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THE SOLAR IRRADIANCE ENVIRONMENT
OF FLORIDA COASTAL WATER DURING FLARE

Kirby J. Hanson
Monte F. Poindexter

Sea-Air Interaction Laboratory

Atlantic Oceanographic and Meteorological Laboratories
Miami, Florida
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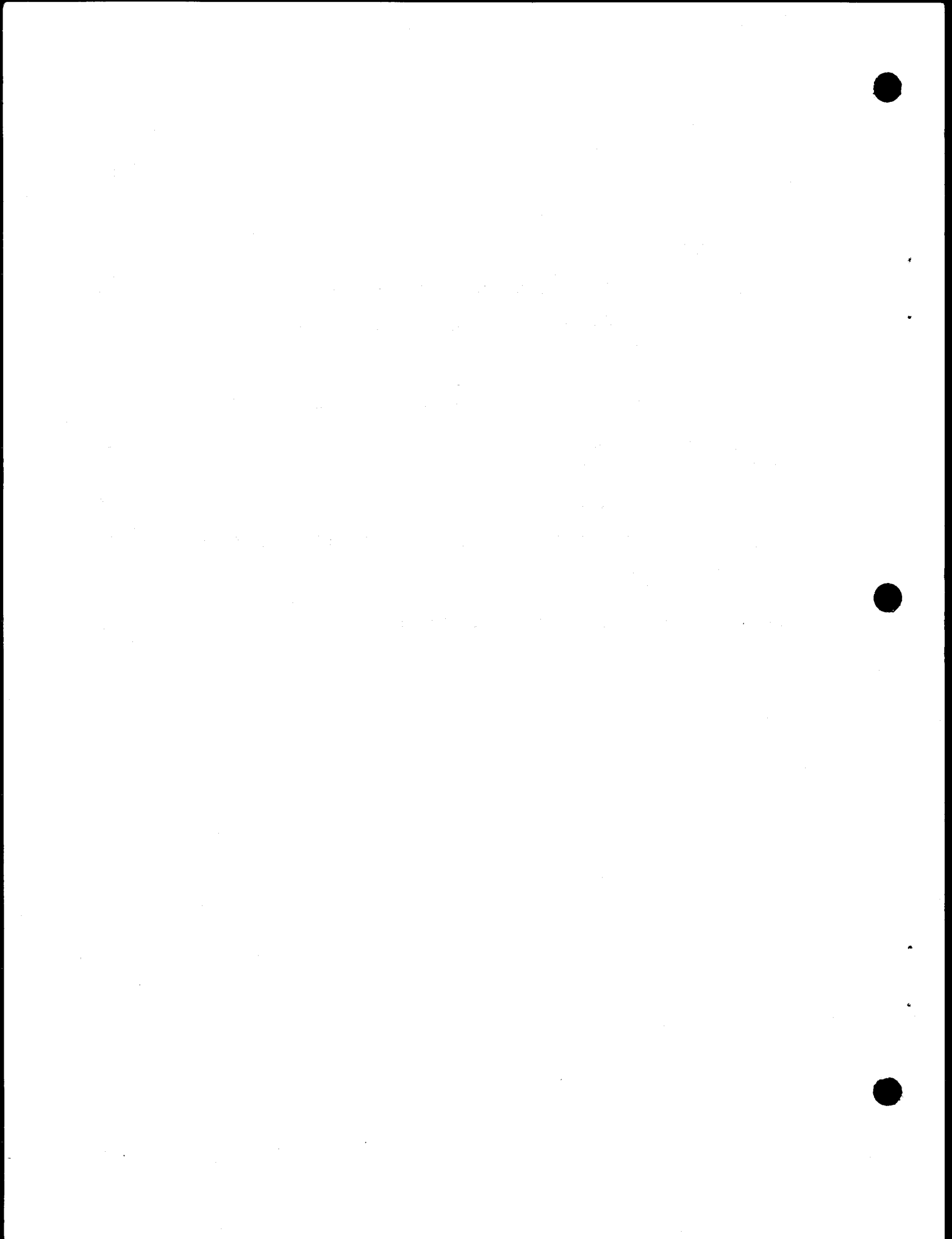
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Solar irradiance measurements both above and within the mixed layer were obtained at three ocean sites along the southeastern Florida coast from Miami Beach (Government Cut) to Key Largo during the Florida Aquanaut Research Expedition of February - March, 1972. The results show that even though the transmittance of the water varied considerably from day-to-day due to changes in turbidity, the average transmittance at the sites was nearly the same.

The turbidity of the Florida coastal water causes a slight increase in the heating rate due to absorbed solar radiation ($0.36^{\circ}\text{C}/12\text{ hr}$) compared to the clear water of the Sargossa Sea ($0.31^{\circ}\text{C}/12\text{ hr}$) over a column from the surface to 13 m depth.

The reflectance and transmittance of the water column are also examined. The reflectance varied from 3.5 percent at midday to 15-20 percent in early morning and late afternoon. The transmittance of the water from the surface to 13 m depth is dependent on the zenith angle of the sun. With solar zenith angles of 30° , the transmittance was 7-8 percent; this decreased to 5 percent with solar zenith angles of $60-70^{\circ}$. A surprising feature of the measurements was that, as the solar zenith angles approached 90° , the transmittance increased to about 8 percent. Higher transmittance values (up to 17 percent) were also associated with cloudy sky conditions.

Results of studies of the immersion effect of the underwater pyranometer are discussed but have not been applied to the basic irradiance data.

1. INTRODUCTION

During the winter and early spring of 1972 solar irradiance measurements were obtained along the southeast Florida coast as a portion of the NOAA¹ program FLARE². These measurements were made both above the ocean surface and in the water column; they represent spectrally integrated solar irradiance. This report presents the results of these measurements and discusses the physical properties of the coastal shelf water and the influence of turbidity of the water on solar irradiance reaching the shelf and coral reefs.

¹National Oceanic and Atmospheric Administration

²Florida Aquanaut Research Expedition

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The program was carried out from the R/V LULU that was moored at four locations from February 22 to April 16, 1972; these locations are shown in figure 1. The periods in which useful radiation data have been obtained at these locations and the approximate positions are:

<u>Site</u>	<u>Location</u>	<u>Dates (1972)</u>
1. Government Cut (Miami Beach)	25.8°N, 80.1°W	2/22 - 2/23
2. Pacific Reef-A	25.4°N, 80.2°W	2/26 - 3/1
3. Elbow Reef	25.2°N, 80.3°W	4/3 - 4/9
4. Pacific Reef-B	25.4°N, 80.2°W	4/12 - 4/16

2. SOLAR IRRADIANCE MEASUREMENTS DURING FLARE

There were two types of solar irradiance measurements obtained during FLARE. The first type is that of continuous measurement of incident and reflected solar irradiance at the ocean surface from a boom attached to the R/V LULU, and of the subsurface solar irradiance incident on the shelf and coral reefs. The latter measurement was obtained approximately 150 ft south of the R/V LULU to eliminate the shadowing influence of the ship. The second type is that of profile measurements from about 1 m above the shelf to 3 m below the ocean surface, in steps of 3 m in order to obtain the profile. Approximately 45 min were required to obtain a complete profile. On most days one or two profiles were obtained.

A schematic view of the deployment of radiation sensors is shown in figure 2. The habitat (EDELHAB) was not used in the radiation program and is shown for reference only.

2.1 Ocean Surface and Shelf Surface Measurements

Continuous measurement of the incident and reflected irradiance components were obtained just above the sea-air interface, and continuous measurement was obtained of the incident irradiance component at the shelf surface. The dates on which these measurements are available at the various sites is shown in table 1.

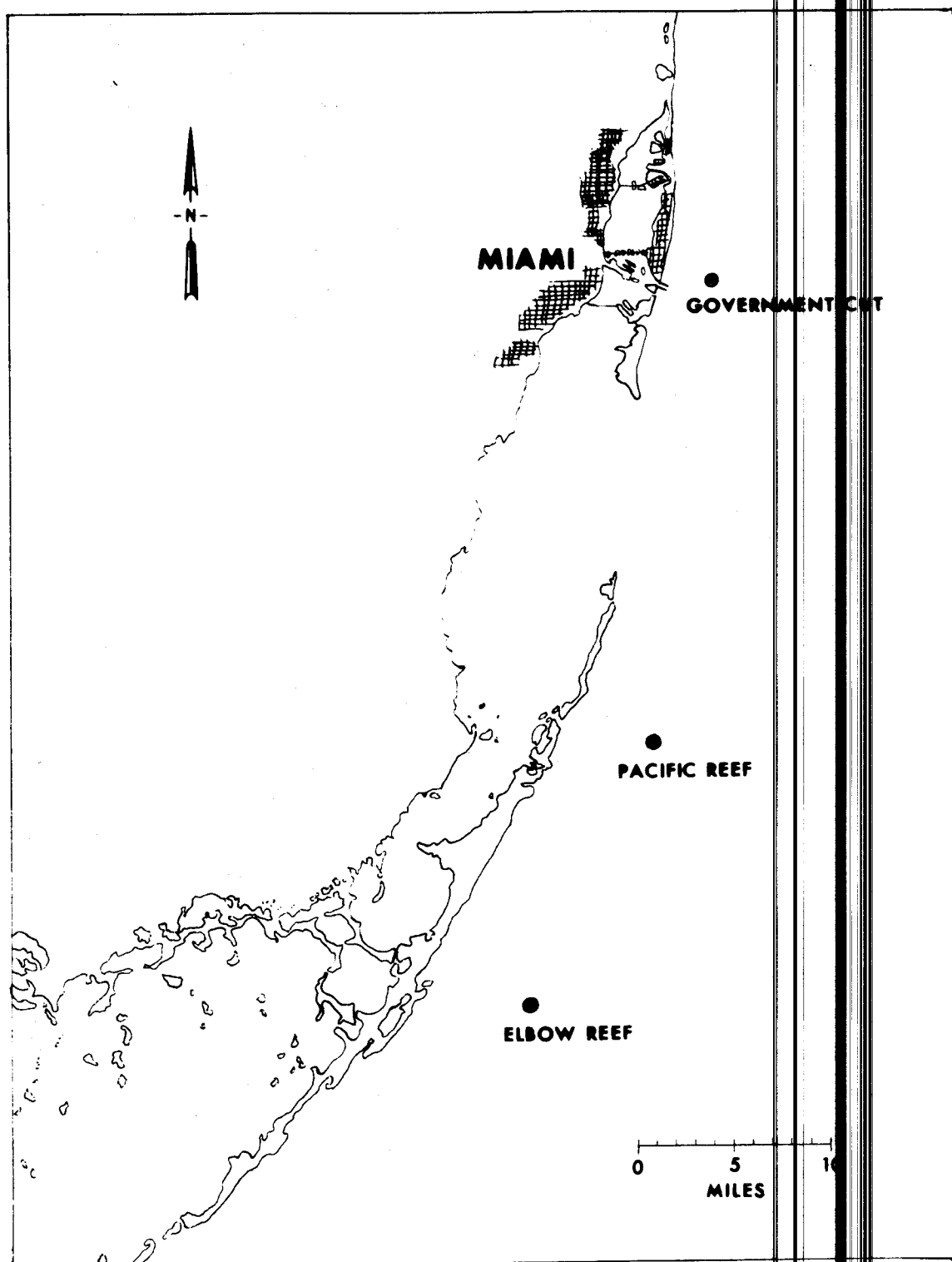


Figure 1. Site in southeast Florida for the Florida Aquanaut Research Expedition (FLARE), February-April, 1972.

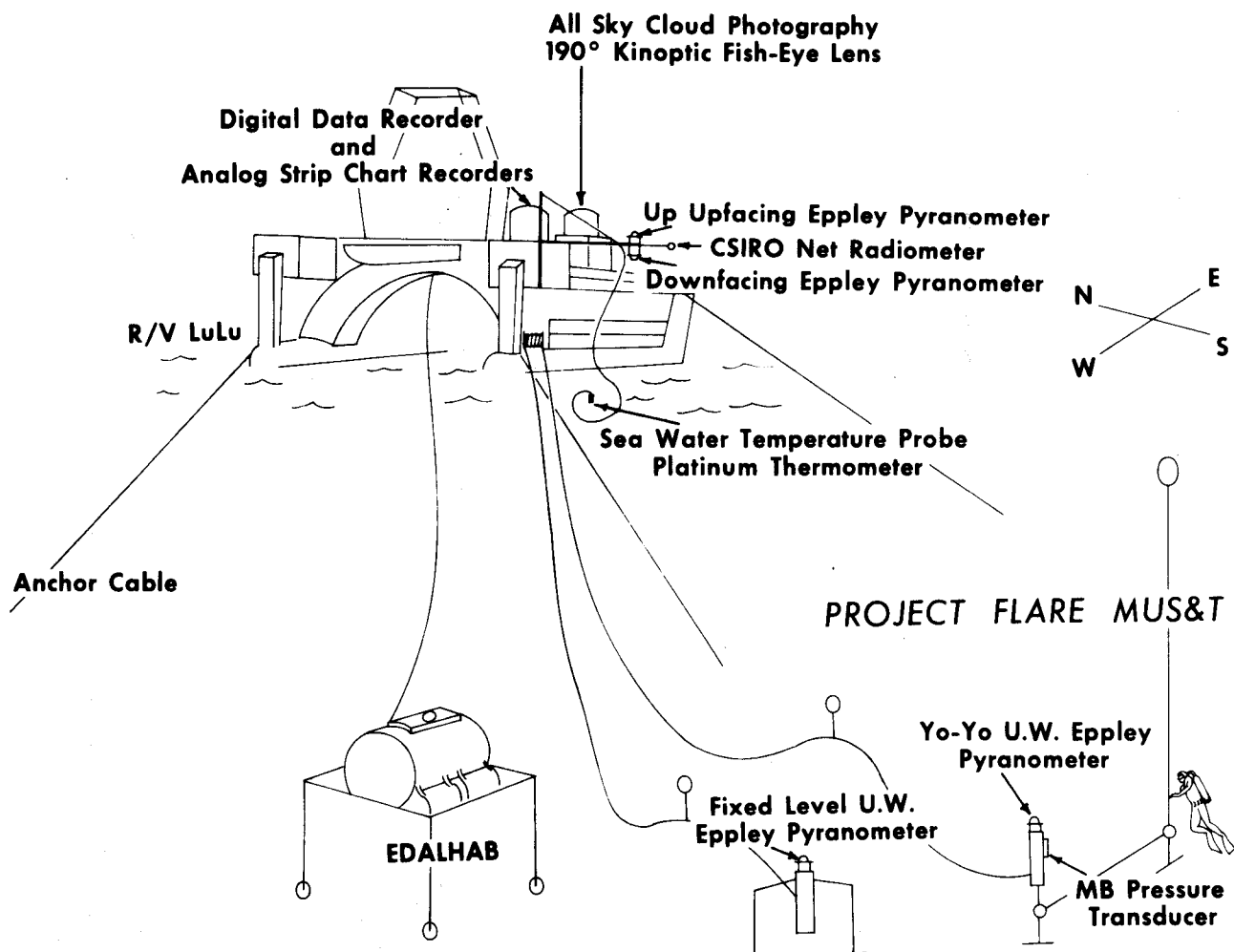


Figure 2. Schematic diagram of the radiation program instrumentation during FLARE, February-April, 1972.

Hourly totals of these three radiation components are given in tables 2, 3, and 4; daily sums and hourly means for the entire period are also given. These hourly means are plotted in figure 3, showing that only a small portion of solar irradiance that reaches the ocean surface is reflected from the ocean surface or reaches the shelf surface. The averages in tables 2, 3, and 4 show that of the $530 \text{ cal/cm}^2 \text{ day}$, which was incident at the ocean surface. Only $25 \text{ cal/cm}^2 \text{ day}$, or 4.8 percent, was reflected from the ocean surface, and only $35 \text{ cal/cm}^2 \text{ day}$, or about 6.6 percent, reached the shelf surface and coral reefs at an average depth of 13 m; thus, the bulk of the solar energy entering the ocean is used to warm the ocean water.

Table 1. Solar Irradiance Data Obtained During the FLARE Program

Location	Date (1972)	Incident Irradiance	Reflected Irradiance	Fixed Depth Irradiance	Underwater Irradiance Profile
Government Cut (Miami Beach)	2/22	X	X	X	X
	2/23	X	X	X	X
Pacific Reef-A	2/26	-	-	X	X
	2/27	X	X	-	X
	2/28	X	X	X	X
	2/29	X	X	X	X
	3/1	X	X	X	X
	3/1	X	X	X	X
Elbow Reef	4/3	X	X	X	X
	4/4	X	X	X	X
	4/5	X	X	X	X
	4/6	X	X	X	X
	4/7	X	X	X	X
	4/8	X	X	X	X
	4/9	X	X	X	X
	4/9	X	X	X	X
Pacific Reef-B	4/12	X	X	-	-
	4/13	X	X	X	X
	4/14	X	X	X	X
	4/15	X	X	X	X
	4/16	X	X	X	X

Table 2. Solar Irradiance Incident at Ocean Surface During FLARE
(cal/cm² hour)

Hour ending (EST)	FEB					MAR					APRIL					Hourly Avg.		
	22	23	27	28	29	1	3	4	5	6	7	8	9	12	13		14	15
7	0.5	0.7	-	1.2	1.4	2.2		0.6	0	0.8	0	4.4	4.7	-	1.7	1.6	0.6	1.9
8	4.0	11.5	-	13.7	12.4	16.5		10.1	3.7	15.5	8.4	20.8	21.0	-	18.1	17.3	14.5	14.3
9	9.5	27.3	-	32.9	28.3	36.8		24.9	31.9	36.2	28.4	40.4	41.1	-	37.8	26.5	34.4	32.2
10	26.7	59.8	-	49.0	51.1	52.4		39.1	53.4	54.3	47.5	58.5	59.3	-	56.1	58.3	52.8	51.9
11	45.2	67.5	63.2	62.2	66.4	67.7		65.8	52.0	69.2	67.8	72.6	73.3	-	70.2	71.6	69.4	66.1
12	33.0	67.9	72.3	69.3	73.4	75.0	80.6	79.9	74.4	77.8	79.3	80.7	81.4	-	79.2	79.8	78.5	74.2
13	33.6	78.3	74.3	72.3	78.0	78.4	84.3	75.9	78.6	79.9	83.6	83.1	84.0	-	81.9	81.4	81.4	77.1
14	62.6	72.9	69.5	66.7	72.1	73.6	82.2	75.0	74.7	76.0	78.6	79.3	49.0	-	78.2	76.8	78.2	73.1
15	54.7	61.4	58.6	56.1	56.4	64.9	72.2	63.9	65.3	65.2	65.7	69.6	3.7	65.1	67.9	65.8	68.4	60.6
16	25.1	41.9	42.4	40.7	42.3	-	54.2	47.3	47.5	49.0	48.0	54.8	16.6	51.2	52.6	49.3	54.0	44.8
17	13.8	18.7	23.5	22.2	23.0	-	29.4	26.9	15.7	28.5	27.1	33.9	12.2	32.1	32.6	29.5	36.4	25.3
18	4.4	2.4	5.6	4.6	4.7	-	10.5	5.6	8.6	8.2	7.4	13.5	6.6	10.7	11.3	8.2	14.2	7.9
19	-	-	-	-	-	-	-	-	-	-	-	0.9	0.8	0	0.3	-	0.5	0.5
Daily Summary	313	510	-	491	509	-	616	515	506	561	542	613	454	-	588	566	583	530

The ocean heating rate can be calculated from these irradiance data, as shown in figure 4, on the basis of conservation of energy. For this calculation it is necessary to assume an average reflectance of the shelf surface of 20 percent. The result gives an average heating of the water column of $0.36^{\circ}\text{C}/12 \text{ hr.}^1$ Thus, the heating rate of these Florida coastal waters is approximately 15 percent greater than that of the Sargasso Sea, which is one of the least turbid regions of the world's oceans.

A basic question which the experiment sought to answer was whether there were significant differences in the transmittance of the water at these sites and whether such differences were related to human activities. The irradiance data in tables 2, 3, and 4 have been used for this purpose. The transmittance (T) of the water was calculated from

$$T = H_z / (H - H_r) \quad (1)$$

where H_z is the irradiance at depth Z and H and H_r are the incident and reflected solar irradiance at the ocean surface, respectively.

Transmittance values based on tables 2, 3, and 4 have been calculated for each day at the three sites and are given in table 5. The mean transmittance values are given for each site, and standard deviations are given for Pacific and Elbow Reefs where the sample is relatively large. At Pacific Reef the standard deviations is 18 percent of the mean transmittance, whereas at Elbow Reef it is 31 percent. Because only 2 days of data are available for Government Cut, it is not possible to obtain an idea of the daily variability in transmittance of the water at that location.

Because the depth of the shelf surface varied from one site to another, it is necessary to normalize the transmittance data to a single depth in order to make comparisons between sites. We have chosen 13 m as a depth for normalization and used the log transmittance profile of the following section to extrapolate the measurements to this standard depth. Table 6 lists the depths at each site, the mean transmittance normalized

³Hanson and Poindexter (1972) measured the heating rate due to absorption of solar radiation over various depths about 200 miles NW of Puerto Rico in October 1971.

Table 3. Solar Irradiance Reflected From the Ocean Surface
During FLARE (cal/cm² hour)

	FEB					MAR		APRIL													Hourly
	22	23	27	28	29	1	3	4	5	6	7	8	9	12	13	14	15	16	Avg.		
Hour ending (EST)																					
7	0.1	0	-	0.4	0.3	0.4		0.5	-	1.1	0.2	1.3	1.5	-	0	0	0	0	0.4		
8	0.2	1.9	-	3.5	2.3	2.5		2.9	(0.7)	3.1	2.5	2.8	3.0	-	0.9	1.2	0.8	0.8	1.9		
9	0.5	2.0	-	3.1	2.6	2.8		2.3	2.0	2.5	2.8	2.7	2.6	-	1.9	1.4	2.0	2.0	2.2		
10	1.3	1.8	-	2.2	3.1	3.3		2.4	1.8	2.0	1.9	2.6	2.5	-	2.0	2.3	2.1	2.1	2.2		
11	1.9	2.7	2.5	2.2	3.0	3.4		2.7	1.6	2.1	2.1	2.9	2.4	-	2.3	2.6	2.4	2.2	2.4		
12	1.4	2.5	2.7	2.3	3.0	3.5	2.5	2.7	2.4	2.2	2.3	3.0	2.8	-	2.6	3.1	2.8	2.6	2.6		
13	1.4	2.9	2.8	2.3	3.3	3.8	2.7	2.6	2.4	2.3	2.8	3.1	3.2	-	3.0	3.1	3.0	2.8	2.8		
14	2.7	3.0	3.0	2.8	3.1	3.5	2.7	2.6	2.3	1.8	3.0	3.3	2.0	-	3.1	2.8	2.9	2.8	2.8		
15	2.3	2.8	3.0	2.8	3.3	3.5	2.8	2.3	2.1	1.2	2.8	3.1	0.3	1.8	2.7	2.5	2.5	2.5	2.5		
16	1.3	2.7	2.7	2.7	3.1	-	2.4	2.3	1.8	1.3	2.6	2.8	1.0	1.7	2.1	2.2	2.3	-	2.2		
17	1.4	2.2	2.5	2.7	3.0	-	2.3	2.2	1.0	1.6	2.5	2.7	0.9	1.6	2.0	2.1	2.1	-	2.1		
18	0.7	0.3	0.9	0.8	0.9	-	1.6	1.0	0.9	0.9	1.2	1.9	0.6	0.7	1.7	1.2	1.7	-	1.1		
19	-	-	-	-	-	-	-	-	-	-	-	0.4	0.3	0	0.5	-	0.4	-	0.3		
Daily Summary	15.2	24.9	-	27.7	31.1	-	24.1	26.4	19.0	22.1	26.7	32.7	23.1	-	24.9	24.4	25.2	-	25.2		

Table 4. Solar Irradiance Incident at Shelf Surface
During FLARE (cal/cm² hour)

	FEB				MAR				APRIL												Hourly
	22	23	27	28	29	1	3	4	5	6	7	8	9	12	13	14	15	16	Avg.		
Hour ending (EST)																					
7	0	0	-	0	0.1	0	-	0.1	0.1	-	0.1	0	0	-	-	0.5	0	0.2	0.1		
8	0.1	0.4	-	0.4	0.6	1.0	-	0.9	0.7	(2.9)	0.8	0.1	0.1	-	-	1.5	0.4	0	0.8		
9	0.2	1.1	-	1.5	1.5	1.9	-	2.0	2.6	(3.0)	2.1	1.1	0.8	-	-	2.4	1.5	0.2	1.8		
10	1.8	1.3	-	2.7	3.3	3.4	-	2.9	4.5	4.0	3.4	2.3	2.1	-	-	5.0	3.5	0	3.2		
11	2.9	3.4	-	4.0	4.4	4.1	-	4.4	4.6	5.3	4.9	3.7	3.0	-	-	6.5	4.7	0.4	4.5		
12	2.2	4.8	-	4.9	5.9	5.5	5.1	6.1	6.3	6.5	6.5	4.0	-	-	-	6.3	6.2	1	5.5		
13	2.0	5.5	4.5	5.4	5.7	5.2	5.6	5.7	6.1	6.6	6.0	3.7	-	-	-	6.5	5.4	0	5.4		
14	3.9	4.6	3.2	4.6	5.0	4.0	5.0	6.3	5.6	5.8	-	3.4	-	-	-	5.7	3.3	0.4	4.9		
15	3.2	3.3	2.0	3.4	3.8	-	4.8	4.9	4.7	5.2	-	3.0	-	-	5.4	4.1	3.3	0.9	4.0		
16	1.7	2.2	0.6	2.2	2.8	-	3.6	3.8	3.3	4.0	-	2.3	-	-	4.1	2.6	2.5	-	2.7		
17	.9	1.0	0	1.0	1.3	-	2.0	2.4	1.5	2.2	-	1.3	-	-	2.4	1.1	1.7	-	1.4		
18	.3	0	0	0.3	0.3	-	0.9	1.2	0.9	0.9	-	0.4	-	-	1.1	0.1	0.9	-	0.6		
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
Daily Summary	19.3	27.6	-	30.3	34.7	-	-	40.5	40.9	46.4	-	25.3	-	-	-	42.4	33.6	-	34.9		

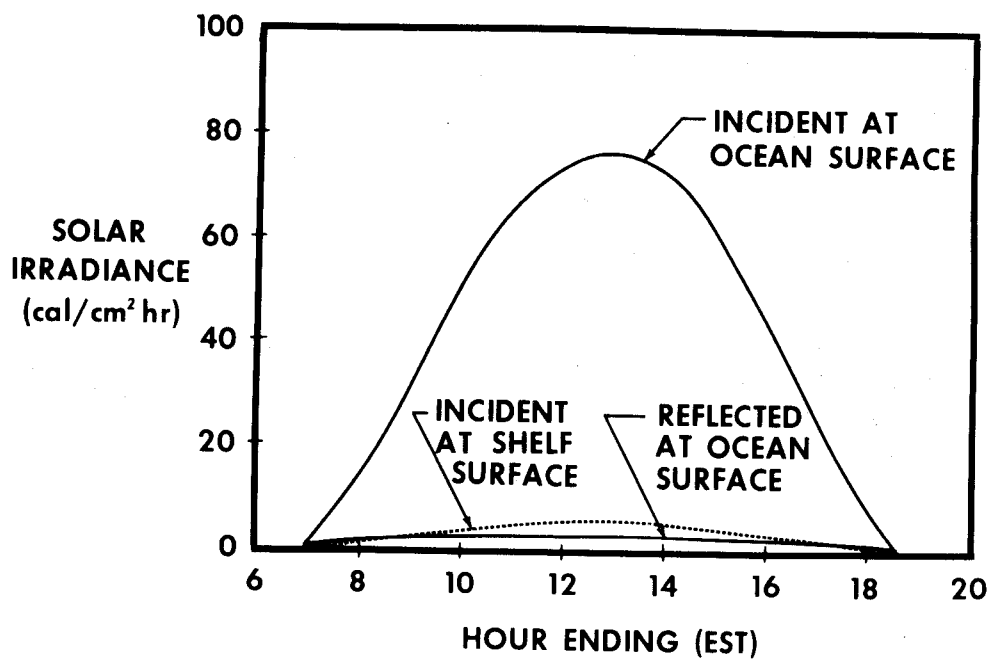


Figure 3. Integrated hourly solar irradiance data for the entire FLARE period.

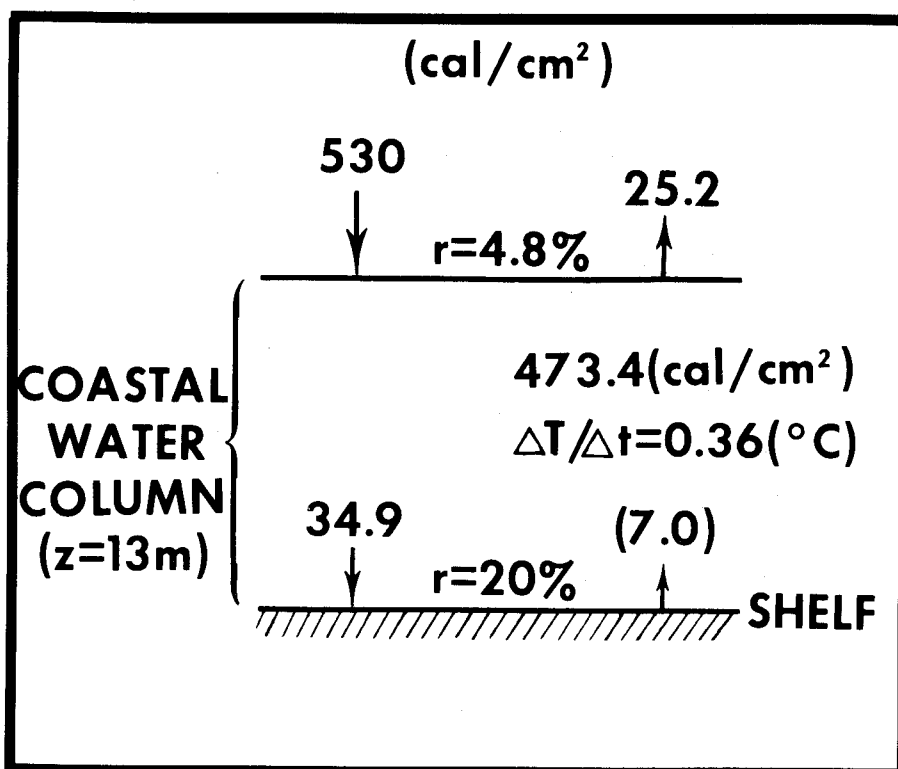


Figure 4. Integrated daily solar irradiance, mean for the entire FLARE period. Heating rate of the water column to 13 meters is also given.

Table 5. Daily Transmittance
by Sites

Date (1972)	Government Cut	Pacific Reef	Elbow Reef
Feb. 22	.065		
23	.057		
27		(.045)	
28		.065	
29		.072	
Mar. 1		(.065)	
Apr. 3			(.068)
4			.083
5			.084
6			.086
7			.072
8			.044
9			(.032)
13		(.081)	
14		.078	
15		.060	
16		(.082)	
Mean	.061	.068	.067
Std.dev.	-	.012	.021

Table 6. Mean Transmittance by Sites
(based on fixed depth pyranometer)

Site	Depth (m)	Mean Transmittance		Standard Deviation
		At Indicated Depth	to Depth of 13 Meters	
Government Cut	14.3	.061	.000	
Pacific Reef	10.7	.068	.005	.012
Elbow Reef	15.2	.067	.001	.021

to the standard depth, and the standard deviation of the daily transmittance values.

It is surprising to see that the mean transmittance at Government Cut (0.070) is higher than that at Pacific Reef (0.055), because pollution at Government Cut and the more turbid outflow water of Biscayne Bay were thought to increase the turbidity at Government Cut. Table 6 shows the mean transmittance values for the sites are in the range 0.06 to 0.08, and the variation from day to day is 0.01 to 0.02; thus, considering the large standard deviation of the transmittance at the sites, it appears that the difference in mean transmittance between the sites is not statistically significant. From another point of view, if man-made changes in turbidity of the water are present at Government Cut, then they are so small compared to the natural occurring variation in turbidity that they are undetectable with the present data sample. Perhaps a much longer record at these sites may show a statistically significant difference between sites.

2.2 Profile Measurements

Measurement of the downwelling solar irradiance at various depths within the water column were obtained with a single pyranometer, which was raised and lowered in a series of steps to obtain a profile. These measurements are not continuous during the day, as are those of the fixed-depth pyranometer, but were obtained one or more times a day on the days indicated in table 1. It required about 45 min to obtain a profile. Most profiles were made between 10 am and 3 pm local time.

The transmittance of the water has been calculated from these data, according to equation 1, and from the incident and reflected solar irradiance at the surface. The individual transmittance profiles are listed in tables 7, 8, and 9 for Government Cut, Pacific Reef, and Elbow Reef, respectively. Means and standard deviations for each site are given in the tables. The mean profiles are also shown in figure 5 with the standard deviations for Pacific Reef.

These mean transmittance profiles show that differences between sites are small compared to the day-to-day variation in transmittance, as indicated by the standard deviation at Pacific Reef, which is shown as error bars in figure 5.

Table 7. Solar Radiation Profile Measurements - Government Cut

Time(GMT)	FEB.					Avg.	Standard Deviation
	22 1742	22 1954	23 1559	23 1634	23 1830		
Depth (m)	Transmittance						
3.0	.207	.249	.164	-	.180	.210	.032
6.1	.186	.138	.125	.128	.137	.140	.016
9.1	.139	.142	.098	.099	.105	.117	.019
12.2	.122	-	.073	.097	.067	.090	.020
13.1	.110	.062	-	-	-	.086	.021

Table 8. Solar Radiation Profile Measurements - Pacific Reef

TIME (GMT)	FEB.																MAR				APRIL				16	16	avg	Standard Deviation																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
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Table 9. Solar Radiation Profile Measurements - Elbow Reef

APRIL												Stand. Devia- tion
Time(GMT)	3	4	4	5	6	7	8	8	9	9	Avg	
Depth (m)	Transmittance											
3.0	.203	.214	.229	.159	.264	.259	.170	.161	.197	.106	.196	.049
6.1	-	.167	.179	-	.189	-	.128	.117	.128	.095	.143	.035
9.1	-	.144	.134	-	.140	-	.105	.107	.098	.077	.115	.025
12.2	-	.119	.124	-	.108	-	.080	.076	.084	.073	.095	.022
15.2	-	.108	.108	-	.091	-	.070	.071	.074	.059	.083	.020

2.3 Discussion

During the FLARE program, two solar radiation pyranometers were used to measure the irradiance underwater. One sensor obtained continuous measurements at the shelf surface and the other obtained irradiance profiles in the water. Transmittance values determined from both measurements show that the mean transmittance value at the Pacific Reef site is lower than at the other two sites. This can be seen by comparing table 6, based on continuous measurement, and table 10, based on profile measurements. Differences between sites are small, however, in comparison to the day to day variations in transmittance.

Large variations in transmittance at the sites are thought to result from changes in turbidity caused by coastal currents, wind driven currents, and tidal currents. For example, very low transmittance values were observed on February 28, 1972, at Pacific Reef (table 8), and on April 8-9, 1972, at Elbow Reef (table 5). Strong currents were observed on those days.

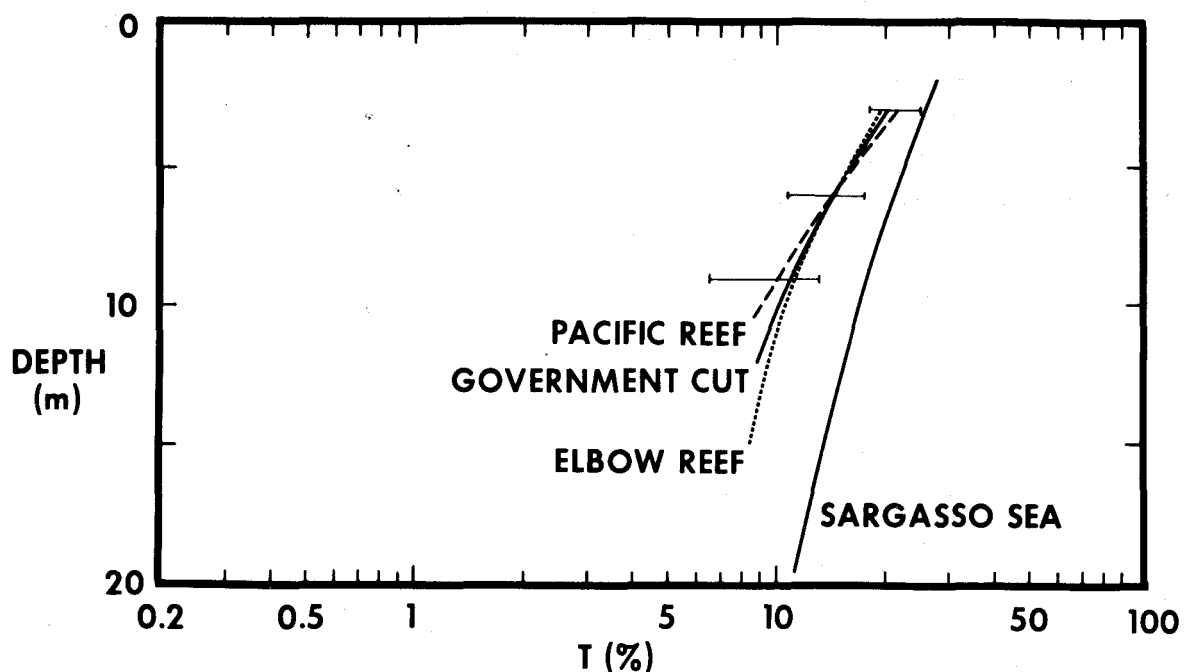


Figure 5. Mean transmittance profiles by sites in comparison to that for the Sargasso Sea. The brackets indicate the standard deviation of the daily transmittance values at three levels at Pacific Reef.

