HEADQUARTERS QUARTERMASTER RESEARCH & DEVELOPMENT COMMAND
Quartermaster Research & Development Center, US Army
Natick, Massachusetts

Environmental Protection Division

EXPLORATORY STUDY TO DETERMINE FAVORABLE LOCATIONS IN THE UNITED STATES FOR CONSTRUCTION OF A SOLAR FURNACE

Blanche B. Hull
Meteorologist

Environmental Analysis Section
Environmental Research Branch

RESEARCH STUDY REPORT EA-4

Prepared for Armed Forces Special Weapons Project
Quartermaster Research & Development Center

7-83-05-004A

November 1955

SUMMARY

The total receipt of radiant solar energy at the earth's surface is dependent upon the clarity of the atmospheric envelope and the number of sunshine hours. For short-wave solar radiation, water vapor and clouds are the two major absorbers and scatterers. The graphs of solar radiation and the average number of sunshine hours shown in this report indicate that the stations in the Southwest United States have the most favorable climatic conditions for the location of a solar furnace that will provide thermal radiation of high intensity throughout the year. This is substantiated by the frequency data. The curves and frequency for Yuma and Phoenix, Arizona, and Alburquerque, New Mexico, are quite similar and indicate favorable conditions. For the warmer months the conditions at Fresno and the Central Sierra Station, both in California, reflect the marked increase in clear sky conditions within the influence of the Pacific high pressure cell. The cloud conditions during the winter months detract from the suitability of the California Valley for year round operations.

The moisture flow over the eastern section of the United States and the resultant clouds contribute significantly to the lower values of radiant energy received at the surface in this section. The curves and frequency data for Blue Hill Observatory in Massachusetts are typical for the North Atlantic states. These same conditions occur over much of the plains and central states. There is not much difference in the data for Blue Hill and Lincoln, Nebraska. A localized area of similar latitude but dissimilar in other respects to those of the Northern Atlantic Coast is the coastal section of the Pacific Northwest as shown by the data for Friday Harbor, Washington.

On a climatological basis the arid Southwest appears to be the logical site for the solar furnace. However, the particular site chosen should be based upon further study of local weather conditions. A micro-climatic study should determine: (1) the influence of topography, such as exposure to moisture bearing winds, the decrease of water vapor with increased elevation, and increased cloud amounts at high elevations; (2) proximity to large bodies of water; (3) ground reflectivity; (4) the source of dust and pollution.

CONTENTS

Figures

TABLES

BLANK PAGE

EXPLORATORY STUDY TO DETERMINE FAVORABLE LOCATIONS IN THE UNITED STATES FOR CONSTRUCTION OF A SOLAR FURNACE

1. Introduction

The attention of the Armed Forces Special Weapons Project is focused on determining a site in the United States where a solar furnace can be built that will provide maximum intensity and maximum frequency of solar radiation throughout the year. The solar furnace is to be used for the testing of many kinds of materials used by all the Armed Forces agencies.

As a preliminary analysis of the possible locations where geographic and climatic factors will contribute most advantageously to the operation of a solar furnace (tentatively designed to produce intensities of solar radiation up to 100 cal/cm^2 sec), this study has utilized all available original and published source material that could be assembled from Department of the Army Test Site observations and from the solar radiation tests and experiments of other research institutions in the Boston area.

2. Data

Hourly and daily solar radiation observations recorded on a horizontal surface were used to produce the frequency distributions for Yuma, Arizona; Albuquerque, New Mexico; Central Sierra, California; and Blue Hill Observatory, Milton, Massachusetts. These observations were tabulated from all the records available in the Boston area. At a later date this Division expects to receive frequency distributions from 95 Weather Bureau stations whose solar radiation observations for approximately 5 years duration are now at the National Weather Records Center at Asheville, North Carolina for EAM processing. When these data are received, it will be possible to add much salient information to the solar radiation frequency distributions contained in this interim report. Sunshine data, except for Yuma, Arizona, were taken from the Weather Bureau's Climatological Data and Technical Paper No. 12. The sunshine hours for Yuma were taken from "Handbook of Yuma Environment", the Office of The Quartermaster General Environmental Protection Branch Report No. 200. The map of Annual Total Sunshine Hours for the United States was excerpted from the Weather Bureau's Annual Sunshine Hours Map of the World. Material for the graphs on solar radiation were taken largely from solar radiation studies of I.F. Hand and G.A. Crabb, Jr.

3. Selection of Possible Climatic Locations in the United States

The possible sites showing favorable climatic conditions or contrast to these conditions, that have been selected for presentation in this paper are listed in Table 1. They consist of:

(1) Five inland stations in the Southwest that have the highest annual average solar radiation and sunshine hours for the United States:

(a) Phoenix, Arizona (elevation 1,114 feet) represents the moderate level, southwest desert area. The maximum intensity and the maximum duration of intensity occur in the late spring and early summer when cloudiness is at a minimum.

(b) Fresno, California (elevation 277 feet) illustrates the West Coast low altitude summer dry climate with intense solar radiation during the season of minimum cloudiness and rain.

(c) Yuma, Arizona (elevation 138 feet) illustrates a low latitude, low altitude desert station with insolation consistently high through the summer half of the year and high at intervals during the winter.

(d) Albuquerque, New Mexico (elevation 4,042 feet) shows the extreme values that are typical of middle altitude stations in upper subtropical latitudes of the Southwest.

(e) Central Sierra, California (elevation 6,900 feet) typifies a high altitude, middle latitude station. Although a summer dry climate characterizes the Central California area, the cloud amounts at high elevations deplete the radiation. The pattern at Central Sierra, except for July, is about the same as that at the low altitude station of Fresno.

(2) Two stations, one on the Northern East Coast and one on the Northern West Coast, that have low amounts of solar radiation and sunshine:

(a) Blue Hill Observatory, Milton, Massachusetts (elevation 640 feet) is representative of stations along the Northern Atlantic Coast. The pattern is similar to that of Boston with a spring "plateau" and a summer peak, except that the effects of industrial pollution are apparent in lesser amounts of insolation at Boston.

(b) Friday Harbor, Washington (elevation 7 feet) differs markedly from Blue Hill Observatory on the Northern Atlantic Coast. The latitudes are similar but the effects of elevation and to a greater extent the general differences in the wind and cloudiness patterns along the two coasts account for the dissimilarities.

(3) One station in the Central Plains for comparison with coastal stations and inland locations of higher elevations:

(a) Lincoln, Nebraska (elevation 1,180 feet) is representative of the middle latitude, middle altitude stations, with a spring "plateau", a high summer peak and a marked decline of insolation in the fall.

In selecting the above stations for study, consideration was given to their proximity to Army, Navy and/or Air Force installations.

4. Analysis of Data at Eight Locations

The solar radiation data that are used in this report (Figures 2, 4, 6, 7 and 8 plotted as weekly means of daily totals and figures 1, 3 and 5 plotted as average daily totals; also Tables 2 through 4) are from observations taken on a horizontal surface. This includes a combination of direct and diffuse radiation. Tables 5, 6 and 7 present data on sunshine and cloudiness that supplement the information on insolation.

Since the furnace when in use would be turned to follow the direct rays of the sun, the most applicable observations would be energy received normal, or perpendicular, to the sun. Normal incidence, however, is not regularly recorded and the data available are scattered and limited; also it is not possible to convert solar radiation values taken on a horizontal surface to normal incidence without knowing the values of diffuse sky radiation. (Hand and Wollaston, 1953).

