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EPICOR-II: A Field Leaching Test of Solidified Radioactively Loaded Ion Exchange Resin

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D. S. Marshall
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ENVIRONMENTAL SCIENCES DIVISION
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EPICOR-II: A FIELD LEACHING TEST OF SOLIDIFIED RADIOACTIVELY LOADED ION EXCHANGE RESIN

E. C. Davis, D. S. Marshall, R. A. Todd,[1] and P. M. Craig[2]

Environmental Sciences Division
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[1]Instrumentation and Controls Division.

[2]Environmental Consulting Engineers, Inc., Knoxville, TN.

NUCLEAR AND CHEMICAL WASTE PROGRAMS
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ABSTRACT

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As part of an ongoing research program investigating the disposal of radioactive solid wastes in the environment, the Oak Ridge National Laboratory (ORNL) is participating with Argonne National Laboratory, the Idaho National Engineering Laboratory, and the Nuclear Regulatory Commission in a study of the leachability of solidified EPICOR-II ion-exchange resin under simulated disposal conditions. To simulate disposal, a group of five 2-m^3 soil lysimeters has been installed in Solid Waste Storage Area Six at ORNL, with each lysimeter containing a small sample of solidified resin at its center. Two solidification techniques are being investigated: a Portland cement and a vinyl ester-styrene treatment. During construction, soil moisture temperature cells were placed in each lysimeter, along with five porous ceramic tubes for sampling soil water near the waste source. A meteorological station was set up at the study site to monitor climatic conditions (primarily precipitation and air temperature), and a data acquisition system was installed to keep daily records of these meteorological parameters as well as lysimeter soil moisture and temperature conditions.

This report documents the first year of the long-term field study and includes discussions of lysimeter installation, calibration of soil moisture probes, installation of the site meteorological station, and

the results of the first-quarter sampling for radionuclides in lysimeter leachate. In addition, the data collection and processing system developed for this study is documented, and the results of the first three months of data collection are summarized in Appendix D.

1. INTRODUCTION

One of the major categories of low-level waste produced by operations at commercial nuclear power plants is spent ion exchange resin (USDOE 1980). This resin, consisting of both inorganic and organic media, is commonly used in conjunction with various filters to remove dissolved radioactive material from contaminated water. Commercial disposal sites, such as the ones located at Barnwell, South Carolina, and Richland, Washington, receive a combined total of about 2.96×10^{15} Bq (80,000 Ci) of activity annually, of which about 1.85×10^{15} Bq (50,000 Ci), or 63%, is spent resin shipments. Thus, of the 76,700 m^3 of low-level waste shipped to commercial disposal sites in 1983, most of the radioactivity was contained in ion exchange resins (USDOE 1984).

The Nuclear Regulatory Commission (NRC) requires that, prior to disposal at commercial sites, all ion exchange resin must be solidified or placed in disposal containers that will maintain the waste form and ensure immobilization of radioactivity. Because the principal fission products present are usually ^{137}Cs and ^{90}Sr, with half lives of 30.2 and 28.1 y, respectively, this solidification process must ensure immobilization and isolation of radioactivity for a minimum of 300 years. If such a solidification process were achieved, these major radionuclides would decay to approximately 1/1024 their original activity in the 300-year storage period and, therefore, be much less likely to cause future groundwater contamination problems.

As part of an ongoing research program investigating the disposal of radioactive solid wastes in the environment, the Oak Ridge National Laboratory (ORNL) is participating with Argonne National Laboratory (ANL), the Idaho National Engineering Laboratory (EG&G), and the NRC in a study of the leachability of solidified ion exchange resin under simulated disposal conditions. The samples being studied have only recently become available and consist of highly loaded resin taken from EPICOR-II prefilter liners used to decontaminate water from the Auxiliary and Fuel Handling Building at Three Mile Island (TMI) Unit-2 (McConnell 1983). The resin samples are being examined under simulated disposal conditions using specially designed stainless steel field lysimeters which facilitate leachate collection at several different points within the soil backfill contained in each lysimeter. Using this approach, radionuclide migration from the resin can be detected and movement through soil studied.

The purpose of this report is to document the ORNL field leaching study including the experimental design, field installation of soil lysimeters, meteorological data acquisition and handling system, and leachate collection and analysis schedule. Because of the long-term nature of the project (planned for approximately 20 years), this report will focus on the experimental setup and data acquisition system, leaving an in-depth analysis of leachate samples for future reports.

2. EXPERIMENTAL DESIGN

2.1 BACKGROUND

The objective of the EPICOR-II lysimeter leaching experiment is to determine the effect of long-term exposure to natural weather elements of solidified radioactively stressed ion exchange resin under simulated disposal conditions. To accomplish this objective, a small area in the northwest corner of ORNL Solid Waste Storage Area Six (SWSA 6) was selected for installation of five 2-m^3 field lysimeters (Fig. 1), each containing a small waste column consisting of solidified ion exchange resin. Each of the five stainless steel lysimeters (0.91-m diameter by 3.12-m height) was designed to be completely self-contained; that is, water entering the top of the lysimeter in the form of natural precipitation can pass through the upper layer of soil, contact the waste form, and drain into the bottom of the lysimeter where there is a leachate collection reservoir. At no time will leachate that has come into contact with the ion exchange resin escape from the lysimeter and enter the surrounding soil or groundwater.

The five lysimeters were set on a 1.2-m by 9.1-m concrete pad that was poured approximately 3 m below the original grade, leaving only the top few centimeters of each lysimeter to extend above the ground surface. As a result, the resin samples experience natural soil temperature and moisture fluctuations that would be typical of a disposal environment.

Four of the lysimeters were filled with soil collected from the Savannah River Plant (SRP) at Barnwell, South Carolina (lysimeters 1-4), while the fifth contains silica sand, which serves as an inert

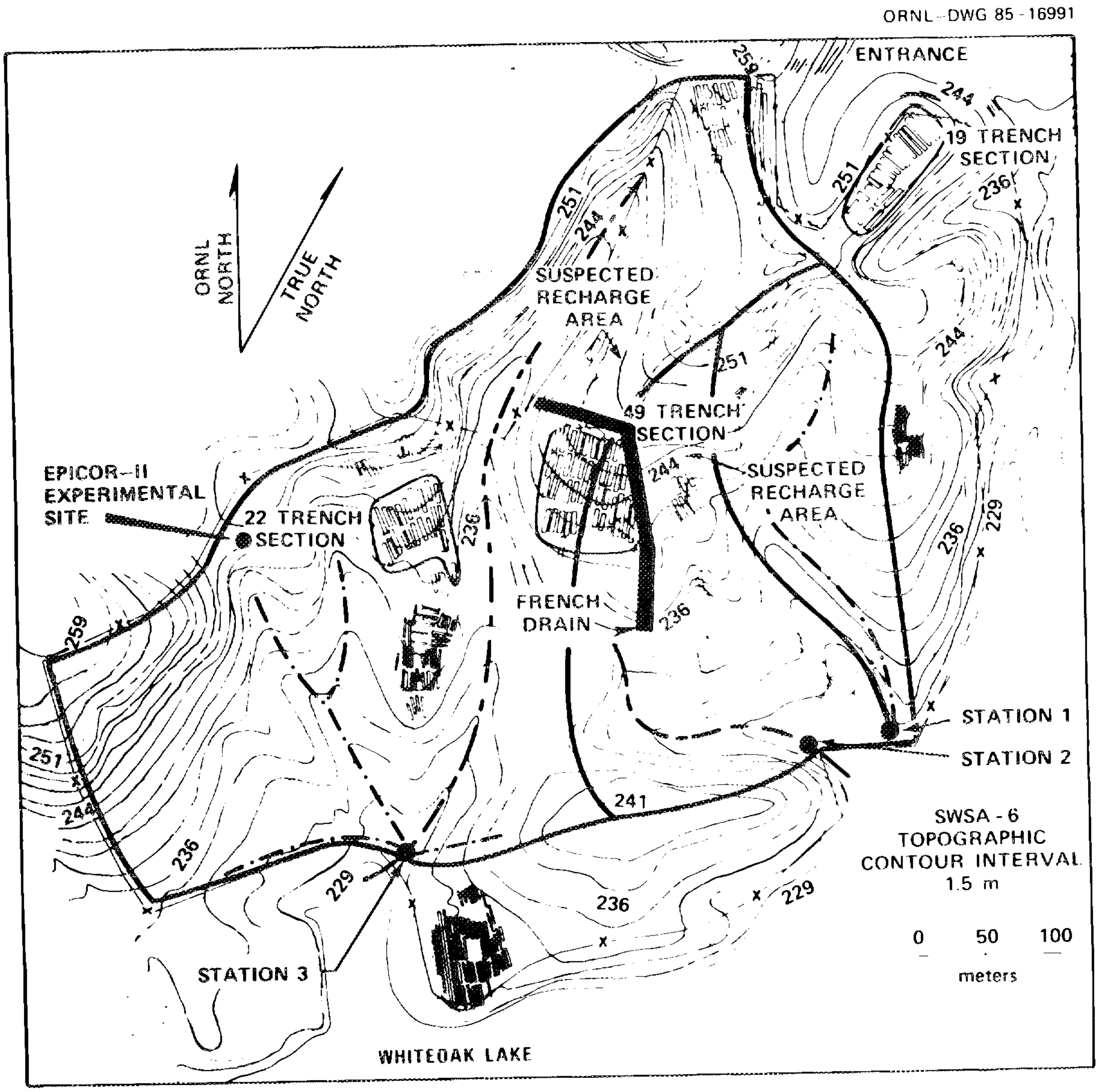

Fig. 1. Location of the EPICOR-II lysimeter experiment in ORNL SWSA 6.

material (lysimeter 5). The important soil characteristics are described in Sect. 2.4. The purpose of the SRP soil is to provide the resin samples with a storage medium similar to that found at the commercial waste disposal site in South Carolina. The site has already received a large amount of contaminated ion exchange resin and will likely play a key role in resin disposal in the future.

Each lysimeter was equipped with three soil moisture/temperature probes and five porous cup soil moisture samplers arranged as shown in Fig. 2. Using this experimental design, leachate can be sampled periodically from any of the five porous cups or from the leachate reservoir located in the bottom of each lysimeter. A radiochemical examination of the leachate can determine if radionuclides are being leached from the resin samples and, if so, how rapidly they are migrating through the soil.

2.2 ION EXCHANGE RESIN SAMPLES

The ion exchange resin samples used in the field leaching experiment were taken from core samples extracted from EPICOR-II filters PF-7 and PF-24 (Neilson and McConnell 1984). Filter PF-7 contained a mixture of synthetic organic ion exchange resin types including phenolic cation, strong acid cation, and strong base anion resins. Filter PF-24 contained a similar mixture of synthetic organic ion exchange resins including strong acid cation and strong base anion resins, but with the addition of an inorganic zeolite. The exact chemical nature of the resin, including the arrangement in layers within the EPICOR-II filters, is proprietary information and is therefore unknown. For an in-depth discussion of the ion exchange

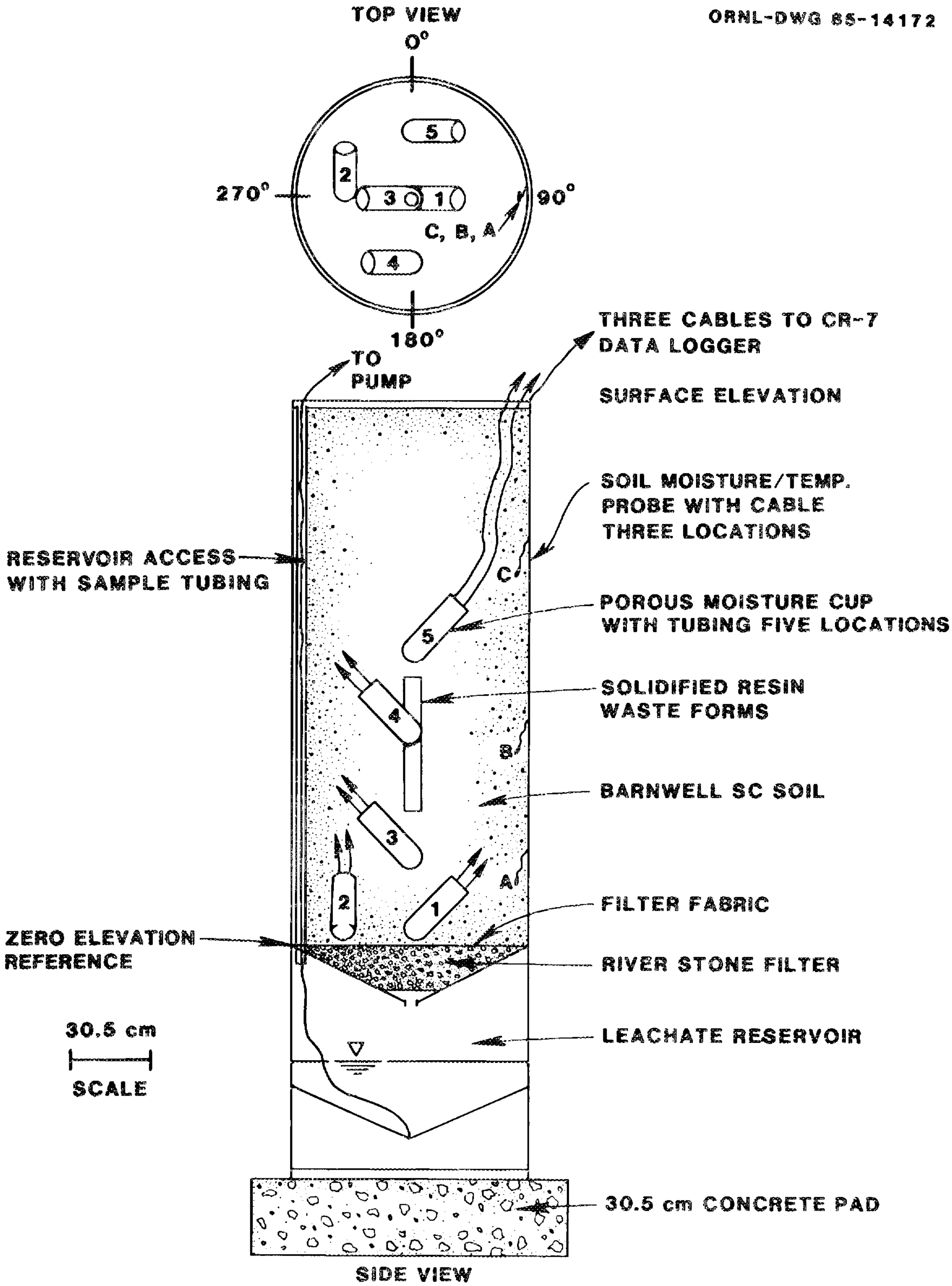

Fig. 2. Cross section of an EPICOR-II field lysimeter.

resin samples and the development of a Portland cement and vinyl ester-styrene solidification technique used to solidify samples used in this experiment, refer to Neilson and McConnell (1984).

As illustrated in Fig. 2, each of the five field lysimeters contains a small column of solidified resin located at the approximate center. Each resin column is actually composed of seven separate cylindrical samples stacked one on top of the other to yield a resin column 4.6 cm in diameter and 53.2 cm in height. Thus, a total of 35 resin samples was needed for the five lysimeters. The 35 samples were solidified at EG&G before being shipped to ORNL where they were taken out of their polyethylene molds. In preparation for loading into the field lysimeters, the samples were extruded from their molds in groups of seven and placed in 5-cm-diam. by 76.2-cm-long transport tubes using the ORNL Hot-Cell Facility (Building 3525) for remote handling. A more detailed description of the resin sample unloading, transport to the experimental site, and lysimeter loading procedure is presented in Sect. 4.4.

The experimental design called for three of the five lysimeters (1, 2, and 5) to be loaded with ion exchange resin solidified with portland cement, and two (3 and 4) to be loaded with ion exchange resin solidified with vinyl ester-styrene. These samples were made in batch experiments carried out at EG&G (Neilson and McConnell 1984) and were transported to ORNL in December 1984 in two lead-lined 207-L transport drums along with the stainless steel lysimeters and additional equipment required to set up a site meteorological station. Table 1 summarizes the EPICOR-II experimental design by showing the leaching matrix (the material the resin is being weathered in), the resin solidification technique, the resin source (PF-7 organic resin or PF-24 organic resin with zeolite), and the individual sample codes assigned by EG&G.

2.3 FIELD LYSIMETERS

Each of the five field lysimeters consisted of a 0.91-m-ID by 3.12-m-high right circular cylinder constructed of number 12 gage stainless steel (Fig. 2). Each was constructed with a 346-L leachate collection reservoir located in the bottom third of the vessel, with a 3.8-cm schedule 40 stainless steel pipe to serve as access to this leachate reservoir. A complete structural engineering analysis of the lysimeter design was conducted by EG&G prior to construction, and a leak test of each unit was performed prior to shipment. The leak test consisted of maintaining an internal pressure of 3515 kg/m^2 (5 psi) for a period of 2 h with no visible signs of water leaking from the unit. Thus, the integrity of each lysimeter was ensured before being accepted for field use.

2.4 SOIL AND SAND BACKFILL

The experimental design called for lysimeters 1 through 4 to be backfilled with subsoil from the commercial waste disposal site located at Barnwell, South Carolina. This subsoil, underlain by the Hawthorn-Barnwell Formation of the Tertiary age, is in the Fuquay series and is classified as a sandy loam (Fowler, Essington, and Polzer 1979). It is considered typical of material the resin would likely be stored in if it were sent to this particular site for

Table 1. Summary of the ORNL EPICOR-II resin leaching experimental design

Lysimeter Number	Leaching Matrix	Resin Solidification Technique	Resin Source	Sample Code
1	Fuquay Soil C-Horizon	Portland Cement	PF-7	C1-13,C1-16 C1A-13,C1A-14 C1A-15,C1A-16 C1A-17
2	Fuquay Soil C-Horizon	Portland Cement	PF-24	C2B-8,C2B-9 C2B-10,C2B-11 C2B-12,C2B-13 C2B-14
3	Fuquay Soil C-Horizon	Vinyl Ester-Styrene	PF-7	D1A-8,D1A-9 D1A-10,D1A-11 D1A-12,D1A-15 D1A-16
4	Fuquay Soil C-Horizon	Vinyl Ester-Styrene	PF-24	D2-7,D2-8 D2-9,D2-10 D2-11,D2-15 D2-16
5	Silica Sand	Portland Cement	PF-24	C2B-22,C2B-23 C2B-24,C2B-25 C2B-26,C2B-27 C2B-28

disposal. After contacting officials at Barnwell and receiving a negative response to requests for soil samples, an alternative approach was taken, and the required soil was collected from a clay borrow pit at the SRP located adjacent to, and slightly east of, the Barnwell commercial waste disposal site (Fig. 3). Subsoil from the C-horizon at this borrow pit is, for all practical purposes, identical to that found at the Barnwell site (Rogers 1985), and this similarity can be seen by comparing of the soil texture of the sample collected with a sample taken previously from a Barnwell trench (Table 2). Perhaps the two most important soil characteristics to look at in Table 2 are the soil pH and percentage clay (3.5: 37.5% and 6.2: 39.2% for the Barnwell sample and the SRP sample, respectively). Any ^{137}Cs that is released from the resin will be adsorbed to the clay particles and hence become immobilized until the point is reached where the adsorption capacity of the clay is exceeded. It is for this reason that soil texture, particularly percentage clay, was the key factor in selecting a soil that would represent that found in the Barnwell trenches.

On May 2, 1985, approximately 15 m^3 of Fuquay sandy loam was collected from a borrow pit at the SRP using a front-end loader. The topsoil (A and B horizon) had been previously removed, and the estimated depth of the sample collected (judging from the surrounding undisturbed area) was between 6 and 9 m. The soil was loaded into a covered dump truck and delivered to the ORNL EPICOR-II experimental site on May 3, 1985.

The inert material selected for use in lysimeter 5 was a fine-textured silica sand purchased from Uniman Sand Company located

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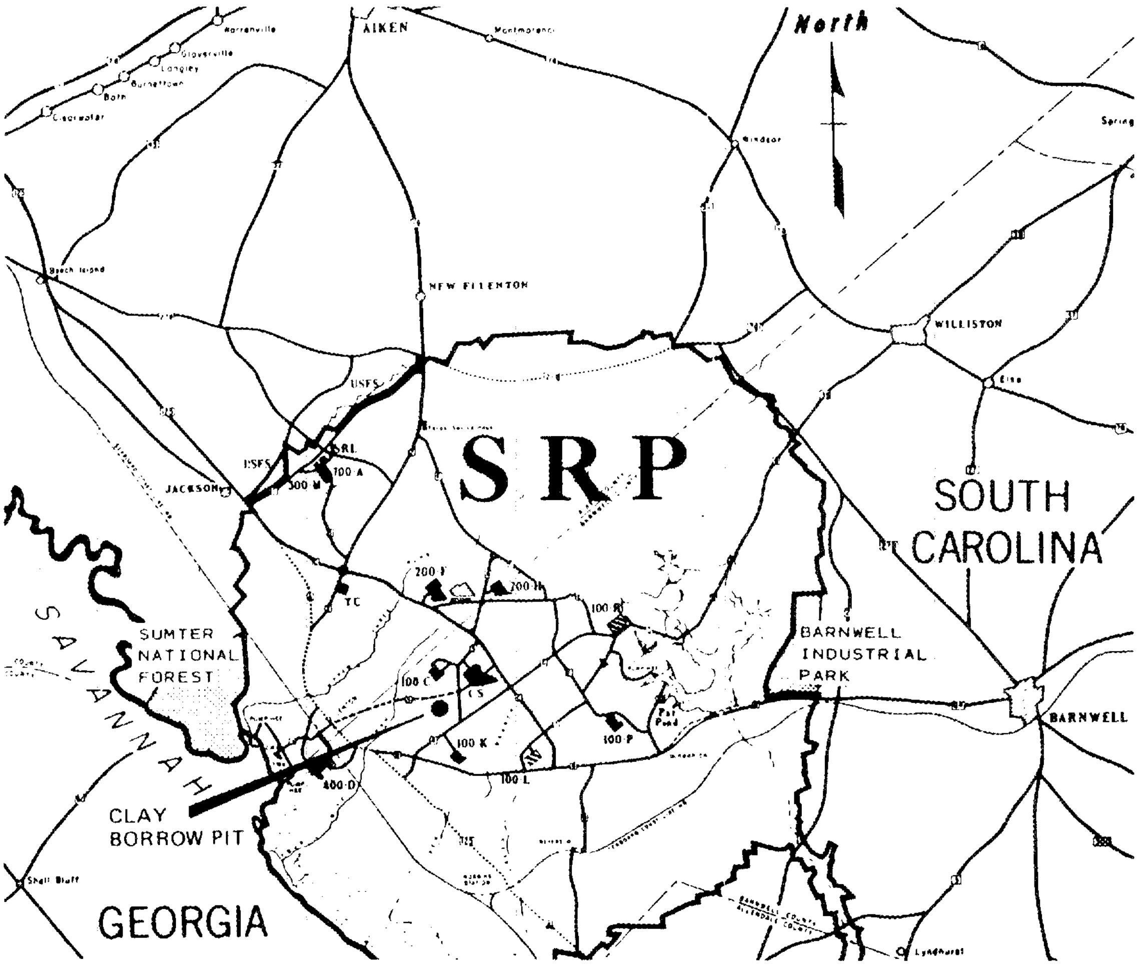

Fig. 3. Map of the Savannah River Plant showing the location of the clay borrow pit.

Table 2. Comparison of soil texture between a sample collected from a trench at the Barnwell waste disposal site and soil from the SRP clay borrow pit

Parameter	Chem Nuclear Sample[a]	SRP Sample[b]
pH	3.5	6.2[c]
% Sand	51.5	58.4
% Silt	11.0	2.4
% Clay	37.5	39.2
% Vermiculite	12	10
% Kaolinite	77	80
% Gibbsite	5	5
Fe, Al, Organic	6	5

[a]Source: Fowler, E. B., E. H. Essington, and W. L. Polzer. 1979. Interactions of Radioactive Wastes with Soils - A Review. Los Alamos Scientific Laboratory, University of California. NUREG/CR-1155. US-UR-79-2910.

[b]SRP clay borrow pit sample used to fill lysimeters for this study.

[c]Twenty grams of soil in 20 mL of distilled water.

in Utica, Illinois. In May 1985, 4.5 metric tons of Gran-U-Sil 100 ® was delivered to the site and stockpiled for use in loading lysimeter 5. The cation exchange capacity (CEC) of silica sand is known to be very low, making it an ideal control material for the study of radionuclide movement in the lysimeters.

2.5 POROUS CUP SOIL MOISTURE SAMPLERS

At five locations within each lysimeter, a 50-mL porous cup was installed for the purpose of collecting soil water (Fig. 2). Each cup was installed by placing it in a soil cavity filled with silica flour paste and then covering it with either soil or sand depending on the particular leaching matrix being used. The purpose of the silica flour was to ensure continuous contact between the porous cup and the surrounding soil, facilitating sample collection at scheduled intervals. The cups were oriented in a specific pattern around the resin sample (top view shown in Fig. 2) and were each set at an approximate 45° angle within the silica flour cavity. Two Tygon tubes used for sampling were connected to each porous cup and were run horizontally to the side of the lysimeter, and then vertically to the top, as the lysimeter was being filled.

2.6 SOIL MOISTURE/TEMPERATURE PROBES

To give an indication of when the soil in each lysimeter is saturated and amenable to collection of a soil pore water sample, each lysimeter was fitted with three soil moisture/temperature probes (Fig. 2). These probes were located approximately 10.2 cm from the lysimeter wall at the 90° location. Probe A is 28.8 cm above the zero reference elevation, probe B is 77.9 cm above this reference, and probe C is on top, 149 cm above this reference. The wire leads from each probe were run to the side of the lysimeter, and then out to the top where they run through underground PVC conduit to a Campbell Scientific CR-7 data logger. A complete discussion of the soil moisture probe laboratory calibration procedure is contained in Sect. 3.

2.7 METEOROLOGICAL STATION

One of the key factors in evaluating the leachability of the solidified resin samples stored in each lysimeter is an accurate summary of the site meteorological conditions. To collect this meteorological data, a station was set up at the EPICOR-II site to monitor (1) precipitation (Weathermeasure model 6011-A tipping bucket rain gage), (2) wind speed (Campbell Scientific model 014A wind speed sensor), (3) wind direction (Campbell Scientific model 024A wind direction sensor), and (4) air temperature and relative humidity (Campbell Scientific model 207 temperature and relative humidity probe). A 3- by 4-m concrete pad was constructed adjacent to the five lysimeters to serve as a permanent location for the meteorological tripod and associated rain gage. Each instrument listed above was directly connected to a Campbell Scientific model CR-7 data logger, which records and stores data on cassette tape on a daily basis. In addition to the meteorological equipment, wire leads from the fifteen soil moisture/temperature probes were connected to the data logger to record soil temperature and moisture on a daily basis.

3. CALIBRATION OF THE SOIL MOISTURE PROBES

3.1 BACKGROUND

The objective of locating three soil moisture probes in each EPICOR-II lysimeter is to monitor soil moisture as a function of depth and, thus, determine when the soil is near saturation and amenable to pore water sampling. Each probe is 2.54 by 3.8 by 0.3 cm thick and consists of two corrosion-resistant metal plates separated by a fiberglass binding which provides a coupling whose resistance varies with soil moisture content. As the soil moisture within a lysimeter increases, the conductivity of each probe increases, and a relationship can be established between cell voltage and soil moisture. This relationship, usually described by a polynomial equation, is specific to a particular soil and probe, and must be verified if a number of probes are going to be used in the same soil for a particular experiment (Soiltest, Inc. 1975). If, for some reason, there is a discrepancy in the voltage readings of a particular probe (e.g., it does not follow the same voltage-moisture curve as the rest of the probes), it is recommended that the probe be discarded and another selected in its place.

Calibration of the soil moisture probes consisted of the following basic steps: (1) determine that all 15 probes yield a similar voltage when placed in the same sample of soil, (2) select two of the 15 probes for detailed calibration studies in Fuquay soil, (3) select three of the 15 probes for detailed calibration studies in silica sand, and (4) derive coefficients for polynomial equations describing the soil and sand calibration curves. These coefficients are required by the

CR-7 data logger for the conversion of probe voltage to percent soil moisture. Each of these four tasks was completed in the laboratory before the equipment was installed at the field site, and is described in the remainder of Sect. 3.

3.2 MOISTURE TRACKING IN FUQUAY SOIL

Before the 15 soil moisture probes could be loaded into the EPICOR-II lysimeters (Fig. 2), it was necessary to establish that the voltage-soil moisture relationship between probes was similar. If this were the case, then a single polynomial equation for each soil type could be programmed into the CR-7 data logger to describe this relationship for all probes. If this were not true, and voltages varied between probes, then additional probes would have to be tested until a "matched set" of 15 could be found. To answer this question of similarity between probes, a laboratory-scale moisture tracking experiment was carried out prior to individual probe calibration. The experiment actually served a second purpose and that was to help the operators become familiar with the CR-7 programming, the probe installation techniques, and the data retrieval system.

Prior to carrying out this moisture tracking experiment, a group of 16 soil moisture probes being considered for use was assigned individual numbers (1-16) and the 7.6-m wire lead length on probes 1, 2, 3, 13, 14, and 15, was increased by 3 m to ensure that there was adequate wire to reach the CR-7 data logger. This lengthening process was necessary because these probes were to be located in the end lysimeters (1 and 5), which were farthest from the data logger and could not be reached by the initial 7.6-m lead.

Next, probes 3 (10.6-m lead) and 9 (7.6-m lead) were selected and set aside for individual calibration studies (Sect. 3.3), while the remaining 14 probes were loaded into two 20-cm-diam. number 270 soil sieves containing a sample of Fuquay soil. Each probe was connected to the CR-7 data logger, and the soil was wetted to saturation and allowed to air dry for a period of several days while the logger recorded individual probe voltages on an hourly basis. Figure 4 summarizes results of the second soil wetting in Fuquay soil under these conditions and suggests that each of the 14 probes tested tracked along a similar path. There did not appear to be any deviation due to the additional lead length of probes 1, 2, 3, 13, 14, and 15, which was an important consideration. The voltage at saturation ranged between 0.55 and 0.70 V and rapidly approached a value below 1 mV during the approximate 3-d drying period. As a result of this exercise, it was determined that each of the 14 probes behaved in a similar fashion and that a single polynomial equation could be used to relate probe voltage to soil moisture.

3.3 CALIBRATION OF PROBES 3 AND 9 IN FUQUAY SOIL

Probes 3 and 9 were selected for in-depth laboratory studies designed to determine the coefficients of a polynomial equation relating probe voltage to soil moisture. The selection of these two probes was based on the results of preliminary tracking experiments (similar to those described in Sect. 3.2 but carried out in soil derived from Conasauga Shale, the native soil material at SWSA 6) which revealed that these probes tracked along the same curve as the other 14 probes and could, thus, be considered representative of the entire

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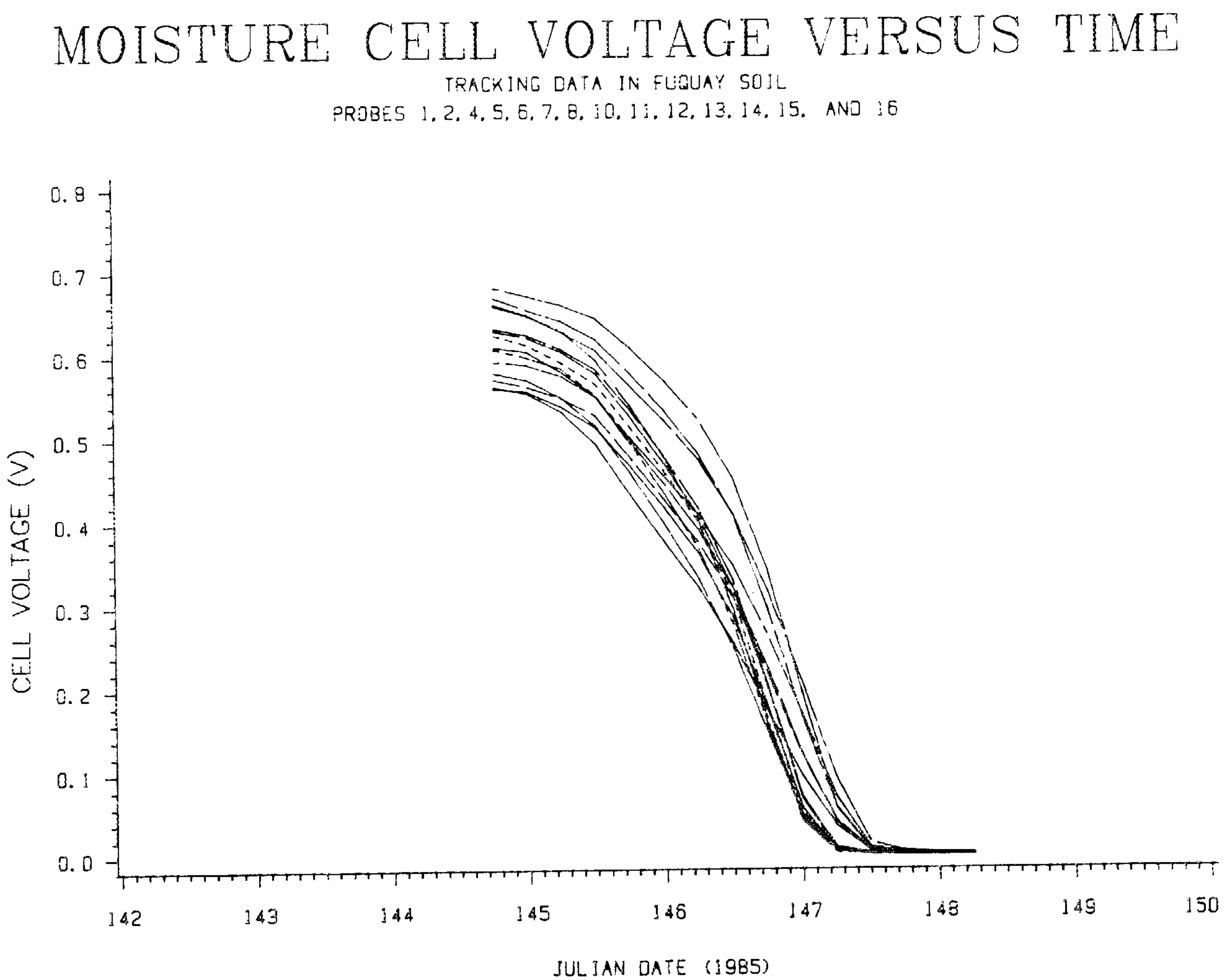

Fig. 4. Voltage tracking data taken for 14 soil moisture probes in Fuquay soil.

population of probes being tested. Probe 3 was selected because of its long lead length (10.6 m), while probe 9 was selected to represent probes with shorter (7.6 m) lead lengths.

Each probe was weighed and placed in a 80-cm^3 calibration box constructed of stainless steel wire mesh. Oven-dried Fuquay soil was compacted around the probe, and a stainless steel lid was set over each box and taped to ensure that none of the contents spilled. After weighing the calibration box, soil, and probe, each unit was saturated with distilled water and allowed to equilibrate in a constant humidity chamber [chamber maintained at 98% relative humidity using a wick-equipped beaker of $Pb(NO_3)_2$] for a 24-h period. After 24 h, the calibration boxes were removed from the constant humidity chamber, weighed to determine the actual soil moisture (percentage of the oven dry weight of the soil), and connected to the CR-7 data logger to record both temperature and probe voltage. After these readings, the calibration boxes were allowed to air dry for several hours and were then returned to the constant humidity chamber for another 24-h period. Using a series of these drying, equilibrating, weighing, and voltage/temperature recording steps, probes 3 and 9 were calibrated from near saturation (approximately 30% moisture) to near dryness over two wetting cycles (Tables 3 and 4). The voltages recorded in Tables 3 and 4 were then temperature corrected to 15.5°C (60°F) using a three-step process. First, the measured voltage (Vr) was used to calculate the moisture cell resistance (Rr) by the equation:

$$Rr = 1K(1 - Vr)/Vr \quad . \tag{1}$$

Table 3. Moisture calibration of probe 9 in Fuquay soil

Soil Moisture (%)	Voltage (V)	Temperature (°C)	Temperature-Corrected Voltage	-ln of Temperature Corrected Voltage (V)
		Wetting Number One		
29.53	0.34387	22.560	0.30573	1.18505
25.60	0.45579	22.416	0.41705	0.37456
22.35	0.28421	23.134	0.24593	1.40270
19.85	0.21038	22.673	0.17964	1.71680
16.54	0.14895	22.924	0.12365	2.09030
13.99	0.11440	22.581	0.09444	2.35974
11.44	0.06736	22.812	0.05387	2.92123
8.70	0.00552	23.006	0.00401	5.51836
6.91	0.00070	23.267	0.00047	7.66010
5.46	0.00022	23.455	0.00014	8.86397
3.96	0.00010	22.177	0.00007	9.60184
		Wetting Number Two		
25.97	0.29230	19.776	0.27029	1.30825
22.80	0.31373	22.345	0.27785	1.28069
19.15	0.17397	22.518	0.14727	1.91548
16.30	0.12284	21.744	0.10412	2.26223
13.04	0.08369	22.498	0.06822	2.68497
10.42	0.03823	21.042	0.03173	3.45038
6.69	0.00070	22.545	0.00049	7.62305
4.85	0.00025	21.958	0.00017	8.64907
2.89	0.00017	22.102	0.00012	9.05284

Table 4. Moisture calibration of probe 3 in Fuquay soil

Soil Moisture (%)	Voltage (V)	Temperature (°C)	Temperature-Corrected Voltage	-ln of Temperature Corrected Voltage (V)
		Wetting Number One		
36.91	0.33138	22.459	0.29421	1.22348
32.87	0.29881	21.649	0.26709	1.32017
30.42	0.33138	22.361	0.29472	1.22174
27.49	0.29947	22.570	0.26311	1.33517
22.42	0.20215	20.543	0.18074	1.71071
17.63	0.10426	20.094	0.09188	2.38726
14.18	0.06226	20.904	0.05268	2.94342
10.32	0.00212	21.437	0.00161	6.43165
7.35	0.00027	22.647	0.00018	8.60812
5.76	0.00017	21.793	0.00012	9.03523
		Wetting Number Two		
27.83	0.25568	22.002	0.22450	1.49388
23.57	0.23878	21.172	0.21240	1.54926
17.45	0.11418	21.969	0.09586	2.34489
11.46	0.03084	22.465	0.02420	3.72130
6.12	0.00020	21.890	0.00014	8.97411

As shown in Fig. 5, this arises from a simple resistor divider network where the excitation voltage of 1 V is applied to the series combination of the moisture probe resistance and a 1-kΩ terminating resistor. From graphs obtained from the moisture probe manufacturer, an expression was derived to calculate what the cell resistance would be at 15.5°C (60°F), a temperature assumed to be typical of field conditions. This equation to correct moisture cell resistance is:

$$Rc = Rr\ e^{(m \ln Rr + b)(T-60)} \quad , \tag{2}$$

where

Rc = corrected probe resistance (ohms),

Rr = resistance read (ohms),

$m = 2.22376 \times 10^{-3}$,

$b = -2.99241 \times 10^{-3}$,

T = temperature (°F).