The data suggest that at Government Cut the effect of pollution on the amount of sunlight reaching the reefs is so minimal that it is undetectable in the present data set. The transmittance data also suggest that the natural variation in turbidity of the water caused by currents is considerably larger than variations caused by human activities.

For biological and other studies it may be useful to estimate the variation that may be expected in the daily integrated solar irradiance reaching the shelf surface and coral reefs. The information for this estimate is presented in table 11. This shows from a previous study for Miami that cloudiness in the atmosphere has a large influence (27 percent) in modulating the amount of solar energy which reaches the ocean surface from day to day. In addition, the present study has shown (table 5) that ocean roughness and turbidity have a significant effect (18-31 percent) in modulating the amount of solar energy transmitted by the water and reaching the coral reefs. These natural variations of the atmosphere and ocean taken together suggest that the day to day variability in solar irradiance reaching the coral reefs may be 45-58 percent. In addition there are other causes of variability, such as

those associated with astronomical (diurnal and seasonal) changes. Thus, the natural variation in radiation reaching the reefs is relatively large and any possible man induced variation must be significantly large to be detectable. In the present case it is too small to be detected.

Future studies should be directed toward establishing the cause and effect relationship between currents and the radiation environment of the reefs, as well as attempting to obtain a sufficiently long data sample that the effect of pollution might be detected.

*Table 10. Mean Transmittance by Sites
(based on profile pyranometer)*

Site	Depth (m)	Mean Transmittance	Standard Deviation
Government Cut	9.1	.117	.019
Pacific Reef	9.1	.098	.033
Elbow Reef	9.1	.115	.025

*Table 11. Variability in Daily Solar
Irradiance Due to Various Sources*

Variability at Ocean Surface due to Cloudiness	27% (from Hanson (1971))
Variability at Shelf Surface due to Ocean Roughness and Turbidity	18-31% (from Table 5)
Estimated Variability in Solar Irradiance at Shelf Surface due to Cloudiness, Ocean Roughness and Turbidity	45-58%

3. RADIATIVE PROPERTIES OF THE COASTAL OCEAN WATER

Of the basic properties of sea water, the two which can be evaluated from the present study are reflectance and transmittance of irradiance. They are given in the following sections.

3.1 Surface Reflectance

The continuous measurements of incident and reflected solar irradiance at the sea surface, given in tables 2 and 3, have been used to determine surface albedo. In this calculation, the albedo has been evaluated as the ratio of the reflected to the incident irradiance. The albedo values were further stratified into "clear" or "cloudy" sky categories. The criteria for determining cloudy sky was that incident irradiance be less than 60 percent of maximum incident irradiance during the entire period of observation (fig. 6). If this case did not apply, the albedo data were included in the clear sky category.

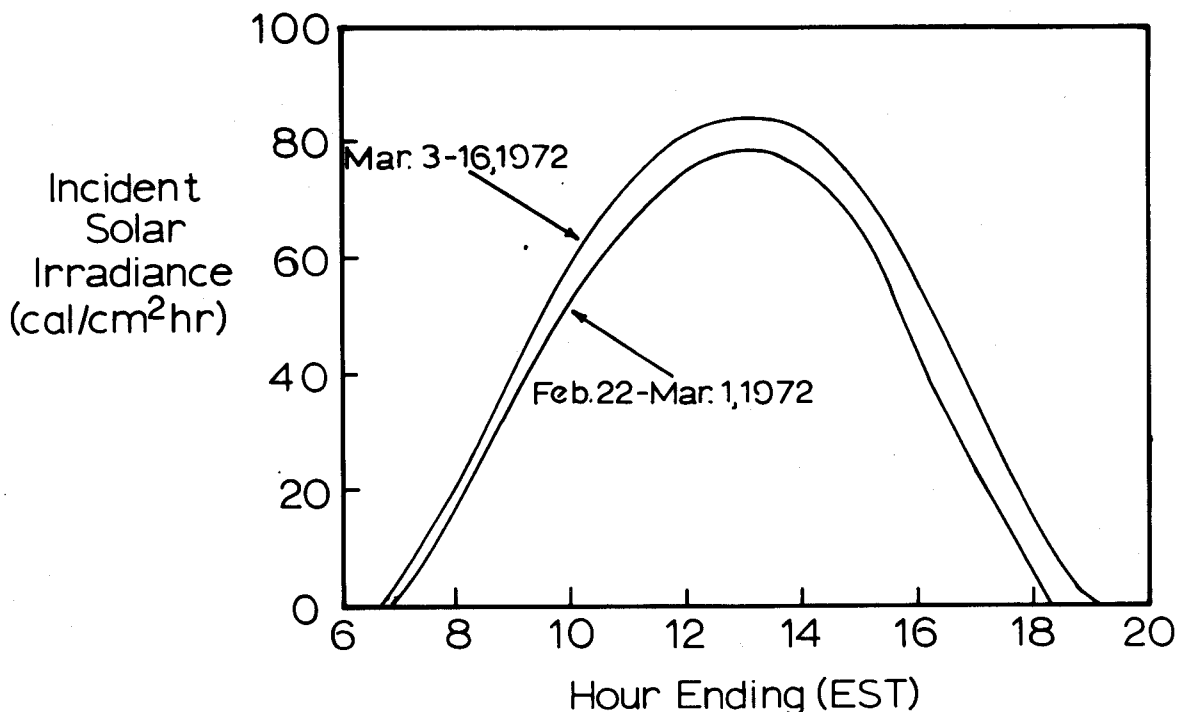


Figure 6. Maximum incident irradiance for two periods during FLARE. The curves simulate clear sky conditions.

Resulting hourly mean albedo values for the two cloud categories are given in table 12 and are plotted in figure 7. Albedo varies with time of day and is nearly symmetrical about solar noon with lowest values (3.5 percent) occurring near midday and higher values (15-20 percent) in early morning

Table 12. Mean Hourly Albedo Values for Clear and Cloudy Sky

Hour Ending (TST)	Clear Sky Albedo	N	Cloudy Sky Albedo	N
07	.217	7	-	-
08	.149	13	.168	2
09	.068	12	.065	4
10	.041	14	.055	2
11	.036	15	.042	2
12	.035	16	.042	1
13	.036	16	.042	1
14	.038	16	.049	1
15	.041	17	-	-
16	.049	14	.055	2
17	.085	13	.079	3
18	.145	13	.131	3

The distinction between clear and cloudy sky is defined in the text. N is the number of hourly albedo values on which the mean is based

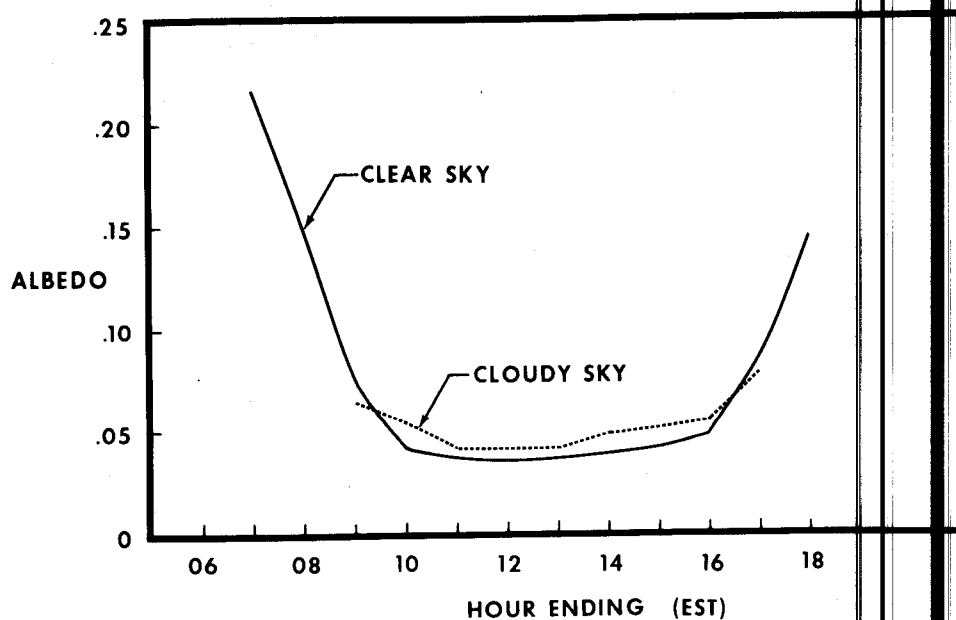


Figure 7. Mean hourly albedo of the ocean surface for all sites during FLARE.

and late afternoon. This effect of solar zenith angle on albedo of a smooth water surface has been evaluated by many others in earlier studies, e.g., see List (1958), Jerlov (1968) Table XVIII, and Anderson (1954).

During mid-morning the albedo appear to be slightly lower than during mid-afternoon. If this is real, it may be a result of the wave slope distribution with predominantly easterly wind and swell or caused by increased turbidity and ocean reflectance in the afternoon.

The dependence of albedo on zenith angle, as determined in this study, is given in table 13 and figure 8. The data agree within a few percent of those for smooth water surfaces given by Jerlov (1968) and List (1958).

Table 13. Clear and Cloudy Sky Albedo Values as a Function of Solar Zenith Angle

Zenith Angle (deg.)	Clear Sky Albedo	Cloudy Sky Albedo
28.5	.036	.042
35.2	.037	.046
45.6	.041	.063
57.8	.059	.060
70.8	.117	.124
84.2	.181	-

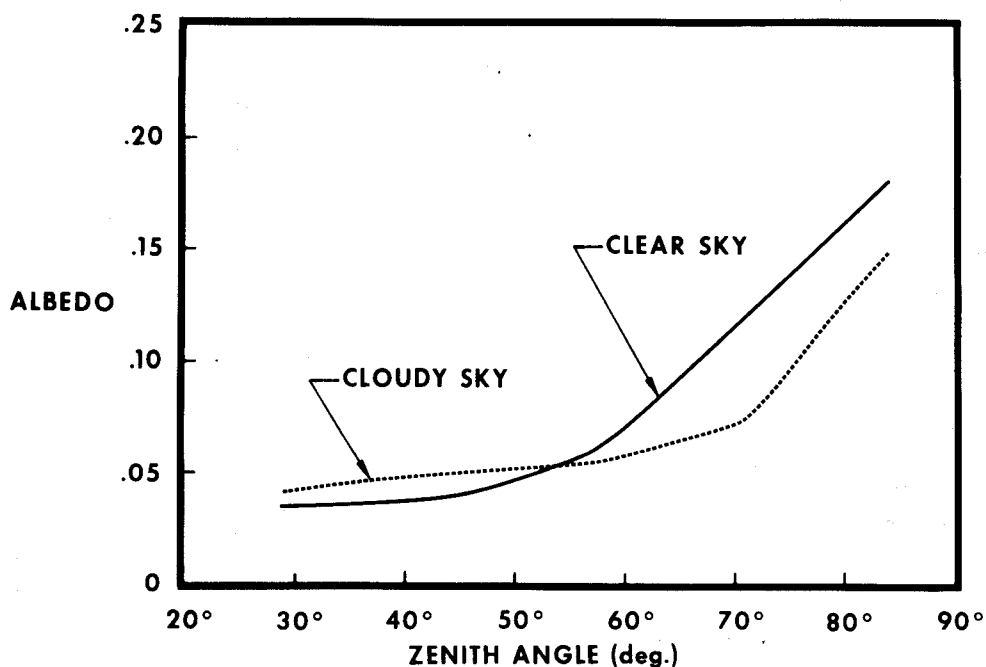


Figure 8. Albedo as a function of solar zenith angle during FLARE.

3.2 Transmittance

The continuous measurements of solar irradiance incident, reflected at the sea surface and incident at the shelf surface, as given in tables 2, 3, and 4, have been used to calculate the transmittance of the coastal water column. The transmittance (T) was calculated from equation 1. As previously discussed for albedo, the transmittance data were further stratified into clear and cloudy sky categories. The resulting hourly mean transmittance values for these two categories are given in tables 14 and 15 and are shown in figures 9 and 10.

In these figures it is apparent that the ocean transmittance varies with time of day and is relatively symmetrical about solar noon. The transmittance of the water column to 13 m with clear skies is highest at local noon, 7-8 percent, and decreases to about 5 percent at zenith angles of 60-70 degrees. As the zenith angle further increases from 70 to 90 degrees, an increase in the transmittance is observed. With cloudy skies the transmittance of the water column increases continuously as the zenith angle increases. A comparison between clear and cloudy sky transmittance values can also be made. This shows that the transmittance is considerably higher in the cloudy sky situation, particularly at higher zenith angles. For example, at 60 degrees and higher the cloudy sky value is larger by a factor of two than with clear skies.

A possible explanation for the increase in transmittance (1) during cloudy conditions and (2) with zenith angles from 70-90 degrees is connected with the spectral distribution of sunlight reaching the ocean surface. In

Table 14. Mean Hourly Transmittance Values for Clear and Cloudy Sky
The distinction between clear and cloudy sky is defined in the text. N
is the number of hourly transmittance values on which the mean is based.

Hour Ending (TST)	Clear Sky Transmittance	N	Cloudy Sky Transmittance	N
07	.080	9	.167	1
08	.049	9	.134	3
09	.049	8	.108	4
10	.064	11	.091	2
11	.069	11	.081	2
12	.076	13	-	-
13	.071	14	-	-
14	.066	15	-	-
15	.063	14	-	-
16	.054	13	-	-
17	.053	11	.095	2
18	.077	11	-	-

Table 15. *Clear and Cloudy Sky Transmittance Values as a Function of Solar Zenith Angle*

Zenith Angle (deg.)	Clear Sky Transmittance	Cloudy Sky Transmittance
28.5	.074	-
35.2	.068	.081
45.6	.064	.091
57.8	.052	.108
70.8	.051	.114
84.2	.078	.167

both cases the amount of near-infrared sunlight relative to the total will decrease because of atmospheric absorption; thus, the relative amount of visible sunlight is greater, and, because water transmits visible sunlight better than near-infrared sunlight, the apparent transmittance of the water will increase.

Future studies should include measurement of the relative spectral distribution of solar irradiance both above the surface and within the water column. This will answer the question of whether the apparent increase in ocean transmittance at zenith angles approaching 90 degrees and under cloudy conditions are a result of changing spectral distribution of the source or not. In addition, relative solar irradiance spectra in the ocean and the absolute pyranometer measurements provide a means for obtaining absolute spectral values, as suggested by the National Academy of Sciences (1969). This is a simple means of solving the difficult problem of obtaining absolute values of spectral distribution of solar irradiance in the ocean.

4. INSTRUMENTATION

The radiation measurements above the ocean surface were obtained with Model 2 pyranometers manufactured by the Eppley Laboratory. The sensing element of these pyranometers is a wire-wound thermopile. Its receiving surface is coated with Parsons black lacquer. The receiving surface is protected from the elements by a pair of precision ground concentric hemispheres of Schott optical glass (WG7) which are transparent from 0.28 to 2.8 micrometer wavelengths.

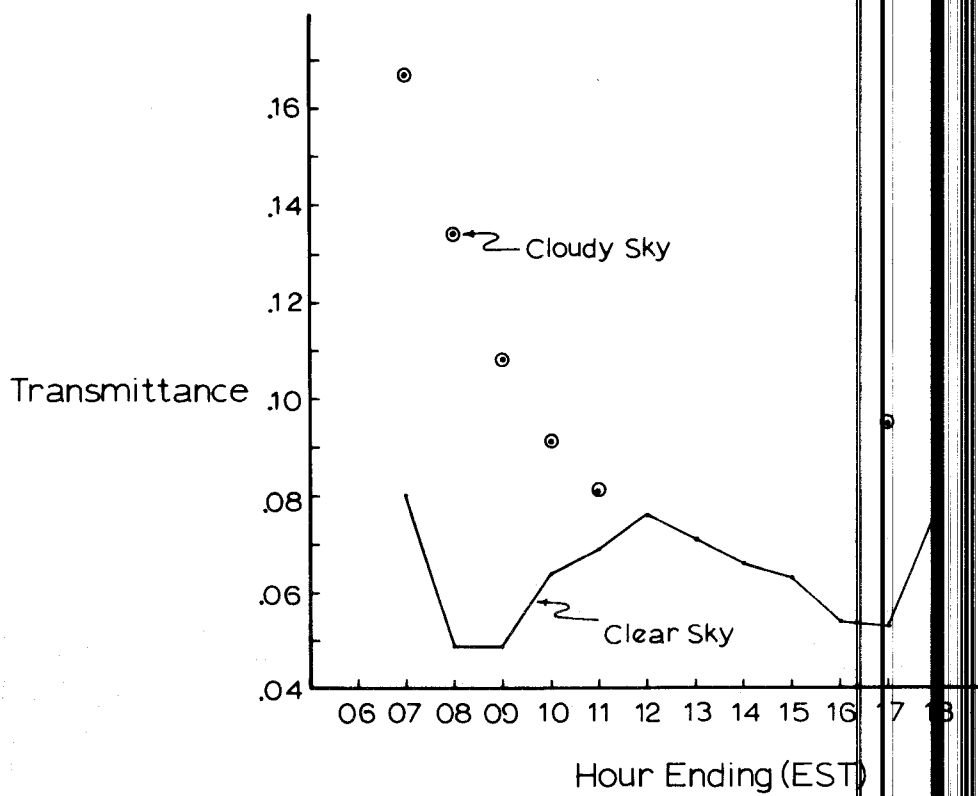


Figure 9. Mean hourly transmittance of the water for all sites during FLARE.

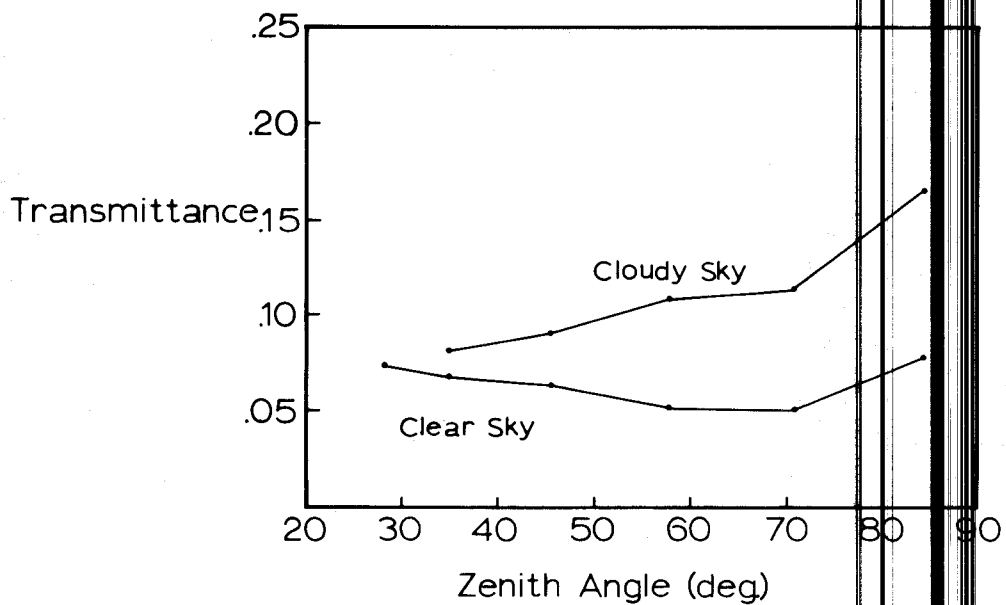


Figure 10. Transmittance of the water as a function of solar zenith angle during FLARE.

The underwater radiation measurements were obtained with pyranometers which have been adapted by the Eppley Laboratory for use underwater. They are identical with the Model 2 pyranometers, except they employ a three pound monel body as a heat sink and have an O-ring seal and underwater connector to make them water tight. Both pyranometers are shown in figure 11.

A net radiometer of the Funk type was also used during the experiment to measure the net (solar and IR) radiation. The data are not included in the present analysis, although the daily curves are included in the Appendix. The radiometer is also shown in figure 11.

Table 16 is a summary of the radiation sensors employed and the sensitivities which were used in processing the measurements.

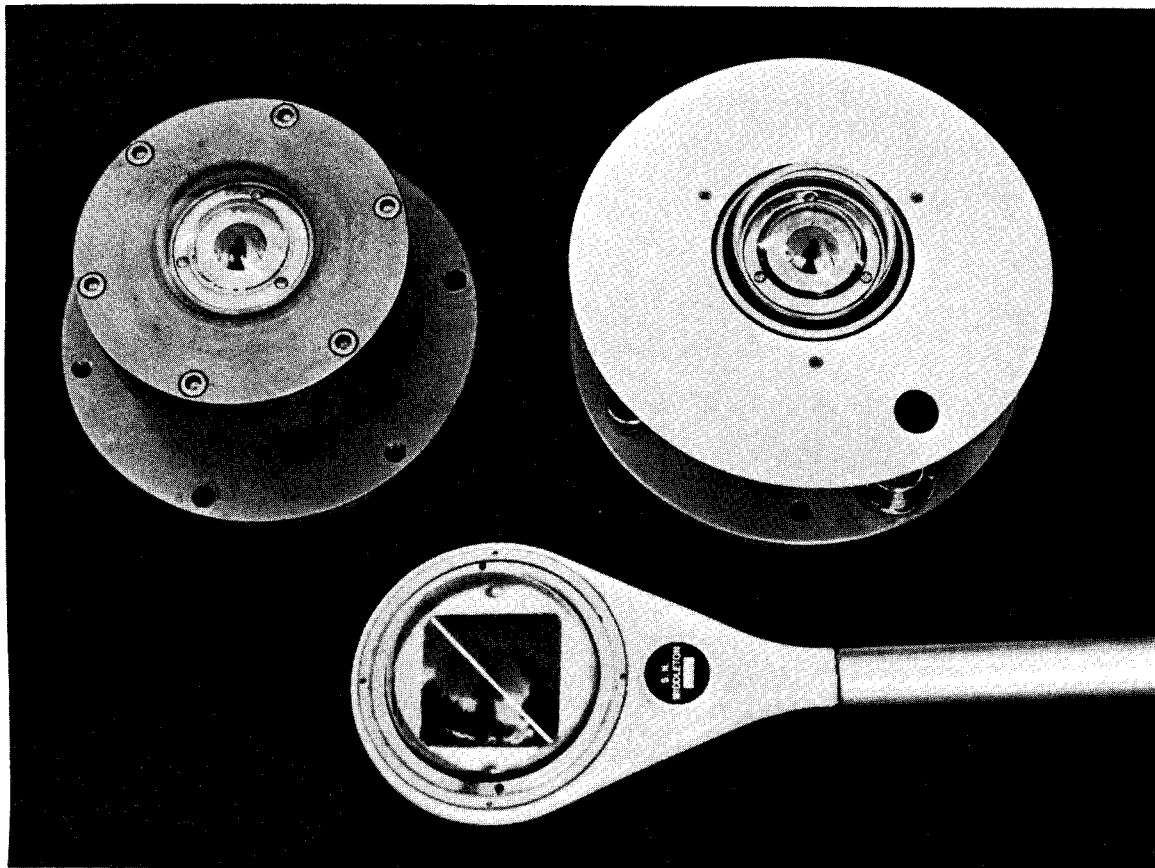
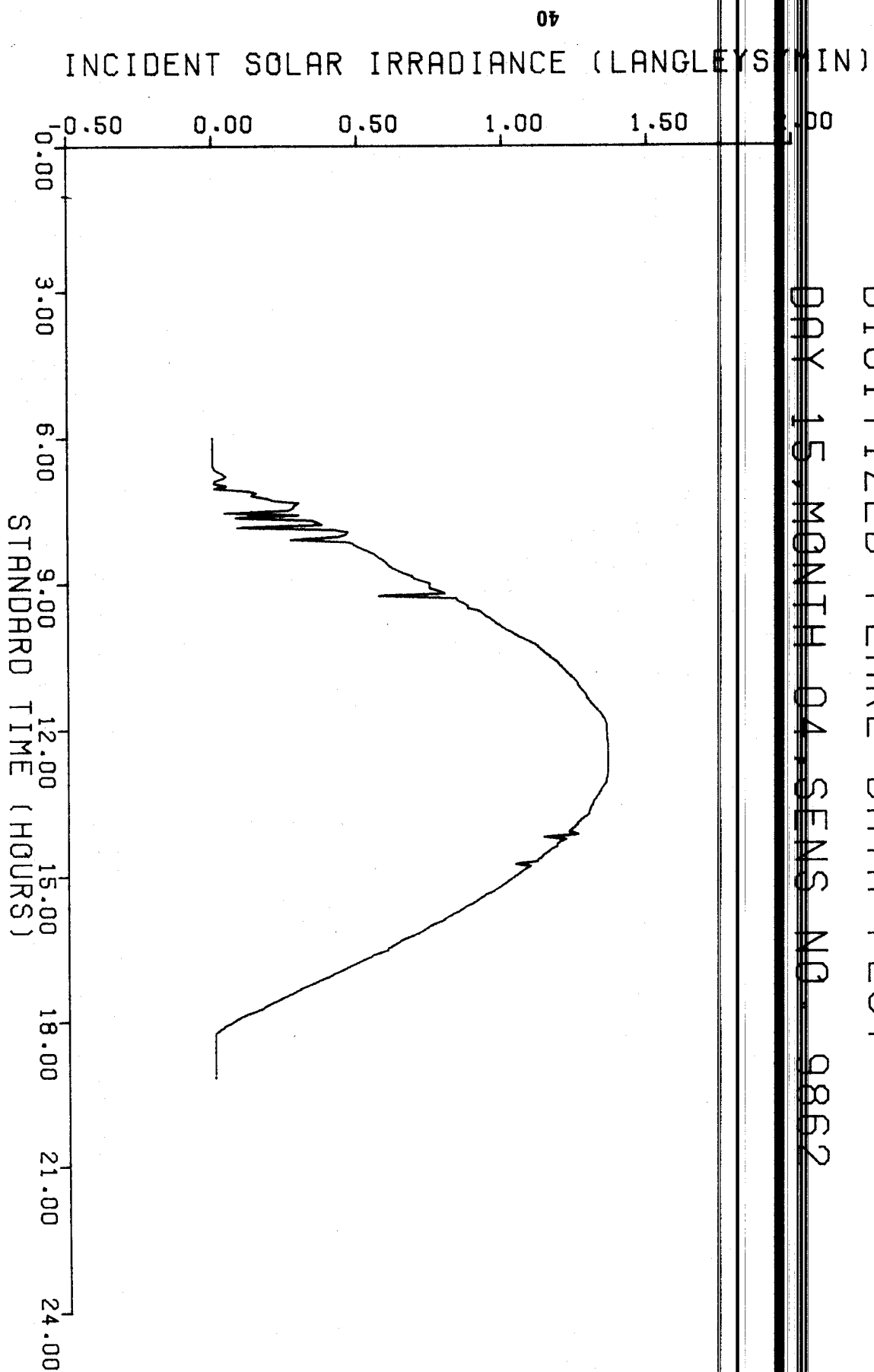


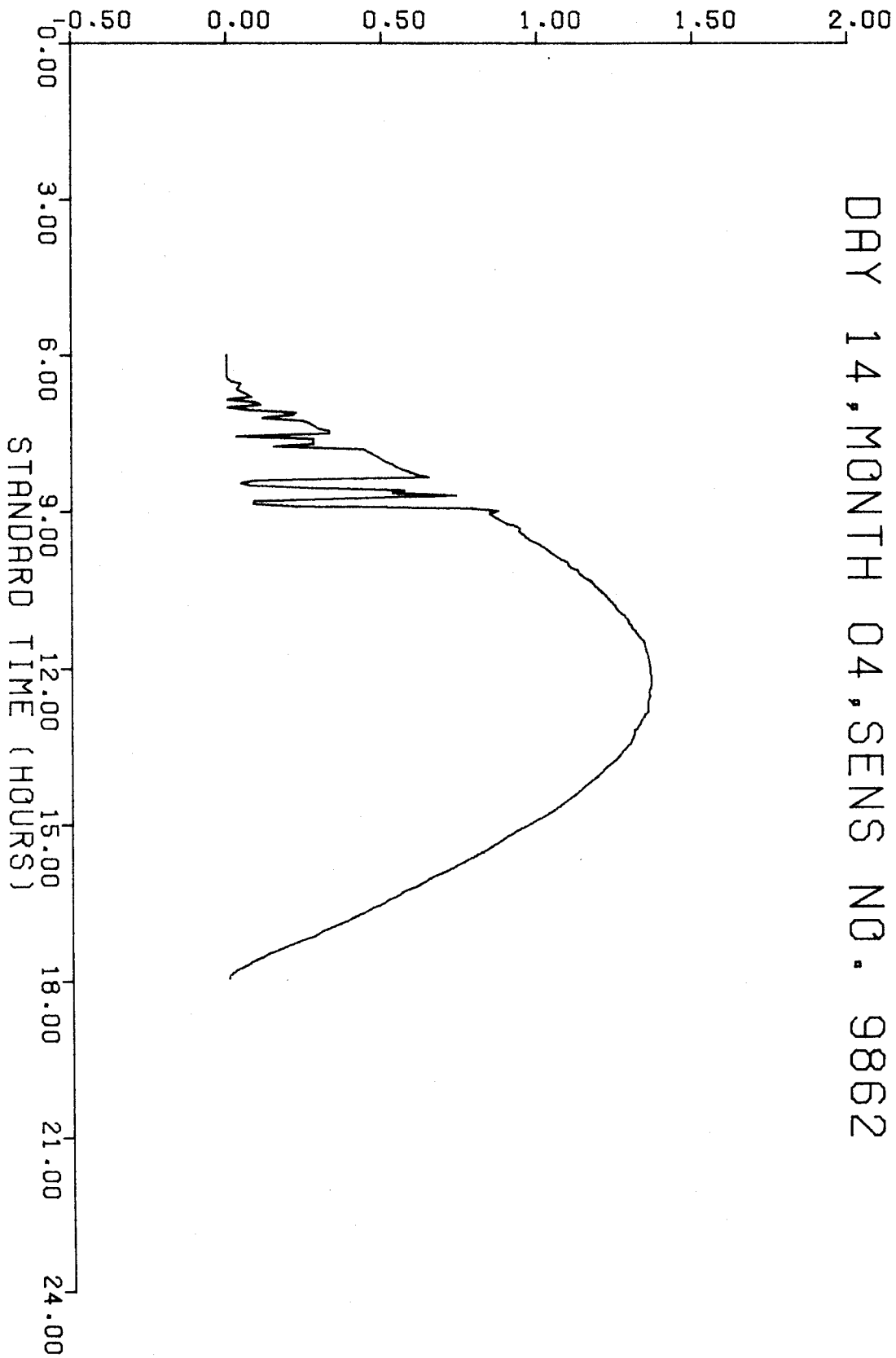
Figure 11. Underwater pyranometer (left) and Model 2 pyranometer (right). Both instruments are manufactured by the Eppley Laboratory and were used in the FLARE program. The Funk-type net radiometer is shown below.

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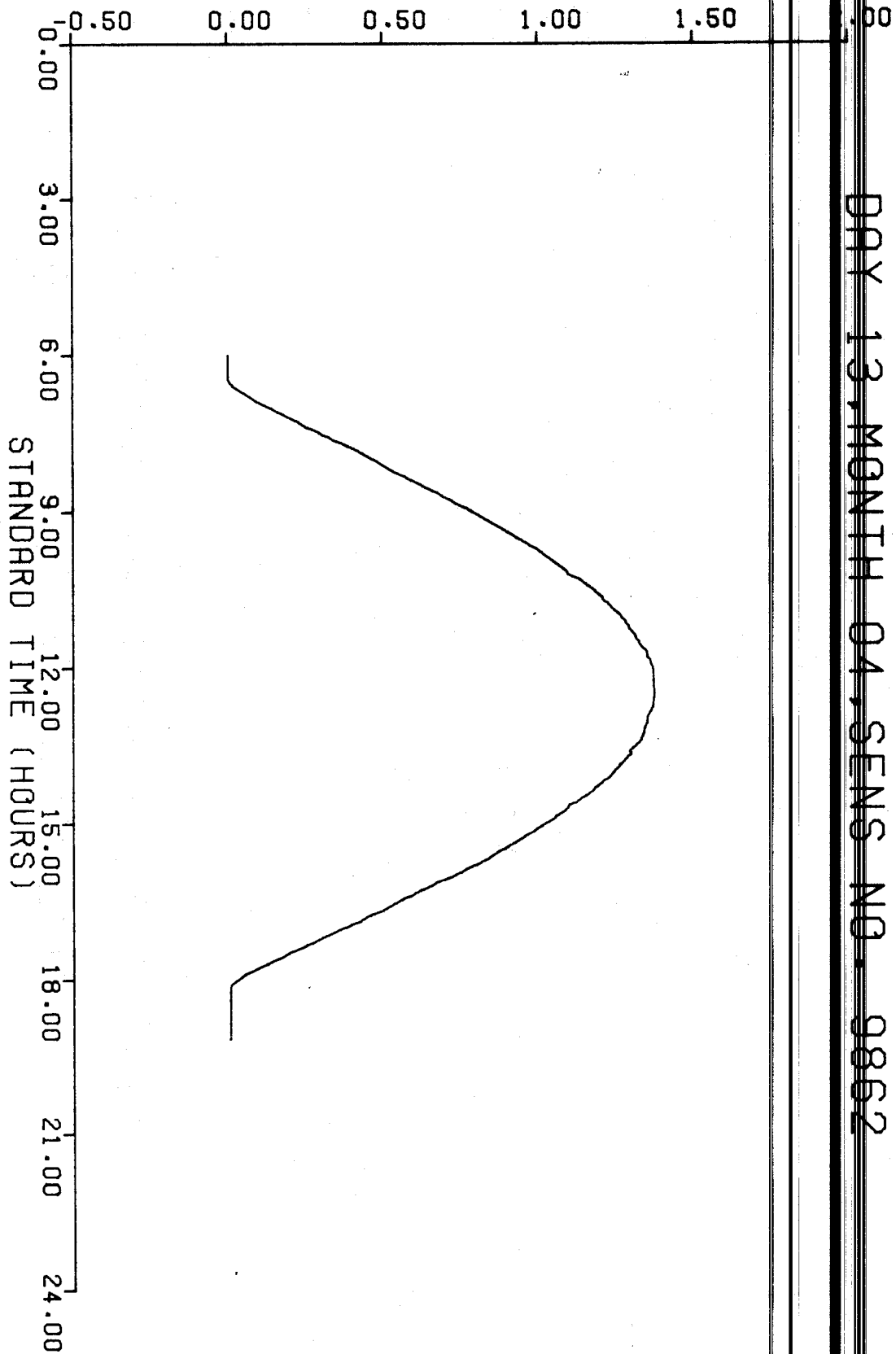
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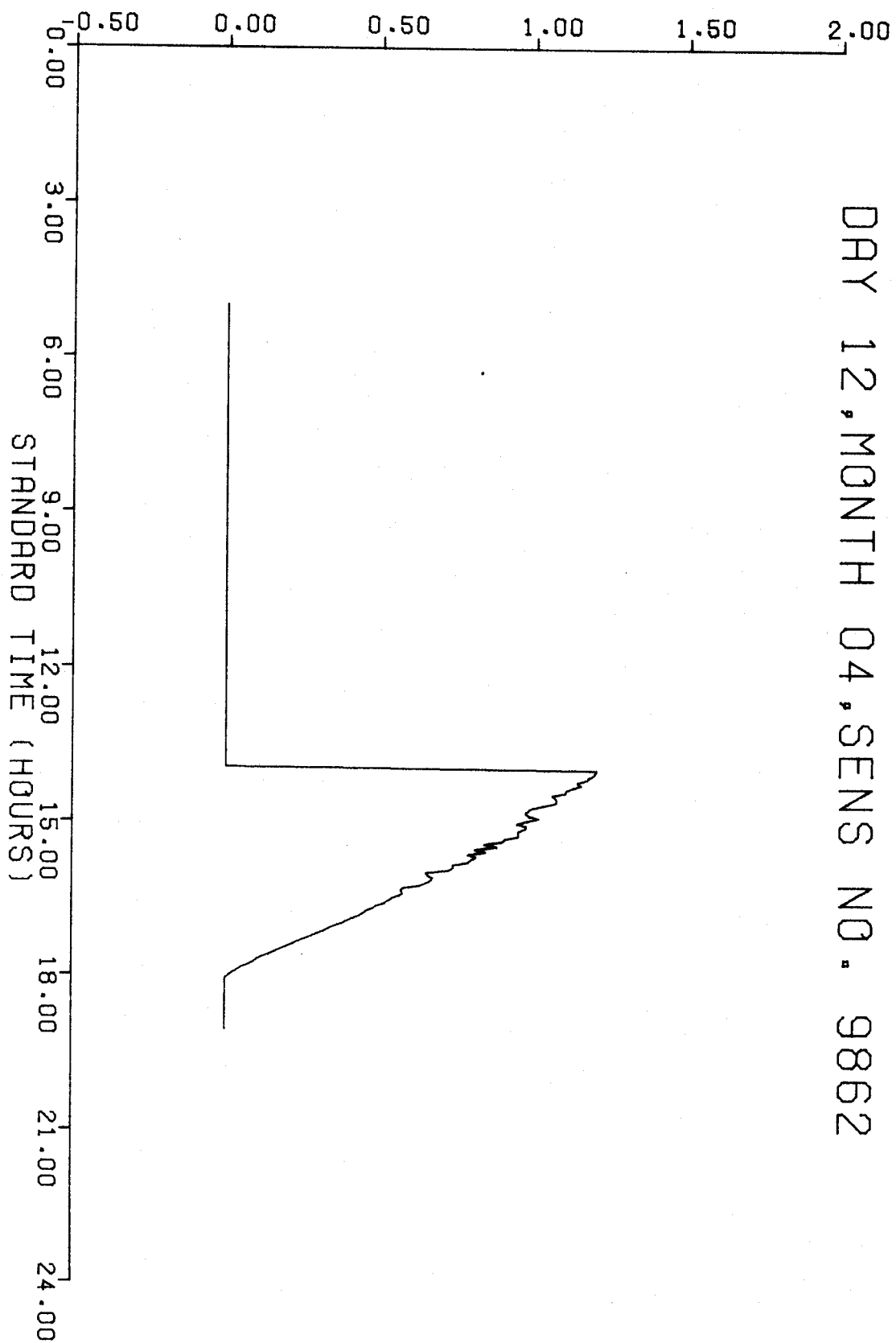
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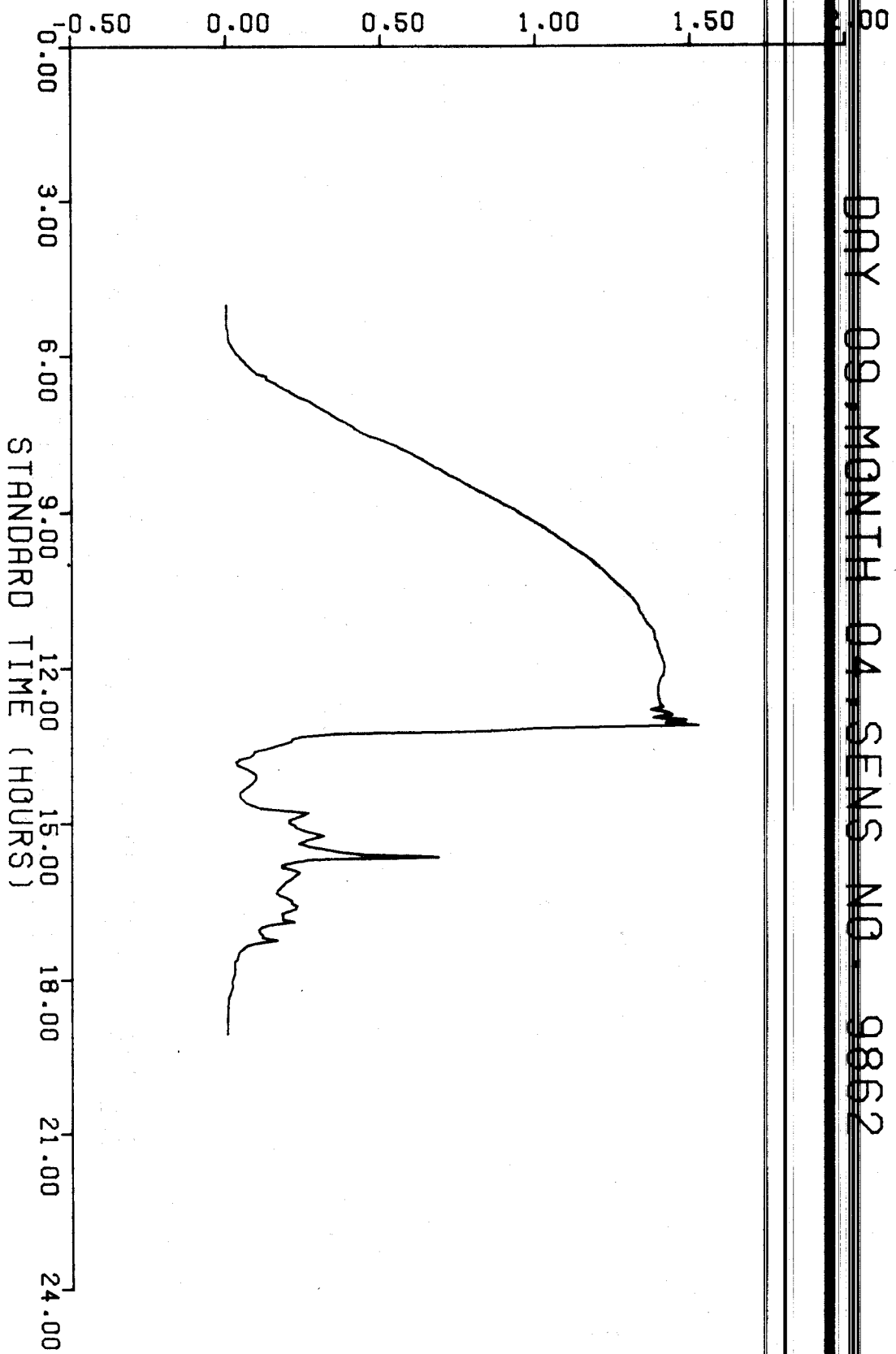
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DAY 13, MONTH 04, SECS NO. 9862

