78.2	193.7	199.8	0.492	300.8	25.1	6.14	30.7	25.0	0.384

THE FIRST ORDER EFFICIENCY CURVE IS: EFFICIENCY = 71.6 -119.6 (TI-TA)/I
 THE UNITS ON (TI-TA)/I ARE (F-HR-SQ FT)/BTU.

THE SECOND ORDER EFFICIENCY CURVE IS: EFFICIENCY = 70.5 -98.7 DT/I -53.2 (DT/I)²
 THE UNITS ON DT/I ARE (F-HR-SQ FT)/BTU. DT=TI-TA

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

27-APR-81

MANUFACTURER: BROOKHAVEN 152 FINAL
1:80152.RE1

MODEL: X-32

GROSS AREA = 19.55 SQ FT

TEST	TILT DEG	AZIM DEG	INCI DEG	MASS LBM/MIN	SPEC HEAT BTU/(LBM-F)	IN P PSI	WIND MPH	WIND DIR	DIF IN B/H-FT2	% DIFF INSOL	TI-TA (F)
4	45.	-72.	8.	4.13	0.998	31.9	8.1	111.	63.7	21.3	5.0
6	45.	-73.	10.	4.13	0.998	32.0	7.0	112.	64.7	21.9	5.1
20	45.	62.	31.	4.12	0.998	33.1	5.1	91.	269.6	91.5	3.7
22	45.	62.	33.	4.12	0.998	33.1	4.1	96.	270.5	91.6	2.9
24	45.	-62.	29.	4.08	0.999	32.9	5.0	102.	272.7	91.4	39.8
25	45.	-62.	28.	4.07	0.999	32.9	5.5	100.	272.3	91.4	40.0
27	45.	-63.	26.	4.07	0.999	32.8	5.2	106.	275.4	91.3	39.8
29	45.	-63.	24.	4.06	0.999	32.7	5.0	101.	276.9	91.2	39.8
30	45.	-66.	15.	4.04	1.002	33.0	4.5	117.	282.5	91.1	86.0
31	45.	-66.	14.	4.01	1.002	32.9	4.3	112.	282.8	91.1	85.7
32	45.	-67.	13.	3.98	1.002	32.8	4.3	98.	282.8	91.1	86.3
36	45.	-68.	8.	4.01	1.002	32.6	4.3	95.	283.2	91.1	86.4
39	45.	-72.	1.	3.96	1.005	32.6	3.9	108.	278.7	91.1	114.5
40	45.	-73.	1.	3.91	1.005	32.6	4.1	111.	277.2	91.1	115.2
41	45.	-74.	2.	3.94	1.005	32.7	3.5	91.	275.6	91.1	115.8
42	45.	-74.	3.	3.96	1.005	32.6	4.5	98.	274.1	91.1	115.5

APPENDIX A
PARTIAL DATA
MODEL X-29

1. COLLECTOR DESCRIPTION

1.1 Collector Identification

Manufacturer and Address: Brookhaven National Laboratories
Solar Technology Group, Bldg. 701
Upton, New York 11973

Collector Model Number: X-29

1.2 Collector Construction

Overall Dimensions:

Length: 2.222 m
Width: 0.816 m
Depth: 0.079 m

Overall Front Area: (length x width) 1.813 m²

Height of outlet above inlet when collector tilt is 90°: 2.222 m

Glazing:

Material: Dupont Tedlar
Thickness: 0.01 cm
Transmittance*: Not Given
No. of Cover Plates: One

Transparent Frontal Dimensions:

Length: 2.171 m
Width: 0.816 m
Area: 1.771 m²

Absorber:

Material: Two sheets of Tefzel Aluminum laminated together with
integral fluid passages.

Length: 2.171 m
Width: 0.816 m
Area: 1.772 m²

Absorber Coating: 99% pure nickel foil with selective surface deposits
top and high temperature silicon adhesive below

Absorptivity*: Not Given

Emissivity*: Not Given

Insulation:

Type: Polyisocyanurate

Dimensions: 3.81 cm.

thick

K-Factor*: 0.02

watts/m²°C (0.14 Btu/hr-ft²-°F/in)

Heat Transfer Fluid:

Material: Water

Density: 977.81 kg/m³ at 70°C

Specific Heat: 4189.6 J/kg °C at 70°C

Collector Weight: 7.0 kg

Collector Weight/Area: 3.86 kg/m²

Collector Fluid Capacity: 0.6 liters

Collector Fluid Capacity/Area: 0.33 liters/m²

Normal Operating Temperature Range: Not Given

Manufacturers Recommended Fluid Flow Rate: 1.9 liter/min (0.5 GPM)

Manufacturers Recommended Maximum Operating Pressure:

0.0 kilopascals (0.0 psig)

THERMAL PERFORMANCE BROOKHAVEN 150 X-29

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

24-APR-81

MANUFACTURER: BROOKHAVEN 150

MODEL: X-29

GROSS AREA = 1.813 SQ M

30150.DA1

TEST	DATE	SOLAR TIME START END	TA (C)	TI (C)	TE (C)	FLOW L/MIN	AVE IN W/SQ M	TOTAL IN J/SQ M	(TE-TI) (C)	DEL T C-MIN	EFFIC %	(TI-TA)/I (C-SQ M)/W
1	11/ 9/80	9:15 9:20	27.1	28.6	35.3	1.89	867.1	260121.	6.73	33.7	56.1	0.0018
2	11/ 9/80	9:20 9:25	27.4	28.6	35.5	1.89	880.9	264258.	6.96	34.8	57.1	0.0014
3	11/ 9/80	9:27 9:32	27.5	28.5	35.7	1.89	904.9	271485.	7.15	35.7	57.0	0.0011
4	11/ 9/80	10: 6 10:11	27.7	28.6	36.2	1.89	958.8	287630.	7.68	38.4	57.8	0.0009
5	11/ 9/80	10:11 10:16	27.8	28.5	36.2	1.89	965.1	289539.	7.74	38.7	57.8	0.0007
6	11/ 9/80	10:42 10:47	28.0	50.7	56.7	1.89	978.3	293485.	5.99	30.0	43.9	0.0233
7	11/ 9/80	10:50 10:55	28.4	50.7	56.9	1.89	979.6	293873.	6.12	30.6	44.7	0.0228
8	11/ 9/80	10:55 11: 0	28.5	50.7	56.9	1.89	987.5	296264.	6.18	30.9	44.8	0.0225
9	11/ 9/80	11:12 11:17	28.1	50.6	57.0	1.89	1031.4	309409.	6.41	32.0	44.5	0.0218

THE FIRST ORDER EFFICIENCY CURVE IS: EFFICIENCY = 57.9 -594.9 (TI-TA)/I
THE UNITS ON (TI-TA)/I ARE (C-SQ M)/W.

