MILLIMETER ARRAY
MEMO NO. 19

VLA Atmospheric Opacity at 225 GHz, June and July 1984

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I. Introduction

Measurements of the transparency of the sky at 225 GHz were made during June and July 1984 in order to help determine the desirability of building a millimeter array near the VLA. The measurements were made using a tipping, room temperature radiometer built at NRAO/Kitt Peak by John Payne and Graham Maury. The radiometer's system temperature, looking at blank sky is

$$Tsky = Tr + (1-e)*T1 + e*Tat*(1-exp(-t*secz)) + T3K*e*exp(-t*secz). \tag{1}$$

Looking at an ambient temperature load on a chopper wheel,

$$Tload = Tr + (1-e)*T1 + e*Tamb. \tag{2}$$

Using a synchronous detector to difference between sky and load, the detector output in volts is:

$$D = g*[e*Tamb - e*Tat*(1 - exp(-t*secz))] \tag{3}$$

where:

Tr = receiver temperature (approximately 2000K)
e = coupling efficiency
T1 = temperature at which losses are terminated
Tat = mean temperature of the atmosphere
t = zenith optical depth of the atmosphere
secz = secant of zenith angle
T3K = temperature of 3K background
Tamb = ambient temperature of the atmosphere at ground
g = gain calibration factor (volts/K)

and T3K has been assumed to be negligible.

If we assume Tat and Tamb are equal:

$$D = g*e*Tamb*exp(-t*secz) \tag{4}$$

or

$$ln(D) = ln(g*e*Tamb) - t*secz \tag{5}$$

allowing us to find t immediately, via a linear least squares analysis.

II. Observations

An observing scan consisted of reading the detector output for 6 standard zenith angles (67.4, 64.2, 60.0, 54.0, 44.4 and 24.6 degrees) equally spaced in secz. This process was repeated 3 times at each observing run.

In general two observing runs were made each day, one in the morning and one in the mid afternoon. The radiometer was pointed northeast from the back of the control building until noon of June 28, when it was moved to the Tech. Services Building. From here it was pointed west from the back of the building. Measurements were discontinued after July 11 in order to modify the radiometer.

The zero point of the synchronous detector was measured for each observing scan in one of two ways. Initially the zero point was measured by pointing the reflector at a piece of absorbing material, located 180 deg. from zenith. Later, placing a large slab of such material in front of the radiometer and looking at it at the standard angles was tried. The two methods agreed typically within .10V. The offset ranged from +.05 to -.30V from day to day. No obvious correlation between the offset change and the weather was noted. In the data analysis, the second method of obtaining an offset was used whenever it was available.

The servo-mechanism which moved the main parabolic reflector was unstable for certain zenith angles (67.4 and less frequently 64.2 and 24.6 deg.). This wobbling of the mirror could lead to uncertainties as high as +/-.15V in D.

III. DATA ANALYSIS

A linear least squares fit was made to the ln(D) vs. secz data for each scan. Figures I., II., and III. show the fits for low, medium and high t days. Typically the calibration factor (g*e in equation (4)) is 50 K/V. The optical depth, t, and its error based on residuals were calculated for each scan. A weighted mean of the three scans gives the results for each observing run. The error for the mean t is derived from the weighted internal errors of the 3 scans. If there was a large difference in t among the three scans, the error is based instead on the dispersion of the scans.

In addition to the random errors discussed above, an error in the measured detector offset and the assumed Tamb - Tat = 0, will produce systematic errors in t. Both of these errors will be proportional to t, since they will effect ln(D) mostly at values of D near zero, i.e., in cases of large t.

A +0.1V detector offset error will lower the measured t by .004 if t = .2 and by .1 if t = 1.0

Likewise, using a standard -6.5 C/km ICAO lapse rate and an effective water vapor height of one kilometer, the Tamb - Tat effect will produce an additional offset error of about +0.1V, resulting in systematic errors similar to those noted above.

Since the magnitude of these systematic errors are quite uncertain, they have not been incorporated into the results.

IV. DISCUSSION

Table I. shows the dates, times, weather conditions, and results of each observing run. The wind direction, speed, temperature, dew point and barometer were measured by the VLA weather station near the control building. The vapor pressure, e, was computed by:

$$\begin{aligned} e &= \exp[(D + 22.82)/13.08] \text{ for } D < 10 \text{ C} \\ e &= \exp[(D + 33.50)/17.34] \text{ for } D > 10 \text{ C} \end{aligned} \qquad (6)$$

where:

D = dew point in deg. celsius.

