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MARINE AEROSOL CHARACTERISTICS IN THE SUBTROPICAL NORTH ATLANTIC AND AT NORTH AMERICAN COASTAL SITES

by
E.J. Mack, C.W. Rogers and B.J. Wattle

Calspan Report No. 6890-M-1

December 1986

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Final Technical Report

Contract No. N00014-81-C-0519

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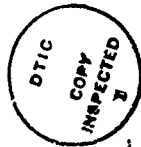
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FOREWORD

The primary author of this report, Eugene J. Mack, died suddenly before the report was completed. Atmospheric aerosols, particularly those found over the ocean, were a career long interest of Gene's, who participated in more than 20 ocean based field trips. Two of these trips were transatlantic cruises, the study of the second of which comprises the body of this report. Section 2 of this report, "A Climatology of Maritime Aerosol Populations", was updated by Gene prior to his death and represents the last scientific effort to his vast body of contributions on marine aerosols. All of Gene's Calspan co-workers benefited immensely from his scientific insight and his constant attention to detail and accuracy. Those scientists from government, universities and other research groups who worked closely with Gene during both field trips and laboratory tests were always impressed with his well thought out and organized experiments which were designed to obtain the data required to subsequently answer the question at hand. The other two authors dedicate this report to Gene in memory of his interest in and contributions to our own scientific endeavors, and, most importantly, in memory of his concern and consideration for the humanity of those around him.



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Keywords: Marine atmosphere;
Marine climatology, North Atlantic Ocean,

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1. INTRODUCTION

In recent years under several Navy contracts, Calspan has made observations of aerosol characteristics at a number of maritime locales in North America and Europe as well as in the mid-Atlantic. Under this contract, N00014-81-C-0519, aerosol data were acquired at Corea, ME(July 1981), Valkaria, FL(July 1982) across the Atlantic between 20-30°N(March 1983), and at San Nicolas Is.(October 1984) off the coast of southern California. Aerosol data for Corea, ME and Valkaria, FL are included as Appendices B and C. Data from the 1983 trans Atlantic cruise were reported in a data volume (Wattle et al., 1983), and those for SNI in an interim report (Mack et al., 1985). These aerosol data were included in an updated "Climatology of Maritime Aerosol Populations" (original version published by Mack et al., 1981), which comprises Section 2 of this report.

The results of the aerosol chemical analyses for the 1983 cruise were not available for inclusion in the data volume. The data are presented in Section 3 and are interpreted in terms of the meteorological conditions experienced during the cruise. Both sea salt aerosol concentration versus wind speed and the behaviour of plumes of continental type aerosol moving westward across the subtropical Atlantic are discussed.

Starting with the Valkaria field trip, Calspan began to acquire sun photometry measurements aimed at studying development of a technique for estimating surface level scattering coefficient from satellite radiance measurements through the use of aerosol optical depth. Sun photometry measurements were

also made in the Alboran Sea (Mack et al., 1983) and during the SNI field trip. Preliminary analyses of the SNI sun photometry data were discussed in connection with a potential estimation technique in Mack et al., 1985. Final analysis of these observations, including vertical profiles of sun photometry data, and a summary of a potential relationship between aerosol optical depth and boundary layer visibility are found in Section 4. This work is continuing at Calspan under Navy sponsorship with the analysis of sun photometry data acquired near Gibraltar during the Western Mediterranean Circulation Experiment of June 1986(Wattle, 1986).

2.0 A CLIMATOLOGY OF MARITIME AEROSOL POPULATIONS

In recent years, Calspan has made observations of aerosol characteristics at a number of maritime locales in North America and Europe as well as in the mid-Atlantic. Briefly summarizing, the data show that the marine aerosol population varies considerably in number concentrations and chemical composition, both spatially and temporally, and does not necessarily comprise solely sea salt aerosols; sulfates and continental/anthropogenically-derived materials--i.e., organics, fly ash, silicates and other minerals--can be found over several thousand kilometers offshore. These data are summarized in Tables 1 and 2.

In remote or mid-ocean areas, total particle concentrations are typically $<500 \text{ cm}^{-3}$, while number concentrations at sizes $>0.1 \mu\text{m}$ and $>1.0 \mu\text{m}$ diameter are typically 100 and 1 cm^{-3} , respectively. Particle concentrations, particularly at larger sizes, fluctuate by an approximate order of magnitude over periods of days; fluctuations of these predominantly sea spray particles appear primarily dependent on sea state and relative humidity. Direct measurements of sea spray (away from surf zones) suggest that number concentrations are constant in the vertical in the lowest few 10's of meters and that sea spray droplets are not necessarily locally generated; maximum sizes at wind speeds of $<15 \text{ m/sec}$ are typically $\sim 40 \mu\text{m}$ diameter. These observations demonstrate that, while mid-ocean aerosols are principally sea salt with equilibrium concentrations controlled by a balance between production and evaporation, sulfate and other continental-source aerosols can at times account for up to 50% of

Table 1

MARINE AEROSOL CLIMATOLOGY *

-- PHYSICAL PROPERTIES --

Typical Aerosol Concentrations Observed in the Marine Boundary Layer

Location	Date of Study	Visibility (km)	RH (%)	Total Particle Conc. (cm ⁻³)	Particle Concentration at Diameter			CCN @ 0.21 SS 1.02 SS (cm ⁻³)	
					>0.1 μm	>0.3 μm (cm ⁻³)	>1.0 μm		
Offshore Coast of Portugal (within 1200 km)	May 77	20-30	75-90	400-1000	400-1000	7-70	0.9-3.0	300-500	600-1000
Offshore Coastal Europe (30-50°N.Lat) (within 1000 km)	Apr 83	-	70-85	1000-20000	50-2000	0.1-100	0.1-0.5	-	-
Mediterranean (150-250 km offshore)	Jun 77	25-60	65-80	800-2500	250-1500	1-30	0.7-3.0	150-900	400-2000
Alboran Sea (Western Mediterr.)	Oct 82	25-80	60-85	1500-10000	-	1-20	0.5-2.0	-	-
Offshore Coast of Nova Scotia (within 150 km)	Aug 75	-	-	400-2000	-	-	-	130	450
Offshore New England Coast of U.S. (200-400 km)	Aug 75	-	-	2000-6000	-	-	-	500	1350
Offshore New England Coast of U.S. (within 300 km)	May 77	20-80	65-75	4000-15000	1000-3000	2-40	0.3-6.0	350	990
Offshore Southeast Coast of U.S. (within 1000 km)	Mar 83	-	55-70	1500-15000	500-2000	0.2-40	0.1-1.0	-	-
Gulf of Mexico (20 km offshore)									
Marine flow (Panama City, FL)	Feb 77	43	65-95	3400	-	2.0	0.1-1.3	-	-
Marine flow	Nov 78	23	75-95	1700	300-1200	-	1.0-10.0	730	1450
Continental flow	Feb 77	32	40-75	5500	-	4.0	0.1-1.2	-	-
Continental flow	Nov 78	20	35-85	70	1500-3500	-	0.1-1.0	1010	2130
Offshore Coast of S. California (within 150 km)	Oct 76	10-40	70-95	-	-	-	-	50-1000	400-2200
(within 150 km)	May 78	10-30	75-95	1000	100-2000	-	6.0	100-700	300-3500
(beyond 150 km)	Sep 76	30-80	70-95	<200-600	-	-	-	20-200	100-400
Offshore N. California (100-150 km)	Aug 74	-	-	-	-	-	-	60	200
Mid-Atlantic (40-45°N Lat.)	May 77	80	50-75	<200-500	30-150	2-10	0.8-4.0	60-140	90-200
Mid-Atlantic (20°N Lat.)	Mar 83	-	65-85	300-1000	50-500	1-15	0.2-5.0	-	-
Cape Cod (12km inland, Otis AFB)	Jul 80	4-60	50-95	4000-35000	500-4000	-	0.5-100	60-600	400-2000
Cape Cod (12km inland, Otis AFB)	Jun 82	-	-	2000-30000	-	-	-	250-1100	300-3000
Coastal Cape Cod (Wood's Hole)	Jun 82	-	-	1000-11000	-	-	-	100-900	350-2000
Coastal Maine (~2km inland at Cores)	Jul 81	3-80	40-95	1000-10000	-	2.0	0.2-1.0	-	-
Coastal Florida (~5km inland, Valparaiso)	Jul 82	3-80	60-90	3000-15000	-	0.5-100	<1.0	-	-

* Single numbers represent averages; multiple figures are typical range values and do not include extremes.

Average Percentage of Particles in the Size Range 0.1-10.0 μm Diameter as Functions of Composition and Sampling Location

Location	Date	Sea Salt (%)	Other Salts Without NaCl or Si (%)	Organics (%)	Silicates (%)	Number of Particles Counted
Offshore Coast of Portugal (within 1200 km)	May 77	42	13	33	12	200
Mid-Mediterranean	Jun 77	30	44	17	9	400
Alboran Sea (Western Mediterr.)	Oct 82	70	17	<1	13	3600
New England Coast (within 300 km offshore)	May 77	92	3	2	2	150
Gulf of Mexico						
Marine air (20 km offshore)	Nov 78	81	2	14	3	240
Continental air (20 km offshore)	Nov 78	28	34	27	11	280
Coast of South California (within 150 km offshore)	May 78	16	24	39	21	1350
Mid-Atlantic (40-45°N.Lat)	May 77	78	8	12	2	300
Cape Cod (12 km inland at Otis AFB)	Jul 80	37	16	21	46	360
Cape Cod (12 km inland at Otis AFB)	Jun 82	61	22	1	17	350
Coastal Cape Cod (Wood's Hole)	Jun 82	60	31	<1	8	300
Heppen, West Germany (~40km inland)	Nov 80	16	47	1	36	675
Coastal Maine (~2km inland at Cores)	Jul 81	74	8	4	14	500
Coastal Florida (~5km inland at Valparaiso)	Jul 82	23	18	<1	58	1150

Table 2

MARINE AEROSOL CLIMATOLOGY *

-- AEROSOL CHEMISTRY --

Average Airborne Concentrations of Selected Constituents of Marine Boundary Layer Aerosols

Location	Date	Na	Cl	S	Absolute Concentrations ($\mu\text{g}/\text{m}^3$)							
					SO_4	Mg	K	Ca	Al	Si	Mn	Fe
Off N. American Coast (Atlantic) (within 300 km)	May 77	1.0	2.01	1.4	1.4	.38	.08	.44	.22	.04	.02	.50
New England Coast (200-400 km offshore)	Aug 75	1.3	0.02	-	14.0	.12	.22	.13	.26	-	-	-
Off Portuguese Coast (within 1200 km)	May 77	0.2	0.17	1.5	2.1	.08	.03	.09	.05	.11	.02	.06
Mediterranean	Jun 77	0.2	0.17	1.7	3.9	.09	.04	.14	.07	.15	.02	.10
Off Nova Scotia (within 150 km)	Aug 75	0.9	<0.02	-	4.0	.05	.19	.09	.22	-	-	-
N. Gulf of Mexico (20 km offshore)												
on-shore wind	Nov 78	1.8	3.01	1.4	-	.25	.12	.17	.03	.16	-	0
off-shore wind	Nov 78	0.2	0.27	1.1	-	.04	.06	.07	.09	.29	-	.06
Coast of South California												
within 100 km	Oct 76	2.1	1.20	-	8.4	.31	.20	.19	.013	-	-	-
within 150 km	May 78	2.1	4.35	0.4	-	.35	.36	.62	.10	.54	0	0
beyond 100 km	Sep 76	2.4	3.10	-	2.5	.30	.14	.08	.004	-	-	-
Mid-Atlantic	May 77	0.4	1.38	0.3	0.3	.10	.02	.06	.02	.03	0	.02
Coastal Maine (~2km inland at Corea)	Jul 81	0.4	0.50	0.4	-	-	.08	.09	<.15	.10	<.04	.04
Coastal Florida (~5km inland, Valhalla)	Jul 82	0.3	0.74	0.8	-	.12	.17	.30	-	.53	-	.19
Cape Cod (12km inland at Otis AFB)	Jun 82	0.4	0.78	1.4	-	-	.20	.15	.13	.41	.03	.17
Coastal Cape Cod (Woods Hole)	Jun 82	1.0	3.37	1.1	-	-	.22	.24	.10	.28	.02	.12

Enrichment Ratios (Relative to Sodium Ratios of Sea Water) for Selected Constituents of Marine Boundary Layer Aerosols