THE SECOND ORDER EFFICIENCY CURVE IS: EFFICIENCY = 58.5 -1188.8 DT/I 25084.5 (DT/I)2
THE UNITS ON DT/I ARE (C-SQ M)/W. DT=TI-TA

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

24-APR-81

MANUFACTURER: BROOKHAVEN 150
80150.DA1

MODEL: X-29

GROSS AREA = 1.813 SQ M

TEST	TILT DEG	AZIM DEG	INCI DEG	MASS KG/SEC	SPEC HEAT J/(KG C)	IN P KN/SQ M	WIND M/S	WIND DIR	DIF IN W/SQ M	% DIFF INSOL	T1-TA (C)
----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1	61.	45.	0.	0.0314	4178.0	225.2	1.3	92.	94.3	10.9	1.5
2	60.	44.	0.	0.0313	4178.0	225.1	1.0	88.	102.5	11.6	1.2
3	59.	43.	0.	0.0313	4178.0	224.9	1.2	94.	120.0	13.3	1.0
4	53.	33.	0.	0.0313	4177.9	224.5	1.7	102.	141.4	14.8	0.9
5	53.	32.	0.	0.0313	4177.9	224.5	1.7	106.	146.1	15.1	0.7
6	50.	23.	0.	0.0311	4181.8	223.9	1.5	107.	152.9	15.6	22.8
7	49.	21.	0.	0.0310	4181.8	223.5	1.9	104.	152.1	15.5	22.3
8	49.	20.	0.	0.0310	4181.8	223.4	1.7	110.	155.6	15.8	22.2
9	48.	14.	0.	0.0310	4181.8	223.6	1.7	103.	193.9	18.8	22.5

THERMAL PERFORMANCE BROOKHAVEN 150 X-29

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

24-APR-81

MANUFACTURER: BROOKHAVEN 150
80150.DA1

MODEL: X-29

GROSS AREA = 19.51 SQ F

TEST	DATE	SOLAR TIME		TA (F)	TI (F)	TE (F)	FLOW GPM	AVE IN B/H-FT2	TOTAL IN BTU/SQ FT	(TE-TI) (F)	DEL T F-MIN	EFF %	(TI-TA)/I (F-H-FT2)/B
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1	11/ 9/80	9:15	9:20	80.7	83.5	95.6	0.500	275.0	22.9	12.12	60.6	56.1	0.010
2	11/ 9/80	9:20	9:25	81.2	83.4	95.9	0.499	279.4	23.3	12.53	62.6	57.1	0.008
3	11/ 9/80	9:27	9:32	81.5	83.4	96.2	0.499	287.1	23.9	12.86	64.3	57.0	0.006
4	11/ 9/80	10: 6	10:11	81.9	83.4	97.2	0.499	304.1	25.3	13.82	69.1	57.8	0.005
5	11/ 9/80	10:11	10:16	82.0	83.3	97.2	0.498	306.1	25.5	13.93	69.7	57.8	0.004
6	11/ 9/80	10:42	10:47	82.3	123.3	134.1	0.499	310.3	25.9	10.79	53.9	43.9	0.132
7	11/ 9/80	10:50	10:55	83.2	123.3	134.3	0.499	310.7	25.9	11.02	55.1	44.7	0.129
8	11/ 9/80	10:55	11: 0	83.3	123.2	134.3	0.498	313.3	26.1	11.13	55.6	44.8	0.127
9	11/ 9/80	11:12	11:17	82.6	123.0	134.6	0.499	327.2	27.3	11.53	57.7	44.5	0.124

THE FIRST ORDER EFFICIENCY CURVE IS: EFFICIENCY = 57.9 -104.8 (TI-TA)/I
THE UNITS ON (TI-TA)/I ARE (F-HR-SQ FT)/BTU.

THE SECOND ORDER EFFICIENCY CURVE IS: EFFICIENCY = 58.5 -209.7 DT/I 777.8 (DT/I)2
THE UNITS ON DT/I ARE (F-HR-SQ FT)/BTU. DT=TI-TA

MANUFACTURER: BROOKHAVEN 150
80150.DA1

MODEL: X-29

GROSS AREA = 19.51 SQ F

TEST	TILT DEG	AZIM DEG	INCI DEG	MASS LBM/MIN	SPEC HEAT BTU/(LBM-F)	IN P PSI	WIND MPH	WIND DIR	DIFF IN B/H-FT2	% DIFF INSOL	TI-TA (F)
1	61.	45.	0.	4.15	0.998	32.7	3.0	92.	29.9	10.9	2.8
2	60.	44.	0.	4.15	0.998	32.6	2.2	88.	32.5	11.6	2.2
3	59.	43.	0.	4.14	0.998	32.6	2.8	94.	38.1	13.3	1.9
4	53.	33.	0.	4.14	0.998	32.6	3.7	102.	44.9	14.8	1.5
5	53.	32.	0.	4.14	0.998	32.6	3.8	106.	46.4	15.1	1.3
6	50.	23.	0.	4.11	0.999	32.5	3.4	107.	48.5	15.6	41.0
7	49.	21.	0.	4.10	0.999	32.4	4.2	104.	48.3	15.5	40.1
8	49.	20.	0.	4.10	0.999	32.4	3.7	110.	49.4	15.8	39.9
9	48.	14.	0.	4.11	0.999	32.4	3.8	103.	61.5	18.8	40.4

APPENDIX B
PARTIAL DATA
MODEL X-31

1. COLLECTOR DESCRIPTION

1.1 Collector Identification

Manufacturer and Address: Brookhaven National Laboratories
Solar Technology Group, Bldg. 701
Upton, New York 11973

Collector Model Number: X-31

1.2 Collector Construction

Overall Dimensions:

Length: 2.337 m
Width: 0.814 m
Depth: 0.078 m

Overall Front Area: (length x width) = 1.903 m²

Height of outlet above inlet when collector tilt is 90°: 2.337 m

Glazing:

Material: Dupont Tedlar
Thickness: 0.01 cm
Transmittance*: Not Given
No. of Cover Plates: One

Transparent Frontal Dimensions:

Length: 2.286 m
Width: 0.764 m
Area: 1.746 m²

Absorber:

Material: Two sheets of Tefzel Aluminum laminated together with
integral fluid passages.