The relative humidity, r, was found by interpolation in tables given in the CRC Handbook of Chemistry and Physics (p. E44). The surface absolute humidity, HO (in gm/m**3), was computed by:

$$HO = 13.239 * r/(\mathrm{Tamb} + 273.16) * 10^{**}X \qquad (7)$$

where:

$$\begin{aligned} X &= 7.5 * T/(\mathrm{Tamb} + 237.3) \text{ for Tamb} > 20 \text{ C} \\ X &= 9.5 * T/(\mathrm{Tamb} + 265.3) \text{ for Tamb} < 20 \text{ C} \end{aligned}$$

The codes for cloud cover given in Table I. refer only to conditions in the beam of the radiometer.

A)

The summer is expected to be the worst time for millimeter observations. The data presented here are therefore examples of poor observing conditions at the VLA.

Table II. gives average values of t as a function of cloud cover, using the same codes as in Table I. While <t> for clear days is .449, on some days t can be as low as .2. The overall <t> for all days, however, is a rather opaque 0.717.

B)

No correlation between t and time of day was noted, as can be seen in Figure IV. This result may be misleading however, since measurements were not made during rain showers which occured in the afternoon on about one third of the days.

C)

The opacity at 225 GHz arises from water vapor and hydrosol in the air. The opacity due to dry air is negligible. Figures V. and VI. plot t vs.

HO for A/B and C/D/E type days (using weather codes in Table I). Coefficients for a linear relationship

$$t = C0 + C1*H0 \tag{8}$$

and linear correlation coefficients, rc, are shown on the figures. There is in general a good correlation between t and H0. It appears that water vapor measured on the ground is a reasonable indicator of optical depth, especially on clearer days.

In the absence of significant hydrosol (day types A and B) the mean ratio <t/H0> can be used to estimate the scale height of the water vapor, h0 (in km). The amount of precipitable water vapor, C (in mm), is given by:

$$C = \int_0^\infty H*dh \tag{9}$$

$$C = \int H0*\exp(-h/h0)*dh \tag{10}$$

$$C = h0*H0. \qquad (\mathrm{mm}) \tag{11}$$

t is related to C by:

$$t = b*C \tag{12}$$

where

$$b = .067 \text{ nepers/mm (Ulich, 1976).}$$

Combining equations (11) and (12), we find

$$h0 = (t/H0)*(1/b). \tag{13}$$

For A and B days combined, <t/H0> is .099, giving h0 = 1.48 km, a rather reasonable value.

REFERENCES

Ulich, B. L., 1976, NRAO 25 Meter Millimeter Wave Telescope Memo #64

Weast, R. C. ed., 1974, Handbook of Chemistry and Physics, CRC Press, Cleveland, OH, 55th edition.

TABLE I.
OBSERVATIONAL RESULTS

DATE	TIME	WDIR (deg)	WSPD (m/s)	TEMP (C)	DEW (C)	e (mb)	r (%)	HO (g/m^3)	BAR (mb)	t (nep)	σ(t)	WX CODE
08-JUN-84	14:30	180.	2.2	9.7	2.4	7.	61.	6.1	789.	0.448	0.008	C
11-JUN-84	13:30	221.	9.0	25.0	-8.6	3.	10.	2.3	788.	0.233	0.009	B
11-JUN-84	15:55	226.	7.7	25.6	-9.4	3.	9.	2.2	786.	0.249	0.013	A
12-JUN-84	08:55	163.	1.4	16.8	-4.2	4.	24.	4.0	790.	0.278	0.010	A
12-JUN-84	16:55	235.	5.8	26.0	-11.2	2.	8.	1.9	787.	0.211	0.007	A
12-JUN-84	20:20	193.	4.4	22.7	-3.3	4.	17.	3.5	788.	0.337	0.012	A
13-JUN-84	08:15	43.	1.3	15.5	-5.3	4.	24.	3.6	791.	0.342	0.011	A
13-JUN-84	13:20	148.	3.7	26.5	-8.1	3.	10.	2.4	790.	0.426	0.022	B
13-JUN-84	15:55	186.	9.4	27.2	-3.1	5.	13.	3.5	789.	0.305	0.008	B
14-JUN-84	12:55	117.	6.3	22.4	7.7	10.	39.	7.7	791.	0.766	0.031	D
14-JUN-84	20:35	34.	1.4	17.6	8.7	11.	56.	10.0	791.	0.796	0.019	D
18-JUN-84	9:35	267.	4.2	18.3	7.1	10.	48.	8.9	792.	0.585	0.015	B
18-JUN-84	14:55	228.	4.0	22.9	2.0	7.	26.	5.2	790.	0.751	0.015	C
19-JUN-84	11:15	225.	7.8	13.9	10.2	12.	79.	10.8	793.	0.976	0.029	B
20-JUN-84	08:55	267.	1.7	13.1	9.9	12.	81.	10.5	794.	0.799	0.095 *	A
20-JUN-84	13:30	239.	5.3	23.1	1.4	6.	24.	5.0	792.	0.695	0.014	D
21-JUN-84	13:05	250.	5.7	23.6	-4.7	4.	15.	3.1	792.	0.472	0.055 *	A
21-JUN-84	16:00	23.	1.2	7.6	4.4	8.	80.	7.0	794.	0.635	0.024	C
22-JUN-84	08:50	261.	2.1	18.8	2.0	7.	33.	6.4	793.	0.447	0.013	A
25-JUN-84	09:00	127.	2.3	17.5	10.2	12.	63.	11.0	797.	0.616	0.143 *	D
25-JUN-84	11:10	246.	4.5	19.6	9.3	12.	52.	10.5	797.	0.771	0.081	D
26-JUN-84	09:45	231.	2.5	19.0	10.6	13.	58.	11.4	794.	0.905	0.049	D
26-JUN-84	12:45	292.	1.8	23.1	8.1	11.	38.	7.9	792.	0.882	0.036	C
27-JUN-84	13:20	180.	2.8	17.3	12.5	14.	74.	12.8	793.	1.660	0.202	D
28-JUN-84	09:00	106.	2.5	17.3	10.3	13.	63.	11.0	795.	0.730	0.027	A
28-JUN-84	13:30	83.	3.9	24.5	5.2	9.	29.	6.5	794.	0.709	0.070 *	B
29-JUN-84	08:55	97.	0.7	19.1	10.2	12.	57.	11.1	795.	0.620	0.016	A