The temperature-corrected resistance (Rc) was then used to calculate the voltage that would be observed had the probe been at 60°F. The corrected voltage (Vc) was then calculated from Eq. (3).

$$Vc = [1000/(1000 + Rc)] \times 1\ V \quad . \tag{3}$$

The negative natural log (-ln) of the temperature-corrected voltage and the actual soil moisture were then plotted for both probes (Fig. 6). The coefficients of the third-order polynomial of best fit were then determined, yielding the following equation to relate the natural log of probe voltage to soil moisture.

$$f(x) = C0 + C1x + C2x^2 + C3x^3 + C4x^4 + C5x^5 \quad , \tag{4}$$

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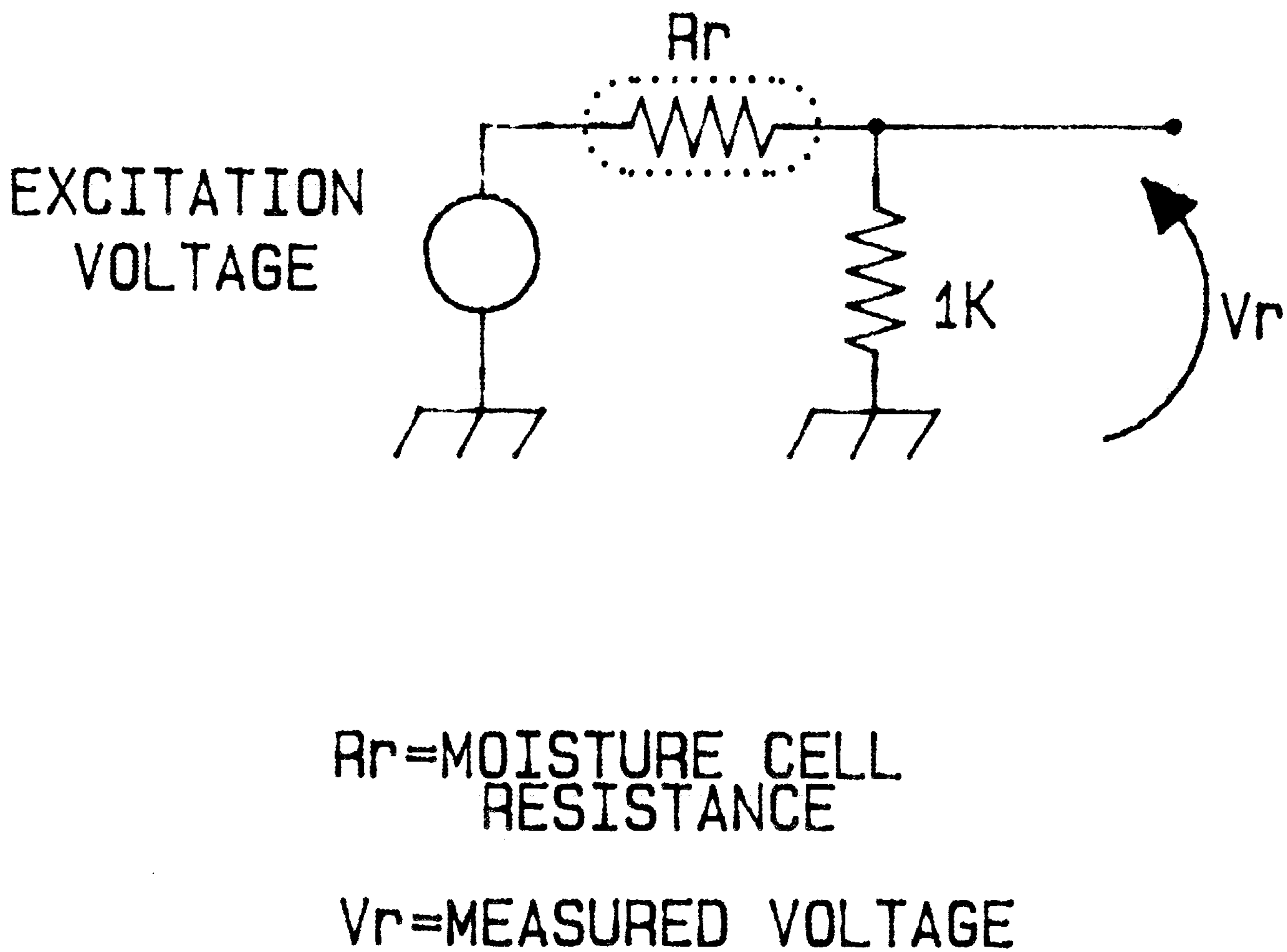

Fig. 5. Schematic of the soil moisture cell resistor divider network.

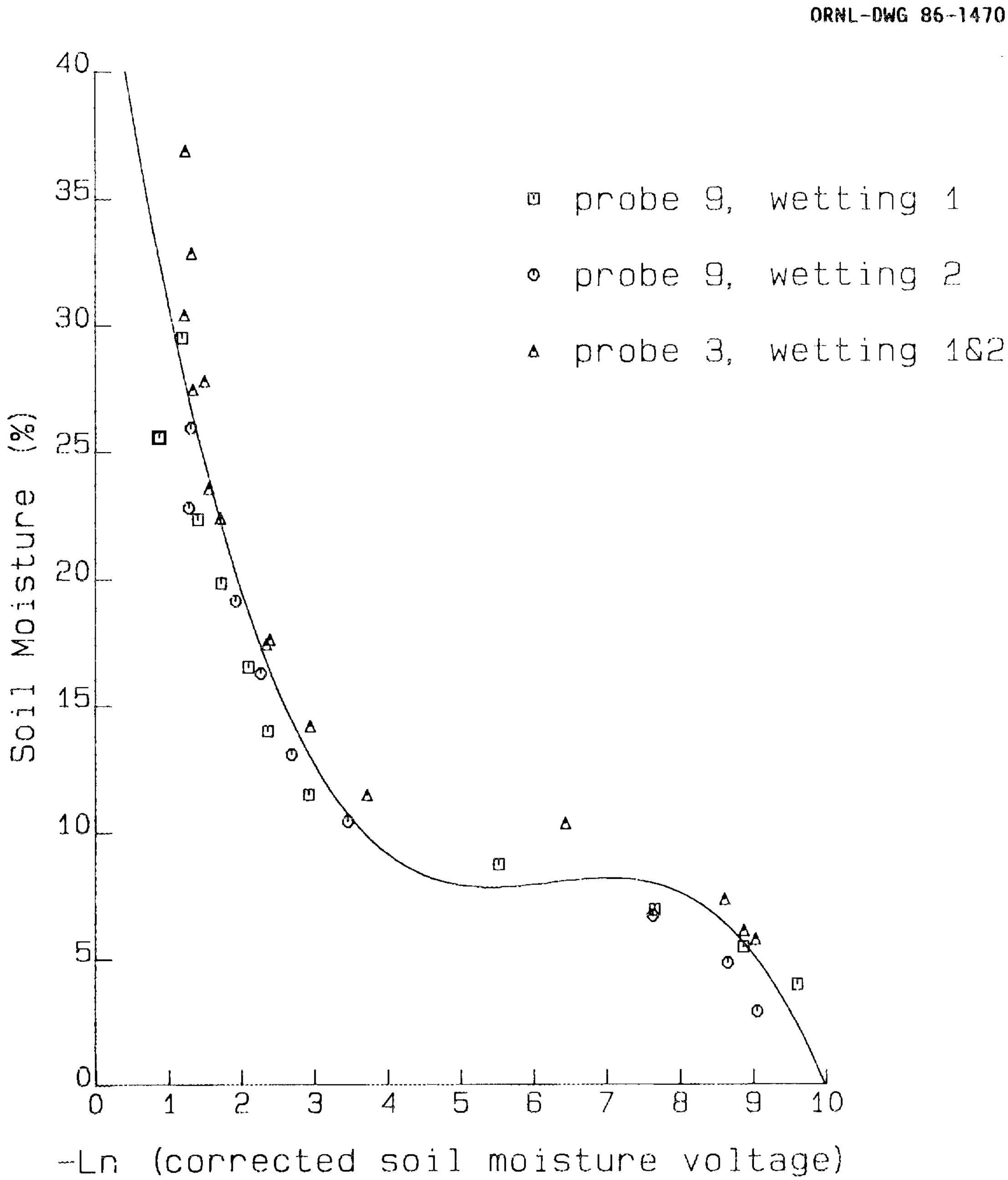

Fig. 6. Calibration curve for soil moisture probes 9 and 3 in Fuquay soil.

where

C0 = 47.574,

C1 = 19.799,

C2 = 3.2416,

C3 = 0.1739,

C4 = 0,

C5 = 0.

The coefficients of this fifth-order polynomial were entered into the CR-7 program (Appendix A) to convert probe voltages to soil moisture percentage for probes 1 through 12. Probes 13, 14, and 15 were located in silica sand and, thus, required development of a different polynomial, considered in Sect. 3.4.

3.4 CALIBRATION OF PROBES 13, 14, AND 15 IN SILICA SAND

The calibration procedure for the probes placed in silica sand was similar to that described in Sect. 3.3 for the Fuquay soil. All three of the probes used in the sand had long lead lengths (10.6 m) in order to reach from lysimeter 5 to the CR-7 data logger. Each of the three probes was weighed and placed in an 80-cm^3 calibration box constructed of stainless steel wire mesh as described before. Oven-dried silica sand was compacted around the sensor, and the stainless steel lid was taped to the box to prevent spillage and to act as a strain relief for the wires coming from the sensors.

The results of the calibration, as shown in Fig. 7, are quite different from those for the Fuquay soil. The probes in the silica sand seemed to retain moisture even when the moisture content by weight was less than 5%, and the electrical conductivity of the moisture probe remained quite high until the sand was absolutely dry. Because of this, the horizontal axis shown for the calibration curve extends only to 1.2, which corresponds to a voltage reading of 0.30 V. Readings in the millivolt range were common for comparable moisture content in the Fuquay soil.

After temperature correcting the laboratory voltage measurements as described in Sect. 3.3, the following polynomial coefficients [coefficients for Eq. (4)] were determined to relate the natural log of probe voltage to soil moisture:

C0 = 53.000,

C1 = 138.62,

C2 = 223.07,

C3 = 124.20,

C4 = 0,

C5 = 0.

The coefficients are entered into the EG&G-modified CR-7 data logger program as shown in Appendix A. The third-order curve produced by this polynomial expression is shown, along with the data points, in Fig. 7.

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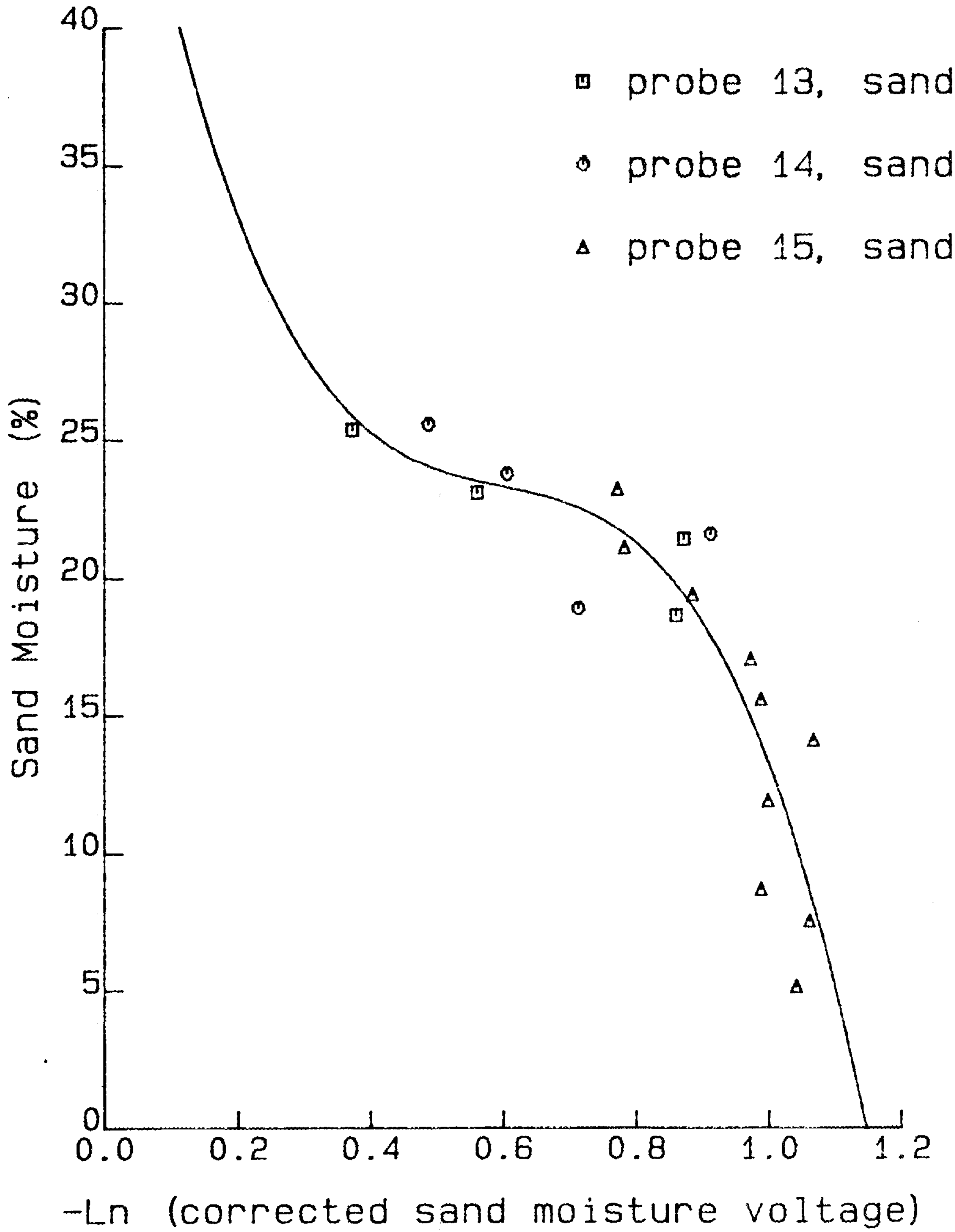

Fig. 7. Calibration curve for soil moisture probes 13, 14, and 15 in silica sand.

4. FIELD INSTALLATION OF THE EPICOR-II LYSIMETERS

4.1 BACKGROUND

A small area of ORNL's currently operating SWSA 6 was selected for installation of the five EPICOR-II field lysimeters. The site had the advantage over other possible sites in that it is located within a restricted area that requires a key card for entry, it has been previously designated as a research area and will not be taken in future years for waste disposal trenches, it is near the top of a hill so that it will not flood or intercept the water table, and it is in a cleared area where there will be little physical interference to the meteorological station. At the completion of the field experiment, the lysimeters can be covered with a stainless steel plate and left in place, or moved to an alternate location if necessary.

4.2 INSTALLATION OF LYSIMETERS

On January 17, 1985, excavation of a trench with sloping sides was initiated in preparation for constructing the concrete pad on which the lysimeters were to be set. The trench was approximately 3.7 m deep (10.7 m long and 1.8 m wide at the bottom) to allow for a layer of crushed stone, a 30-cm-thick concrete pad, and the full 3.12-m height of the lysimeters. The lower 1.2 m of the side walls of the trench were shored up with plywood sheets to prevent possible slumping of the side walls during the concrete pouring and lysimeter installation.

The concrete pad was constructed according to EG&G Drawing Number 164326, which specified that the concrete be 2.1×10^6 kg/m^2 (3000 psi) at 28 d, be level with a tolerance of 0.3 cm in 1.2 m, and be reinforced with a network of number 4 and number 5 steel rebar. The size of the pad (1.2 by 9.1 m) allowed for a spacing of 1.8 m between lysimeter centers and ensured that the lysimeters would remain vertical and stationary during the soil backfilling process.

On May 1, 1985, the concrete pad was completed, and the five lysimeters were set in place and secured to the pad with steel bolts (Fig. 8). The soil from the trench excavation was then backfilled around the lysimeters and compacted in place using a one-man gas-powered soil compacter. Extensive hand work was required in the spaces between the lysimeters, and care was taken so that none of the lysimeters were damaged. Figure 9 shows a view of the site after the soil backfilling was completed.

Several days after the lysimeters were in place, the inside walls were washed with water to remove dirt that had collected during shipment. Wash water draining to the leachate collection reservoir was pumped out using a Masterflex model 7535-10 pump and a 4-m length of Tygon tubing. After this cleaning operation, 410 kg of silica quartz river rock was delivered to the site from a local limestone company (American Limestone, Knoxville, Tennessee) that purchased the rock from the W.S. Bonsal Company in Lilesville, North Carolina. The rock was thoroughly washed to remove fine particles and stored in 132-L containers prior to loading into the lysimeters.

After both the stone and the lysimeters were washed and a stainless steel filter was placed in the hole that drains to the leachate collection reservoir, 80 kg of stone was added to each lysimeter to serve as a support medium for the soil and sand. The

ORNL-PHOTO 3972-85

Fig. 8. EPICOR-II lysimeters being lowered into place.

ORNL-PHOTO 3964-85

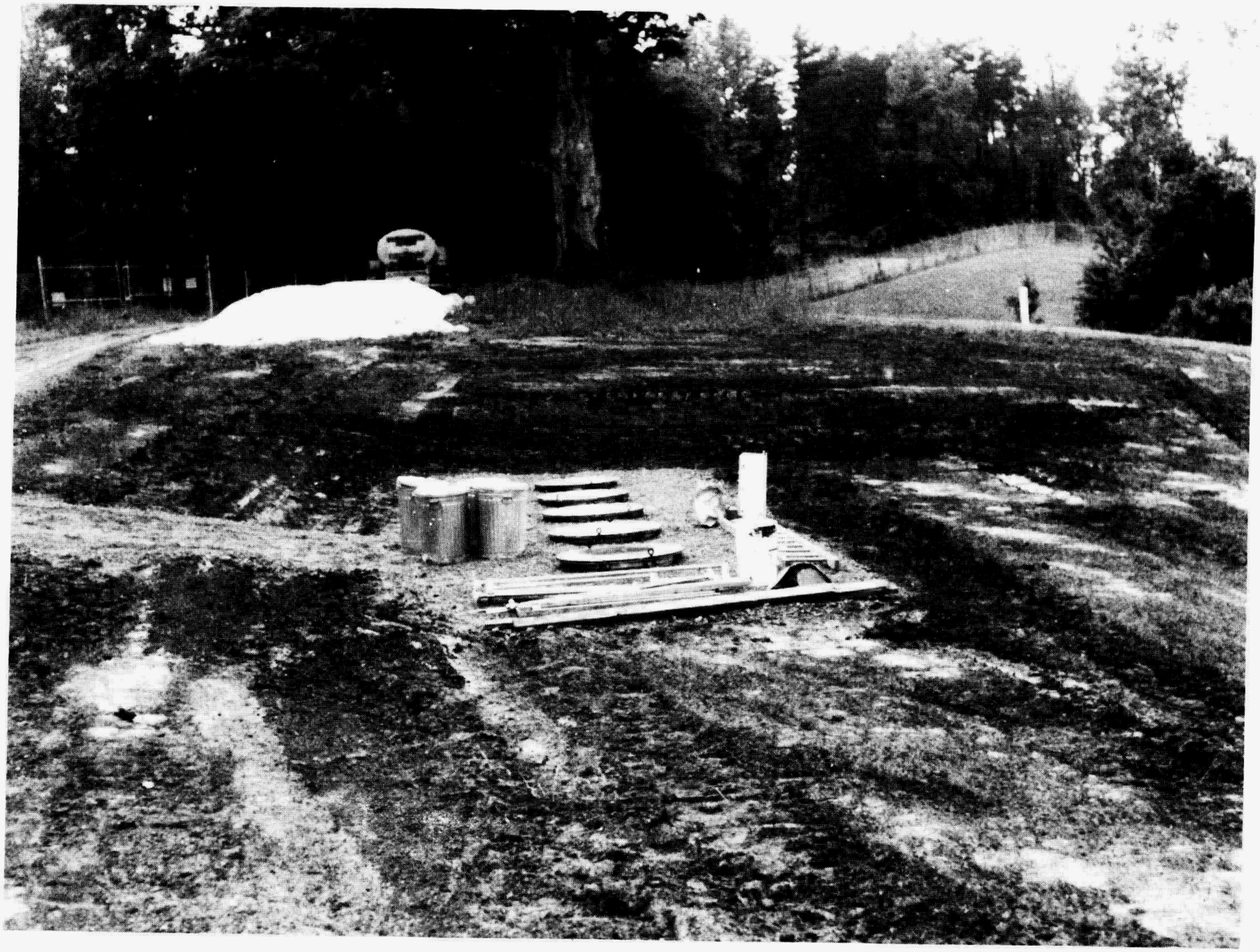

Fig. 9. EPICOR-II site after lysimeter installation.

volume occupied by 80 kg just filled the lysimeter to reference elevation zero (Fig. 2). Next, a 91-cm-diam. circular piece of filter fabric was placed over the stone to separate it from the soil matrix. At this point, the lysimeters were ready to be loaded with soil (sand for lysimeter 5) and the instruments detailed in Fig. 2.

In early June 1985, a portable gas-powered soil crushing machine was transported to the site, and filling of the lysimeters was initiated. Buckets containing approximately 14 kg of Fuquay soil were taken from the soil crusher (Fig. 10) and lowered into each lysimeter where they were spread and compacted using the weight of the person working in the lysimeter. Metal measuring tapes were placed down the sides of each lysimeter at four positions (0, 90, 180, and 270 degrees) to assist in keeping track of the depth of soil and the position of various probes. When the elevation of a particular soil moisture cup was reached, a solid aluminum, cylindrical-shaped mold was set in place at the specified orientation and soil was packed around the mold until the top shoulder was reached (Fig. 11). The mold was then removed, leaving a small cavity in the soil that was immediately filled with a stiff mixture of silica flour paste (Fig. 12). A porous soil moisture cup was then placed in the silica flour mixture, with care being taken to suspend the cup within the flour and not let it touch any side of the cavity. Soil was then added to the top of the cavity to bury the cup, and the two Tygon tubes attached to each porous cup were run horizontally to the lysimeter wall, and then vertically to the surface.

At elevations 28.8, 77.9, and 149.0 cm, the soil moisture probes were placed 10.2 cm from the side wall in a vertical position. Soil was compacted around the probes, and the wire leads were run to the

ORNL-PHOTO 4099-85

Fig. 10. Soil crusher used to process the Fuquay soil.

ORNL-PHOTO 4080-85

Fig. 11. Cylindrical mold used to soil cavity prior to soil moisture cup installation.

ORNL-PHOTO 4071-85

Fig. 12. Soil cavity filled with silica flour paste during installation of porous cup.

lysimeter walls and out, in the same manner as the tubing from the porous cups. At elevation 51.2 cm, a 5-cm-ID steel pipe was positioned in the center of the lysimeter to serve as an access tube for later insertion of the solidified resin samples (Fig. 13). The pipe was open ended at the bottom and placed directly on the soil surface. At the top end, the pipe had a threaded connector that was machined on the inside to allow a slip-fit connection to a similar-sized pipe serving as a resin sample transport tube. This top of the pipe was set flush with the top of a piece of plywood spanning the diameter of the lysimeter and containing a centering hole. The plywood template was clamped to the outer edges of the lysimeter to hold the top of the access pipe secure and in place. The remainder of the lysimeter was then filled with soil until an elevation approximately 13 cm below the top of the lysimeter was reached (Fig. 14). Table 5 summarizes the lysimeter loading process by tabulating the weight of the soil added, the in-place density, and the moisture content of the soil as it was being loaded.

4.3 PLACEMENT OF THE RESIN SAMPLES IN THE LYSIMETERS

After the last lysimeter (lysimeter 5) was filled, the resin samples were loaded into the access wells, and the wells were removed. To accomplish this, the 35 resin samples were removed from their plastic molds in the ORNL Hot-Cell Facility. The cylindrical samples were then washed in a pan of water to remove dust particles and placed in one of five resin sample transport tubes that were constructed of the same diameter steel pipe as the lysimeter access well (Fig. 15). The transport tubes were closed at the top but open at the bottom to

ORNL-PHOTO 4073-85

Fig. 13. Steel access tube used as a well for loading resin samples into lysimeters.

ORNL-PHOTO 4083-85

Fig. 14. View of a lysimeter after filling was completed.

ORNL-PHOTO 4082-85

Fig. 15. Steel transport tubes being loaded with resin samples in ORNL hot-cell facilities.

Table 5. Summary of amounts of Fuquay soil added to each lysimeter

Lysimeter	Total Soil Added (kg)	Soil Density (g/cm^3)	Soil Moisture[a] (%)
1	1837.5	1.33	9.59
2	1905.5	1.38	8.91
3	1840	1.33	9.90
4	1846	1.33	8.91
5	2262	1.64	0.04

[a]Average soil moisture determined from samples collected at several different depths during the lysimeter loading process.

allow insertion of the resin samples. After each of the five tubes was loaded with the correct resin samples (Table 1), a removable brass pin was placed across the bottom opening to keep the samples from falling out of the tubes. The labeled tubes were then connected at the top to individual 10-m lengths of wire cable and loaded into a bottom-loading shielded carrier that was placed on an open-bed truck for transport to the site. The wire attached to each transport tube was threaded through a small hole in the top of the carrier and taped to the outside wall where it could be reached during the transfer process.

A crane was used to position the lead carrier over each lysimeter while a single transport tube was lowered from the carrier by the attached cable. Care was taken to position the bottom door of the carrier directly over the access well before the transfer process began. The transfer tube was then attached to the access well via the slip-fit joint in the top of the access well, and the removable brass pin was pulled using a 3-m rod with a hook attached to the end. As soon as the pin was removed, the seven resin samples fell from the transport tube into the access well (Fig. 16). After the first lysimeter was loaded, the carrier was moved to the next lysimeter, and the unloading steps described above were repeated. In total, the resin loading procedure required 1 h and resulted in only minimal ground contamination, which was easily cleaned using a survey meter and shovel. Exposure to the persons manipulating the transfer tubes was held to a total of 5 mR for the entire operation. It was felt that this exposure was well within the ALARA (As Low As Reasonably Achievable) principle, as the activity at approximately 30 cm from resin sample D2-9 was measured earlier to be 10 R/h.

ORNL-PHOTO 4101-85

Fig. 16. Operator pulling the removable pin in the transport tube, allowing the resin samples to fall into place.

When loading was completed, the lysimeter access wells were removed by the crane and were immediately bagged for disposal. Care was taken to see that none of the resin samples were pulled out of the hole along with the access wells, and an additional small amount of soil was added and compacted to fill the remaining hole above the resin samples. After the hole was filled and several contaminated spots on the ground surface were removed, the gamma radiation measured at the surface of each lysimeter was equal to background, and the transfer process was completed. Tops were put over all five lysimeters and were not removed until August 1, after several trial runs with the meteorological data acquisition system had been completed.

4.4 INSTALLATION OF THE METEOROLOGICAL STATION

The meteorological station installed at the EPICOR-II site consists of a tipping-bucket rain gage, a wind speed sensor, a wind direction sensor, and an air temperature-relative humidity probe. All equipment, except the rain gage, is mounted on a 3-m electrically grounded tripod located on a concrete pad adjacent to lysimeter number 3. The CR-7 data logger is located in a weatherproof housing at the edge of the concrete pad and receives wires from the 15 soil moisture probes and all of the meteorological instruments. Wires from these instruments were run directly into the CR-7 housing, while wires from the soil moisture probes were run through 5-cm PVC conduit to the side of the housing. Electrical power was supplied to the CR-7 unit, and the 12-V dc batteries are reserved for a backup source of power.

All the meteorological equipment was tested in the laboratory prior to field installation and, when possible, the data being collected have been field checked. For example, a weighing bucket rain gage located approximately 60 m from the EPICOR-II site has been used to compare site rainfall with that being collected at the meteorological station. Table 6 summarizes this comparison for the period June 26, 1985, to September 30, 1985.

During the trial data collection period conducted in July 1985, a problem with the CR-7 unit was noted and resulted in extremely high values of precipitation being recorded on certain days (Table 6). The problem was traced to one of the UART chips in the logger electronics, which was replaced on July 30. At that point, the data collection system was judged to be working properly, and the lysimeter covers were removed to expose the soil to precipitation and thus initiate the experiment.

The data logger worked without problem from July 30 to September 6, however, total rainfalls were reported to be approximately 80% of that measured with the weighing bucket gage. A second problem with the UART chip was noted after September 6, causing the extremely high precipitation values occurring after this date. Backup precipitation data collected near the EPICOR site was used until the CR-7 electronic problems could be solved.

Table 6. Comparison of EPICOR-II precipitation data with a weighing bucket gage located in SWSA 6

Date	Julian Day (1985)	SWSA 6 Precipitation (mm)	EPICOR Precipitation (mm)
6-26-85	177	10.2	9.4
6-27-85	178	0	a
6-28-85	179	0	0
6-29-85	180	0	0
6-30-85	181	40.1	a
	TOTAL	50.3	
7-01-85	182	4.6	5.6
7-02-85	183	0	0
7-03-85	184	0	0
7-04-85	185	0	a
7-05-85	186	0	0.5
7-06-85	187	1.3	2.3
7-07-85	188	0	a
7-08-85	189	b	0
7-09-85	190	b	a
7-10-85	191	b	14.2
7-11-85	192	0	a
7-12-85	193	0	0.7
7-13-85	194	0	0
7-14-85	195	0	0
7-15-85	196	0	a
7-16-85	197	0	0.7
7-17-85	198	2.5	a
7-18-85	199	0	0
7-19-85	200	0	a
7-20-85	201	0	a
7-21-85	202	0	a
7-22-85	203	0.6	a
7-23-85	204	29.2	a
7-24-85	205	0	a
7-25-85	206	0	a
7-26-85	207	15.2	a
7-27-85	208	0	a
7-28-85	209	22.9	a
7-29-85	210	3.8	a
7-30-85	211	6.4	0.2[c]
7-31-85	212	0	0
	TOTAL	86.5	

Table 6. (Continued)

Date	Julian Day (1985)	SWSA 6 Precipitation (mm)	EPICOR Precipitation (mm)
8-02-85	213	5.7	6.1
8-02-85	214	0	0
8-03-85	215	0	0
8-04-85	216	0	0
8-05-85	217	0	0
8-06-85	218	15.9	d
8-07-85	219	2.5	d
8-08-85	220	0	0.2
8-09-85	221	0	0
8-10-85	222	0	0
8-11-85	223	0	0
8-12-85	224	0	0
8-13-85	225	1.9	1.5
8-14-85	226	0	0
8-15-85	227	1.3	1.5
8-16-85	228	101.0	82.5
8-17-85	229	38.1	21.6
8-18-85	230	0	0
8-19-85	231	0	0
8-20-85	232	0	0.5
8-21-85	233	0	0
8-22-85	234	0	0
8-23-85	235	0.6	0.5
8-24-85	236	25.4	17.5
8-25-85	237	9.5	6.9
8-26-85	238	12.7	10.2
8-27-85	239	0	0
8-28-85	240	0	0
8-29-85	241	0	0
8-30-85	242	15.9	12.4
8-31-85	243	0	0
	TOTAL	230.5	

Table 6. (Continued)

Date	Julian Day (1985)	SWSA 6 Precipitation (mm)	EPICOR Precipitation (mm)
9-01-85	244	0	0
9-02-85	245	0	0
9-03-85	246	0	0
9-04-85	247	0	0
9-05-85	248	1.9	1.0
9-06-85	249	12.7	a
9-07-85	250	0	a
9-08-85	251	0	a
9-09-85	252	0	a
9-10-85	253	0	a
9-11-85	254	0	a
9-12-85	255	0	a
9-13-85	256	0	a
9-14-85	257	0	a
9-15-85	258	0	a
9-16-85	259	0	a
9-17-85	260	0	a
9-18-85	261	0	a
9-19-85	262	0	a
9-20-85	263	0	a
9-21-85	264	0	a
9-22-85	265	0	a
9-23-85	266	11.4	a
9-24-85	267	11.4	a
9-25-85	268	0	a
9-26-85	269	5.1	a
9-27-85	270	0	a
9-28-85	271	0	a
9-29-85	272	0	a
9-30-85	273	0	a
	TOTAL	42.5	

[a]Data logger malfunction due to hardware failure.

[b]Missing data due to operator error.

[c]Data logger hardware failure repaired.

[d]Missing data due to malfunction of rainfall gage.

5. DATA ACQUISITION SYSTEM

5.1 BACKGROUND

The EPICOR-II data acquisition system consists of the following sequence of steps: (1) the CR-7 data logger receives an electronic signal from each of the instruments (soil moisture probes, etc.) at a specified time dependent upon how the CR-7 is programmed; (2) at the beginning of a day (0000 h), the CR-7 averages or totals the data in memory for the previous day and writes the daily average or total to cassette tape (e.g., average air temperature or total rainfall); and (3) the cassette tape is retrieved from the site at scheduled intervals and translated using a Campbell Scientific C20 cassette interface. The tape translation process of step 3 consists of transferring a block of 200 numbers for each day from storage on the tape to a disk file on an IBM PC. Once the data have been transferred, they can be kept in files, arranged in tables for presentation in reports, or input into graphics programs to display a specific variable (e.g., rainfall) as a function of time. Figure 17 summarizes the flow of data from the field instruments to final storage on the IBM PC.