Length: 2.286 m
Width: 0.815 m
Area: 1.864 m²

Absorber Coating: 99% pure nickel foil with selective surface deposits
top and high temperature silicon adhesive below

Absorptivity*: Not Given

Emissivity*: Not Given

Insulation:

Type: Polyisocyanurate

Dimensions: 3.81 cm. Thick

K-Factor*: 0.02 watts/m²°C (0.14 Btu/hr-ft²-°F/in)

Heat Transfer Fluid:

Material: Water

Density: 977.81 kg/m³ at 70°C

Specific Heat: 4189.6 J/kg °C at 70°C

Collector Weight: 7.3 kg

Collector Weight/Area: 3.84 kg/m²

Collector Fluid Capacity: 0.6 liters

Collector Fluid Capacity/Area: 0.32 liters/m²

Normal Operating Temperature Range: Not Given °C to °C

Manufacturers Recommended Fluid Flow Rate: 1.9 liter/min (0.5 GPM)

Manufacturers Recommended Maximum Operating Pressure:

0. kilopascals (0. psig)

THERMAL PERFORMANCE BROOKHAVEN 151 X-31

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

24-APR-81

MANUFACTURER: BROOKHAVEN 151

MODEL: X-31

GROSS AREA = 1.903 SQ M

80151.DA1

TEST	DATE	SOLAR TIME START END	TA (C)	TI (C)	TE (C)	FLOW L/MIN	AVE IN W/SQ M	TOTAL IN J/SQ M	(TE-TI) (C)	DEL T C-MIN	EFFIC %	(TI-TA)/I (C-SQ M)/W
1	11/ 9/80	9:15 9:20	27.1	28.6	36.6	1.89	860.5	258149.	8.05	40.2	64.3	0.0017
2	11/ 9/80	9:20 9:25	27.4	28.5	36.8	1.89	873.2	261963.	8.23	41.2	64.7	0.0013
3	11/ 9/80	9:27 9:32	27.5	28.5	37.0	1.88	897.8	269335.	8.45	42.2	64.5	0.0011
4	11/ 9/80	10: 6 10:11	27.7	28.5	37.5	1.89	953.4	286009.	8.93	44.7	64.5	0.0008
5	11/ 9/80	10:11 10:16	27.8	28.4	37.4	1.88	959.8	287941.	8.99	45.0	64.2	0.0007
6	11/ 9/80	10:42 10:47	28.0	50.7	57.7	1.88	973.4	292028.	7.00	35.0	48.8	0.0234
7	11/ 9/80	10:50 10:55	28.4	50.7	57.7	1.90	975.6	292689.	7.02	35.1	49.3	0.0229
8	11/ 9/80	10:55 11: 0	28.5	50.7	57.8	1.90	984.0	295196.	7.07	35.4	49.3	0.0225
9	11/ 9/80	11:12 11:17	28.1	50.6	57.8	1.89	1026.9	308075.	7.27	36.3	48.3	0.0219

THE FIRST ORDER EFFICIENCY CURVE IS: EFFICIENCY = 65.3 -720.2 (TI-TA)/I
THE UNITS ON (TI-TA)/I ARE (C-SQ M)/W.

THE SECOND ORDER EFFICIENCY CURVE IS: EFFICIENCY = 65.8 -1178.2 DT/I 19242.1 (DT/I)2
THE UNITS ON DT/I ARE (C-SQ M)/W. DT=TI-TA

MANUFACTURER: BROOKHAVEN 151
80151.DA1

MODEL: X-31

GROSS AREA = 1.903 SQ M

TEST	TILT DEG	AZIM DEG	INCL DEG	MASS KG/SEC	SPEC HEAT J/(KG C)	IN P KN/SQ M	WIND M/S	WIND DIR	DIF IN W/SQ M	% DIFF INSOL	TI-TA (C)
1	61.	45.	0.	0.0313	4177.9	225.2	1.3	92.	87.7	10.2	1.5
2	60.	44.	0.	0.0313	4177.9	225.1	1.0	88.	94.8	10.9	1.2
3	59.	43.	0.	0.0312	4177.9	224.9	1.2	94.	112.8	12.6	1.0
4	53.	33.	0.	0.0313	4177.9	224.5	1.7	102.	136.0	14.3	0.8
5	53.	32.	0.	0.0312	4177.9	224.5	1.7	106.	140.8	14.7	0.7
6	50.	23.	0.	0.0309	4181.9	223.9	1.5	107.	148.1	15.2	22.8
7	49.	21.	0.	0.0312	4181.9	223.5	1.9	104.	148.2	15.2	22.3
8	49.	20.	0.	0.0312	4181.9	223.4	1.7	110.	152.0	15.5	22.2
9	48.	14.	0.	0.0310	4181.9	223.6	1.7	103.	189.4	18.4	22.4

THERMAL PERFORMANCE BROOKHAVEN 151 X-31

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

24-APR-81

MANUFACTURER: BROOKHAVEN 151
80151.DA1

MODEL: X-31

GROSS AREA = 20.48 SQ F

TEST	DATE	SOLAR TIME START END	TA (F)	TI (F)	TE (F)	FLOW GPM	AVE IN B/H-FT2	TOTAL IN BTU/SQ FT	(TE-TI) (F)	DEL T F-MIN	EFF %	(TI-TA/I (F-H-FT2))/R
1	11/ 9/80	9:15 9:20	80.7	83.4	97.9	0.499	273.0	22.7	14.48	72.4	64.3	0.010
2	11/ 9/80	9:20 9:25	81.2	83.3	98.2	0.498	277.0	23.1	14.82	74.1	64.7	0.008
3	11/ 9/80	9:27 9:32	81.5	83.3	98.5	0.498	284.8	23.7	15.20	76.0	64.5	0.006
4	11/ 9/80	10: 6 10:11	81.9	83.3	99.4	0.499	302.4	25.2	16.08	80.4	64.5	0.005
5	11/ 9/80	10:11 10:16	82.0	83.2	99.4	0.498	304.5	25.4	16.18	80.9	64.2	0.004
6	11/ 9/80	10:42 10:47	82.3	123.3	135.9	0.497	308.8	25.7	12.59	63.0	48.8	0.133
7	11/ 9/80	10:50 10:55	83.2	123.3	135.9	0.502	309.5	25.8	12.63	63.2	49.3	0.130
8	11/ 9/80	10:55 11: 0	83.3	123.2	136.0	0.501	312.1	26.0	12.73	63.7	49.3	0.128
9	11/ 9/80	11:12 11:17	82.6	123.0	136.1	0.499	325.7	27.1	13.08	65.4	48.3	0.124

THE FIRST ORDER EFFICIENCY CURVE IS: EFFICIENCY = 65.3 -126.9 (TI-TA)/I
THE UNITS ON (TI-TA)/I ARE (F-HR-SQ FT)/BTU.