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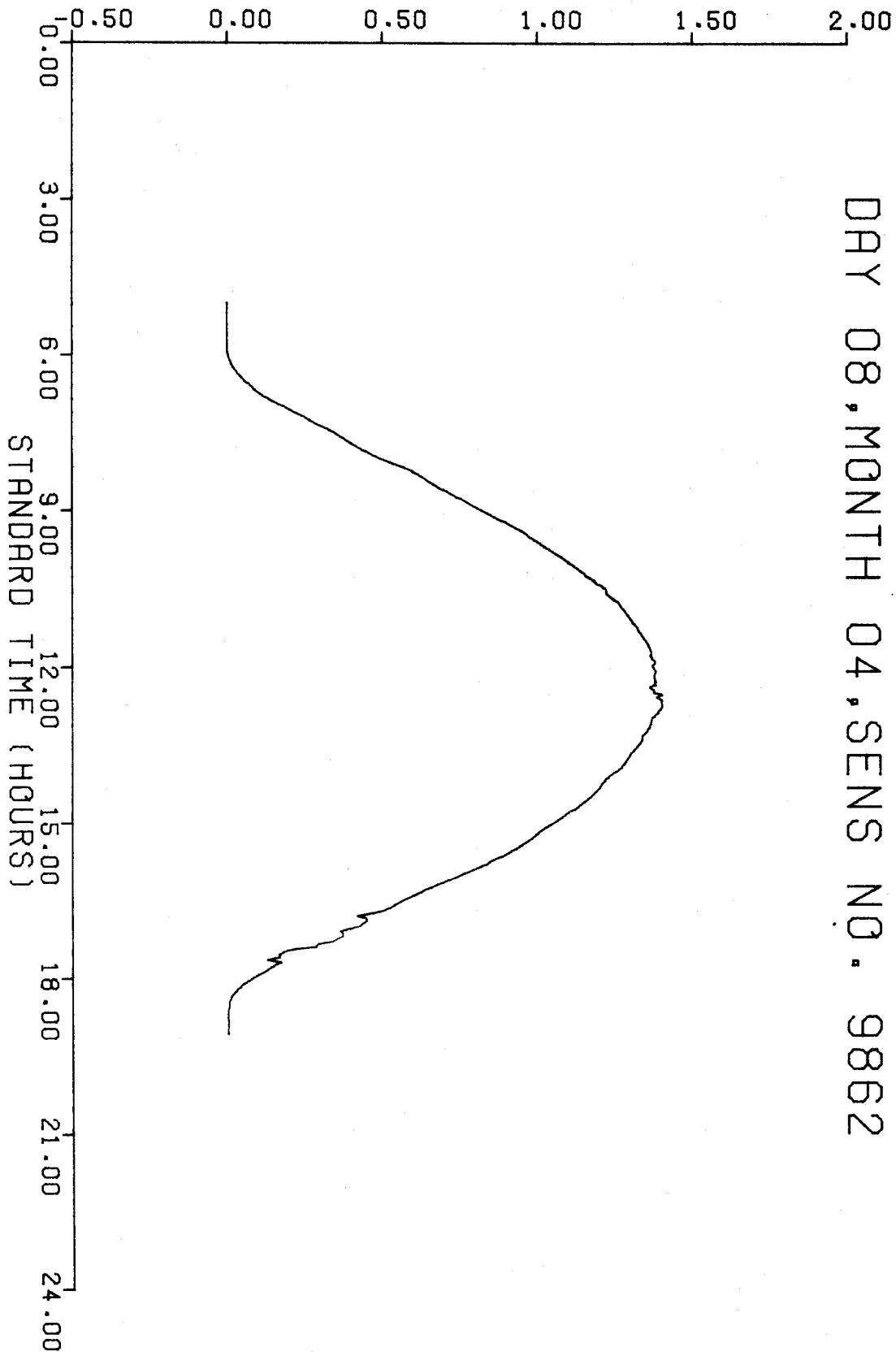
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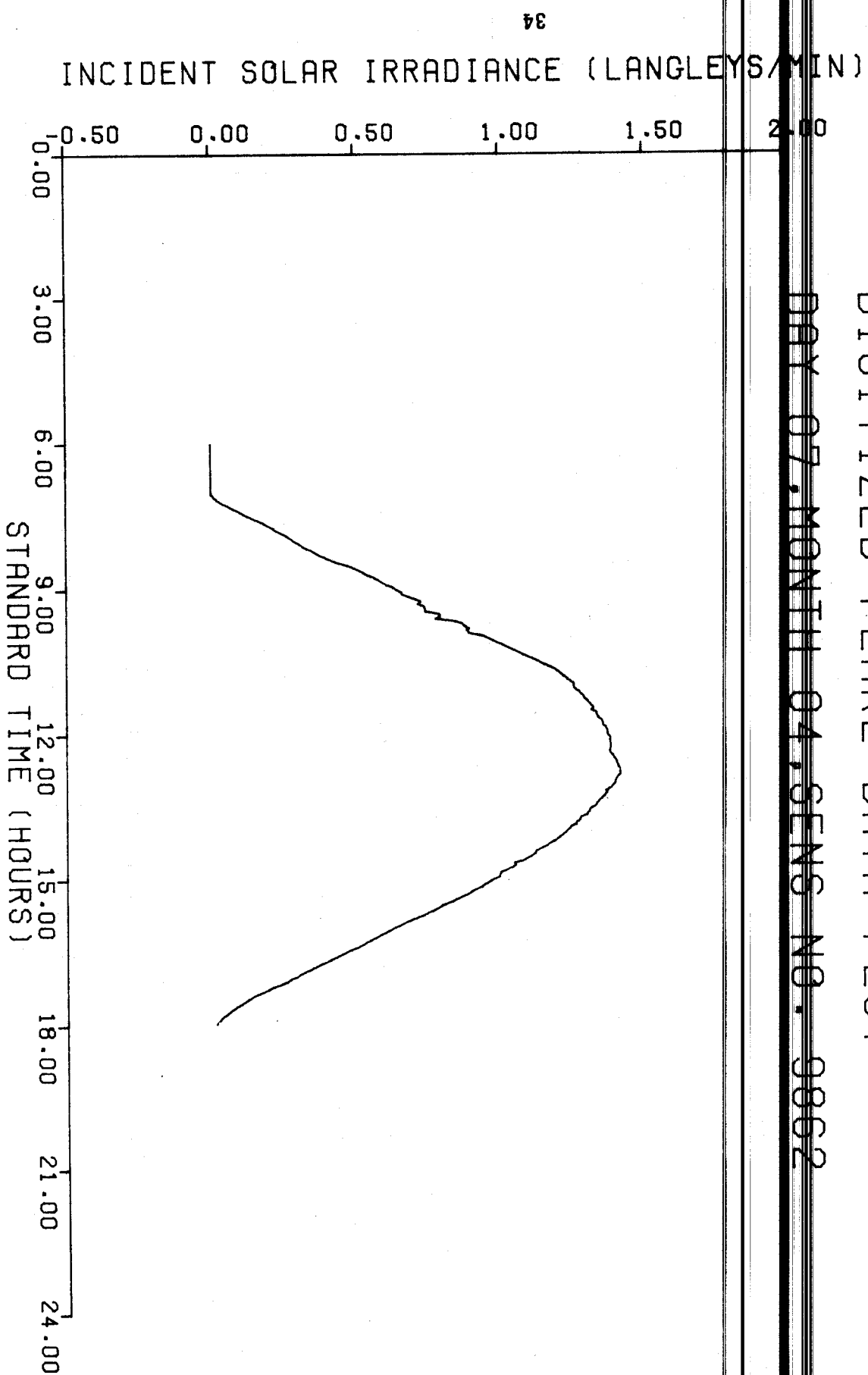
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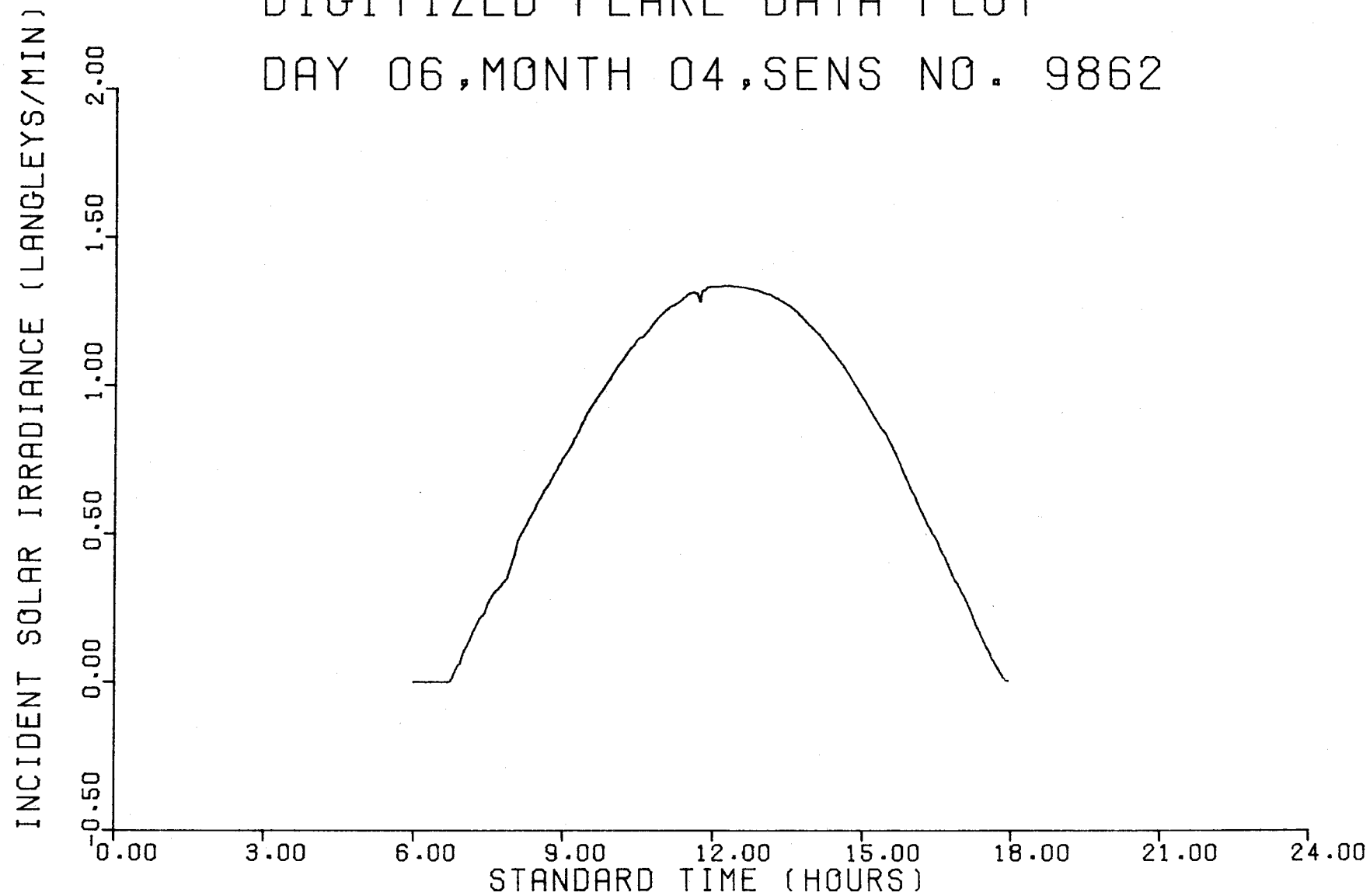


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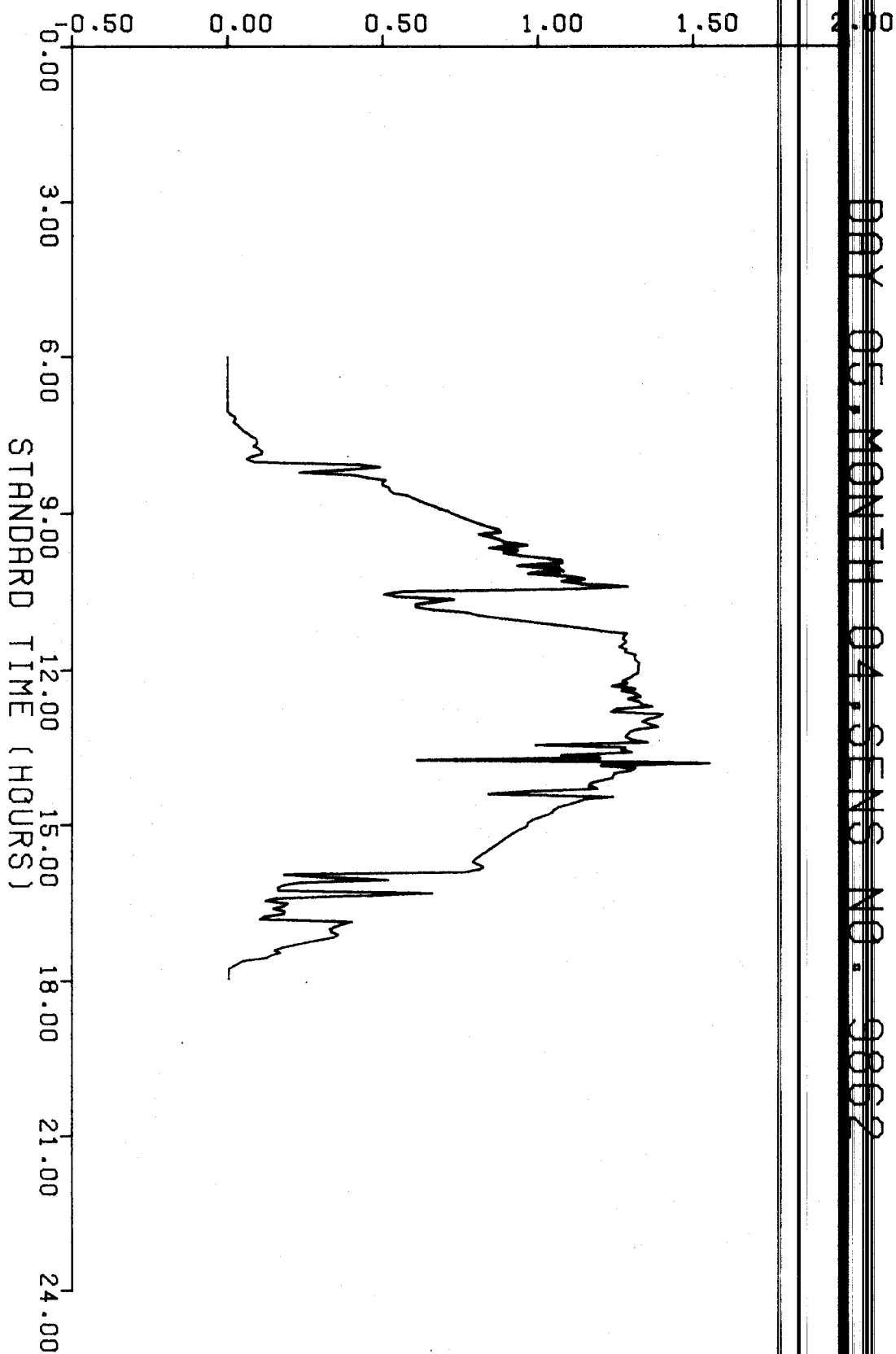
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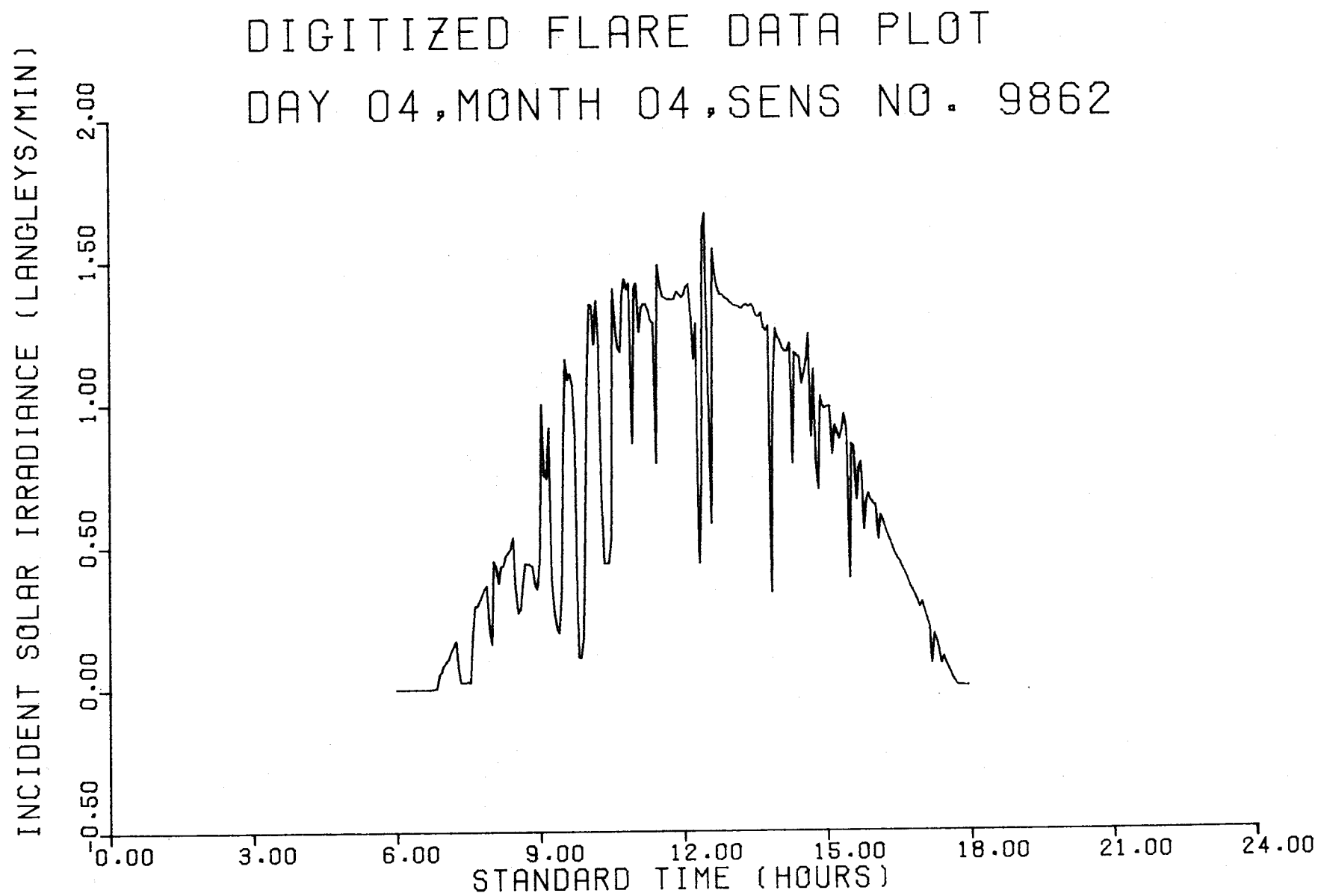


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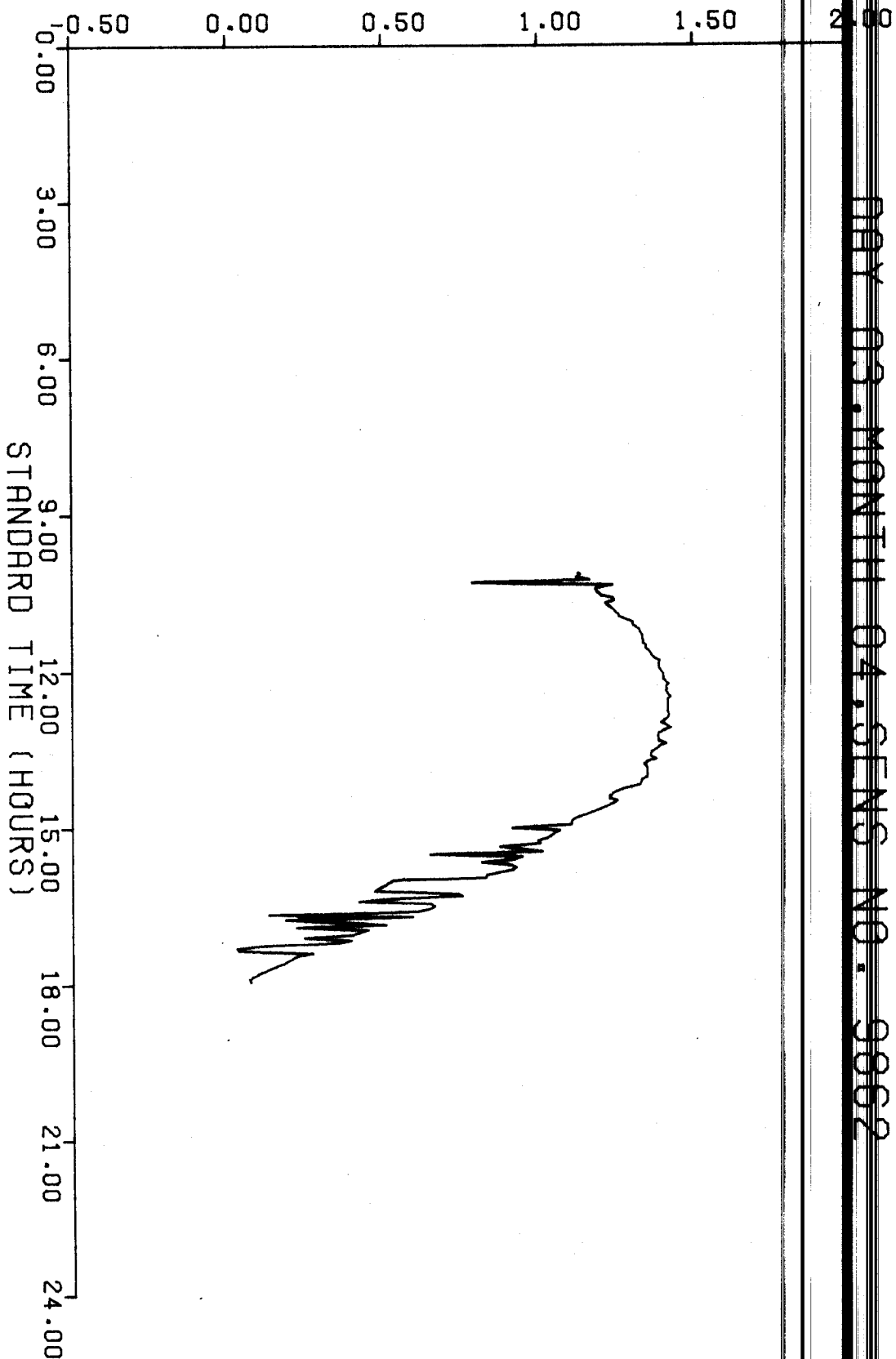


INCIDENT SOLAR IRRADIANCE (LANGLEY/SEC MIN)





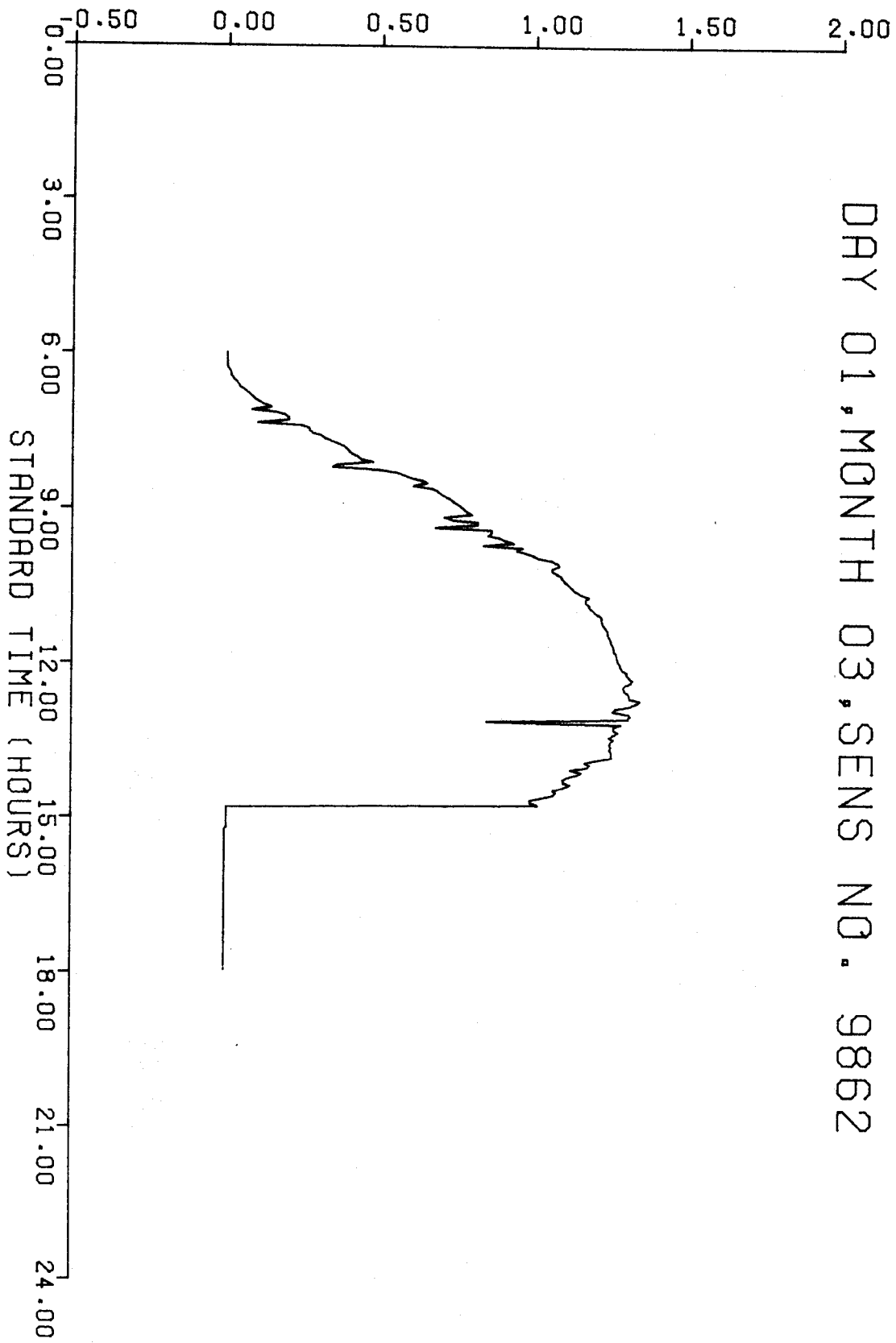
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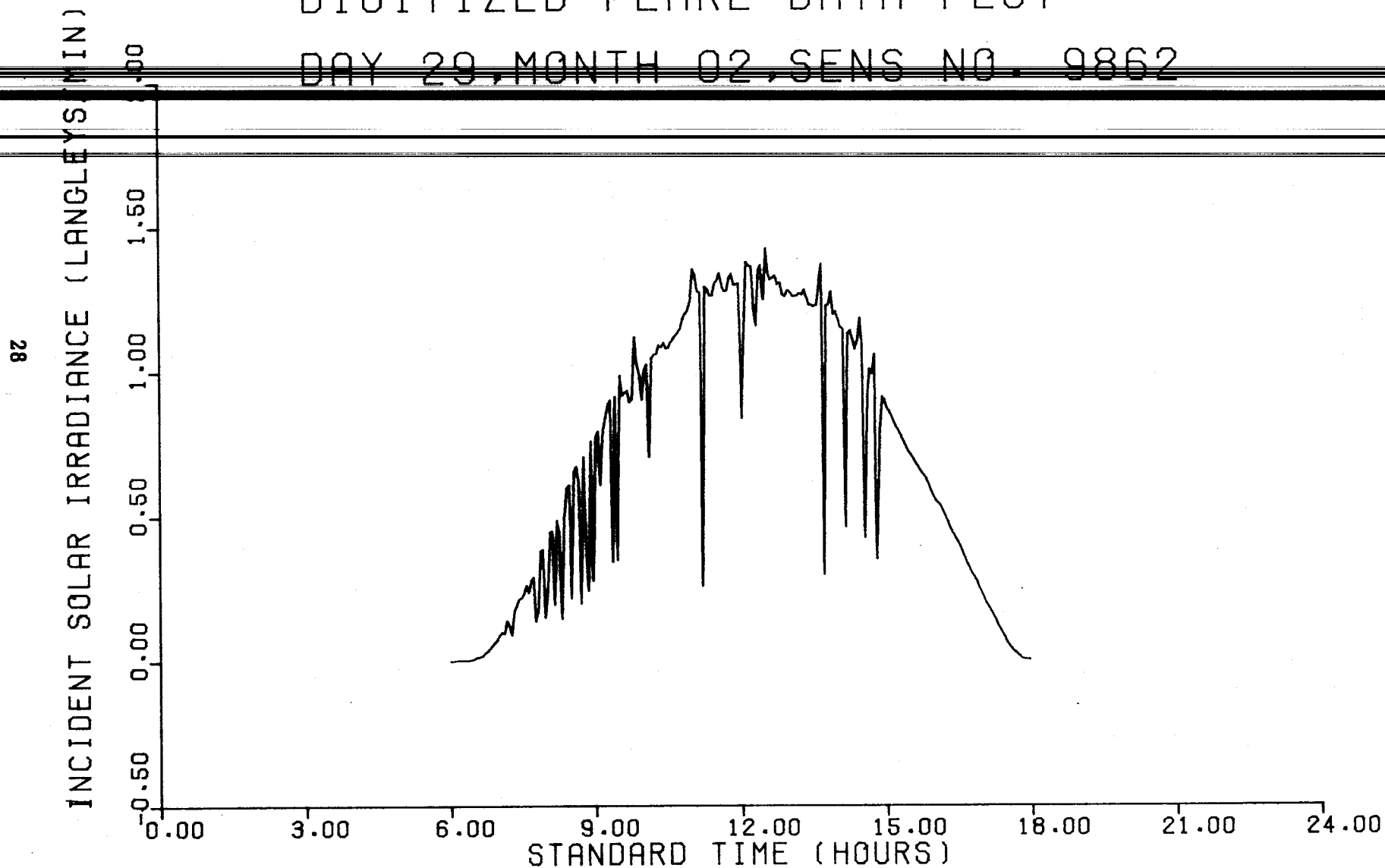
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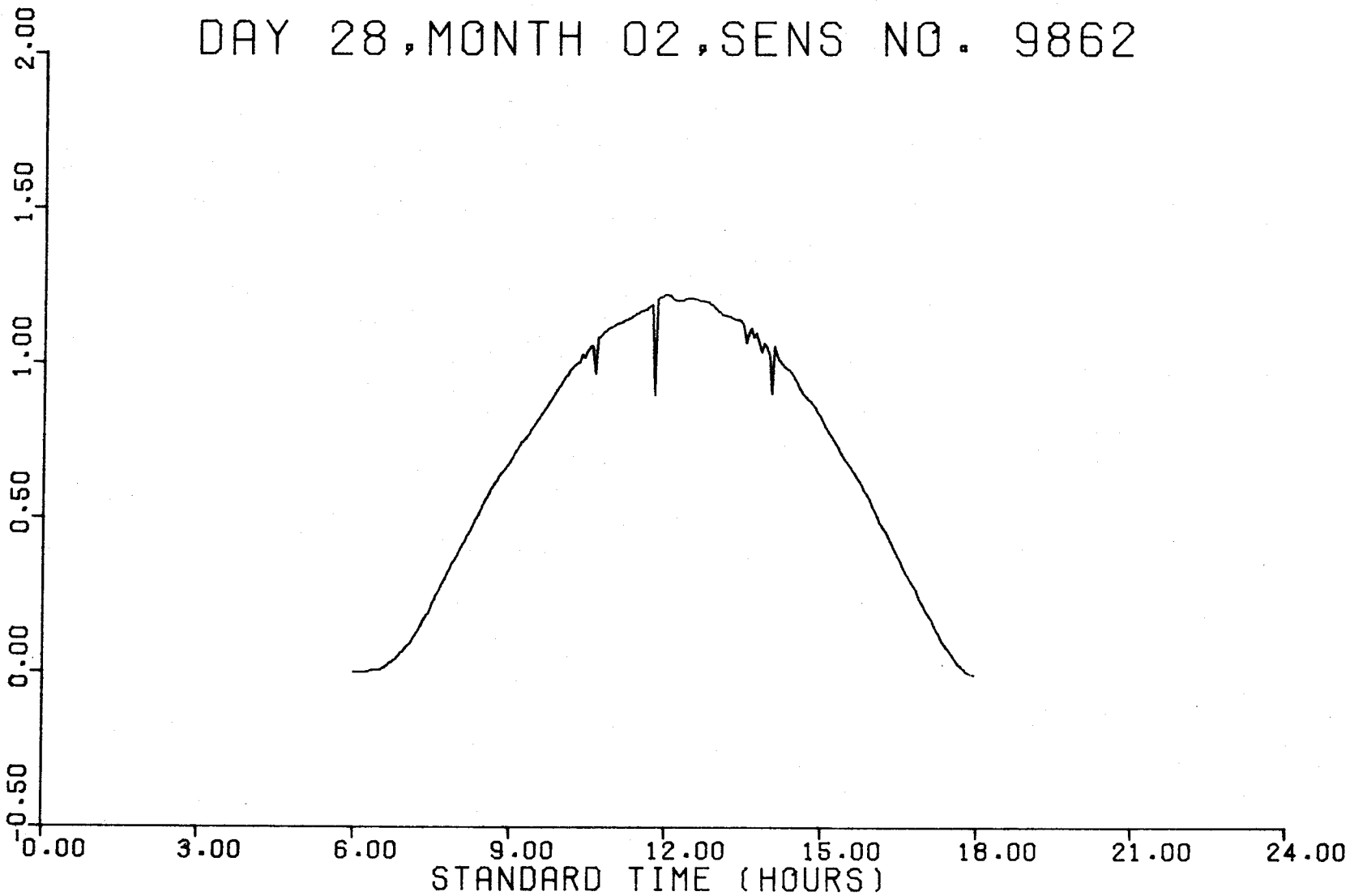