Location	Date	Cl	S	SO_4	Mg	K	Enrichment Ratios $\frac{X/\text{Na (Sample)}}{X/\text{Na (Sea Water)}}$				
							Ca	Al ($\times 10^5$)	Si ($\times 10^3$)	Mn ($\times 10^5$)	Fe ($\times 10^4$)
Off N. American Coast (Atl) (within 300 km)	May 77	1.6	17.0	5.6	3.2	2.0	11.0	2.2	1.5	0.5	0.5
New England Coast (200-400 km offshore)	Aug 75	<.01	-	43.0	0.8	4.3	2.5	2.0	-	-	-
Off Portuguese Coast (within 1200 km)	May 77	0.5	89.0	42.0	3.3	3.8	11.0	2.5	1.8	2.5	2.5
Mediterranean	Jun 77	0.5	101.0	78.0	3.8	5.0	18.0	3.5	2.5	2.5	2.5
Off Nova Scotia (within 150 km)	Aug 75	<.01	-	18.0	.5	5.3	2.5	2.4	-	-	-
N. Gulf of Mexico (20 km offshore)											
on-shore wind	Nov 78	0.9	9.5	-	1.2	1.8	2.3	0.2	0.3	0	0
off-shore wind	Nov 78	0.6	55.0	-	1.3	6.3	7.8	3.6	4.1	0	0.3
Coast of South California											
within 100 km	Oct 76	0.3	-	16.0	1.3	2.5	2.4	0.06	-	-	-
within 150 km	May 78	1.2	2.2	-	1.4	4.7	7.9	0.5	0.9	0	0
beyond 100 km	Sep 76	0.7	-	4.2	1.1	1.6	0.8	0.02	-	-	-
Mid-Atlantic	May 77	1.9	9.5	3.2	2.1	1.3	3.8	0.5	0.3	1.5	1.3
Coastal Maine (~2km inland at Corea)	Jul 81	0.6	9.6	-	-	4.1	5.9	-	2.5	-	0.06
Coastal Florida (~5km inland at Valhalla)	Jul 82	1.5	32.7	-	3.3	16.9	28.2	-	0.2	-	0.7
Cape Cod (12km inland at Otis AFB)	Jun 82	1.1	41.7	-	-	13.9	9.9	3.3	10.0	3.8	0.4
Coastal Cape Cod (Woods Hole)	Jun 82	1.9	13.1	-	-	6.1	6.3	1.0	2.8	1.0	0.1

the aerosol at sizes $>0.2 \mu\text{m}$.

In immediate coastal areas total particle concentrations (Aitken nuclei) are of the order of 10^4 cm^{-3} , while number concentrations at sizes $>0.1 \mu\text{m}$ and $>1.0 \mu\text{m}$ diameter are typically $\sim 10^3$ and 1 cm^{-3} , respectively. Dramatic fluctuations in the aerosol population (including up to several orders of magnitude in number concentration) occur diurnally as a result of at least four diurnal cycles: photochemical gas-to-particle conversion processes, industrial and other anthropogenic activity, and land/sea breeze cycles and relative humidity cycles. At mid-day, concentrations of small particles $<0.1 \mu\text{m}$ diameter peak due to photochemical processes and anthropogenic activity, while concentrations of larger particles reach minima as a result of daytime heating and relative humidity minima. With the onset of the afternoon sea breeze and influx of fresh 'marine' air, small-particle concentrations rapidly decrease and concentrations of larger particles ($>0.1 \mu\text{m}$ diameter) begin to increase. Large-particle concentrations reach maxima during nocturnal hours, coincident with maxima in relative humidity. Independent of changes in the large particle spectrum due to deliquescence effects, wind shifts produce local changes in aerosol chemistry related to sources and source regions, air mass characteristics, and anthropogenic activities. As a result of the combined effects of these processes in coastal regions, particle concentrations at opposite ends of the size spectrum can fluctuate simultaneously in opposite directions, while aerosol composition can fluctuate independently of number concentration.

Some of these anthropogenic/continental-related effects have been observed, with diminished intensity and influence, at distances of $>10^3$ kilometers to sea.

3.0 AEROSOL CHARACTERISTICS OF NRL-705-83 CRUISE

Aerosol composition over the ocean depends both on the history of the air mass with respect to aerosol sources encountered over the land and aerosols acquired from the underlying ocean. In general, the aerosol over the ocean is composed of sea salts at concentrations related to wind speed and continental constituents whose concentrations reflect upwind land surface and anthropogenic aerosol sources modified by aging processes as the air moves out to sea. The variability of aerosol composition and concentration which can result over the ocean was illustrated in data acquired by Calspan during the NRL-705-83 cruise aboard the USNS LYNCH, which traversed the Atlantic west to east between 20-30°N in March of 1983. These data were analyzed in terms of the wind fields and pressure patterns and interpreted both from the input of aerosols from the underlying ocean and the characteristics of continental aerosol plumes moving over the ocean.

Aerosol particle concentrations and standard meteorological parameters measured during the cruise were previously reported in a data volume(Wattle et al,1983). Subsequently, cascade impactor samples were analyzed for composition of individual particles via energy dispersive X-ray in Calspan's Scanning Electron Microscope. Hi-volume samples taken on Millipore polycarbonate membrane filters were analyzed at Florida State University by proton induced X-ray emission(PIXE)(Hudson et al., 1980) for elemental mass concentrations with atomic numbers at and above sodium. Gelatin slide particle samples were analyzed and used to extend

the aerosol size spectrum to sizes greater than 5 μm diameter. These latter data are presented as Appendix D. All the data were merged with the meteorological data to provide a description of the aerosol variability during the cruise and of various mechanisms which appear to operate to account for aerosol populations in the marine boundary layer over the open ocean.

Briefly, the aerosol composition and concentration along the cruise track showed small amounts of both sea salts and land type elements in nearly calm winds near the center of the sub-tropical high at a location midway between the eastern and western land masses bordering the Atlantic. Moderate concentrations of both sea salts and land type elements were observed in light to moderate easterly wind from off Europe and Africa while the ship was still some 1900 km southwest of the Canary Is. Large concentrations of both sea salt and land-type elements were found in a strong southerly flow which occurred north of the Lesser Antilles in the western part of the cruise. These three large scale aerosol and meteorological regimes are discussed in the following section, along with smaller fluctuations both in aerosol properties and meteorological conditions which occurred over smaller time and space scales.

The fluctuations and the meteorological conditions are first presented in chronological order. The observations are then discussed with respect to aerosol generation mechanisms from the ocean and the behaviour of continental aerosols in a plume moving out over the ocean away from the source region. Aerosol composition is considered both from the standpoint of sea salt

concentrations in relation to wind speed and of continental type concentrations in relation to exposure to land sources and residence time over the ocean.

3.1 OVERVIEW OF AEROSOL VARIABILITY IN THE ATLANTIC ALONG 20-30°N

The large scale track for the NRL-705-83 cruise is shown in Figure 1. Elemental concentration data were available for the period 14 March-24 March 1983. Time periods with differing amounts and distributions of elemental concentrations are letter coded and henceforth referred to as episodes. Approximate average winds from the ships observations (Wattle et al., 1983) are also shown for each Episode. These winds were interpreted in terms of the surface synoptic flow patterns as depicted on surface maps supplied by NRL.

The wind field experienced along the cruise track is typical of this region for this time of year. The west-southwest wind of the 14th giving way to easterly on the 15th followed the transition from off-shore flow behind a cold front to easterly flow as low pressure developed near Florida. This low continued to intensify and became a major storm along the east coast on the 17th-18th when the winds at the ship were strong southerly. During the 19th-20th the lightest winds (1.0 to 1.5 m/sec) encountered during the cruise were experienced on the western edge of the subtropical high. The 22nd and 23rd were characterized by northeasterly flow at the eastern end of a high pressure system which had moved and built across the Atlantic at higher latitudes. The wind variation on the 23rd and 24th

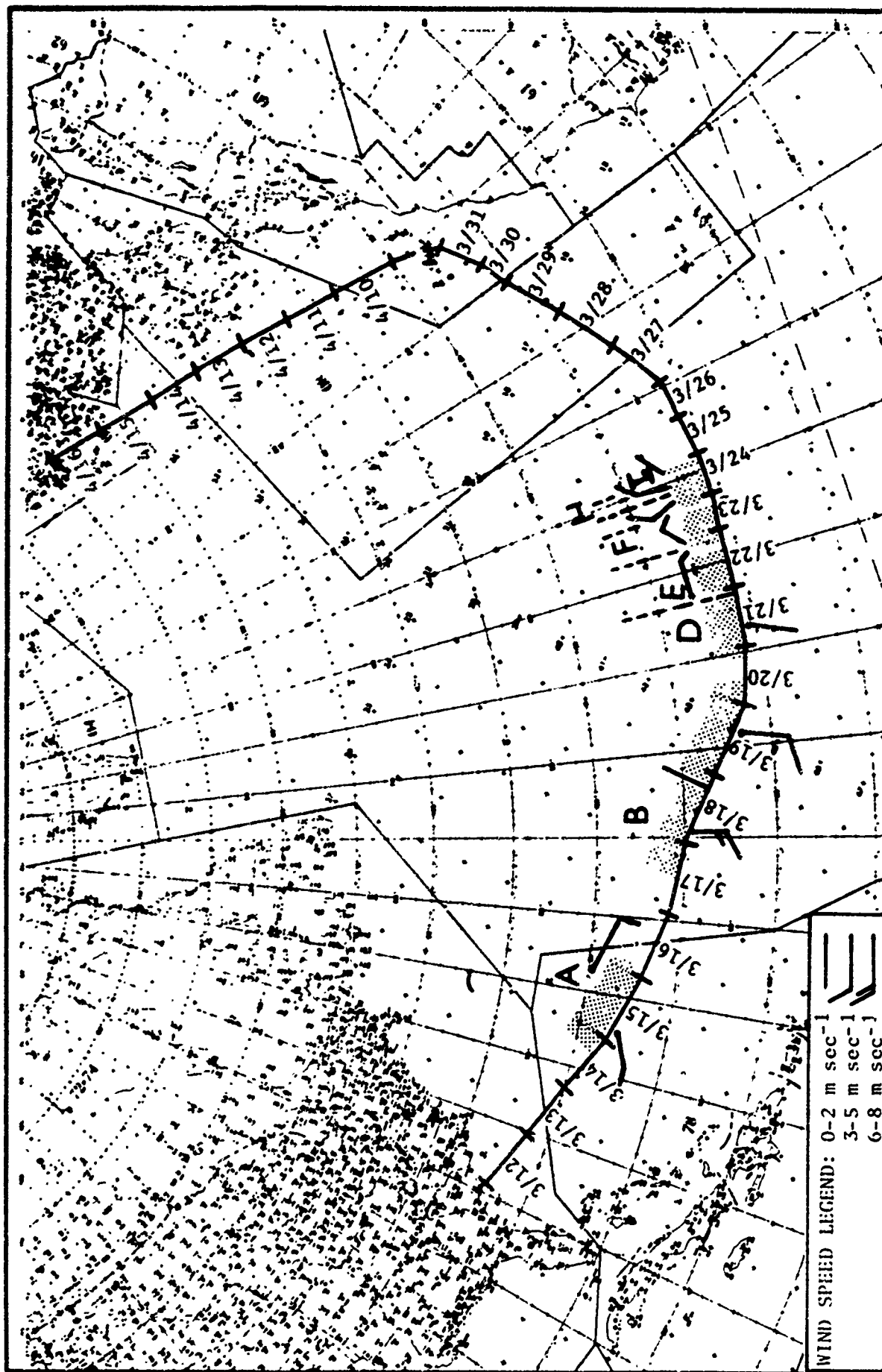


Figure 1. APPROXIMATE TRACK FOR USNS LYNCH, 11 MARCH - 17 APRIL 1983. TIME PERIOD AND LOCATION OF EACH EPISODE ARE SHOWN ALONG WITH MEAN WIND VELOCITY DURING THE EPISODE.

resulted from the movement of the ship through the circulation on the west side of a weak low pressure system which was centered some 150-200 n mi north of the ship.

Fig. 2 repeats Fig. 1 with the addition of mean values of total aerosol concentration (Aitken count), relative characterizations (High, Medium and Low) of both sea salt elemental concentration indicated by Na, Cl, Mg and K and continental elemental concentrations indicated by Si, Al and Fe. The average aerosol concentration per cubic centimeter in the diameter range $0.562\text{ }\mu\text{m}$ to $1.78\text{ }\mu\text{m}$, hereafter called the $1\text{ }\mu\text{m}$ concentration, are also presented.

The Aitken count shows a typical value of 1000-2000 in air flowing off-shore on the 14th, and then the decrease to mid-ocean levels of 400-500 through the 24th. The Aitken counts remained at this level until late on the 30th when they again rose above 1000 as the USNS LYNCH neared the Canary Is.

The sea salt type elemental concentration remained at medium levels ($2\text{-}3\text{ }\mu\text{g}/\text{m}^3$ for Na) during Episodes A and B with the $5\text{-}7\text{ m/sec}$ average wind speed. For Episodes C, D and E with speeds $<4\text{ m/sec}$, Na dropped below $2\text{ }\mu\text{g}/\text{m}^3$, and reached a minimum of $0.5\text{ }\mu\text{g}/\text{m}^3$ (with an average speed of less than 1 m/sec) for 11.5 hours ending at 2130 GMT on the 21st. For average wind speed less than 2 m/sec , the Cl/Na ratios were very near that of 1.8 for sea water.