THE SECOND ORDER EFFICIENCY CURVE IS: EFFICIENCY = 65.8 -207.5 DT/I 595.6 (DT/I)2
THE UNITS ON DT/I ARE (F-HR-SQ FT)/BTU. DT=TI-TA

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

24-APR-81

MANUFACTURER: BROOKHAVEN 151
K0151.DA1

MODEL: X-31

GROSS AREA = 20.48 SQ F

TEST	TILT DEG	AZIM DEG	INC1 DEG	MASS LBM/MIN	SPEC HEAT BTU/(LBM-F)	IN P PSI	WIND MPH	WIND DIR	DIF IN B/H-FT2	% DIFF INSOL	TI-TA (F)
1	61.	45.	0.	4.14	0.998	32.7	3.0	92.	27.8	10.2	2.7
2	60.	44.	0.	4.14	0.998	32.6	2.2	88.	30.1	10.9	2.1
3	59.	43.	0.	4.13	0.998	32.6	2.8	94.	35.8	12.6	1.8
4	53.	33.	0.	4.15	0.998	32.6	3.7	102.	43.2	14.3	1.5
5	53.	32.	0.	4.13	0.998	32.6	3.8	106.	44.7	14.7	1.2
6	50.	23.	0.	4.09	0.999	32.5	3.4	107.	47.0	15.2	41.0
7	49.	21.	0.	4.13	0.999	32.4	4.2	104.	47.0	15.2	40.1
8	49.	20.	0.	4.13	0.999	32.4	3.7	110.	48.2	15.5	39.9
9	48.	14.	0.	4.11	0.999	32.4	3.8	103.	60.1	18.4	40.4

APPENDIX C
PARTIAL DATA
MODEL X-32

THERMAL PERFORMANCE BROOKHAVEN 152 X-32

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

24-APR-81

MANUFACTURER: BROOKHAVEN 152

MODEL: X-32

GROSS AREA = 1.816 SQ M

80152.DA1

TEST	DATE	SOLAR TIME START END	TA (C)	TI (C)	TE (C)	FLOW L/MIN	AVE IN W/SQ M	TOTAL IN J/SQ M	(TE-TI) (C)	DEL T C-MIN	EFFIC %	(TI-TA)/I (C-SQ M)/W
1	11/ 9/80	9:15 9:20	27.1	28.5	37.0	1.89	857.4	257223.	8.45	42.2	71.0	0.0017
2	11/ 9/80	9:20 9:25	27.4	28.5	37.2	1.89	870.2	261046.	8.67	43.3	71.8	0.0013
3	11/ 9/80	9:27 9:32	27.5	28.5	37.4	1.89	895.1	268523.	8.90	44.5	71.5	0.0011
4	11/ 9/80	10: 6 10:11	27.7	28.5	38.0	1.88	951.3	285403.	9.45	47.2	71.3	0.0008
5	11/ 9/80	10:11 10:16	27.8	28.4	38.0	1.88	957.8	287332.	9.52	47.6	71.4	0.0007
6	11/ 9/80	10:42 10:47	28.0	50.5	58.1	1.88	970.8	291233.	7.60	38.0	55.7	0.0232
7	11/ 9/80	10:50 10:55	28.4	50.5	58.1	1.88	972.3	291678.	7.65	38.2	55.9	0.0226
8	11/ 9/80	10:55 11: 0	28.5	50.4	58.1	1.88	980.5	294148.	7.72	38.6	56.1	0.0223
9	11/ 9/80	11:12 11:17	28.1	50.3	58.4	1.89	1023.0	306901.	8.03	40.1	56.2	0.0217

THE FIRST ORDER EFFICIENCY CURVE IS: EFFICIENCY = 72.2 -721.9 (TI-TA)/I
THE UNITS ON (TI-TA)/I ARE (C-SQ M)/W.

THE SECOND ORDER EFFICIENCY CURVE IS: EFFICIENCY = 72.3 -793.0 DT/I 3119.3 (DT/I)²
THE UNITS ON DT/I ARE (C-SQ M)/W. DT=TI-TA

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

24-APR-81

MANUFACTURER: BROOKHAVEN 152
80152.DA1

MODEL: X-32

GROSS AREA = 1.816 M

TEST	TILT DEG	AZIM DEG	INCI DEG	MASS KG/SEC	SPEC HEAT J/(KG C)	IN P KN/SQ M	WIND M/S	WIND DIR	DIF IN W/SQ M	Z DIF INSOL	T1-TA (C)
1	61.	45.	0.	0.0313	4177.9	225.2	1.3	92.	84.6	9.9	1.5
2	60.	44.	0.	0.0313	4177.9	225.1	1.0	88.	91.8	10.5	1.2
3	59.	43.	0.	0.0313	4177.9	224.9	1.2	94.	110.1	12.3	1.0
4	53.	33.	0.	0.0312	4177.9	224.5	1.7	102.	134.0	14.1	0.8
5	53.	32.	0.	0.0312	4177.9	224.5	1.7	106.	138.8	14.5	0.7
6	50.	23.	0.	0.0309	4181.9	223.9	1.5	107.	145.4	15.0	22.5
7	49.	21.	0.	0.0309	4181.9	223.5	1.9	104.	144.8	14.9	22.0
8	49.	20.	0.	0.0309	4181.9	223.4	1.7	110.	148.6	15.2	21.9
9	48.	14.	0.	0.0311	4182.0	223.6	1.7	103.	185.5	18.1	22.2