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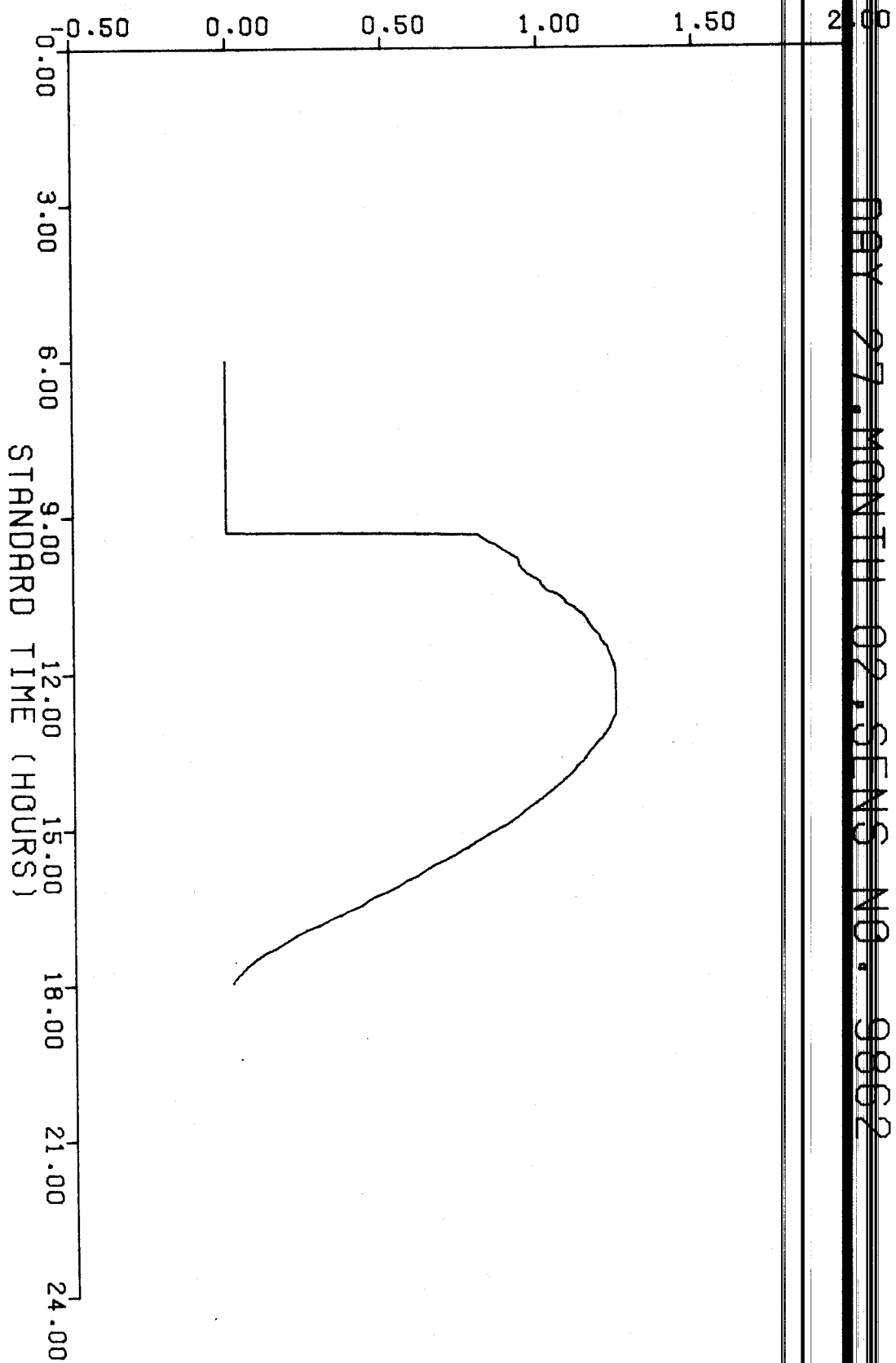
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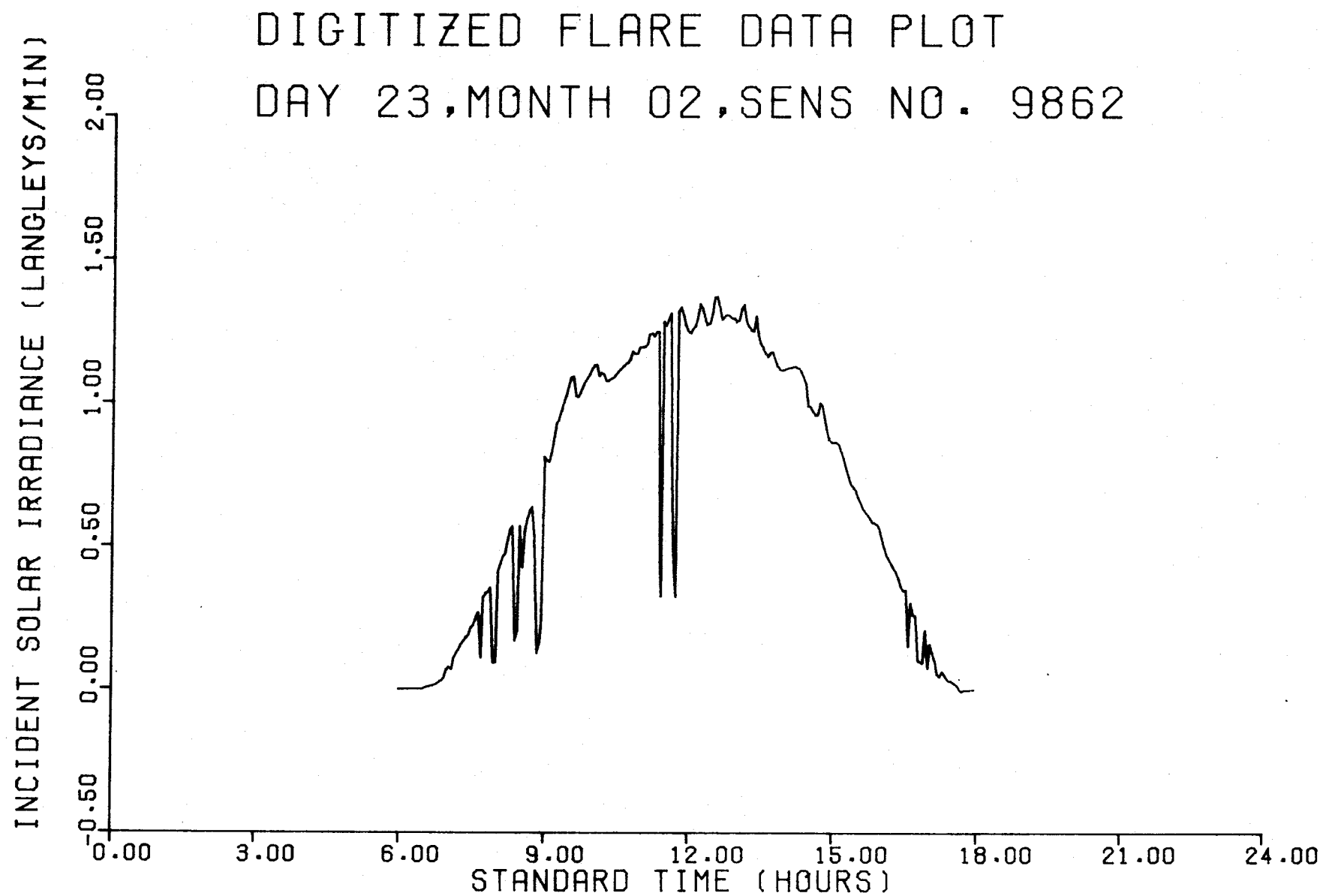


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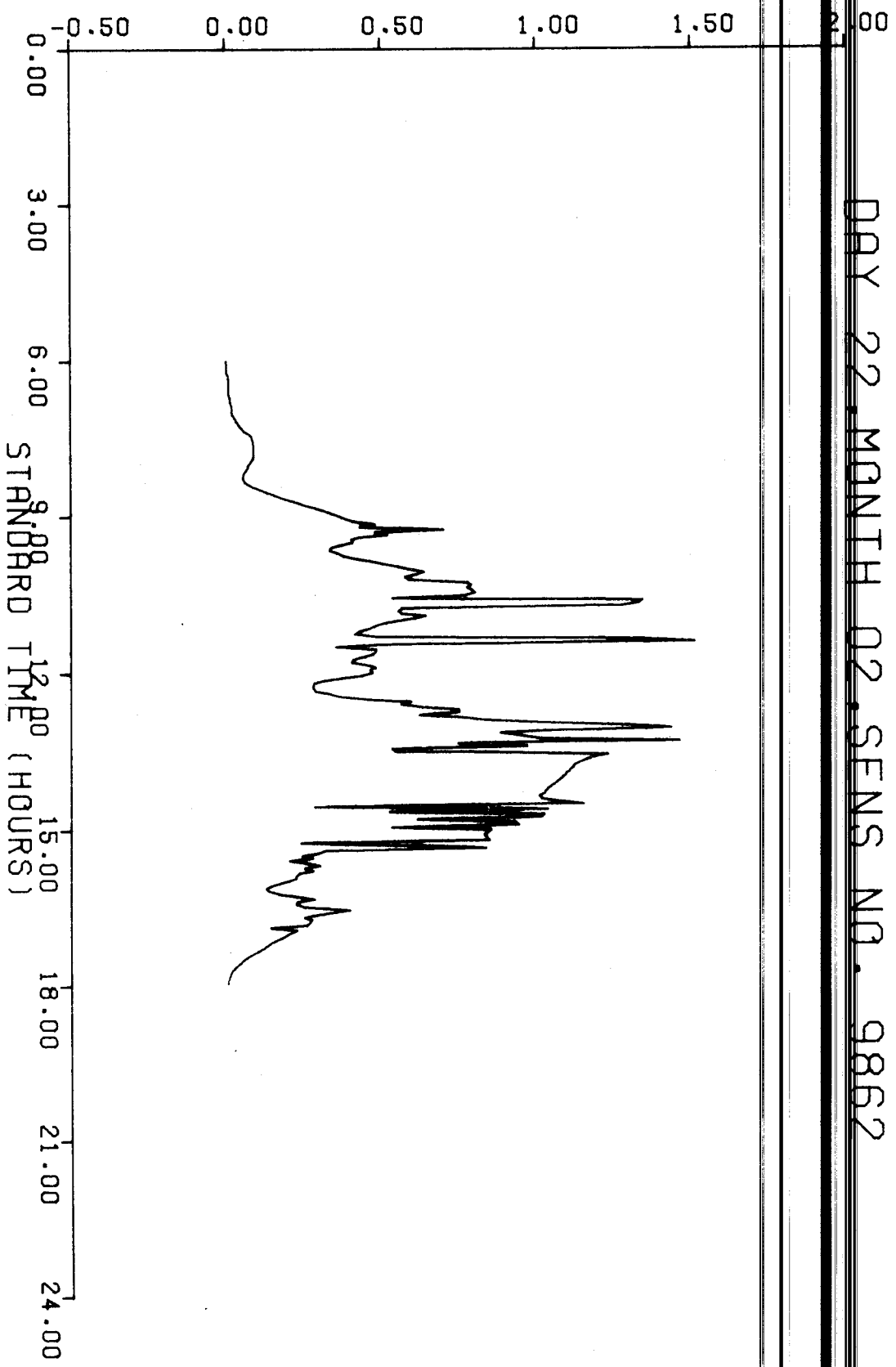


INCIDENT SOLAR IRRADIANCE (LANGLEYS/MIN)





INCIDENT SOLAR IRRADIANCE (LANGLEYS/MIN)



DIGITIZED FLARE DATA PLOT

DAY 22 MONTH 02 SENS NO. 9862

APPENDIX
DAILY SOLAR IRRADIANCE CURVES

DIGITIZED DATA PLOTS

FLARE PROGRAM

	Page
1) INCIDENT SOLAR IRRADIANCE	24
2) REFLECTED SOLAR IRRADIANCE	42
3) FIXED DEPTH IRRADIANCE	60
4) YO-YO IRRADIANCE	77
5) NET RADIATION	81

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The second change is caused by the lens properties of the outer hemisphere when used underwater. The hemisphere acts as a diverging lens which will cause the instrument to measure too small an irradiance value. A study of this effect is being done by Gordon and Brown (1972), who have indicated that, for the indices of refraction given above, the correction factor necessary to increase the measurements to their proper value is 1.76 for solar zenith angles of 0-30 degrees and increased values at larger zenith angles. Thus, the second change caused by the lens effect is considerably more significant than the first caused by reflection.

In the present study no corrections have been applied to the data for the immersion effect. When present studies of this effect have been completed, and an adequate model for applying the corrections has been determined, the basic irradiance data will be revised. This will not alter the results given here based on relative measurements.

6. REFERENCES

- Anderson, E. R. (1954), Energy-budget studies. In Water Loss Investigations, Lake Hefner Studies, U. S., Geol. Surv., Prof. Paper, 269, 71-117.
- Gordon, R. R. and O. B. Brown (1972), Immersion corrections for the Eppley underwater pyranometer, Conf. on Atmospheric Radiation, Amer. Meteorol. Soc., Ft. Collins, Colorado, August, 1972.
- Hanson, R. J. (1971), Studies of cloud and satellite parameterization of solar irradiance at the earth's surface, Proc. of the Miami Workshop on Remote Sensing, NOAA, ERL, Boulder, Colorado, July, 1971.
- Hanson, R. J. and M. F. Poindexter (1972), Attenuance of broadband solar irradiance in the ocean, Conf. on Atmospheric Radiation, Amer. Meteorol. Soc., Ft. Collins, Colorado, August, 1972.
- Jerlov, N. G. (1968), Optical Oceanography, Elsevier Publishing Company, New York.
- List, R., (Ed.) (1958), Smithsonian meteorological tables, 6th Revised Edition, Smithsonian Institution, Washington, D. C.
- National Academy of Sciences (1969), Recommended procedures for measuring the productivity of plankton standing stock and related oceanic properties, prepared by the Biological Methods Panel, Committee on Oceanography, Division of Earth Sciences, National Research Council.

Table 16. Summary of Radiation Sensors Used
in FLARE Radiation Program

Sensor	Measurement	Mfgr.	Sensor Number	Sensitivity (mv/cal cm ⁻² min ⁻¹)
Pyranometer	Incident Solar Irradiance	Eppley	9862	4.10 ⁹
Pyranometer	Reflected Solar Irradiance	Eppley	9863	3.936
Net Radiometer	Net Radiation	Middleton & Co.	465	21.85
Underwater Pyranometer	Solar Irradiance, Fixed Depth	Eppley	9860	4.366
Underwater Pyranometer	Solar Irradiance, Profile	Eppley	9861	4.626

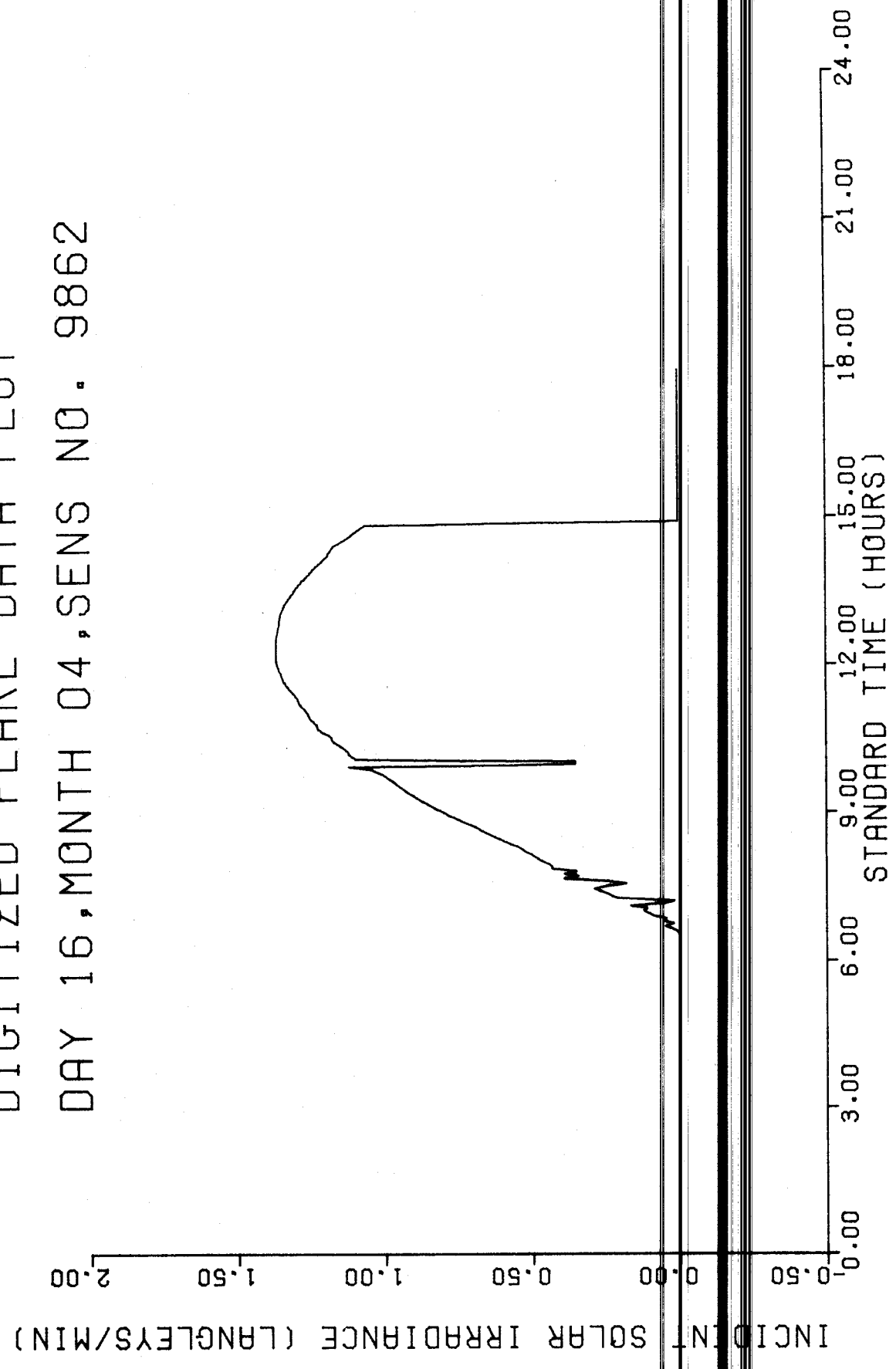
5. IMMERSION EFFECT OF THE UNDERWATER PYRANOMETERS

The underwater pyranometers used in this study have an immersion effect that must be determined before one can evaluate the absolute value of the measurements. Originally the sensors were calibrated in the air with the sun as a source by direct comparison with another pyranometer. Use of the instrument underwater changes the optical characteristics of the instrument from those in air in two ways - this is called the immersion effect. The first change results from a difference between the reflectivity of the outer hemisphere in water as compared to air. At normal incidence the reflectivity is

$$r = \left[\frac{n_1 - n_2}{n_1 + n_2} \right]^2 \quad (2)$$

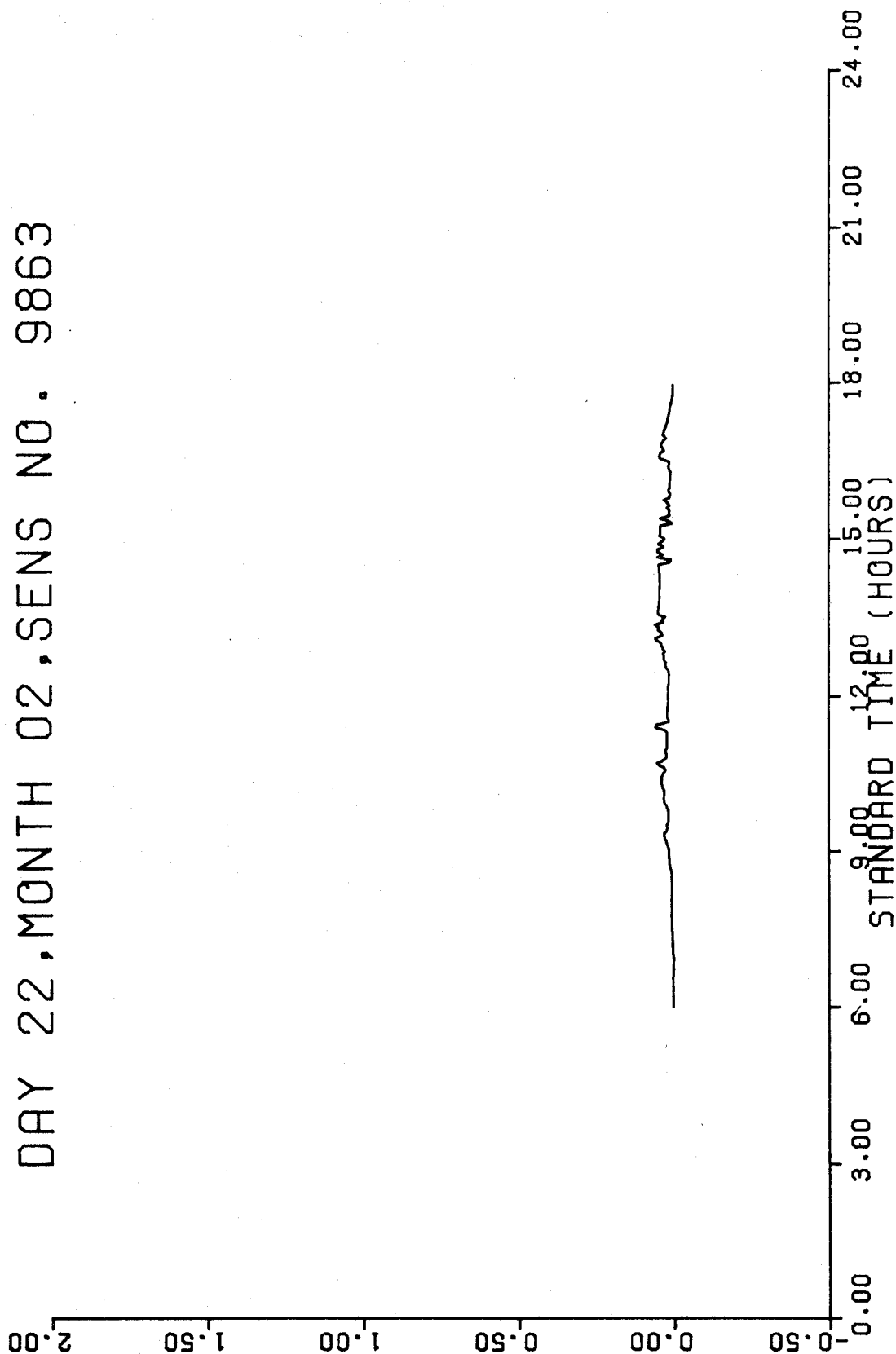
where n_1 is the index of refraction for the medium adjacent to the glass hemisphere and n_2 is that of the hemisphere. Because the indices of refraction of air, water, and glass have values of approximately 1.00, 1.33, and 1.5, respectively, it is apparent that the reflectance of the outer hemisphere will be smaller in water than in air. Although this effect is relatively small (about 3 percent), it will cause the instrument to measure too large an irradiance value.

DIGITIZED FLARE DATA PLOT
DAY 16, MONTH 04, SENS NO. 9862

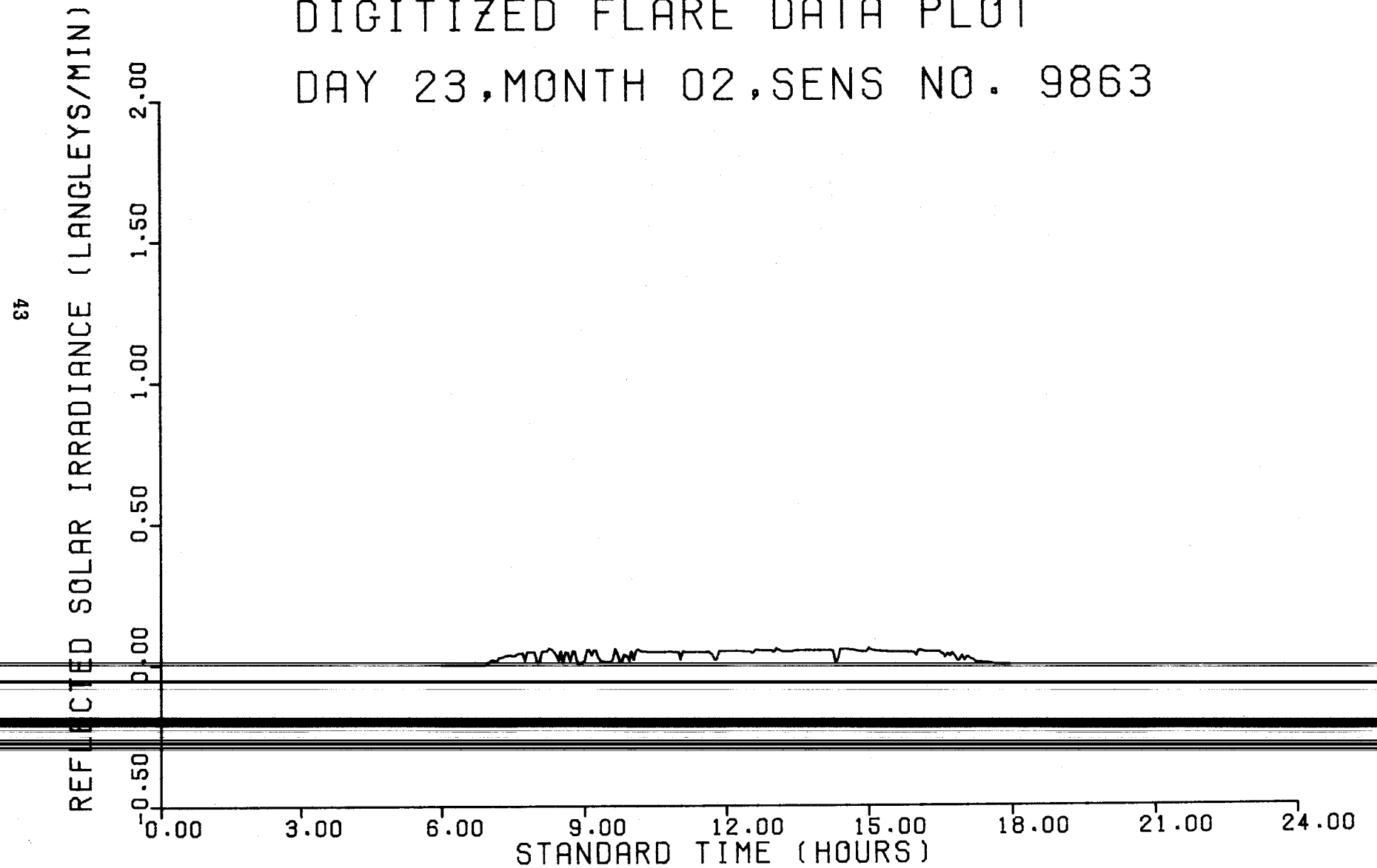


DIGITIZED FLARE DATA PLOT
DAY 22, MONTH 02, SENS NO. 9863

REFLECTED SOLAR IRRADIANCE (LANGLEYS/MIN)

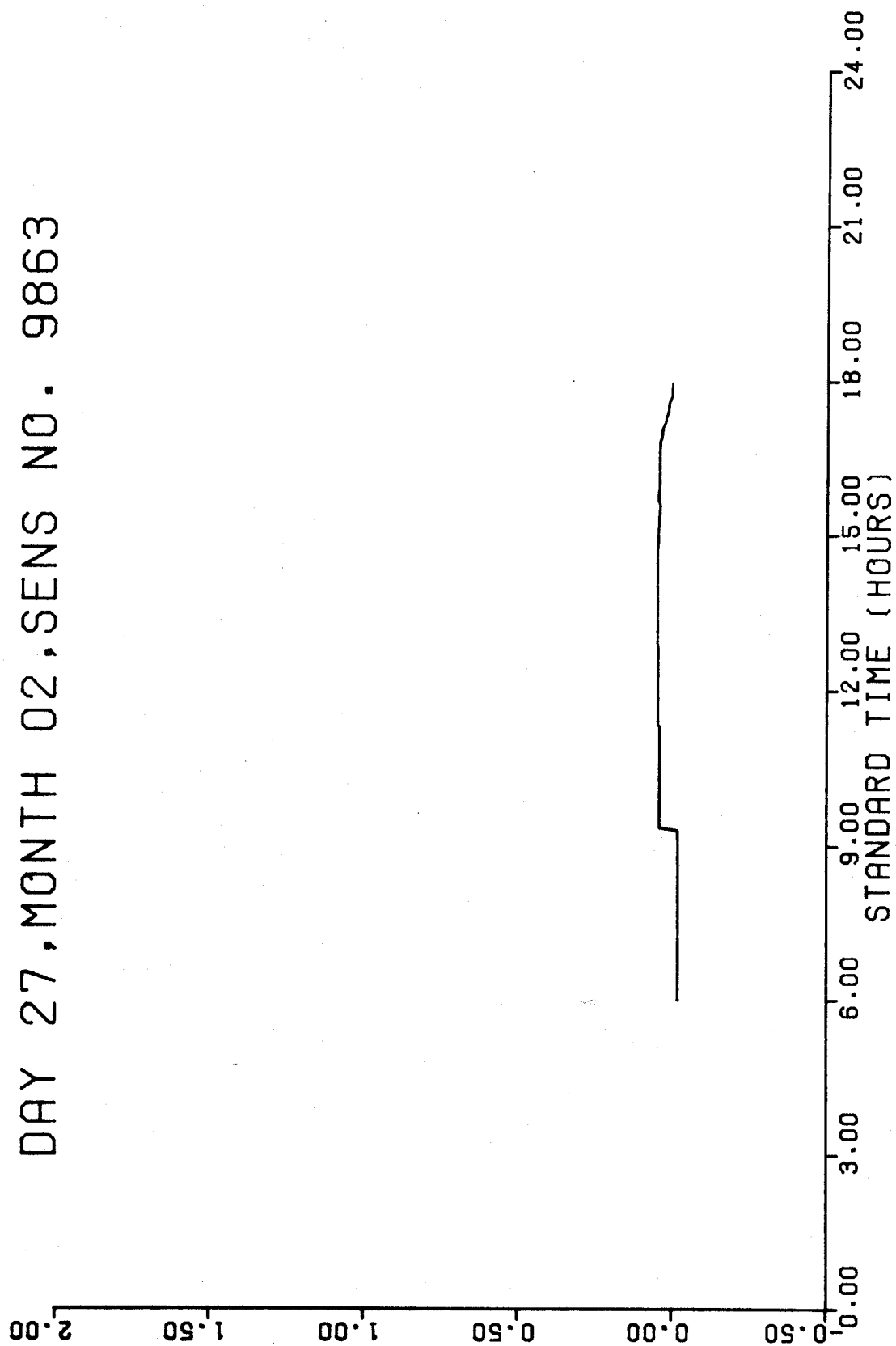


DIGITIZED FLARE DATA PLOT
DAY 23, MONTH 02, SENS NO. 9863



DIGITIZED FLARE DATA PLOT
DAY 27, MONTH 02, SENS NO. 9863

REFLECTED SOLAR IRRADIANCE (LANGLEYS/MIN)



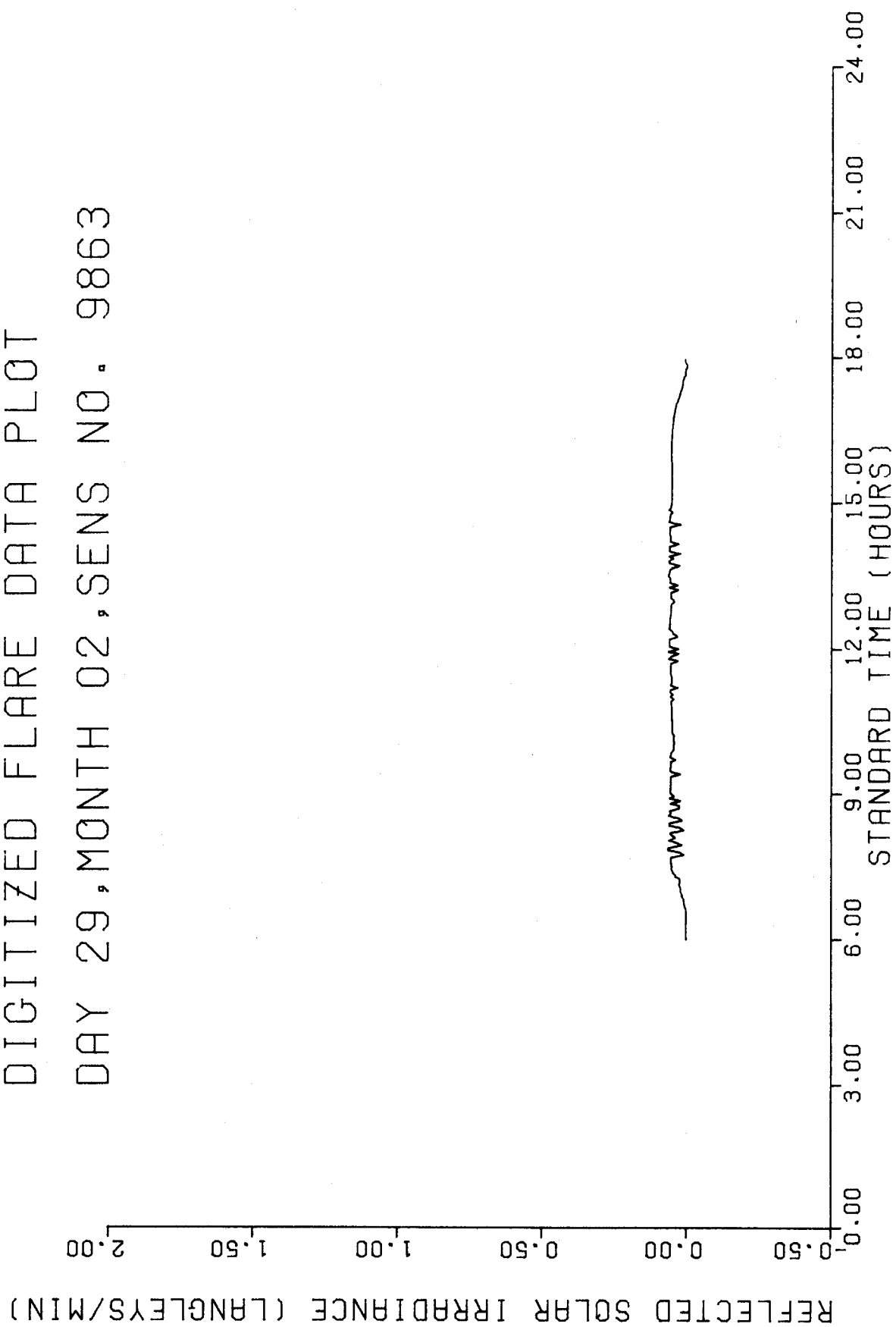
DIGITIZED FLARE DATA PLOT
DAY 28, MONTH 02, SENS NO. 9863

REFLECTED SOLAR IRRADIANCE (LANGLEYS/MIN)

2.00
1.50
1.00
0.50
0.00
0.50

0.00 3.00 6.00 9.00 12.00 15.00 18.00 21.00 24.00
STANDARD TIME (HOURS)

DIGITIZED FLARE DATA PLOT
DAY 29, MONTH 02, SENS NO. 9863



DIGITIZED FLARE DATA PLOT
DAY 01, MONTH 03, SENS NO. 9863

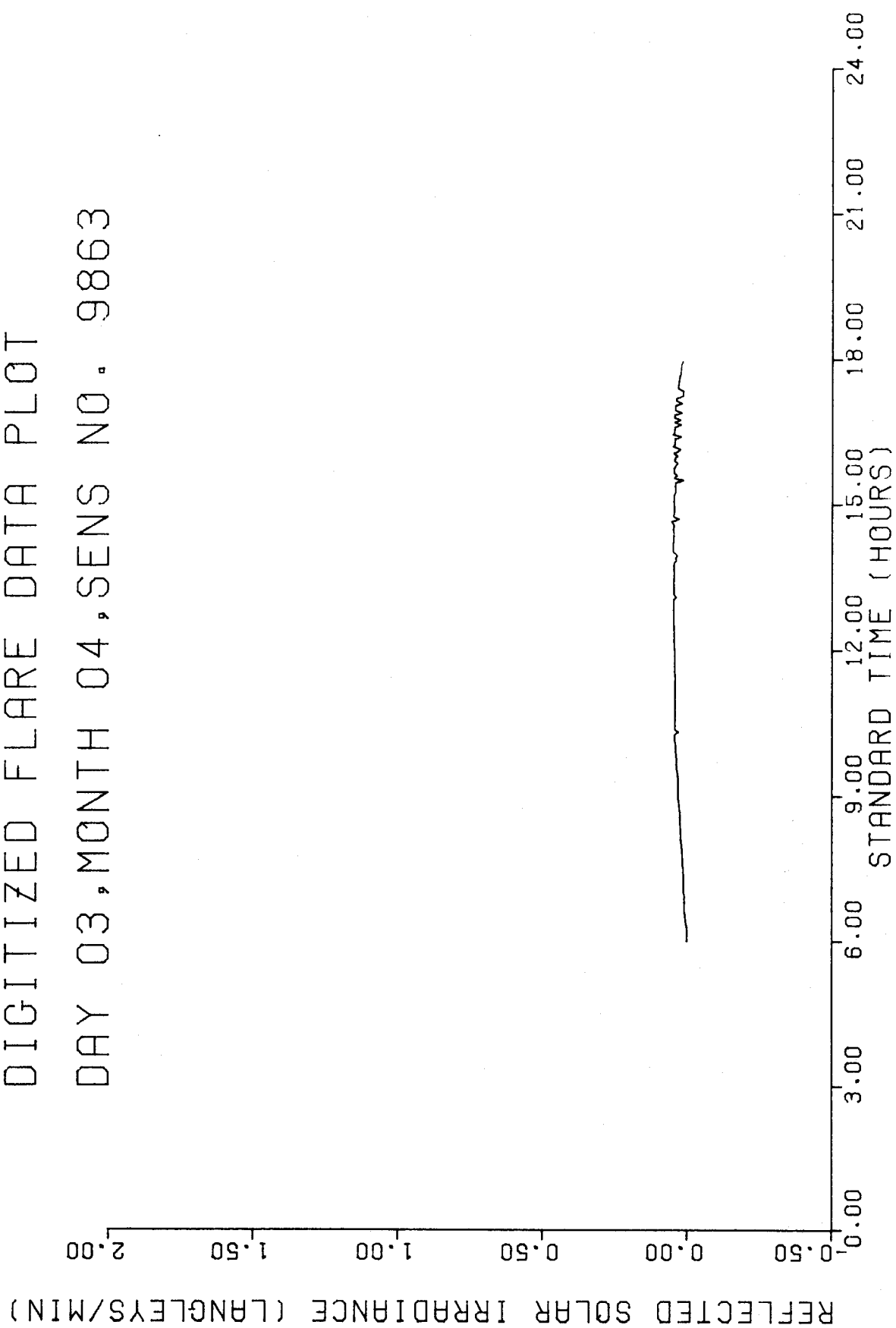
REFLECTED SOLAR IRRADIANCE (LANGLEYS/MIN)