For the Episodes E-H, the wind speed was between $3\text{-}5\text{ m/sec}$ and the behaviour of the Na concentration was erratic with the minimum of $0.5\text{ }\mu\text{g}/\text{m}^3$ occurring with maximum speed of 4.9 m/sec

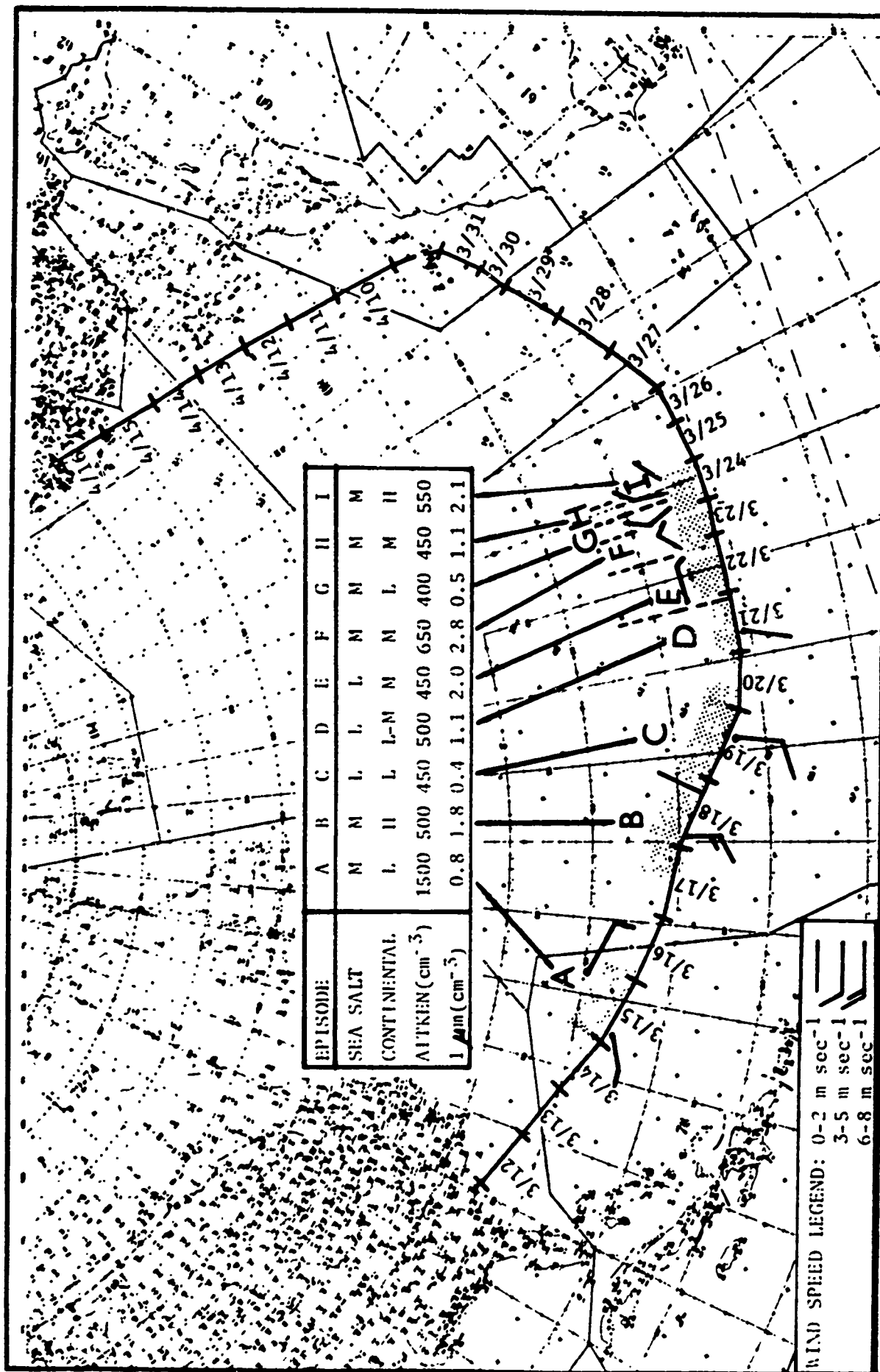


Figure 2. FIGURE 1 MODIFIED TO INCLUDE QUALITATIVE CONCENTRATIONS OF SEA SALT AND CONTINENTAL TYPE AEROSOLS, AITKEN AND 0.56-1.78 μ m DIAMETER AEROSOL PARTICLE COUNTS (cm⁻³).

and maximum $2.5 \mu\text{g}/\text{m}^3$ occurring with a minimum speed of 2.9 m/sec. However, the minimum of $0.5 \mu\text{g}/\text{m}^3$ still had a Cl/Na ratio of 2.0, similar to the near sea water values found with the generally small Na concentrations.

While the sea salt aerosol concentration appeared to be related to the wind speed for air which had not been exposed to land based sources, the continental aerosol on the other hand was more related to wind direction, i.e. exposure to land surface types and/or anthropogenic source activity. During Episode A, the air first was coming out of the Gulf of Mexico and crossing Florida, and then this type air was reencountered on the 15th as the wind direction turned 180 degrees into the east. The continental aerosol concentrations were mainly at or near zero, with a maximum value of $0.8 \mu\text{g}/\text{m}^3$ for Fe and $0.0 \mu\text{g}/\text{m}^3$ for both Si and Al. Although the air had been exposed to land surfaces, the region had recently experienced rain which may have minimized soil particulate injection into the air.

By the 17th the wind had turned into the south and was blowing at 5-7 m/sec. The afternoon and evening samples taken on the 17th showed the highest concentration of continental elements, Si, Al, Fe and Mn during the cruise. During this sampling period with its southerly wind, the LYNCH was located only some 1000 km north of the Lesser Antilles and the continental aerosols could have originated from there, or perhaps further south from South America. Another possibility is that the

aerosols were from Europe/Africa and were transported across the Atlantic in the easterly winds on the south side of the subtropical high.

After the light winds and low concentrations of continental aerosols observed during Episodes C and D, the continental aerosol concentrations again rose as wind direction turned into the east and northeast and Europe/Africa source air was again sampled. During this period, the concentrations reached the third highest level encountered on the cruise with values generally one-half those measured during the maximum concentration observed during Episode B.

During the next three Episodes, the wind first veered into the north-northwest during which clean air from the central Atlantic was tapped, and then the wind returned to the easterly direction under which continental aerosol concentrations returned to the second highest values measured during the cruise. This period obviously represented a return to air which had received continental aerosols from the Europe/Africa source region.

3.2 DATA DESCRIPTIONS

The aerosol elemental data that are discussed and interpreted in this section comprise both concentrations and element frequency per particle. The elemental concentrations were obtained from hi-volume samples taken on Millipore polycarbonate membrane filters exposed for periods ranging from 5 to 12 hours. The flow rates were measured and total volume sampled was determined for each sample. The filters were analyzed at Florida State University by proton induced X-ray emission (PIXE) (Hudson et al., 1980) for 26 more common elemental mass concentrations ranging from sodium to mercury in atomic number. The total mass measured for each element was converted to concentration via the total volume sampled and reported in units of $\mu\text{g}/\text{m}^3$. Only elements whose concentration exceeded their minimum detectable level were used in our analysis.

Table 3 presents the elemental concentration by sample for the period 14-24 March 1983, with the time and lengths of sampling periods. This table contains only those elements which were consistently above $0.1 \mu\text{g}/\text{m}^3$ in concentration. The elements are arranged with major sea water elements on the left and continental type elements (starting with Si) on the right. Examination of the table immediately reveals the distinct variations in the concentration of continental type elements discussed in the OVERVIEW; for example Si with a value near $10.0 \mu\text{g}/\text{m}^3$ on the 17th to low values near $0.5 \mu\text{g}/\text{m}^3$ on the 18th-20th and then back to moderate values around $5.0 \mu\text{g}/\text{m}^3$ on the 22nd.

Sampling Period		Aerosol Elemental Concentration ($\mu\text{g}/\text{m}^3$)									
Date/Time	Length	Na	Cl	Mg	S	K	Ca	Si	Al	Fe	Mn
3/14/83	1425-2316	2.3	8.9	0.7	2.1	0.3	0.3	0.0	0.0	0.8	-
3/14	2330-1030	1.9	1.8	0.3	3.2	0.2	0.2	0.1	0.0	0.6	-
3/15	1045-1630	2.1	1.7	0.4	3.2	0.2	0.2	0.0	0.0	0.06	0.0
3/15	1635-2236	2.3	2.4	0.4	3.0	0.2	0.2	0.0	0.0	0.06	0.0
3/17	1145-1645	2.8	7.6	1.1	1.1	1.2	1.1	12.4	5.7	3.8	0.07
3/17	1645-2210	2.0	5.2	0.7	0.9	0.8	0.6	8.0	3.6	2.3	0.03
3/17	2220-1010	2.4	6.7	0.5	0.9	0.4	0.3	2.4	1.1	0.7	0.01
3/18	1045-1645	1.9	5.3	0.5	0.9	0.2	0.2	1.1	0.6	0.3	0.0
3/18	1645-2231	0.9	2.9	0.4	0.6	0.1	0.1	0.7	0.4	0.2	0.0
3/18	2245-0915	0.9	1.9	0.3	0.6	0.1	0.1	0.5	0.3	0.1	0.00
3/19	0940-2210	0.7	1.2	0.2	0.5	0.08	0.08	0.3	0.2	0.09	-
3/19	2230-1000	0.7	1.4	0.2	0.5	0.08	0.1	0.5	0.3	0.1	0.0
3/20	2210-0945	0.6	0.9	0.2	0.4	0.2	0.3	2.3	1.1	0.8	0.007
3/21	1000-2130	0.5	1.0	0.2	0.4	0.2	0.3	2.5	1.2	0.8	0.007
3/21	2145-0945	0.8	2.1	0.3	0.6	0.3	0.3	3.2	1.4	1.0	0.014
3/22	1000-1450	1.7	5.7	0.8	0.9	0.6	1.1	5.5	2.5	1.6	0.020
3/22	2125-0830	0.5	1.1	0.3	0.2	0.4	0.3	3.8	1.7	1.2	0.007
3/23	0945-1500	2.5	9.1	0.8	1.4	0.5	0.8	3.1	1.4	1.0	0.016
3/23	2015-0845	1.8	8.3	0.4	0.8	0.2	0.3	0.5	0.2	0.2	0.003
3/24	0910-1515	1.3	4.3	0.5	0.7	0.3	1.4	2.3	1.0	0.7	0.010
3/24	1519-2015	2.2	6.0	0.9	1.0	1.0	1.6	10.0	4.2	3.0	0.047

TABLE 3
Concentration of Major aerosol elements,
NRL Transatlantic Cruise, 14-25 March 1983,
by sampling period.

To delineate distinct episodes of aerosol concentration and meteorological conditions the average wind direction and speed were computed for each of the sampling periods. These wind directions are meaningful since the wind direction varied minimally during the periods. These wind data and concentrations for major elements are shown in Table 4, along with episodes defined for discussion of aerosol concentration in the context of the attendant meteorological conditions. The episodes were defined basically on the Si concentration and wind direction with Na concentration and wind speed added to define some boundaries. For example, Episode B was defined as starting with the obvious $12.4 \mu\text{g}/\text{m}^3$ concentration observed on the 17th. The midday sample (1045-1645GMT) on the 18th was included in Episode B since the Si concentration, wind direction and wind speed were judged to be closer to their respective values in Episode B than in the subsequent Episode C. Similarly the shift to easterly wind and increase in wind speed for the 2145-0946GMT, 21-22 March sample indicated defining the start of Episode E, although the concentration of Si ($3.2 \mu\text{g}/\text{m}^3$) was not that much higher than in Episode D ($2.5 \mu\text{g}/\text{m}^3$). Table 4 presents the primary elemental concentration data considered in discussing the individual episodes.