THERMAL PERFORMANCE BROOKHAVEN 152 X-32

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

24-APR-81

MANUFACTURER: BROOKHAVEN 152

MODEL: X-32

GROSS AREA = 19.55 SQ F

80152.DA1

TEST	DATE	SOLAR TIME		TA	TI	TE	FLOW	AVE IN	TOTAL IN	(TE-TI)	DEL T	EFF	(TI-TA/I
		START	END	(F)	(F)	(F)	GPM	B/H-FT2	BTU/SQ FT	(F)	F-MIN	%	(F-H-FT2)/B
1	11/ 9/80	9:15	9:20	80.7	83.4	98.6	0.499	272.0	22.7	15.20	76.0	71.0	0.010
2	11/ 9/80	9:20	9:25	81.2	83.3	98.9	0.499	276.0	23.0	15.60	78.0	71.8	0.008
3	11/ 9/80	9:27	9:32	81.5	83.3	99.3	0.498	283.9	23.7	16.02	80.1	71.5	0.006
4	11/ 9/80	10: 6	10:11	81.9	83.3	100.3	0.497	301.8	25.1	17.01	85.0	71.3	0.005
5	11/ 9/80	10:11	10:16	82.0	83.2	100.3	0.498	303.8	25.3	17.14	85.7	71.4	0.004
6	11/ 9/80	10:42	10:47	82.3	122.8	136.5	0.497	307.9	25.7	13.67	68.4	55.7	0.132
7	11/ 9/80	10:50	10:55	83.2	122.8	136.6	0.496	308.4	25.7	13.76	68.8	55.9	0.128
8	11/ 9/80	10:55	11: 0	83.3	122.7	136.6	0.498	311.0	25.9	13.90	69.5	56.1	0.127
9	11/ 9/80	11:12	11:17	82.6	122.6	137.0	0.500	324.5	27.0	14.45	72.3	56.2	0.123

THE FIRST ORDER EFFICIENCY CURVE IS: EFFICIENCY = 72.2 -127.2 (TI-TA)/I
 THE UNITS ON (TI-TA)/I ARE (F-HR-SQ FT)/BTU.

THE SECOND ORDER EFFICIENCY CURVE IS: EFFICIENCY = 72.3 -139.9 DT/I 96.6 (DT/I)2
 THE UNITS ON DT/I ARE (F-HR-SQ FT)/BTU. DT=TI-TA

FLORIDA SOLAR ENERGY CENTER, CAPE CANAVERAL, FLORIDA

24-APR-81

MANUFACTURER: BROOKHAVEN 152
80152.DA1

MODEL: X-32

GROSS AREA = 19.55 SQ F

TEST	TILT DEG	AZIM DEG	INCL DEG	MASS LBM/MIN	SPEC HEAT BTU/(LBM-F)	IN P PSI	WIND MPH	WIND DIR	DIF IN R/H-FT2	% DIFF INSOL	TI-TA (F)
1	61.	45.	0.	4.15	0.998	32.7	3.0	92.	26.8	9.9	2.6
2	60.	44.	0.	4.14	0.998	32.6	2.2	88.	29.1	10.5	2.1
3	59.	43.	0.	4.14	0.998	32.6	2.8	94.	34.9	12.3	1.8
4	53.	33.	0.	4.13	0.998	32.6	3.7	102.	42.5	14.1	1.4
5	53.	32.	0.	4.13	0.998	32.6	3.8	106.	44.0	14.5	1.2
6	50.	23.	0.	4.09	0.999	32.5	3.4	107.	46.1	15.0	40.5
7	49.	21.	0.	4.08	0.999	32.4	4.2	104.	45.9	14.9	39.6
8	49.	20.	0.	4.09	0.999	32.4	3.7	110.	47.1	15.2	39.4
9	48.	14.	0.	4.11	0.999	32.4	3.8	103.	58.8	18.1	49.0

THERMAL PERFORMANCE BROOKHAVEN 152 X-32

MANUFACTURER: BROOKHAVEN 152

MODEL: X-32

GROSS AREA = 1.816 SQ M

TEST	DATE	SOLAR TIME		TA	TI	TE	FLOW	AVE IN	TOTAL IN	(TE-TI)	DEL T	EFFIC	(TI-TA)/I
		START	END	(C)	(C)	(C)	L/MIN	W/SQ M	J/SQ M	(C)	C-MIN	%	(C-SQ M)/W
13	11/25/80	9:47	9:52	21.4	71.9	77.1	1.90	969.2	290746.	5.20	26.0	38.2	0.0521
14	11/25/80	9:52	9:57	21.6	71.8	77.0	1.89	965.3	289590.	5.21	26.0	38.3	0.0519
15	11/25/80	9:57	10: 2	21.9	71.8	76.9	1.89	950.8	285247.	5.07	25.4	37.9	0.0525
16	11/25/80	10: 2	10: 7	21.9	71.8	76.8	1.89	948.1	284442.	5.07	25.3	37.9	0.0526
21	11/25/80	10:53	10:58	22.6	91.2	94.9	1.89	982.5	294760.	3.77	18.8	27.0	0.0698
22	11/25/80	10:58	11: 3	22.8	91.3	95.1	1.90	979.7	293898.	3.82	19.1	27.5	0.0699
23	11/25/80	11: 3	11: 8	22.6	91.2	94.9	1.90	983.4	295011.	3.72	18.6	26.7	0.0697
25	11/25/80	11:40	11:45	22.8	48.4	55.9	1.89	994.1	298223.	7.55	37.7	54.3	0.0257
26	11/25/80	11:45	11:50	22.8	48.5	56.0	1.89	994.8	298452.	7.55	37.7	54.2	0.0258
28	11/25/80	11:55	12: 0	22.9	48.2	55.8	1.88	994.4	298315.	7.61	38.1	54.6	0.0255
29	11/25/80	12: 0	12: 5	22.9	48.0	55.6	1.89	997.0	299110.	7.62	38.1	54.7	0.0252
30	11/25/80	12:30	12:35	23.0	23.4	32.7	1.89	994.5	298357.	9.33	46.7	67.9	0.0003
32	11/25/80	12:40	12:45	23.1	23.4	32.7	1.89	992.4	297721.	9.35	46.8	68.1	0.0002
33	11/25/80	12:45	12:50	23.1	23.3	32.7	1.89	991.2	297368.	9.33	46.7	68.0	0.0002

THE FIRST ORDER EFFICIENCY CURVE IS: EFFICIENCY = 68.8 -590.9 (TI-TA)/I
 THE UNITS ON (TI-TA)/I ARE (C-SQ M)/W.