02-JUL-84	09:05	237.	1.8	17.3	11.2	13.	68.	11.8	794.	1.111	0.028	D
02-JUL-84	16:20	335.	1.5	15.0	11.2	13.	78.	11.6	794.	1.140	0.148	C
03-JUL-84	08:50	218.	3.3	13.2	8.8	11.	75.	9.7	793.	0.925	0.028	B
05-JUL-84	11:15	277.	2.3	24.4	6.8	10.	33.	7.3	791.	0.822	0.020	B
06-JUL-84	08:50	215.	4.1	20.3	10.8	13.	55.	9.6	793.	0.972	0.022	B
09-JUL-84	10:40	19.	1.7	24.0	7.6	10.	35.	7.7	792.	0.900	0.022	B
09-JUL-84	12:45	196.	0.9	26.4	3.6	8.	23.	5.7	791.	0.622	0.176 *	B
10-JUL-84	08:30	267.	1.2	20.6	9.1	11.	48.	8.5	792.	0.963	0.017	B
10-JUL-84	12:45	256.	1.7	26.7	5.7	9.	26.	6.6	791.	1.310	0.241	E
11-JUL-84	09:00	80.	4.0	17.0	10.8	13.	67.	11.4	795.	1.132	0.055	D

CODES FOR WEATHER CONDITIONS:

A = CLEAR
B = SCATTERED CLOUDS
C = BROKEN CLOUD COVER
D = OVERCAST
E = STORM CLOUDS

* = ERROR FROM SCAN DISPERSION, NOT BASED ON INTERNAL ERRORS

TABLE II.
AVERAGE OPACITIES

Weather Codes	<t>	<t/HO>	% DAYS
A DAYS	0.449	0.090	27.
B	0.703	0.106	32.
C	0.771	0.104	14.
D	0.939	0.095	24.
AB	0.587	0.099	
CDE	0.908	0.104	
ALL	0.717	0.101	