Although sulfur is the fourth most abundant element in sea water, sulfur is discussed independently in Section 3.5 of this report. Sulfur aerosol from the ocean is unique in that it is thought to have a biological source in the ocean microlayer,

Sampling Period	Episode	Wind		Aerosol Elemental Concentrations ($\mu\text{g}/\text{m}^3$)								
		Average Direction	Average Speed (m/sec)	Na	Cl	Mg	Si	Al	Fe			
3/14/83	1425-2316	A	250	4.3	2.3	8.9	0.7	0.0	0.0	0.8		
3/14/83	2330-1030	A	244	3.6	1.9	1.8	0.3	0.1	0.0	0.6		
3/15/83	1045-1630	A	114	1.9	2.1	1.7	0.4	0.0	0.0	0.06		
3/15/83	1635-2236	A	108	4.0	2.3	2.4	0.4	0.0	0.0	0.06		
3/17/83	1145-1645	B	174	7.2	2.8	7.6	1.1	12.4	5.7	3.8		
3/17/83	1645-2210	B	175	5.8	2.0	5.2	0.7	8.0	3.6	2.3		
3/17/83	2220-1010	B	185	5.4	2.4	6.7	0.5	2.4	1.1	0.7		
3/18/83	1045-1645	B	183	3.3	1.9	5.3	0.5	1.1	0.6	0.3		
3/18/83	1645-2231	C	173	2.9	0.9	2.9	0.4	0.7	0.4	0.2		
3/18/83	2245-0915	C	165	1.9	0.9	1.9	0.3	0.5	0.3	0.1		
3/19/83	0940-2210	C	219	1.5	0.7	1.2	0.2	0.3	0.2	0.09		
3/19/83	2230-1000	C	169	1.4	0.7	1.4	0.2	0.5	0.3	0.1		
3/20/83	2210-0945	D	190	1.5	0.6	0.9	0.2	2.3	1.1	0.8		
3/21/83	1000-2130	D	207	0.7	0.5	1.0	0.2	2.5	1.2	0.8		
3/21/83	2145-0945	E	094	3.3	0.8	2.1	0.3	3.2	1.4	1.0		
3/22/83	1000-1450	E	081	3.5	1.7	5.7	0.8	5.5	2.5	1.6		
3/22/83	2125-0830	F	042	4.9	0.5	1.1	0.3	3.8	1.7	1.2		
3/23/83	0945-1500	F	050	2.9	2.5	9.1	0.8	3.1	1.4	1.0		
3/23/83	2015-0845	G	339	4.9	1.8	8.3	0.4	0.5	0.2	0.2		
3/24/83	0910-1515	H	007	3.5	1.3	4.3	0.5	2.3	1.0	0.7		
3/24/83	1519-2015	I	052	1.2	2.2	6.0	0.9	10.0	4.2	3.0		

TABLE 4 Definition of Episodes for NRL Transatlantic Cruise Along with Average Wind and Concentrations of Major Sea Salt and Continental Aerosol Elements for the Sampling Periods within each Episode.

and therefore shows concentration fluctuations over and above those expected from production from the bulk concentration in sea water.

In addition to absolute elemental concentration in Table 4, two other types of elemental presence data will be used. The first, derived from the PIXE analysis, is the percentage of the total mass of the 26 elements analyzed that is represented by each element's mass. These data are shown in Table 5 for elements which generally provided 1% or more of the total mass. Secondly in Table 6 we have the percentage of particles which contain a given element as determined by the SEM analysis. Generally 50 particles per sample were examined for their elemental composition, with Na again being the lower limit. It should be recognized that a single particle may show more than two elements. Also notice that these samples were acquired over 10-30 minutes and care should be taken when comparing them to PIXE samples which could cover as much as 12 hours of sampling.

The Aitken counts and the 1 μ m diameter concentration referred to in the discussion are found in the previously published data volume (Wattle et al., 1983). Detailed discussions of the individual episodes, including all the types of data, are presented as Appendix A.

<u>Sampling Period</u>		<u>Episode</u>	<u>Percent of Total Mass</u>									
<u>Date/Time</u>			Na	Cl	Mg	S	K	Ca	Si	Al	Fe	
3/14/83	1425-2316	A	16	60	5	14	2	3	0	0	1	
3/14/83	2330-1030	A	24	23	4	41	2	3	2	0	1	
3/15/83	1045-1630	A	27	21	5	41	2	3	0	0	1	
3/15/83	1635-2236	A	26	28	5	34	3	3	0	0	1	
3/17/83	1145-1645	B	8	21	3	3	5	3	33	15	10	
3/17/83	1645-2210	B	8	21	3	4	3	3	32	15	10	
3/17/83	2220-1010	B	16	43	3	6	2	2	16	7	5	
3/18/83	1045-1645	B	17	48	5	8	2	2	10	5	3	
3/18/83	1645-2231	C	14	44	6	10	2	2	11	7	3	
3/18/83	2245-0915	C	19	39	6	13	2	2	13	6	3	
3/19/83	0940-2210	C	21	34	6	15	2	2	10	7	3	
3/19/83	2230-1000	C	18	35	6	12	2	4	12	7	4	
3/20/83	2210-0945	D	8	14	3	6	3	4	35	16	11	
3/21/83	1000-2130	D	7	13	3	6	4	4	35	16	11	
3/21/83	2145-0945	E	8	21	3	5	3	4	31	14	10	
3/22/83	1000-1450	E	8	28	4	4	3	6	27	12	8	
3/22/83	2125-0830	F	5	12	4	3	4	3	39	18	12	
3/23/83	0945-1500	F	12	44	4	7	2	4	15	7	5	
3/23/83	2015-0845	G	14	65	4	6	2	2	4	2	1	
3/24/83	0910-1515	H	11	37	4	6	2	4	20	9	6	
3/24/83	1519-2015	I	7	20	3	3	3	5	33	14	10	

TABLE 5 Percent each Element was of Total Mass, PIXE Analysis. Elements with $\geq 1\%$.

Date/Time	Na	Cl	Mg	K	Ca	S	Si	Al	Fe	P	Organics	Number of Particles
3/14/83	1509-1524	50	16	33	33	83	50	33	33			6
3/14/83	2310-2330	10	20	10	60	30	70	40	10			10
3/15/83	1450-1510	2	68	4	8	16	8	70	16	62	2	50
3/16/83	1450-1510	40	10	30	18	16	36	40	36	36		50
3/17/83	1042-1102	0	0	18	34	4	4	98	90	64		50
3/18/83	1020-1040	62	60	18	14	12	4	22	32	18		50
3/19/83	0917-0937	44	3	36	11	33	8	53	47	36		36
3/20/83	1006-1030	4	6	30	10	12	6	78	70	52	4	50
3/20/83	1551-1611	24	3	45	21	28	3	41	45	41	17	29
3/21/83	1006-1036	12	8	34	34	34	8	76	14	62	4	50
3/21/83	1850-1910	60	60	24	8	10	8	34	26	10		50
3/22/83	1005-1030	32	34	22	14	30	4	80	70	18	2	50
3/22/83	1350-1410	46	46	32	4	30	10	74	58	22	28	50
3/22/83	1855-1920	78	78	32	14	12	2	42	36	26		50
3/23/83	0911-0931	60	54	20	12	28	12	44	42	18		50
3/24/83	2052-2111	39	50	43	34	36	2	91	84	55	5	44
3/25/83	1005-1025	38	52	14	20	26	6	88	62	30		50
3/25/83	2014-2033	55	63	27	31	16	6	61	59	31		48

TABLE 6 Percentage of Particles Containing the Indicated Elements. NRL Cruise, 1983.

3.3 GENERAL BEHAVIOR OF CONTINENTAL PLUMES OVER THE OCEANS

An interesting aspect of the episodes with large to moderate absolute concentrations of continental elements is the relatively uniform percentage of total mass among the continental elements, Si, Al and Fe. Table 7 shows these data with the samples ranked by absolute concentration of Si. Of the eight samples, seven have Si percentages between 30-40%, and similar uniform ranges can be seen for the other continental elements, Al and Fe. Whether this feature indicates air from the same general source strength region, similar aerosol loading from different source strength regions or uniform decay of all aerosol elements in a given plume cannot be determined without detailed source and trajectory data which are not available. However the meteorological situations suggest the following scenario based on the uniform decay interpretation.

A plume of continental aerosols (from the general source region of Europe and Africa to the east and northeast) had moved eastward over the Atlantic and experienced a decrease in concentration due to decay with distance from the source region. At the westernmost point, Episode D, the LYNCH encountered the leading edge of this plume (lowest absolute concentration) in light south-southwest winds as the plume reached the western edge of the semi-permanent high. During Episodes E and F the plume was encountered at a location nearer the source and moderate concentrations were measured. Finally, in Episode I the plume was sampled nearest the source and high concentrations were measured.

Date/Time	Episode	Concentration of Si (ug/m ³)	Percent of Total Mass						
			Si	Al	Fe	Ca	Na	Cl	Mg
3/17/83	B	12.4	33	15	10	3	8	21	3
3/24/83	I	10.0	33	14	10	5	7	20	3
3/17/83	B	8.0	32	15	10	3	8	21	3
3/22/83	E	5.5	27	12	8	6	8	28	4
3/22/83	F	3.8	39	18	12	3	5	12	4
3/21/83	E	3.2	31	14	10	4	8	21	3
3/21/83	D	2.5	35	16	11	4	7	13	3
3/20/83	D	2.3	35	16	11	4	8	14	3

TABLE 7 Percent of Total Mass by Element for Samples Dominated by Continental Aerosol, NRL Cruise 1983. Samples Ranked by Si Concentration.

It is not clear whether Episode B's aerosol source was the Lesser Antilles and/or northern region of South America or the core of a plume from Africa/Europe. If the latter, then Episodes D, E and F may represent measurements taken at those longitudes on the northern edge of a plume similar to the one that may have produced the high concentration at Episode B, rather than measurements taken in the core of a plume whose concentration had decayed as the plume moved farther away from the source region.

3.4 SEA SALT AEROSOL CONCENTRATIONS VS. WIND SPEED

Table 8 presents the episodes with Na concentrations less than $1 \mu\text{g}/\text{m}^3$ and average wind speeds less than 3m/sec. These conditions were satisfied only by Episodes C and D which occurred in the central Atlantic near the center of the subtropical high pressure system. The Na concentration at these low levels was related to the wind speed, with Na concentration increasing with increasing wind speed.

The Cl/Na enrichment ratio is defined as the ratio of Cl/Na concentration in the aerosol sample to the ratio of the Cl/Na concentration found in sea water (1.8). An enrichment value of one suggests that the source of Na and Cl aerosols was sea water. The first five samples in Table 8 show an enrichment ratio near one and these are the five which cover the lowest wind speed episodes during the 19th-21st, when the ship was near the center of the subtropical high and sea water would be expected to be the primary aerosol source for Na and Cl. The sixth sample has a Cl/Na enrichment ratio of 1.8. Since this

Date/Time	Episode	Concentration of Na (ug/m ³)	Average Wind Speed (m/sec)	Cl/Na Enrichment	Percent of Total Mass							
					Cl	Na	Mg	K	Ca	Si	Al	Fe
3/21/83	1000-2130	0.5	0.7	1.11	13	7	3	4	4	35	16	11
3/20/83	2210-0945	0.6	1.5	0.83	14	8	3	3	4	35	16	11
3/19/83	2230-1000	0.7	1.4	1.11	35	18	6	2	3	12	7	4
3/19/83	0940-2210	0.7	1.5	0.95	34	21	6	2	2	10	7	3
3/18/83	2245-0915	0.9	1.9	1.17	39	19	6	2	2	13	6	3
3/18/83	1645-2231	0.9	2.9	1.79	44	14	6	2	2	11	7	3

TABLE 8 Average Wind Speed, Cl/Na Enrichment Ratio and Percent of Total Mass by Element for Samples with low Na Concentration and Low Wind Speed, NRL Cruise 1983. Samples Ranked by Na Concentration.

sample was the first one taken after the ship exited the continental plume of the 17th-18th, some relative abundance of Cl from continental sources is not unlikely.

An intriguing aspect of these data is that Episode D, with the two lowest absolute concentrations of Na, also has high relative percentages of total mass of continental elements, Si, Al and Fe, similar to the relative percentages found in continental plumes with high absolute concentrations of Si, Al and Fe. Since the Cl/Na enrichment ratio is low indicating little Cl component from continental sources, one interpretation is that this observation of high continent. ' percentage indicates these measurements were taken in a mixing zone in which clean ocean air with low wind speeds and low Na and Cl concentrations had mixed with low concentration continental plume air. The continental air had little Na and Cl in it as indicated by the Cl/Na ratio being near that of sea water. This interpretation is supported by the Mg (the next most abundant element after Na and Cl in sea water) percentage in Episode D being a smaller percentage relative to that found in Episode C. On the other hand, K and Ca, which are relatively less abundant in sea water than the first three elements, showed slightly higher percentages with respect to Episode C, thus indicating some continental source component to their mass.

3.5 SULFUR OVER THE OCEAN

An emerging conclusion from our extensive study in maritime scenarios is that the marine aerosol population varies considerably both spatially and temporally, and does not necessarily comprise solely sea salt particles, particularly in non-storm conditions. Chemical analyses of aerosol samples from the marine atmosphere generally always reveal the presence of particulate sulfur. Even in remote marine locales, aerosol populations frequently show concentrations of sulfur many times that expected from sea water alone. Sulfur bearing particles are found at micrograms per cubic meter concentrations, and occasionally account for more than 50% of the aerosol population by number. These data are discussed in more detail below.