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0.00 3.00 6.00 9.00 12.00 15.00 18.00 21.00 24.00
STANDARD TIME (HOURS)

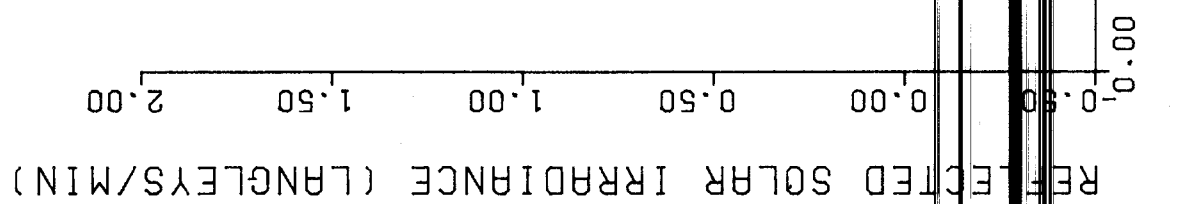


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DAY 03, MONTH 04, SENS NO. 9863

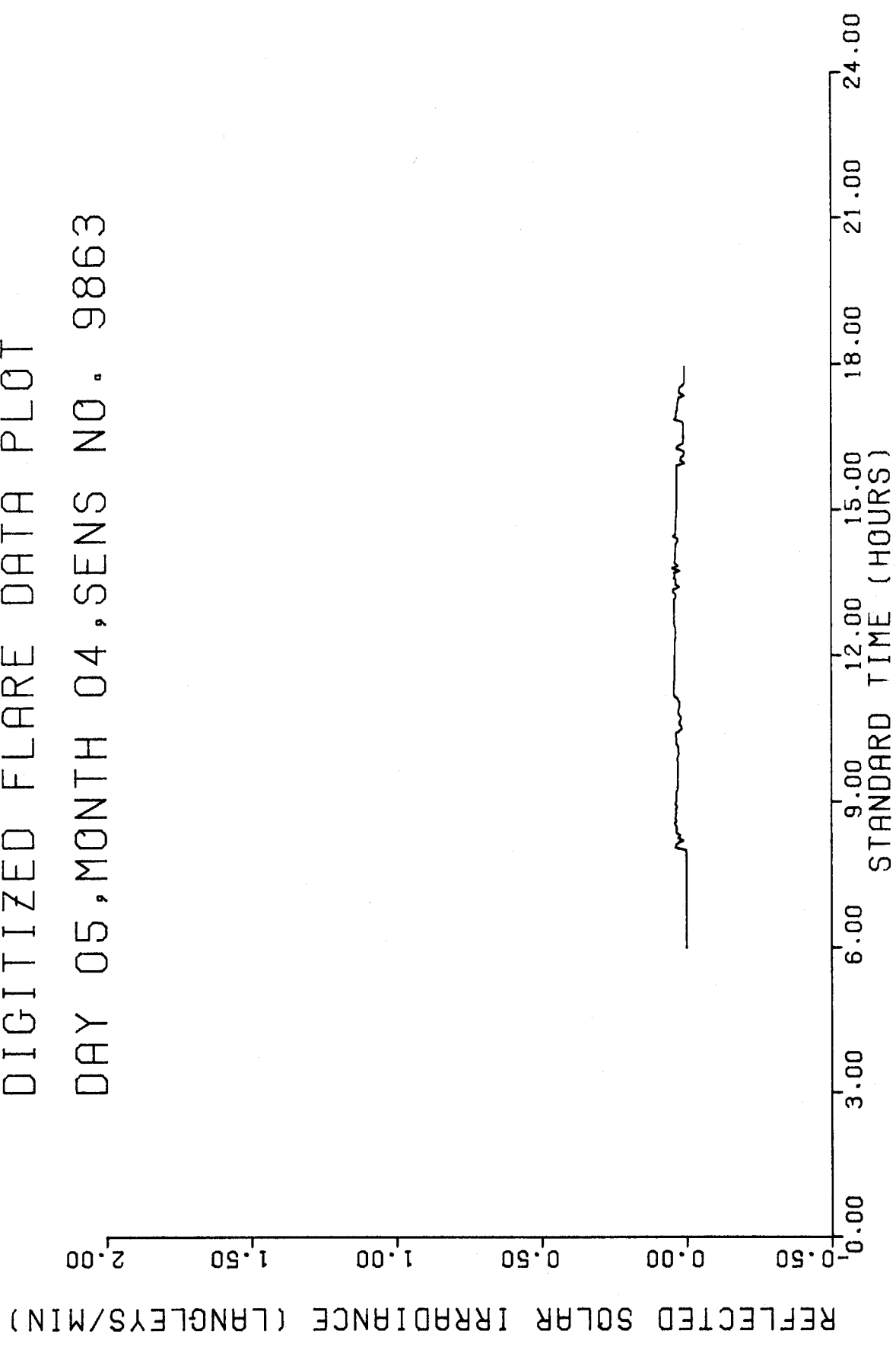


DIGITIZED FLARE DATA PLOT

DAY 04, MONTH 04, SENS NO. 9863



DIGITIZED FLARE DATA PLOT
DAY 05, MONTH 04, SENS NO. 9863



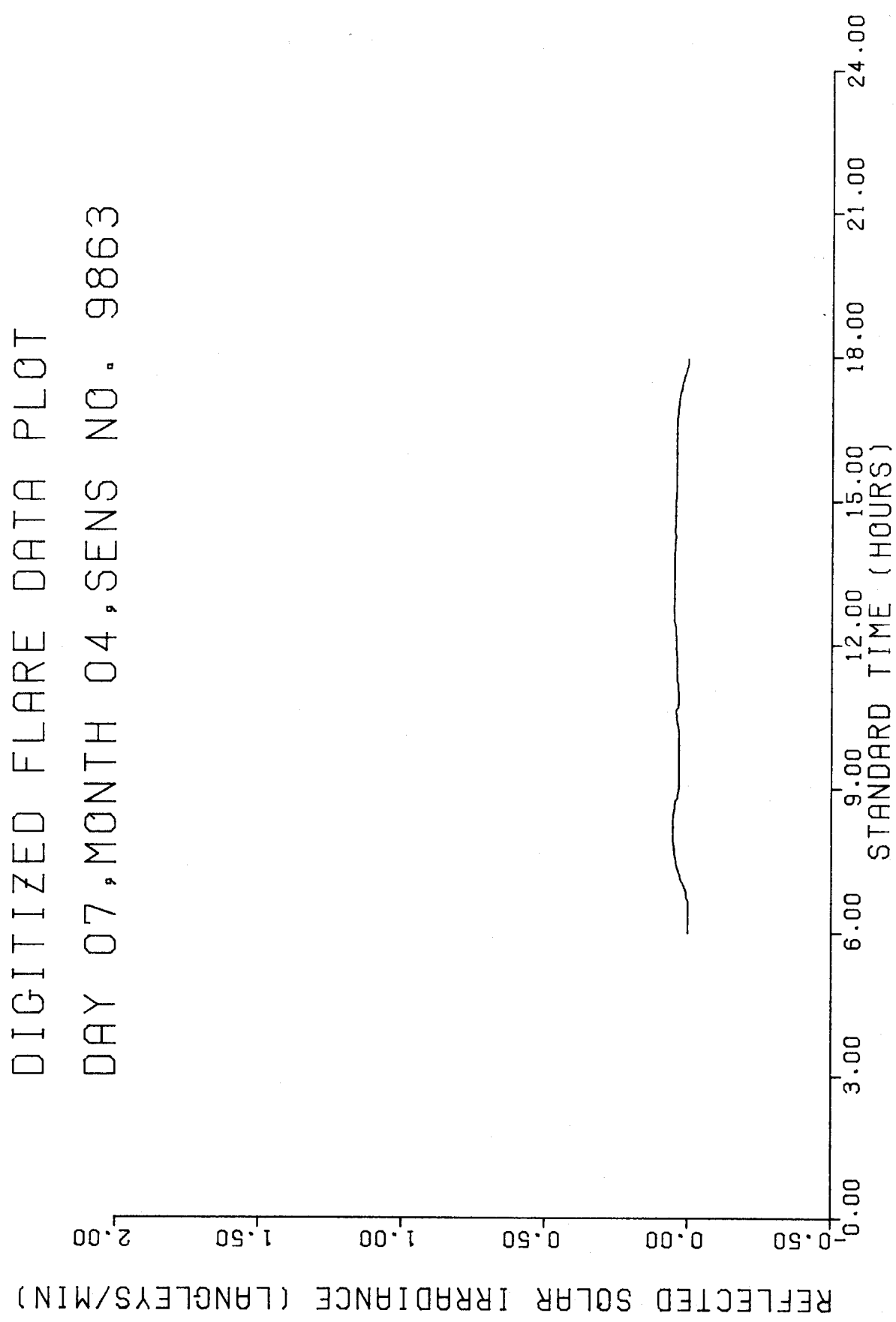
DIGITIZED FLARE DATA PLOT
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REFLECTED SOLAR IRRADIANCE (LANGLEYS/MIN)

2.00
1.50
1.00
0.50
0.00
-0.50

3.00 6.00 9.00 12.00 15.00 18.00 21.00 24.00
STANDARD TIME (HOURS)

DIGITIZED FLARE DATA PLOT
DAY 07, MONTH 04, SENS NO. 9863



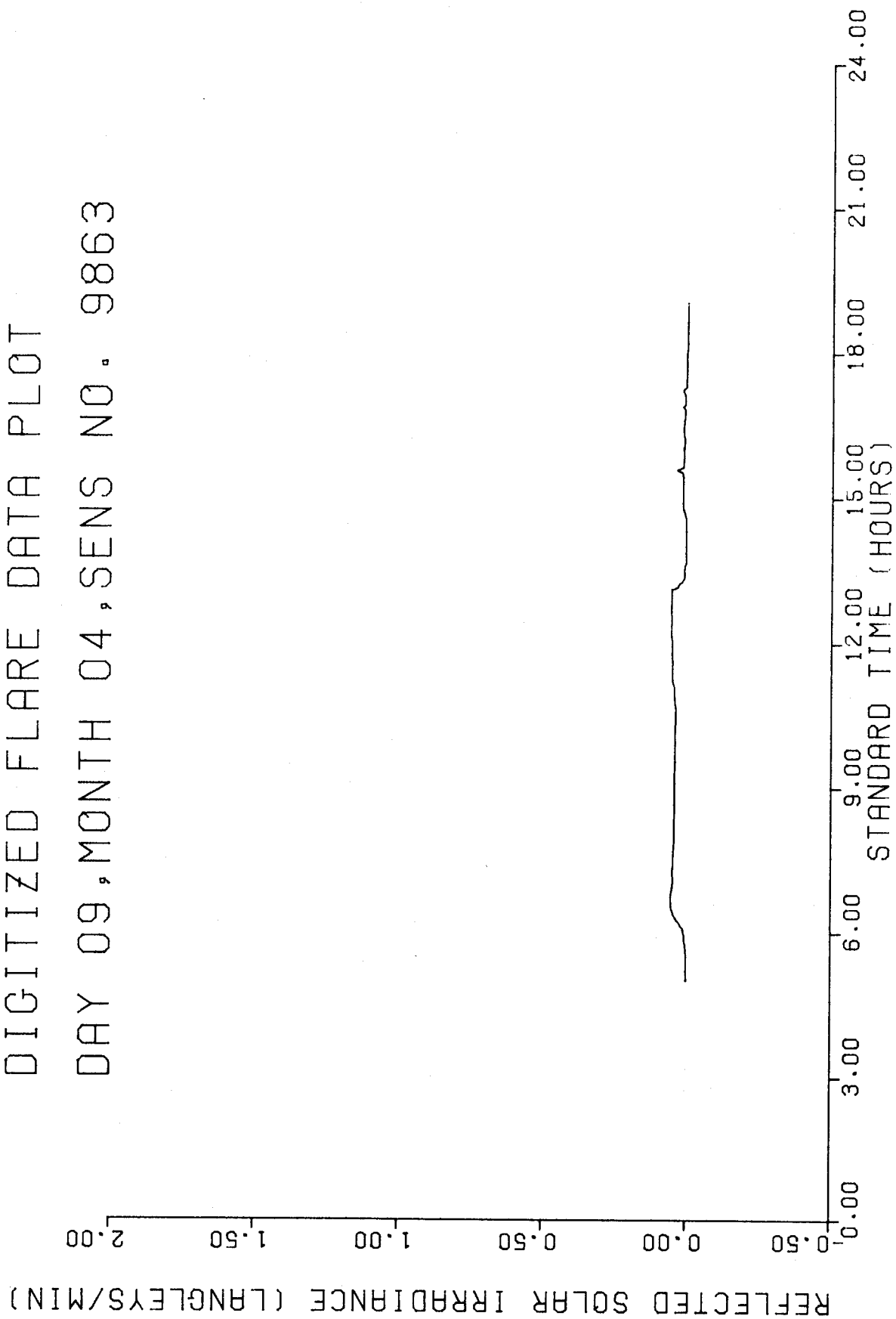
DIGITIZED FLARE DATA PLOT
DAY 08, MONTH 04, SENS NO. 9863

REFLECTED SOLAR IRRADIANCE (LANGLEYS/MIN)

2.00
1.50
1.00
0.50
0.00
-0.50

3.00 6.00 9.00 12.00 15.00 18.00 21.00 24.00
STANDARD TIME (HOURS)

DIGITIZED FLARE DATA PLOT
DAY 09, MONTH 04, SENS NO. 9863



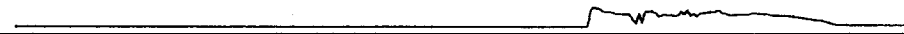
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REFLECTED SOLAR IRRADIANCE (LANGLEYS/MIN)

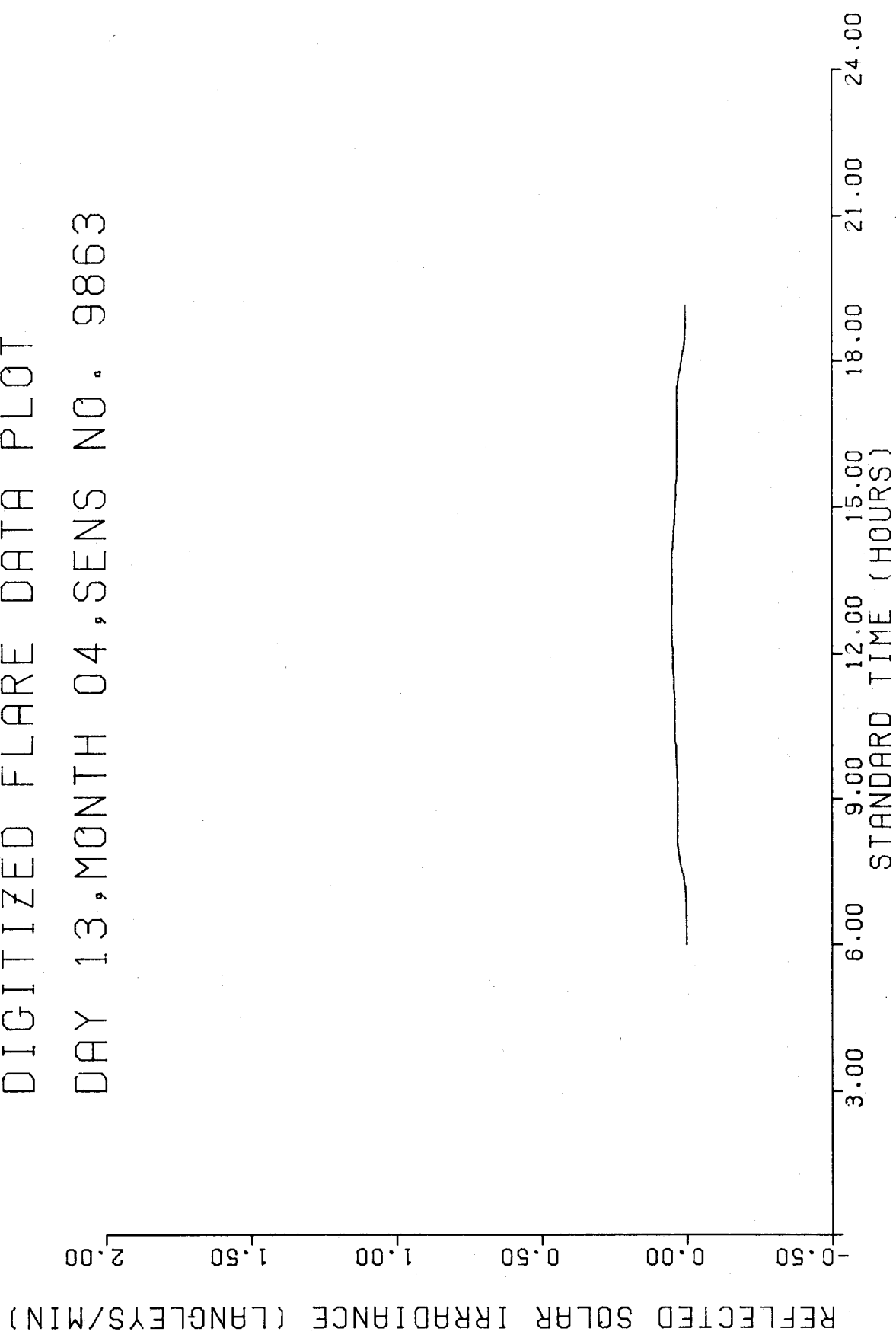
2.00
1.50
1.00
0.50
0.00
-0.50

DIGITIZED FLARE DATA PLOT
DAY 12, MONTH 04, SENS NO. 9863

0.00 3.00 6.00 9.00 12.00 15.00 18.00 21.00 24.00
STANDARD TIME (HOURS)



DIGITIZED FLARE DATA PLOT
DAY 13, MONTH 04, SENS NO. 9863



57

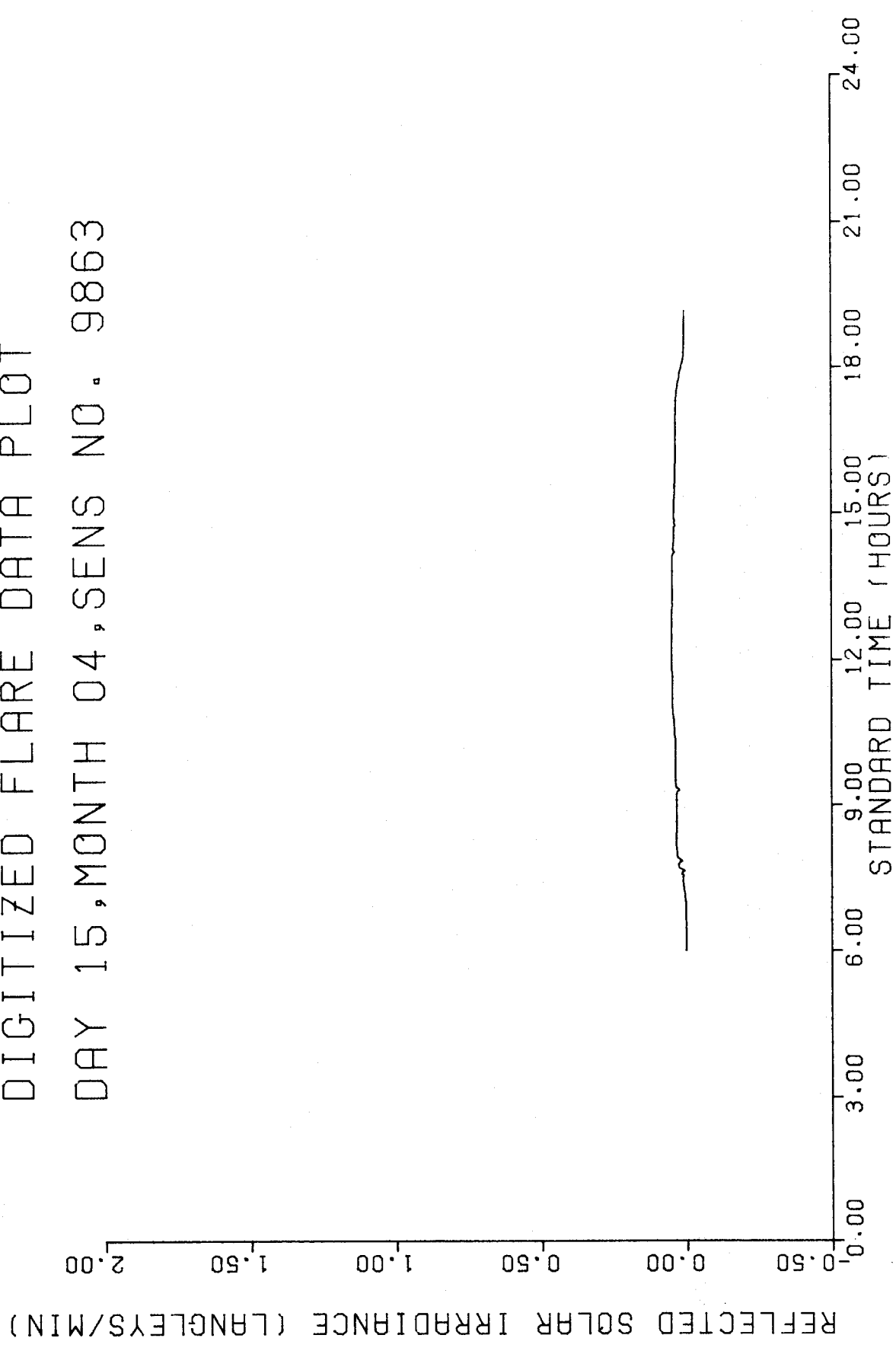
REFLECTED SOLAR IRRADIANCE (LANGLEYS/MIN)

2.00
1.50
1.00
0.50
0.00
-0.50

DIGITIZED FLARE DATA PLOT
DAY 14, MONTH 04, SENS NO. 9863

0.00 3.00 6.00 9.00 12.00 15.00 18.00 21.00 24.00
STANDARD TIME (HOURS)

DIGITIZED FLARE DATA PLOT
DAY 15, MONTH 04, SENS NO. 9863



DIGITIZED FLARE DATA PLOT
DAY 16, MONTH 04, SENS NO. 9863

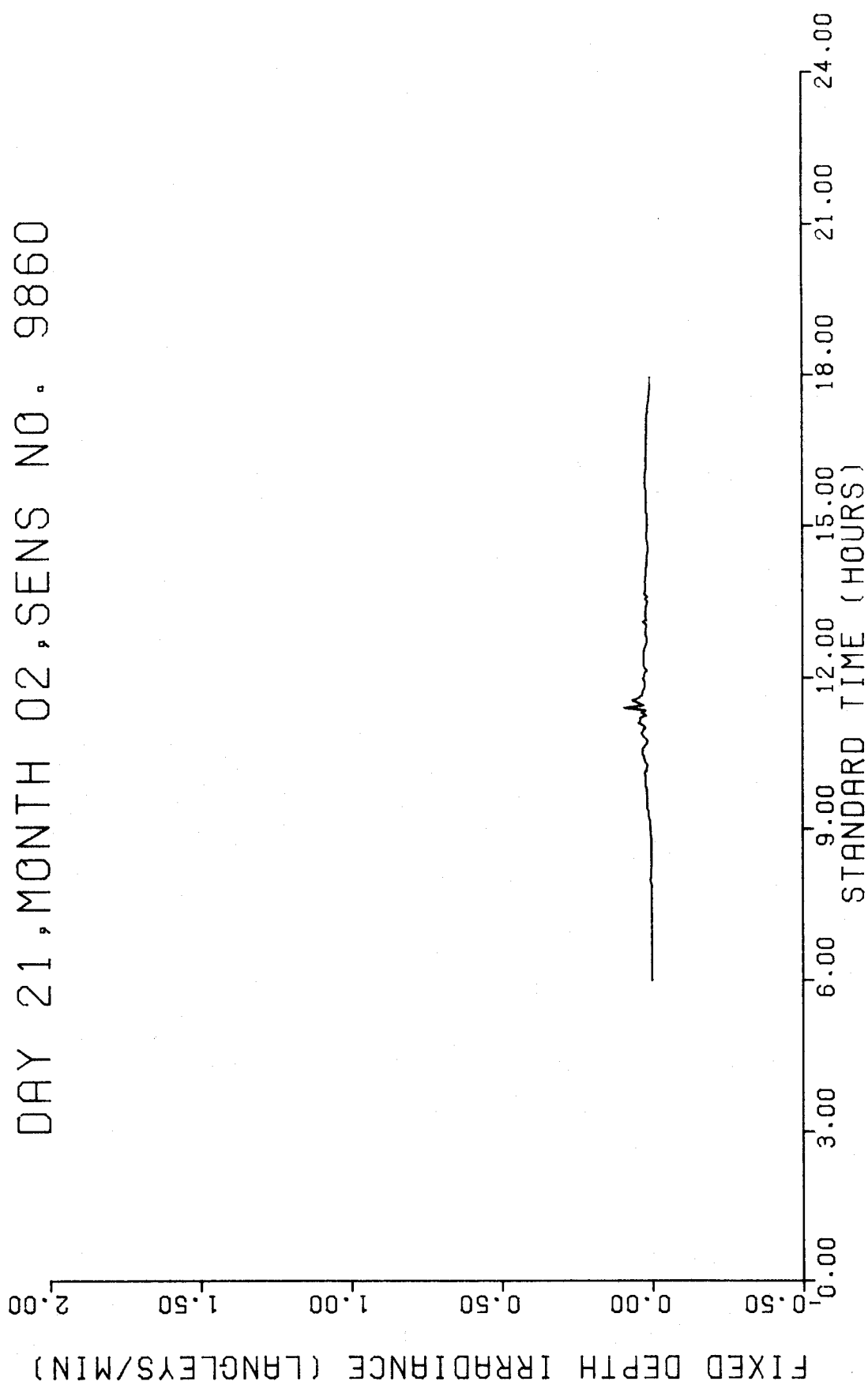
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2.00
1.50
1.00
0.50
0.00
-0.50

3.00 6.00 9.00 12.00 15.00 18.00 21.00 24.00
STANDARD TIME (HOURS)

DIGITIZED FLARE DATA PLOT

DAY 21, MONTH 02, SENS NO. 9860



DIGITIZED FLARE DATA PLOT

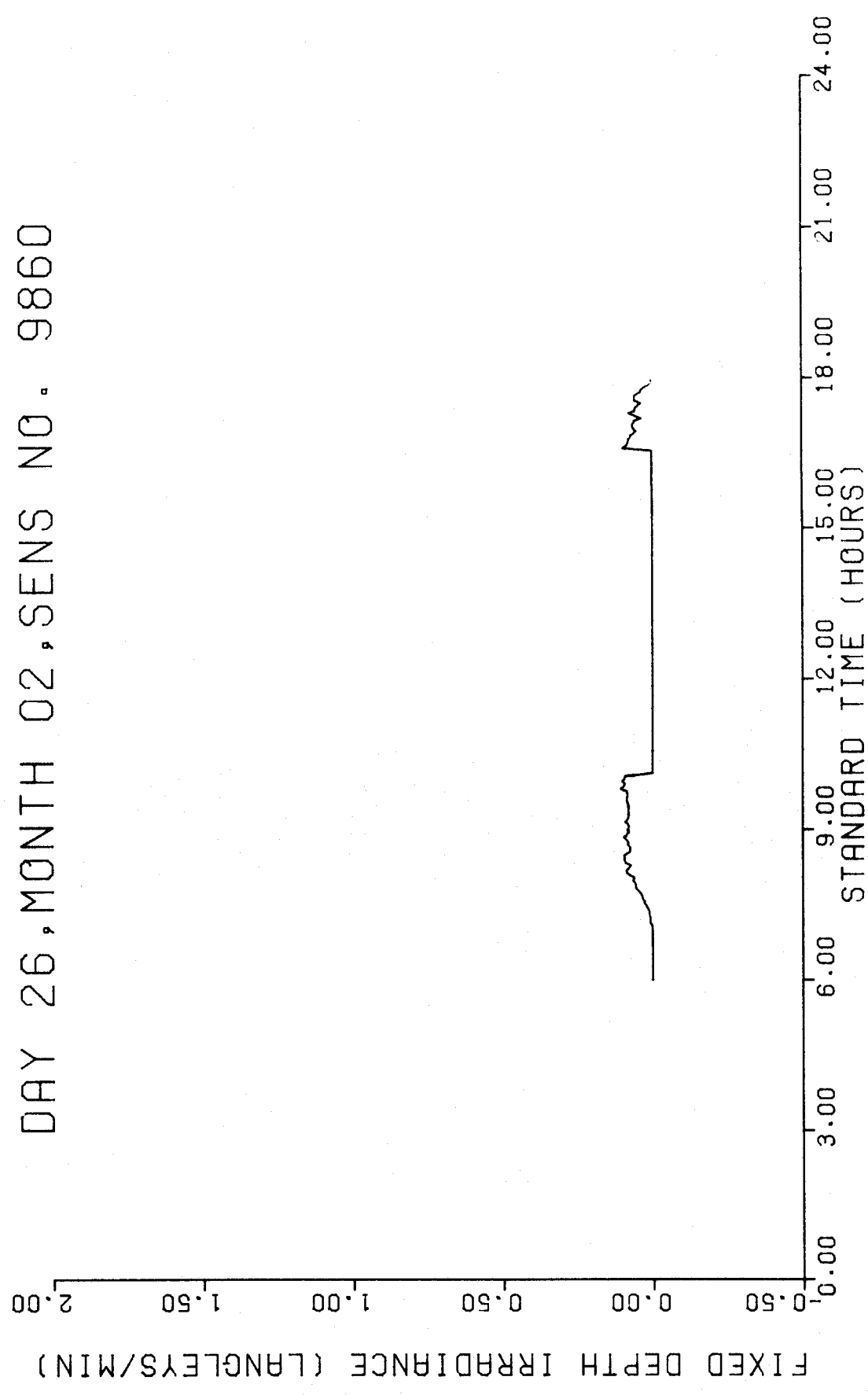
DAY 23, MONTH 02, SENS NO. 9860

FIXED DEPTH IRRADIANCE (LANGLEYS/MIN)

61



DIGITIZED FLARE DATA PLOT
DAY 26, MONTH 02, SENS NO. 9860



FIXED DEPTH IRRADIANCE (LANGLEYS/MIN)

DIGITIZED FLARE DATA PLOT

DAY 27, MONTH 02, SENS NO. 9860

FIXED DEPTH IRRADIANCE (LANGLEYS/MIN)

2.00
1.50
1.00
0.50
0.00
-0.50
-1.00

STANDARD TIME (HOURS)

0.00

3.00

6.00

9.00

12.00

15.00

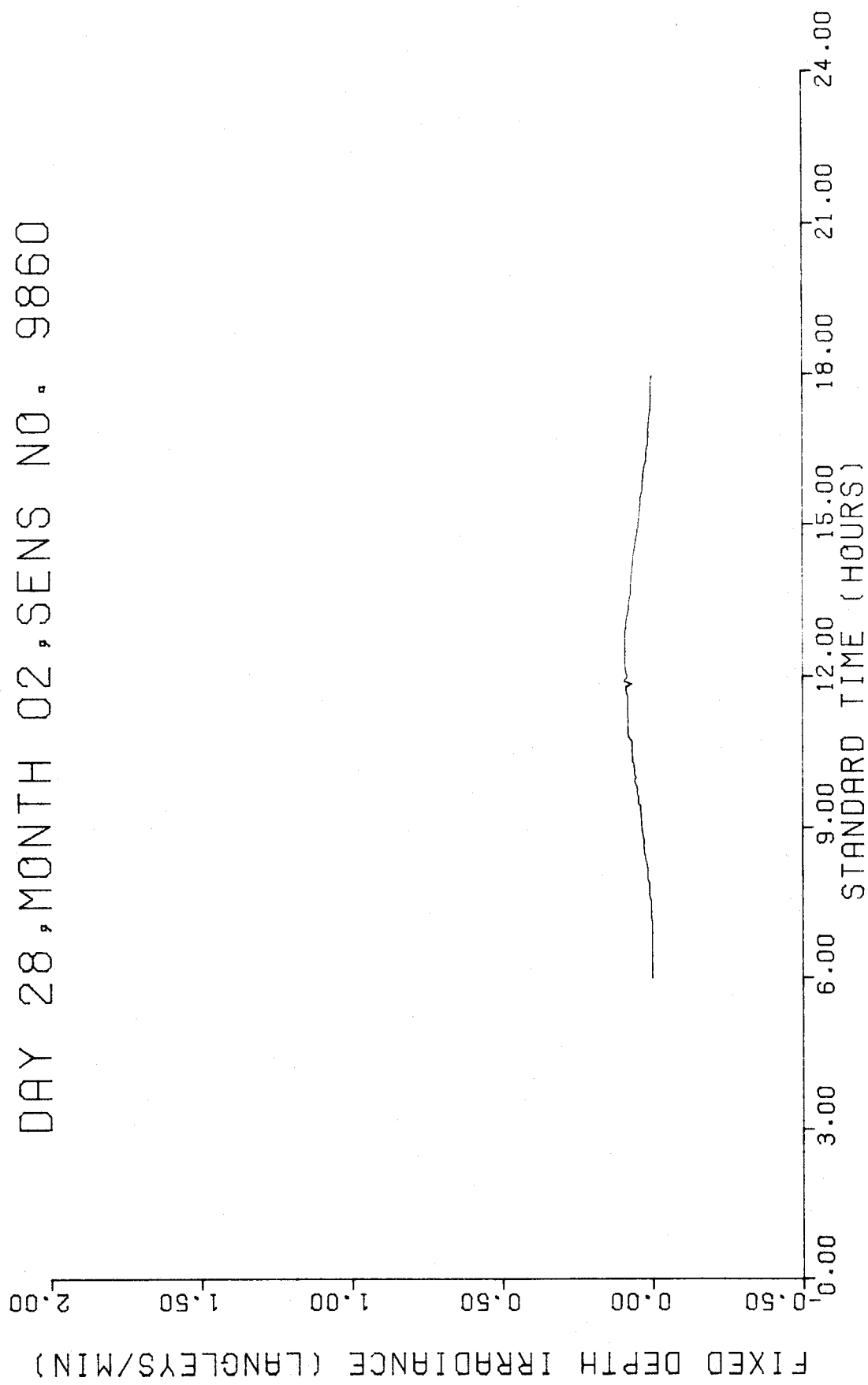
18.00

21.00

24.00



DIGITIZED FLARE DATA PLOT
DAY 28, MONTH 02, SENS NO. 9860



DIGITIZED FLARE DATA PLOT

DAY 29, MONTH 02, SENS NO. 9860

FIXED DEPTH IRRADIANCE (LANGLEYS/MIN)