5.2 DATA TRANSFER FROM CASSETTE TAPE TO IBM PC

When a cassette tape is retrieved from the field and brought back into the laboratory for translation, an IBM PC, a Campbell Scientific C20 cassette interface unit, and an IBM Basic software program (TRANS.BAS, Appendix B) are required to translate each tape. A detailed description of the C20, including the required hardware for

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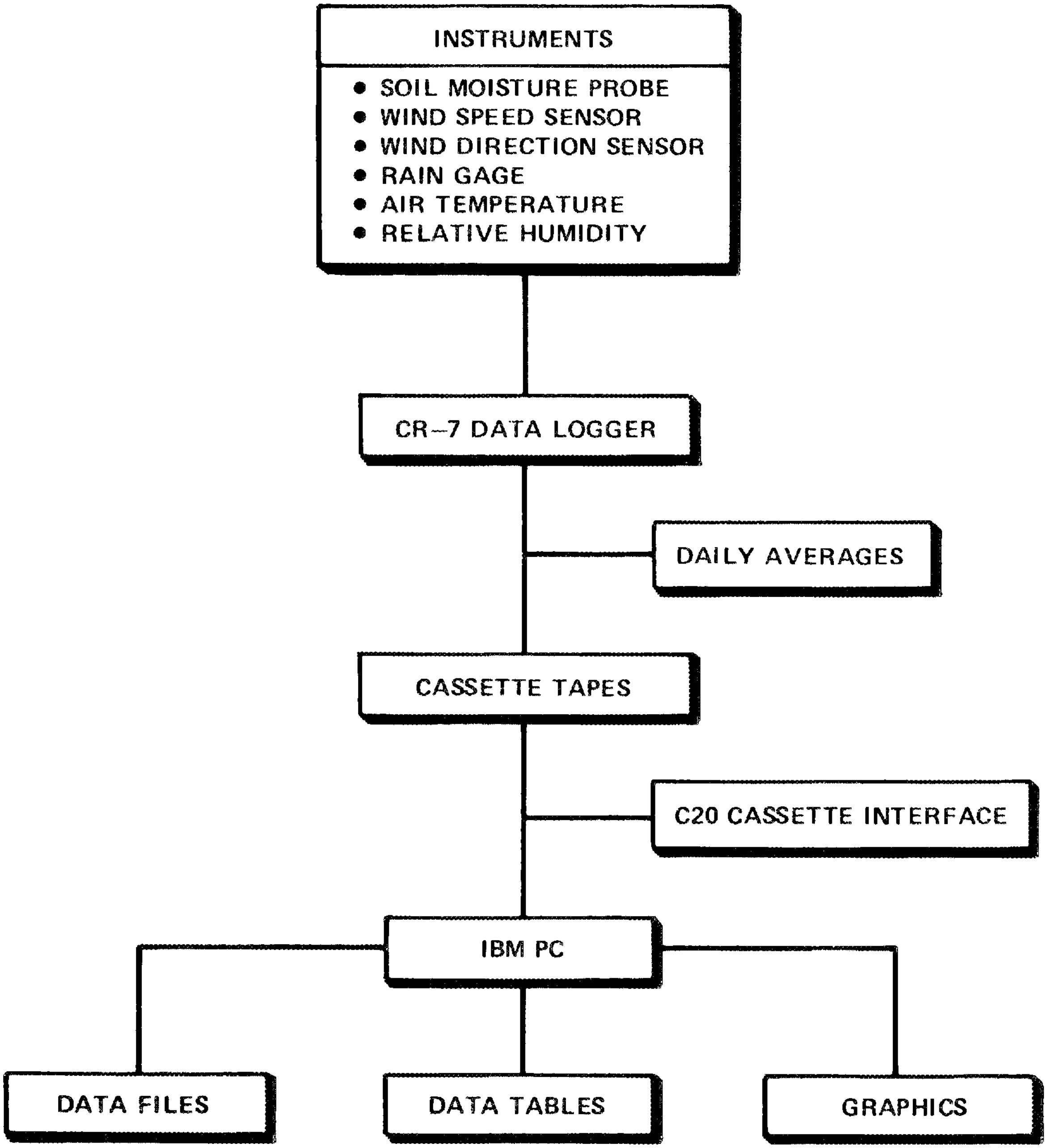

Fig. 17. Schematic of the EPICOR-II data acquisition system.

interface with a PC, can be found in the Operator's Manual (Campbell Scientific, Inc. 1983); however, the general steps required to process tapes are as follows:

1. Turn on the PC and enter IBM Basic by typing BASICA /C:1024.
2. Turn on the C20 interface and clear memory by pressing the reset button.
3. Advance tape in tape player to desired position and connect to C20 interface with two cable wire, one to the dc power position on the player and one to the monitor jack on the player.
4. Load TRANS.BAS by typing LOAD "D: EPICOR TRANS.BAS" where the program TRANS.BAS is stored on disk D: in directory EPICOR.
5. Run TRANS.BAS by typing RUN.
6. The program will prompt the user for the name of the file the data are to be stored in. Respond by typing D: EPICOR NAME.EXT where NAME.EXT is the selected filename and three-digit extension.
7. Press the PLAY button on the tape player.
8. When the data translation is complete, press the F6 key to close the data file and exit from basic by typing SYSTEM.

If the above sequence of steps is followed, the data will be displayed across the PC monitor as it is being transferred, or output directly to a printer if that option is selected by the user.

Each number in the block of 200 data points stored for each 24-h period is preceded by a two-digit identifier, making it easy to separate the individual blocks of numbers as they scroll across the screen. An example of one such block of data, including data point identifier translation, is shown in Tables 7 and 8.

Table 7. Example of a one-day block of data collected by the CR-7 data logger

01+0104.	02+0214.	03+0000.	04+0.240	05+24.76	06+084.5	07+1.366	08+201.1
09+22.04	10+23.28	11+25.73	12+24.43	13+23.38	14+25.69	15+65.35	16+23.42
17+25.60	18+20.95	19+23.24	20+25.71	21+19.40	22+22.27	23+24.72	24+36.66
25+34.68	26+10.04	27+39.12	28+29.60	29+07.92	30+07.65	31+38.17	32+07.59
33+07.59	34+07.61	35+17.58	36+10.80	37+15.26	38+09.21	39+0.933	40+0.961
41+1.015	42+0.986	43+0.962	44+1.014	45+1.616	46+0.964	47+1.012	48+0.910
49+0.960	50+1.014	51+0.875	52+0.939	53+0.992	54+0.798	55+0.705	56+0.042
57+0.924	58+0.498	59+0.000	60+0.004	61+0.874	62+0.006	63+0.006	64+0.008
65+0.163	66+0.051	67+0.119	68+0.031	69+22.24	70+62.84	71+1.000	72+0.193
73+22.03	74+23.28	75+25.66	76+24.26	77+23.37	78+25.56	79+63.45	80+23.42
81+25.47	82+20.97	83+23.23	84+25.59	85+19.20	86+22.28	87+24.62	88+36.24
89+34.27	90+09.89	91+38.87	92+28.85	93+07.81	94+07.64	95+37.98	96+07.60
97+07.60	98+07.60	99+16.32	00+10.69	01+15.04	02+08.97	03+0.934	04+0.961
05+1.014	06+0.983	07+0.963	08+1.012	09+1.601	10+0.964	11+1.010	12+0.910
13+0.960	14+1.012	15+0.871	16+0.939	17+0.991	18+0.776	19+0.685	20+0.040
21+0.909	22+0.470	23+0.000	24+0.004	25+0.863	26+0.005	27+0.005	28+0.007
29+0.138	30+0.050	31+0.115	32+0.028	33+31.35	34+090.4	35+09.00	36+360.6
37+22.08	38+23.34	39+25.82	40+24.86	41+23.42	42+25.78	43+68.22	44+23.47
45+25.70	46+20.99	47+23.30	48+25.81	49+19.66	50+22.33	51+24.81	52+37.01
53+34.97	54+10.16	55+39.39	56+30.00	57+07.98	58+07.69	59+38.35	60+07.62
61+07.61	62+07.64	63+18.86	64+10.89	65+15.43	66+09.43	67+0.935	68+0.963
69+1.017	70+0.996	71+0.964	72+1.016	73+1.640	74+0.966	75+1.014	76+0.911
77+0.962	78+1.017	79+0.881	80+0.940	81+0.995	82+0.814	83+0.717	84+0.043
85+0.937	86+0.511	87+0.001	88+0.005	89+0.882	90+0.007	91+0.007	92+0.009
93+0.189	94+0.052	95+0.122	96+0.034	97+1.366	98+0.185	99+318.7	00+075.3

Table 8. Translation of the two-digit identifiers used by the CR-7

01	Output Array ID	73-87	Min gnd temp
02	Date	88-102	Min Gnd Moisture
03	Time	103-117	Min Thermistor Volts
04	Rainfall	118-132	Min Moisture Volts
05	Avg Temp (Air)	133	Max Air Temp
06	Avg Humidity	134	Max Humidity
07	Avg Wind Speed	135	Max Wind Speed
08	Avg Wind Direction	136	Max Wind Direction
09-23	Avg Gnd Temp	137-151	Max Gnd Temp
24-38	Avg Gnd Moisture	152-166	Max Gnd Moisture
39-53	Avg Thermistor Volts	167-181	Max Thermistor Volts
54-68	Avg Moisture Volts	182-196	Max Moisture Volts
69	Min Air Temp	197	Mean Wind Speed
70	Min Humidity	198	Mean Wind Vector Mag
71	Min Wind Speed	199	Mean Wind Vector Dir
72	Min Wind Dir	200	Std Dev of Dir

In addition to the TRANS.BAS program described above and listed in Appendix B, a second IBM Basic program was written to extract all 200 numbers from a block of data and tabulate them on a single page for use in reports and papers. This program (TABLE.BAS) is listed in Appendix C and is executed through the following steps:

1. Turn on the PC and enter IBM Basic by typing BASICA /C:1024.
2. Load TABLE.BAS by typing LOAD "D: EPICOR TABLE.BAS" where the program TABLE.BAS is stored on disk D: in directory EPICOR.
3. Run TABLE.BAS by typing RUN.
4. The program will prompt the user for the name of the data set containing the blocks of 200 numbers to be tabulated and the name of the file to put the completed tables in. Respond by typing D: EPICOR NAME.EXT and D: EPICOR NAME.TAB where NAME.EXT is the file containing the blocks of 200 numbers and NAME.TAB is the file to contain the completed files.

If these steps are followed, the summary tables (one per page) can easily be examined by printing the file D: EPICOR NAME.TAB. An example of the summary table corresponding to the block of data in Table 7 is shown in Table 9.

5.3 GRAPHICAL DISPLAY OF METEOROLOGICAL DATA

The summary tables described in the previous section were designed to look at data for individual days but are more difficult to use when trends of a particular variable (rainfall, air temperature, or soil moisture) are being examined. For this purpose, plotting routines have been written to plot a single (or more than one) variable of interest as a function of time. These graphical capabilities are necessary for examining such a large data base and allow the user to quickly look at trends in data, thus determining when to sample for leachate and to try extracting soil moisture from the porous cups. A summary of the meteorological data, including soil moisture and temperature, collected through August 1985, is presented in Appendix D.

Table 9. Daily summary table resulting from TABLE.BAS program

ORNL EPICOR-II FIELD TEST

STATION ID= 104 DATE= 214 TIME= 0

RAINFALL= .24	AIR TEMP= 24.76	AVG HUM= 84.5	WIND SPD= 1.366
WIND DIR= 201.1	TEMP1= 22.04	TEMP2= 23.28	TEMP3= 25.73
TEMP4= 24.43	TEMP5= 23.38	TEMP6= 25.69	TEMP7= 65.35
TEMP8= 23.42	TEMP9= 25.6	TEMP10= 20.95	TEMP11= 23.24
TEMP12= 25.71	TEMP13= 19.4	TEMP14= 22.27	TEMP15= 24.72
MOIST1= 36.66	MOIST2= 34.68	MOIST3= 10.04	MOIST4= 39.12
MOIST5= 29.6	MOIST6= 7.92	MOIST7= 7.65	MOIST8= 38.17
MOIST9= 7.59	MOIST10= 7.59	MOIST11= 7.61	MOIST12= 17.58
MOIST13= 10.8	MOIST14= 15.26	MOIST15= 9.21	THR VLT1= .933
THR VLT2= .961	THR VLT3= 1.015	THR VLT4= .986	THR VLT5= .962
THR VLT6= 1.014	THR VLT7= 1.616	THR VLT8= .964	THR VLT9= 1.012
THR VLT10= .91	THR VLT11= .96	THR VLT12= 1.014	THR VLT13= .875
THR VLT14= .939	THR VLT15= .992	MOI VLT1= .798	MOI VLT2= .705
MOI VLT3= .042	MOI VLT4= .924	MOI VLT5= .498	MOI VLT6= 0
MOI VLT7= .004	MOI VLT8= .874	MOI VLT9= .006	MOI VLT10= .006
MOI VLT11= .008	MOI VLT12= .163	MOI VLT13= .051	MOI VLT14= .119
MOI VLT15= .031	MIN TEMP= 22.24	MIN HUM= 62.84	MIN WSPD= 1
MIN WDIR= .193	MIN TEMP1= 22.03	MIN TEMP2= 23.28	MIN TEMP3= 25.66
MIN TEMP4= 24.26	MIN TEMP5= 23.37	MIN TEMP6= 25.56	MIN TEMP7= 63.45
MIN TEMP8= 23.42	MIN TEMP9= 25.47	MIN TEMP10= 20.97	MIN TEMP11= 23.23
MIN TEMP12= 25.59	MIN TEMP13= 19.2	MIN TEMP14= 22.28	MIN TEMP15= 24.62
MIN MOI1= 36.24	MIN MOI2= 34.27	MIN MOI3= 9.89	MIN MOI4= 38.87
MIN MOI5= 28.85	MIN MOI6= 7.81	MIN MOI7= 7.64	MIN MOI8= 37.98
MIN MOI9= 7.6	MIN MOI10= 7.6	MIN MOI11= 7.6	MIN MOI12= 16.32
MIN MOI13= 10.69	MIN MOI14= 15.04	MIN MOI15= 8.97	MIN TVLT1= .934
MIN TVLT2= .961	MIN TVLT3= 1.014	MIN TVLT4= .983	MIN TVLT5= .963
MIN TVLT6= 1.012	MIN TVLT7= 1.601	MIN TVLT8= .964	MIN TVLT9= 1.01
MIN TVLT10= .91	MIN TVLT11= .96	MIN TVLT12= 1.012	MIN TVLT13= .871
MIN TVLT14= .939	MIN TVLT15= .991	MIN MVLT1= .776	MIN MVLT2= .685
MIN MVLT3= .04	MIN MVLT4= .909	MIN MVLT5= .47	MIN MVLT6= 0
MIN MVLT7= .004	MIN MVLT8= .863	MIN MVLT9= .005	MIN MVLT10= .005
MIN MVLT11= .007	MIN MVLT12= .138	MIN MVLT13= .05	MIN MVLT14= .115
MIN MVLT15= .028	MAX TEMP= 31.35	MAX HUM= 90.4	MAX WSPD= 9
MAX WDIR= 360.6	MAX TEMP1= 22.08	MAX TEMP2= 23.34	MAX TEMP3= 25.82
MAX TEMP4= 24.86	MAX TEMP5= 23.42	MAX TEMP6= 25.78	MAX TEMP7= 68.22
MAX TEMP8= 23.47	MAX TEMP9= 25.7	MAX TEMP10= 20.99	MAX TEMP11= 23.3
MAX TEMP12= 25.81	MAX TEMP13= 19.66	MAX TEMP14= 22.33	MAX TEMP15= 24.81
MAX MOI1= 37.01	MAX MOI2= 34.97	MAX MOI3= 10.16	MAX MOI4= 39.39
MAX MOI5= 30	MAX MOI6= 7.98	MAX MOI7= 7.69	MAX MOI8= 38.35
MAX MOI9= 7.62	MAX MOI10= 7.61	MAX MOI11= 7.64	MAX MOI12= 18.86
MAX MOI13= 10.89	MAX MOI14= 15.43	MAX MOI15= 9.43	MAX TVLT1= .935
MAX TVLT2= .963	MAX TVLT3= 1.017	MAX TVLT4= .996	MAX TVLT5= .964
MAX TVLT6= 1.016	MAX TVLT7= 1.64	MAX TVLT8= .966	MAX TVLT9= 1.014
MAX TVLT10= .911	MAX TVLT11= .962	MAX TVLT12= 1.017	MAX TVLT13= .881
MAX TVLT14= .94	MAX TVLT15= .995	MAX MVLT1= .814	MAX MVLT2= .717
MAX MVLT3= .043	MAX MVLT4= .937	MAX MVLT5= .511	MAX MVLT6= .001
MAX MVLT7= .005	MAX MVLT8= .882	MAX MVLT9= .007	MAX MVLT10= .007
MAX MVLT11= .009	MAX MVLT12= .189	MAX MVLT13= .052	MAX MVLT14= .122
MAX MVLT15= .034	AVG WSPD= 1.366	AVG WMAG= .185	AVG WDIR= 318.7
SD WDIR= 75.3			

6. LEACHATE COLLECTION

6.1 BACKGROUND

The experimental design allows for sampling soil leachate at six points within each lysimeter. One point is the reservoir located at the bottom of each lysimeter, and the other five are at the locations of the five porous cups. Initially, only leachate from the bottom reservoir and cup number three (located immediately below the waste form) is being collected and analyzed for radioactivity. If activity is noted in soil leachate from cup three, additional cups located below the waste form can be added to the sampling program. Samples are collected on a quarterly basis, with the first set being taken in September 1985.

6.2 RESULTS OF THE FIRST LEACHATE SAMPLING

On September 25, 1985, the first set of leachate samples was collected from the five EPICOR-II lysimeters. The covers had been off for a total of 56 d (since August 1), and a total of 267.9 mm of precipitation (173.8 L volume over each lysimeter) had been recorded at the site. Samples were drawn from the number three porous cup of each lysimeter using a hand-operated vacuum pump that could deliver a suction of 63.5 cm Hg to the porous cup via the Tygon tubing. When the vacuum had dissipated to approximately 13 cm Hg, the liquid in the cup was drawn to the surface and into a 100-mL test tube fitted with a two-hole rubber stopper using the portable hand pump. In this manner approximately 100 mL of liquid was sampled from the number three porous cups of each lysimeter.

To sample the leachate that had drained to the bottom collection reservoir, a vacuum pump was connected to a 10-L Erlenmeyer flask, which was in turn connected to a Tygon tube that ran to the bottom of the reservoir. All the leachate was pumped from the reservoir and emptied into a 54-L plastic carboy. During the sampling process, the liquid was monitored continuously for radioactivity using a Geiger-Muller counter, and a small sample of the leachate was set aside for later radiochemical analysis. Immediately after sampling, the pH and electrical conductivity of the five liquid samples collected from the lysimeter reservoirs were measured. In addition, a 1-L sample was prepared for a gross gamma screening analysis using the Environmental Sciences Division low-level gamma-ray spectrometry laboratory with its high-resolution, lithium-drifted germanium [Ge(Li)] detector. The purpose of this gamma scan was to determine if any gamma-emitting radionuclides, particularly ^{137}Cs, were present in the liquid before the samples were acidified and sent to the Analytical Chemistry Division for further analysis. Table 10 summarizes the volumes of leachate and the chemical characteristics of the ten samples collected in September 1985.

Volumes collected from the bottom reservoir (Table 10) ranged from 30 to 48% of the input precipitation, indicating that 52 to 70% of the rainfall was held in the lysimeter fill or evaporated to the atmosphere. This is not surprising given the fact that the soil contained only 10% moisture when it was loaded into the lysimeters. Continued volume measurements will determine if the lysimeters will continue to exhibit such a wide variation in percentage of input rainfall attenuated.

Table 10. Volumes and gamma activity of leachate samples collected in September 1985

Sample	Volume (L)	pH	Electrical Conductivity (mmhos/cm)	Cs-137 (Bq/L)	CO-60 (Bq/L)
Reservior					
1	52	6.1	2.200	<0.2	<0.2
2	58.5	6.7	7.500	<0.1	0.14 ± 0.12
3	65.5	6.4	4.600	0.20 ± 0.12	<0.2
4	83.5	6.8	.120	<0.2	<0.2
5	74	6.9	.380	<0.1	<0.2
Cup 3					
1	0.1	---	---	0.93 ± 0.62	<0.6
2	0.1	---	---	0.36 ± 0.29	<0.4
3	0.1	---	---	<0.3	0.70 ± 0.44
4	0.1	---	---	<0.5	<0.6
5	0.1	---	---	<0.5	<0.6

Data in Table 10 also indicate that there were no radionuclides present in either of the two leachate samples collected from each lysimeter. Continued sampling on a quarterly basis will determine if this condition changes and radionuclides become mobilized with continued leach time.

7. PROJECT SUMMARY

This report documents the first year of ORNL's participation with ANL, EG&G, and the NRC in a field experiment designed to investigate the long-term leaching characteristics of solidified, radioactively stressed ion exchange resins. The work involved the installation of five soil lysimeters, providing conditions similar to those expected of shallow land disposal in the humid eastern United States. Calibration of 15 soil moisture/temperature probes used in the lysimeters was an important part of the effort, as was development of a data acquisition system that would allow for fast and simple processing of the large amounts of data being collected. Leachate collection and analysis, though an integral part of the experimental design, has only just begun and is, therefore, covered briefly in Sect. 6. A more detailed analysis of leachate characteristics and trends that might be observed through time are the subjects of future reports.

A brief summary of the first year of the field study is as follows:

1. Installation of the field lysimeters, including loading with Fuquay soil, placement of moisture cells and porous cups, and placement of ion exchange samples, was completed in June 1985. An initial data collection period was carried out in July 1985, and the lysimeters were opened to precipitation on August 1, 1985. Since that time several problems have been noted with the CR-7 data logger, and repairs are being made as the experiment is in progress.

2. Laboratory calibration of the soil moisture cells, which was a large part of the first year's effort, was successful with two mathematical relationships (third-order polynomial of negative natural log of cell voltage versus soil moisture) being derived to describe the moisture calibration curve in Fuquay soil and silica sand.
3. Soil moisture data presented in Appendix D indicate that several of the soil moisture cells (1, 2, 4, 5, 7, and 12) began to show an increase in moisture during the July data collection period while the lysimeters were still covered. A possible explanation for this is the detection of migrating water associated with the silica flour paste used to surround the porous ceramic sampling tubes. No other source of water was introduced into the lysimeters until the covers were removed on August 1, 1985. The probes that did not register this increase in soil moisture during June and July uniformly showed a large increase in moisture on Julian day 228 (August 16, 1985) when 101 mm of precipitation was recorded. Further monitoring will be required to determine if the soil in the lysimeters ever dries to the point where less than saturated conditions are measured by the soil moisture probes.
4. The data acquisition system required to process data tapes from the CR-7 logger was constructed and consists of software designed to extract a particular parameter of interest and plot its fluctuation by month. Examples of these data are presented in Appendix D. These monthly plots appear to be an excellent way of managing the quantity of data produced by the lysimeters and the meteorological station.

5. The first leachate sampling was completed in September 1985 and indicates that, during the first two months of exposure to rainfall, no radionuclides migrated from the solidified resin samples. Only continued monitoring will answer the question of resin decomposition and contaminant migration through time.

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APPENDIX A
LISTING OF THE CR-7 DATA LOGGER PROGRAM

APPENDIX A
LISTING OF THE CR-7 DATA LOGGER PROGRAM

Command	Parameter	Value	Description
*	1	1.789	Exec. cycle time
1	P	3	Pulse count
	1	1	Reps
	2	2	Input card 2
	3	1	Input channel 1
	4	12	Configuration
	5	4	Data location
	6	1	Multiplier
	7	1	Offset
2	P	3	Pulse count
	1	1	Reps
	2	2	Input card 2
	3	2	Input channel
	4	2	Configuration
	5	1	Data location
	6	0.01	Multiplier
	7	0	Offset
3	P	4	Excite, delay, measure
	1	1	Reps
	2	16	Range (500 mv)
	3	1	Input card
	4	1	Input channel
	5	1	Excitation card
	6	1	Excitation channel
	7	1	Measurements per excitation channel
	8	1	Delay (.01 s)
	9	1000	Excitation voltage
	10	5	Storage location
	11	0.71952	Multiplier
	12	0	Offset
4	P	92	If time interval
	1	1440	Minutes
	2	10	Command
5	P	77	Output time of day
	1	110	Day, hours, minutes
6	P	72	Totalize
	1	1	Reps
	2	1	Start input loc
7	P	71	Average
	1	64	Reps
	2	2	Starting input loc
8	P	74	Minimize
	1	64	Reps
	2	00	Include time
	3	2	Starting input loc

APPENDIX A. (Continued)

Command	Parameter	Value	Description
9	P	73	Maximize
	1	64	Reps
	2	00	Time
	3	2	Starting input loc
10	P	76	Wind vector
	1	1	Reps
	2	0	Sensor type
	3	4	Wind speed data loc
	4	5	Wind dir. data loc
*	2	300	Execution cycle time
1	P	11	Read temp. probe
	1	1	Reps
	2	1	Input card
	3	4	Input channel
	4	1	Excitation card
	5	2	Excitation channel
	6	2	Output location
	7	1	Multiplier
	8	0	Offset
2	P	12	Read temp compensated R.H. probe
	1	1	Reps
	2	1	Input card
	3	3	Input channel
	4	1	Excitation card
	5	2	Excitation channel
	6	1	Measurements/temp.
	7	2	Temp. input data loc
	8	3	R.H. data location
	9	1	Multiplier
	10	0	Offset
3	P	5	A C bridge
	1	15	Reps
	2	17	Range
	3	3	Input card
	4	1	First input channel
	5	1	First excitation card
	6	3	First excitation channel
	7	5	Measurements per excitation channel
	8	2000	Excitation voltage
	9	36	First measurement storage location
	10	2	Multiplier
	11	0	Offset

APPENDIX A. (Continued)

Command	Parameter	Value	Description
4	P	55	Polynomial
	1	15	Reps
	2	36	Starting input loc
	3	6	Destination
	4	-44.168	Coefficient 1
	5	169.78	Coefficient 2
	6	-264.52	Coefficient 3
	7	288.56	Coefficient 4
	8	-162.23	Coefficient 5
	9	37.596	Coefficient 6
5	P	5	A C bridge
	1	15	Reps
	2	17	Range
	3	2	Input card
	4	1	First input channel
	5	1	First excitation card
	6	3	First excitation channel
	7	5	Measurements per excitation channel
	8	1000	Excitation voltage
	9	51	First measurement storage location
	10	1	Multiplier
	11	0.00001	Offset
6	P	40	Instructions 6 - 20
	1	51	take voltage
	2	66	measurements stored in
7	P	40	locations 51 - 65 and
	1	52	put ln in locations
	2	67	66 - 80
8	P	40	
	1	53	
	2	68	
9	P	40	
	1	54	
	2	69	
10	P	40	
	1	55	
	2	70	
11	P	40	
	1	56	
	2	71	
12	P	40	
	1	57	
	2	72	

APPENDIX A. (Continued)

Command	Parameter	Value	Description
13	P	40	
	1	58	
	2	73	
14	P	40	
	1	59	
	2	74	
15	P	40	
	1	60	
	2	75	
16	P	40	
	1	61	
	2	76	
17	P	40	
	1	62	
	2	77	
18	P	40	
	1	63	
	2	78	
19	P	40	
	1	64	
	2	79	
20	P	40	
	1	65	
	2	80	
21	P	55	Polynomial
	1	12	Reps
	2	66	Starting input loc
	3	21	Destination
	4	47.574	Coefficient 1
	5	19.799	Coefficient 2
	6	3.2416	Coefficient 3
	7	0.1739	Coefficient 4
	8	0	Coefficient 5
	9	0	Coefficient 6
22	P	55	Polynomial
	1	3	Reps
	2	78	Starting input loc
	3	33	Destination
	4	53.000	Coefficient 1
	5	138.62	Coefficient 2
	6	223.07	Coefficient 3
	7	124.20	Coefficient 4
	8	0	Coefficient 5
	9	0	Coefficient 6
*	3	1	Execution cycle time
	P	10	Battery volt
	1	99	Storage location
*	4	20	Tape enabled

APPENDIX B
LISTING OF TRANS.BAS PROGRAM

APPENDIX B
LISTING OF TRANS.BAS PROGRAM

```
100 REM ***  this program transfers data from com 2 to a disk file
110 DEFINT I,J,K,L,M,N : DIM LIN$(510)
120 P$="Y" : HP$ = "N"
130 ON ERROR GOTO 830
140 ON KEY(1) GOSUB 1180 : ON KEY(2) GOSUB  1060 : ON KEY(5) GOSUB 1260
150 ON KEY(3) GOSUB 1200 : ON KEY(4) GOSUB 1080  : ON KEY(6) GOSUB 1320
160 KEY(1) ON : KEY(2) ON : KEY(3) ON : KEY(4) ON : KEY(5) ON : KEY(6) ON
161 FOR K = 1 TO 10 : KEY K,"" : NEXT K
162 KEY 1,"SCR OF" : KEY 2,"SCR ON" : KEY 3,"PTR OF" : KEY 4,"PTR ON"
163 KEY 5,"PAUSE" : KEY 6,"STOP"
170 CLS : FOR J = 1 TO 4 : PRINT : NEXT J
180 TIM1$ = TIME$
190 INPUT "Enter the file name to save the data in: ";FIL$
200 OPEN FIL$ FOR APPEND AS #3
210 OPEN "COM2:9600,E,7,1,LF,PE" AS #1
220 J = 0 : I = 0 : L1$ = CHR$(17) : CR$=CHR$(13) : LF$=CHR$(10)
230 REM ***
240 REM ***  LOOP ON THE INPUT FROM COM2
250 REM ***
260 NENDS = 0
270 PRINT #1,L1$
280 J = J+1 : I = I+1 : NL = 0
290 IF EOF(1)=0 THEN 530
300 NENDS = NENDS +1 : IF NENDS=2 THEN 370
310 FOR X = 1 TO 200 : NEXT X
320 IF EOF(1)=0 THEN 530
330 PRINT "Waiting . . . ."
340 Y = 0
350 FOR X = 1 TO 2500 : Y = Y+1 : NEXT X
360 GOTO 290
370 NENDS = 0 : BEEP : PRINT : PRINT : PRINT "Possible   End of Data."
380 PRINT "Press:   E - End the transfer and close files, or  C - Try again."
390 T$ = INKEY$ : IF T$="" THEN 390
400 IF T$="C" OR T$="c" THEN I = I-1 : J = J-1 : GOTO 270
410 IF T$<"E" AND T$<"e" THEN BEEP : GOTO 390
420 PRINT #1,CHR$(20)
430 FOR X = 1 TO 5000 : NEXT X
440 LOC1 = LOC(1) : IF LOC1<70 THEN N = I-1 : GOTO 700
450 FOR J = 1 TO LOC1
460 T$ = INPUT$(1,#1) : IF T$=LF$ THEN 490
465 PRINT T$;
470 IF T$=CR$ THEN PRINT A$ : LIN$(I) = A$ : I = I+1 : A$="" : GOTO 490
480 A$ = A$+T$
490 NEXT J
500 IF A$<"" THEN PRINT A$ : LIN$(I) = A$ : N = I : GOTO 700
520 N = I-1 : GOTO 700
530 LOC1 = LOC(1) : IF LOC1=81 THEN 620
540 NL = NL+1 : IF NL<10 THEN 530
550 IF LOC181 THEN 600
560 PRINT "Waiting to fill the buffer."
570 FOR X = 1 TO 100 : NEXT X
580 LOC1 = LOC(1)
590 GOTO 620
600 LIN$(I)=INPUT$(81,#1)
610 I = I+1 : GOTO 530
```

APPENDIX B. (Continued)

```
 620 LIN$(I) = INPUT$(LOC1,#1)
 630 NENDS = 0 : PRINT #1,L1$
 640 LIN$(I) = LEFT$(LIN$(I),79)
 650 IF P$="Y" THEN PRINT LIN$(I)
 660 IF HP$="N" THEN 670
 662 LPRINT LIN$(I)
 665 FOR X = 1 TO 200 : NEXT X
 670 IF J/500<INT(J/500) THEN GOTO 280
 680 REM ***  EITHER 500 LOOPS HAVE OCCURE[ OR THE END OF FILE HAS OCCURRED
 690 N = 500
 700 FOR L = 1 TO N
 710 PRINT #3,LIN$(L)
 720 NEXT L
 730 IF J<510 THEN TIM2$ = TIM1$ ELSE TIM2$ = TIM3$
 740 TIM3$ = TIME$
 750 PRINT : PRINT : PRINT
 760 PRINT N;"Lines read and written in the time period from ";TIM2$;" to ";TIM3$
 770 PRINT
 780 I = 0 : IF N=500 THEN 280
 790 GOTO 920
 800 REM ***
 810 REM ***  ERROR TRAPPING ROUTINE
 820 REM ***
 830 IF ERR<61 THEN 860
 840 CLOSE #3 : BEEP : BEEP : PRINT : PRINT "The disk is Full.
     Please insert another formated disk in drive being used."
 850 GOSUB 950 : OPEN FIL$ FOR OUTPUT AS #3 : RESUME 0
 860 IF ERR=57 THEN PRINT "I/O Error in LINE # ";ERL;".
     Will Continue." : RESUME NEXT
 865 CLOSE #3 : CLOSE #1
 870 BEEP : PRINT "ERROR # = ";ERR,"ERROR LINE = ";ERL
 880 ON ERROR GOTO 0
 890 REM ***
 900 REM ***  CLOSE FILES AND EXIT
 910 REM ***
 920 CLOSE #3 : CLOSE #1
 930 PRINT : PRINT :PRINT  " THE TIME STARTED: ";TIM1$;TAB(35);"TIME ENDING: ";TIME$
 940 END
 950 REM *********************************************************************
 960 REM ***
 970 REM ***  Pause function
 980 REM ***
 990 PRINT : PRINT "Hit any key when Ready."
1000 T$ = INKEY$ : IF T$="" THEN 1000
1010 RETURN
1020 REM *********************************************************************
1030 REM ***
1040 REM ***  Turn on the printing
1050 REM ***
1060 P$ = "Y
1070 RETURN
1080 REM *********************************************************************
1090 REM ***
1100 REM ***  Turn ON the printer
1110 REM ***
```

APPENDIX B. (Continued)

```
1120 HP$ = "Y"
1130 RETURN
1140 REM *********************************************************************
1150 REM ***
1160 REM ***  Turn off the printing
1170 REM ***
1180 P$ = "N"
1190 RETURN
1200 REM *********************************************************************
1210 REM ***
1220 REM ***  Turn OFF the printer
1230 REM ***
1240 HP$ = "N"
1250 RETURN
1260 REM *********************************************************************
1270 REM ***
1280 REM ***  Pause the data transfer
1290 REM ***
1300 GOSUB 990
1305 RETURN
1320 REM *********************************************************************
1330 REM ***
1340 REM ***  Stop the data transfer
1350 REM ***
1360 N = I-1
1370 GOTO 700
1380 END
```