THE SECOND ORDER EFFICIENCY CURVE IS: EFFICIENCY = 68.2 -518.2 DT/I -1041.5 (DT/I)2
 THE UNITS ON DT/I ARE (C-SQ M)/W. DT=TI-TA

MANUFACTURER: BROOKHAVEN 152

MODEL: X-32

GROSS AREA = 1.816 SQ M

TEST ----	TILT DEG -----	AZIM DEG -----	INCI DEG -----	MASS KG/SEC -----	SPEC HEAT J/(KG C) -----	IN P KN/SQ M -----	WIND M/S -----	WIND DIR -----	DIF IN W/SQ M -----	% DIFF INSOL -----	T1-TA (C) -----
13	59.	36.	0.	0.0308	4192.5	214.8	1.8	321.	159.0	16.4	50.5
14	58.	35.	0.	0.0308	4192.4	214.3	2.0	317.	197.6	20.5	50.1
15	58.	33.	0.	0.0308	4192.4	214.1	1.4	323.	126.4	13.3	49.9
16	57.	32.	0.	0.0308	4192.3	214.0	1.8	319.	115.3	12.2	49.9
21	52.	19.	0.	0.0304	4208.4	215.0	1.1	333.	107.9	11.0	68.6
22	52.	18.	0.	0.0304	4208.5	215.7	1.5	336.	105.4	10.8	68.5
23	51.	16.	0.	0.0304	4208.3	215.6	1.8	335.	112.0	11.4	68.6
25	50.	5.	0.	0.0311	4181.2	218.7	1.8	336.	119.6	12.0	25.6
26	50.	4.	0.	0.0310	4181.3	218.7	1.9	341.	118.3	11.9	25.6
28	50.	1.	0.	0.0310	4181.2	218.5	1.7	339.	119.9	12.1	25.3
29	50.	-1.	0.	0.0311	4181.1	219.7	1.8	341.	118.2	11.9	25.1
30	50.	-10.	0.	0.0315	4178.7	218.8	2.0	342.	119.4	12.0	0.3
32	51.	-13.	0.	0.0314	4178.7	218.5	1.8	337.	117.8	11.9	0.2
33	51.	-14.	0.	0.0314	4178.7	218.3	2.0	338.	112.6	11.4	0.2

THERMAL PERFORMANCE BROOKHAVEN 152 X-32

MANUFACTURER: BROOKHAVEN 152

MODEL: X-32

GROSS AREA = 19.55 F

TEST	DATE	SOLAR TIME START END	TA (F)	TI (F)	TE (F)	FLOW GPM	AVE IN B/H-FT2	TOTAL IN BTU/SQ FT	(TE-TI) (F)	DEL T F-MIN	EFF %	(TI-TA/I (F-H-FT2)
13	11/25/80	9:47 9:52	70.6	161.5	170.8	0.501	307.4	25.6	9.36	46.8	38.2	0.296
14	11/25/80	9:52 9:57	71.0	161.2	170.6	0.500	306.2	25.5	9.38	46.9	38.3	0.295
15	11/25/80	9:57 10: 2	71.4	161.2	170.4	0.500	301.6	25.1	9.13	45.7	37.9	0.298
16	11/25/80	10: 2 10: 7	71.4	161.2	170.3	0.500	300.8	25.1	9.12	45.6	37.9	0.299
21	11/25/80	10:53 10:58	72.7	196.1	202.9	0.500	311.7	26.0	6.78	33.9	27.0	0.396
22	11/25/80	10:58 11: 3	73.0	196.3	203.2	0.501	310.8	25.9	6.88	34.4	27.5	0.397
23	11/25/80	11: 3 11: 8	72.7	196.1	202.8	0.501	311.9	26.0	6.69	33.5	26.7	0.396
25	11/25/80	11:40 11:45	73.1	119.1	132.7	0.499	315.3	26.3	13.58	67.9	54.3	0.146
26	11/25/80	11:45 11:50	73.1	119.2	132.8	0.499	315.6	26.3	13.58	67.9	54.2	0.146
28	11/25/80	11:55 12: 0	73.1	118.7	132.4	0.498	315.4	26.3	13.70	68.5	54.6	0.145
29	11/25/80	12: 0 12: 5	73.2	118.4	132.1	0.499	316.3	26.4	13.71	68.5	54.7	0.143
30	11/25/80	12:30 12:35	73.5	74.1	90.9	0.500	315.5	26.3	16.80	84.0	67.9	0.002
32	11/25/80	12:40 12:45	73.6	74.0	90.9	0.500	314.8	26.2	16.84	84.2	68.1	0.001
33	11/25/80	12:45 12:50	73.6	74.0	90.8	0.499	314.4	26.2	16.80	84.0	68.0	0.001

THE FIRST ORDER EFFICIENCY CURVE IS: EFFICIENCY = 68.8 -104.1 (TI-TA)/I
THE UNITS ON (TI-TA)/I ARE (F-HR-SQ FT)/BTU.

THE SECOND ORDER EFFICIENCY CURVE IS: EFFICIENCY = 68.2 -91.3 DT/I -32.3 (DT/I)2
THE UNITS ON DT/I ARE (F-HR-SQ FT)/BTU. DT=TI-TA