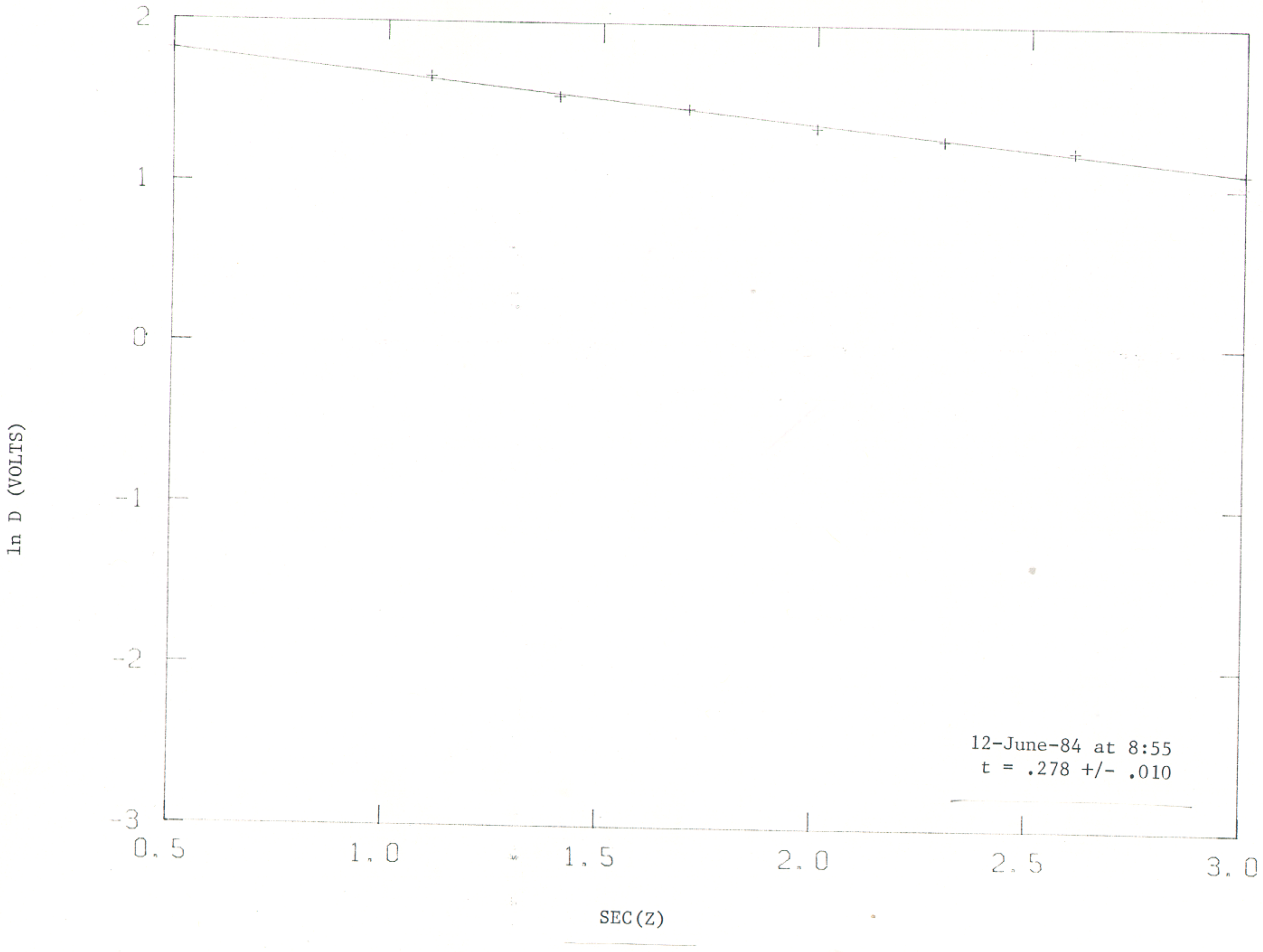

2
1
0
-1
-2
-3
0.5
1.0
1.5
2.0
2.5
3.0
ln D (VOLTS)
SEC(Z)
12-June-84 at 8:55
t = .278 +/- .010

FIGURE I.