Normal incidence, therefore, has been computed only from the data available at Blue Hill Observatory, Massachusetts (Tables 8 and 9). Table 8 shows the average hourly insolation on a surface perpendicular to the sun and Table 9, a comparison of the normal incidence with that received on a horizontal surface during January, April, July and October. Hand (1950) made a detailed analysis of normal and diffuse insolation on clear days at the time of the solstices and equinoxes for latitude 42°N. In a recent article by Cuniff (1955), normal monthly curves of solar radiation at normal incidence are shown for Blue Hill Observatory, Milton, Massachusetts; Madison, Wisconsin; Lincoln, Nebraska; Albuquerque, New Mexico; Boston, Massachusetts and Table Mountain, California. All the curves except Table Mountain show great year-to-year variation. Since the measurements are taken only at times when the sky in front of the sun is cloudless, the variations in the curves indicate that factors other than clouds, particularly smoke and haze, contribute greatly to the depletion of solar radiation for brief or long intervals. Kimball (1930) in preparing monthly means of solar radiation and atmospheric transmission considered the differences at various United States stations in the depletion of solar radiation by atmospheric dust. Thus, it is important to make a study of pollution and depletion factors in any area tentatively selected as favorable for year-round operation of a solar furnace.

This study uses the energy received on a horizontal surface for comparing different sections of the country rather than estimating the normal incidence. As supporting information, graphs of the average number of sunshine hours available for all stations except Central Sierra, California, are combined with the graphs of total radiation received in gram-calories per square centimeter per day (Figures 1-8). It is apparent that areas of high sunshine hours show a high incidence of solar energy. The maps of total hours of sunshine (U.S. Weather Bureau, 1954) and solar heat per square foot per average day (Hand, 1953) show the maximum sunshine hours and the maximum solar heat concentrated in the Southwest States. (Figures 9 and 10).

Frequency distributions of hourly and daily amounts of solar radiation for Albuquerque, New Mexico, Yuma, Arizona, Blue Hill

Observatory, Milton, Massachusetts, and Central Sierra, California for January, April, July, and October are tabulated in Tables 2 and 3. From these tables the number of days and hours having various intensities of solar radiation can be determined and a comparison made of the stations.

An areal comparison of sunshine and radiation elements in eastern Massachusetts, Washington, D.C. and Arizona is given in Table 4. The eastern Massachusetts and Washington, D.C. areas show identical values in all elements compared except the annual sunshine hours and winter solar radiation, which are greater for the more southern latitude of Washington, D.C.

5. Discussion

Discussions with scientists at Harvard University, and at the Massachusetts Institute of Technology, where a solar radiation furnace capable of concentrating 400/cal/cm^2 min has been used for testing materials in recent years, have aided an appreciation of the climatic problems that may be involved in operating a much larger furnace anywhere except in areas of maximum solar radiation and sunshine hours. Discussions with Dr. Brooks, and members of his research staff at Blue Hill Observatory, and with Mr. Cuniff, Weather Bureau representative in charge of solar radiation observations at the observatory, resulted in the evaluation of the current available original data of usable proportions that could be used; i.e., solar energy received on a horizontal surface. The discussions helped exhaust the possibility that some mathematical, empirical or theoretical means could be employed to convert solar radiation observations on a horizontal surface to the energy values of direct rays. This conversion would require observations of diffuse sky radiation, which are not regularly recorded at any station selected except Blue Hill.

The problem of selecting a general location for further study is a comparatively simple one since all the climatic evidence points favorably to the Southwest. A final determination, however, should be based on further investigation of the immediate environment and local climate.

To illustrate the extent to which two sites under the influence of the same general climatic controls may differ because of exposure to cloud bearing winds and configuration of the land, the insolation for the months of maximum intensity, May, June and July, is tabulated below for two additional stations, Grand Lake and Grand Junction, Colorado.

Percentage Total Days Solar Radiation on Horizontal Surface*

Langleys/day

Station	Elev. Ft.	600-649	650-699	700-749	750-799	800-849	850-899	Total %
Grand Lake, Colorado	8,380	9	8	6	9	16	9	57
Grand Junction, Colorado	4,849	11	9	13	19	18	4	74

*Percentage Total for 3 months, May, June and July. 1 to 3 year record.

At Grand Lake, elevation 8,380 feet, surrounded by cloud-capped Rocky Mountain peaks and ridges, 57 percent of the days observed had total daily insolation greater than 600 langleys. At Grand Junction, 3,531 feet lower than Grand Lake, where the mountain ridges lower and the Colorado plateau begins, 74 percent of the days observed had insolation greater than 600 langleys. However, the number of days having insolation greater than 850 langleys were twice as many at Grand Lake as at Grand Junction. When clouds are not present, the higher location has a clearer and thinner atmosphere than the lower.

Therefore, it is important in selecting a site to determine whether maximum duration of lesser intensities is preferred to maximum intensity for shorter periods. This, of course, would depend on the nature and consistency of the demands on the furnace.

In addition to the effects of elevation and exposure, a site located too near a large body of water would be subject to marine climatic influences which may augment or weaken the general climate controls. Land and sea breeze effects, fog along the coast of California and high humidities in Gulf air flowing into Arizona may influence locally the conditions in some areas of the Southwest. Dust from the desert or smoke and pollution from the industries of cities are often factors in depleting the amounts of solar radiation received.

For these reasons and others meteorologically too intricate to define without further studies of the areas considered in this report, it is strongly urged that any site selected for preliminary consideration should be subjected to micro-meteorological investigation and analysis.

6. Recommendations

The most favorable area in the United States for the location of a solar furnace is in the arid Southwest. It is recommended that the specific site within the Southwest for building the furnace should be determined only after a micro-meteorological investigation of the local environment.

Comparative analysis of stations presented in this study justifies the construction of the furnace at some location of moderate elevation with meteorologic conditions similar to those at Grand Junction, Colorado, or at a higher elevation if a study of cloud frequencies proves the feasibility.

7. Acknowledgments

This report was prepared under the direction of Dr. D. H. Miller, Chief, Environmental Analysis Section. The author had the benefit of consultation with Dr. C.F. Brooks and Mr. C.V. Cuniff at Blue Hill Observatory and with Mr. Enrique Ho Leong at the Massachusetts Institute of Technology. Mr. Owen Parmele and Miss Gertrude Barry assisted in the preparation of the statistical tables and charts.

APPROVED:

D. H. MILLER
Chief
Environmental Analysis Section

AUSTIN HENSCHEL
Chief
Environmental Protection Division

Prepared by:

BLANCHE B. HULL
Meteorologist
Environmental Analysis Section
Environmental Research Branch

8. References

Crabb, G.A., Jr.
1950. Solar radiation investigations in Michigan. Michigan Agricultural Experiment Station, Technical Bulletin 222, pp. 30-74.

Cuniff, C.V.
1955. Variations in the intensity of solar radiation at normal incidence on the surface of the earth. Monthly Weather Review, 83, pp. 101-103.

Fritz, S., and T. MacDonald
1949. Average solar radiation in the United States. Heating and Ventilating, 46, pp. 61-64.

Fritz, S.
1949. Solar radiation on cloudless days. Heating and Ventilating, 46, pp. 47-69.

Hand, I.F.
1950. Insolation on clear days at the time of solstices and equinoxes for latitude 42 N. Heating and Ventilating, 46, pp. 92-93.

Hand, I.F.
1953. Distribution of solar energy over the United States. Heating and Ventilating, 50, pp. 73-75.

Hand, I.F., and F.A. Wollaston
1953. Measurements of diffuse solar radiation at Blue Hill Observatory. U.S. Weather Bureau Technical Paper, 18.

Kimball, H.H.
1930. Measurements of solar radiation intensity and determination of its depletion by the atmosphere. Monthly Weather Review, 58, pp. 43-52.

U.S. Corps of Engineers and Weather Bureau, Cooperative Snow Investigations
1951. 1952. 1953. Hydrometeorological Logs of the Central Sierra Snow Laboratory, for the Water Years 46-47, 47-48, 48-49, 49-50, 50-51, San Francisco, California.

U.S. Office of The Quartermaster General
1953. Handbook of Yuma Environment. Environmental Protection Branch Report No. 200, pp. 35-37, Washington, D. C.

U.S. Signal Corps
1949-1953. Manuscript data. Original daily and hourly observations of solar radiation at Yuma, Arizona.

U.S. Weather Bureau
1954. Annual total hours sunshine. World sunshine map. U.S. Weather Bureau, Washington, D. C.