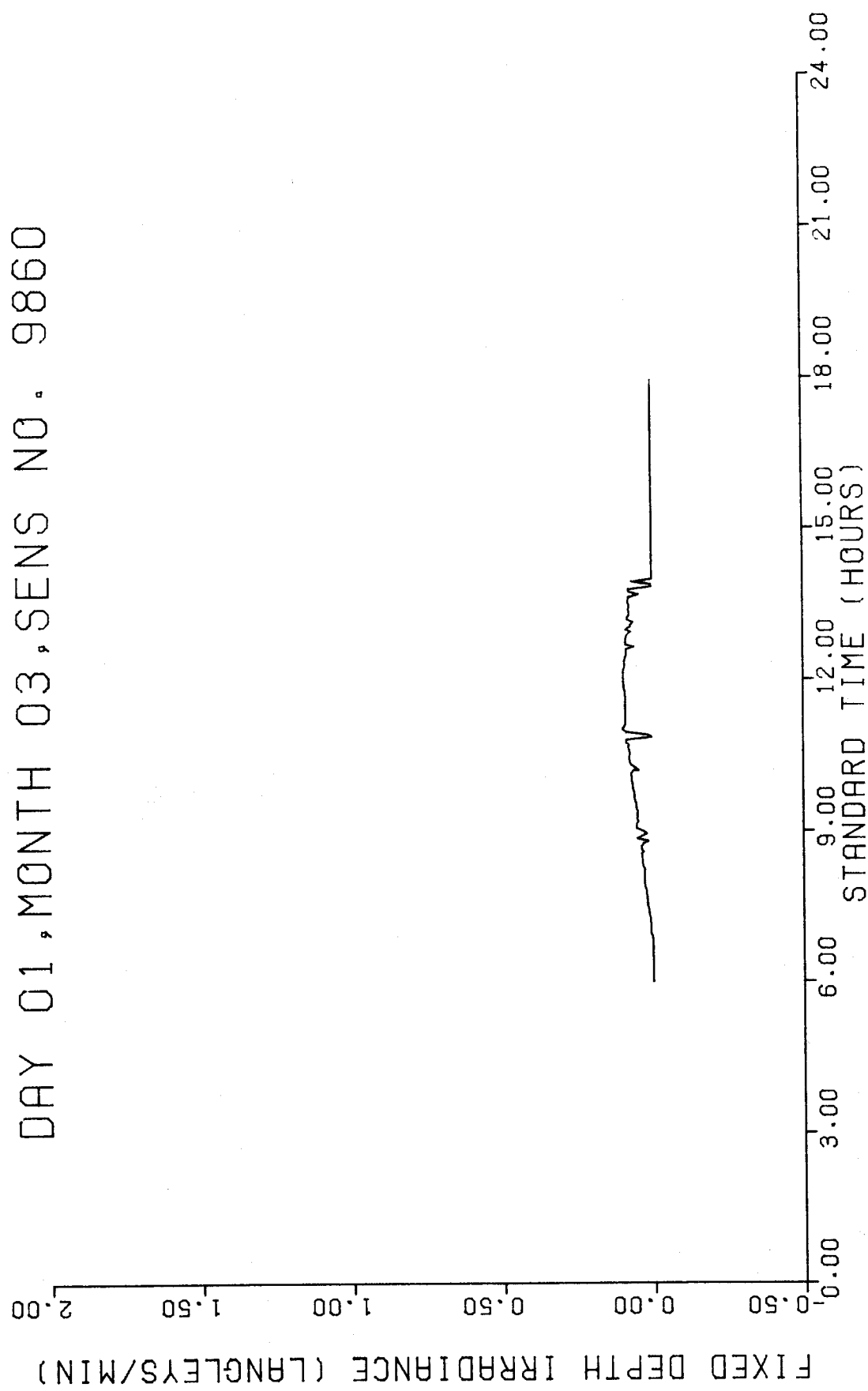
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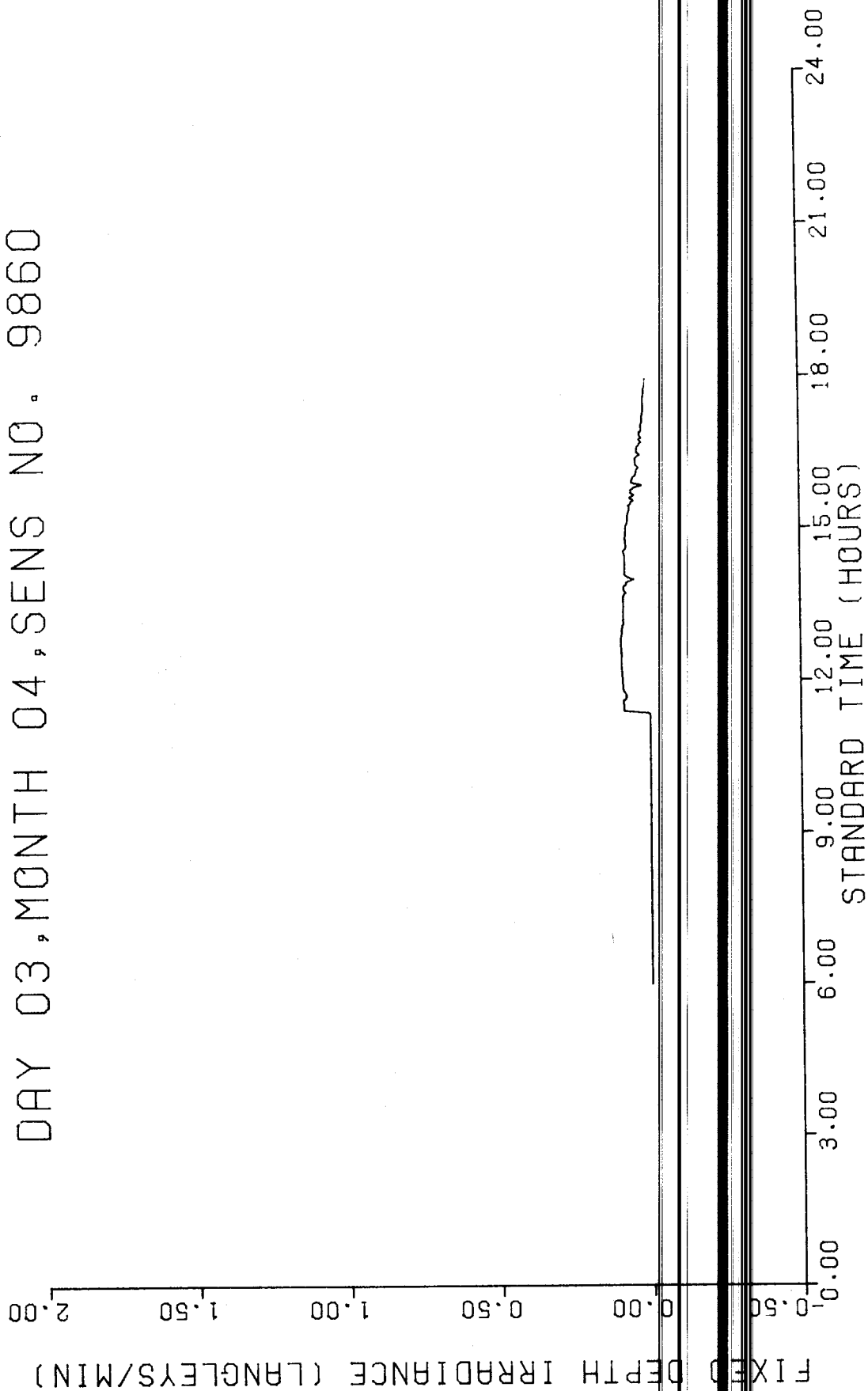
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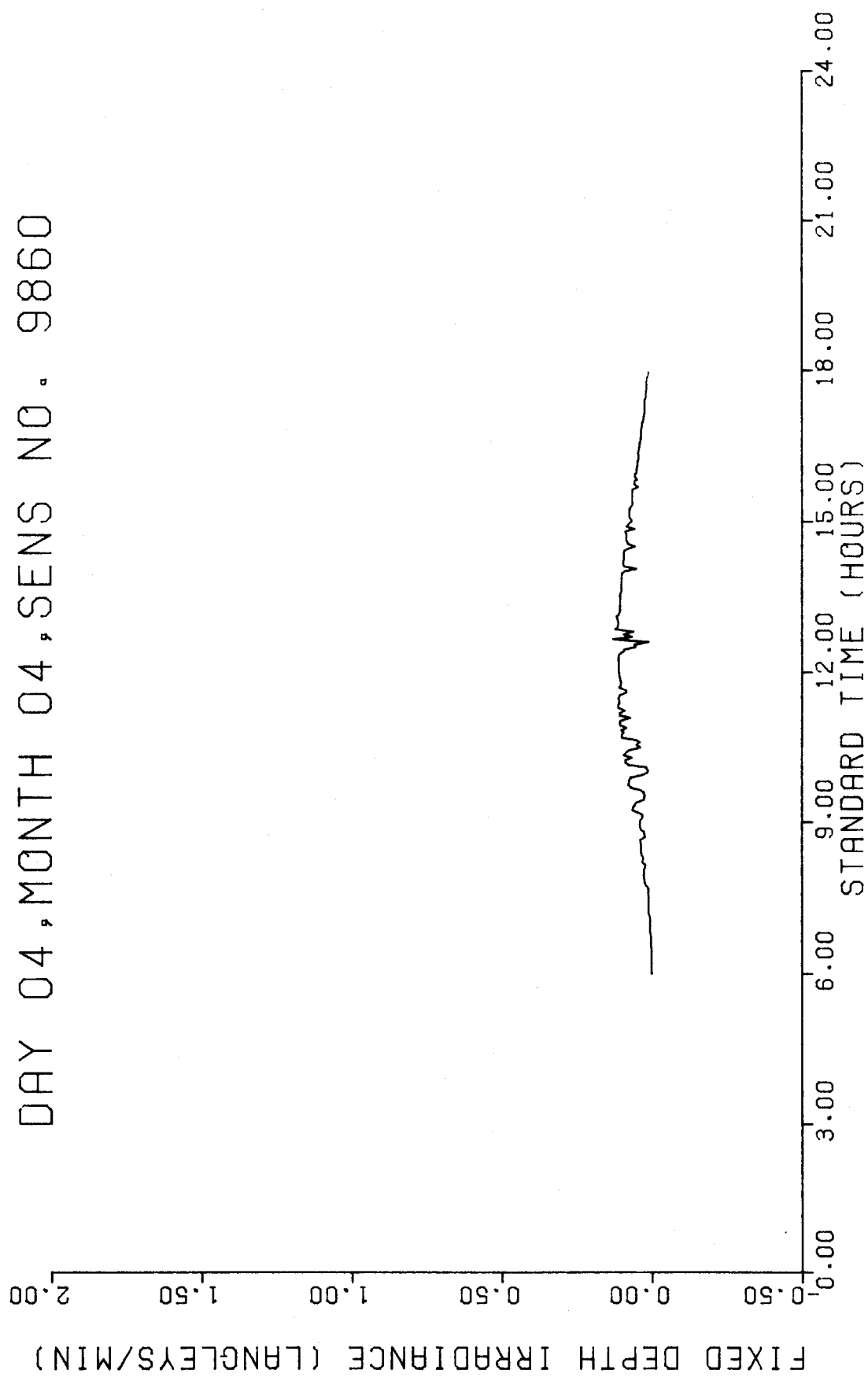
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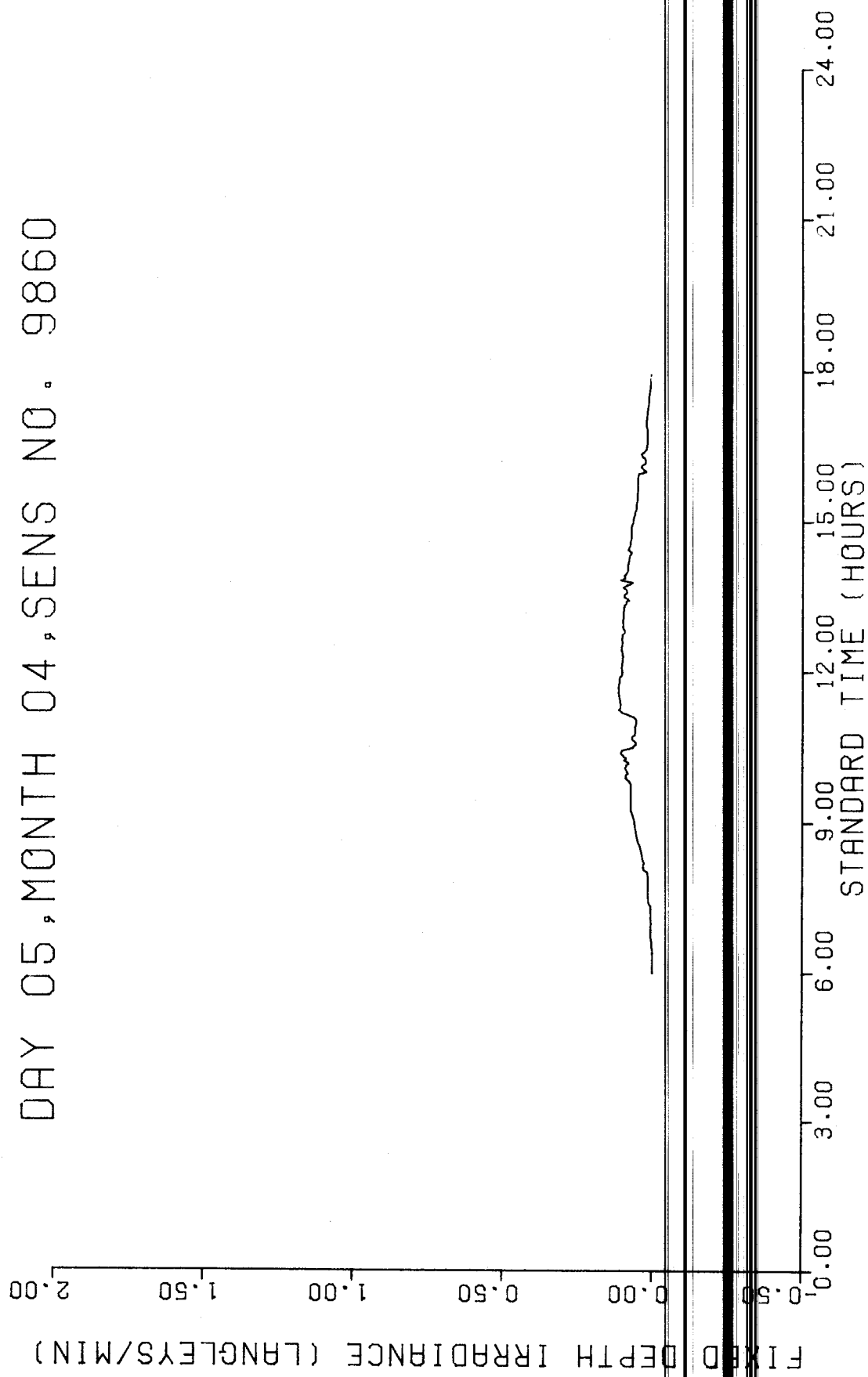
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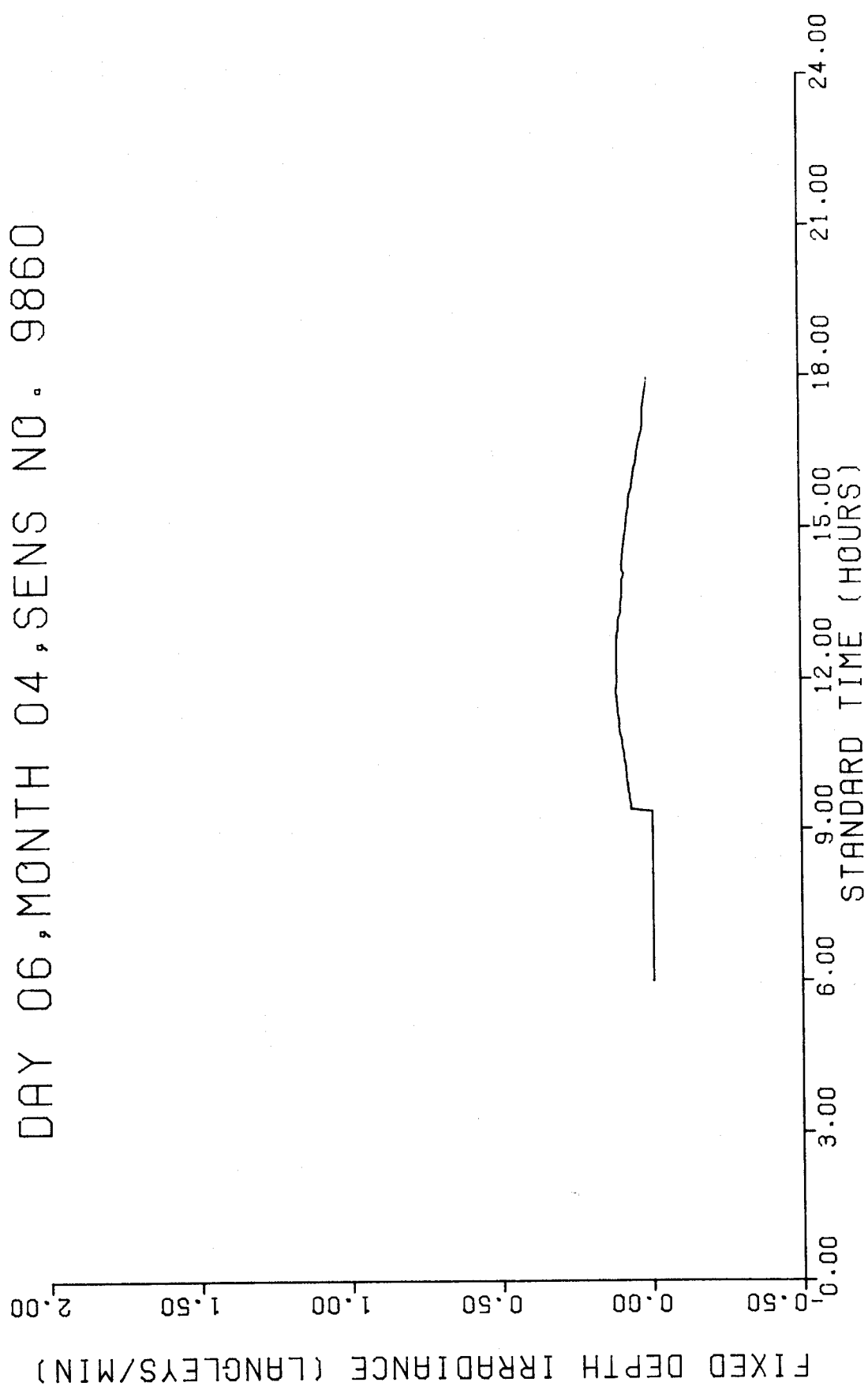
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DIGITIZED FLARE DATA PLOT
DAY 05, MONTH 04, SENS NO. 9860



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DAY 06, MONTH 04, SENS NO. 9860



DIGITIZED FLARE DATA PLOT

DAY 07, MONTH 04, SENS NO. 9860

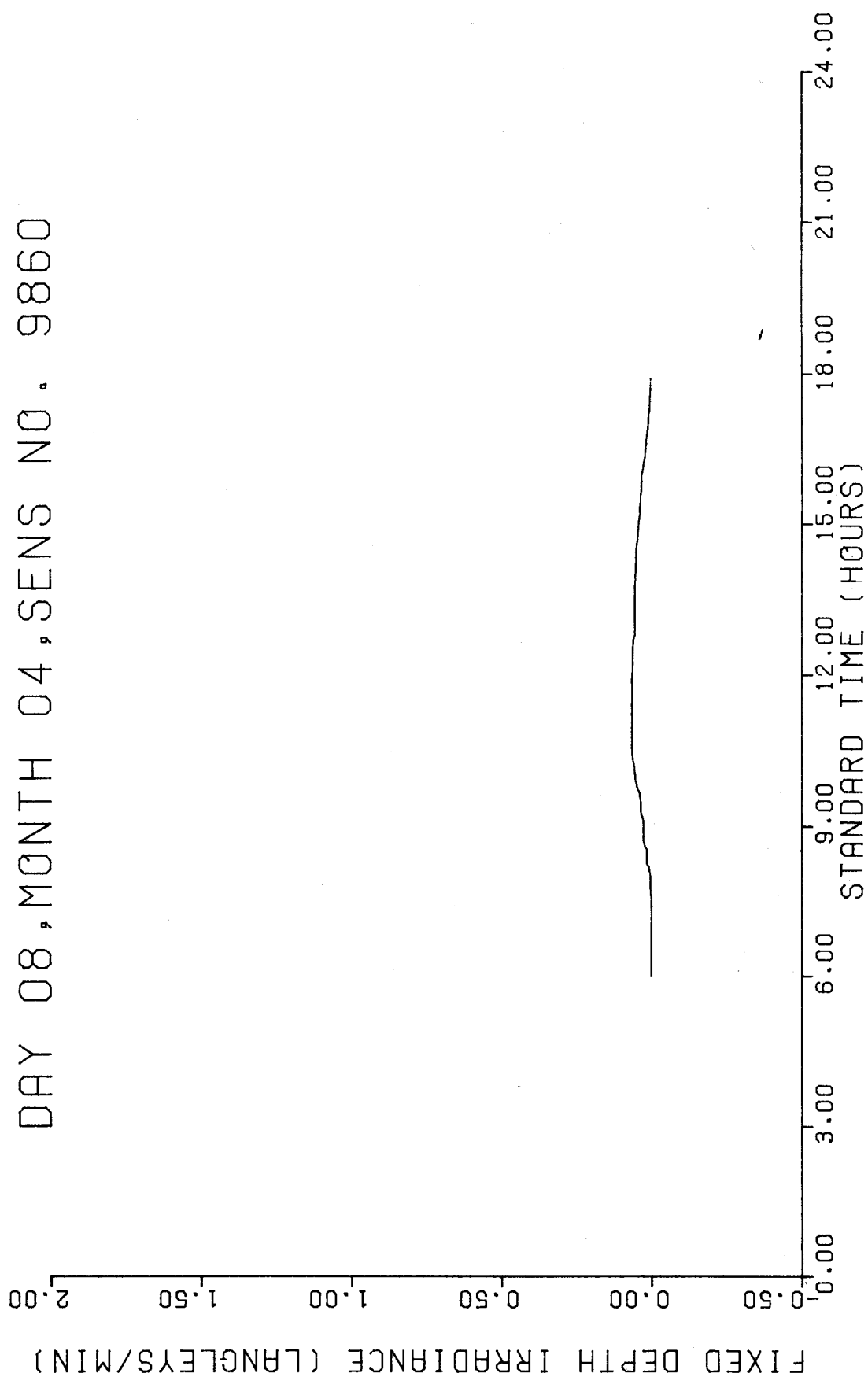
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2.00 1.50 1.00 0.50 0.00 -0.50

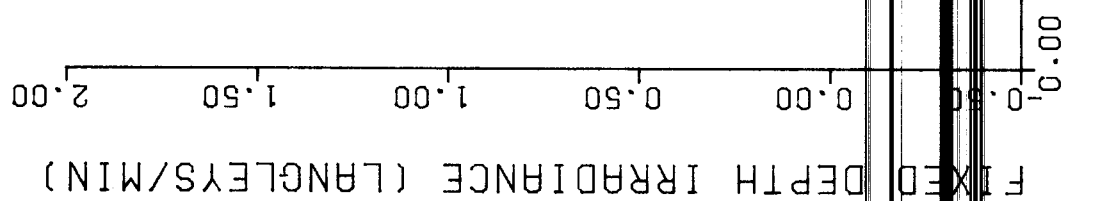
3.00 6.00 9.00 12.00 15.00 18.00 21.00 24.00

STANDARD TIME (HOURS)

DIGITIZED FLARE DATA PLOT
DAY 08, MONTH 04, SENS NO. 9860

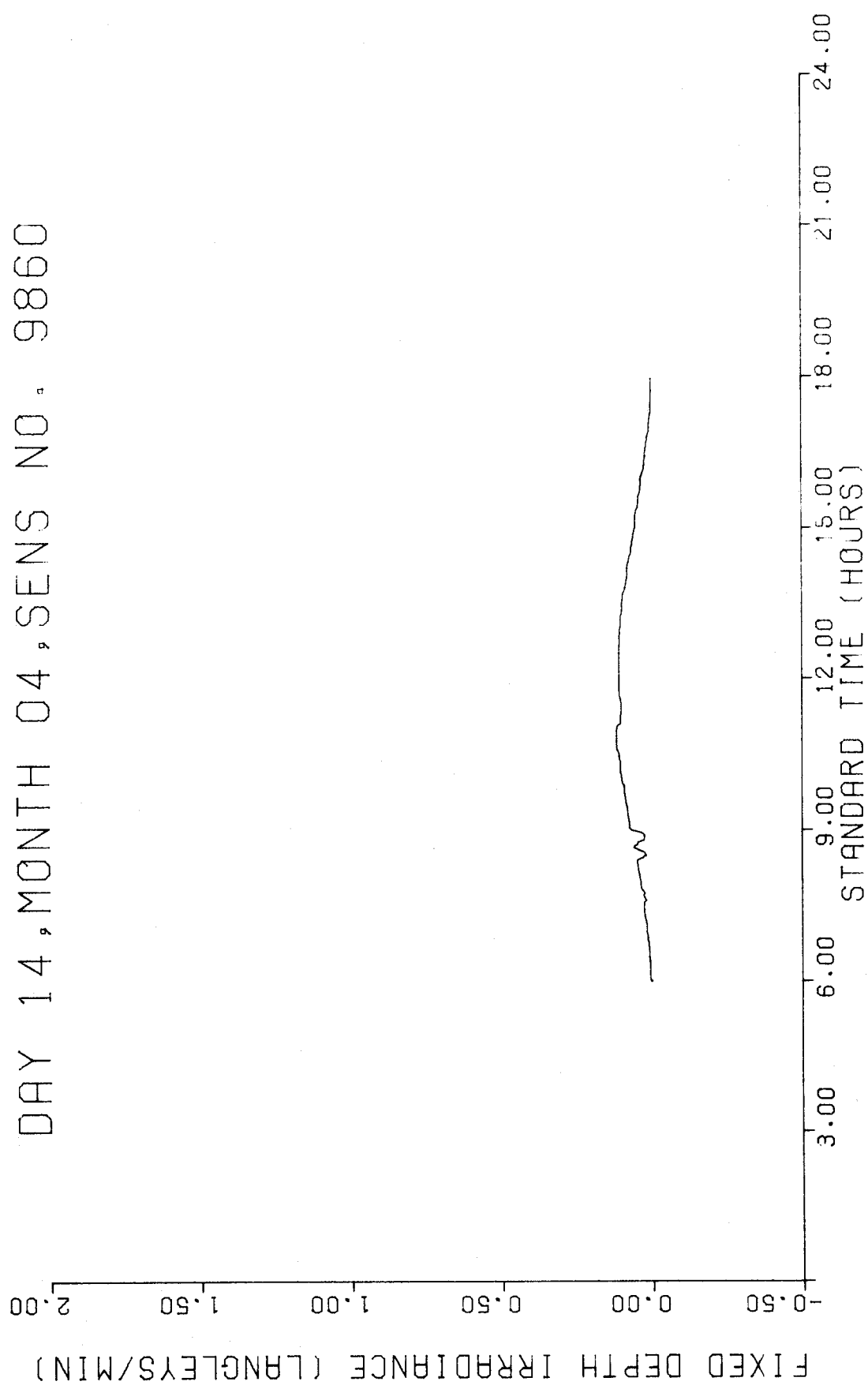


DIGITIZED FLARE DATA PLOT
DAY 13, MONTH 04, SENS NO. 9860



DIGITIZED FLARE DATA PLOT

DAY 14, MONTH 04, SENS NO. 9860



DIGITIZED FLARE DATA PLOT

DAY 15, MONTH 04, SENS NO. 9860

75
FIXED DEPTH IRRADIANCE (LANGLEYS/MIN)

STANDARD TIME (HOURS)

24.00

21.00

18.00

15.00

12.00

9.00

6.00

3.00

0.00

0.00

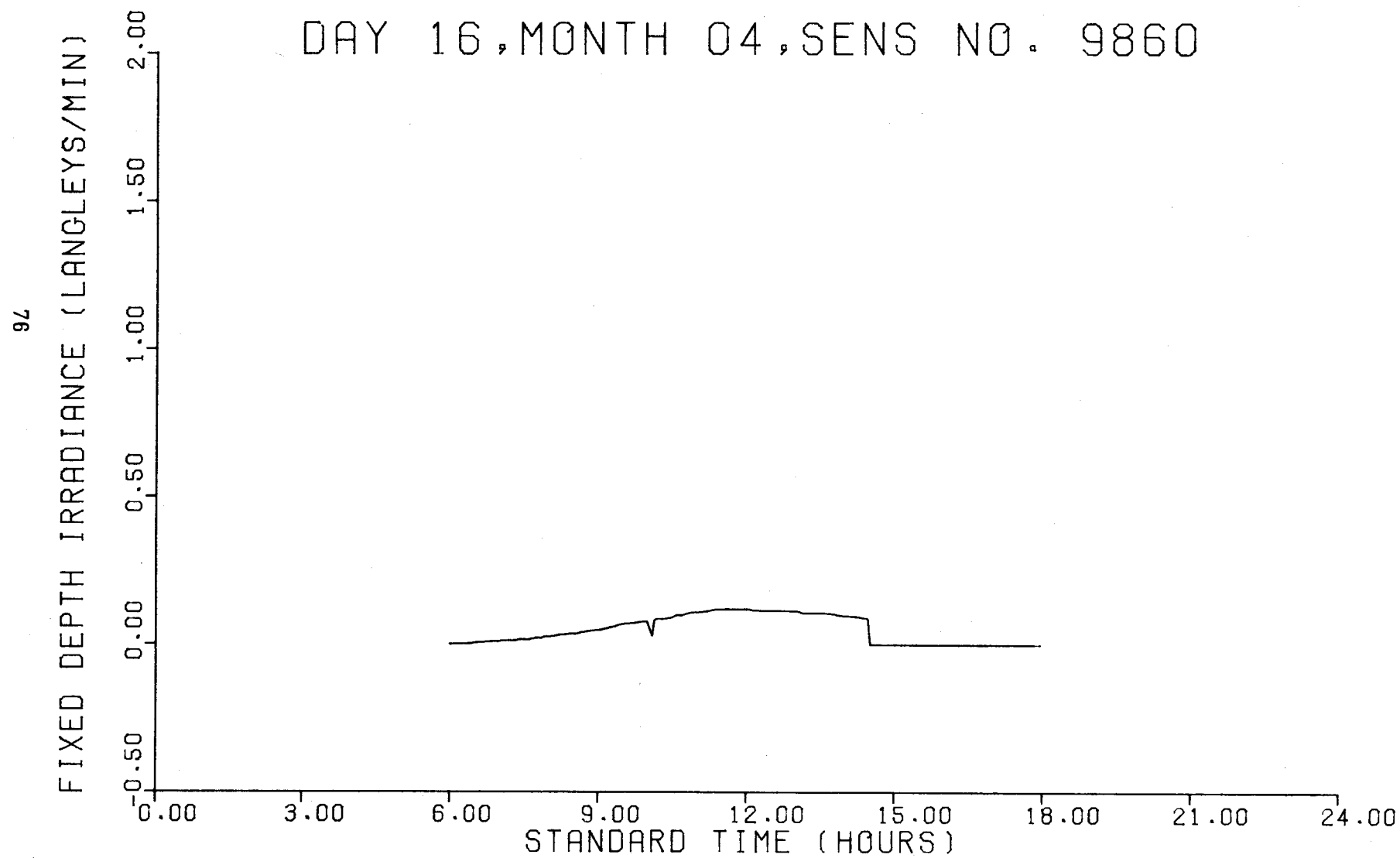
0.50

1.00

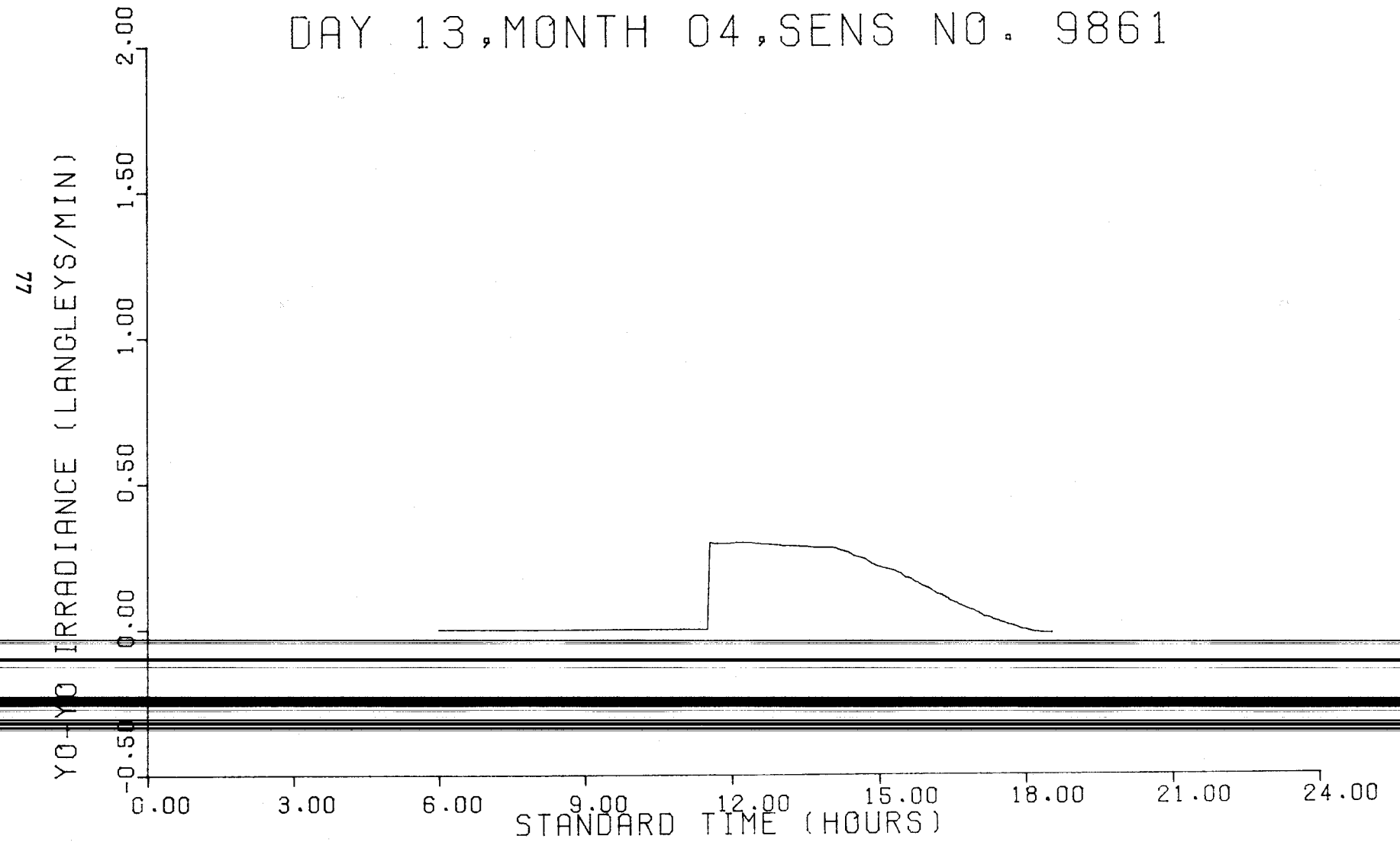
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2.00