While traditionally thought to be a result of anthropogenic/ industrial activity, increasing evidence suggests that this 'excess' sulfur may be a product of the natural environment-- i.e., resulting from biological and chemical processes which produce a number of gaseous sulfur compounds, chief among these DMS and H_2S . It is hypothesized that biogenic DMS is released from the ocean to react with photochemically-generated free hydroxyl radicals producing methane sulfonic acid (MSA) which is very hygroscopic; in aqueous solution droplets, the MSA in turn reacts with OH to produce particulate sulfate. Some investigators estimate that the contribution of gaseous sulfur from natural sources such as these to the global sulfur budget is equivalent to that from industrial sources.

Many investigators have measured the sulfur concentration in oceanic areas. During a number of our previous cruises, we obtained data on sulfur and sulfate concentration in aerosols and these data are summarized in Table 2. Note that sulfur concentrations range from 0.3 to 1.7 micrograms per cubic meter, exhibiting enrichment ratios approaching 100. On the transatlantic cruise in March-April 1983, we observed sulfur concentrations of 0.4 to 3.2 micrograms per cubic meter (Figure 3). Since sulfur concentrations are generally highest in the near shore zone, this maritime sulfur has traditionally been attributed to industrial activity; but more recent study suggests that the natural environment can be a significant contributor of sulfur to the marine atmosphere.

Many sulfur compounds are produced by biological and chemical activity in the natural world. The contribution of the biogenically generated sulfur to the total atmospheric sulfur budget is estimated to be of the order of $70-100 \times 10^{12}$ g S per year equalling the contribution from anthropogenic sources. Dimethyl sulfide (DMS-- $(\text{CH}_3)_2\text{S}$), one of the more common of these compounds, is released by bacteria and algae, and hence the highest DMS concentrations are found in biologically active oceanic zones (estuaries, upwelling areas, etc.). DMS concentrations are patchy (probably associated with the patchiness of nutrient rich areas), and relatively high concentrations are found nearest phytoplankton blooms, floating sea lettuce, etc. In nutrient rich areas, concentrations of approximately 70-500 nanograms of sulfur per liter are typical.

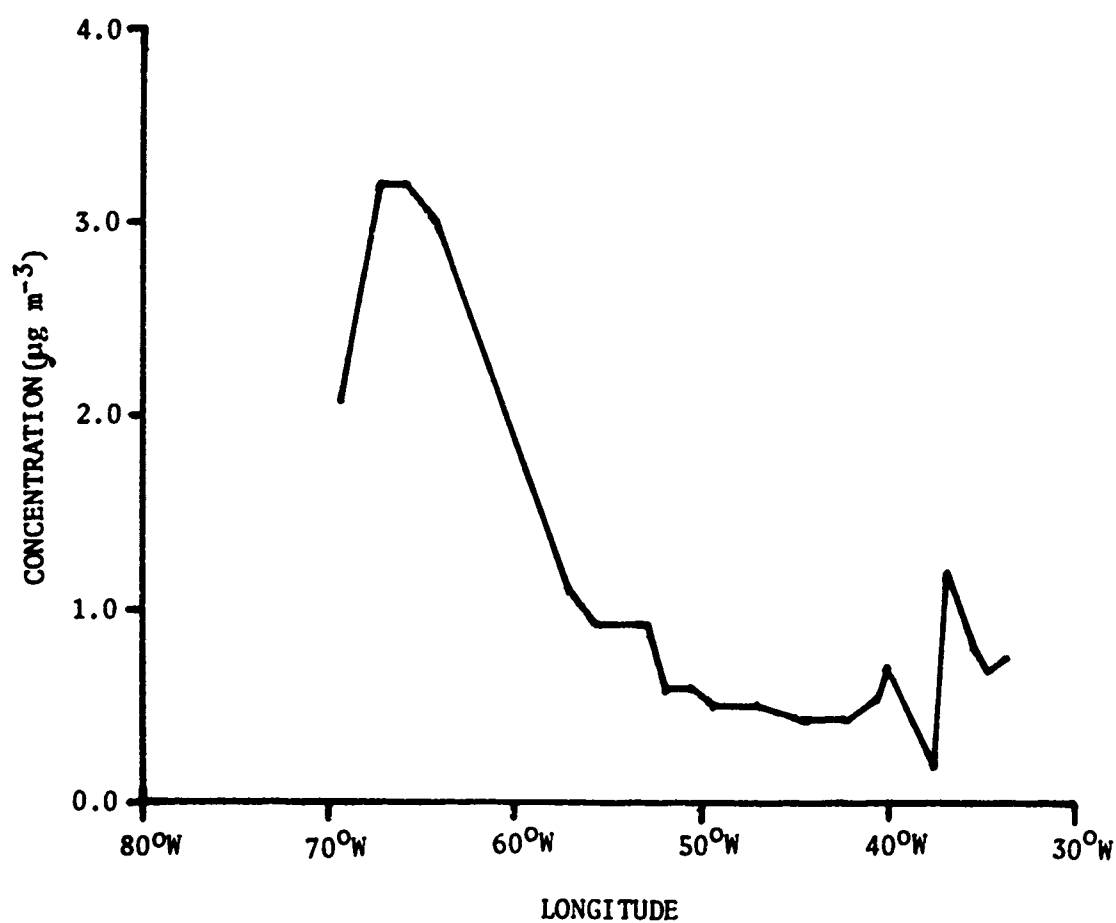


Figure 3 CONCENTRATION OF SULFUR VS LONGITUDE FOR NRL-705-83 CRUISE, MARCH 1983 BETWEEN 20° AND 30°N.

Oligotrophic areas (nutrient deficient) have DMS concentrations of 40-90 ng S per liter.

DMS as a constituent in the marine atmosphere has a short lifetime (on the order of 1 day). The primary removal mechanism appears to be the reaction of DMS with the photochemically generated hydroxyl (OH) radical. Photo-oxidation of DMS in the absence of free radicals does not likely occur because DMS does not absorb UV light above 290 nm wavelength. The primary product of the $\text{DMS} + \text{OH}$ reaction is methane sulfonic acid (MSA), a more stable but highly hygroscopic compound compared to DMS. It is highly likely that MSA rapidly equilibrates in the high humidity marine environment producing solution droplets. Further oxidation of MSA by reaction with OH in the aqueous phase produces particulate SO_4^{2-} (sulfate), thus potentially accounting for the excess sulfate and sulfur found in aerosol populations even in remote marine locations.

4.0 A POTENTIAL RELATIONSHIP BETWEEN ATMOSPHERIC AEROSOL OPTICAL DEPTH AND BOUNDARY LAYER VISIBILITY.

Under Navy sponsorship, Calspan has acquired solar intensity measurements via sun photometry and boundary layer aerosol and extinction data for a geographical distribution of sites--coastal Florida (Valkaria), the Alboran Sea (western Mediterranean), and San Nicolas Is. (west coast US). From these data, we have been able to relate an estimated aerosol optical depth in the planetary boundary layer to total atmospheric aerosol optical depth. Consequently, from a measure of total atmospheric aerosol optical depth and an estimate of boundary layer depth, one can obtain a mean aerosol extinction coefficient; further, by assuming a well-mixed aerosol in the boundary layer, an estimate of the aerosol extinction coefficient near the surface can be obtained. Using a relationship between satellite-observed radiance and atmospheric aerosol optical depth (Griggs (1983)), a remote-estimation method for mean boundary-layer visibility is possible. This section presents our observations, discusses the resulting relationship between aerosol optical depth in the planetary boundary layer and total atmospheric aerosol optical depth and outlines the remote estimation technique for boundary-layer visibility.

4.1 INSTRUMENTATION AND OBSERVATIONS

Sun photometer radiance measurements were acquired with a Calspan-modified UDT Model 40X Opto-meter fitted with a 0.005 micrometer-wide filter centered at 0.502 micrometers. The measured radiance was converted to aerosol optical depth by

Volz's (1959) equation, which corrects for Rayleigh and ozone optical depths, solar viewing geometry and earth orbital geometry. The extraterrestrial solar radiation value for 0.502 micrometers was taken from Thekaekara et al.(1969). Photometer measurements were taken hourly at each observation site, but only data from those days when cloud cover was absent or minimal were used in the analysis. By averaging the data for each day, a mean optical depth was obtained for the period of several hours centered on local noon.

Corresponding to these mid-day sun photometry data, a mean aerosol optical depth was also computed for the planetary boundary layer. Aerosol optical depth was computed from a vertical profile of extinction coefficient generated from surface measurements of aerosol extinction coefficient, and radiosonde observations of humidity structure in the vertical (assuming that the aerosol in the boundary layer was well-mixed) through a relationship derived by Hanel (1976). For the same aerosol constituent, Hanel's expression relates changes in aerosol extinction coefficient(β) to changes in humidity(f) as follows:

$$\frac{\beta_2}{\beta_1} = \left[\frac{(1-f_1)}{(1-f_2)} \right]^{2\epsilon} \quad (1)$$

where ϵ is an empirical constant which depends on the type of aerosol present (0.26 for the maritime aerosols considered here). The surface β (β_1) was obtained by subtracting the molecular scattering coefficient (0.02 Km^{-1}) from the surface extinction coefficient measured by an MRI nephelometer operating at 0.474

micrometers wavelength. Again, a mean value was obtained over the same time period as that used to obtain the mean optical depth. Radiosonde data provided the relative humidity profile and planetary boundary layer depth which were input to (1) to obtain the β profile and its associated aerosol optical depth within the planetary boundary layer. Average mid-day data were obtained on four days at both the Florida and Alboran sites and on eight days at San Nicolas Is. (see Table 9).

4.2 RESULTS

Fig. 4 presents the plot of estimated boundary layer aerosol optical depth vs. total atmospheric aerosol optical depth from the three sites. The letters identify the sites, and the boundary layer depth (in meters) for each data point is shown in parentheses. Two separate groups of data points are immediately apparent. The first set, with boundary layer optical depth values greater than 0.03 and boundary layer depths greater than 200 m, lies close to the 1:1 line. These data follow a trend with San Nicolas Is. data at the low values with boundary layer depths of 300-1000 m; Alboran Sea data at the middle values with boundary layer depths of 1000-2000 m and Florida data at the highest values with boundary layer depths at 3000-5000 m. The distribution reflects the meteorological situations and conditions under which the data were taken.

The San Nicolas Is. field trip was during the Fall, near the west coast of the US when inversions are frequently below 1000 m. The Alboran Sea data were also obtained during

TABLE 9

Averaged atmospheric aerosol optical depth, surface-level aerosol extinction coefficient, boundary layer depth and estimated boundary layer aerosol optical depth at San Nicolas Is., on the Alboran Sea and at Valkaria, Florida

SAN NICOLAS ISLAND

DATE	DATA AVERAGING PERIOD (TIME OF DAY) (PDT)	MEASURED AVERAGE ATMOSPHERIC AEROSOL OPTICAL DEPTH	AEROSOL SCATTERING COEFFICIENT (Km^{-1})	MEASURED BOUNDARY LAYER DEPTH (m)	ESTIMATED BOUNDARY LAYER AEROSOL OPTICAL DEPTH
17 OCT 1984	11-15	0.04	.15	400	0.07
17 OCT 1984	10-15	0.04	.17	700	0.09
20 OCT 1984	12-15	0.02	.08	380	0.03
22 OCT 1984	09-15	0.12	.13	100	0.01
23 OCT 1984	10-15	0.06	.12	120	0.01
24 OCT 1984	10-14	0.05	.10	170	0.01
25 OCT 1984	10-15	0.08	.18	50	0.01
28 OCT 1984	11-15	0.06	.12	350	0.04

ALBORAN SEA

	(GMT)				
10 OCT 1982	10-15	0.10	.06	1500	0.08
11 OCT 1982	10-14	0.12	.06	1130	0.07
13 OCT 1982	11-15	0.12	.10	150	0.02
16 OCT 1982	10-14	0.20	.10	2010	0.19

FLORIDA

	(EDT)				
26 JUL 1982	12-14	0.54	.14	5180	0.83
27 JUL 1982	09-11	0.41	.08	4000	0.40
28 JUL 1982	10-12	0.25	.04	4440	0.30
29 JUL 1982	10-11	0.20	.05	3130	0.26