U.S. Weather Bureau
1950-1954. Climatological Data, National Summary, Annual.

U.S. Weather Bureau
1947-1955. Manuscript data. Original daily and hourly observations of solar radiation at Albuquerque, New Mexico, and Blue Hill Observatory, Milton, Massachusetts.

U.S. Weather Bureau
1949. Weekly mean values of daily total solar and sky radiation. Technical Paper, 11.

U.S. Weather Bureau
1951. Sunshine and cloudiness at selected stations in the United States, Alaska, Hawaii, and Puerto Rico. Technical Paper 12.

Visher, S.S.
1954. Climatic atlas of the United States, pp. 182-183. Harvard University Press, Cambridge.

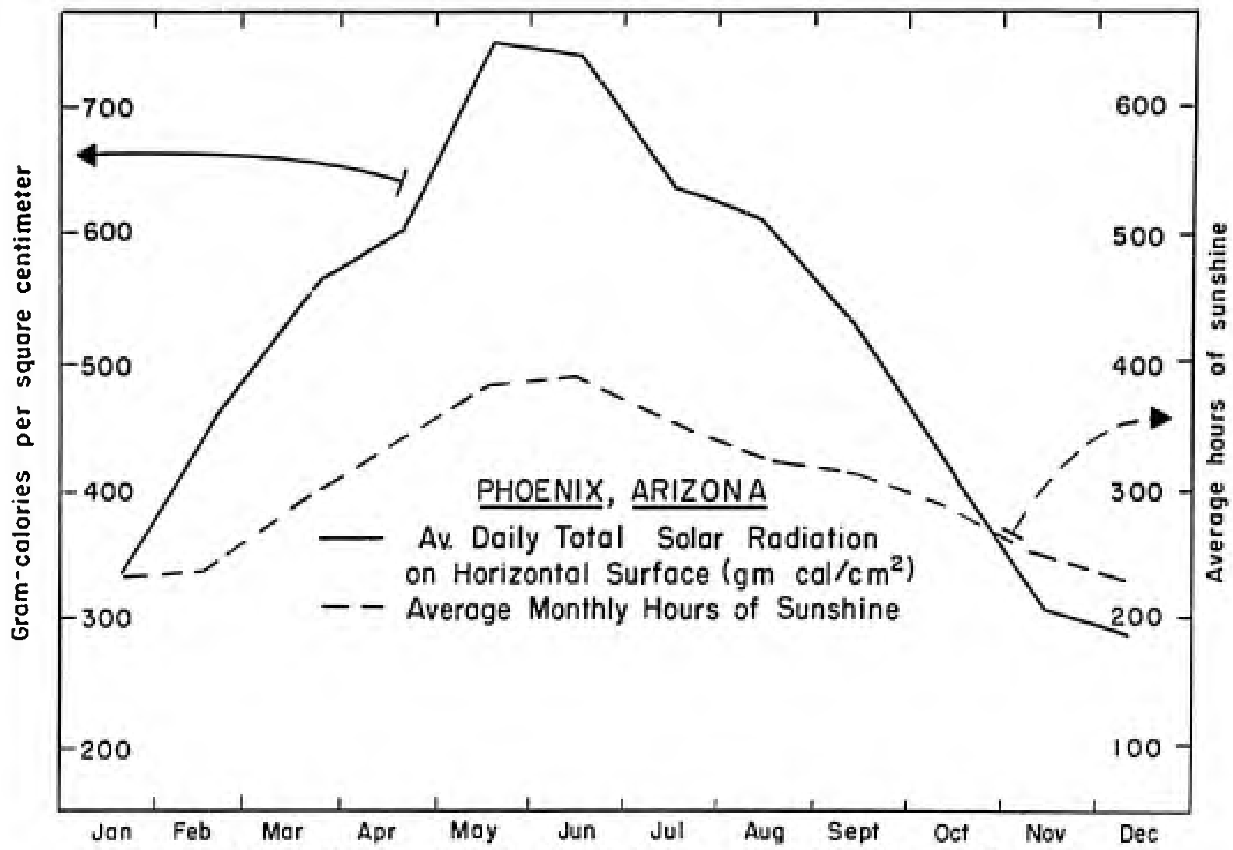

Fig. 1: Av. Daily Total Solar Radiation and Av. Mo. Hrs. of Sunshine

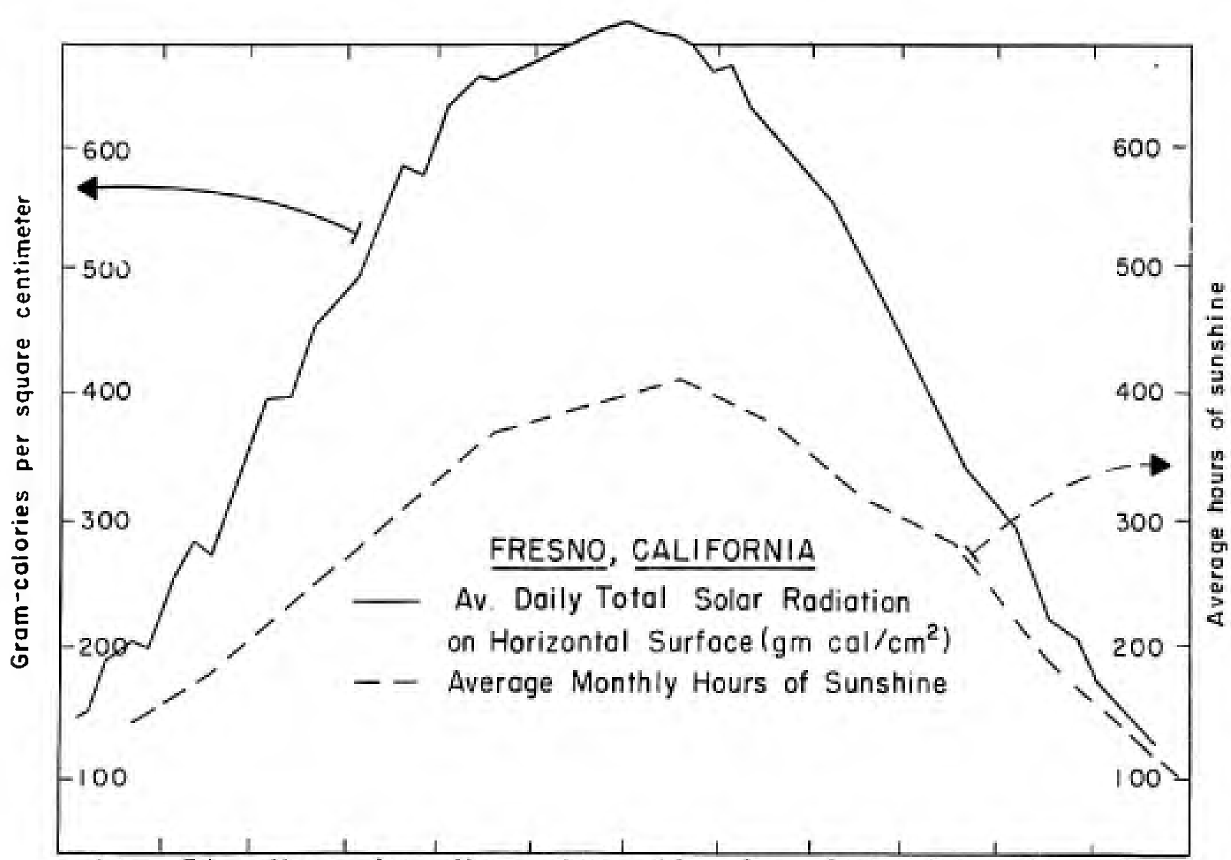

Fig. 2: Av. Daily Total Solar Radiation and Av. Mo. Hrs. of Sunshine