APPENDIX C
LISTING OF TABLE.BAS PROGRAM

APPENDIX C
LISTING OF TABLE.BAS PROGRAM

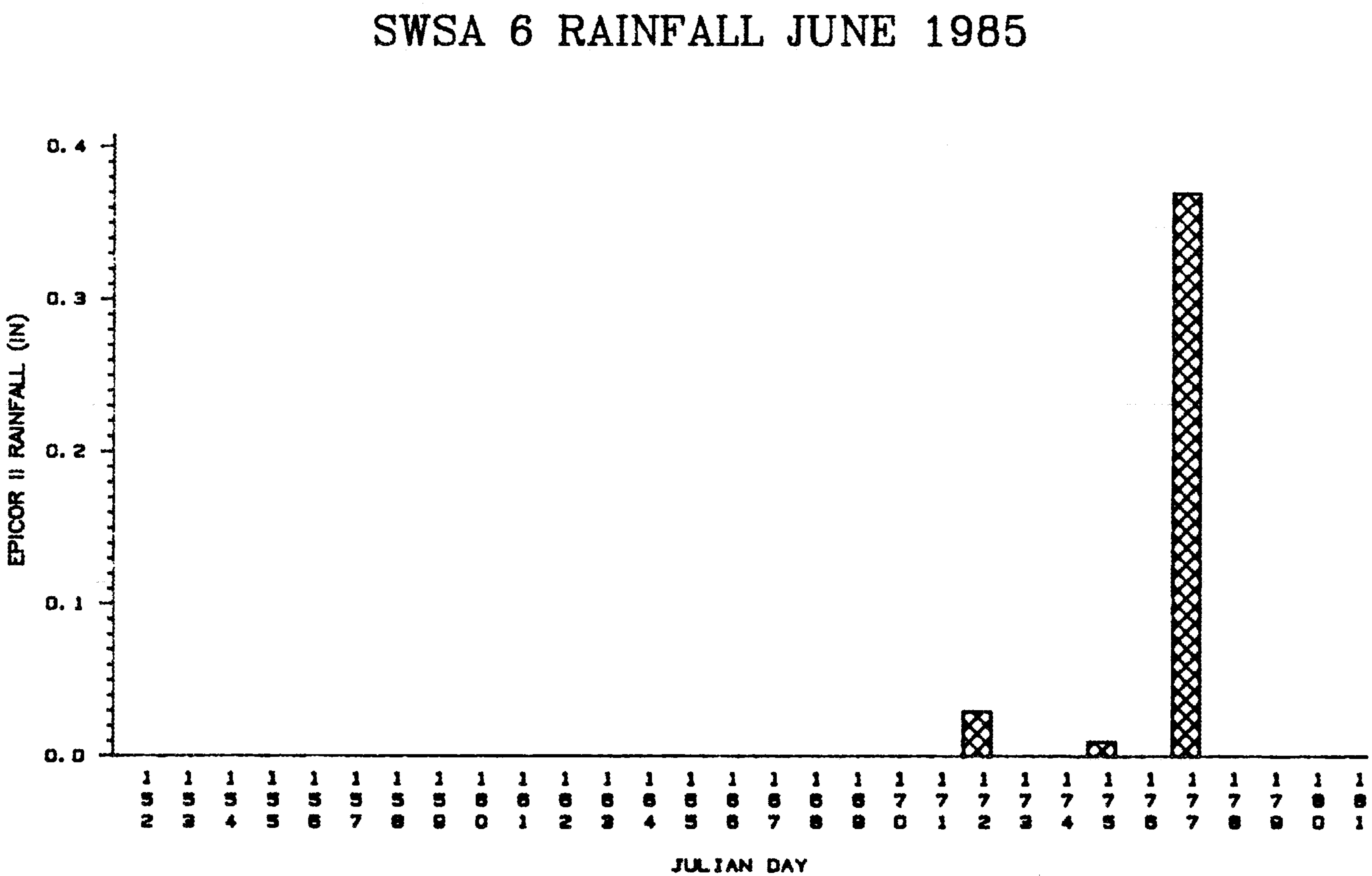
```
10 REM THIS PROGRAM EXTRACTS MET DATA AND PUTS IT IN A FILE
20 CLS
30 LOCATE 10,10
40 INPUT  "ENTER THE FILE NAME OF THE DATA TO BE TABULATED:" ; FIL1$
50 CLS
60 LOCATE 10,10
70 INPUT "ENTER THE FILE NAME TO SAVE THE SUMMARY TABLES IN:" ; FIL3$
80 PRINT CHR$(12);
90 LOCATE 10,10 : PRINT "********** PLEASE WAIT, DATA BEING PROCESSED **********"
100 OPEN FIL1$ FOR INPUT AS #1
110 OPEN FIL3$ FOR OUTPUT AS #3
120 REM SET UP AN ARRAY A WITH A DIMENSION OF 200
130 DIM A#(200)
140 GOTO 170
150 REM NOW 200 NUMBERS HAVE BEEN ENTERED INTO ARRAY A SO GO TO THE PRINT ROUTINE
155 PRINT "JULIAN DAY = ";A#(2); "      TIME = ";A#(3)
160 GOSUB 350
170 I=1
180 IF EOF(1) GOTO 260
190 LINE INPUT #1, L$
200 IC=3
210 FOR J=1 TO 8
220 A#(I)=VAL(MID$(L$,IC,6))
230 IF J=4 THEN IC=IC-1
240 IC=IC+10: I=I+1: NEXT J
250 IF I<200 GOTO 180 ELSE GOTO 155
260 GOSUB 920
270 CLOSE #3 : CLOSE #1
280 PRINT CHR$(12);
290 PRINT "*******FINISHED, FILE " FIL3$ " HAS BEEN CREATED*******"
300 PRINT "*******TO OBTAIN A HARD COPY OF THE SUMMARY TABLES PRINT THE FILE " FIL3$ " *******"
310 BEEP : BEEP : BEEP
320 END
330 REM LINES 230 TO 820 SET UP THE OUTPUT TABLE IN COLUMNS OF FOUR
340 REM OUTPUT IS TO DISK, FILE NAME DEFINED IN LINE 110
350 PRINT #3,CHR$(12);
360 PRINT #3,"********************************************************************************"
370 PRINT #3,SPC(27)"ORNL EPICOR-II FIELD TEST"
380 PRINT #3,TAB(10)"STATION ID="A#(1) TAB(36)"DATE="A#(2) TAB(60)"TIME="A#(3)
390 PRINT #3,"********************************************************************************"
400 PRINT #3,"RAINFALL="A#(4) TAB(20)"AIR TEMP="A#(5) TAB(40)"AVG HUM="A#(6) TAB(60)"WIND SPD="A#(7)
410 PRINT #3,"WIND DIR="A#(8) TAB(20)"TEMP1="A#(9) TAB(40)"TEMP2="A#(10) TAB(60)"TEMP3="A#(11)
420 PRINT #3,"TEMP4="A#(12) TAB(20)"TEMP5="A#(13) TAB(40)"TEMP6="A#(14) TAB(60)"TEMP7="A#(15)
430 PRINT #3,"TEMP8="A#(16) TAB(20)"TEMP9="A#(17) TAB(40)"TEMP10="A#(18) TAB(60)"TEMP11="A#(19)
440 PRINT #3,"TEMP12="A#(20) TAB(20)"TEMP13="A#(21) TAB(40)"TEMP14="A#(22) TAB(60)"TEMP15="A#(23)
450 PRINT #3,"MOIST1="A#(24) TAB(20)"MOIST2="A#(25) TAB(40)"MOIST3="A#(26) TAB(60)"MOIST4="A#(27)
460 PRINT #3,"MOIST5="A#(28) TAB(20)"MOIST6="A#(29) TAB(40)"MOIST7="A#(30) TAB(60)"MOIST8="A#(31)
470 PRINT #3,"MOIST9="A#(32) TAB(20)"MOIST10="A#(33) TAB(40)"MOIST11="A#(34) TAB(60)"MOIST12="A#(35)
480 PRINT #3,"MOIST13="A#(36) TAB(20)"MOIST14="A#(37) TAB(40)"MOIST15="A#(38) TAB(60)"THR VLT1="A#(39)
490 PRINT #3,"THR VLT2="A#(40) TAB(20)"THR VLT3="A#(41) TAB(40)"THR VLT4="A#(42) TAB(60)"THR VLT5="A#(43)
500 PRINT #3,"THR VLT6="A#(44) TAB(20)"THR VLT7="A#(45) TAB(40)"THR VLT8="A#(46) TAB(60)"THR VLT9="A#(47)
510 PRINT #3,"THR VLT10="A#(48) TAB(20)"THR VLT11="A#(49) TAB(40)"THR VLT12="A#(50) TAB(60)"THR VLT13="A#(51)
520 PRINT #3,"THR VLT14="A#(52) TAB(20)"THR VLT15="A#(53) TAB(40)"MOI VLT1="A#(54) TAB(60)"MOI VLT2="A#(55)
530 PRINT #3,"MOI VLT3="A#(56) TAB(20)"MOI VLT4="A#(57) TAB(40)"MOI VLT5="A#(58) TAB(60)"MOI VLT6="A#(59)
540 PRINT #3,"MOI VLT7="A#(60) TAB(20)"MOI VLT8="A#(61) TAB(40)"MOI VLT9="A#(62) TAB(60)"MOI VLT10="A#(63)
550 PRINT #3,"MOI VLT11="A#(64) TAB(20)"MOI VLT12="A#(65) TAB(40)"MOI VLT13="A#(66) TAB(60)"MOI VLT14="A#(67)
560 PRINT #3,"MOI VLT15="A#(68) TAB(20)"MIN TEMP="A#(69) TAB(40)"MIN HUM="A#(70) TAB(60)"MIN WSPD="A#(71)
570 PRINT #3,"MIN WDIR="A#(72) TAB(20)"MIN TEMP1="A#(73) TAB(40)"MIN TEMP2="A#(74) TAB(60)"MIN TEMP3="A#(75)
580 PRINT #3,"MIN TEMP4="A#(76) TAB(20)"MIN TEMP5="A#(77) TAB(40)"MIN TEMP6="A#(78) TAB(60)"MIN TEMP7="A#(79)
590 PRINT #3,"MIN TEMP8="A#(80) TAB(20)"MIN TEMP9="A#(81) TAB(40)"MIN TEMP10="A#(82) TAB(60)"MIN TEMP11="A#(83)
600 PRINT #3,"MIN TEMP12="A#(84) TAB(20)"MIN TEMP13="A#(85) TAB(40)"MIN TEMP14="A#(86) TAB(60)"MIN TEMP15="A#(87)
610 PRINT #3,"MIN MOI1="A#(88) TAB(20)"MIN MOI2="A#(89) TAB(40)"MIN MOI3="A#(90) TAB(60)"MIN MOI4="A#(91)
620 PRINT #3,"MIN MOI5="A#(92) TAB(20)"MIN MOI6="A#(93) TAB(40)"MIN MOI7="A#(94) TAB(60)"MIN MOI8="A#(95)
630 PRINT #3,"MIN MOI9="A#(96) TAB(20)"MIN MOI10="A#(97) TAB(40)"MIN MOI11="A#(98) TAB(60)"MIN MOI12="A#(99)
640 PRINT #3,"MIN MOI13="A#(100) TAB(20)"MIN MOI14="A#(101) TAB(40)"MIN MOI15="A#(102) TAB(60)"MIN TVLT1="A#(103)
650 PRINT #3,"MIN TVLT2="A#(104) TAB(20)"MIN TVLT3="A#(105) TAB(40)"MIN TVLT4="A#(106) TAB(60)"MIN TVLT5="A#(107)
660 PRINT #3,"MIN TVLT6="A#(108) TAB(20)"MIN TVLT7="A#(109) TAB(40)"MIN TVLT8="A#(110) TAB(60)"MIN TVLT9="A#(111)
670 PRINT #3,"MIN TVLT10="A#(112) TAB(20)"MIN TVLT11="A#(113) TAB(40)"MIN TVLT12="A#(114) TAB(60)"MIN TVLT13="A#(115)
680 PRINT #3,"MIN TVLT14="A#(116) TAB(20)"MIN TVLT15="A#(117) TAB(40)"MIN MVLT1="A#(118) TAB(60)"MIN MVLT2="A#(119)
690 PRINT #3,"MIN MVLT3="A#(120) TAB(20)"MIN MVLT4="A#(121) TAB(40)"MIN MVLT5="A#(122) TAB(60)"MIN MVLT6="A#(123)
700 PRINT #3,"MIN MVLT7="A#(124) TAB(20)"MIN MVLT8="A#(125) TAB(40)"MIN MVLT9="A#(126) TAB(60)"MIN MVLT10="A#(127)
710 PRINT #3,"MIN MVLT11="A#(128) TAB(20)"MIN MVLT12="A#(129) TAB(40)"MIN MVLT13="A#(130) TAB(60)"MIN MVLT14="A#(131)
720 PRINT #3,"MIN MVLT15="A#(132) TAB(20)"MAX TEMP="A#(133) TAB(40)"MAX HUM="A#(134) TAB(60)"MAX WSPD="A#(135)
730 PRINT #3,"MAX WDIR="A#(136) TAB(20)"MAX TEMP1="A#(137) TAB(40)"MAX TEMP2="A#(138) TAB(60)"MAX TEMP3="A#(139)
740 PRINT #3,"MAX TEMP4="A#(140) TAB(20)"MAX TEMP5="A#(141) TAB(40)"MAX TEMP6="A#(142) TAB(60)"MAX TEMP7="A#(143)
```

APPENDIX C. (Continued)

```
750 PRINT #3,"MAX TEMP8="A#(144) TAB(20)"MAX TEMP9="A#(145) TAB(40)"MAX TEMP10="A#(146) TAB(60)"MAX TEMP11="A#(147)
760 PRINT #3,"MAX TEMP12="A#(148) TAB(20)"MAX TEMP13="A#(149) TAB(40)"MAX TEMP14="A#(150) TAB(60)"MAX TEMP15="A#(151)
770 PRINT #3,"MAX MOI1="A#(152) TAB(20)"MAX MOI2="A#(153) TAB(40)"MAX MOI3="A#(154) TAB(60)"MAX MOI4="A#(155)
780 PRINT #3,"MAX MOI5="A#(156) TAB(20)"MAX MOI6="A#(157) TAB(40)"MAX MOI7="A#(158) TAB(60)"MAX MOI8="A#(159)
790 PRINT #3,"MAX MOI9="A#(160) TAB(20)"MAX MOI10="A#(161) TAB(40)"MAX MOI11="A#(162) TAB(60)"MAX MOI12="A#(163)
800 PRINT #3,"MAX MOI13="A#(164) TAB(20)"MAX MOI14="A#(165) TAB(40)"MAX MOI15="A#(166) TAB(60)"MAX TVLT1="A#(167)
810 PRINT #3,"MAX TVLT2="A#(168) TAB(20)"MAX TVLT3="A#(169) TAB(40)"MAX TVLT4="A#(170) TAB(60)"MAX TVLT5="A#(171)
820 PRINT #3,"MAX TVLT6="A#(172) TAB(20)"MAX TVLT7="A#(173) TAB(40)"MAX TVLT8="A#(174) TAB(60)"MAX TVLT9="A#(175)
830 PRINT #3,"MAX TVLT10="A#(176) TAB(20)"MAX TVLT11="A#(177) TAB(40)"MAX TVLT12="A#(178) TAB(60)"MAX TVLT13="A#(179)
840 PRINT #3,"MAX TVLT14="A#(180) TAB(20)"MAX TVLT15="A#(181) TAB(40)"MAX MVLT1="A#(182) TAB(60)"MAX MVLT2="A#(183)
850 PRINT #3,"MAX MVLT3="A#(184) TAB(20)"MAX MVLT4="A#(185) TAB(40)"MAX MVLT5="A#(186) TAB(60)"MAX MVLT6="A#(187)
860 PRINT #3,"MAX MVLT7="A#(188) TAB(20)"MAX MVLT8="A#(189) TAB(40)"MAX MVLT9="A#(190) TAB(60)"MAX MVLT10="A#(191)
870 PRINT #3,"MAX MVLT11="A#(192) TAB(20)"MAX MVLT12="A#(193) TAB(40)"MAX MVLT13="A#(194) TAB(60)"MAX MVLT14="A#(195)
880 PRINT #3,"MAX MVLT15="A#(196) TAB(20)"AVG WSPD="A#(197) TAB(40)"AVG WMAG="A#(198) TAB(60)"AVG WDIR="A#(199)
890 PRINT #3,"SD WDIR="A#(200)
900 PRINT #3,"********************************************************************************"
910 RETURN
920 REM THIS ROUTINE CONSTRUCTS A FOOTNOTE TABLE
930 PRINT #3,CHR$(12);
940 PRINT #3,"********************************************************************************"
950 PRINT #3,SPC(27)"ORNL EPICOR-II FIELD TEST"
960 PRINT #3,SPC(19)"DEFINITION OF VARIABLES USED IN DATA TABLES"
970 PRINT #3,"********************************************************************************"
980 PRINT #3,TAB(10)"RAINFALL = PRECIPITATION (IN)"
990 PRINT #3,TAB(10)"AIR TEMP = AIR TEMPERATURE (DEGREES C)"
1000 PRINT #3,TAB(10)"AVG HUM = AVERAGE RELATIVE HUMIDITY (%)"
1010 PRINT #3,TAB(10)"WIND SPD = AVERAGE WIND SPEED ( )"
1020 PRINT #3,TAB(10)"WIND DIR = AVERAGE WIND DIRECTION ( )"
1030 PRINT #3,TAB(10)"TEMP1-TEMP15 = AVERAGE PROBE TEMPERATURE (DEGREES C)"
1040 PRINT #3,TAB(10)"MOIST1-MOIST15 = AVERAGE PROBE MOISTURE (%)"
1050 PRINT #3,TAB(10)"THR VLT1-THR VLT15 = AVERAGE THERMISTOR VOLTS (VOLTS)"
1060 PRINT #3,TAB(10)"MOI VLT1-MOI VLT15 = AVERAGE MOISTURE VOLTS (VOLTS)"
1070 PRINT #3,TAB(10)"MIN TEMP = MINIMUM AIR TEMPERATURE (DEGREES C)"
1080 PRINT #3,TAB(10)"MIN HUM = MINIMUM RELATIVE HUMIDITY (%)"
1090 PRINT #3,TAB(10)"MIN WSPD = MINIMUM WIND SPEED ( )"
1100 PRINT #3,TAB(10)"MIN WDIR = MINIMUM WIND DIRECTION ( )"
1110 PRINT #3,TAB(10)"MIN TEMP1-MIN TEMP15 = MINIMUM PROBE TEMPERATURE (DEG C)"
1120 PRINT #3,TAB(10)"MIN MOI1-MIN MOI15 = MINIMUM PROBE MOISTURE (%)"
1130 PRINT #3,TAB(10)"MIN TVLT1-MIN TVLT15 = MINIMUM THERMISTOR VOLTS (VOLTS)"
1140 PRINT #3,TAB(10)"MIN MVLT1-MIN MVLT15 = MINIMUM MOISTURE VOLTS (VOLTS)"
1150 PRINT #3,TAB(10)"MAX TEMP = MAXIMUM AIR TEMPERATURE (DEGREES C)"
1160 PRINT #3,TAB(10)"MAX HUM = MAXIMUM RELATIVE HUMIDITY (%)"
1170 PRINT #3,TAB(10)"MAX WSPD = MAXIMUM WIND SPEED ( )"
1180 PRINT #3,TAB(10)"MAX WDIR = MAXIMUM WIND DIRECTION ( )"
1190 PRINT #3,TAB(10)"MAX TEMP1-MAX TEMP15 = MAXIMUM PROBE TEMPERATURE (DEG C)"
1200 PRINT #3,TAB(10)"MAX MOI1-MAX MOI15 = MAXIMUM PROBE MOISTURE (%)"
1210 PRINT #3,TAB(10)"MAX TVLT1-MAX TVLT15 = MAXIMUM THERMISTOR VOLTS (VOLTS)"
1220 PRINT #3,TAB(10)"MAX MVLT1-MAX MVLT15 = MAXIMUM MOISTURE VOLTS (VOLTS)"
1230 PRINT #3,TAB(10)"AVG WSPD = AVERAGE WIND SPEED ( )"
1240 PRINT #3,TAB(10)"AVG WMAG = AVERAGE WINDVECTOR MAGNITUDE ( )"
1250 PRINT #3,TAB(10)"AVG WDIR = AVERAGE WINDVECTOR DIRECTION ( )"
1260 PRINT #3,TAB(10)"SD WDIR = STANDARD DEVIATION OF WIND DIRECTION ( )"
1270 PRINT #3,"********************************************************************************"
1280 RETURN
```