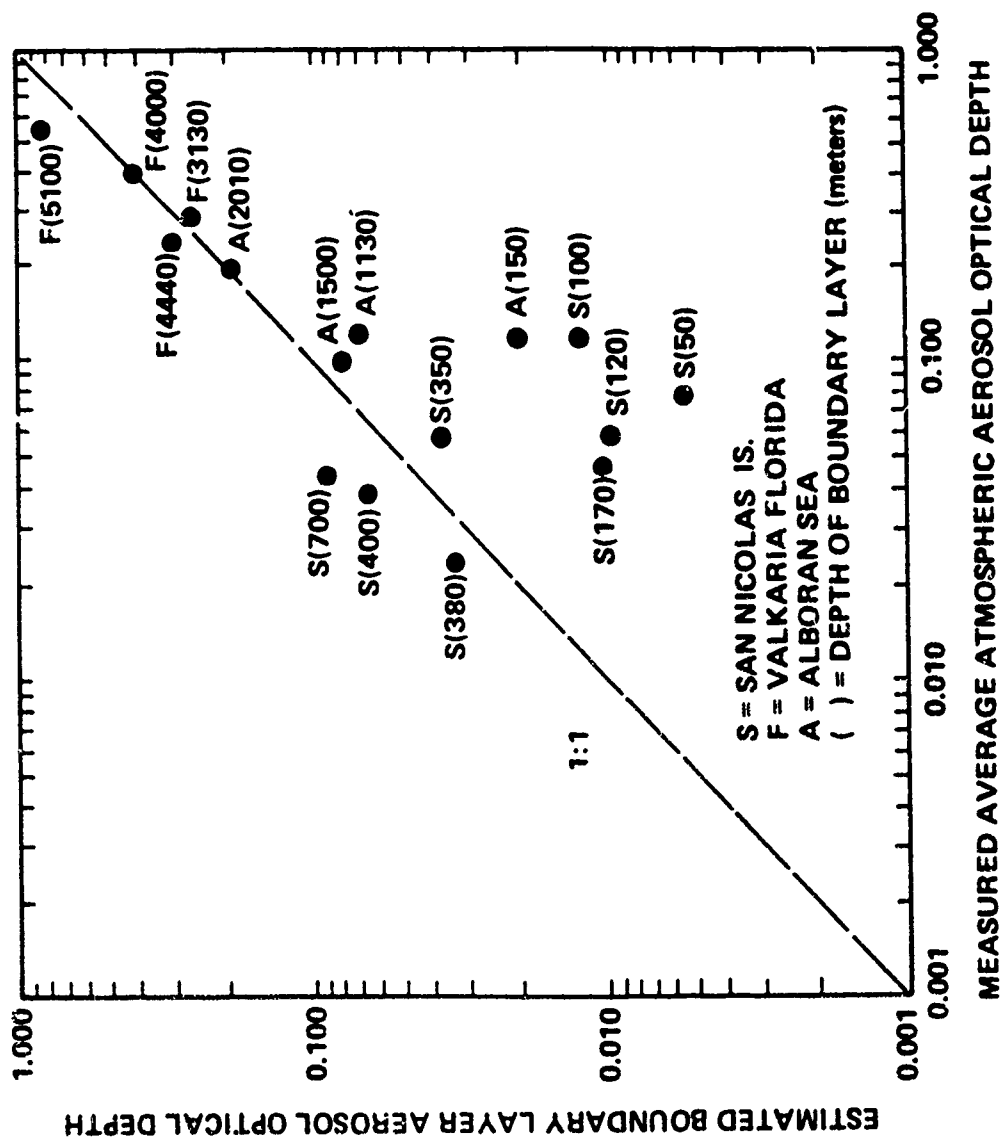


Figure 4 ESTIMATED BOUNDARY LAYER AEROSOL OPTICAL DEPTH (DERIVED FROM SURFACE-LEVEL AEROSOL EXTINCTION AT $0.474 \mu\text{m}$ AND THE VERTICAL PROFILE OF RELATIVE HUMIDITY WITHIN THE BOUNDARY LAYER) VS. SURFACE-MEASURED TOTAL ATMOSPHERIC AEROSOL OPTICAL DEPTH (AT $0.502 \mu\text{m}$) FOR THREE MARITIME LOCATIONS.

Fall, but the meteorological flow patterns in the western Mediterranean produced inversions greater than 1000 m. Finally, the Florida data were taken during Summer in tropical air with a correspondingly deep boundary layer. Thus, the data cover a wide range of meteorological conditions and suggest a broad range of validity for the relationship.

The other group of data points is clustered below and to the right of the 1:1 line, with boundary layer optical depth values of 0.05 to 0.15 and planetary boundary layer depths less than 200 m. Four of these five data points are from San Nicolas Is. Apparently, below a threshold inversion height of ~ 200 m (in our data set), the boundary layer is so thin that the aerosol extinction within it represents only a small fraction of the total extinction in the column. Obviously, the threshold height will depend on aerosol and humidity structure within and above the boundary layer, and the threshold observed here may be unique to our data set.

Some insight into the threshold boundary layer depth can be gained from measured vertical profiles of aerosol optical depth which were acquired within the boundary layer at San Nicolas Is. Optical depth measurements were also obtained as a function of altitude at San Nicolas Is.--near sea level (14 m) and at 46 m, 152 m and 275 m along a hillside. If these observed vertical gradients of aerosol optical depth were present, what boundary layer depth would be required for aerosol optical depth in the boundary layer to equal the total aerosol optical depth?

Table 10 presents results of the computations for the maximum and minimum observed gradients in optical depth and the observed boundary layer depths below 200 m.

Comparison shows that all the observed boundary layer depths are less than their respective "threshold" depths. Conversely, the boundary layer depths for all but one of the data points which fall close to the 1:1 line in Fig. 4 are equal to or larger than the "threshold" values. Thus the concept of a threshold boundary layer depth, below which the boundary layer aerosol optical depth lies well below the 1:1 relation with total aerosol optical depth, appears to have some validity.

In addition to dependency on boundary layer depth and humidity structure, the relationship depicted in Fig. 4 would be expected to depend also on the value of ϵ -- i.e., composition of the aerosol population. Literature values of ϵ range from 0.23 for maritime aerosols containing Saharan dust (Hanel, 1976) to 0.41 suggested by Fitzgerald (1986). However, analysis of the sensitivity of calculated boundary layer aerosol optical depth in our data set to the reported range of ϵ showed no effect up to boundary layer depths of 2 Km, and a maximum increase of 25% at depths of 4 Km.

The relationship demonstrated by Figure 4 may be applicable to the estimation of surface-level extinction coefficient or visibility from satellite radiance measurements. Given a relationship between measured radiance and aerosol optical depth (e.g., Griggs, 1983) and an estimate of the boundary layer depth, the mean boundary layer aerosol extinc-

TABLE 10

Boundary layer depth (m) required for boundary layer aerosol optical depth to equal atmospheric aerosol optical depth for the indicated measured vertical gradient in aerosol optical depth and observed boundary layer depth (m)

MEASURED ATMOSPHERIC AEROSOL OPTICAL DEPTH	MINIMUM OBSERVED OPTICAL DEPTH GRADIENT (100m) ⁻¹ .013	MAXIMUM OBSERVED OPTICAL DEPTH GRADIENT (100m) ⁻¹ .0265	OBSERVED BOUNDARY LAYER DEPTH (m)
0.05	385m	190 m	170m
0.06	460	225	120
0.08	615	300	50
0.12	925	450	100,150
0.55	4230	2075	5180

tion coefficient ($\bar{\beta}$) could be obtained. Assuming that the surface aerosol $\beta_{sf} = \bar{\beta}$, the surface visibility could then be computed from Koschmieder's expression

$$V = \frac{-\ln \alpha}{\bar{\beta}}$$

where α is the threshold contrast and $\bar{\beta}$ is the sum of aerosol extinction and extinction due to molecular scattering. (It should be noted that the optical depth relationships observed here are for specific wavelength data--0.474 μm for estimated aerosol optical depth and 0.5 μm for measured atmospheric aerosol optical depth). Of course, relative humidity profile information would help provide better definition of surface-level visibility through use of the Hanel-type equation.

REFERENCES

Fitzgerald, J.W., 1986: "A Simple Model of Aerosol Optical Properties in a Well-mixed Marine Boundary Layer for a Wavelength of 0.50 μm ." NRL Memorandum Report 5764, 25 March 1986. Naval Research Laboratory, Washington, D.C. 20375-5000. AD A166433.

Griggs, M. 1983: "Satellite Measurements of Maritime Aerosol Parameters." April 1983. Science Applications, Inc., La Jolla, CA 92037. NAVENPREDRSCHFAC Contractor Report CR 83-04. AD-A128749.

Hanel, G., 1976: "The Properties of Atmospheric Aerosol Particles as Functions of the Relative Humidity at Thermodynamic Equilibrium with the Surrounding Moist Air," Advances in Geophysics, Vol 19, Ed. H.E. Landsburg & J. Van Mieghem, Academic Press, New York, pp 74-171.

Mack, E.J., Hanley, J.T., Pilié, R.J., Akers, C.K., and Wattle, B.J., 1981: "Aerosol Composition in the Marine and Coastal Boundary Layer," Proceedings 25th Annual SPIE Symposium, Vol. 305, San Diego, 27-28 August 1981.

Mack, E.J., Rogers, C.W., and Kile, J.N., 1983: "Aerosol Characteristics on the Alboran Sea, 9-18 October 1982," Calspan Report 7076-M-1, September 1983, 139 pp.

Mack, E.J., Rogers, C.W., Wattle, B.J., and Hanley, J.T., 1985: "Optical Depth and Aerosol Characteristics on San Nicolas Island During the SNI-84 Vertical Structure Experiment," Interim Report, November 1985, Contract No. N00014-81-C-0519, Calspan Corp., P.O. Box 400, Buffalo, NY 14225.

Thekaekara, M.P., R. Kruger and C.H. Duncan, 1969: "Solar Irradiance Measurements from a Research Aircraft," Applied Optics, 8, No. 8, p. 1713-1732, August.

Volz, F. E., 1959: Photometer mit selen-photoelement zur spektralen messung der sonnenstrahlung und zur bestimmung der Wellenlangenabhängigkeit der dunsttrubung. Arch. Meteor. Geophys. Bioklim., B10, 100-139.

Wattle, B.J., 1986: "Aerosol and Meteorological Characteristics Over the Straits of Gibraltar--A Data Volume," December 1986. Contract No. N00014-85-C-2393, Calspan Corp., P.O. Box 400, Buffalo, NY 14225.

Wattle, B.J., Mack, E.J., and Hanley, J.T., 1983: "Aerosol Characteristics in the Marine Boundary Layer, Charleston(SC) to Canary Islands to Scotland, March-April 1983--A Data Volume," Interim Report, November 1983. Contract No. N00014-81-C-0519, Calspan Corp., P.O. Box 400, Buffalo, NY 14225.

APPENDIX A

INDIVIDUAL EPISODE DESCRIPTIONS

A.1 EPISODE A--1430GMT, 14 March-2236GMT, 15 March 1983

The first half of episode A (1430/14th to 1030/15th) was characterized by west-southwest winds of around 4 m/sec to the south of a coastal low. The second half of the episode (1045/15th to 2236/15th) was characterized by easterly winds which developed as the subtropical ridge rebuilt northward and the east coast cyclone moved northeast into the Atlantic. The air sampled in the first half of the episode was flowing eastward from Florida and the Gulf of Mexico; the air sampled in the second half of the episode was air which had flowed eastward from these same regions earlier, but which was now being encountered on easterly winds.

The Aitken count was near 2000/cc for the early period and near 1500/cc for the later period; these values represent air which had flowed off the coast and the decrease with distance was compatible with values measured under similar conditions. The average particle concentration in the 1 μ m diameter range for this entire episode was 0.8/cc, which was about a third of the value measured later on in the maximum continental concentration plume.

The Na concentrations were near 2.0 μ g/m³ for the episode, while Cl was around 9 μ g/m³ early but dropped to near 2.0 μ g/m³ later in the episode. Since the other large sea salt cations

(Mg, K and Ca) were relatively uniform during the episode it appears there was an anthropogenic source of Cl during the initial sampling period.

The Cl/Na ratio for the latter three sampling periods is around 0.5 which indicates a relative abundance of Na. Since this is the beginning of the growing season in the upstream continental region, the presence of sodium nitrates in fertilizer is a possibility.

The continental aerosol concentrations were mainly at or near zero with maximum values of $0.8 \mu\text{g}/\text{m}^3$ for Fe and zero for Si and Al. Although the air had been exposed to land based sources as suggested by the increased Na amounts, the rain which the area had previously experienced may have minimized soil particulate injection into the air.

A.2 EPISODE B--1145GMT, 17 March-1645GMT, 18 March 1983

This episode contained four periods of sampling for aerosols which contiguously covered the 29-hour period. The wind direction for this episode was southerly, with the speed varying from 7 m/sec early in the period to 3 m/sec at the end. This southerly wind developed in response to a strong pressure gradient which formed between a developing low over the Gulf of Mexico and a subtropical ridge located in the central Atlantic.