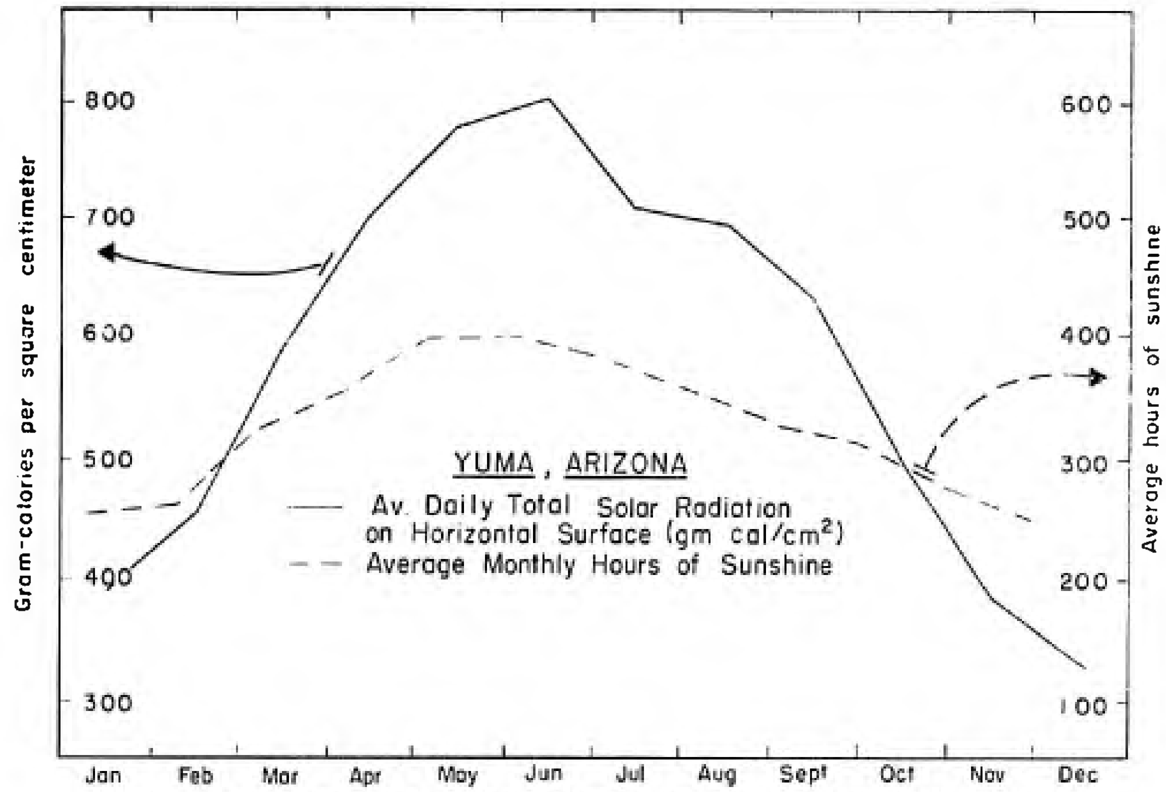

Fig. 3: Av. Daily Total Solar Radiation and Av. Mo. Hrs. of Sunshine

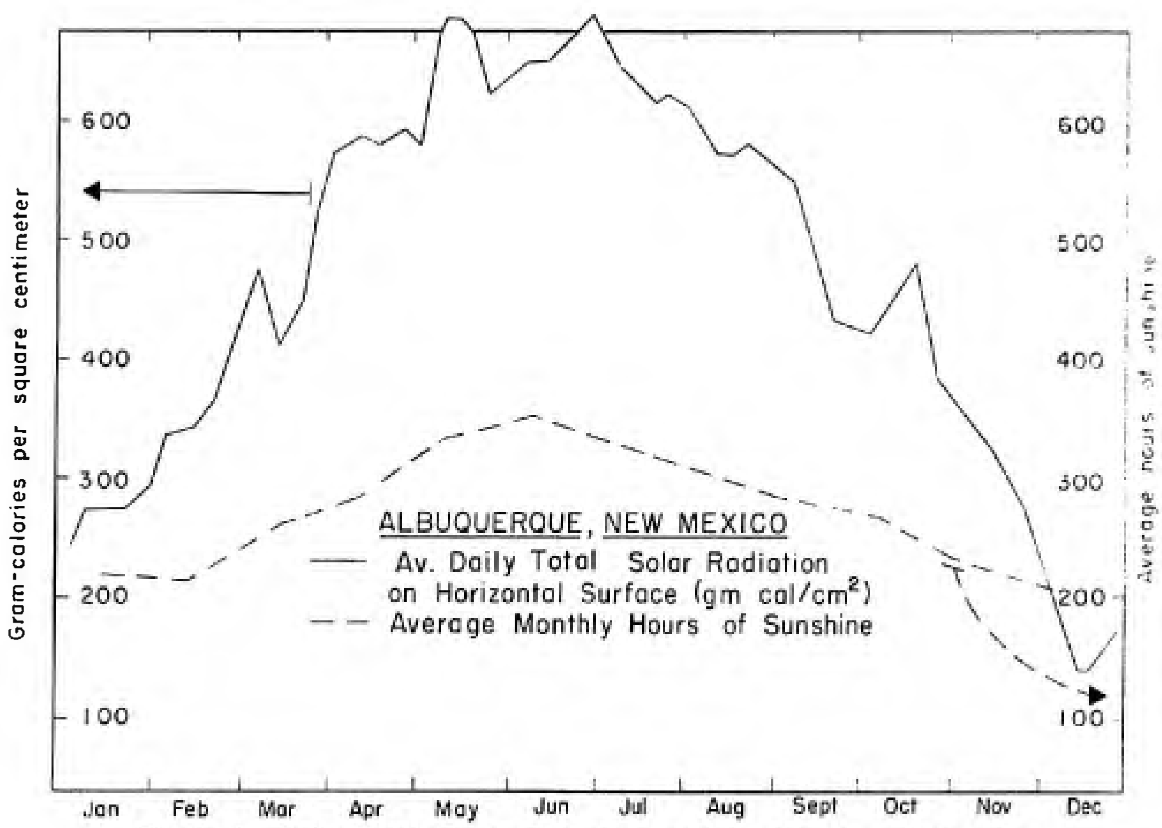

Fig. 4: Av. Daily Total Solar Radiation and Av. Mo. Hrs. of Sunshine

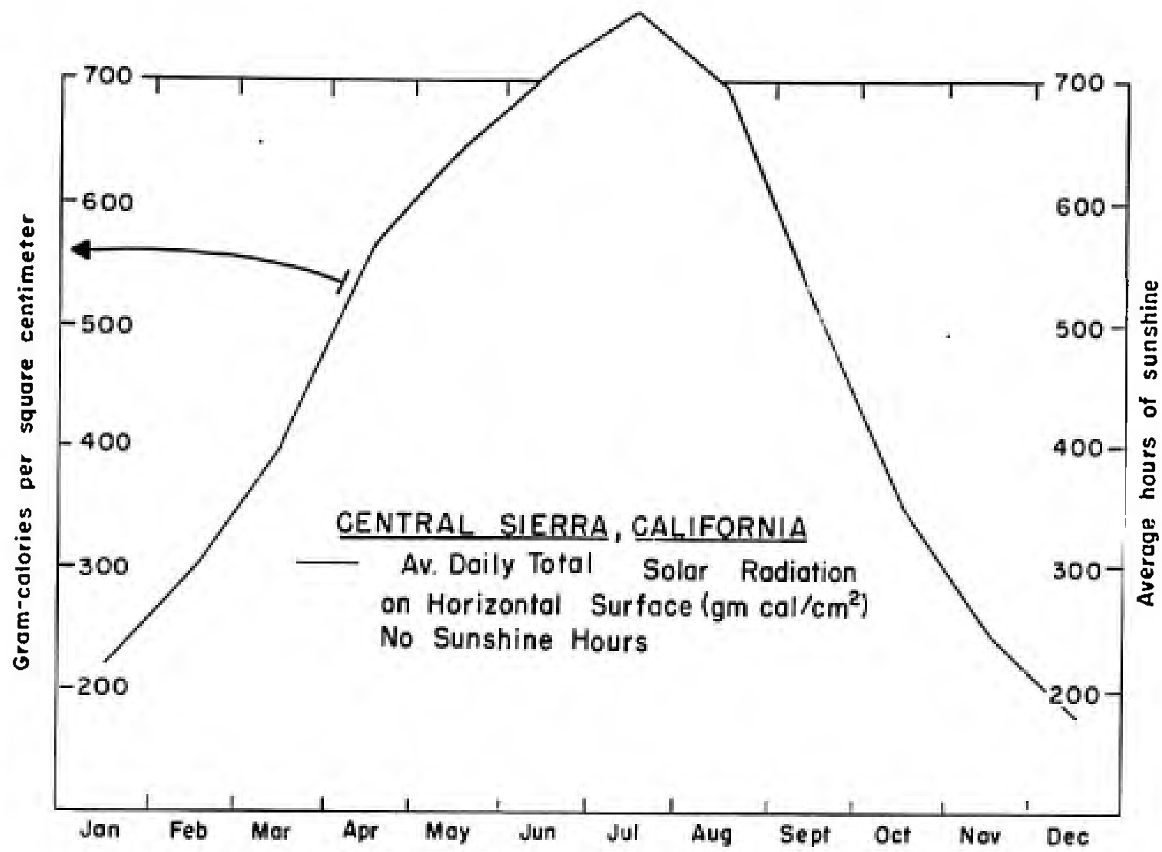

Fig. 5: Av. Daily Total Solar Radiation and Av. Mo. Hrs. of Sunshine

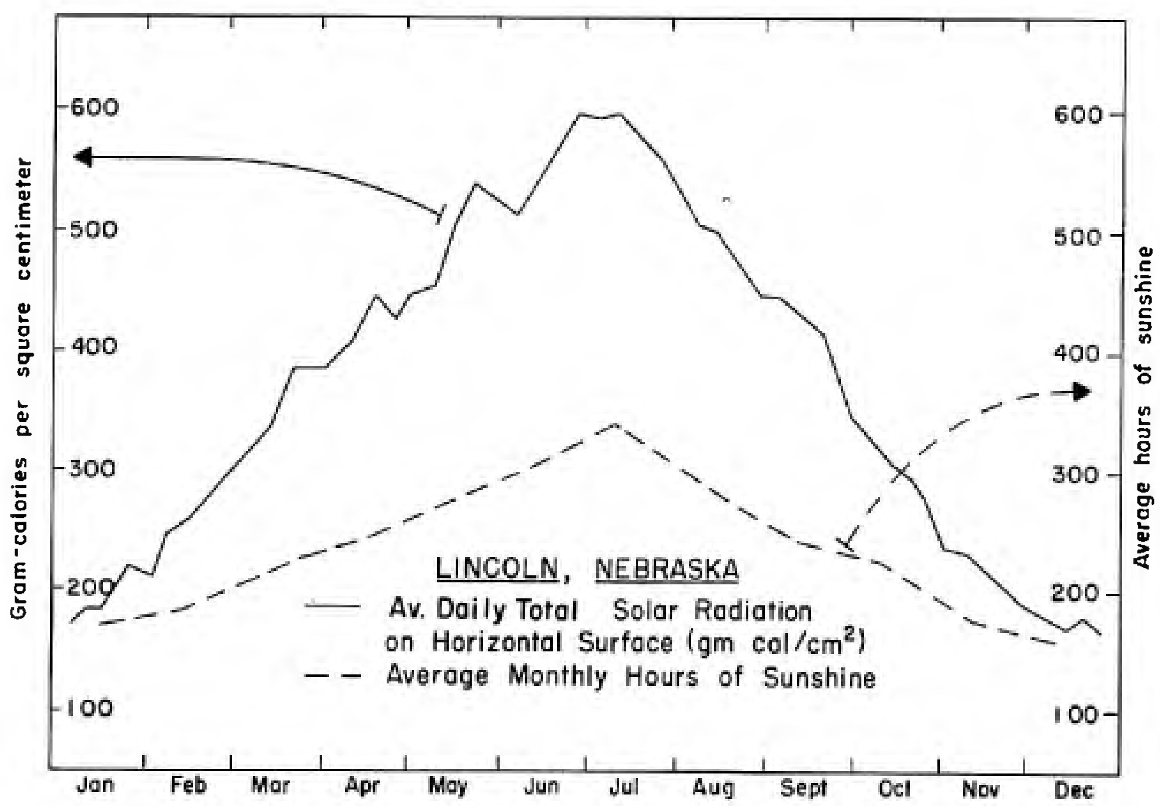