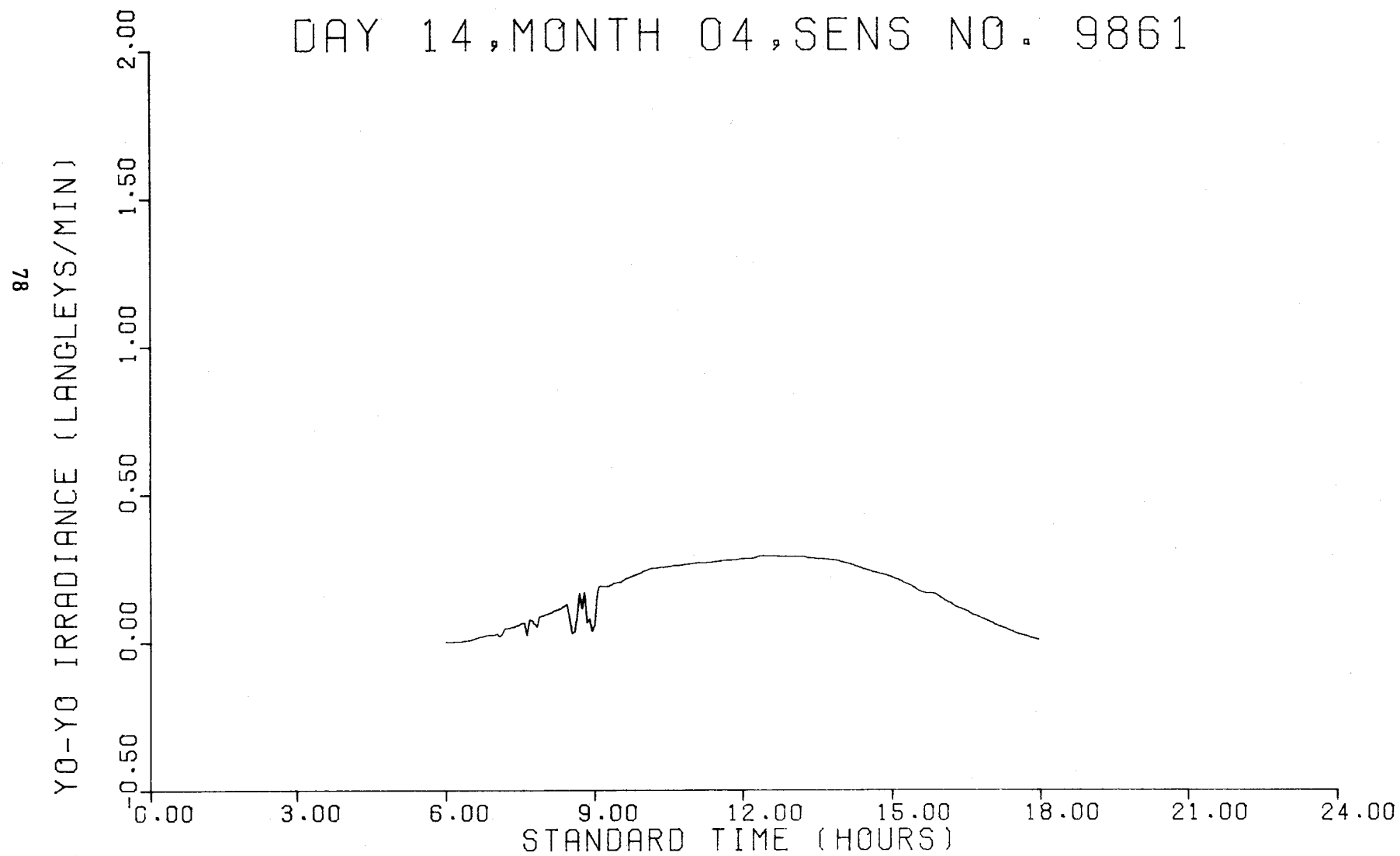
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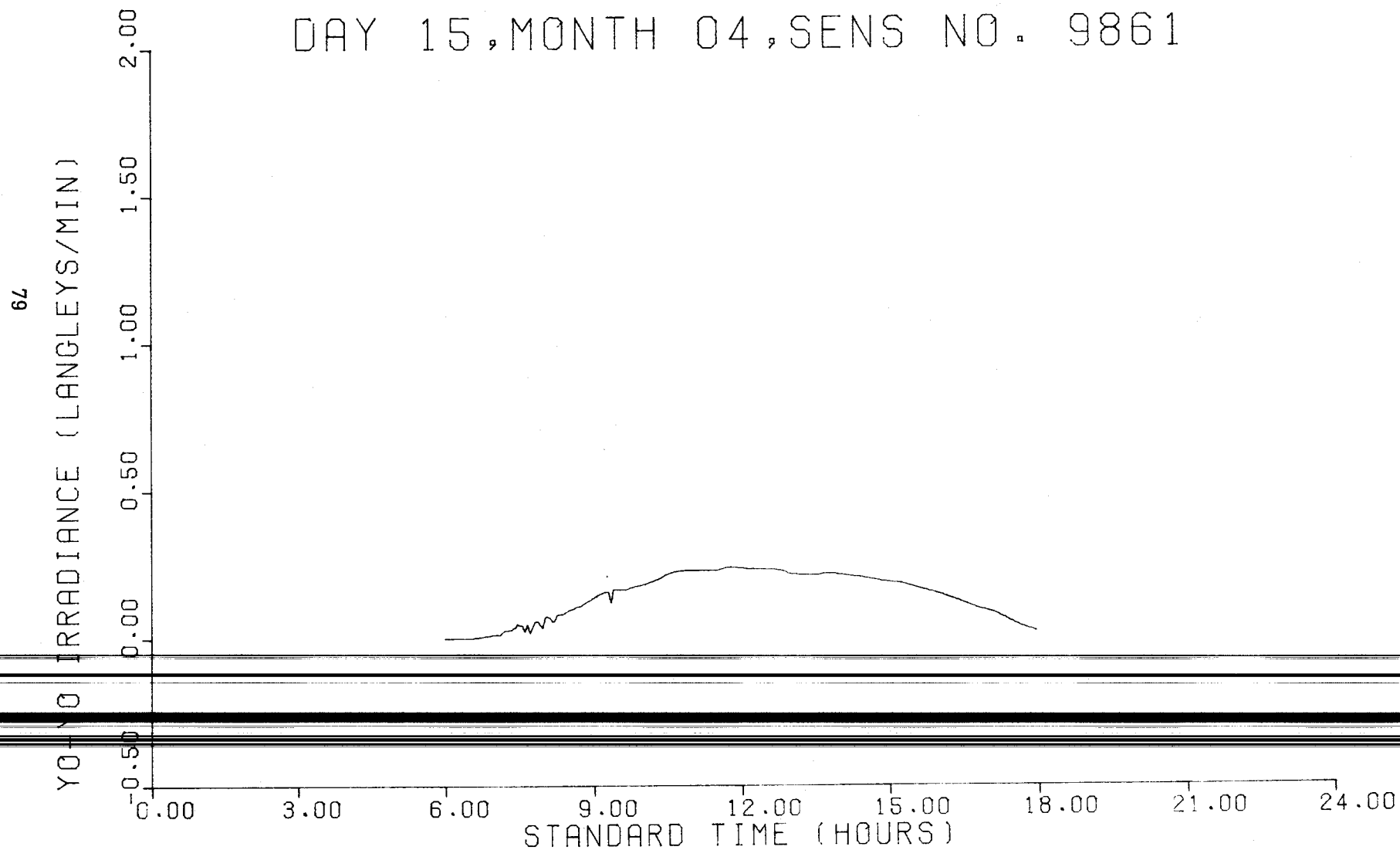
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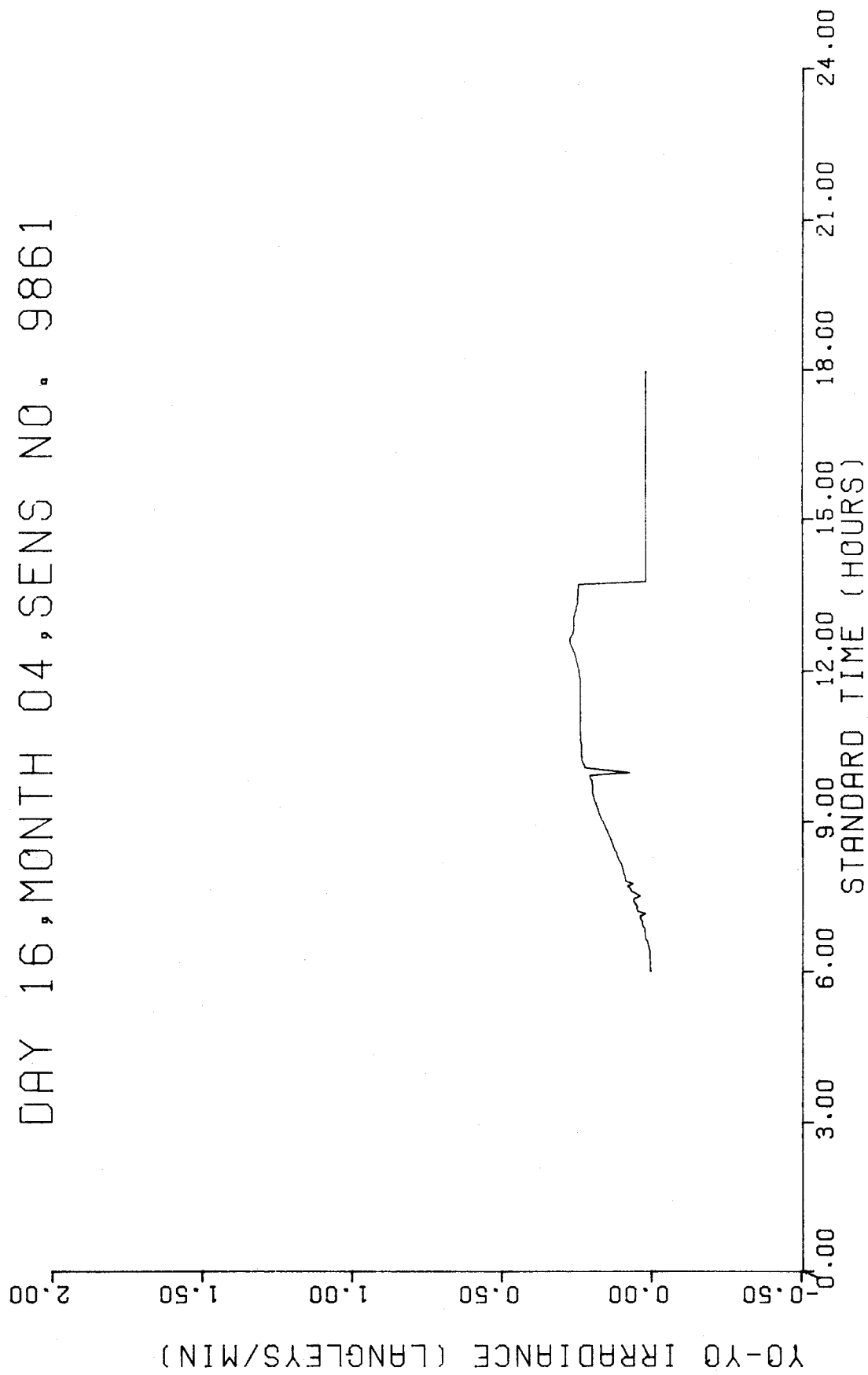
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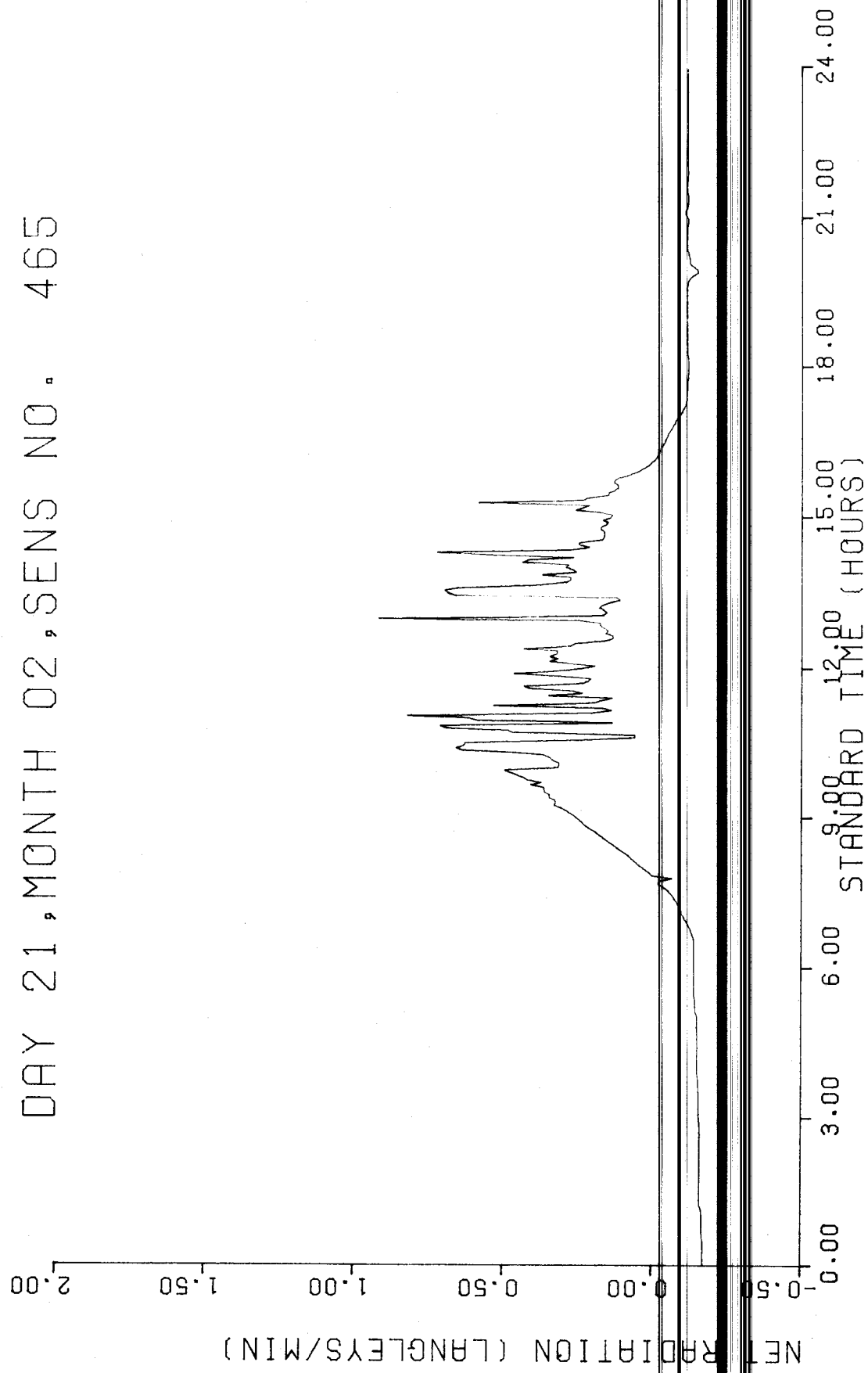
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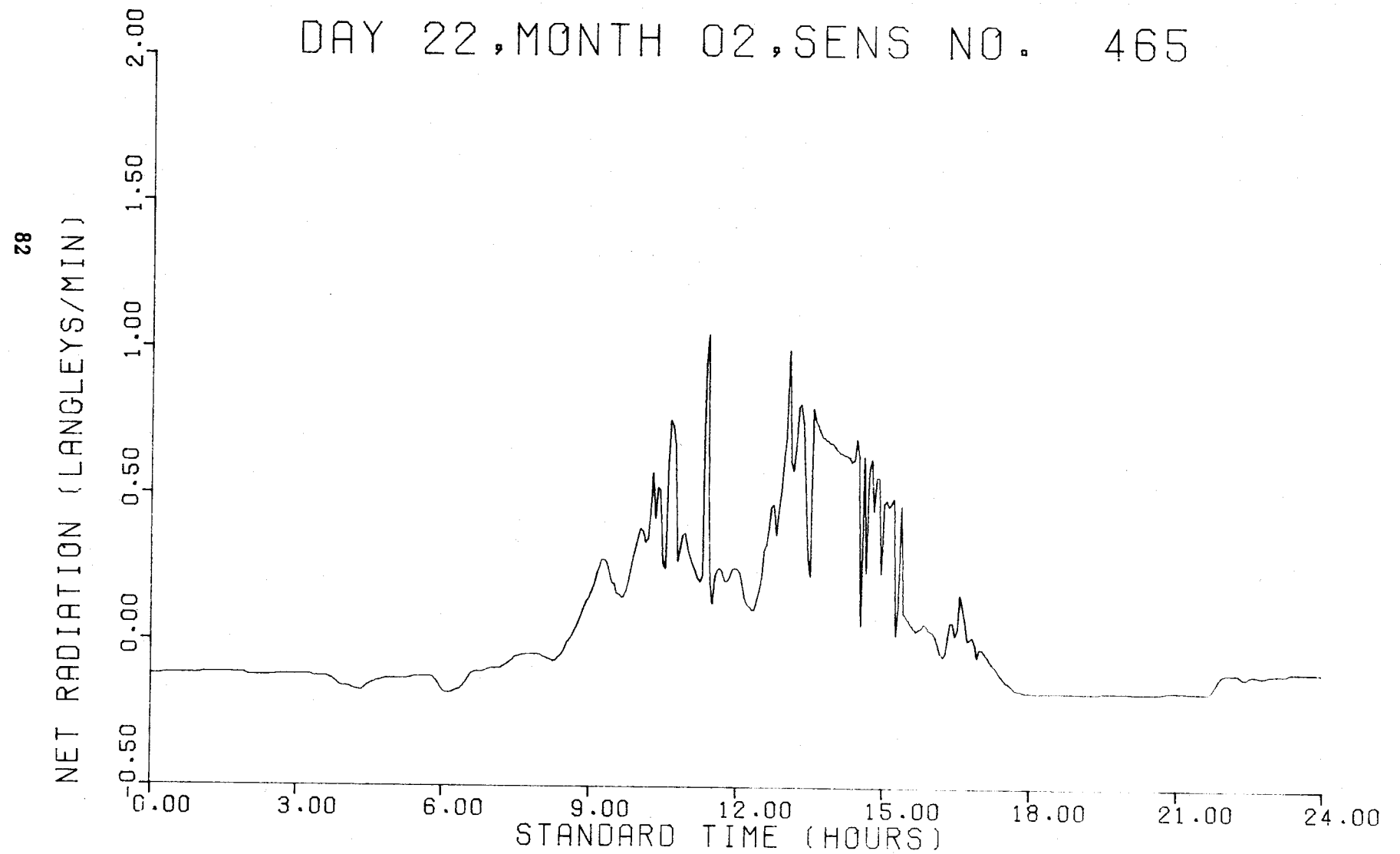
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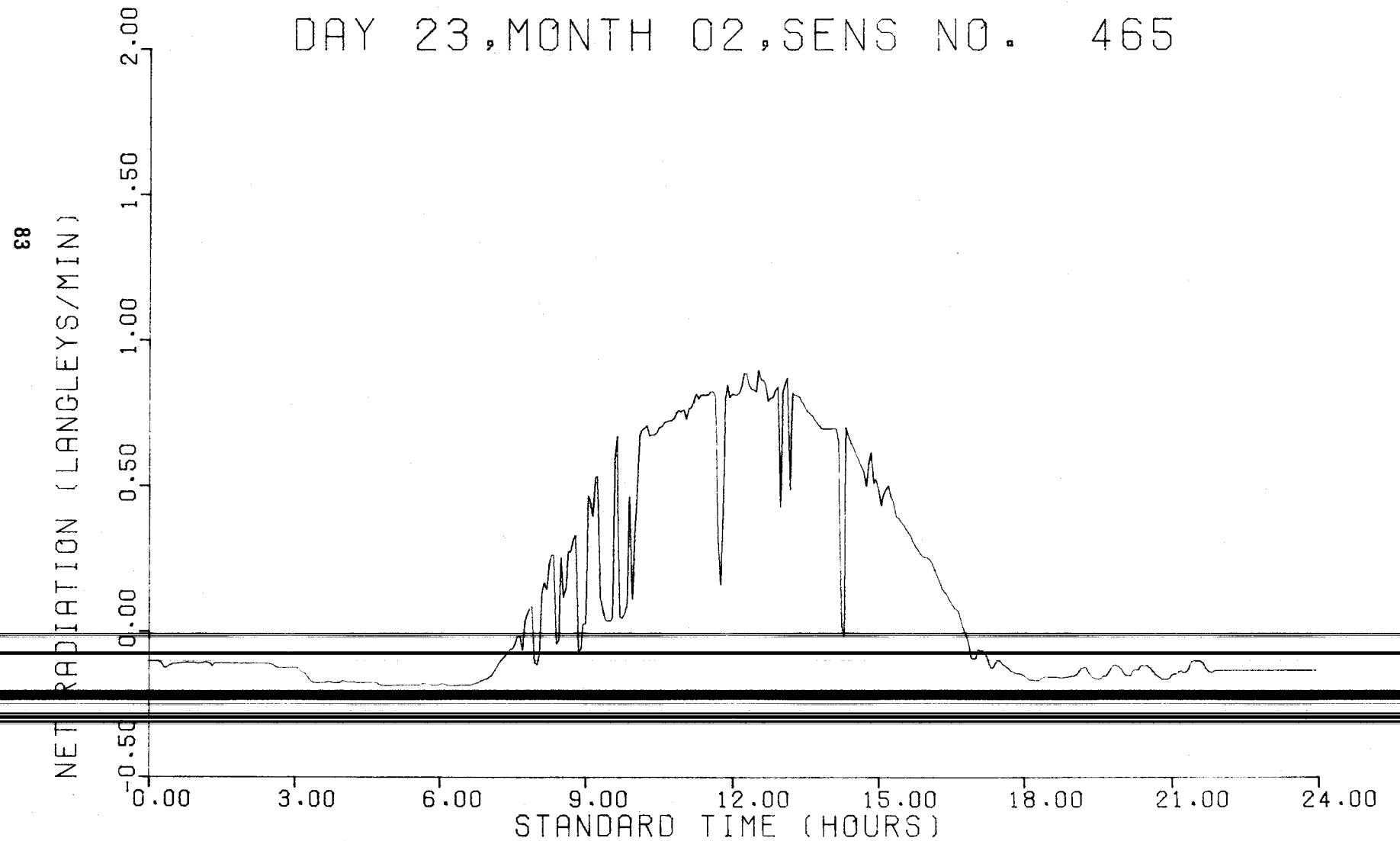
DIGITIZED FLARE DATA PLOT
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DIGITIZED FLARE DATA PLOT
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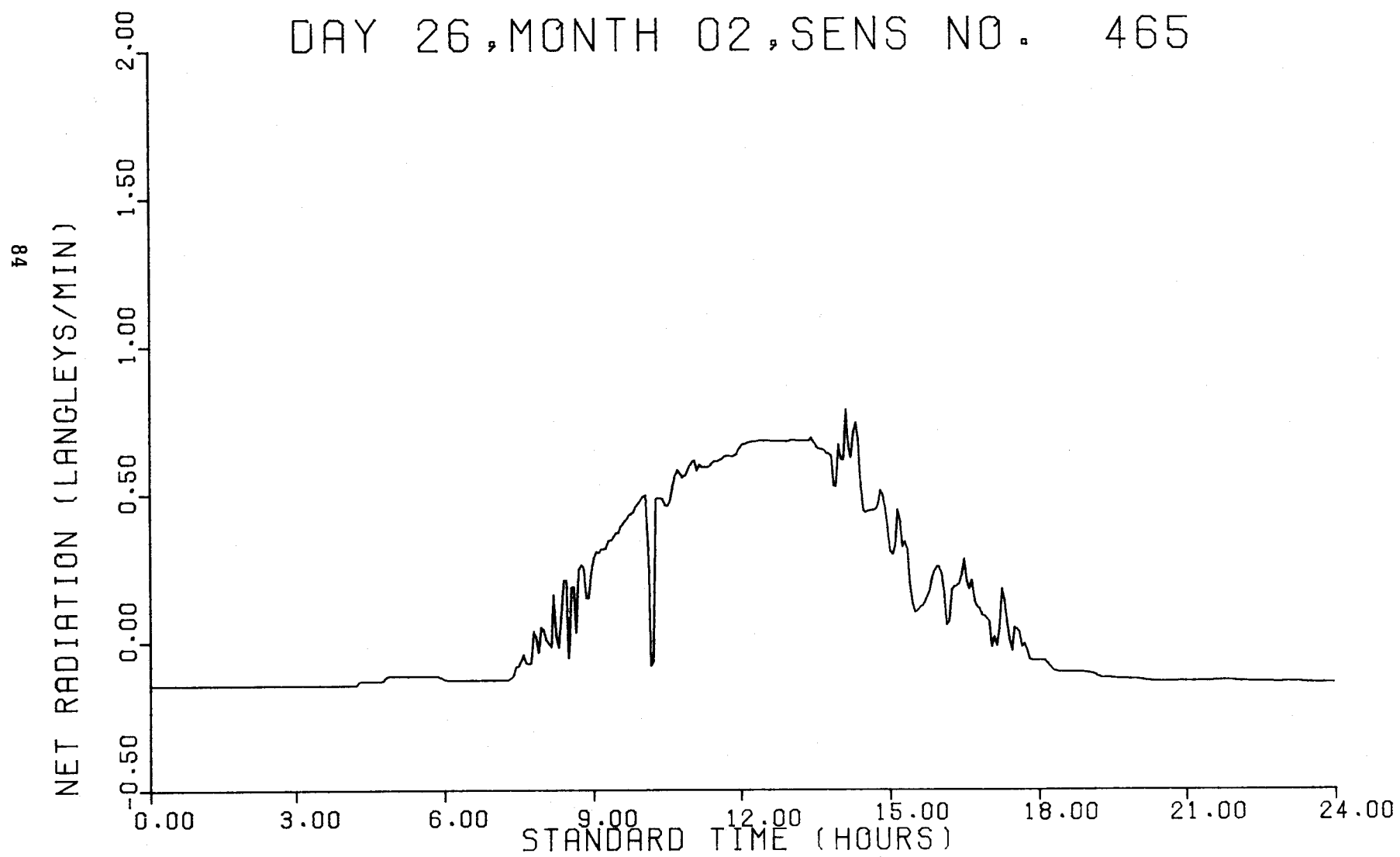


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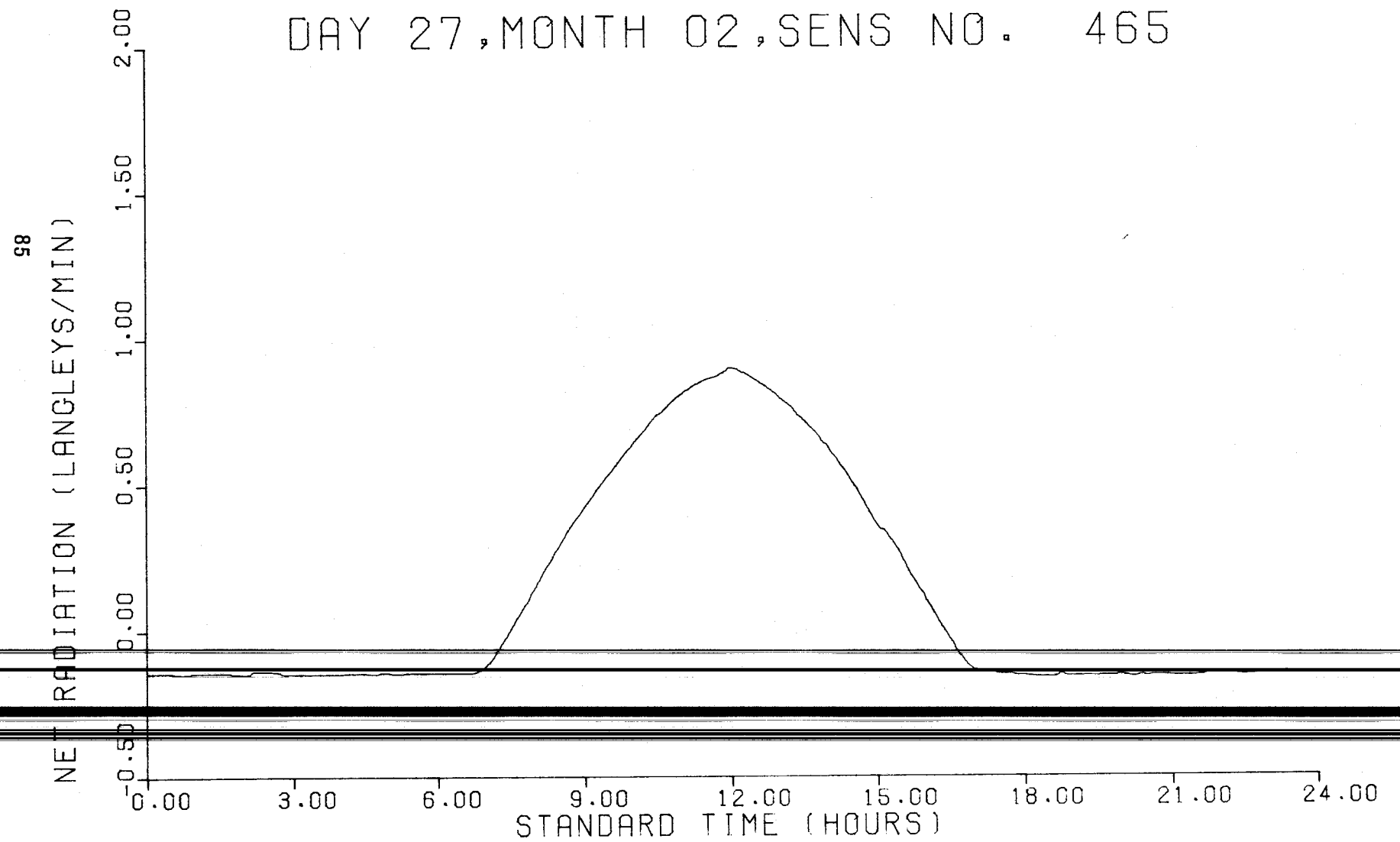
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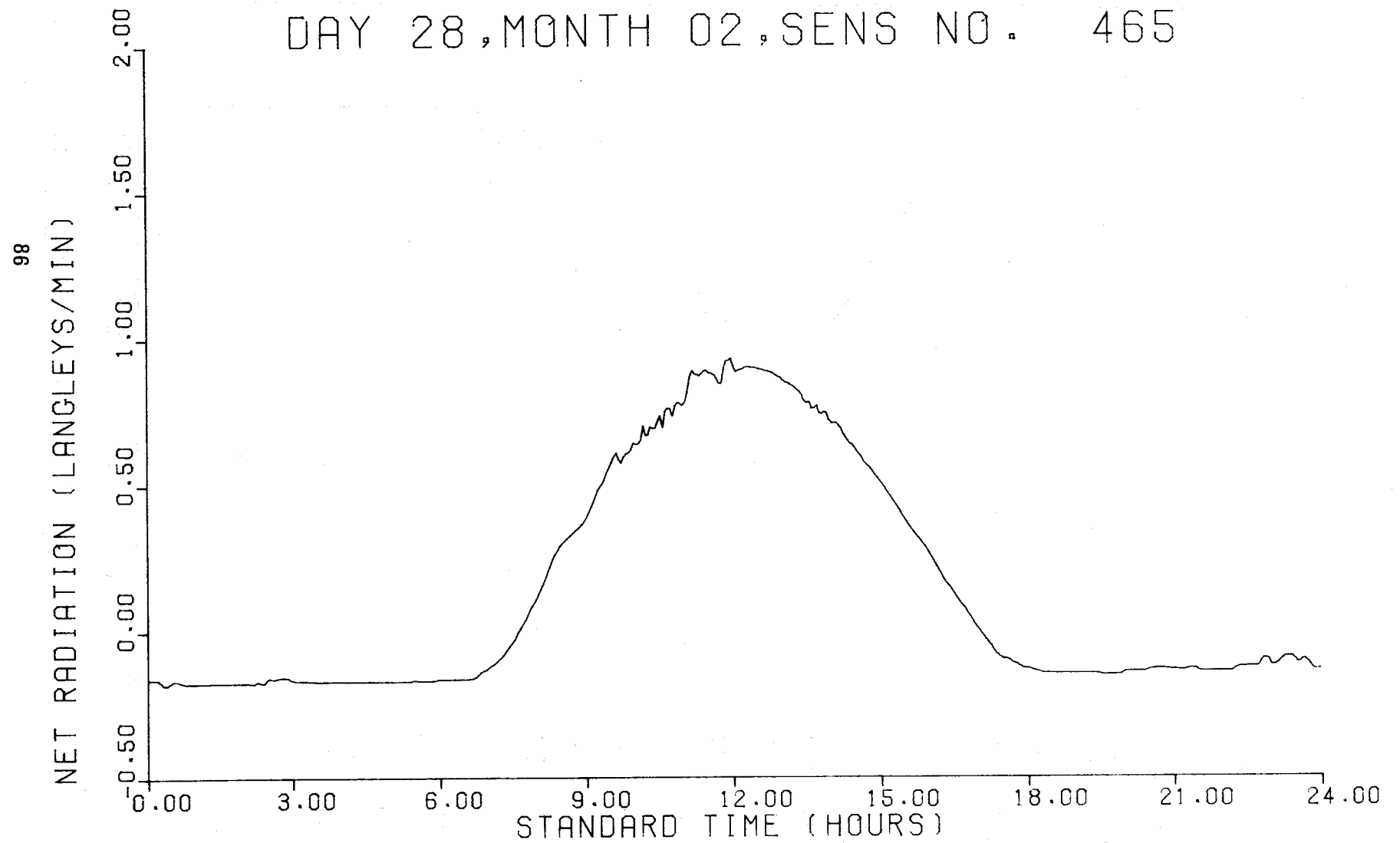
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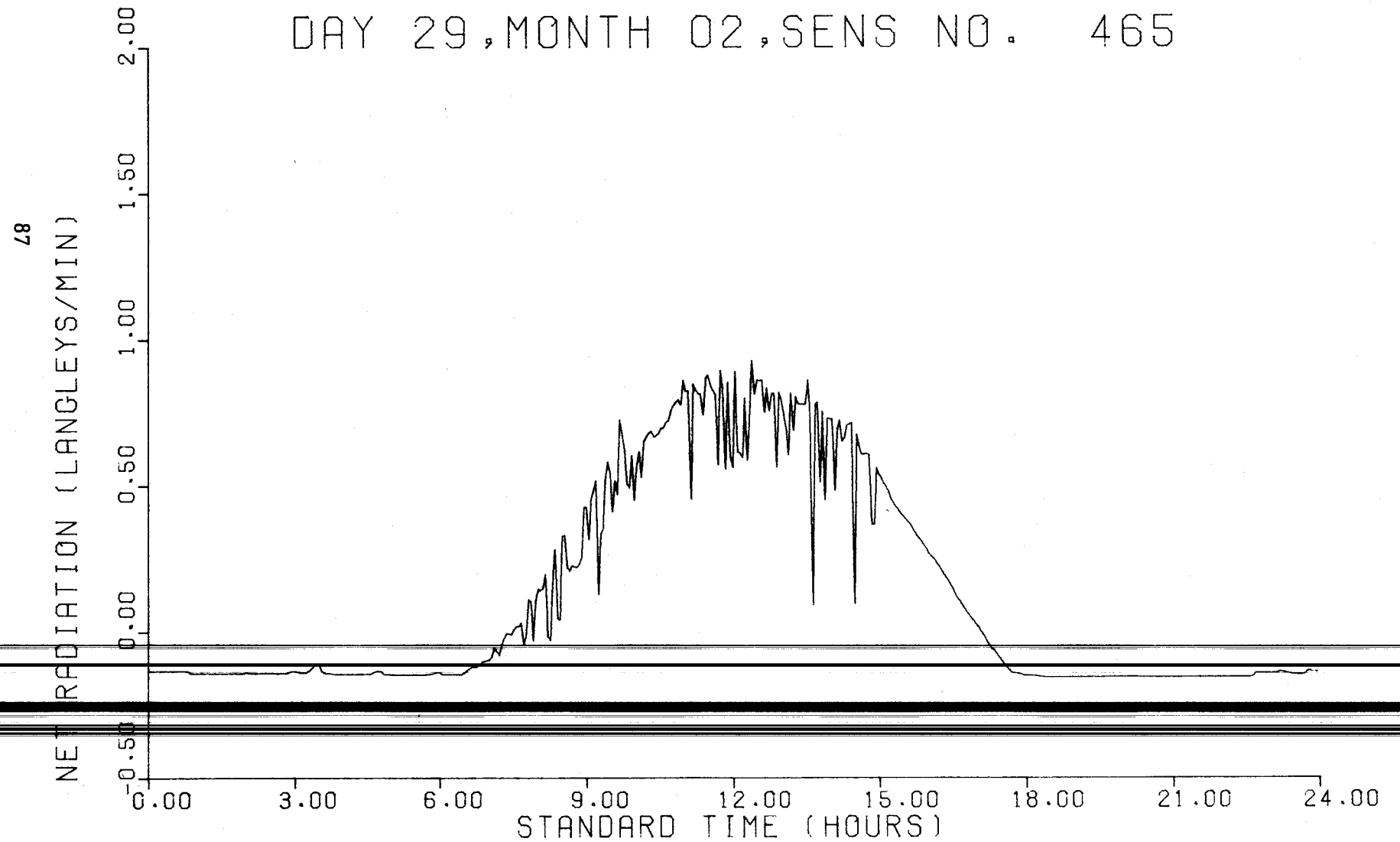
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DAY 28, MONTH 02, SENS NO. 465



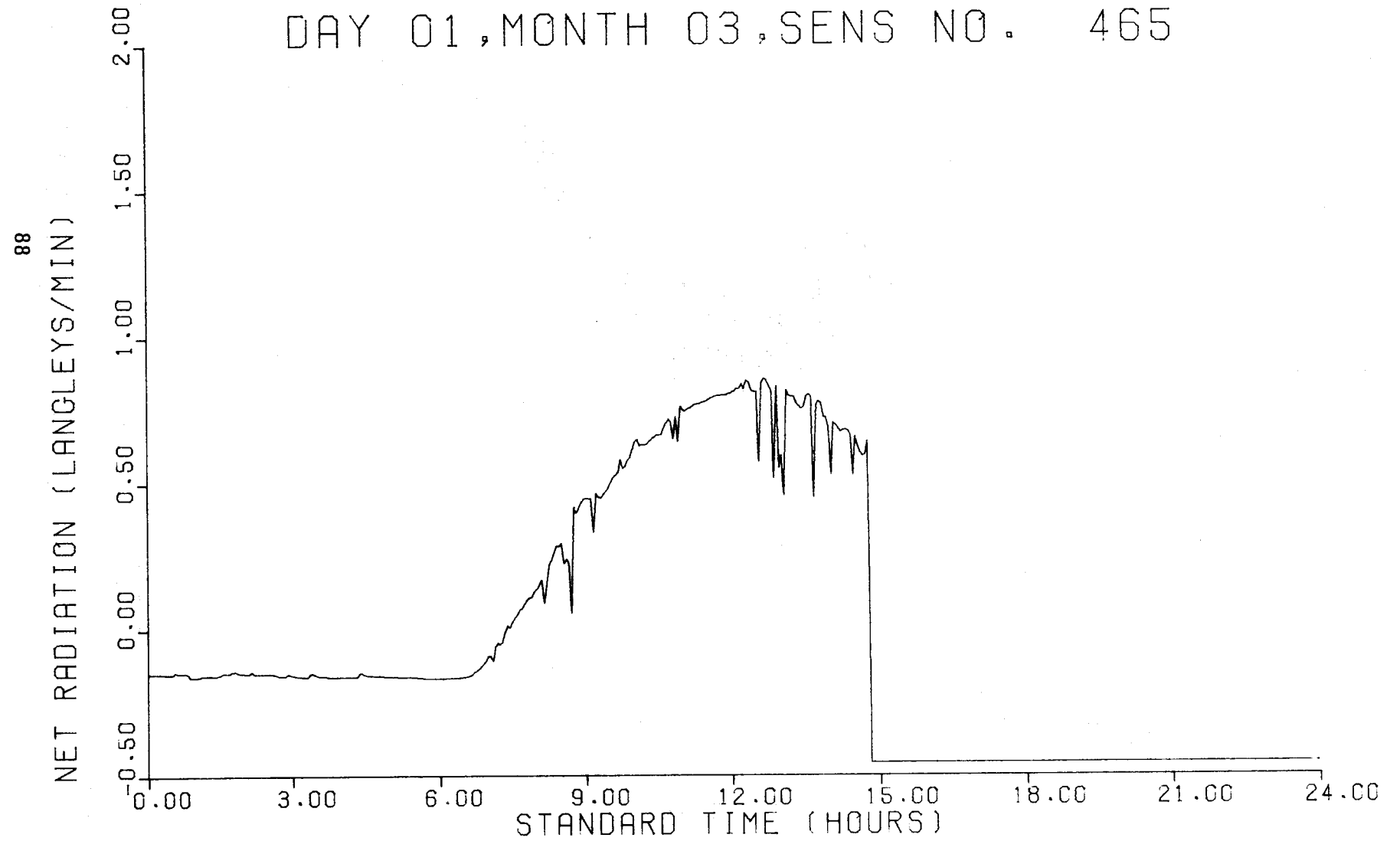
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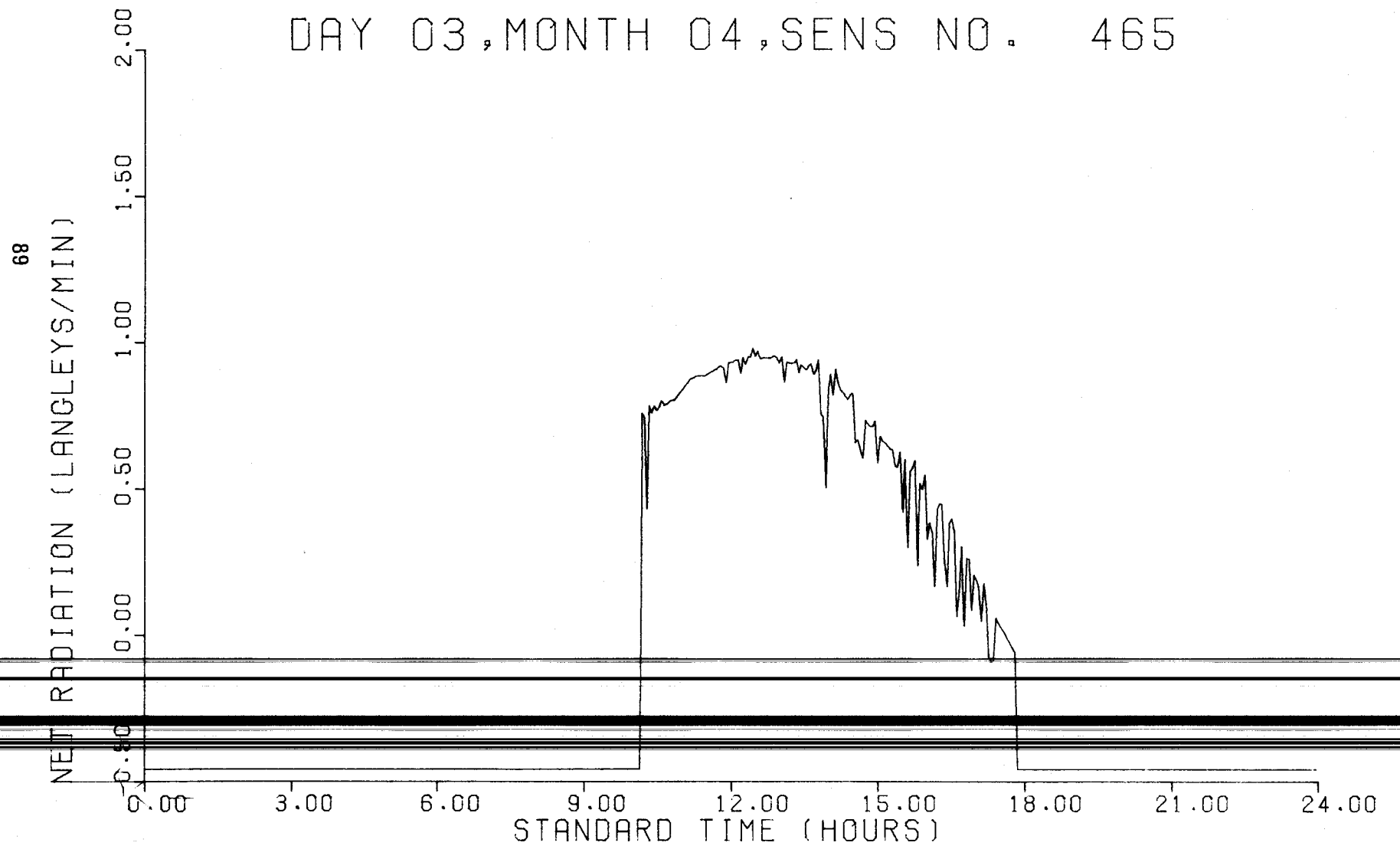