The Aitken count was in the 500-600/cc range which is characteristic of mid-ocean levels. On the other hand, the absolute concentration for continental aerosols reached the maximum observed during the entire cruise for the sample taken between 1145 and 2210 on the 17th, 12.4, 5.7 and $3.8 \mu\text{g}/\text{m}^3$ respectively

for Si, Al and Fe. With the high wind speeds, Na also reached its highest absolute concentration observed on the cruise. Analysis of individual particles shows that greater than 90% of the particles contained both Si and Al, and that Si, Al and Fe accounted for almost 60% of the total mass measured. In addition, the number of particles in the 1 μ m diameter range reached values greater than 3/cc which is similar to values measured later on in a plume with the second largest maximum concentrations measured. The concentrations decreased slightly from the maximum values during the 1645-2210 sampling period and then decreased dramatically during the 12-hour overnight sample. The concentrations returned to low levels during midday on the 18th as the ship moved eastward out of the strong southerly flow.

During this episode, the USNS LYNCH was only some 1000km north of the Lesser Antilles and the continental type aerosols could have originated from this island group. Another possibility is that these were African aerosols which had been transported across the Atlantic in the easterly winds on the southern edge of the subtropical high and then transported northward as the strong southerly flow developed at that longitude.

A.3 EPISODE C--1645GMT, 18 March to 1000GMT 20 March 1983

During this episode the wind speed was between 1.5 and 3 m/sec from the south as the ship traveled along the east-west centerline of the subtropical ridge. Toward the end of the 20th the ship was located in a col between two centers of the subtropical high.

The Aitken count for this 41-hour period averaged around 450/cc, a value found to be typical of mid-ocean conditions. The continental aerosol concentrations fell to their second lowest values of the cruise; the only lower values were the zero concentrations detected at the beginning of the cruise. Sea salt concentrations were also low as the Na values fell below $1.0 \mu\text{g}/\text{m}^3$ for the first time during the cruise. Correspondingly, Na and Cl accounted for 50-60% of the total mass while the other sea cations accounted for another 10%. The major continental aerosol (Si, Al and Fe) accounted for approximately another 20%, with Si the largest contributor. The number of particles in the $1 \mu\text{m}$ diameter range was in the range 0.7 to 0.3/cc, with the lower value being very near the minimum observed during the cruise (0.2/cc).

The air sampled during this episode was some of the most aerosol free air encountered on the cruise. The sea salt concentrations were the second lowest measured; only those measured during the subsequent episode with speeds around 1 m/sec were lower. The continental aerosol concentrations were also the second lowest, being beaten out only by the zero aerosol levels found in the air flowing out of the Gulf of Mexico in the 14-15 March period. As well, both the Aitken and $1 \mu\text{m}$ diameter particle concentrations were near their lowest value. The sea salt concentration was low because of the low wind speeds and the continental aerosol was low because probably because the air had either last passed over land with low continental aerosol source

strength or had passed over land far enough in the past for aerosol ageing processes to have reduced the concentrations.

A.4 EPISODE D--2210GMT 20 March to 2130GMT 21 March 1983

During this period the wind speed was around 1 m/sec from the south-southwest. The ship was passing through a col located south of a weak low pressure area to the north. Toward the end of the period, a weak cold front approached the ship from the west.

The Aitken count for this episode averaged around 450/cc, again indicating the mid-ocean character of the air mass. The sea salt aerosol concentrations reached their lowest values of the cruise during this episode with Na at $0.5 \mu\text{g}/\text{m}^3$, Cl at $1.0 \mu\text{g}/\text{m}^3$ and Mg at $0.2 \mu\text{g}/\text{m}^3$. On the other hand, continental aerosols showed a return to moderate concentrations with Si at values of $2.5 \mu\text{g}/\text{m}^3$ and Al and Fe around $1.0 \mu\text{g}/\text{m}^3$. With the reappearance of continental constituents, their contribution to the total mass rose to levels encountered during Episode B, i.e. Si, Al and Fe accounted for 60% of the mass. The individual particle analysis showed that around 70% of the particles contained continental aerosol elements, while sea salt elements were found in only about 10% of the particles.

The air sampled during this episode was characterized by low sea salt aerosol concentrations associated with the low wind speeds and moderate continental aerosol concentrations apparently associated with the northern edge of a plume of

continental aerosol bearing air moving westward from Africa/ Europe in the easterly flow on the south side of the subtropical high.

A.5 EPISODES E AND F-- 2145GMT 21 March to 1500GMT 23 March 1983

Although the wind direction varied from easterly for Episode E to northeasterly for Episode F, the two episodes are discussed together because the continental aerosol concentrations behave in a consistent manner with the wind direction. For the first part of Episode E the wind is slightly south of east as the ship entered light winds on the south side of the subtropical high. During the midday sample of 4.5 hours on the 22nd, the wind shifted to east-northeast as the ship began to enter northeasterly flow around a high centered at 43N, 25W. For Episode F, the wind backed further to the northeast as the ship moved to the eastern side of the high centered at 43N, 29W.

The Aitken count maintained the 450/cc level of Episodes C and D until the wind shifted to the east-northeast in the morning of the 22nd. The Aitken count then rose through the 700-800/cc level during the 22nd and reached a peak value of 1050/cc at midnight on the 22nd as the wind held steady from the east-northeast. Then as the wind backed into the northeast during midday on the 23rd, the Aitken counts fell back to around the 700/cc level. The 1 μ m diameter concentrations show a very similar behaviour with an increase to maximum values of around 3/cc at midnight on the 22nd and then a decrease to 2/cc during midday on the 23rd. The time history of both these parameters

indicates the sampling of a continentally originating plume with the maximum during the 24-hours centered around midnight on the 22nd.

The continental aerosol concentrations showed moderate values at the beginning and end of this double episode period, with peak values during the 24-hour period 1200GMT on the 22nd to 1200GMT on the 23rd. Si for example had a maximum concentration of $5.5 \mu\text{g}/\text{m}^3$ which was the fourth highest value reached during the cruise and which was almost half the maximum value recorded for Si during Episode B. Identical behaviour was observed for the continental aerosol components Al and Fe.

The sea salt aerosol concentration behaviour was erratic during these two episodes, both from any variation with wind speed and variation with content of continental aerosols. The Na concentration varied from $0.5 \mu\text{g}/\text{m}^3$ to $2.5 \mu\text{g}/\text{m}^3$ with the lowest value occurring with the highest wind speed (5 m/sec) and the highest value occurring with the lowest wind speed (3 m/sec). The elevated Na concentrations were accompanied by increased concentrations in other sea salt elements (Cl, K and Mg) with all these raised values occurring during the periods of sampling of the continental plume. This characteristic of increased values in the continental plume is not unexpected since sources for these elements exist over land surfaces as well. However, for these episodes the maximum values of the sea salt elements do not occur with maximum values of the

continental elements indicating perhaps that the air which was variously sampled had experienced different overland trajectories and exposure to different land-based aerosol sources.

A.6 EPISODE G-- 2015GMT 23 March to 0845GMT 24 March 1983

During the last three Episodes G, H and I(12, 6 and 5 hours long respectively) the wind direction first veered from north-northwest through north and then backed to the quasi-steady northeasterly flow encountered during Episode F. This wind direction sequence was produced by an inverted pressure trough which was located north of the cruise track and which moved eastward relative to the ship's movement.

The northwesterly flow tapped air from around 25N, 40W which had probably been driven into the Atlantic by the East Coast storm of 13-15 March. This air was very clean as shown by the lowest Aitken counts measured on the cruise(300/cc), the lowest $1\text{ }\mu\text{m}$ concentrations measured on the cruise (0.2/cc) and continental aerosol concentrations (0.5, 0.2 and $0.2\text{ }\mu\text{g}/\text{m}^3$ for Si, Al and Fe respectively) at levels measured in the mid-Atlantic minimum observed during Episode C. The Na, K and Mg concentrations were not unreasonable in terms of the wind speed of this episode. However, the Cl concentration was much larger relative to the other sea salt elements(Cl/Na enrichment ratio of 2.5) indicating a relative abundance of Cl. With very low continental aerosol concentrations, the source of this high Cl concentration remains unclear.

A.7 EPISODE H-- 0910GMT to 1515GMT 24 March 1983

The wind direction returned to northerly as the inverted trough passed to the east of the ship and the pressure pattern was returning to northeasterly around the high center at mid-latitudes. With this wind pattern the air being sampled was returning to that which had come from Europe.

Aitken counts rose back to mid-ocean levels of around 450/cc and 1 μ m diameter particle counts were slightly above 1/cc. Continental aerosol concentrations returned to medium levels with values of 2.3, 1.0 and 0.7 μ g/m³ for Si, Al and Fe respectively. These values are very similar to those found on the plume edges during both Episodes B and D. These values are all consistent with the return of the wind to the north and a tapping of the air which had passed over the land mass to the northeast.

A.8 EPISODE I-- 1519GMT to 2015GMT 24 March 1983

By this time period, the LYNCH had passed through the wind field west of the inverted trough and reentered the northeasterly flow around the high pressure center located to the north. This wind direction was bringing air into the region from off the African/European continental region. In this air the Aitken count rose to the mid 500/cc level and the 1 μ m aerosol count rose to around 2/cc.

The continental nature of this air can be seen in the concentrations of Si, Al and Fe of 10.0, 4.2 and 3.0 μ g/m³ respectively, which were the second highest values measured on the cruise. Correspondingly, K and Mg rose to relatively high

concentrations indicating an increase in the continental component for these sea salt elements. The relative percentage of the various elements present was similar to that observed in other continental type air masses, with Si, Al and Fe accounting for about 60% of the mass, and Na and Cl accounting for around 25%. Again, the percentage of particles containing the various elements confirmed the concentration measurements, with Si and Al appearing in 90% of the particles and Na and Cl appearing in 50% of the particles. Thus as the ship neared the African coast it again entered air coming from continental aerosol sources.

APPENDIX B

AEROSOL DATA FOR COREA, MAINE, JULY 1981

Table B-1

Percentage of Particles (0.2-10.0 μ m dia) in the Indicated Composition Category
for Each Aerosol Sample Acquired at Corea, Maine, July 1981

Date	Time (LMT)	Mixed:		Other Salts Without NaCl	Silicates	Number of Particles Counted	
		Organics	Sea Salt & Others				
22 Jul	2030	2%	30%	54%	6%	8%	50
23 Jul	1600	2	12	60	2	24	50
24 Jul	1530	0	36	48	6	10	50
25 Jul	1600	2	48	22	10	18	50
26 Jul	1830	0	46	38	10	6	50
27 Jul	1930	0	46	54	0	0	50
28 Jul	1730	0	58	40	0	2	50
29 Jul	1930	16	18	14	22	30	50
30 Jul	1700	6	70	14	6	4	50
31 Jul	0830	12	24	2	22	40	50
AVERAGE		4	39	35	8	14	500

TABLE-2 AVERAGE AEROSOL CONCENTRATIONS OBSERVED AT COREA, MAINE, JULY 1981

Date	Time Interval	Avg Wind	Total (Aitken)	- - At Sizes Larger than Indicated - -				
				$\frac{\#}{\text{cm}^3} > 0.5 \mu\text{m}$	$\frac{\#}{\text{cm}^3} > 0.7 \mu\text{m}$	$\frac{\#}{\text{cm}^3} > 1.4 \mu\text{m}$	$\frac{\#}{\text{cm}^3} > 3.0 \mu\text{m}$	$\frac{\#}{\text{cm}^3} > 5.0 \mu\text{m}$
22 Jul	1000-2100	WSW-NW	5700	-	-	-	-	-
23 Jul	1500-2000	SW-WSW	6700	1.63	0.69	0.16	3.7×10^{-3}	5.6×10^{-4}
24 Jul	0800-1600	SSW-SW	5800	1.14	0.44	0.11	4.7×10^{-3}	9.2×10^{-4}
25 Jul	1500-1700	SSW	2400	1.67	0.70	0.18	4.2×10^{-3}	7.1×10^{-4}
26 Jul	0800-1930	SSW	1700	2.87	1.44	0.45	5.5×10^{-3}	6.8×10^{-4}
27 Jul	1100-2100	NW	3300	3.62	1.39	0.35	3.7×10^{-3}	9.9×10^{-4}
28 Jul	0900-2000	SW-W	6200	0.78	0.33	0.09	3.9×10^{-3}	4.4×10^{-4}
29 Jul	1000-2000	ESE-ENE	1700	2.57	1.63	0.69	11.6×10^{-3}	10.0×10^{-4}
30 Jul	0700-2000	NW	3200	1.18	0.54	0.18	3.7×10^{-3}	2.8×10^{-4}
31 Jul	0700-0900	NW	5400	2.45	1.14	0.42	11.1×10^{-3}	9.7×10^{-4}
AVERAGE				2.0	0.9	0.3	5.8×10^{-3}	7.3×10^{-4}

Table B-3

Percentage of Sampled Aerosols (0.2-10.0 μm dia) Containing the
Indicated Chemical Elements as a Function of Time
at Corea, Maine, 22-31 July 1981