Fig. 6: Av. Daily Total Solar Radiation and Av. Mo. Hrs. of Sunshine

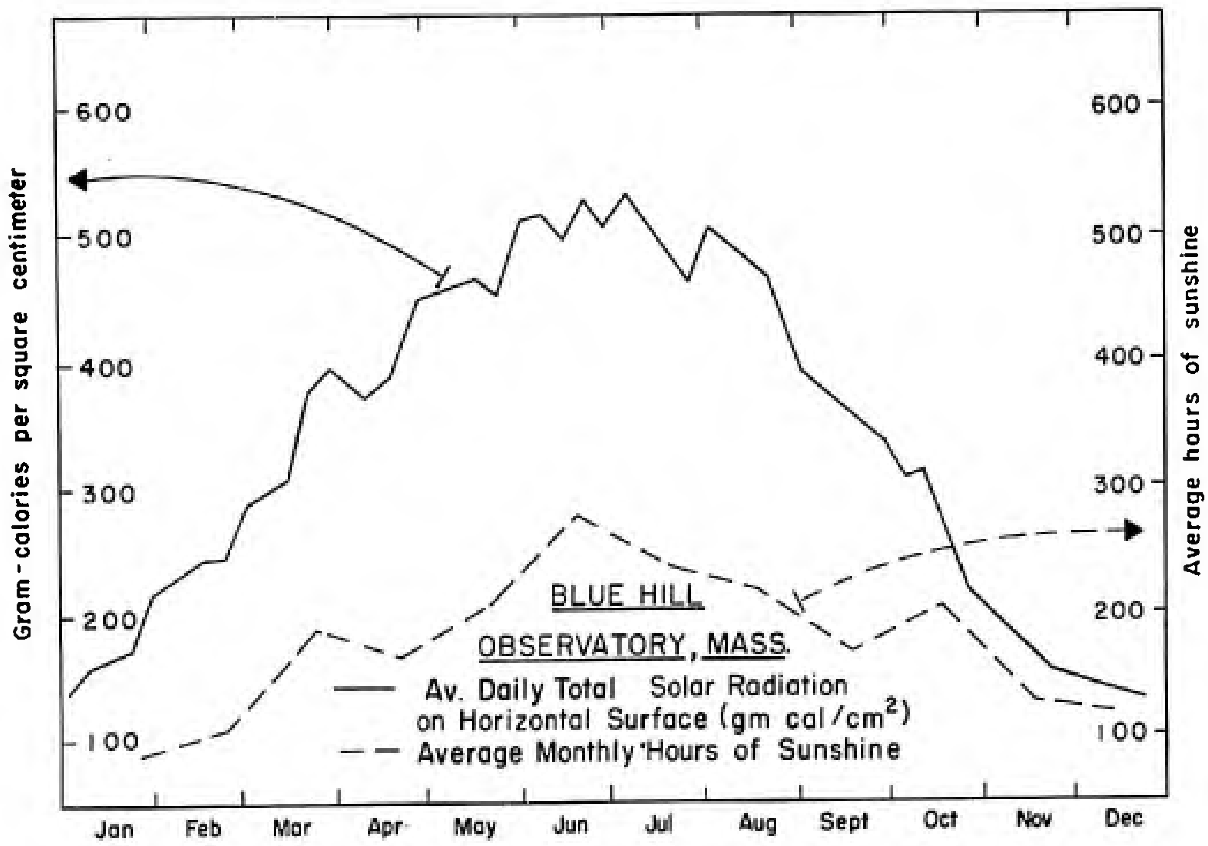

Fig. 7: Av. Daily Total Solar Radiation and Av. Mo. Hrs. of Sunshine

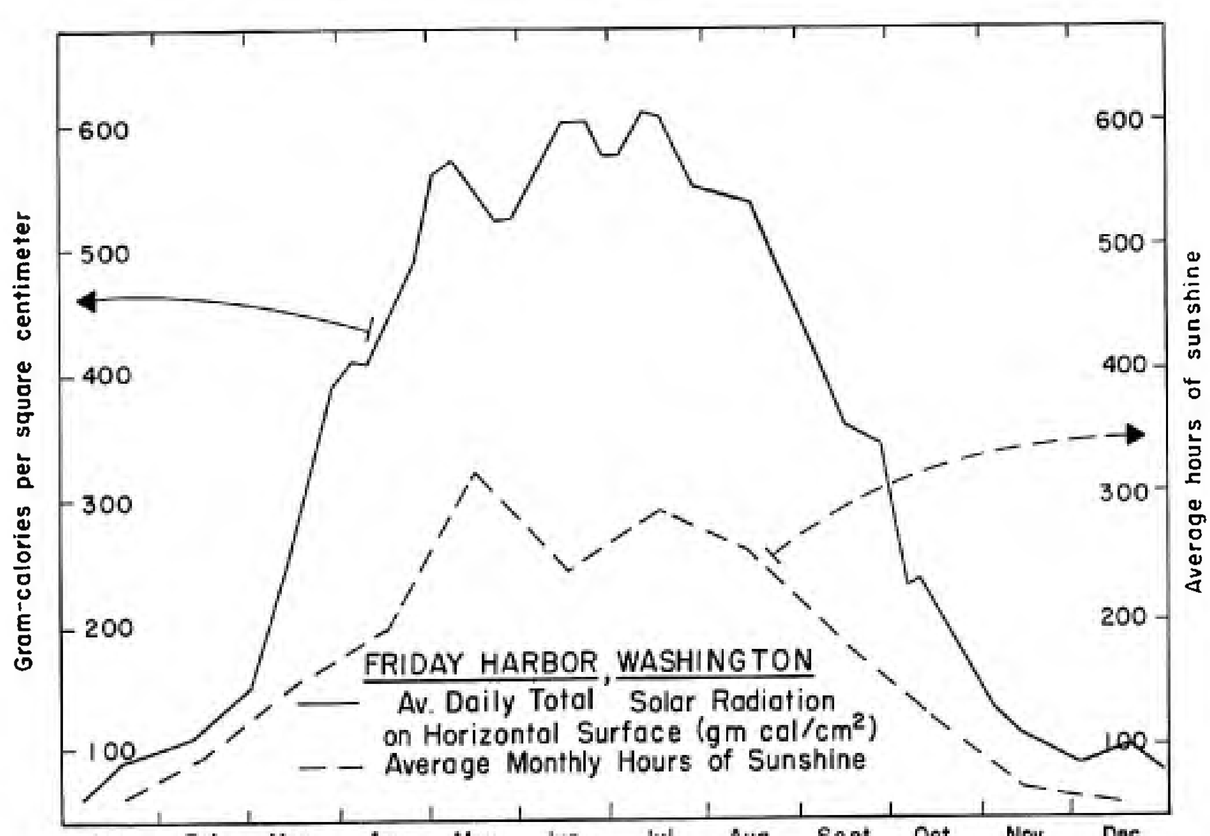

Fig. 8: Av. Daily Total Solar Radiation and Av. Mo. Hrs. of Sunshine

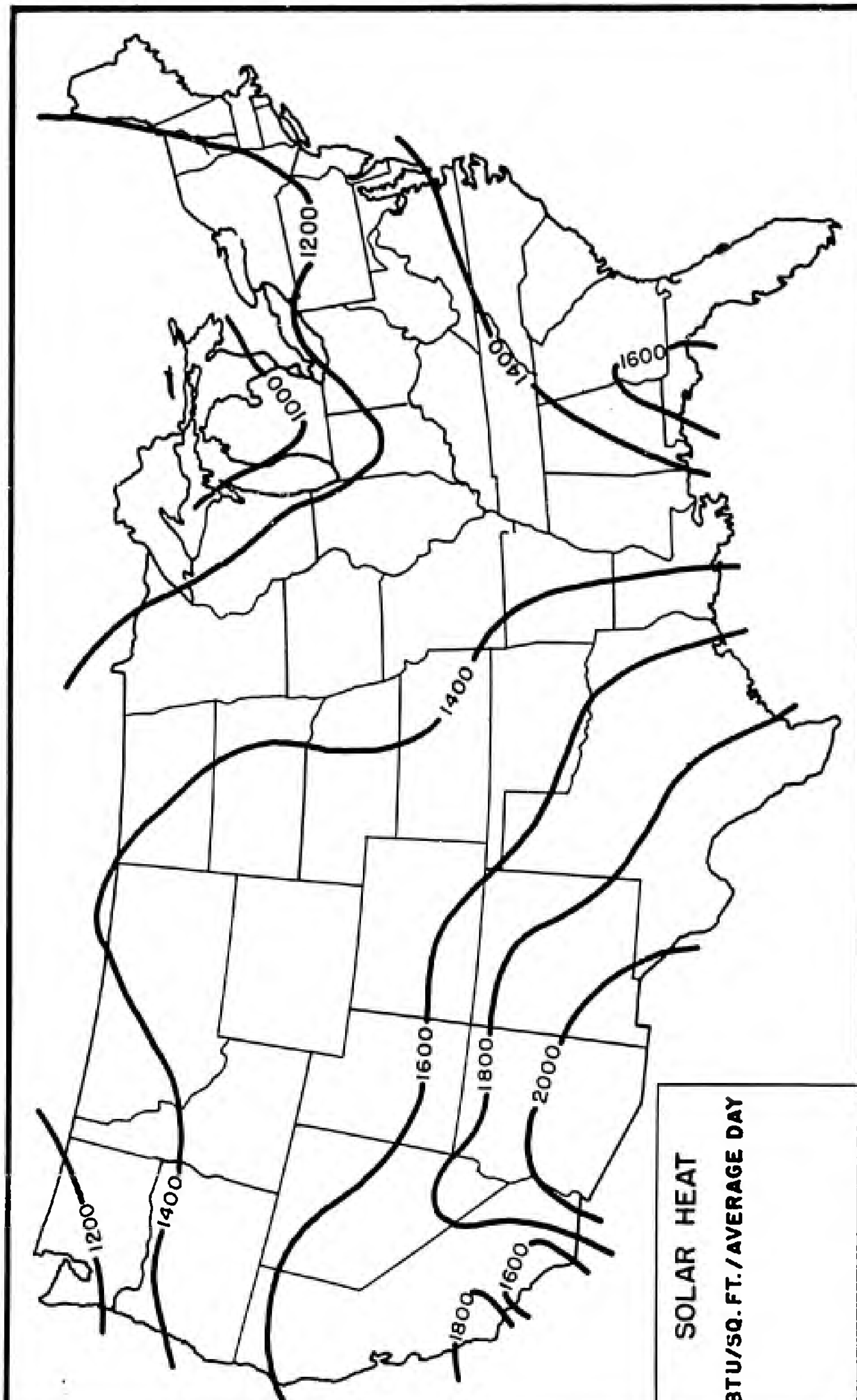
SOLAR HEAT
BTU/SQ. FT./AVERAGE DAY
1200
1400
1000
1400
1600
1400
1600
1800
2000
1200
1400
1600
1800