MANUFACTURER: BROOKHAVEN 152

MODEL: X-32

GROSS AREA = 19.55 S F

TEST	TILT DEG	AZIM DEG	INCI DEG	MASS LBM/MIN	SPEC HEAT BTU/(LBM-F)	IN P PSI	WIND MPH	WIND DIR	DIF IN B/H-FT2	% DIFF INSOL	TI-TA (F)
13	59.	36.	0.	4.08	1.001	31.1	4.0	321.	50.4	16.4	90.9
14	58.	35.	0.	4.07	1.001	31.1	4.4	317.	62.7	20.5	90.3
15	58.	33.	0.	4.07	1.001	31.1	3.1	323.	40.1	13.3	89.9
16	57.	32.	0.	4.07	1.001	31.0	4.0	319.	36.6	12.2	89.8
21	52.	19.	0.	4.02	1.005	31.2	2.6	333.	34.2	11.0	123.4
22	52.	18.	0.	4.03	1.005	31.3	3.3	336.	33.4	10.8	123.3
23	51.	16.	0.	4.03	1.005	31.3	4.0	335.	35.5	11.4	123.4
25	50.	5.	0.	4.11	0.999	31.7	4.1	336.	37.9	12.0	46.0
26	50.	4.	0.	4.11	0.999	31.7	4.3	341.	37.5	11.9	46.2
28	50.	1.	0.	4.10	0.999	31.7	3.9	339.	38.0	12.1	45.6
29	50.	-1.	0.	4.11	0.999	31.9	4.1	341.	37.5	11.9	45.2
30	50.	-10.	0.	4.16	0.998	31.7	4.4	342.	37.9	12.0	0.6
32	51.	-13.	0.	4.15	0.998	31.7	4.1	337.	37.4	11.9	0.4
33	51.	-14.	0.	4.15	0.998	31.7	4.4	338.	35.7	11.4	0.4

FLORIDA SOLAR ENERGY CENTER

300 State Road 401, Cape Canaveral, Florida 32920. Telephone: (305) 783-0300

State University System of Florida

June 9, 1981

RECEIVED

JUN 11 1981

William G. Wilhelm
Brookhaven National Laboratory
Building 701
Upton, New York 11973

SOUTHERN SOLAR ENERGY
CENTER

Dear Bill:

Enclosed is a revision sheet to the test report on your Model X-29, X-31 and X-32 solar collectors. The specific change is a more detailed description of the condition of the Model X-32 after exposure.

The initial report stated that "the absorber buckled." A close reexamination showed that what was described as buckling were a number of creases caused by loss of adhesion between the absorber coating laminate and the absorber itself along the fusion lines of the absorber. The adhesive did not degrade above the fluid flow path but only above the fusion lines.

I understand that all of the degradations that appeared after exposure were due to the prototype nature of the collector. We were told when the collectors were delivered that problems were expected with the adhesive and that the adhesive material was being changed. Breakdown of the foil tape holding the collector together was not totally unexpected either. I assume the foil tape was only a temporary measure. Certainly, other methods of fastening the enclosure are available.

Overall, I was impressed with the results. Performance of the collector compares favorably with other collectors of its type. A trial energy rating, in accordance with the Florida rating method, shows that the collector produces 14,800 BTU per day at the intermediate temperature (122°F). Energy rating per gross area is 757 BTU per square foot. Collectors with higher ratings generally use glass as a cover plate. The only plastic glazed collectors with higher intermediate ratings used two covers or used a black chrome selective surface on copper sheet and tube. Enclosed is a copy of the March 1981 Thermal Performance Ratings of the FSEC approved solar collectors. You may wish to make your own comparison.

Based on the thermal performance results, I believe further development is justified. If the collector can be produced for relatively low cost, its potential is great.

If I can be of further assistance or if you have any questions, please contact me.

Sincerely,

James D. Roland

James D. Roland
Director, Testing and Laboratories Division

**Thin-Film Plastic Solar Collector
Technical Review**

**January 13, 1981
Brookhaven National Laboratory**

Agenda

8:30 - 9:00 AM	Coffee and Danish
9:00 - 9:10 AM	Opening Remarks, T.E. O'Hare
9:10 - 10:00 AM	Thin-Film Plastic Collector Update, W.G. Wilhelm
10:00 - 10:15 AM	Coffee
10:15 - 11:00 AM	Questions
11:00 - 12:00 AM	Field Visit - Collector Fabrication Test Facility
12:00 - 1:00 PM	Lunch
1:00 - 3:30 PM	Deliberation of Committee
3:30 - 3:45 PM	Coffee
3:45 - 4:45 PM	Discussion of Committee Findings

LIST OF ATTENDEES

Thin-Film Plastic Solar Collector Technical Review

January 13, 1981

Mr. Kirk Collier
Solar Energy Research Institute
1536 Cole Boulevard
Golden, CO 80401
(FTS) 327-1761

Mr. G. W. Knowles
Grumman Energy Systems, Inc.
10 Orville Drive
Bohemia, NY 11716
(516) 244-2786

Mr. Bud Nickelson
Polymer Products Department
E. I. DuPont DeNemours & Co.
Wilmington, DE 19898
(302) 744-8695

Dr. Louis A. Ross
General Manager
Polymer and Plastics Technology
The Continental Group, Inc.
One Harbor Plaza
Stamford, CT 06902
(203) 964-6109

Mr. Kenneth H. Speiser, Manager
Grumman Energy Systems, Inc.
10 Orville, Drive
Bohemia, NY 11716
(516) 244-2786

Mr. William Stony
Southern Solar Energy Center
61 Perimeter Park
Atlanta, GA 30341
(404) 458-8765

Mr. Thomas Wiggins, Manager
Resin and Catalyst Sales
Vistron Corp.
1653 Midland Building
Cleveland, OH 44113

Mr. Ralph Williams
Polymer Products Department
E. I. DuPont DeNemours & Co.
Wilmington, DE 19898
(302) 744-8695

Dr. John Andrews
Solar Technology Group
Brookhaven National Laboratory
Building 701
Upton, NY 11973
(516) 345-7726
(FTS) 666-7726

Dr. Philip D. Metz
Solar Technology Group
Brookhaven National Laboratory
Building 701
Upton, NY 11973
(516) 345-3596
(FTS) 666-3596

Mr. William G. Wilhelm
Solar Technology Group
Brookhaven National Laboratory
Building 701
Upton, NY 11973
(516) 345-4708
(FTS) 666-4708

Mr. Robert J. Isler
Brookhaven National Laboratory
Building 120
(516) 345-2405
(FTS) 666-2405

Mr. Thomas E. O'Hare
Brookhaven National Laboratory
Building 120
Upton, NY 11973
(516) 345-3428
(FTS) 666-3428

<u>Cost Item for a 4'x8' Collector</u>	<u>New Material</u>	<u>Available Material</u>
Frame (.10 per ft.)	\$ 2.40	\$ 2.40
Glazing Film	3.97	8.96
Absorber 2 polyester	1.36	14.08
2 aluminum foil	1.79	1.79
Absorber coating (.2/sq.ft.)	.64	.64
Coupling	.40	.40
Exterior hardware	.50	.50
Insulation (.10/sq.ft.)	3.20	3.20
Product Labor	1.10	1.10
	<hr/>	<hr/>
	15.36	33.07
+15% waste	<u>2.30</u>	<u>4.96</u>
	17.66	38.00
	 55¢/sq.ft.	 \$1.19/sq.ft.