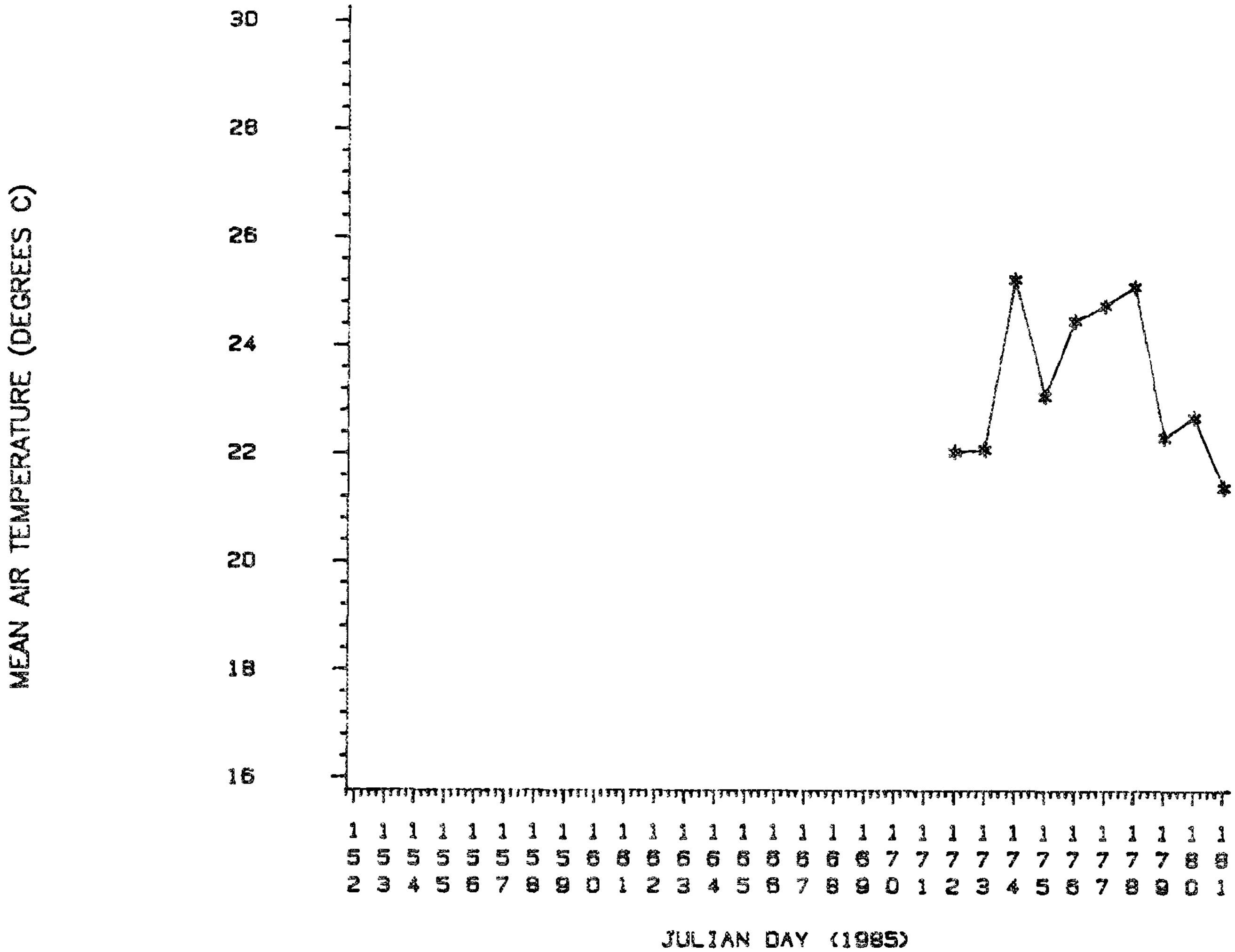
APPENDIX D
METEOROLOGICAL DATA FROM JUNE THROUGH AUGUST 1985

ORNL-DWG 86-1472



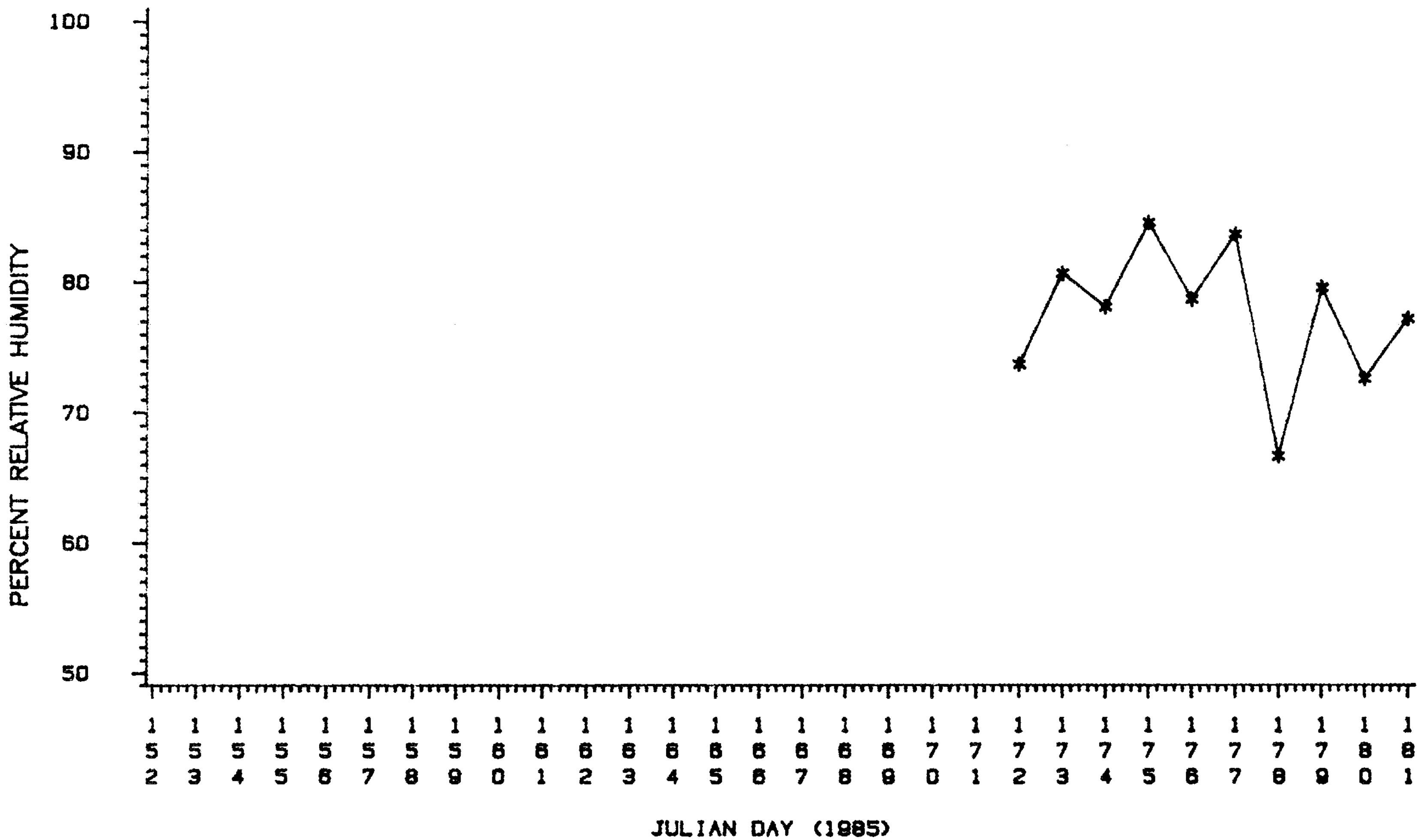
ORNL-DWG 86-1473

SWSA 6 AIR TEMPERATURE JUNE 1985



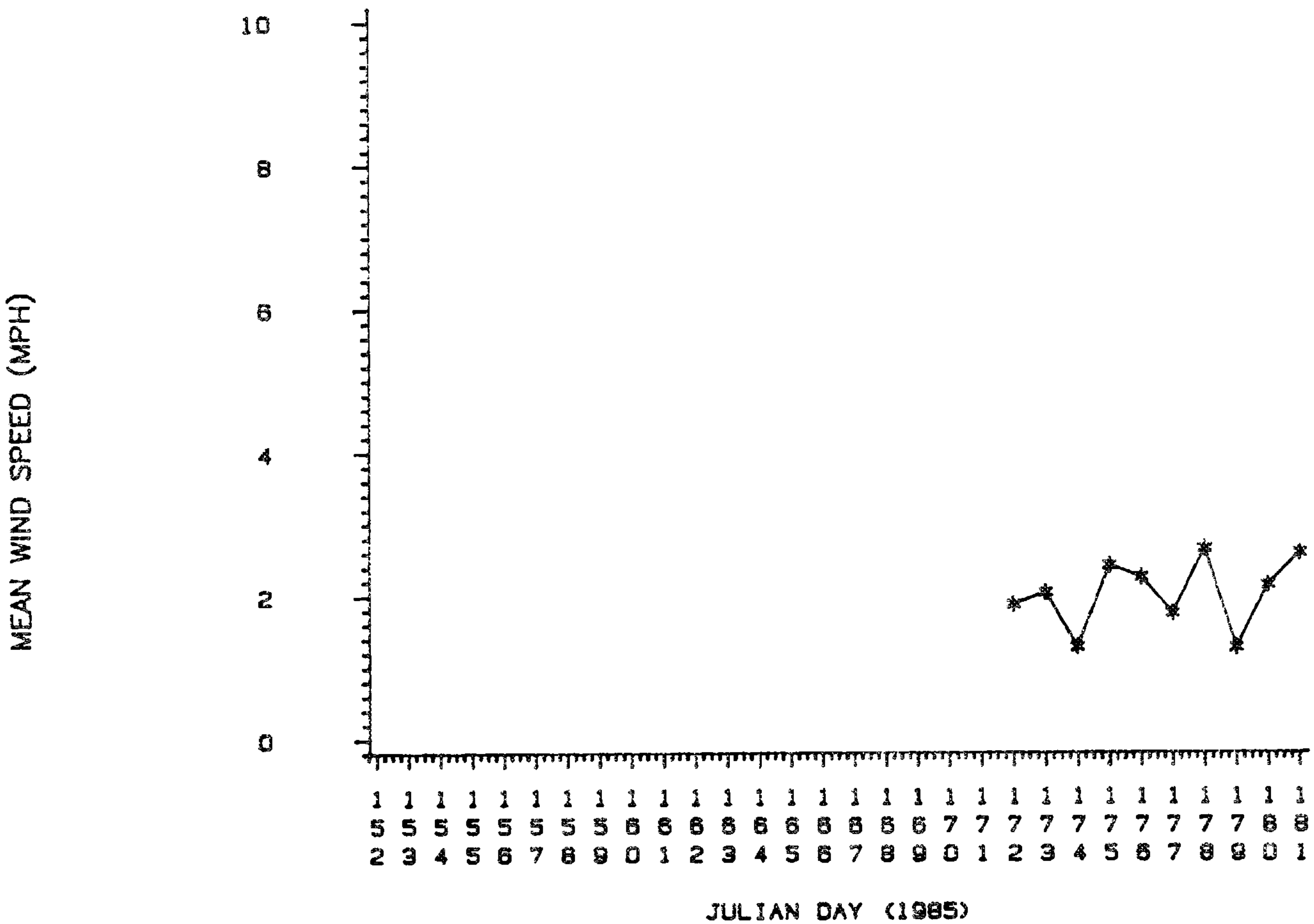
ORNL-DWG 86-1474

SWSA 6 RELATIVE HUMIDITY JUNE 1985



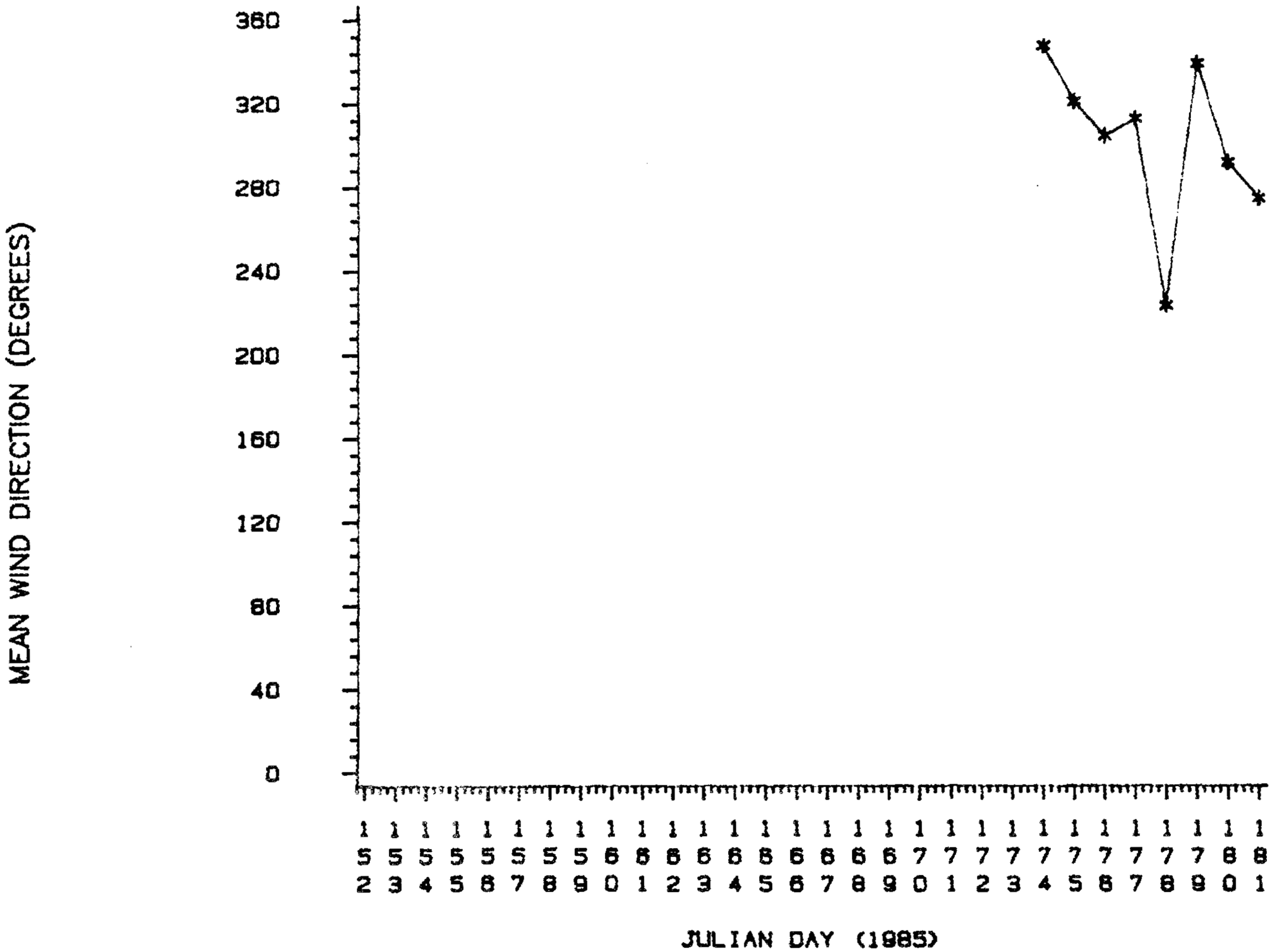
ORNL-DWG 86-1475

SWSA 6 WIND SPEED JUNE 1985



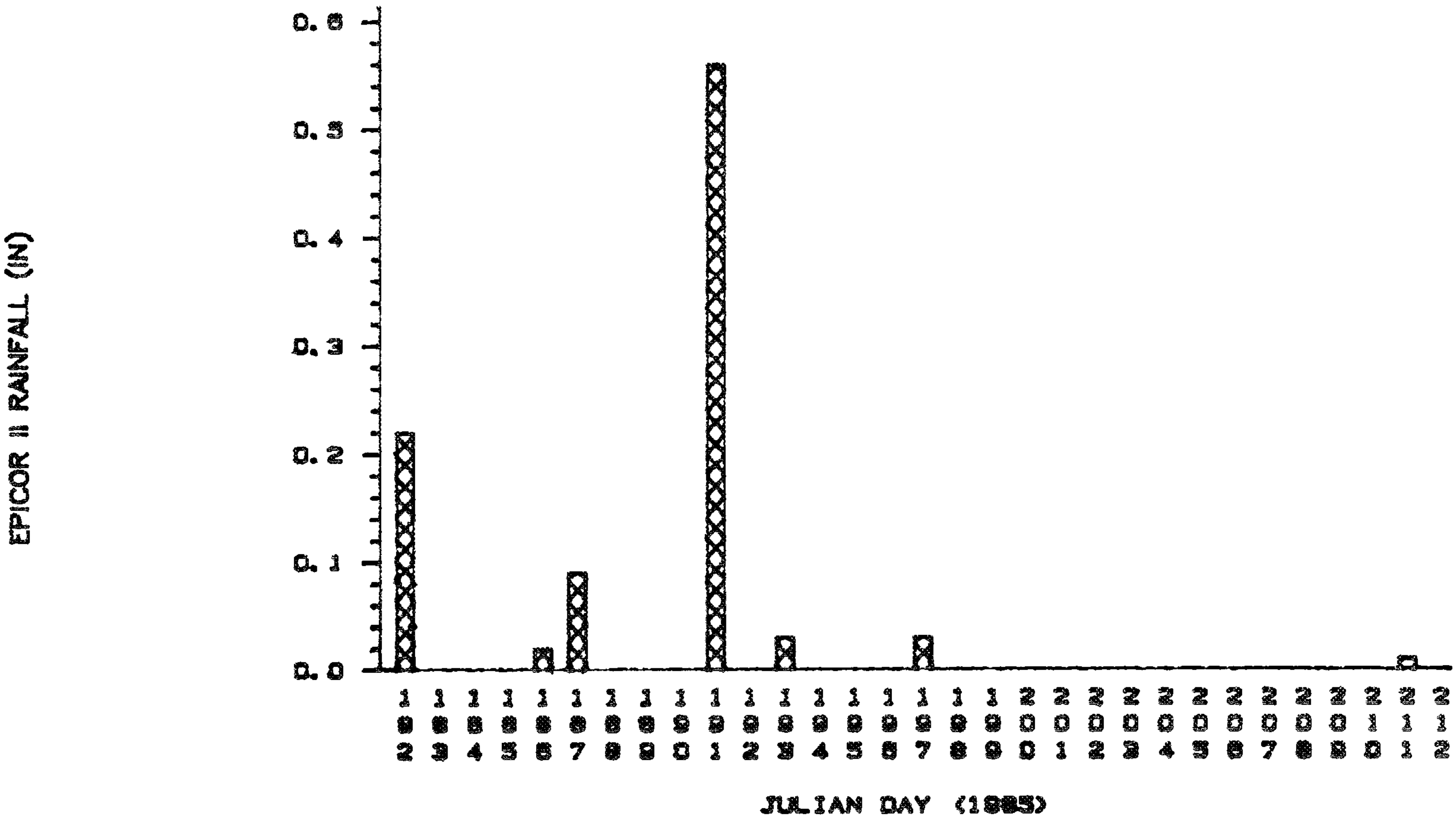
ORNL-DWG 86-1476

SWSA 6 WIND DIRECTION JUNE 1985

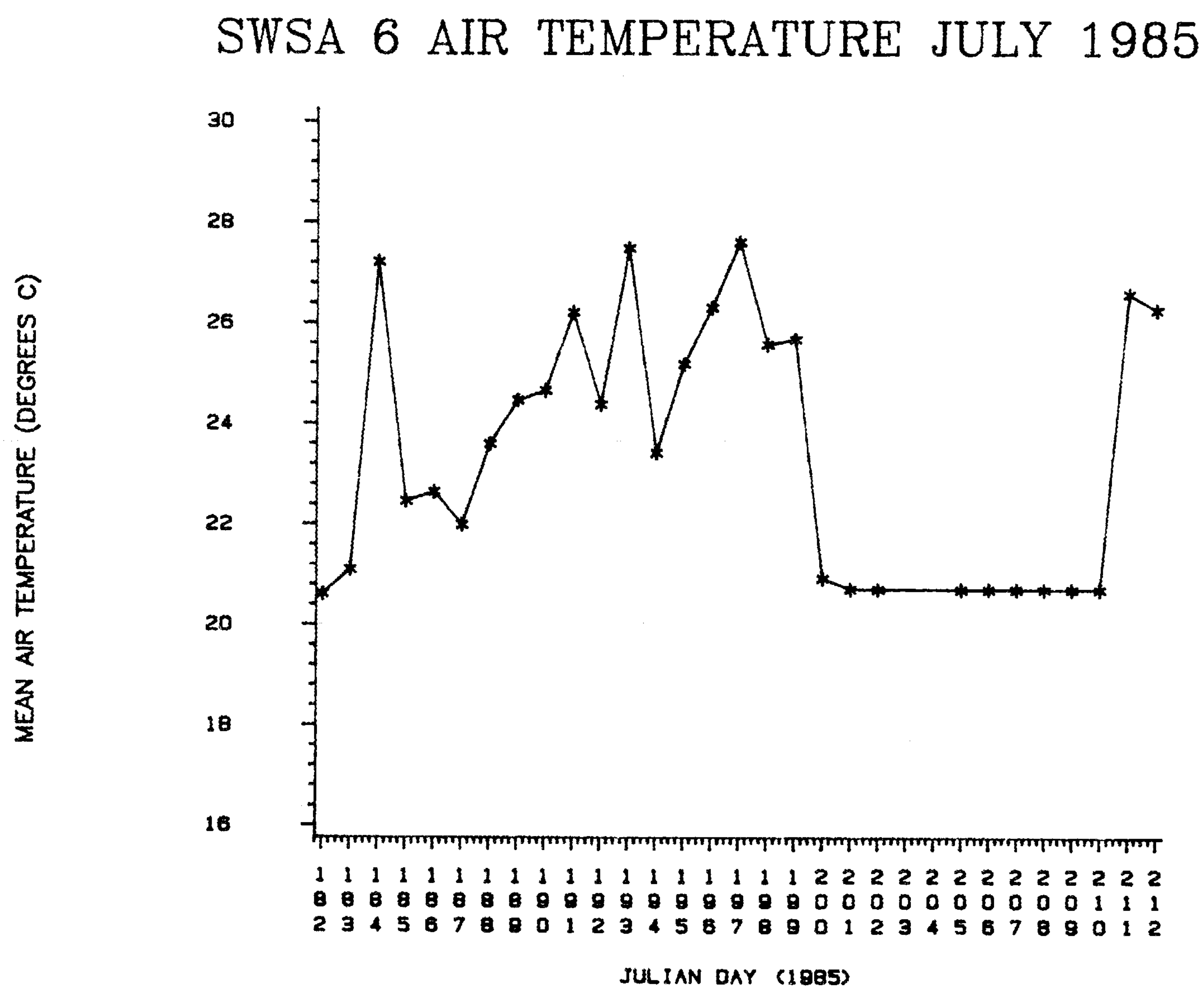


ORNL-DWG 86-1477

SWSA 6 RAINFALL JULY 1985

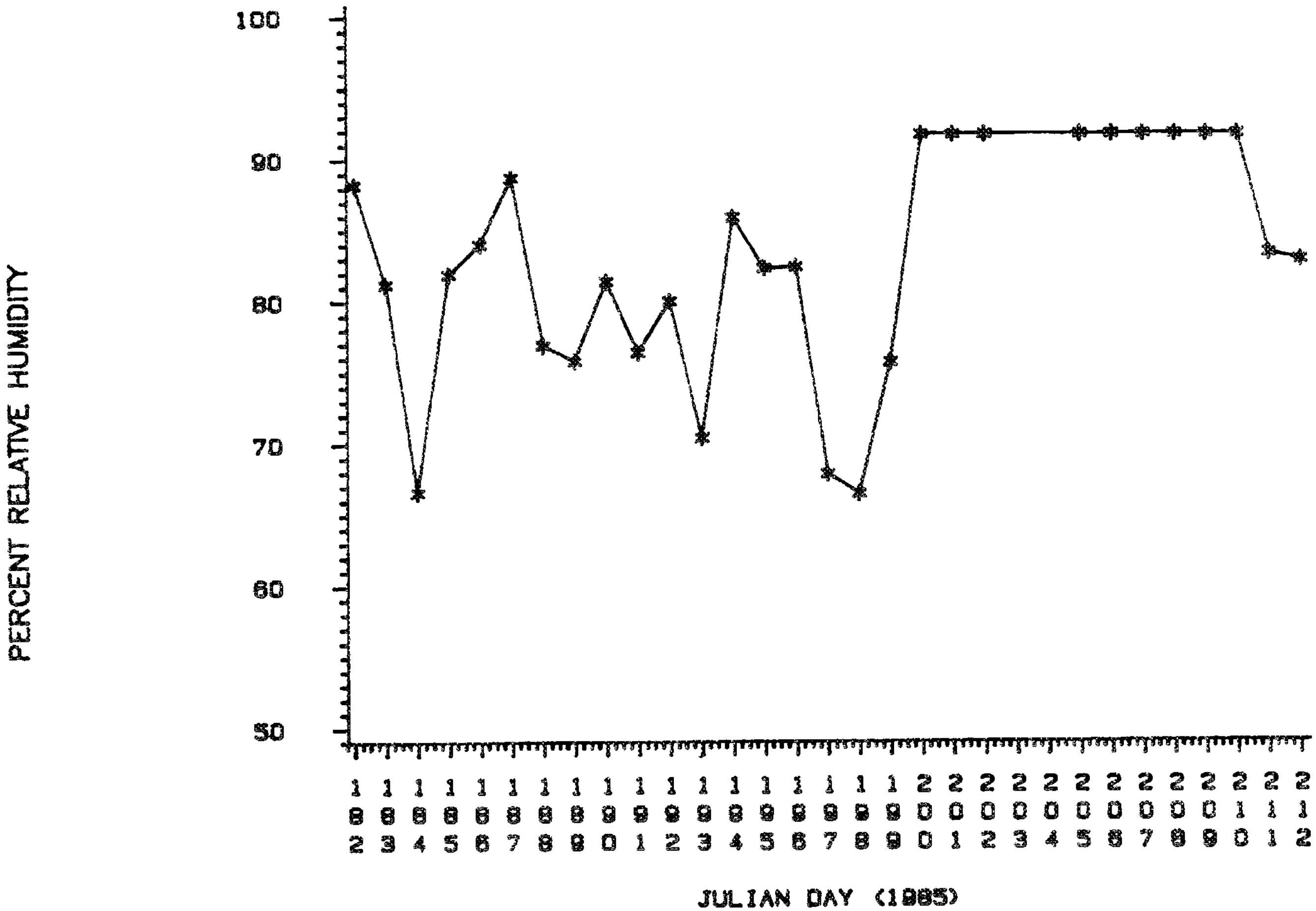


ORNL-DWG 86-1458



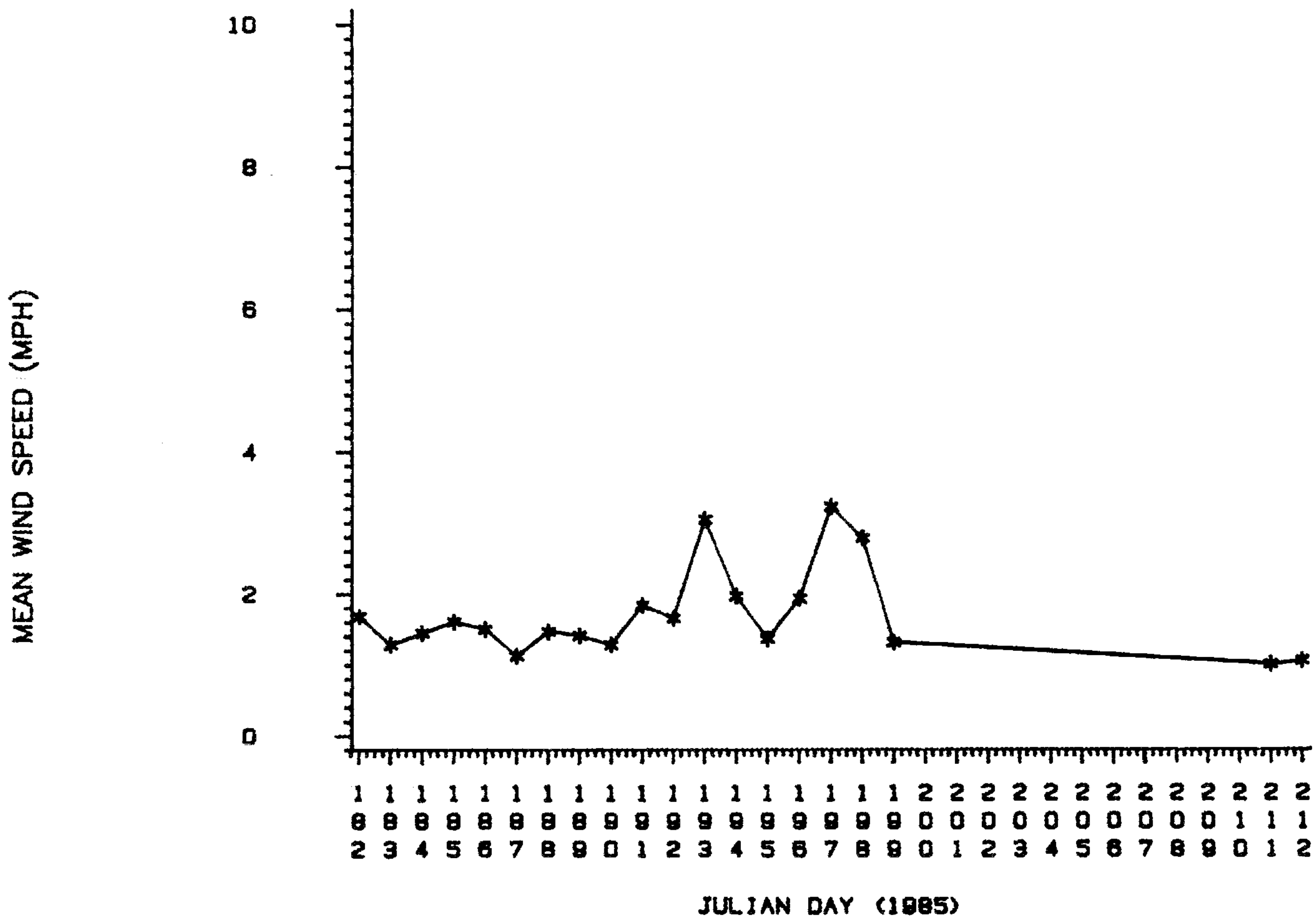
ORNL-DWG 86-1459

SWSA 6 RELATIVE HUMIDITY JULY 1985



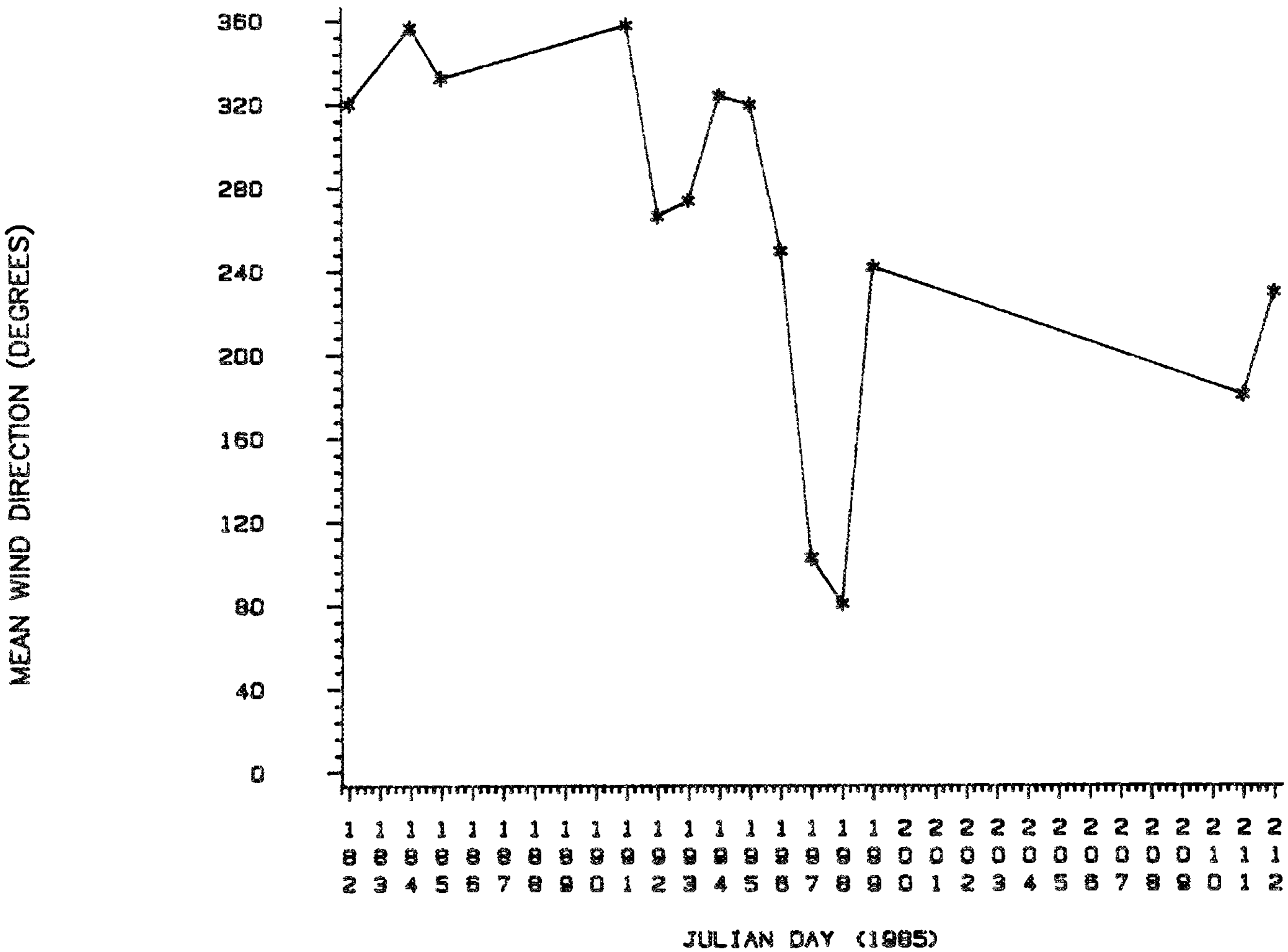
ORNL-DWG 86-1460

SWSA 6 WIND SPEED JULY 1985



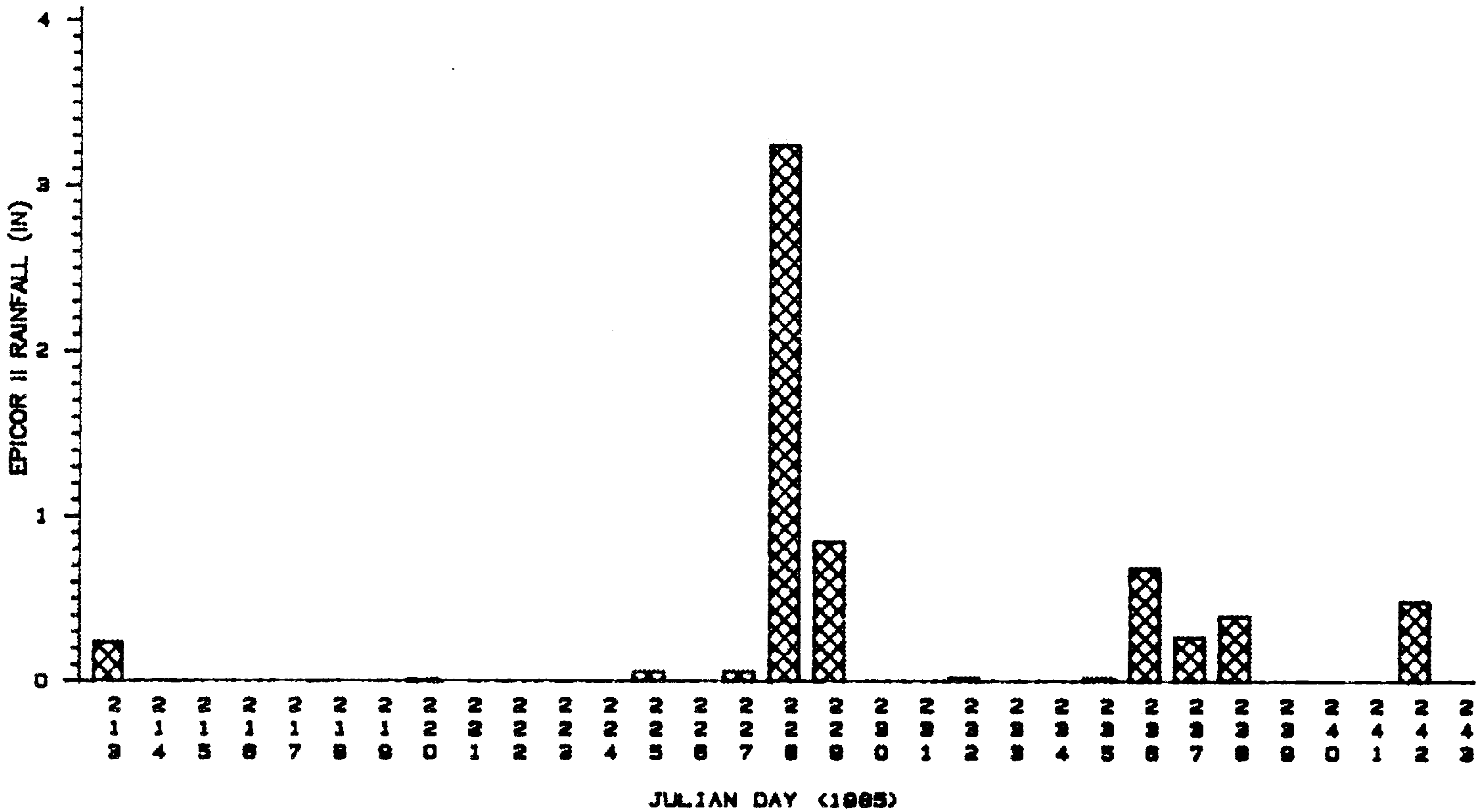
ORNL-DWG 86-1461

SWSA 6 WIND DIRECTION JULY 1985



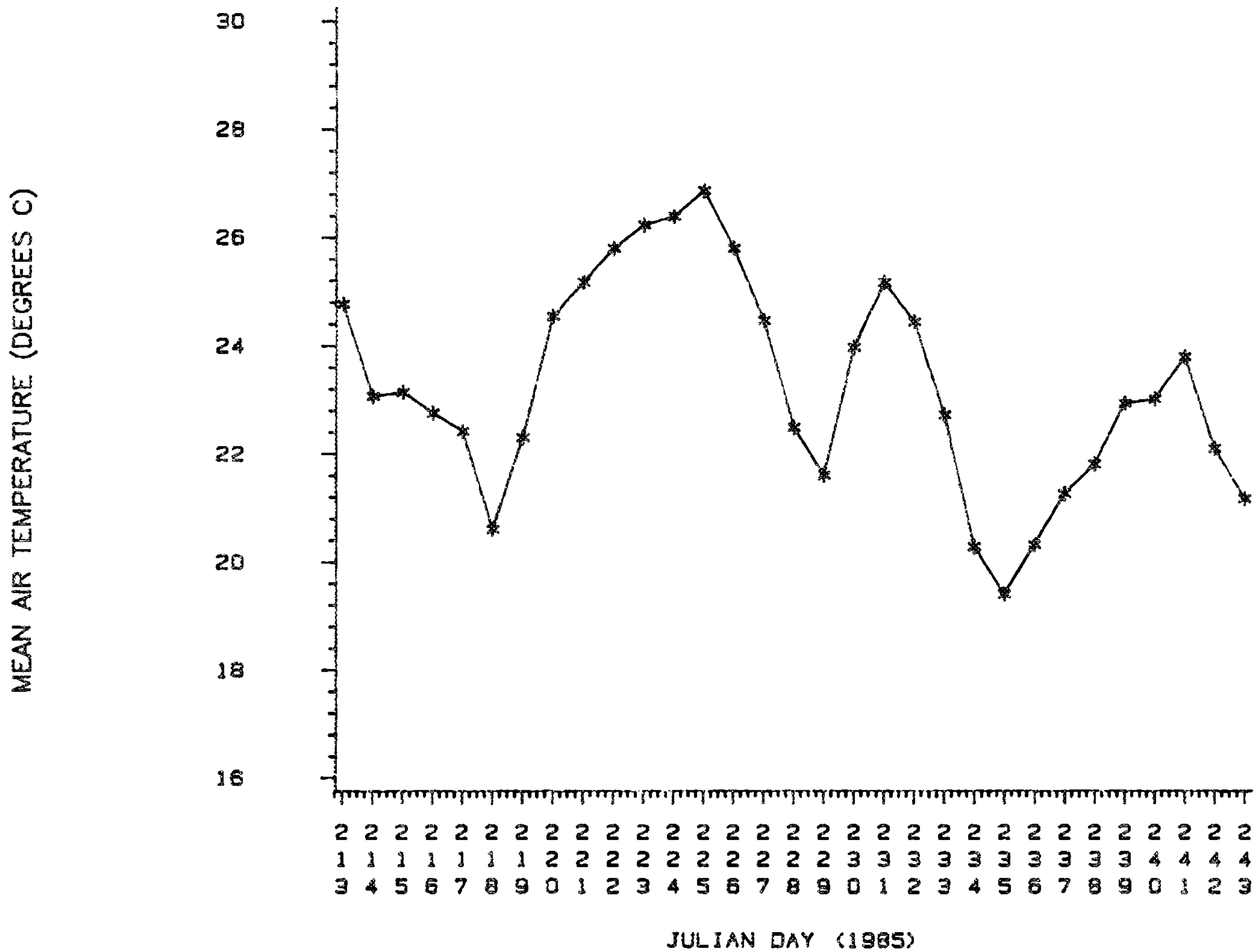
ORNL-DWG 86-1462

SWSA6 RAINFALL AUGUST 1985