Figure 9

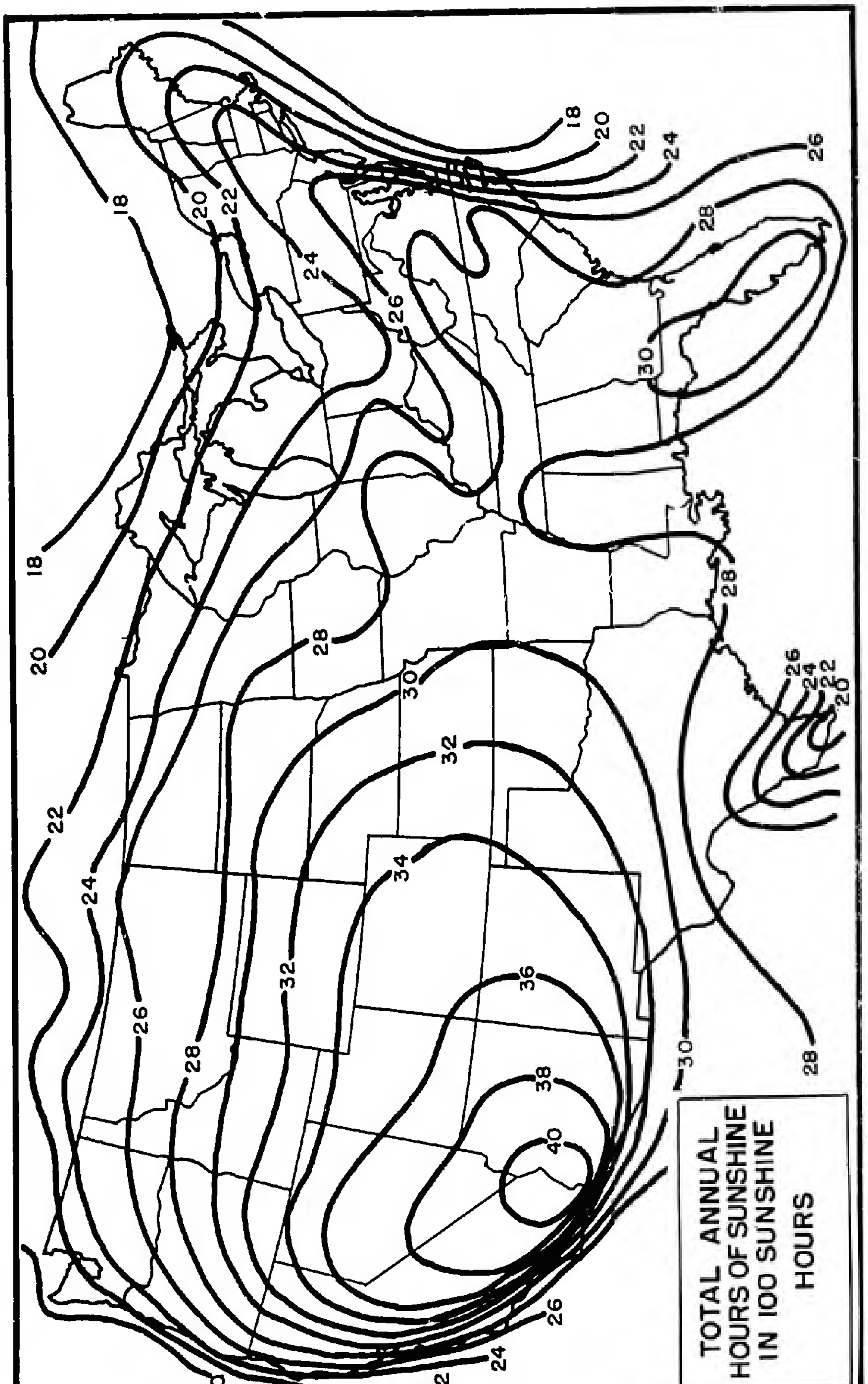

Figure 10

TABLE 1: SELECTED STATION LOCATIONS NEAR MILITARY BASES

Station Locations	Elevation (ground) Ft.	Army, Navy and/or Air Force Installations Near Station Locations
Phoenix, Ariz.	1,114	Luke Air Force Base Naval Air Facility - Litchfield Park
Fresno, Calif.	277	Between Castle Air Force Base, and Naval Air Station - Moffett Field
Yuma, Ariz.	138	Army Test Station
Albuquerque, New Mex.	4,042	Kirtland Air Force Base Kirtland AFSD
Central Sierra, Calif.	6,900	Between Stead Air Force Base and Beale AFB/N
Lincoln, Nebr.	1,180	Naval Air Station
Blue Hill Observatory, Mass.	640	Army, Navy and Air Force Installations
Friday Harbor, Wash.	7	Army, Navy and Air Force Installations

TABLE 2: HOURLY INTENSITIES OF SOLAR RADIATION (DIRECT AND DIFFUSE) RECEIVED ON A HORIZONTAL SURFACE AT SELECTED STATIONS*

Station	Month	Average Number of Hours langleys/hr		
		≧ 30	≧ 60	≧ 100
Albuquerque, New Mexico /1	Jan	154	13	0
	Apr	266	148	**
	Jul	278	191	0
	Oct	228	102	0
Length of Record: 3 to 4 years (1949-1953)				
Yuma, Arizona /2	Jan	167	24	0
	Apr	272	188	**
	Jul	276	182	0
	Oct	239	147	0
Length of Record: 3 to 4 years (1952-1955)				
Central Sierra, California /3	Jan	103	4	0
	Apr	202	134	4
	Jul	255	207	6
	Oct	167	73	0
Length of Record: 5 to 6 years (1946-1952)				
Blue Hill, Massachusetts /1	Jan	51	0	0
	Apr	147	66	0
	Jul	236	110	0
	Oct	111	13	0
Length of Record: 4 years (1951-1954)				

*Compiled from original observations taken by: /1 Weather Bureau, /2 Signal Corps, /3 Corps of Engineers and Weather Bureau Snow Investigations.
**Average less than 1.

TABLE 3: DAILY INTENSITIES OF SOLAR RADIATION (DIRECT AND DIFFUSE) RECEIVED ON HORIZONTAL SURFACE AT SELECTED STATIONS*

Intensities, from 0 to 950 langleys/days, in class intervals of 50

Station	Mo.	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699	700-749	750-799	800-849	850-899	900-949	Total Days
										Number of Days											
Albu-	Jan			3	6	5	10	40	21	8											93
querque,	Apr				1			3	3	3	5	3	12	10	26	22	2				90
N. Mex.	Jul									1	4	4	6	12	20	31	14	1			92
	Oct				1	3		0	9	20	25	26	5								89
Length of Record: 3 years. Missing Observations: 1 in July, 4 in October.																					
										Number of Days											
Yuma,	Jan		2	3	4	5	18	18	31	12	0										93
Ariz.	Apr									1	1	1	2	2	5	22	39	14	1		88
	Jul					1				2	1	3	1	3	9	9	25	23	4	5	85
	Oct				1		1	2	1	1	6	16	29	8	5	20	1				91
Length of record: 3 years. Missing observations: 2 in April, 8 in July, 2 in October																					
										Number of Days											
Central	Jan	9	13	13	10	14	46	22	7	0											144
Sierra,	Apr			3	5	4	5	9	4	9	4	5	6	9	26	32	17	2			141
Calif.	Jul			1						1	1	1	1		5	10	59	45	6		130
	Oct	1	11	12	3	3	7	25	34	26	27	4									153
Length of Record: 5 years. Missing observations: 11 in Jan., 14 in Apr., 25 in Jul., 2 in Oct.																					
										Number of days											
Blue	Jan	21	26	13	26	19	16	2													123
Hill,	Apr	2	9	3	10	6	8	3	9	9	9	13	15	13	8	3					120
Mass.	Jul			3	4	5	4	7	7	7	10	8	12	17	21	16	3				120
	Oct	4	7	10	5	11	17	23	26	15	3										121

Length of Record: 4 years. Missing observations: 1 in Jan., 4 in Jul., 3 in Oct.

*Compiled from original observations taken by: (1) Weather Bureau, (2) Signal Corps, (3) Weather Bureua and Army Engineers Snow Investigations.