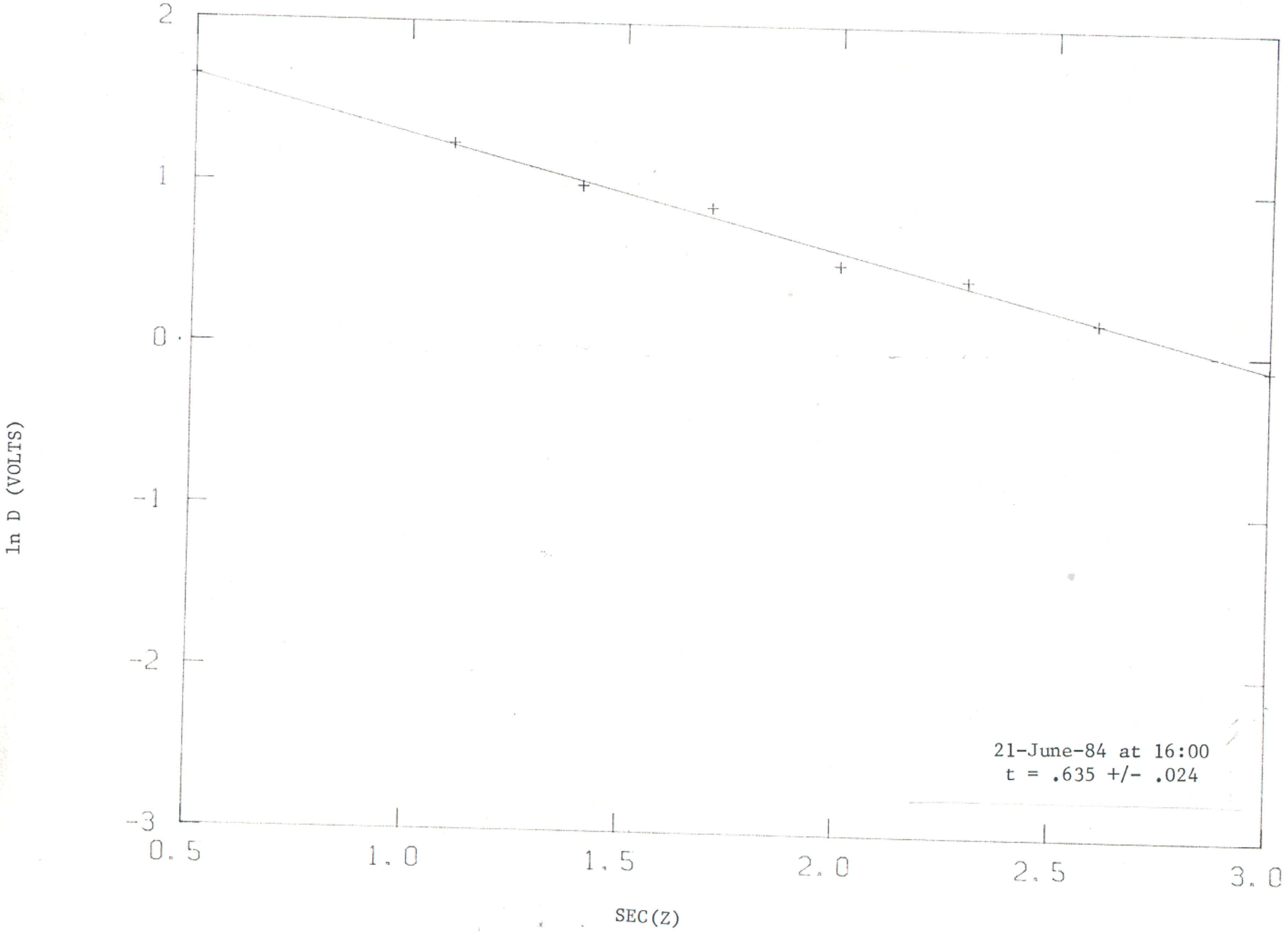
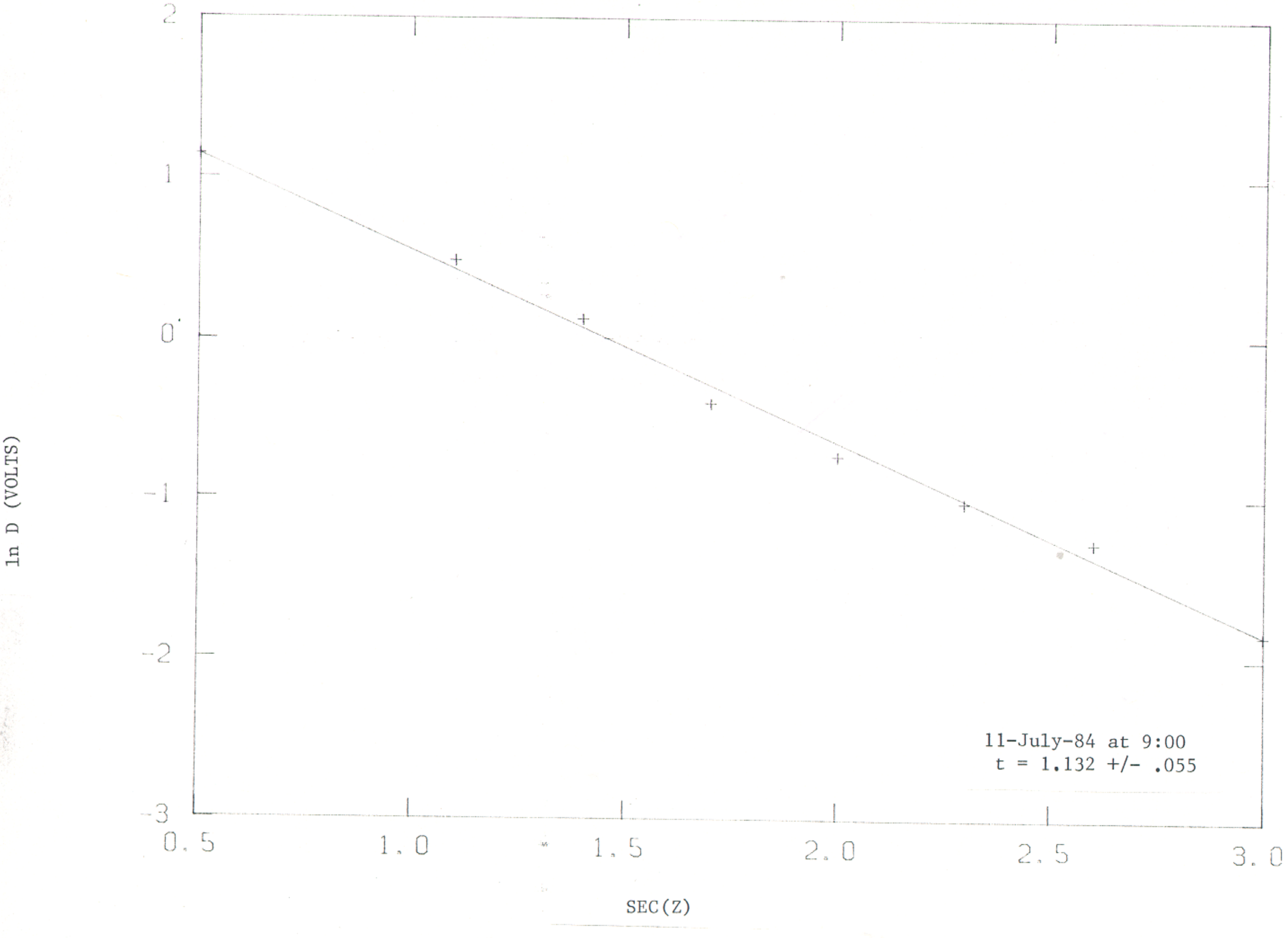