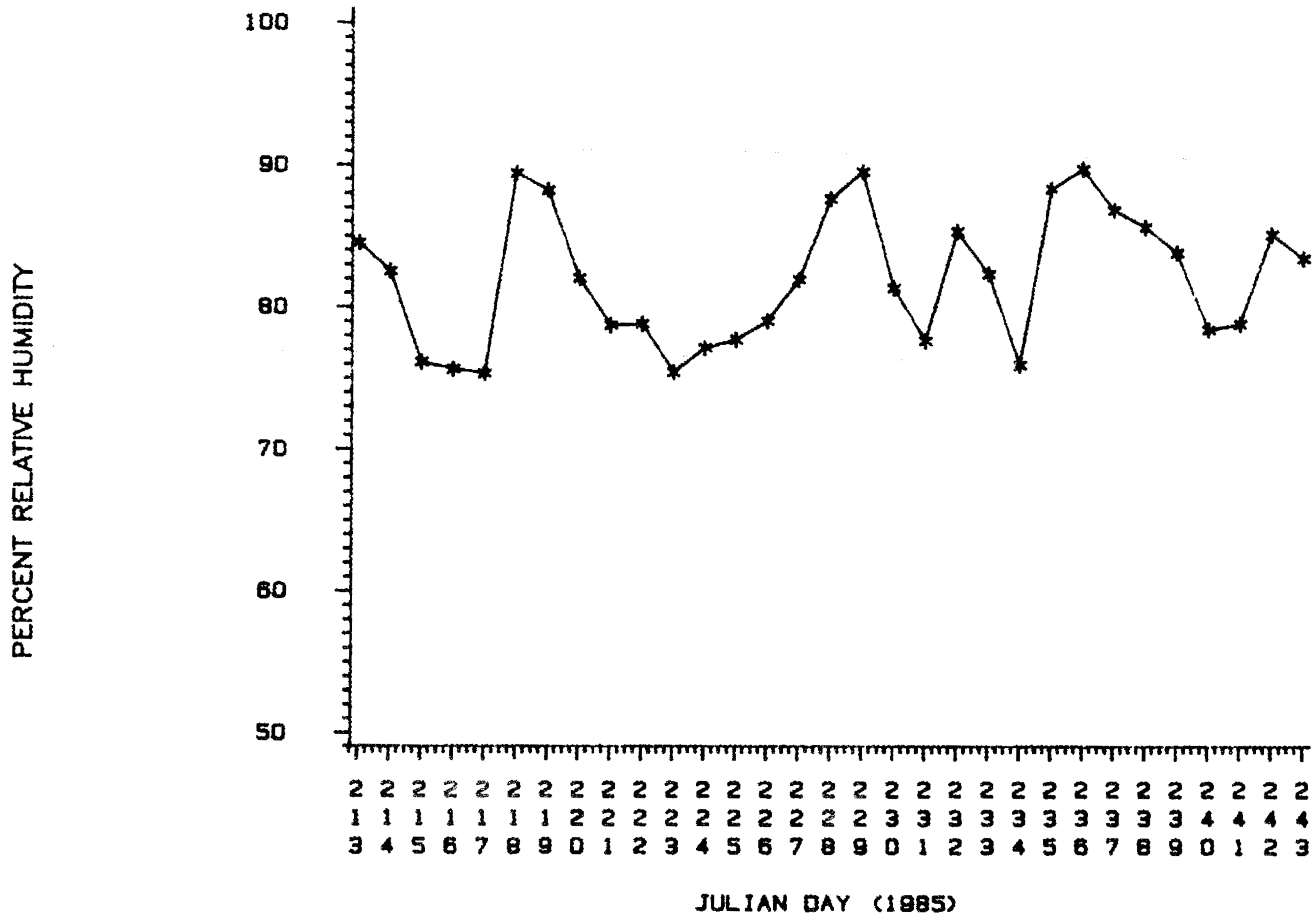
ORNL-DWG 86-1463

SWSA 6 AIR TEMPERATURE AUGUST 1985

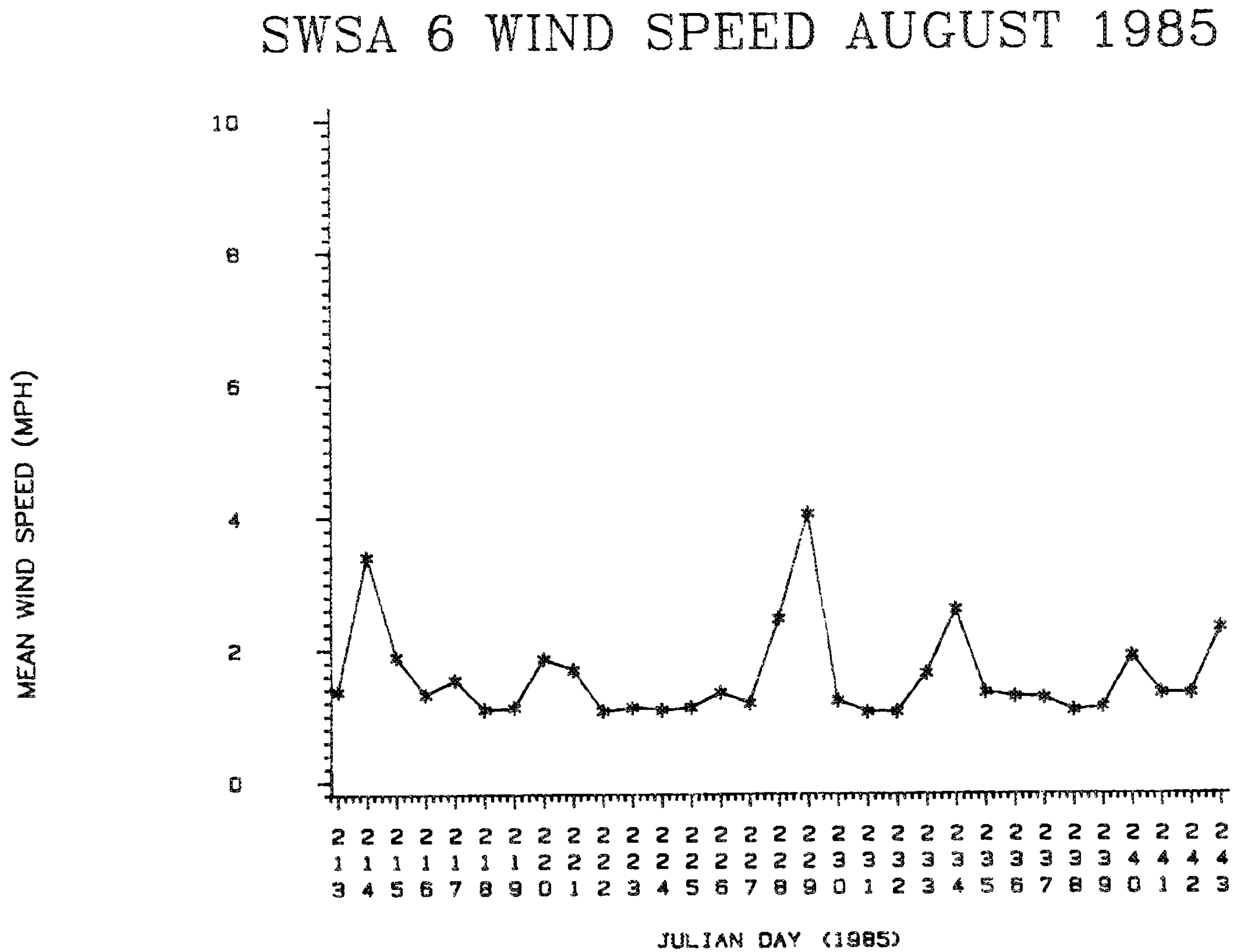


ORNL-DWG 86-1464

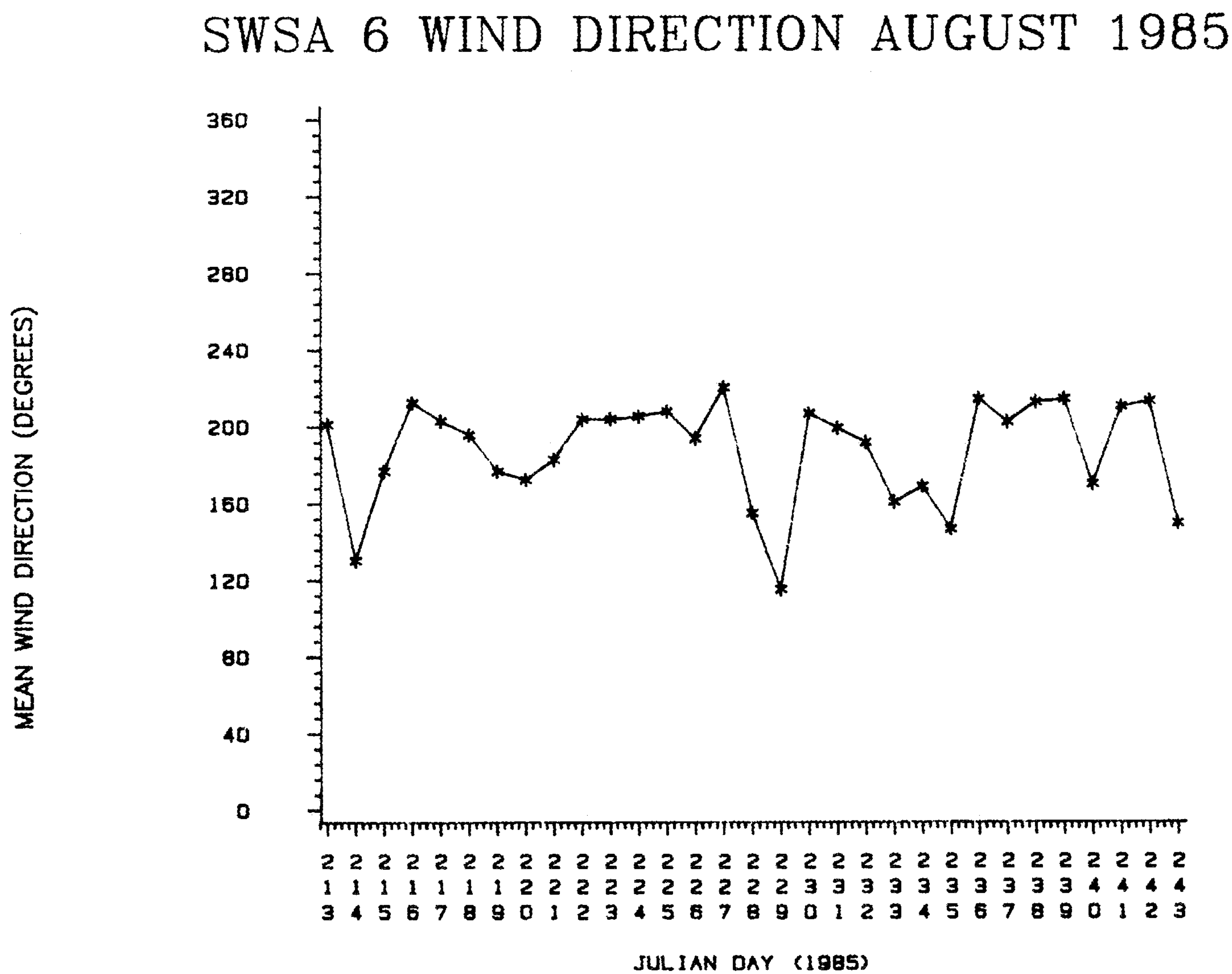
SWSA 6 RELATIVE HUMIDITY AUGUST 1985



ORNL-DWG 86-1465



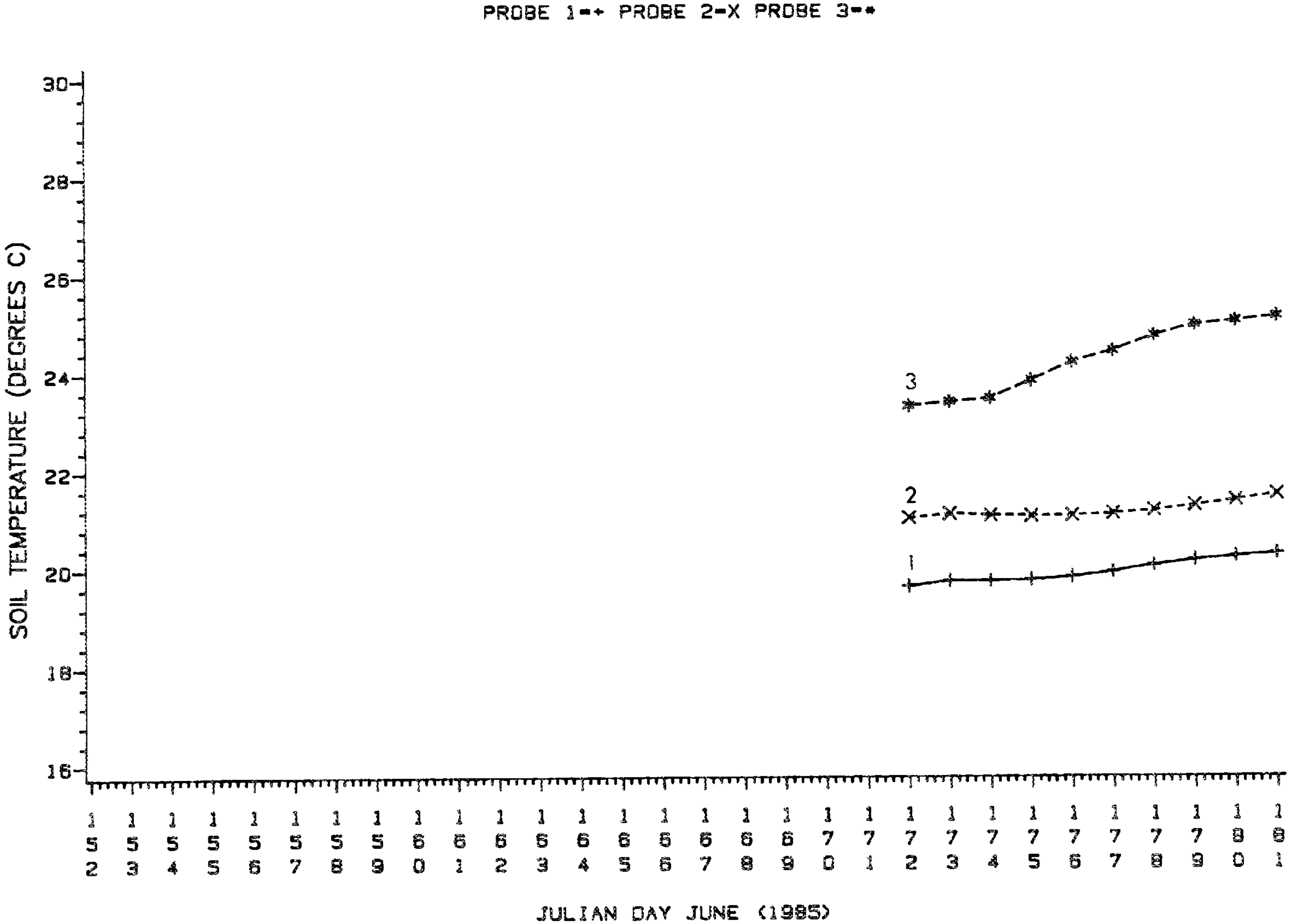
ORNL-DWG 86-1466



D-17

ORNL-DWG 86-1467

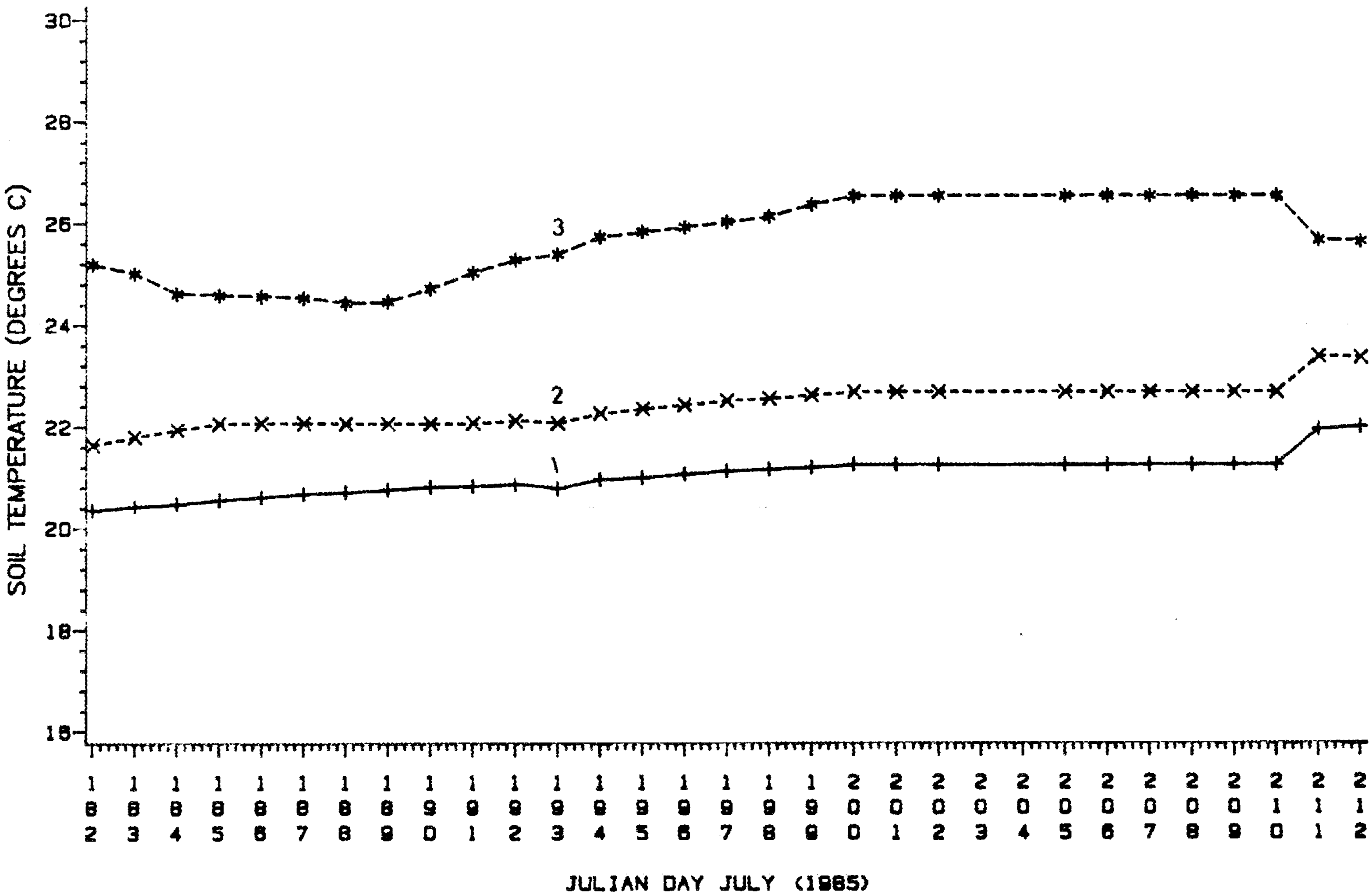
LYSIMETER ONE SOIL TEMPERATURE



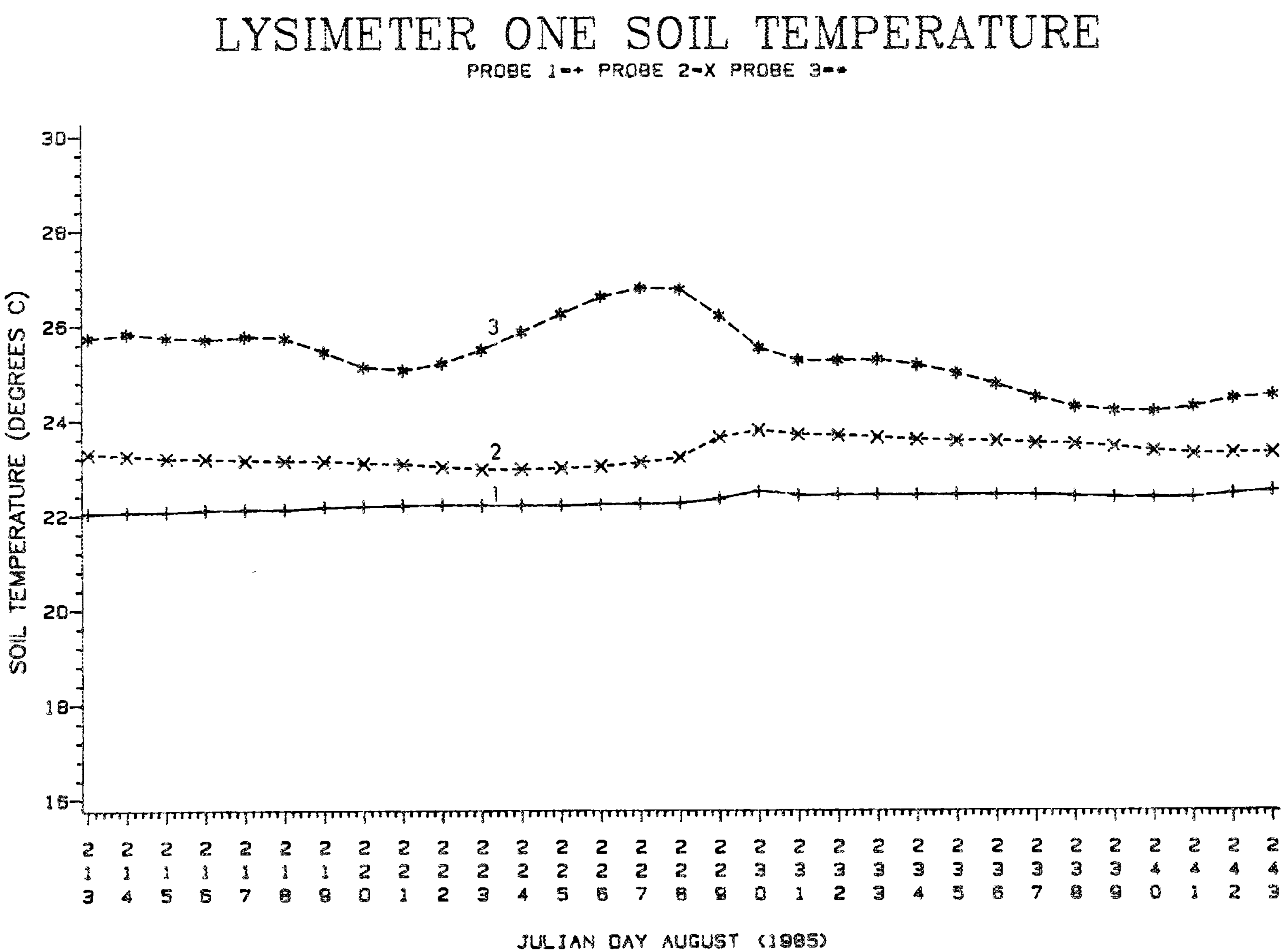
ORNL-DWG 86-1448

LYSIMETER ONE SOIL TEMPERATURE

PROBE 1=+ PROBE 2=X PROBE 3=*



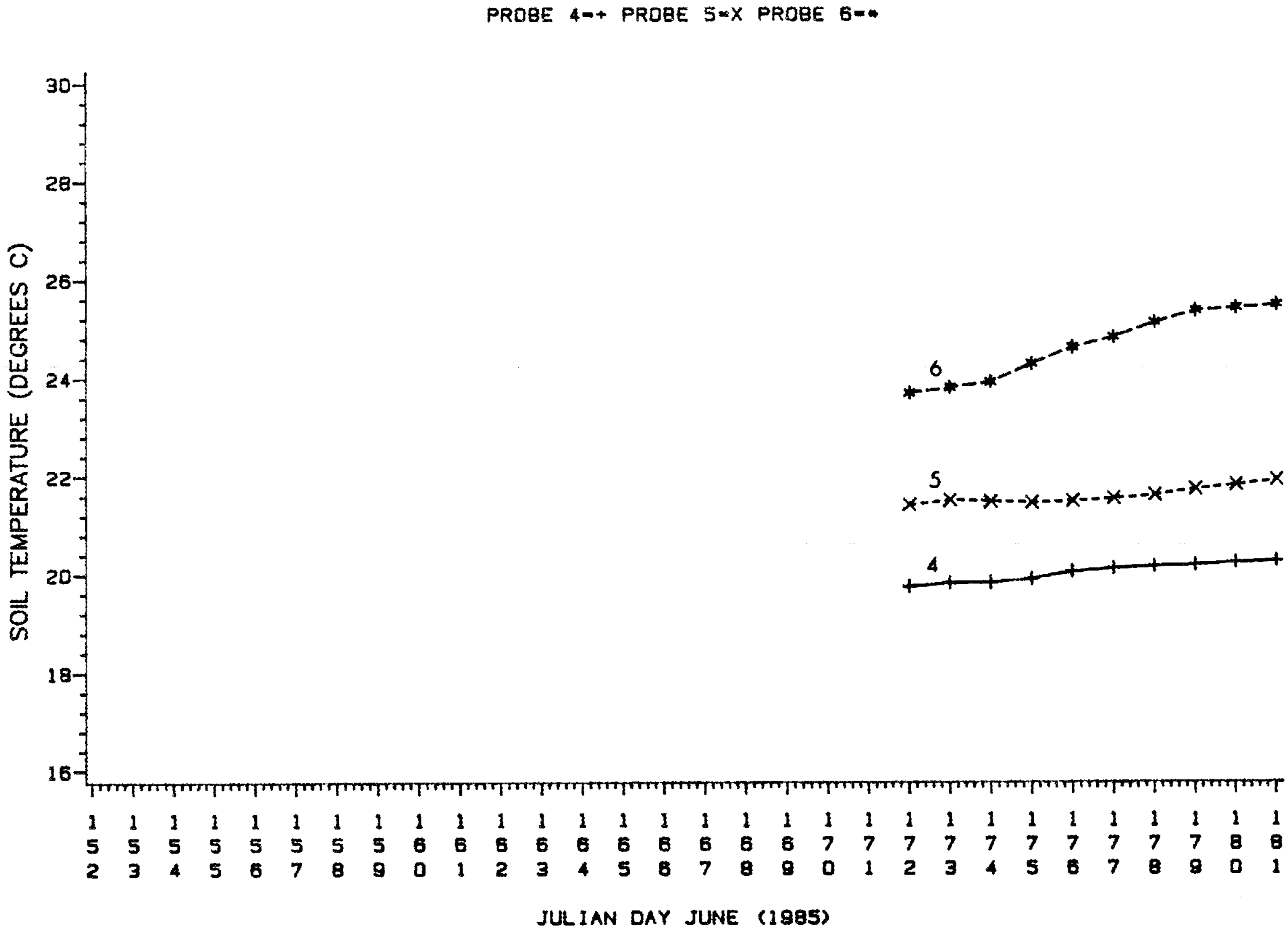
ORNL-DWG 86-1449



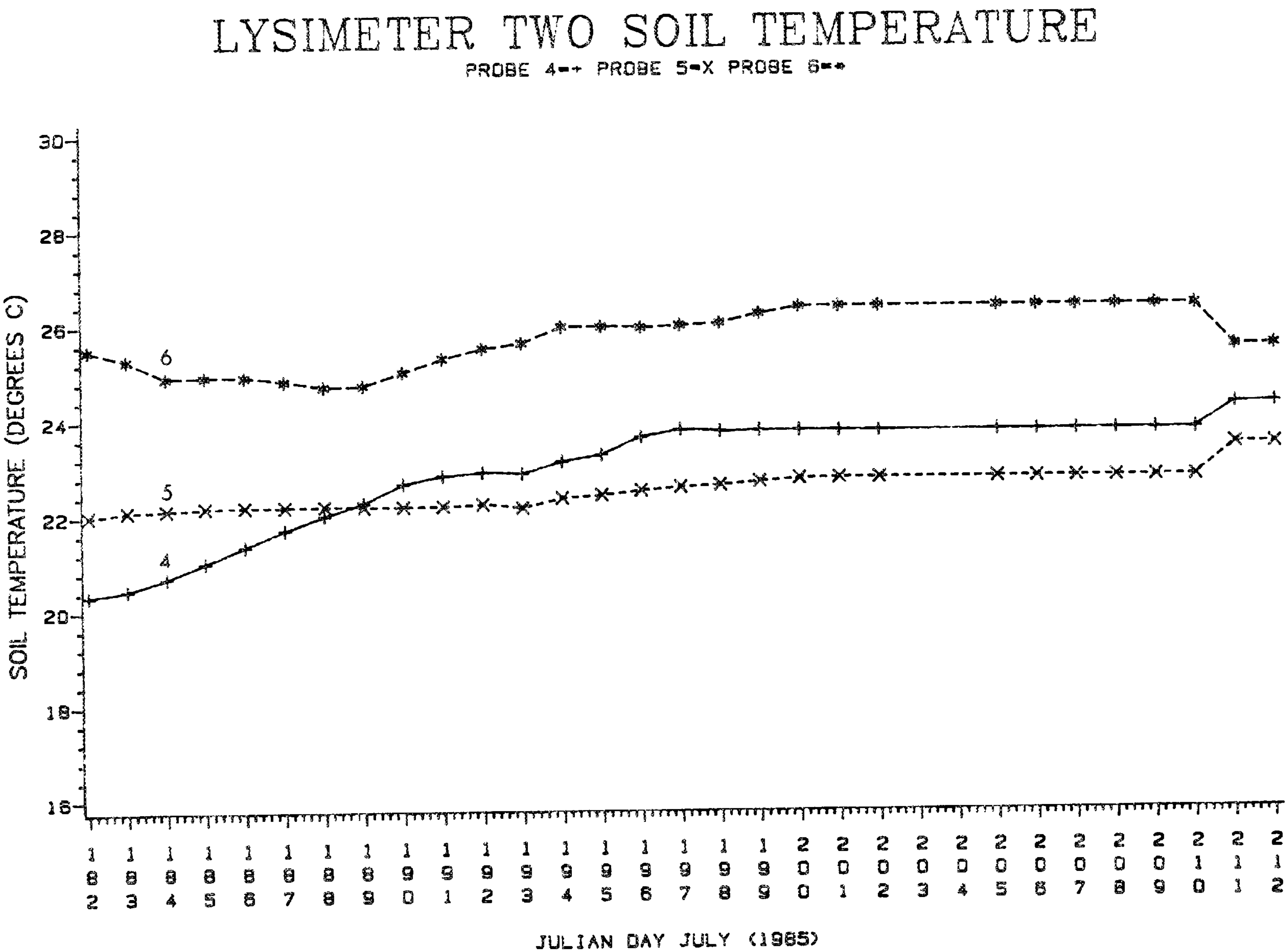
D-20

ORNL-DWG 86-1450

LYSIMETER TWO SOIL TEMPERATURE

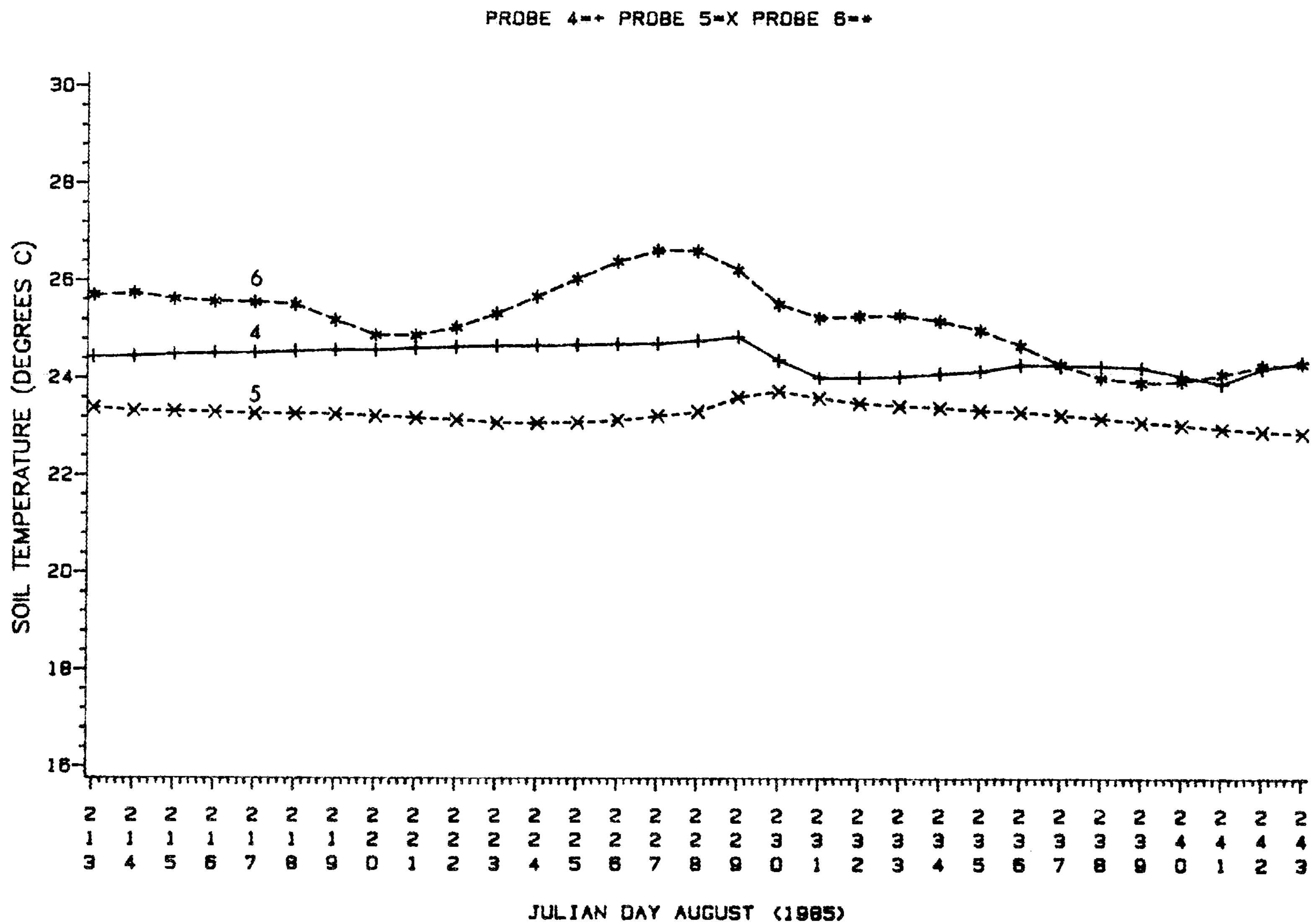


ORNL-DWG 86-1451



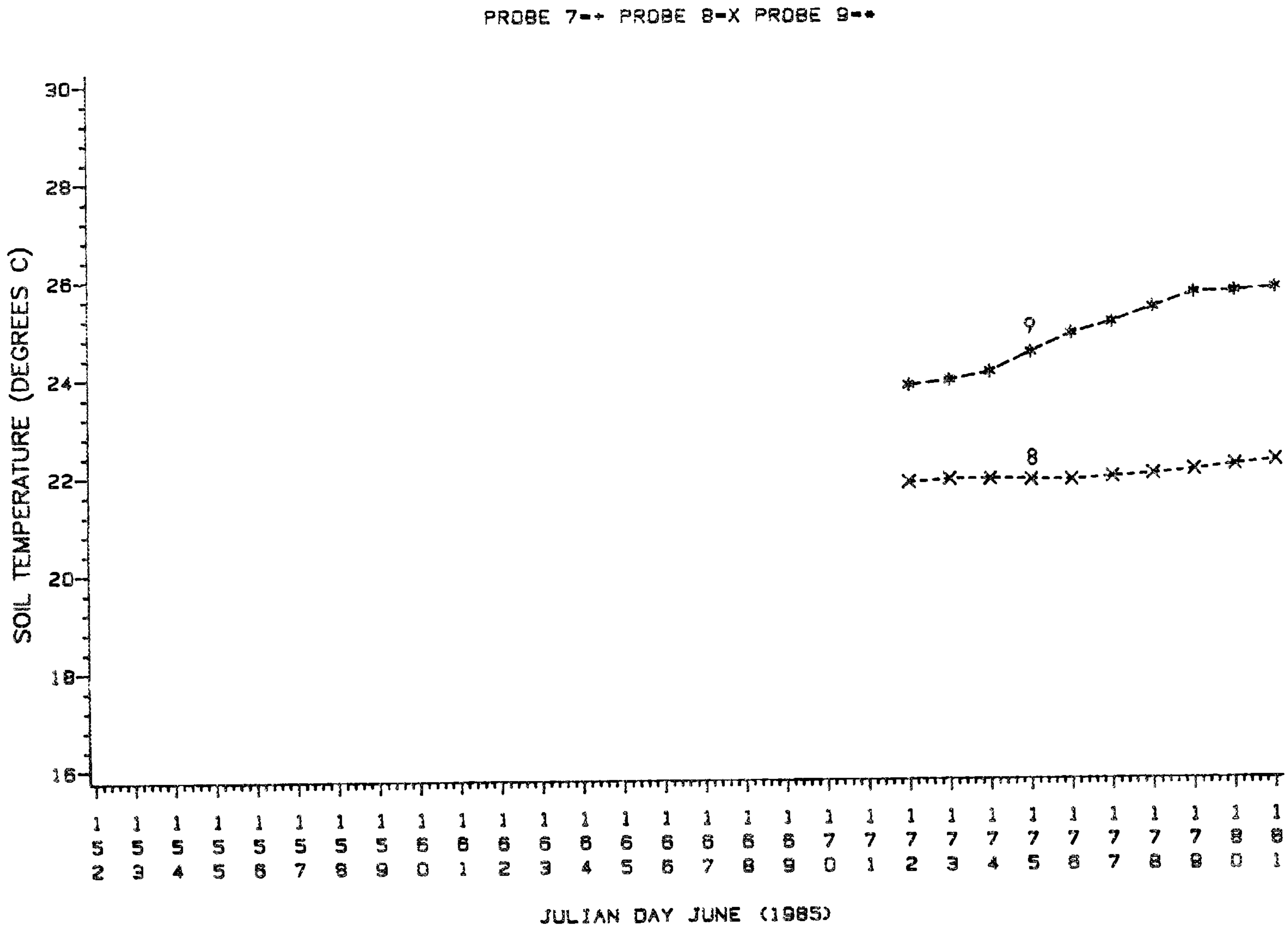
ORNL-DWG 86-1452

LYSIMETER TWO SOIL TEMPERATURE



ORNL-DWG 86-1453

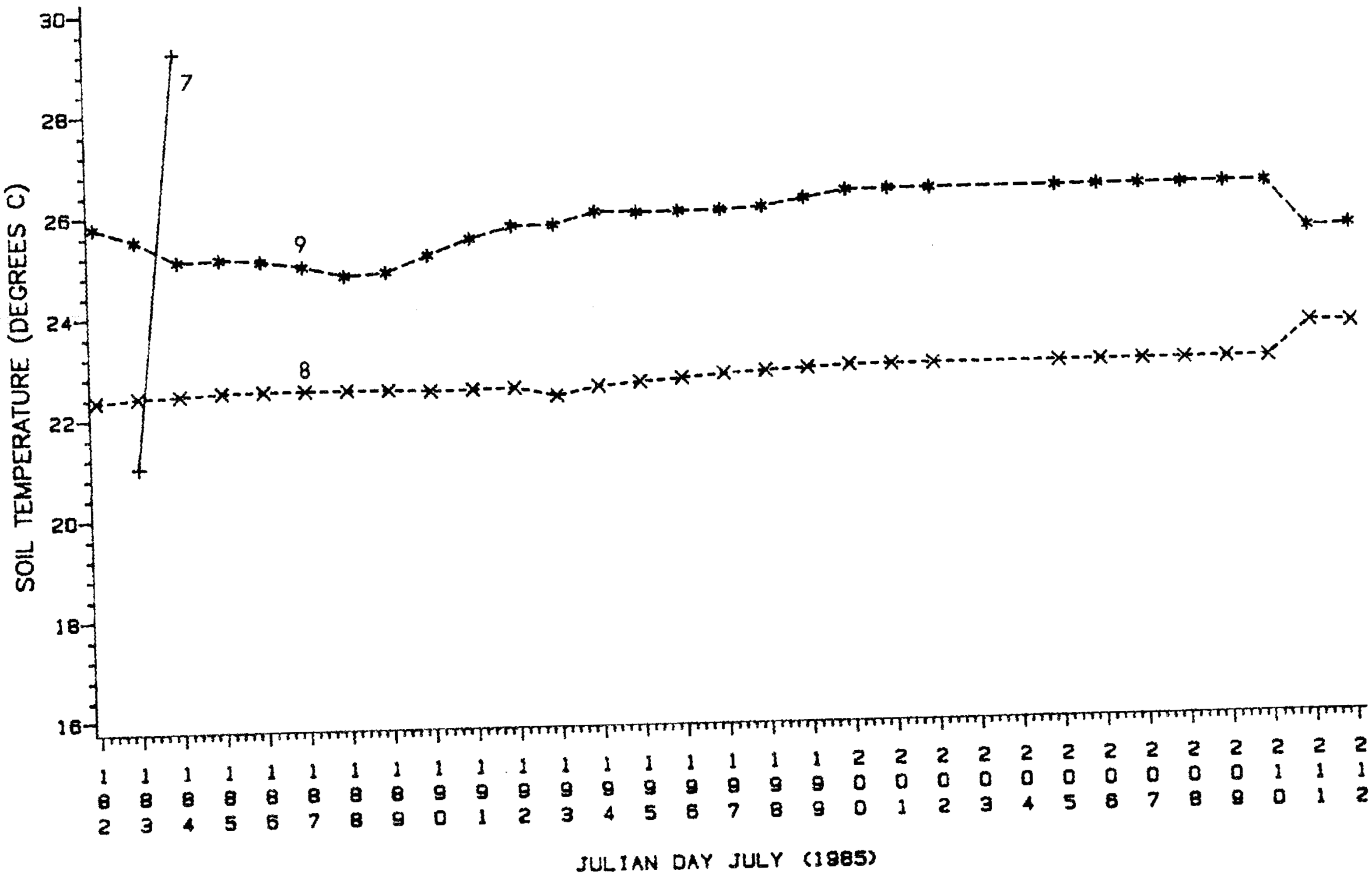
LYSIMETER THREE SOIL TEMPERATURE



ORNL-DWG 86-1454

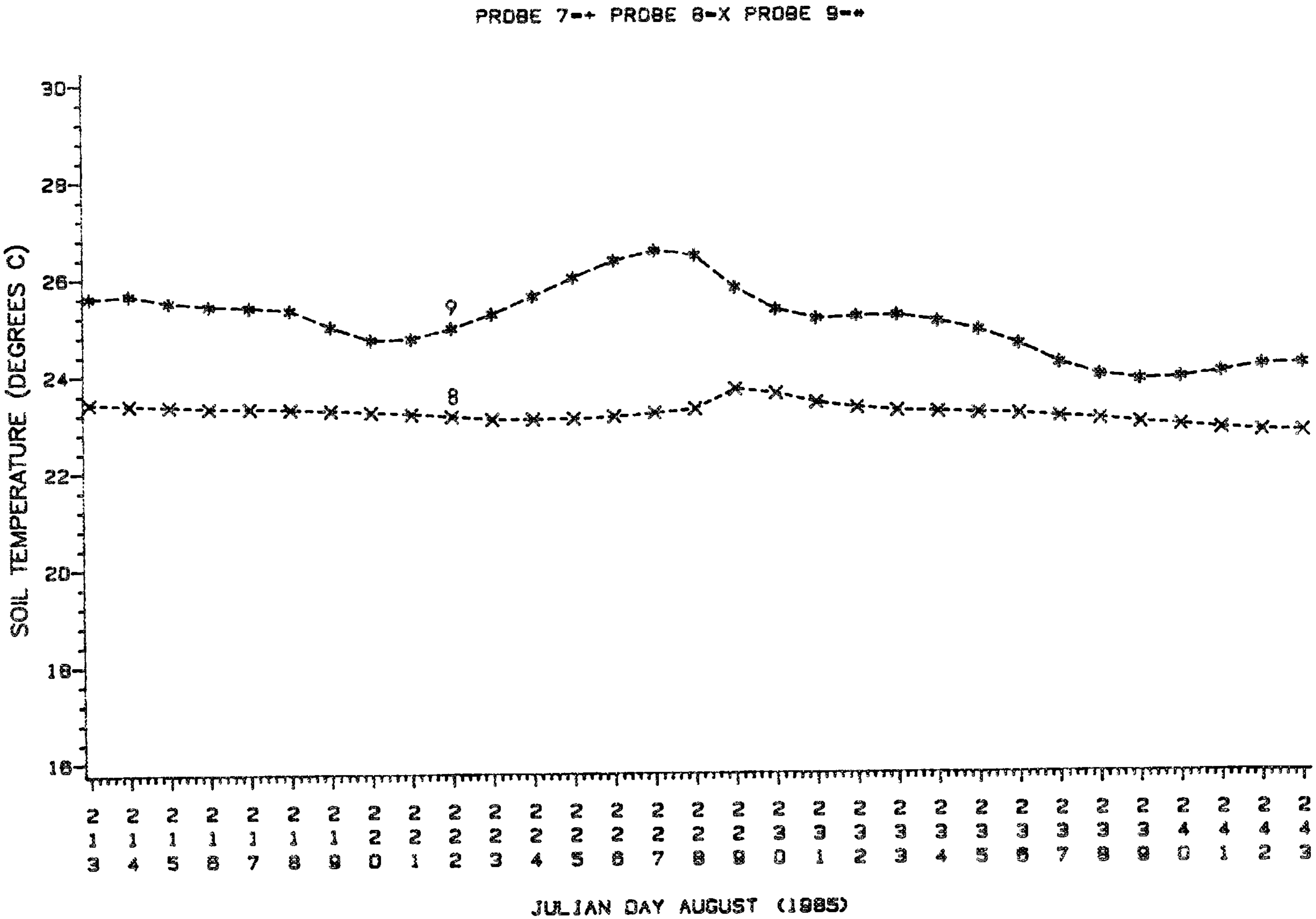