TABLE 4: COMPARISON OF SEASONAL SUNSHINE AND SOLAR RADIATION ON A HORIZONTAL SURFACE FOR SELECTED AREAS*

Element Compared	Period	Eastern Mass.	Arizona	D.C. Area
Hours sunshine (total)	Year	2,600	4,000	2,700
Hours sunshine (per day)	Summer	9	12	9
Hours sunshine (per day)	Winter	5	8	5
No. clear days (total)	Year	120	260	120
Sunshine (percent of possible)	Year	55	85	55
Sunshine (percent of possible)	Summer	60	90	60
Sunshine (percent of possible)	Winter	50	80	50
Radiation (langleys per day)	June	550	700	500
Radiation (langleys per day)	December	130	260	160

*Data interpolated from small scale maps in Visher's Climatic Atlas of the United States.

TABLE 5: AVERAGE NUMBER OF HOURS AND PERCENTAGE OF POSSIBLE SUNSHINE AT SELECTED STATIONS*

	No. Yrs. Record Thru 1948	Jan Hrs	Jan %	Feb Hrs	Feb %	Mar Hrs	Mar %	Apr Hrs	Apr %	May Hrs	May %	Jun Hrs	Jun %
Albuquerque, N. Mex.	25	224	71	216	70	273	74	298	76	345	80	366	84
Phoenix, Ariz.	52	238	75	240	78	303	81	340	87	397	92	401	93
Yuma, Ariz.	39	257	81	261	84	332	89	365	95	415	97	418	97
Fresno, Calif.	50	136	44	188	61	266	72	325	82	386	88	413	94
Lincoln, Nebr.	43	171	57	178	59	224	60	238	60	280	62	312	69

	Jul Hrs	Jul %	Aug Hrs	Aug %	Sep Hrs	Sep %	Oct Hrs	Oct %	Nov Hrs	Nov %	Dec Hrs	Dec %	Annual Hrs	Annual %
Albuquerque, N. Mex.	340	77	317	77	293	79	279	80	239	77	218	72	3408	77
Phoenix, Ariz.	363	83	342	83	327	88	308	88	260	83	233	75	3752	84
Yuma, Ariz.	401	92	375	91	346	93	327	93	280	89	254	82	4031	90
Fresno, Calif.	432	97	404	96	344	92	300	86	222	72	141	47	3557	80
Lincoln, Nebr.	351	76	298	70	245	66	222	64	170	57	154	54	2843	63

TABLE 6: AVERAGE CLOUDINESS (0 TO 10) AT SELECTED STATIONS*

	No. Yrs. Record Thru 1948	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Albuquerque, N.Mex.	16	4.2	4.9	4.6	4.7	4.3	3.6	4.3	4.4	3.7	3.2	3.1	3.9	4.1
Phoenix, Ariz.	53	3.8	3.9	3.6	2.9	2.2	1.6	1.5	3.4	2.3	2.3	2.8	3.6	3.0
Yuma, Ariz.	70	2.4	2.4	2.1	1.5	1.0	0.6	1.6	1.8	1.1	1.2	1.7	2.4	1.6
Fresno, Calif.	52	6.4	5.2	4.6	3.5	2.7	1.5	1.0	0.9	1.4	2.3	3.9	6.0	3.3
Lincoln, Nebr.	51	5.4	5.6	5.7	5.8	5.8	5.2	4.3	4.6	4.5	4.5	5.2	5.6	5.2

*From U.S. Weather Bureau Technical Paper 12.

TABLE 7: AVERAGE NUMBER OF CLEAR, PARTLY CLOUDY, AND CLOUDY DAYS AT SELECTED STATIONS*

	No. Yrs. Thru 1948	Jan Clear	Jan Ptly Cloudy	Jan Cloudy	Feb Clear	Feb Ptly Cloudy	Feb Cloudy	Mar Clear	Mar Ptly Cloudy	Mar Cloudy	Apr Clear	Apr Ptly Cloudy	Apr Cloudy	May Clear	May Ptly Cloudy	May Cloudy	Jun Clear	Jun Ptly Cloudy	Jun Cloudy	Jul Clear	Jul Ptly Cloudy	Jul Cloudy
Albuquerque, N. Mex.	53	18	7	6	14	8	6	16	10	5	15	10	5	17	10	4	18	10	2	12	15	4
Phoenix, Ariz.	52	16	8	7	14	8	6	17	8	6	19	7	4	23	6	2	24	5	1	17	11	3
Yuma, Ariz.	64	22	6	3	20	6	2	23	6	2	25	4	1	27	4	0	28	2	0	25	5	1
Fresno, Calif.	60	8	7	16	11	8	9	14	9	8	17	8	5	21	7	3	25	4	1	28	2	1
Lincoln, Nebr.	51	11	8	12	9	8	11	10	9	12	9	9	12	8	11	12	10	12	8	13	12	6

	No. Yrs. Thru 1948	Aug Clear	Aug Ptly Cloudy	Aug Cloudy	Sep Clear	Sep Ptly Cloudy	Sep Cloudy	Oct Clear	Oct Ptly Cloudy	Oct Cloudy	Nov Clear	Nov Ptly Cloudy	Nov Cloudy	Dec Clear	Dec Ptly Cloudy	Dec Cloudy	Annual Clear	Annual Ptly Cloudy	Annual Cloudy
Albuquerque, N. Mex.	53	12	15	4	17	9	4	20	7	4	20	6	4	18	7	6	197	114	54
Phoenix, Ariz.	52	18	10	3	22	6	2	22	6	3	19	7	4	17	8	6	228	90	47
Yuma, Ariz.	64	24	6	1	26	3	1	27	3	1	24	5	1	23	5	3	294	55	16
Fresno, Calif.	60	28	2	1	25	3	2	22	6	3	16	8	6	10	7	14	225	71	69
Lincoln, Nebr.	51	12	12	7	14	8	8	15	7	9	11	8	11	10	9	12	132	113	120

*From U.S. Weather Bureau Technical Paper 12.

TABLE 8: INSOLATION ON A SURFACE PERPENDICULAR TO THE RAYS OF THE SUN FOR A TYPICAL CLOUDLESS DAY IN JANUARY, APRIL, JULY, AND OCTOBER AT BLUE HILL, MASSACHUSETTS*

	AM							Noon	PM						
	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
January															
Langleys per min. Sunrise 7:27 A.M. Sunset 4:51 P.M.			0	.652	1.140	1.328	1.389	1.414	1.410	1.356	1.305	.987	0		
April															
Langleys per min. Sunrise 5:19 A.M. Sunset 6:41 P.M.	0	.610	.985	1.168	1.232	1.288	1.290	1.296	1.285	1.255	1.210	1.113	.952	.410	0
July															
Langleys per min. Sunrise 4:34 A.M. Sunset 7:39 P.M.	.378	.788	1.038	1.190	1.296	1.351	1.370	1.380	1.372	1.358	1.296	1.188	1.038	.755	0
October															
Langleys per min. Sunrise 6:15 A.M. Sunset 5:15 P.M.		0	.670	1.020	1.185	1.265	1.290	1.296	1.275	1.220	1.124	.946	.498	0	

*Values computed from Weather Bureau Climatological Data, Annual Summaries, since 1945.

TABLE 9: COMPARISON OF AVERAGE DAILY SOLAR RADIATION AT BLUE HILL, MASSACHUSETTS

	Clear Day		Typical Day (Clear and Cloudy)
	*Average insolation received on surface perpendicular to rays of sun	**Average insolation received on a horizontal surface at the ground	***Average insolation received on a horizontal surface at the ground
	Langleys per day	Langleys per day	Langleys per day
January	659	250	160
April	846	620	410
July	947	740	510
October	707	390	280

*Computed from Weather Bureau Climatological Data, and Hand since 1945.
**From "Solar Radiation During Cloudless Days" Fritz, (1949).
***From "Average Solar Radiation in the United States" Fritz and MacDonald, (1949).