2
1
0.
-1
-2
-3
0.5
1.0
1.5
2.0
2.5
3.0
ln D (VOLTS)
SEC(Z)
21-June-84 at 16:00
t = .635 +/- .024

FIGURE II.



11-July-84 at 9:00
t = 1.132 +/- .055

FIGURE III.

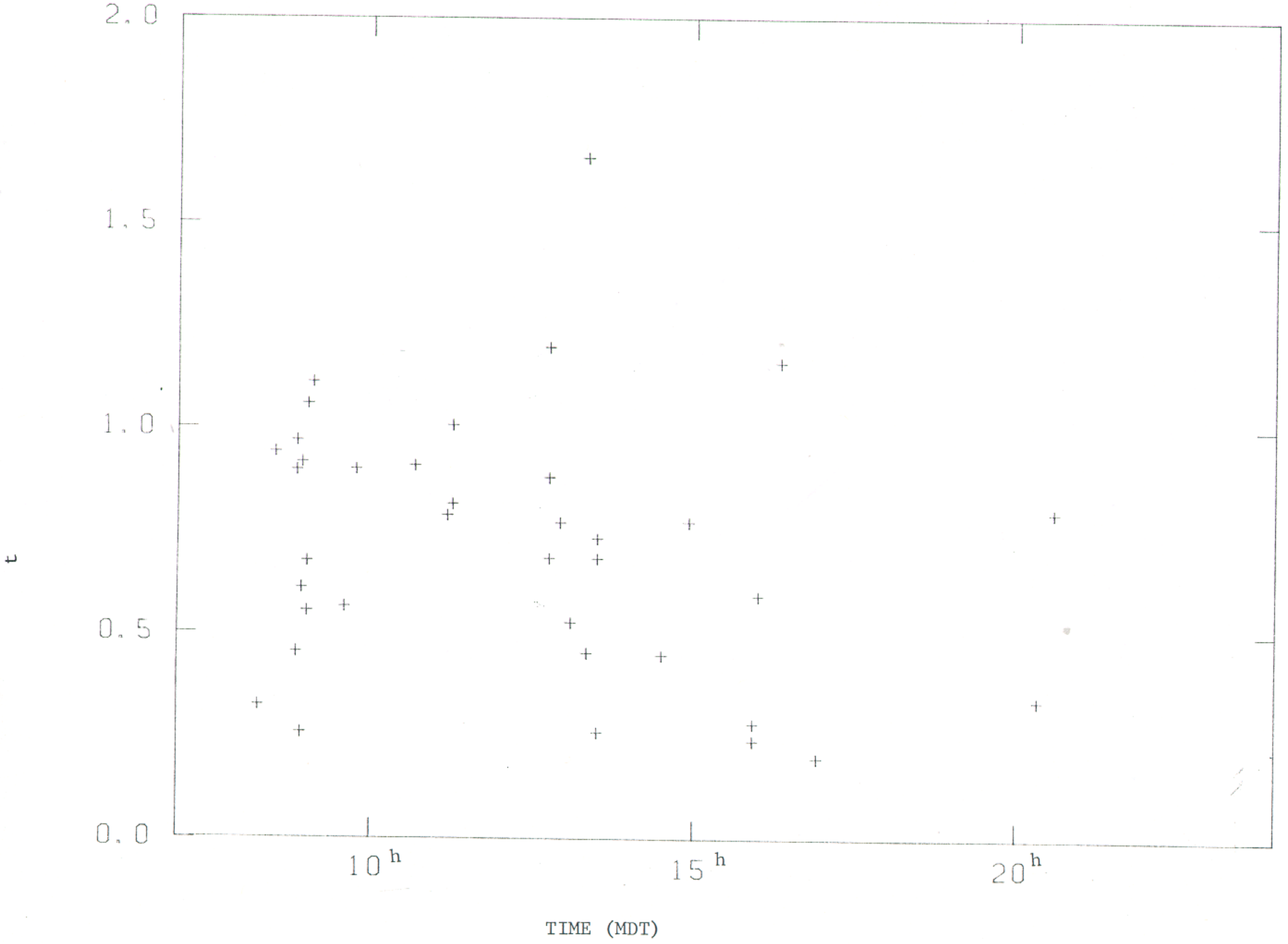