LYSIMETER THREE SOIL TEMPERATURE

PROBE 7=+ PROBE 8=X PROBE 9=*



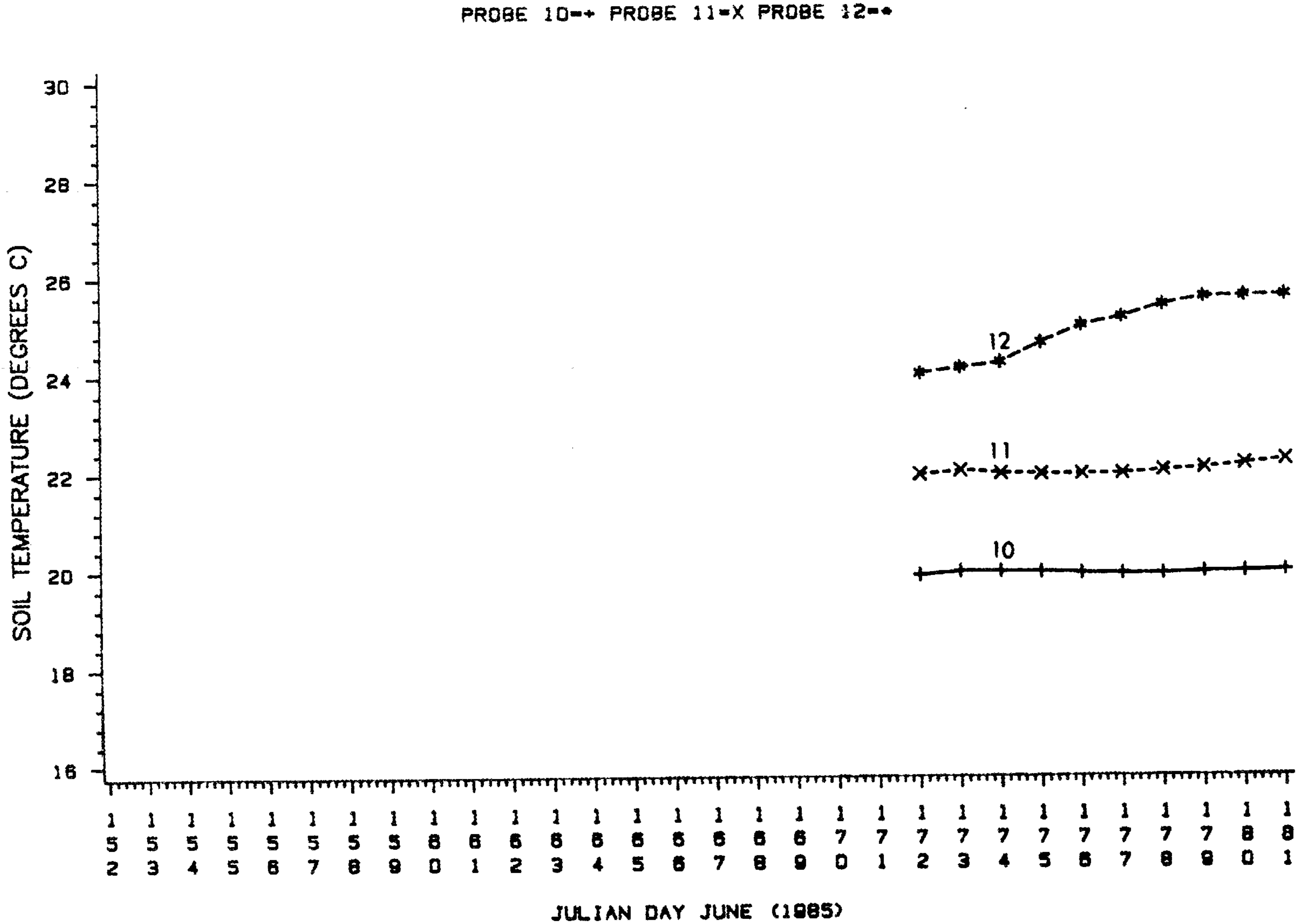
ORNL-DWG 86-1455

LYSIMETER THREE SOIL TEMPERATURE



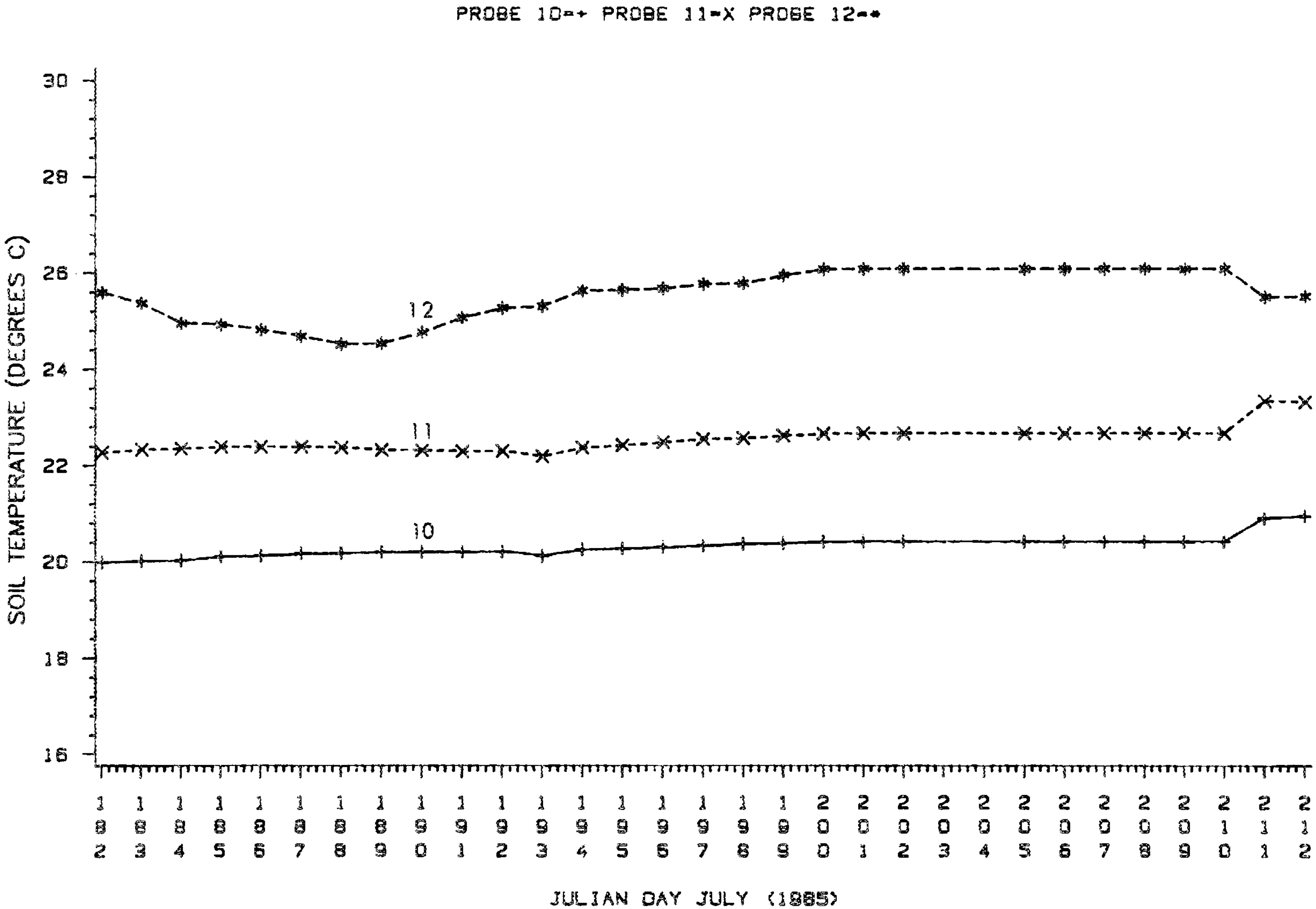
ORNL-DWG 86-1456

LYSIMETER FOUR SOIL TEMPERATURE



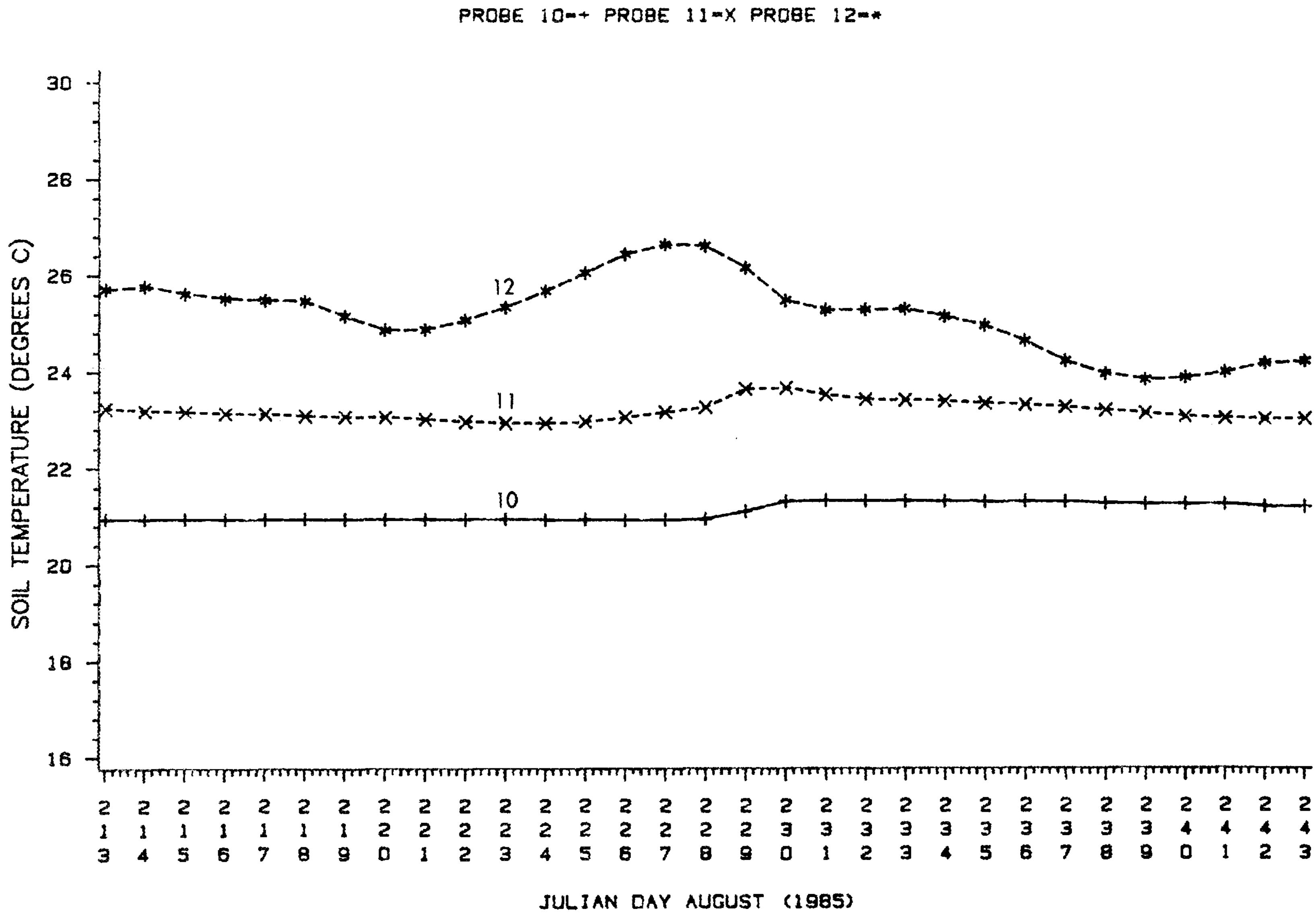
ORNL-DWG 86-1457

LYSIMETER FOUR SOIL TEMPERATURE

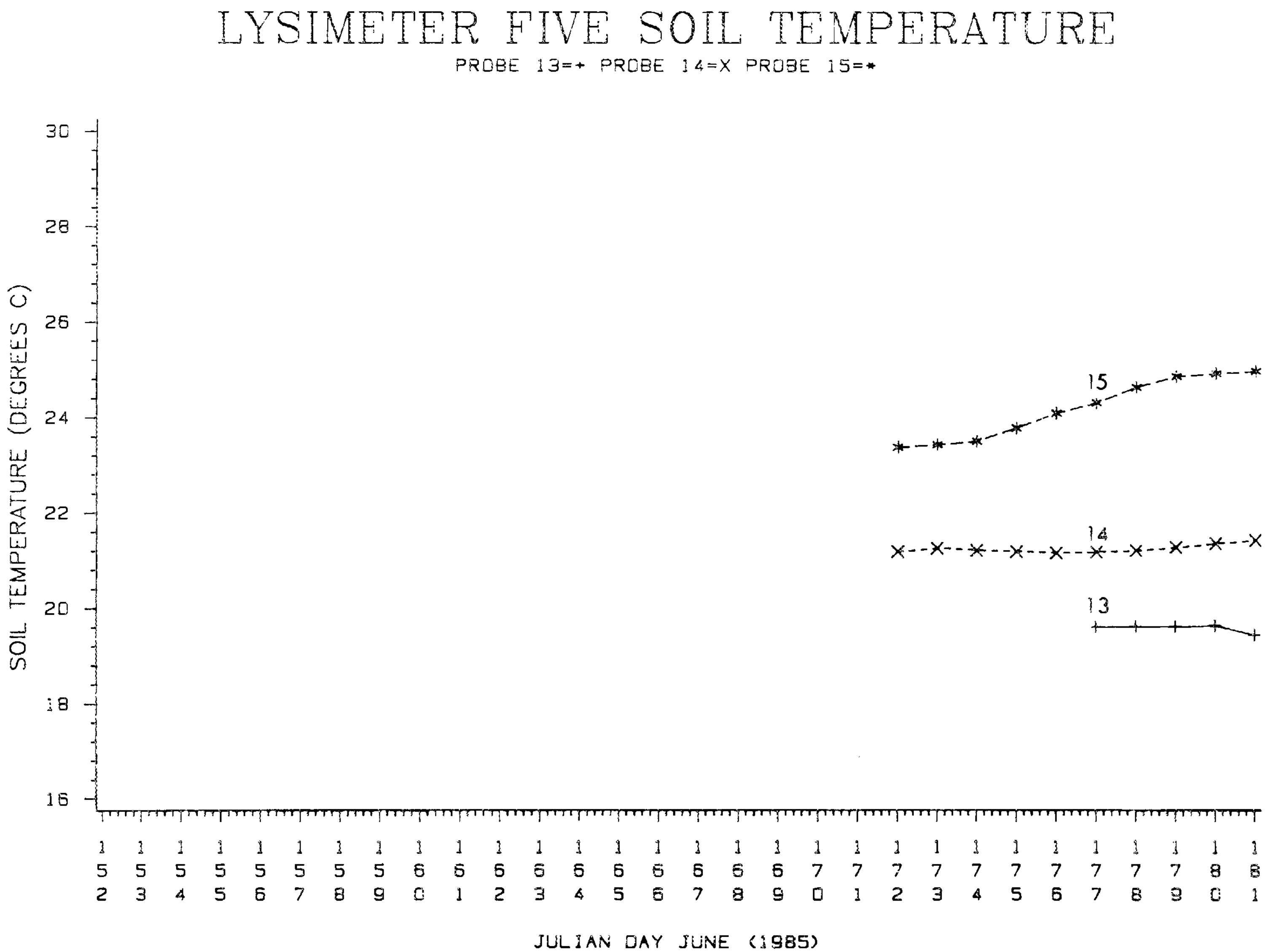


ORNL-DWG 86-1438

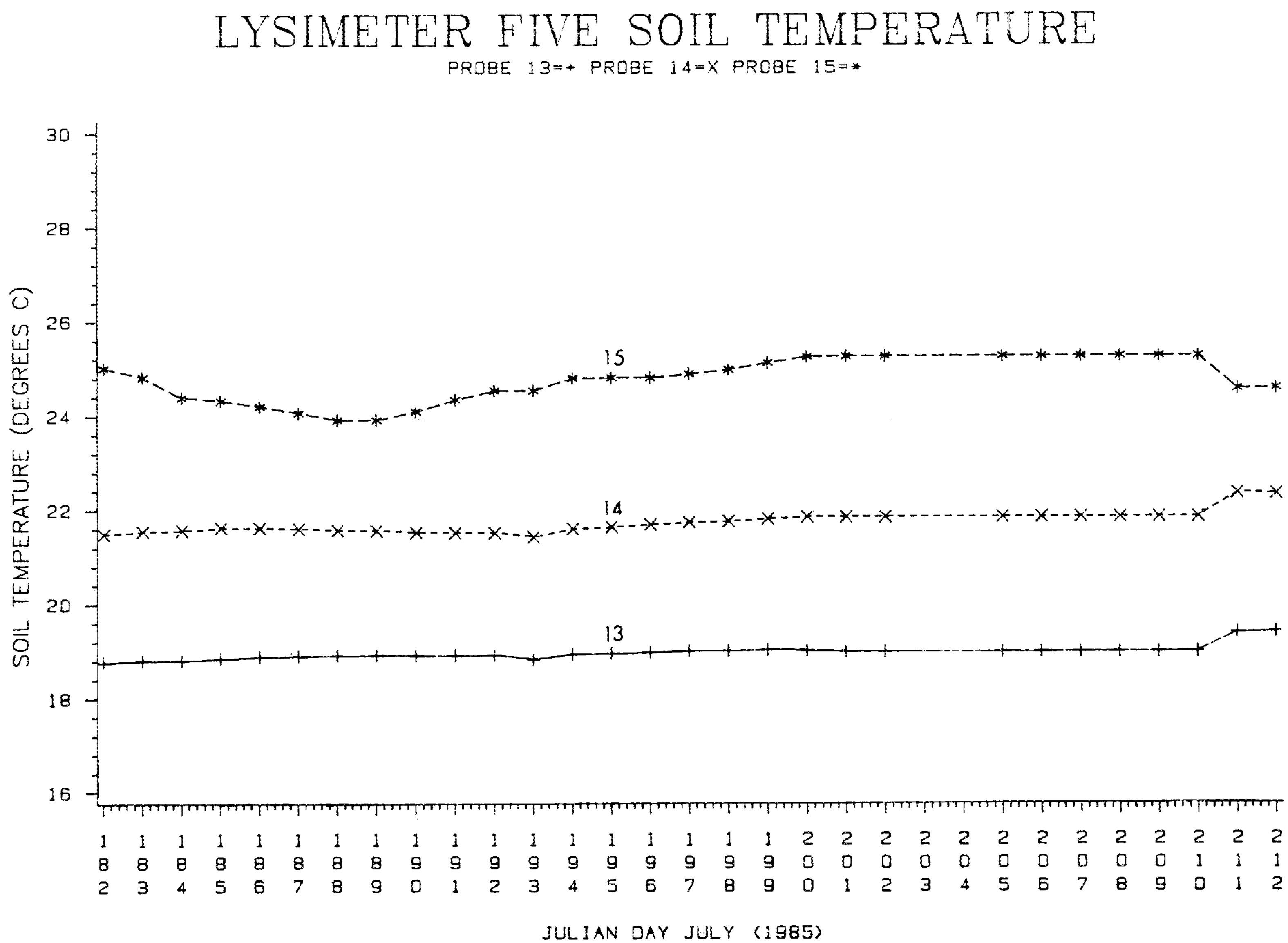
LYSIMETER FOUR SOIL TEMPERATURE



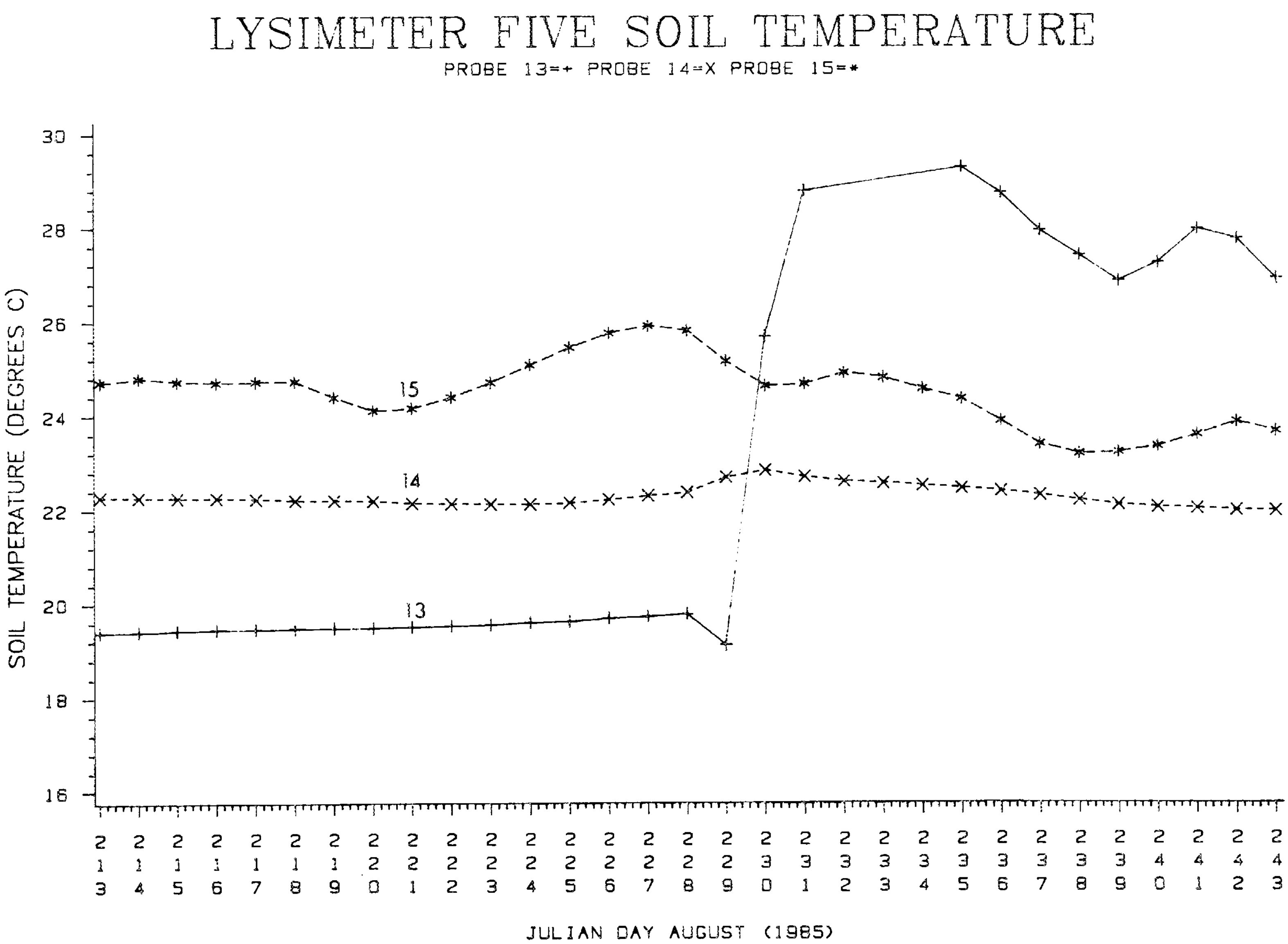
ORNL-DWG 86-1439



ORNL-DWG 86-1440



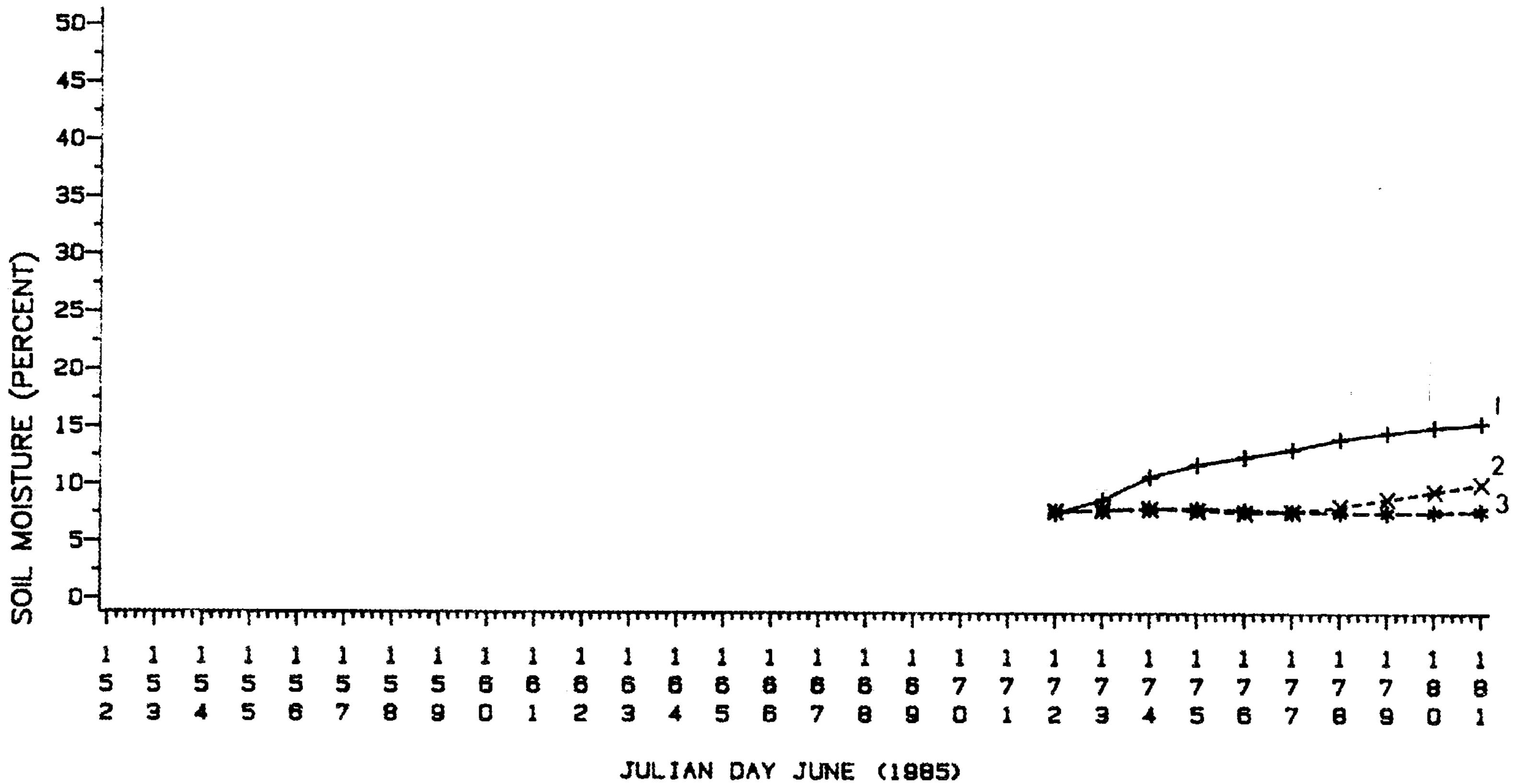
ORNL-DWG 86-1441



ORNL-DWG 86-1442

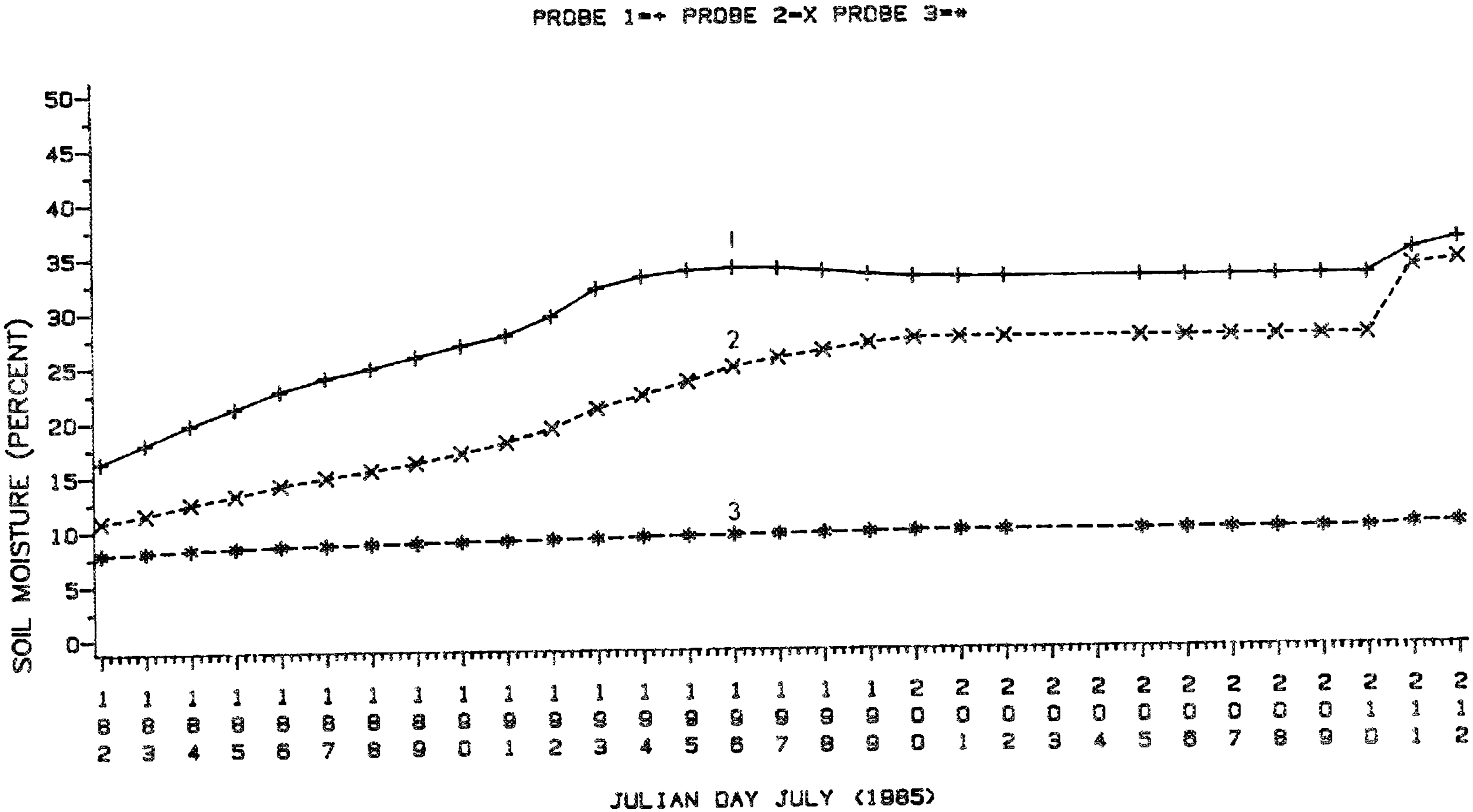
LYSIMETER ONE SOIL MOISTURE

PROBE 1=+ PROBE 2=X PROBE 3=*



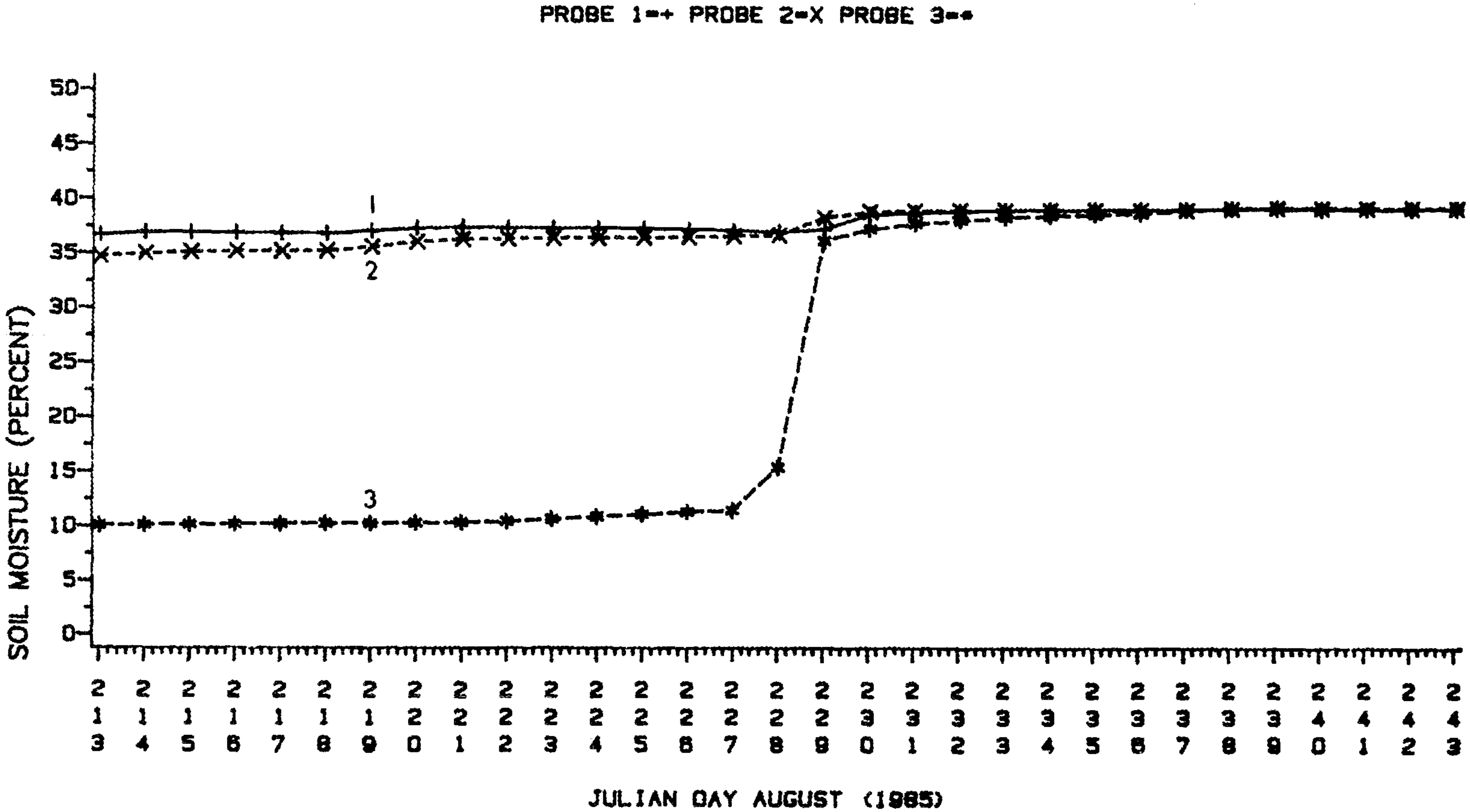
ORNL-DWG 86-1443

LYSIMETER ONE SOIL MOISTURE

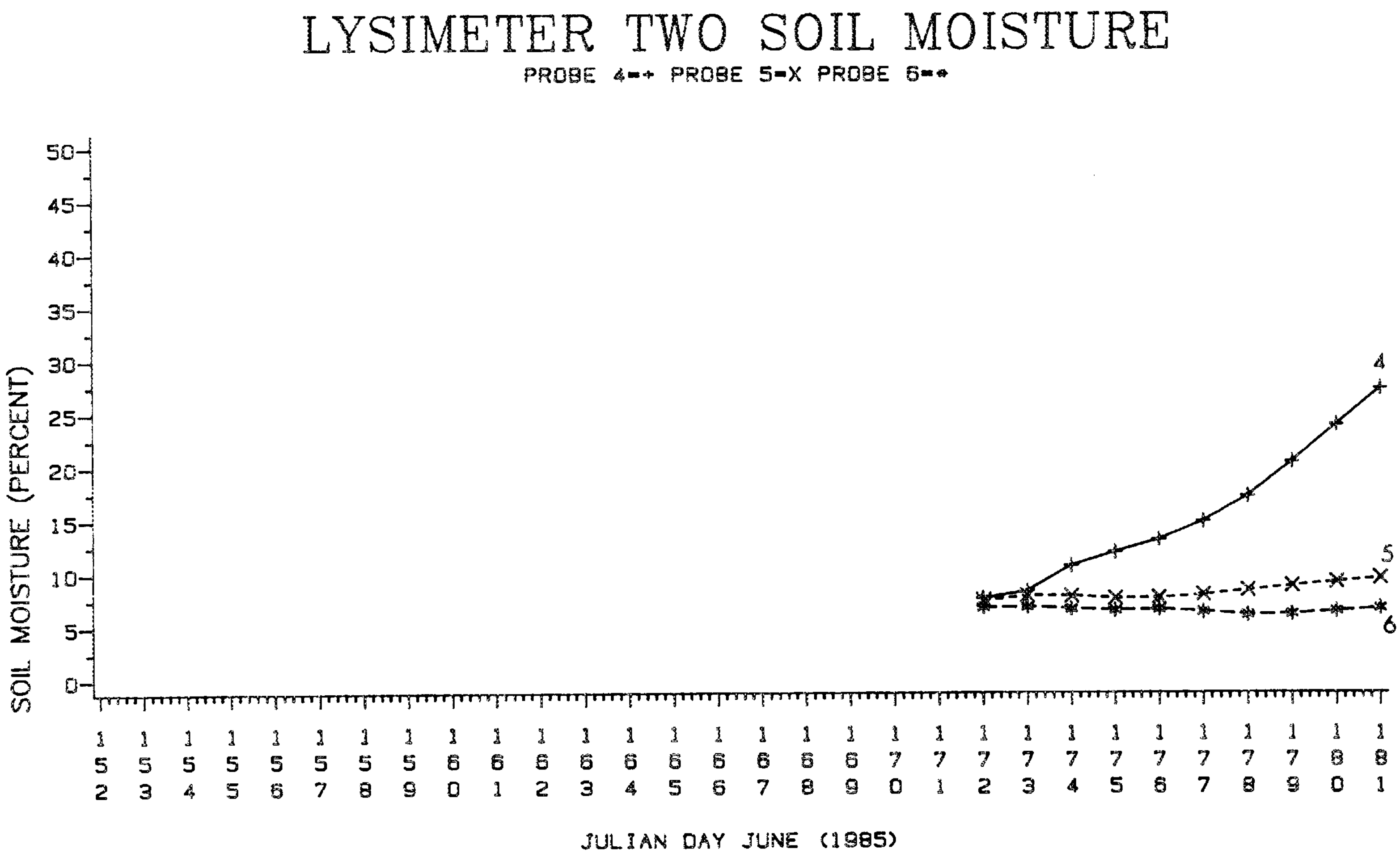


ORNL-DWG 86-1444

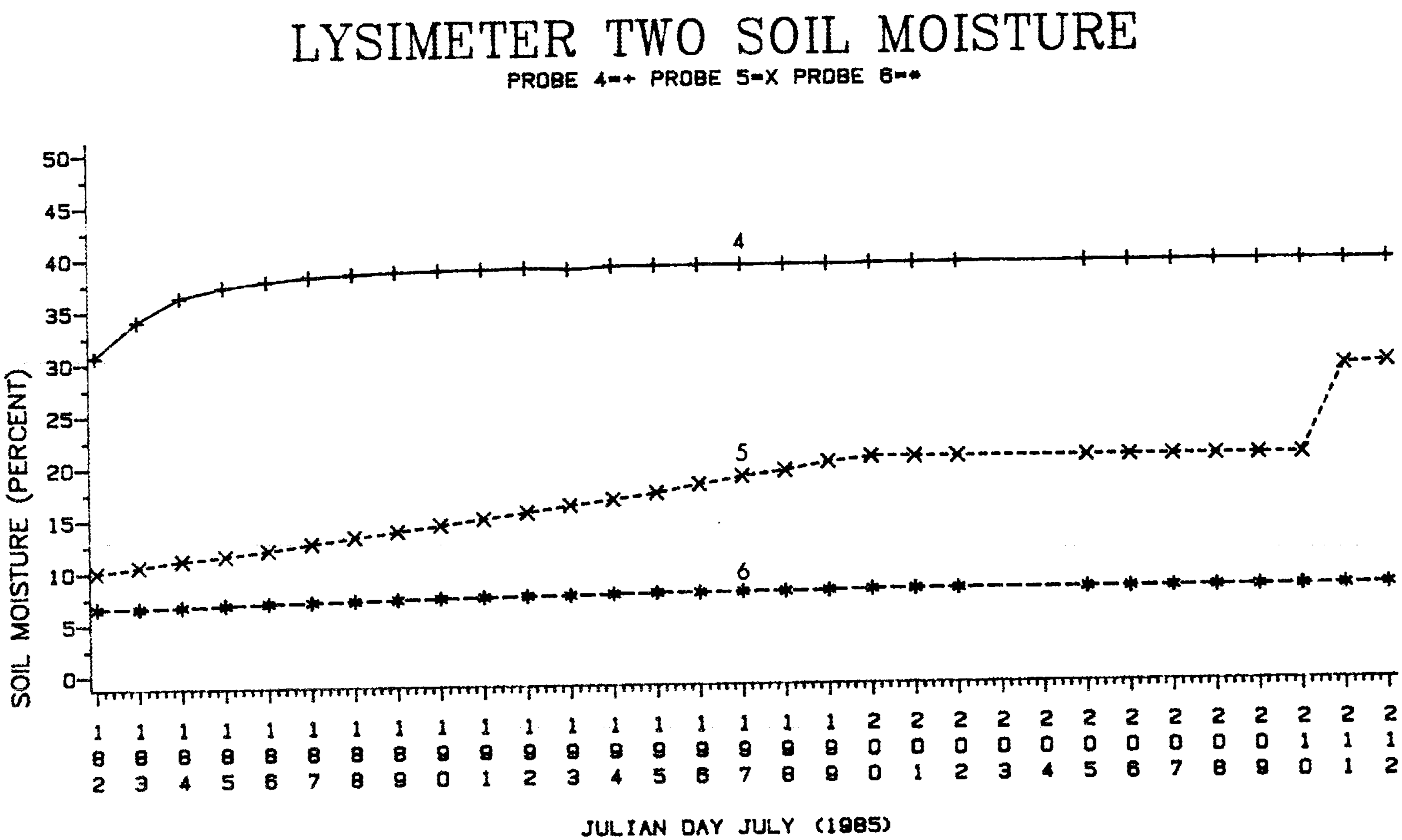
LYSIMETER ONE SOIL MOISTURE



ORNL-DWG 86-1445



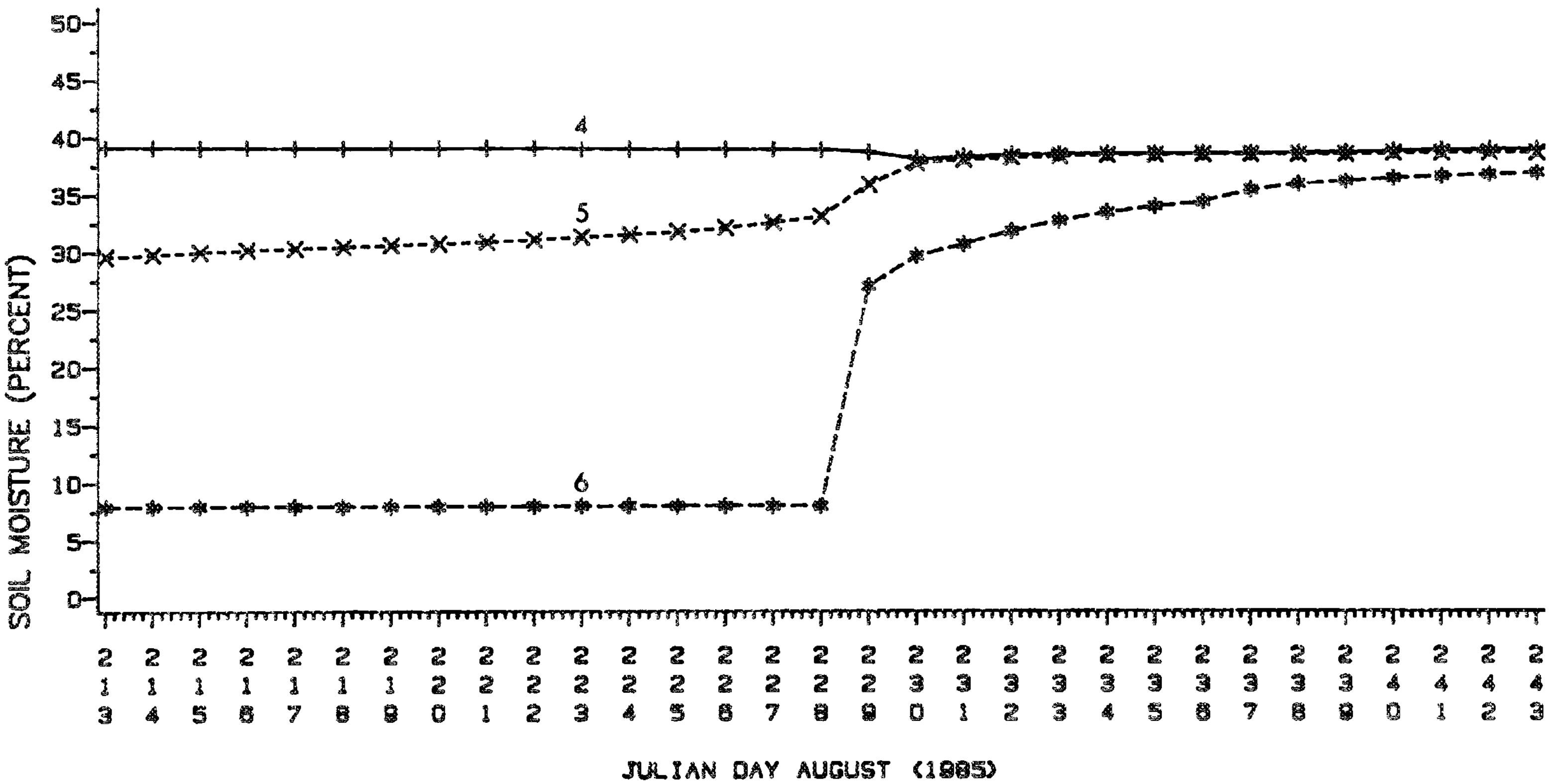