THIN-FILM COLLECTOR EVALUATION QUESTIONNAIRE

BROOKHAVEN NATIONAL LABORATORY

January 13, 1981

Reviewer _____

In addressing the first two questions, consider all of the following: suitability of the materials, amenability to low-cost fabrication, marketing and distribution, system life vs cost, as well as any others you think appropriate.

1. What are the strong points of the thin-film collector concept?

2. What are the greatest potential problems or weaknesses associated with the concept?

The following two questions should be addressed in the light of your answers to Questions 1 and 2.

3. Are our economics sound? Consider both the solar system cost goals and the BNL collector manufacturing cost projections.

4. Is this technology sufficiently promising to warrant further effort? Why or why not?

The remaining questions are appropriate if you feel further development is warranted. If not, leave them blank.

5. Which of the following actions are most needed to bring this technology into the marketplace? Place a 1 beside the action you feel is most critical, a 2 beside the second most important, etc. If you feel an action is relatively unimportant place no number alongside. Use the space below to elaborate as you feel necessary.

ACTION

- A. Develop improved materials
- B. Refine collector design
- C. Develop fabrication techniques
- D. Solve balance-of-system problems
- E. Develop marketing and distribution channels
- F. Other (describe)

6. This set of questions is intended to obtain your opinion concerning the proper role of each of the various actors in this program. What should be the role of industry in any further development? What segments of industry are most needed? What role, if any, should BNL play? Is further government funding needed? If so, how much? Is a partnership between BNL and industry desirable?

SOUTHERN SOLAR ENERGY CENTER

MEMORANDUM

TO: Files *WES*

DATE: January 14, 1981

FROM: William E. Stoney

SUBJECT: Trip Report

On January 13, I attended a meeting at Brookhaven National Laboratory (see attached agenda and list of attendees). The meeting was called by Brookhaven to obtain outside opinions on what should be the next steps in their thin-film plastic collector program.

Of the invited outside attendees (see list), myself, the two gentlemen from Grumann, and the two from DuPont attended. The format of the meeting followed the agenda. The morning was spent discussing the planning rationale, the technical performance, the construction details, and potential cost reductions of the thin-film plastic collector. This material is contained in the two reports: "Low-Cost Solar Collectors Using Thin-Film Plastics Absorbers and Glazing" and "Thin-Film Flat-Plate Solar Collectors for Low-Cost Manufacture and Installation." In the afternoon the five outside members met alone and discussed and answered the questions (collectively) asked in the attached questionnaire.

The essence of the group's, essentially unanimous, conclusions follows:

- It was agreed that the essential contribution of the Brookhaven effort was the demonstration that a thin-film plastic absorber could be built to produce performance equal to at least the mid-range or better of the conventional designs.
- The various collector configurations and construction details conceived and built by the laboratory were felt to be useful but not unique contributions.
- The committee noted that the major deterrent to the adoption of the plastic collector would be the common perception that plastics are not as good as copper. It was noted that this is a generic problem which any plastic system must overcome, but that therefore, a long term outdoor exposure program should be started immediately because it would always be necessary to convince the skeptics with test data.
- The committee also noted that none of the laboratory tests had included a heat-welded absorber (the configuration tests had been constructed with adhesive binding because of the lack of welding capability at the laboratory). It was therefore recommended that several sets of heat-welded configurations be constructed and tested as quickly as possible.
- The group felt that the cost estimates presented at the meeting, which range from 55¢ per square foot for advanced materials to \$1.19 per square foot with presently available films, were probably optimistic. Dr. Wilhelm had made these estimates based on a single glazed optimum

SOUTHERN SOLAR ENERGY CENTER

MEMORANDUM (continued)

PAGE 2

FROM: William E. Stoney

DATE: January 14, 1981

absorption coated design. He used a value of 2¢ per square foot for the absorptive coating having received quotes in that range. Conventional techniques cost \$1-2 per square foot and thus, the Grumann representatives registered some skepticism at the low number. In any case, it was agreed that a production cost of \$5 per square foot was certainly reasonable with currently available materials and that that was sufficient to be of interest to the industry.

- It was pointed out that the collector itself represented approximately 1/3 the cost of installed hot water systems and thus, a 50% reduction in the collector cost should result in a 16-20% savings in the total savings--not revolutionary, but extremely worthwhile.
- It was noted that the plastic absorber required an ambient pressure drain down system configuration. The Grumann representatives noted that this might be considered a problem by some designers especially those who had initially experimented with drain down systems and had had troubles due to freezing.

The above summarizes the more or less factual findings of the committee. On the crucial question of what next, the committee strongly recommended transferring the good news to industry as rapidly and forcefully as possible. In particular, it was suggested that:

- The feasibility of high performance plastic absorbers should be presented to those segments of industry capable of adapting it as soon as possible. It was pointed out that industry could adapt the concept in a wide variety of configurations going all the way from relatively simple substitution of plastic absorbers for the copper absorber in conventional glass and metal collectors, to the creation of all plastic thin-film configurations which could include simple replacement of the glazing film as a design feature should the use of currently available plastics require that.
- The discussion on transferring the technology to industry brought forth an idea from Mr. Speiser that the laboratory consider producing perhaps as many as fifty or so plastic absorbers that would be handed out to attendees at the technology transfer meeting. He pointed out that the main problem in the adaptation of any new technology involves first convincing the technical staff of a corporation who must in turn have the hard material to convince management to spend hard resources in the development process. He felt that there would be nothing better than a sample which could be tested and displayed back at the home plant.

SOUTHERN SOLAR ENERGY CENTER

MEMORANDUM (continued)

PAGE 3

FROM: William E. Stoney

DATE: January 14, 1981

- Mr. Speiser noted that it might be useful to combine the regional centers' technology transfer capabilities with the laboratory's R&D function in developing the approach to disclosure to industry.
- It was finally noted that there were areas, especially in component and total system configuration design which should receive further R&D by Brookhaven, especially in the development of low-cost drain down systems of the type necessary for use with the plastic absorber.

WES:smb

Attachments (4)

cc: L. Leonaitis
B. Denny
K. Turkia