FIGURE IV.

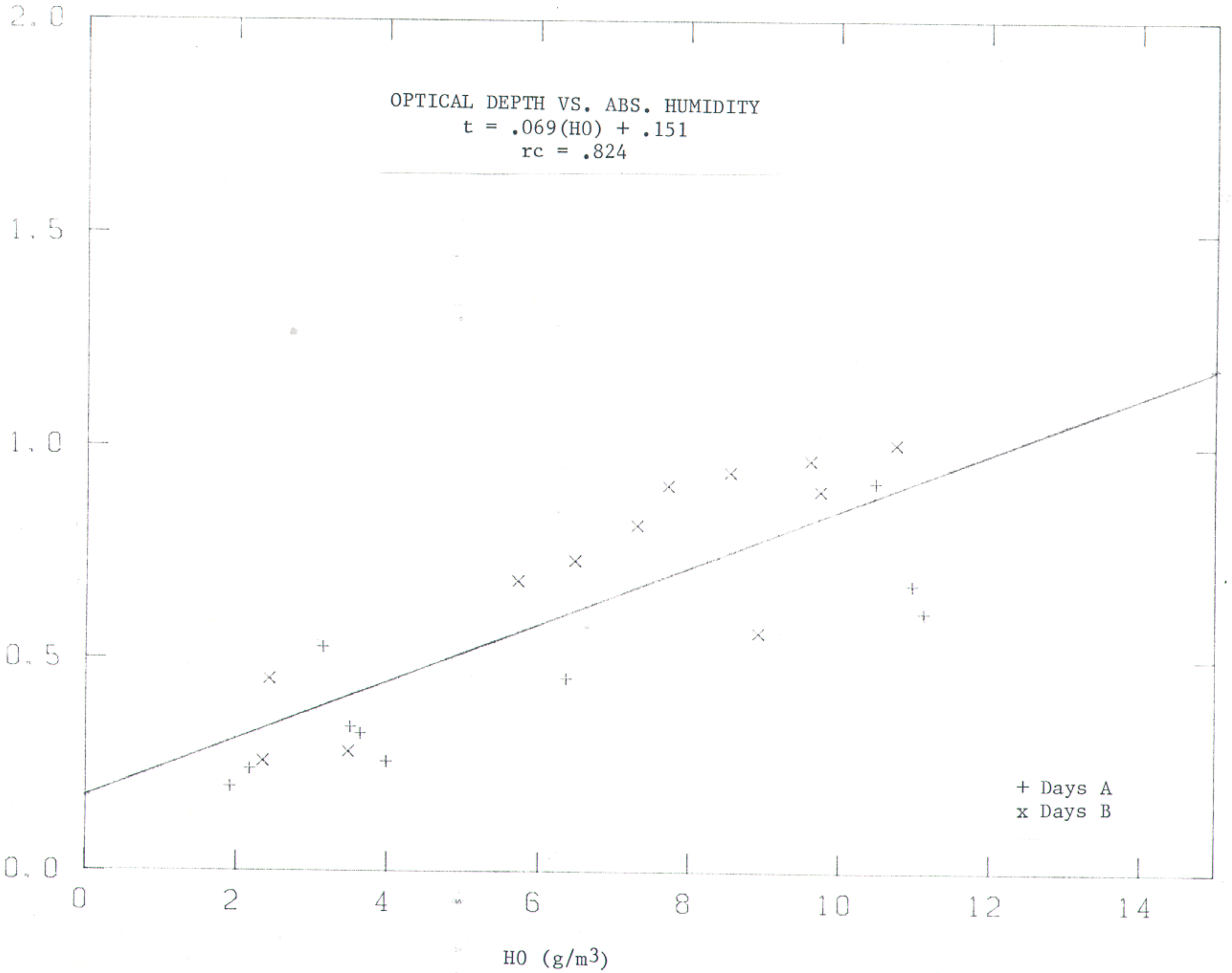

OPTICAL DEPTH VS. ABS. HUMIDITY
t = .069(HO) + .151
rc = .824
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
12
14
HO (g/m3)
+ Days A
x Days B

FIGURE V.