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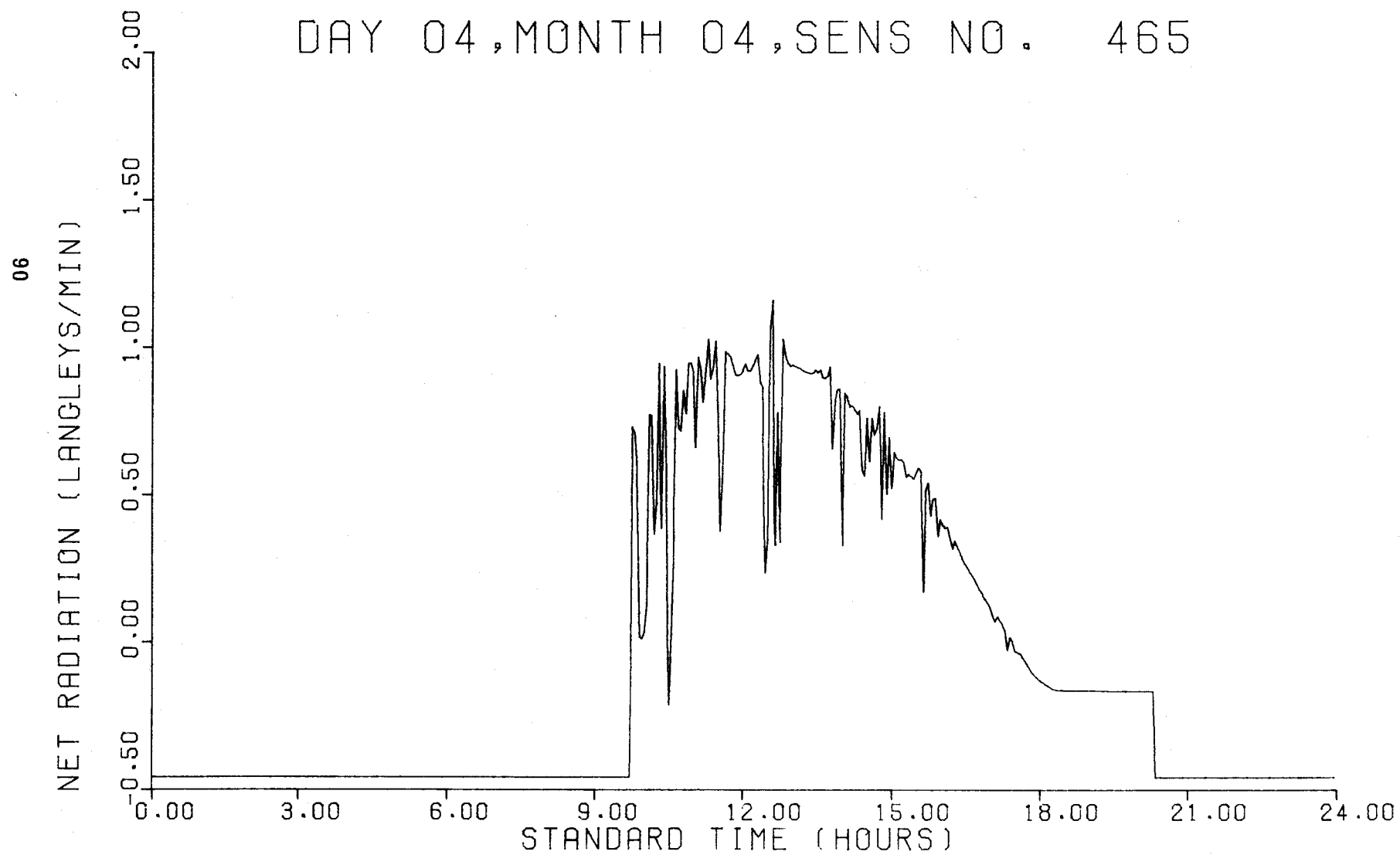
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DAY 03, MONTH 04, SENS NO. 465

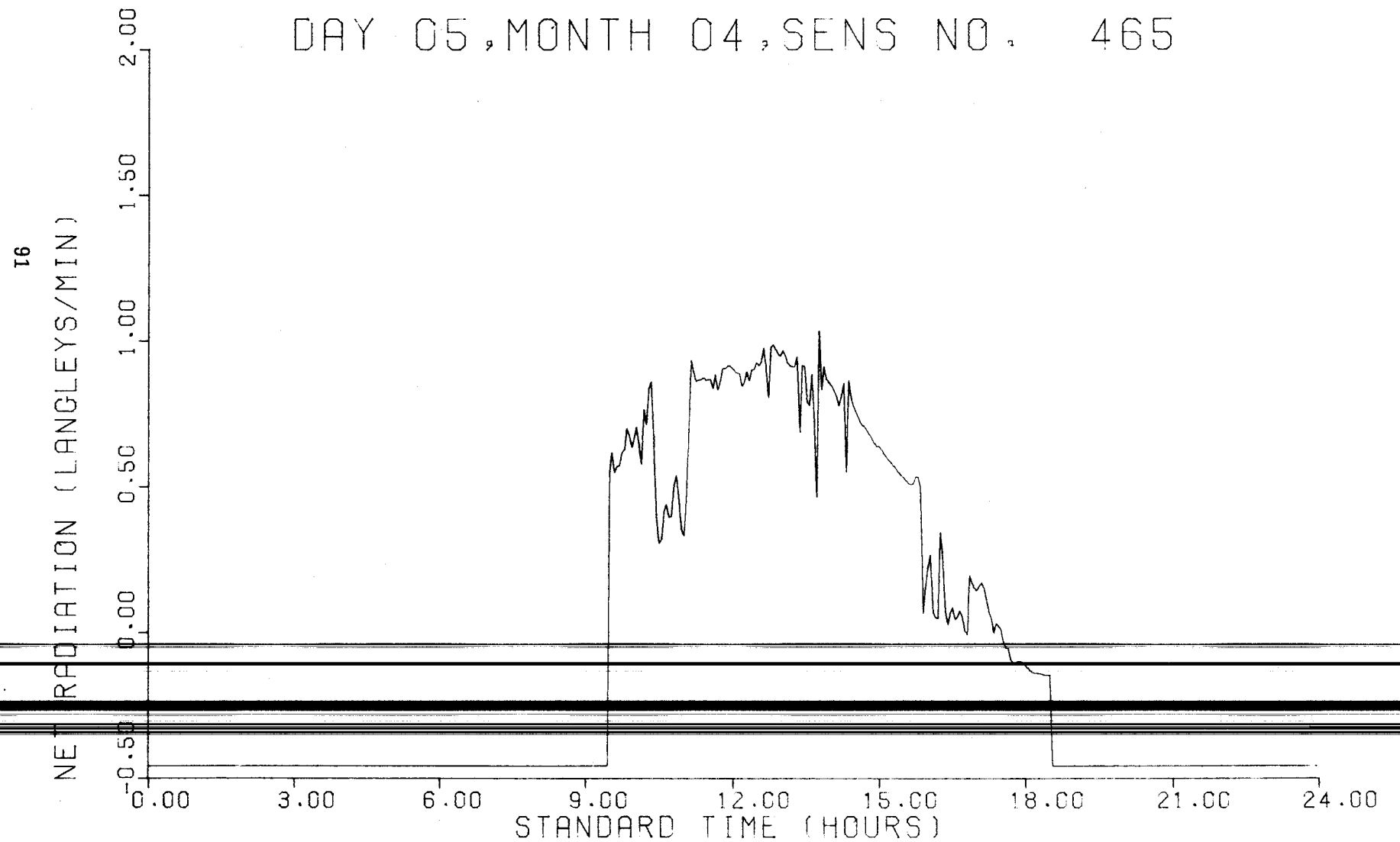


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DAY 04, MONTH 04, SENS NO. 465

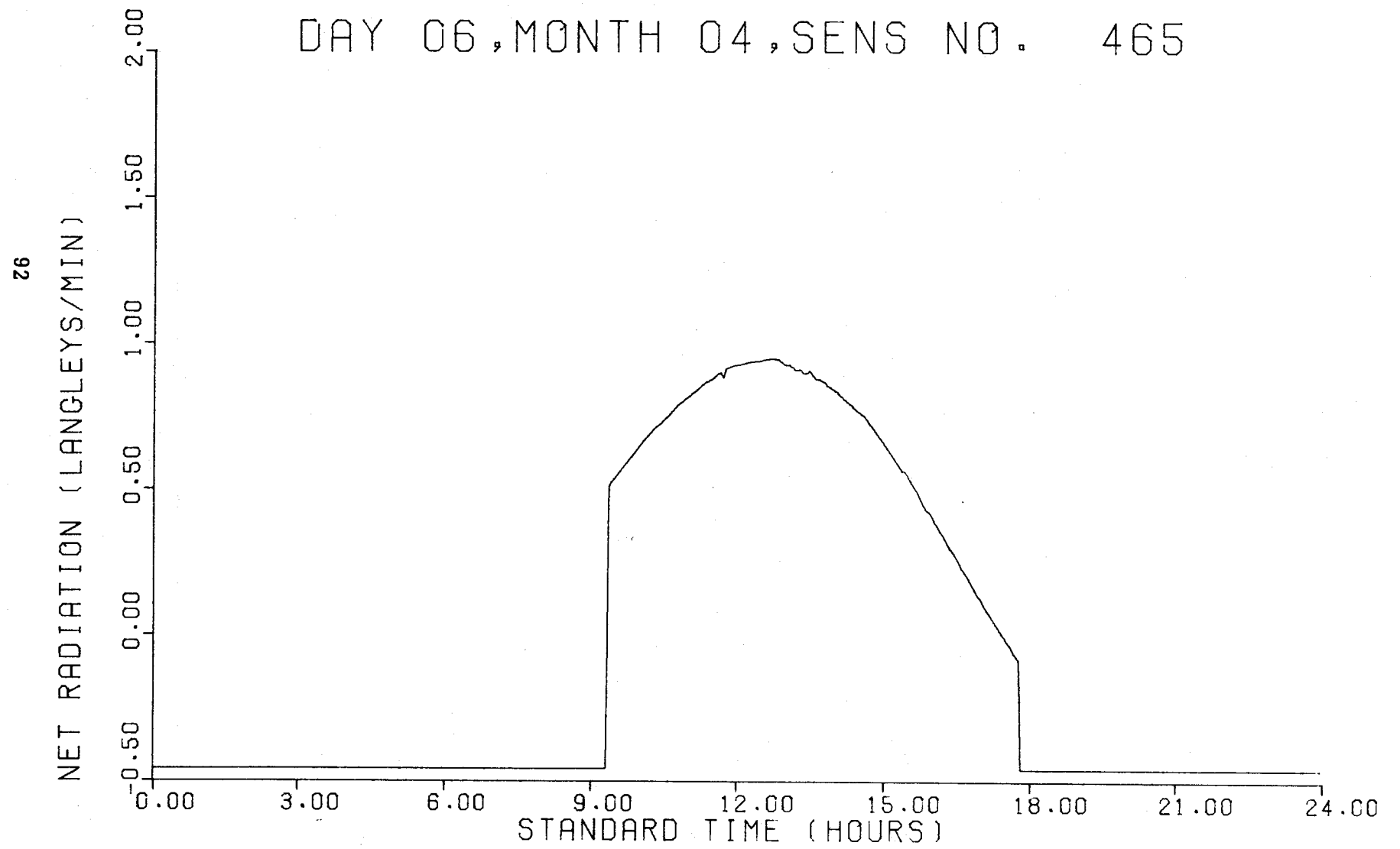


DIGITIZED FLARE DATA PLOT

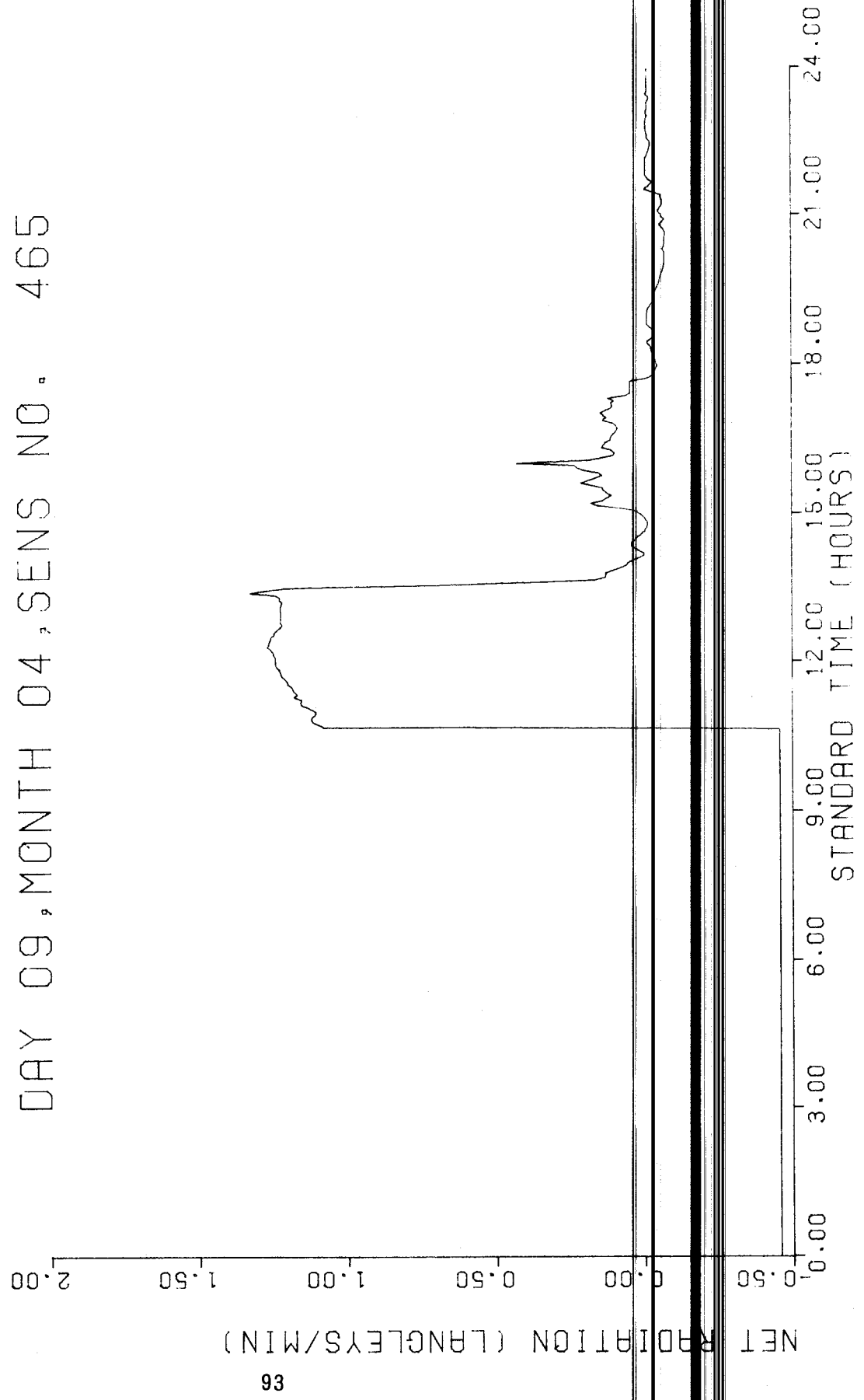
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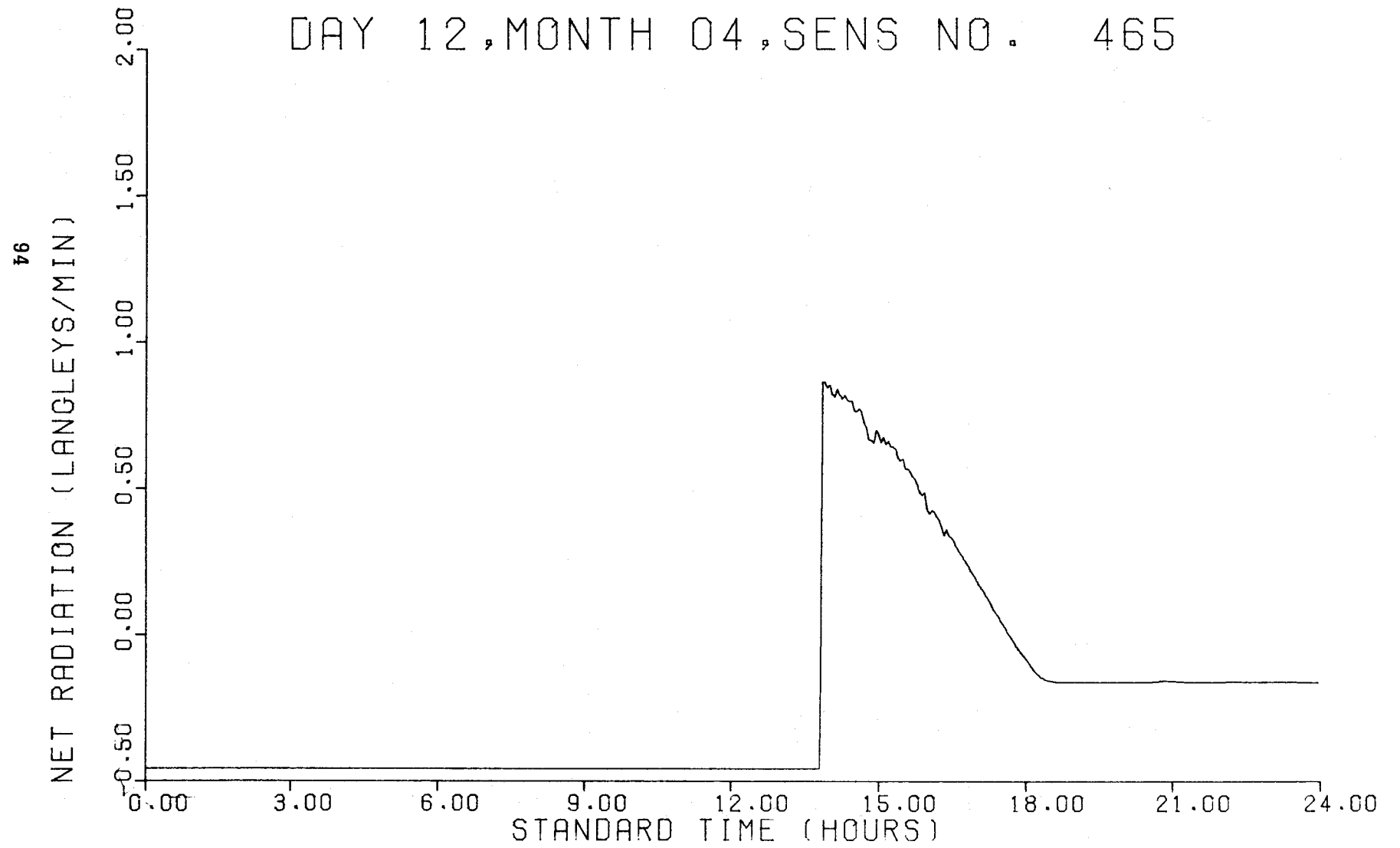
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DAY 06, MONTH 04, SENS NO. 465



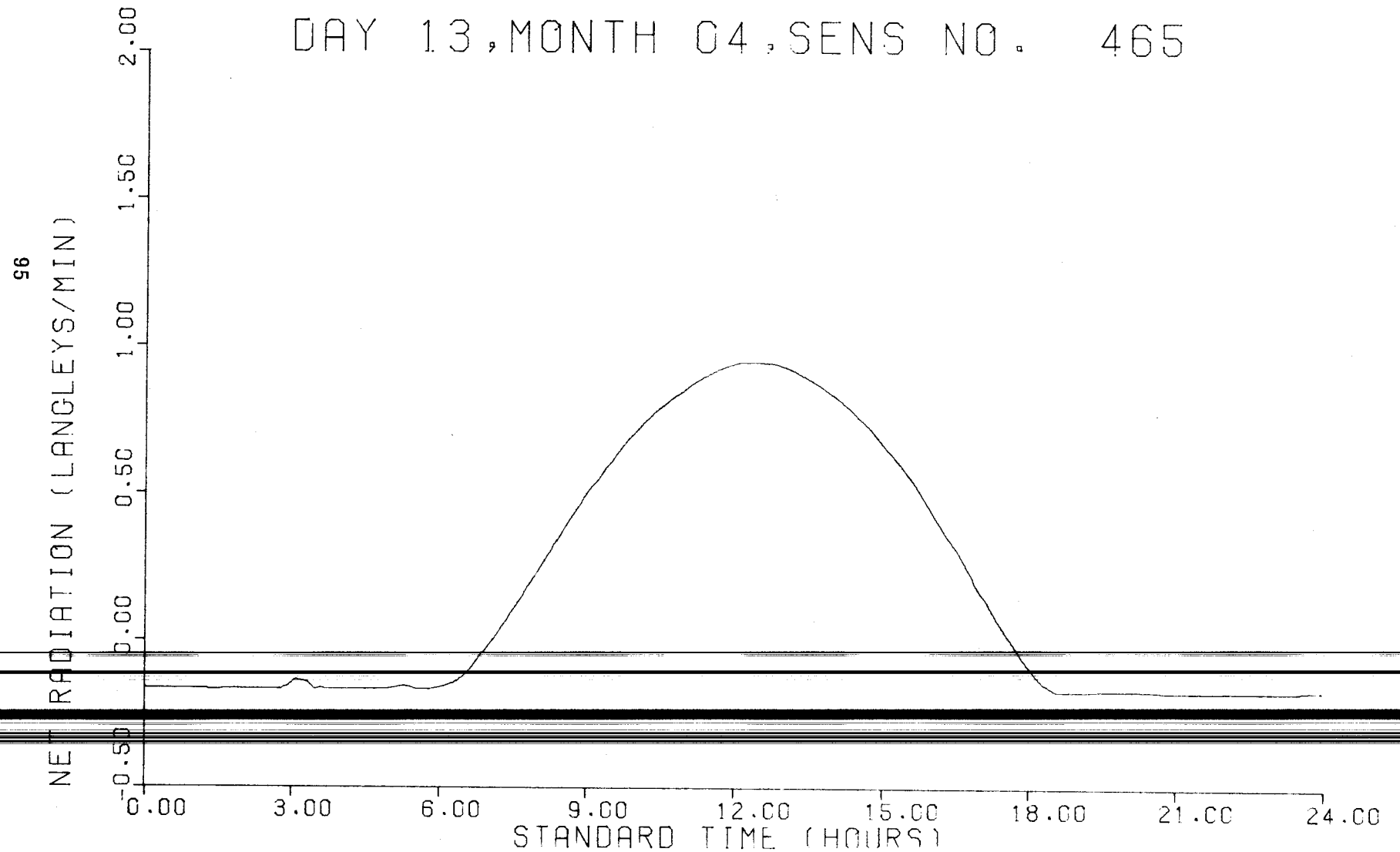
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DAY 09, MONTH 04, SENS NO. 465



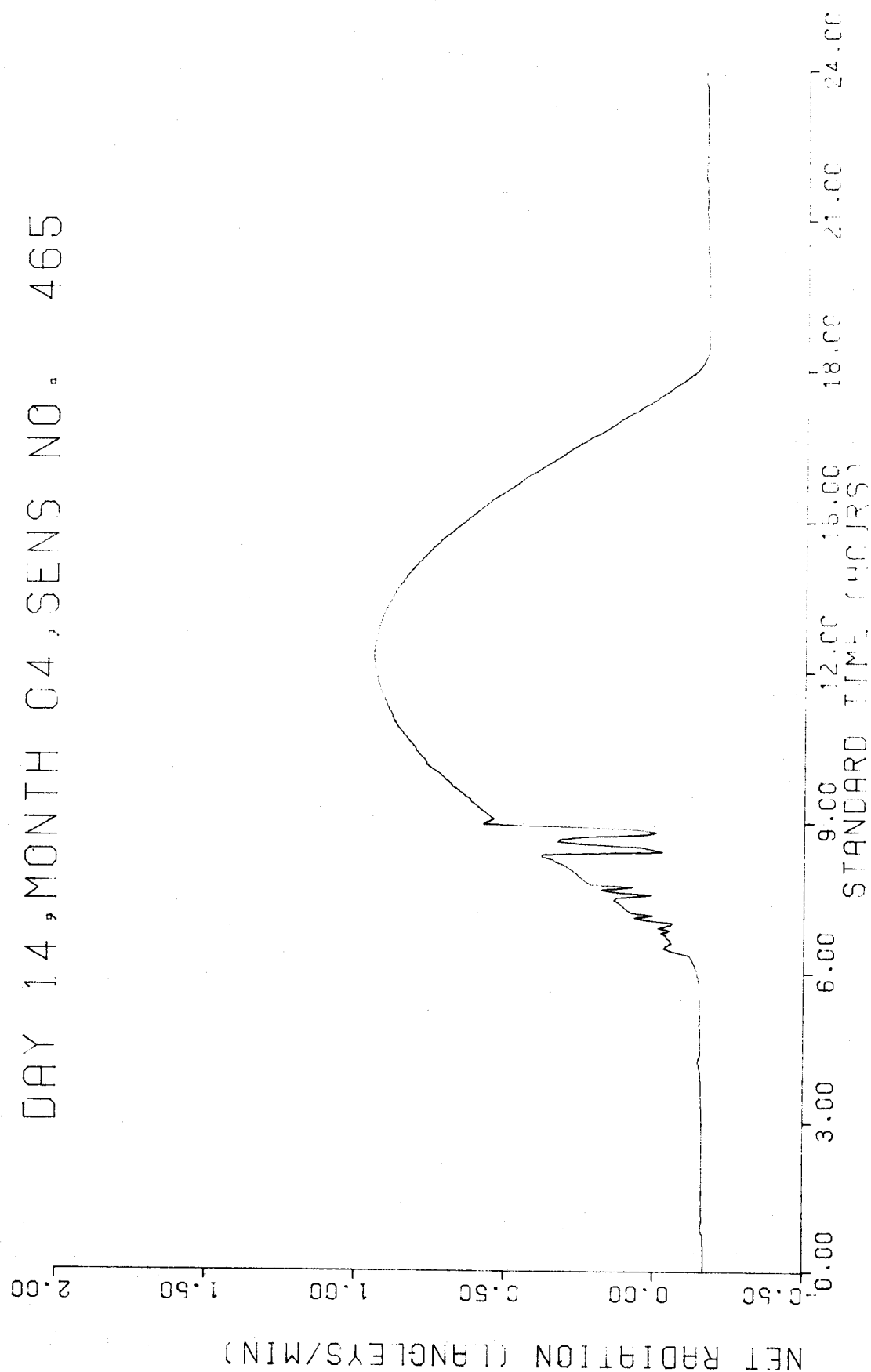
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DAY 12, MONTH 04, SENS NO. 465



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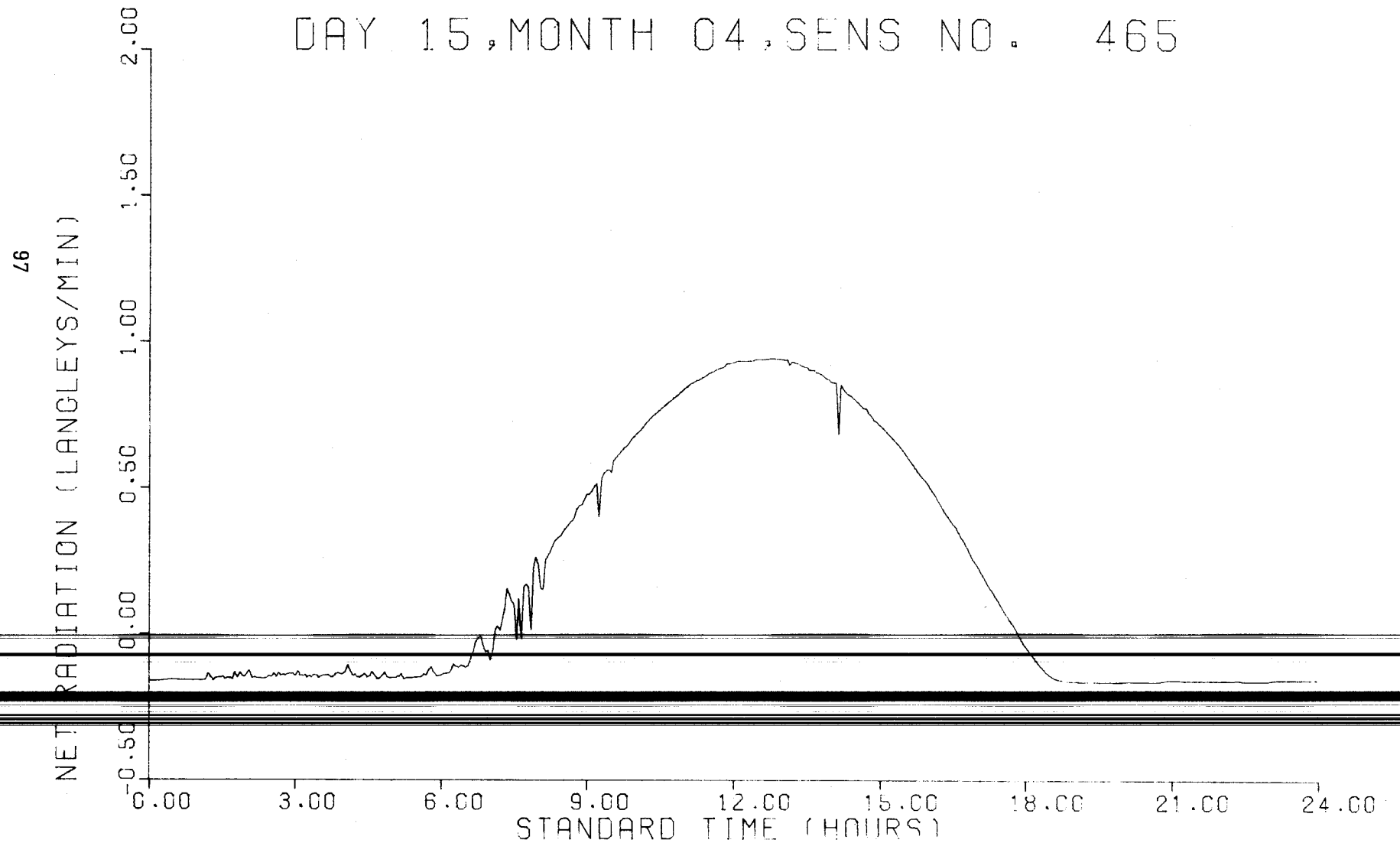


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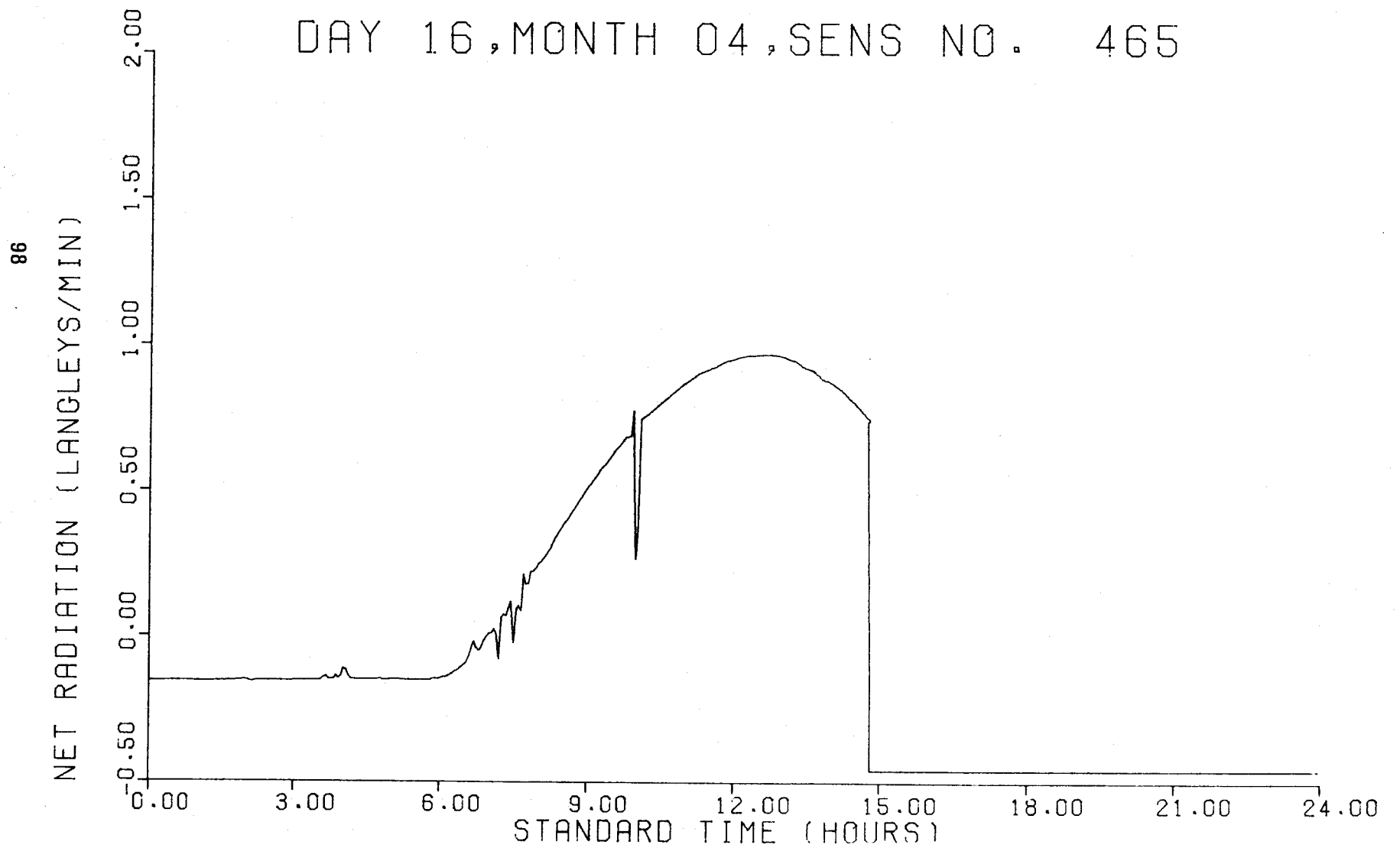


DIGITIZED FLARE DATA PLOT

DAY 15, MONTH 04, SENS NO. 465



DIGITIZED FLARE DATA PLOT
DAY 16, MONTH 04, SENS NO. 465



ATLANTIC OCEANOGRAPHIC AND METEOROLOGICAL LABORATORIES*

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Richard H. Bennett, Douglas N. Lambert, Paul J. Grim
(COM-71-00955)
- No. 14 Free-Air Gravity Anomalies South of Panama and Costa Rica
Robert J. Barday
(COM-71-01028)
- No. 15 Tests of Modified Radiosonde Hygristor Duct.
W. W. Shinnars, G. E. Putland, P. B. Conners
(COM-72-10175)

*Note: Until July 1968, AOML was called Atlantic Oceanographic Laboratories.

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