ORNL-DWG 86-1446



ORNL-DWG 86-1447

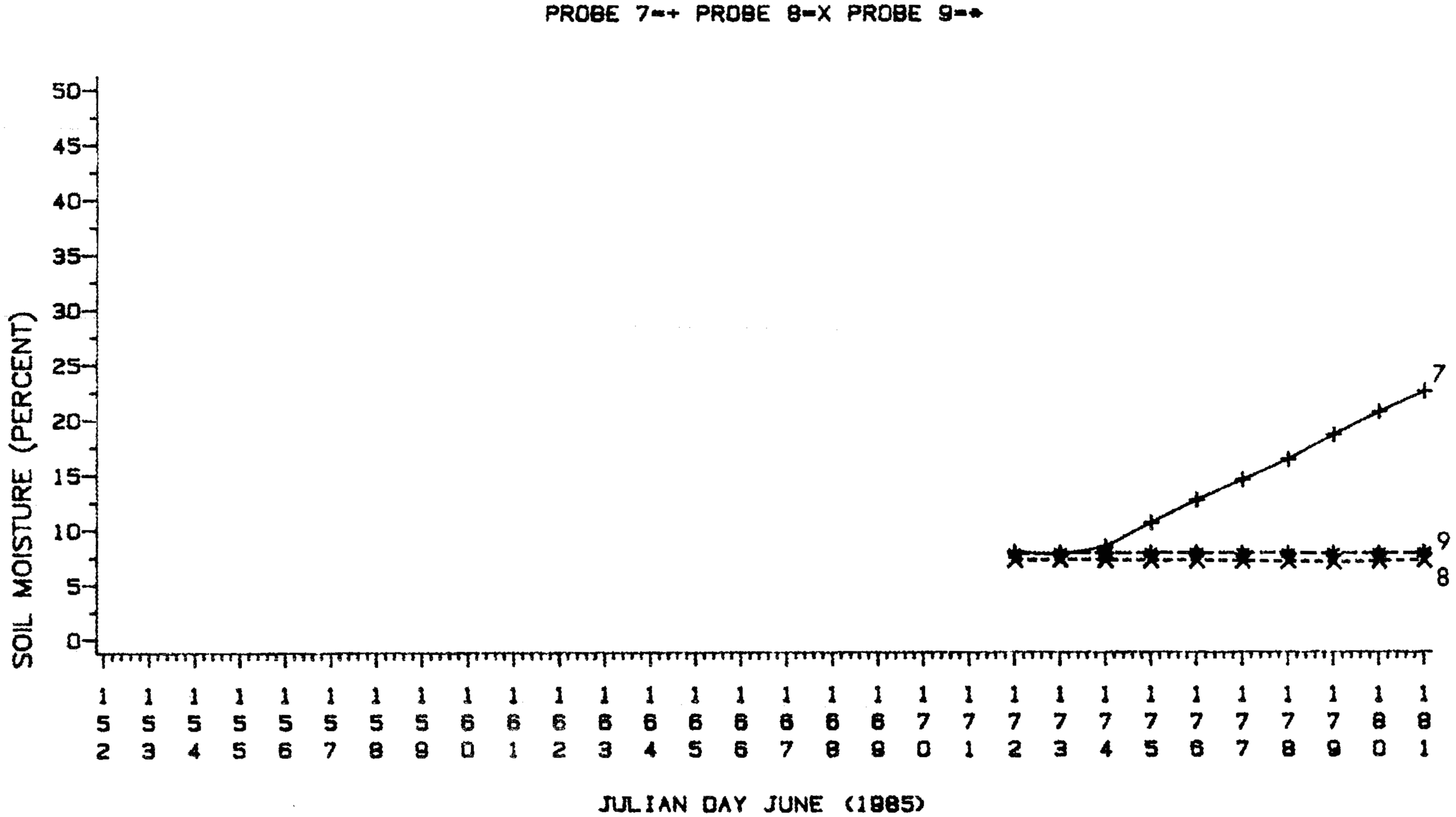
LYSIMETER TWO SOIL MOISTURE

PROBE 4=+ PROBE 5=X PROBE 6=*



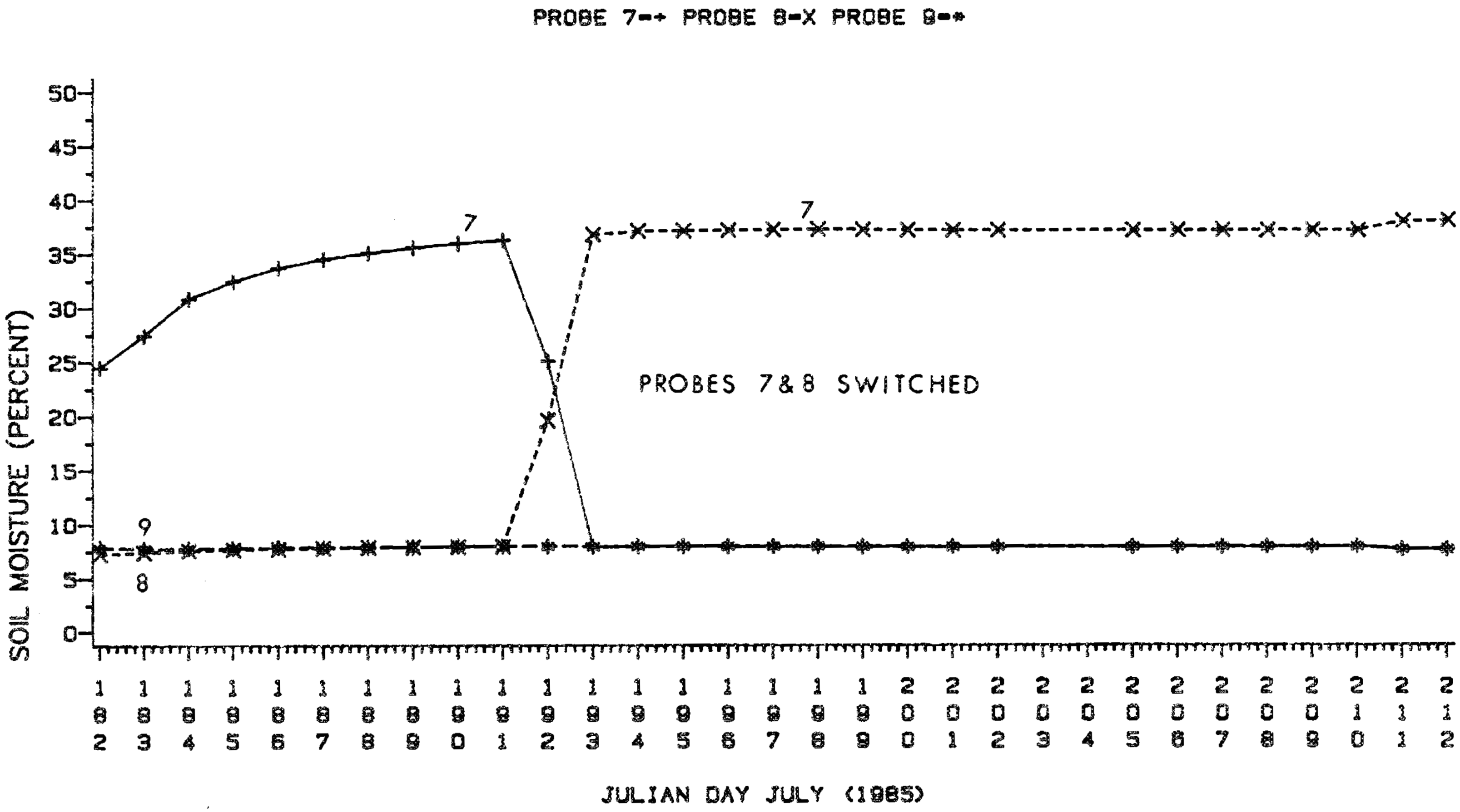
ORNL-DWG 86-1429

LYSIMETER THREE SOIL MOISTURE



ORNL-DWG 86-1430

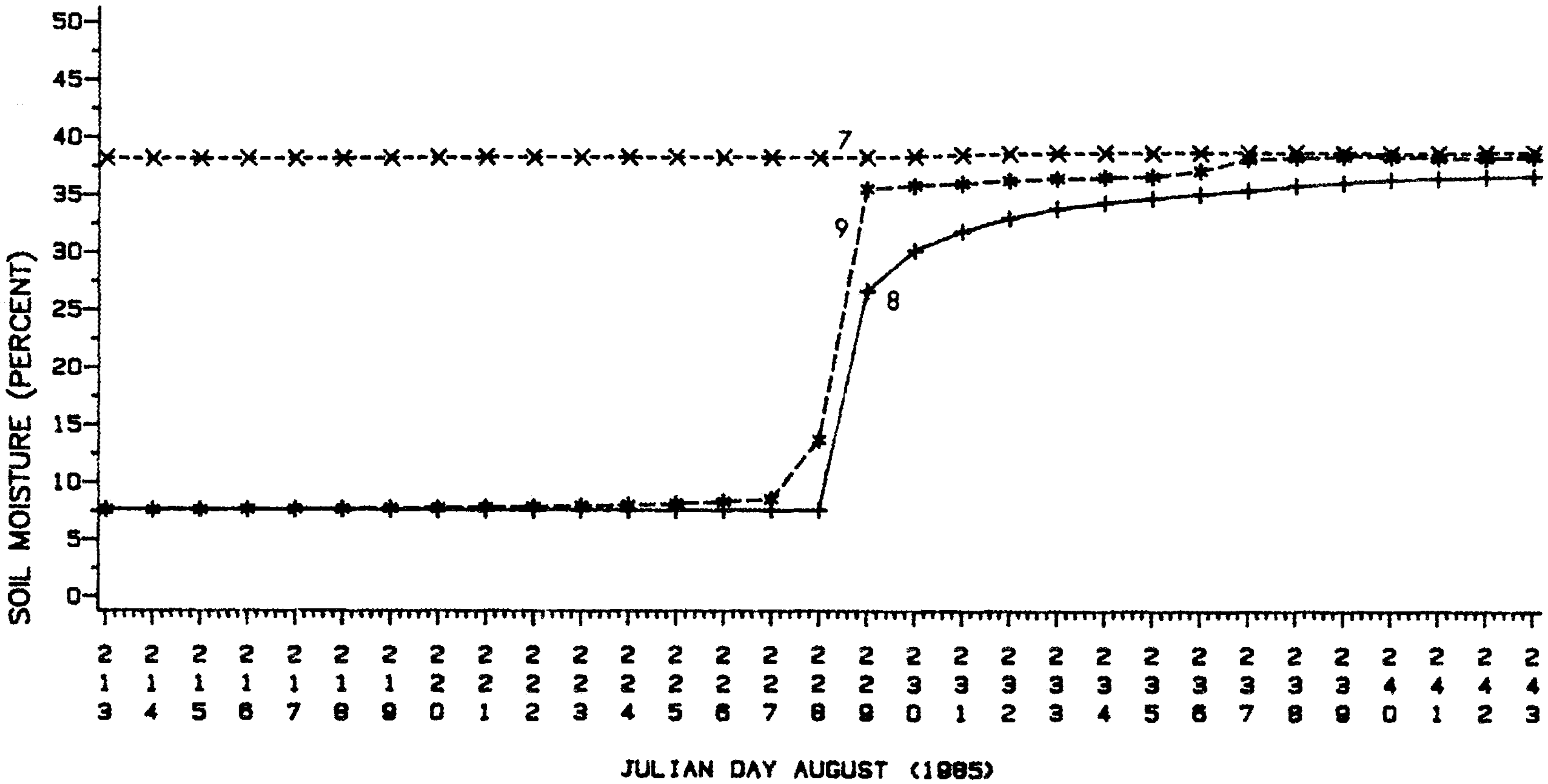
LYSIMETER THREE SOIL MOISTURE



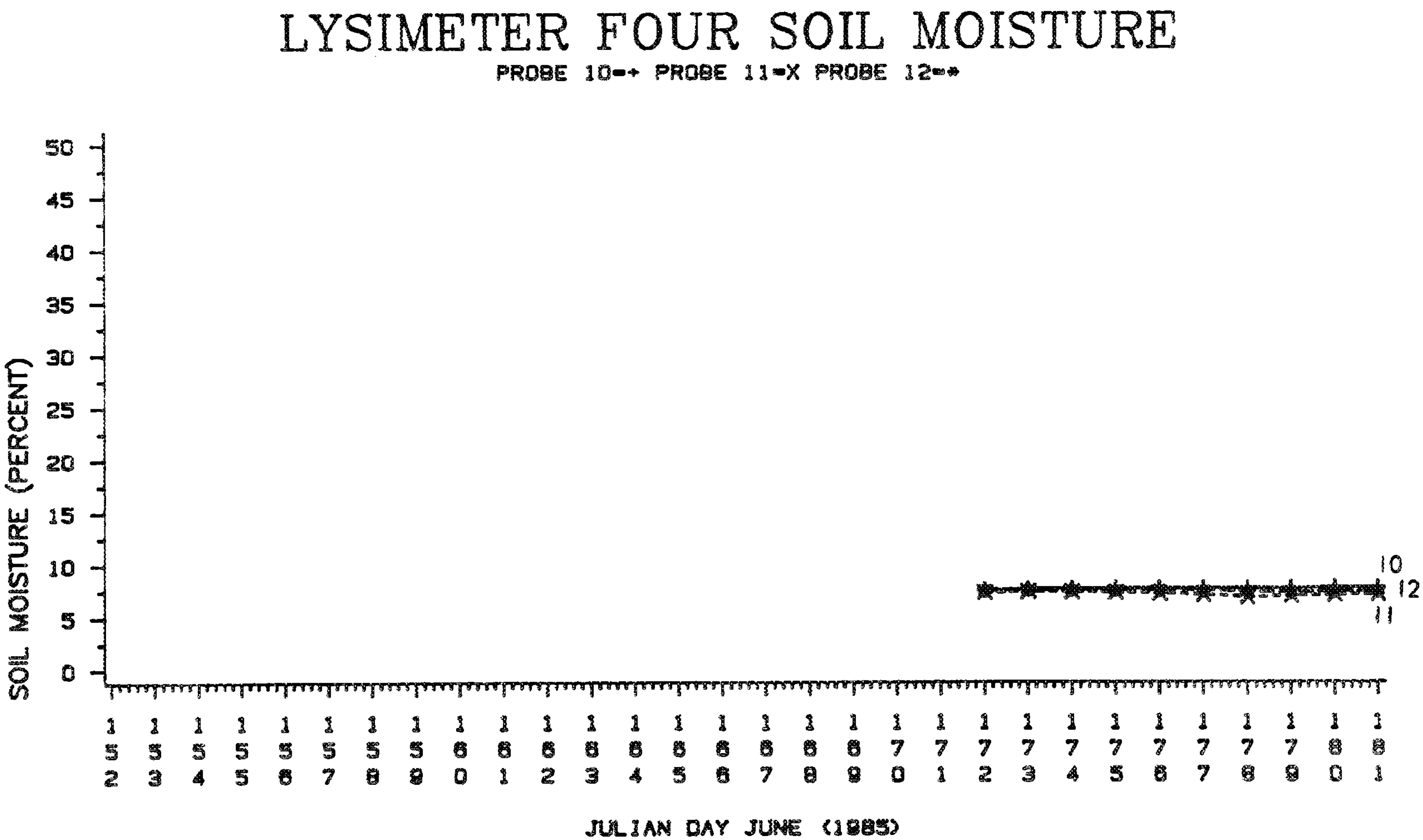
ORNL-DWG 86-1431

LYSIMETER THREE SOIL MOISTURE

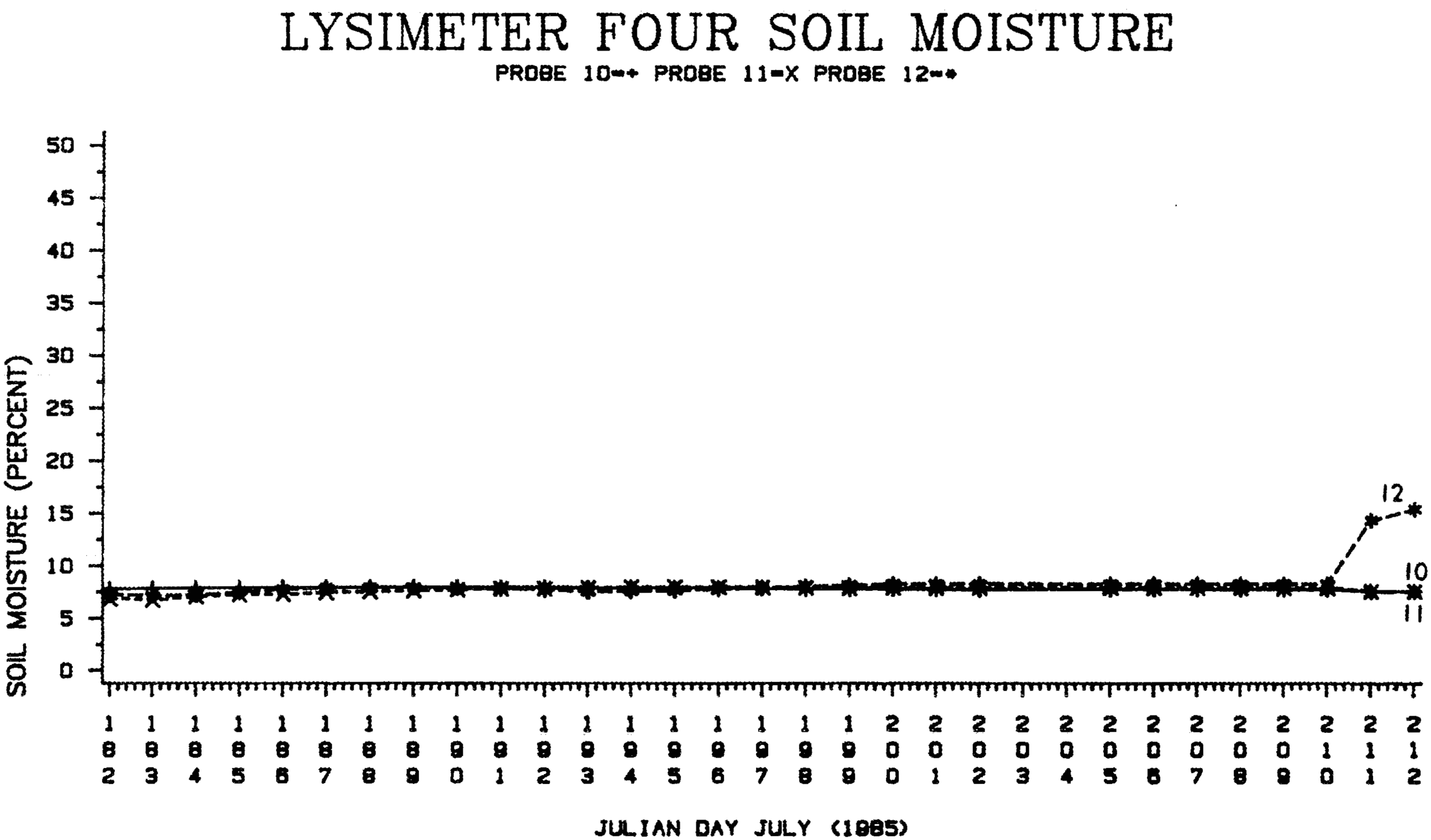
PROBE 7=+ PROBE 8=X PROBE 9=*



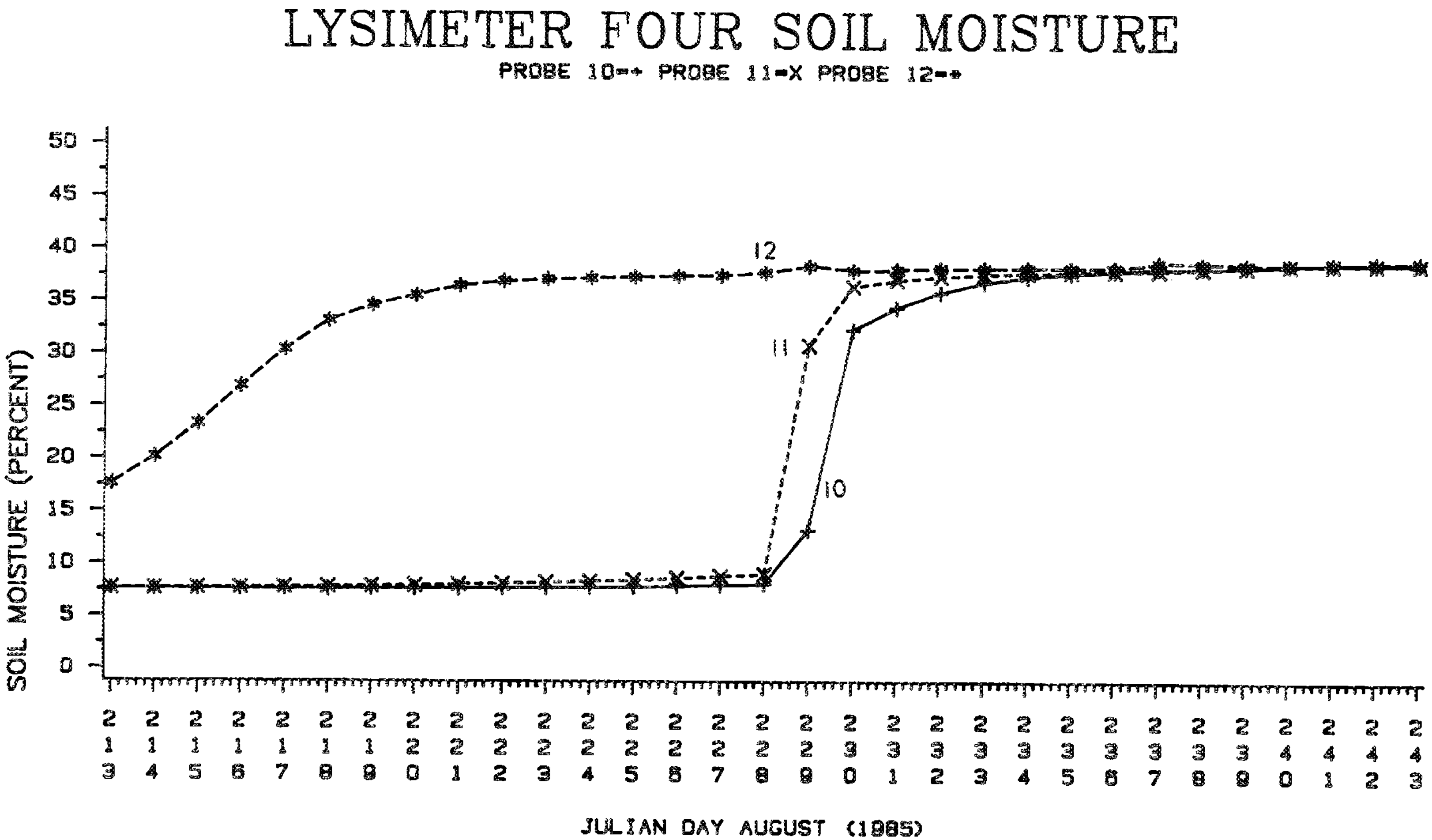
ORNL-DWG 86-1432



ORNL-DWG 86-1433

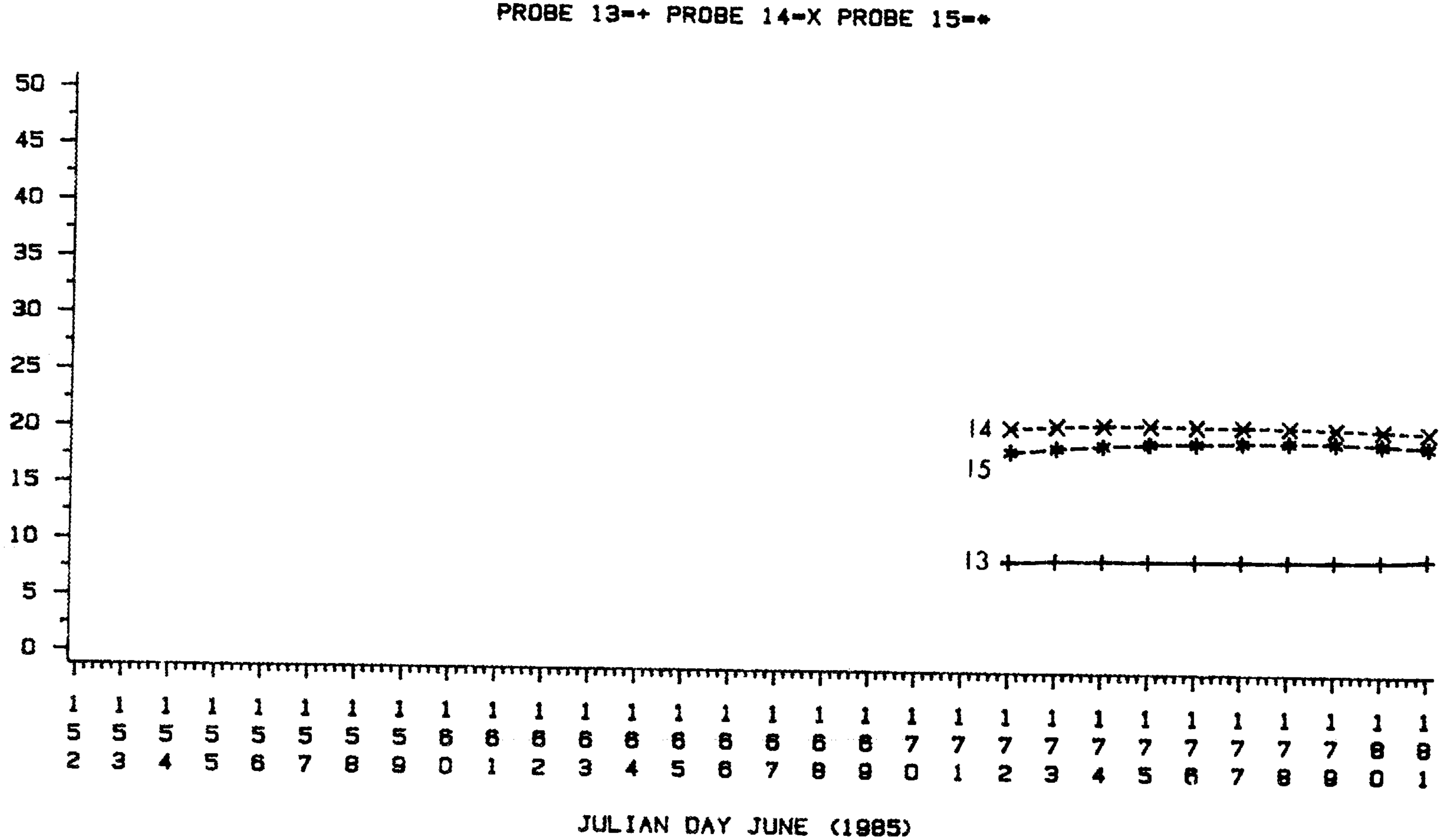


ORNL-DWG 86-1434



ORNL-DWG 86-1435

LYSIMETER FIVE SOIL MOISTURE

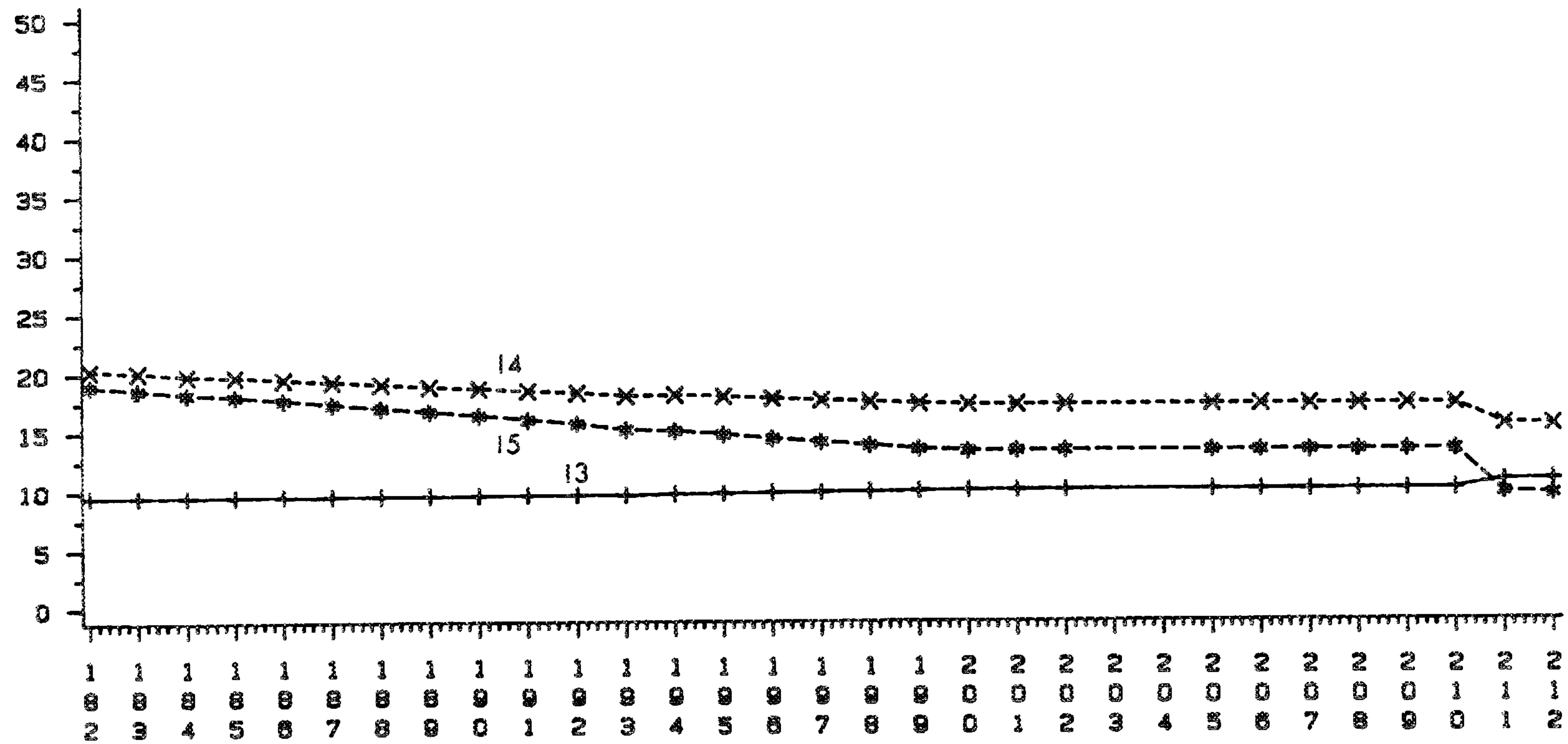


D-45

ORNL-DWG 86-1436

LYSIMETER FIVE SOIL MOISTURE

PROBE 13=+ PROBE 14=X PROBE 15=*

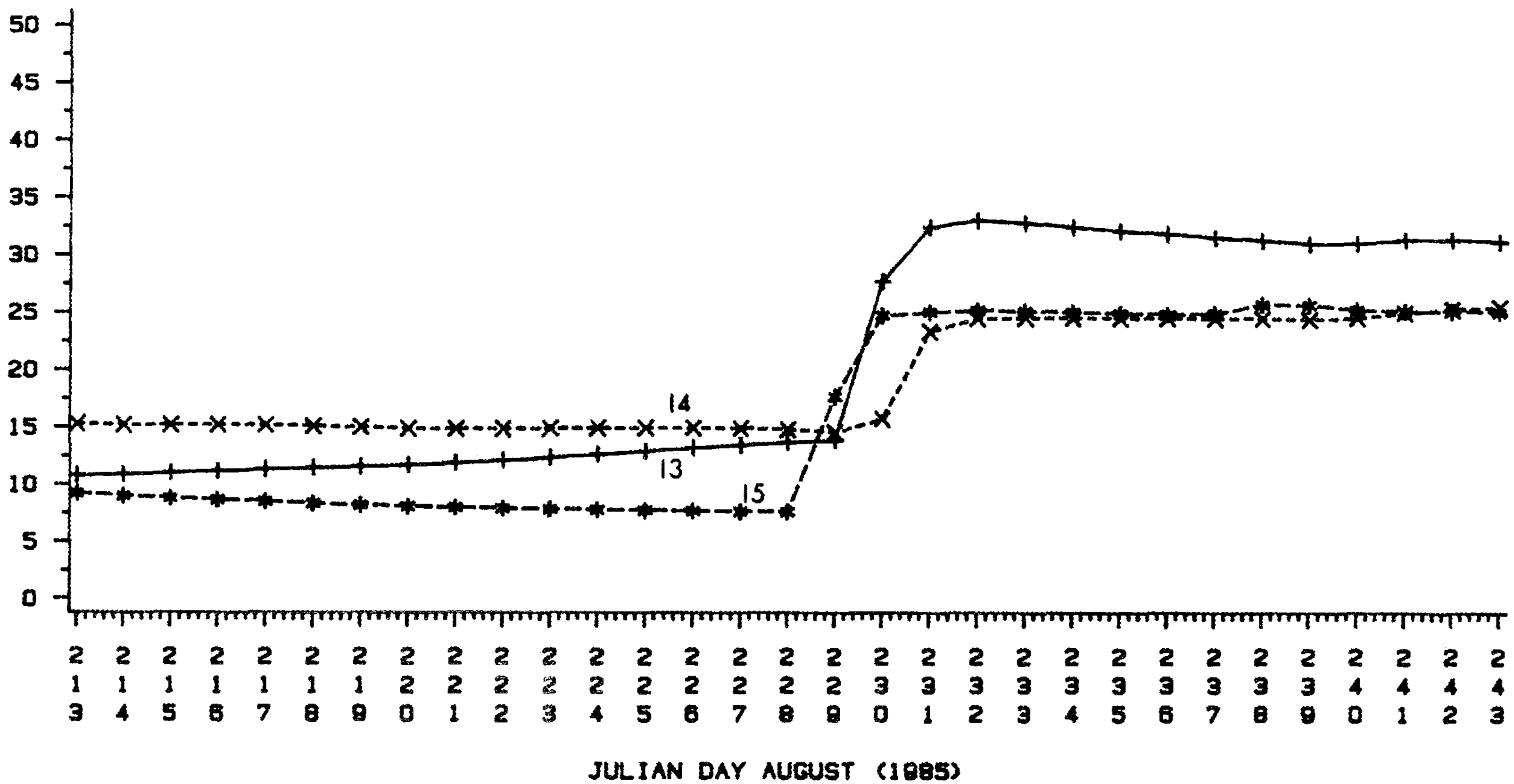


JULIAN DAY JULY (1985)

ORNL-DWG 86-1437

LYSIMETER FIVE SOIL MOISTURE

PROBE 13=+ PROBE 14=X PROBE 15=*



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