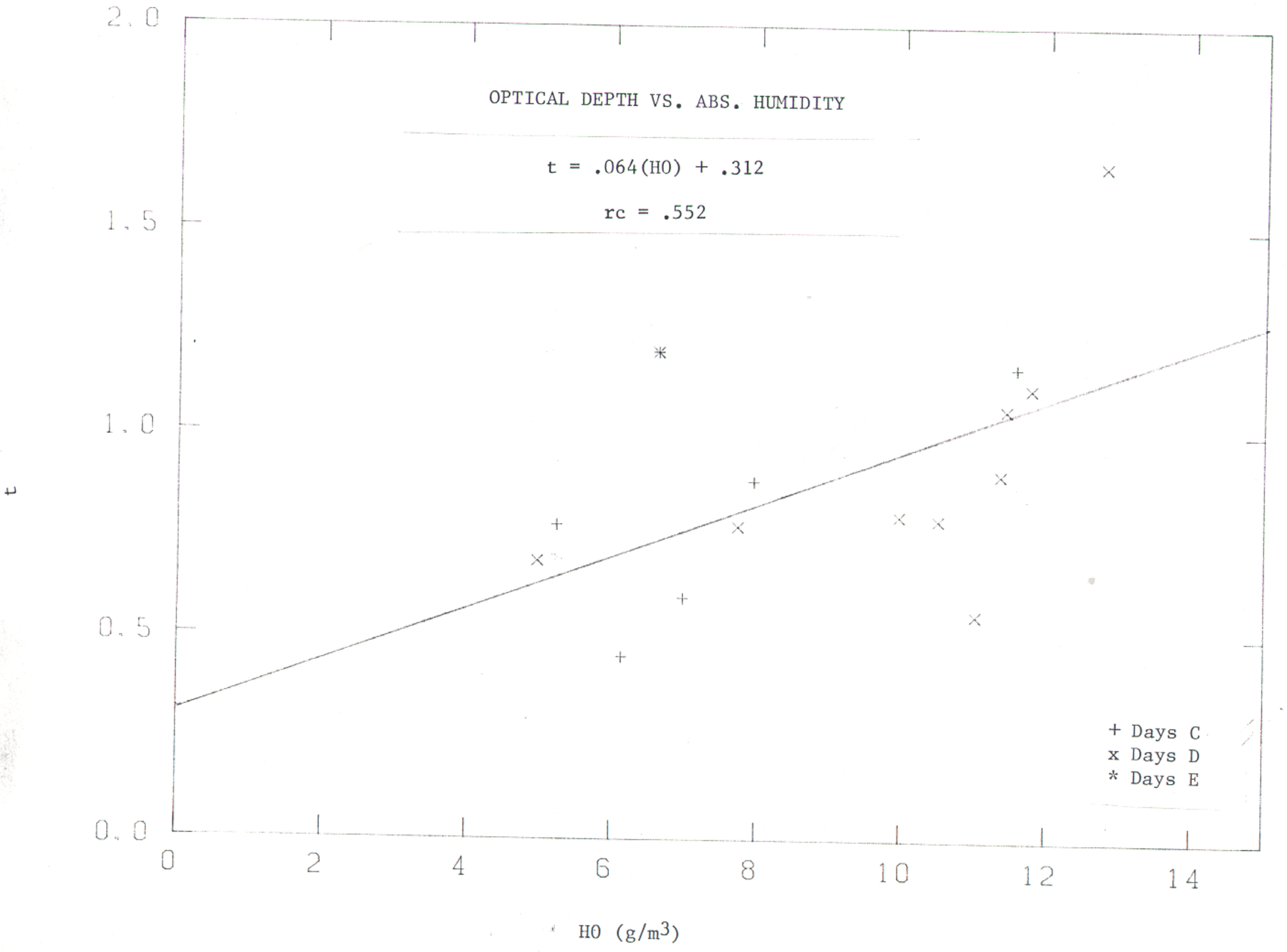

OPTICAL DEPTH VS. ABS. HUMIDITY
t = .064(HO) + .312
rc = .552
t
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
12
14
HO (g/m3)
+ Days C
x Days D
* Days E

FIGURE VI.