Element	-----Date/Time (LDT)-----										Avg
	22 Jul (2030)	23 Jul (1600)	24 Jul (1530)	25 Jul (1600)	26 Jul (1830)	27 Jul (1930)	28 Jul (1730)	29 Jul (1930)	30 Jul (1700)	31 Jul (0830)	
Na	84%	74%	86%	78%	94%	100%	98%	44%	84%	20%	76%
Mg	32	30	30	20	26	26	4	16	8	16	21
Al	28	40	20	24	16	14	12	32	4	28	22
Si	30	46	22	22	22	10	20	32	4	40	25
P	26	8	0	0	6	2	0	0	0	0	-
S	8	18	20	20	4	14	0	24	2	10	12
Cl	90	80	84	80	84	100	98	34	88	48	79
K	24	24	20	26	8	18	8	30	2	22	18
Ca	12	60	26	18	16	36	16	18	10	56	27
Ti	2	8	0	2	0	2	2	2	0	0	2
Fe	6	14	6	14	6	2	0	16	2	12	7
Nothing (organic)	2	2	0	2	0	0	0	16	6	12	4

Table B-4

Airborne Concentrations of Selected Chemical Constituents*
of Aerosol Samples Collected at Corea, Maine, July 1981

Date	Exposure Period (LDT)	-----Absolute Concentration ($\mu\text{g}/\text{m}^3$)-----						
		Na	Cl	S	K	Ca	Fe	Si
24 Jul	0930-1630	0.47	0.31	0.43	0.09	0.10	0.06	0.20
26 Jul	0800-1900	0.72	0.53	0.54	0.06	0.11	0.03	0.06
27 Jul	1130-2030	0.50	0.37	0.60	0.07	0.11	<0.02	<0.1
28 Jul	0845-2000	0.29	0.46	0.22	0.05	0.09	<0.02	<0.1
29 Jul	1000-2030	0.46	1.16	0.19	0.06	0.10	0.02	<0.1
30 Jul	0700-1800	<0.2	<0.1	0.29	0.13	0.05	0.09	0.17
AVERAGE		0.4	0.5	0.4	0.08	0.09	0.04	0.1

* The elements Al, Cu, Mn, P, Pb, Ti, V & Zn were below detectable levels.

Table B-5

Number of Observed Mixed-Composition Particles (0.2-10.0 μ m dia) Containing NaCl as a Function of Additional Elemental Composition for each Sample Obtained at Corea, Maine, July 1981

Elemental Composition	Total Number Observed	Date and Time (LNT) of Samples											
		22 Jul (2030)	23 Jul (1600)	24 Jul (1530)	25 Jul (1600)	26 Jul (1830)	27 Jul (1930)	28 Jul (1730)	29 Jul (1930)	30 Jul (1700)	31 Jul (0830)		
Ca	32	2	8	3	1	3	7	6		2	1		
Mg	21	4	2	2	1	6	3		1	2			
Si	13	2	1	1	1	3		4	1	1			
Si, Al, Mg	10	2		3	1	2	2						
Al	9	1		1	1	1	1	2	3				
K	9	1	1	2	2			2					
Si, Al	8	1	1	1	2	1		2					
Ca, Mg	6		2	2				2					
Ca, K	6				1		5			2			
Si, Al, Mg, K, Ca	5		1	2			1	1					
S	5	1	1	1	2		1						
S, Mg, K, Ca	5	1	2	1	1		1						
S, Ca	4	1	1	1			1						
Si, Al, Ca	4		3					1					
Si, Al, Mg, K, Ca, P	3	2	1				1						
Si, Mg, Ca	2		1										
Si, Al, K, Fe	2	1				1							
Si, Al, Mg, K, Ca, Fe	2		2										
Si, Al, Mg, P	2	1				1							
Si, Al, Mg, K, P, Ti	2	1	1										
Si, Al, Mg, K, S	2			1			1						
S, K, Ca	2			1									
S, Ca, Mg	2			1	1		2						
K, Ca, Mg	2			2									
K, Mg	2	1							1				
P	2	2											
Al, P	1					1							
Si, Al, K	1												
Si, K, Mg	1							1					
K, Mg, P	1	1											
Si, Al, Ca, P	1		1										
Si, Al, Mg, P, Fe	1												
Si, Al, S	1		1										
Al, Ca, S	1		1										
Si, Al, Mg, Ca, S	1		1										
Si, Al, Mg, P, S	1		1				1						
Si, Al, Mg, K, P, Ca, S	1		1										
Si, Al, Ca, Fe, S	1		1										
K, Mg, P, S	1	1											
Ti	1												
Si, Al, Mg, K, Fe, Ti	1				1								

Table B-6

Number of Observed Particles (0.2-10.0 μ m dia) Containing Si as a Function of Additional Elemental Composition (exclusive of NaCl) for each Sample Obtained at Corea, Maine, July 1981

Elemental Composition	Total Number Observed	Date and Time (LMT) of Samples										
		22 Jul (2030)	23 Jul (1600)	24 Jul (1550)	25 Jul (1600)	26 Jul (1830)	27 Jul (1930)	28 Jul (1730)	29 Jul (1930)	30 Jul (1700)	31 Jul (0830)	
Si, Al, Ca	5		1						1		3	
Si, Al, Ca, K, Mg, Fe	5								3		2	
Si	4	1	2								1	
Si, Al	4				1					1		
Si, Al, Ca, K	4							2			3	
Si, Al, K, Mg, Fe	4		1		2			1			1	
Si, Al, K	3	1					1					
Si, Mg, Fe	2			1		1						
Si, Al, Mg, Ca, Fe	2				1						1	
Si, Al, Ca, Fe	2		1									
Si, Al, Ca, K, S	2			1								
Si, Al, K, S, Na	2							2			2	
Si, Ca, Cl	2											
Si, Na	1					1					1	
Si, Mg	1											
Si, Al, Fe	1								1			
Si, Al, K, Fe	1							1				
Si, Al, K, Mg	1							1				
Si, Al, Mg, Ca	1									1		
Si, Al, Mg, Fe	1			1								
Si, Al, K, Ca, Fe, Na	1							1			1	
Si, Al, K, Ca, Mg	1											
Si, P, Mn	1		1									
Si, Al, Ca, P	1	1										
Si, Al, Ti	1		1									
Si, Al, Mg, Ti	1		1									
Si, Al, Mg, K, Fe, Ti	1		1									
Si, Al, P, Mg, K, Ca, Fe, Ti	1		1					1				
Si, Al, Na, S	1			1								
Si, Al, Ca, S	1									1		
Si, Al, Ca, S, P, Fe	1	1										
Si, Al, Ca, S, K, Fe, Na	1					1						
Si, Al, Ca, K, Fe, Mn	1											
Si, Al, Cl	1		1									
Si, Al, Fe, Cl	1											
Si, Mg, Ca, Cl	1		1									
Si, Al, K, Fe, Cl	1				1							
Si, Mg, Ca, S, Cl	1				1							
Si, Al, Mg, K, Ca, Fe, Cl	1				1							
Si, Al, Mg, Ca, Cl, Mn	1				1							
Si, Al, Mg, K, Fe, Ti, Cl	1				1						1	
Si, Al, Mg, K, Ca, Fe, Ti, Cl	1		1									
Si, Al, K, Ca, S, Fe, Ti, Cl, Mn	1										1	

Table B-7

Number of Observed Particles (0.2-10.0 μm dia) Composed of Non-NaCl Inorganic Salts as Indicated
Mixed Elemental Composition for each Sample Obtained at Corea, Maine, July 1981

Elemental Composition	Total Number Observed	Date and Time (LMT) of Samples										
		22 Jul (2030)	23 Jul (1600)	24 Jul (1530)	25 Jul (1600)	26 Jul (1830)	27 Jul (1930)	28 Jul (1730)	29 Jul (1930)	30 Jul (1700)	31 Jul (0830)	
S	10			3					5	1	1	
Ca, Cl	8				1					1	6	
K, Cl	3	1	1							1		
S, K, Na	3				3							
S, Ca	2							2				
S, Ca, K	2										2	
S, Ca, Na	2				1			1				
Ca	2					1					1	
S, K	1							1				
S, Ca, Mg, Na	1					1						
S, Fe	1							1				
K	1								1			
Mg, Na	1											
Mg, K, Ca, Na	1							1				
K, Ca, P	1											
K, P, Cl	1	1										
Mg, P, Cl	1	1										
Ca, Cl, Mn	1										1	

APPENDIX C

AEROSOL DATA FOR VALKARIA, FLORIDA, JULY 1982

TABLE C-1

AIRBORNE CONCENTRATIONS OF SELECTED CHEMICAL CONSTITUENTS*
OF AEROSOL SAMPLES COLLECTED AT VALKARIA, FLORIDA. JULY 1982

<u>Date</u>	<u>Time</u>	<u>($\mu\text{g}/\text{m}^3$)</u>							
		<u>Na</u>	<u>Cl</u>	<u>S</u>	<u>K</u>	<u>Ca</u>	<u>Fe</u>	<u>Si</u>	<u>Mg</u>
23 Jul	1100-2000	0.51	1.75	0.37	0.15	0.33	0.31	0.80	0.07
23-24 Jul	2015-0830	0.23	1.08	0.32	0.17	0.25	0.07	0.11	-
24 Jul	0900-2000	0.50	1.65	0.28	0.14	0.21	0.16	0.43	0.04
24-25 Jul	2010-0925	0.04	0.02	0.27	0.13	0.10	0.05	0.19	-
25 Jul	0935-1335	-	0.33	0.31	0.14	0.27	0.12	0.22	-
25 Jul	1345-2045	0.55	0.32	0.82	0.12	0.29	0.11	0.41	0.16
25-26 Jul	2100-0845	0.03	-	0.68	0.10	0.14	0.05	0.11	-
26 Jul	0910-2010	0.17	-	2.25	0.10	0.62	0.08	0.22	-
26-27 Jul	2105-0815	0.11	-	3.58	0.12	0.17	0.08	0.37	0.13
27 Jul	0830-1330	0.26	0.11	0.92	0.22	0.58	0.39	1.17	0.17
27 Jul	1330-2000	0.39	0.48	0.41	0.12	0.14	0.06	0.28	-
27-28 Jul	2000-0800	0.11	-	0.40	0.28	0.07	0.02	0.10	-
28 Jul	0800-1900	0.13	0.25	0.52	0.13	0.35	0.17	0.47	-
28-29 Jul	1900-0800	0.20	0.09	0.64	0.12	0.25	0.13	0.38	0.08
29 Jul	0815-2015	0.74	2.20	0.36	0.45	0.81	0.89	2.53	0.20
29-30 Jul	2015-0900	0.16	0.55	0.16	0.26	0.28	0.27	0.69	0.14
30 Jul	0915-1845	1.17	4.68	0.72	1.59	2.52	3.78	9.45	0.62
30-31 Jul	1900-0715	0.92	3.63	0.71	1.61	2.75	3.91	9.67	0.52
AVG		0.28	0.74	0.77	0.17	0.30	0.19	0.53	0.12

* The elements Cu, Cr, Mn, P, Pb, Ti, V, and Zn were generally below detectable levels.

TABLE C-2

PERCENTAGE OF PARTICLES (0.2-10.0 μ m DIA) IN THE INDICATED COMPOSITION
CATEGORIES FOR EACH SAMPLE ACQUIRED AT VALKARIA, FLORIDA, JULY 1982

<u>Date</u>	<u>Time</u> (LDT)	<u>Wind</u> <u>Dir</u>	<u>Avg.</u> <u>Particle</u> <u>Conc.</u> <u>>0.3μ dia</u> (#/cc)	<u>Organics</u>	<u>Sea salt</u>	<u>Mixed:</u> <u>Sea Salt</u> <u>& Others</u>	<u>Other salts</u> <u>without</u> <u>NaCl</u>	<u>Silicates</u>	<u>Number of</u> <u>Particles</u> <u>Counted</u>
23 Jul	1125	SSE	1.38	0%	0%	62%	8%	30%	50
23 Jul	1955	SE	5.64	0	0	0	0	100	50
24 Jul	0900	SSW	3.93	0	2	0	8	90	50
24 Jul	1340	ESE	2.85	0	36	44	2	18	50
24 Jul	1815	SSW	1.39	0	12	26	22	40	50
25 Jul	0940	WSW	1.17	0	2	32	34	32	50
25 Jul	1340	E	1.53	0	0	6	32	62	50
25 Jul	1830	E	3.27	0	0	6	18	76	50
26 Jul	0930	N	2.25	0	0	12	28	60	50
26 Jul	1035	E	1.89	0	0	4	40	56	50
26 Jul	1420	E	2.22	0	0	6	44	50	50
26 Jul	1940	ESE	19.69	0	0	4	62	34	50
27 Jul	0830	Calm -SW	2.01	2	0	4	22	72	50
27 Jul	1330	ENE	2.93	0	8	28	10	54	50
27 Jul	1930	WNW	10.33	0	16	26	18	40	50
28 Jul	1420	WSW	0.98	0	0	0	52	48	50
28 Jul	1845	ENE -ESE	0.52	0	46	54	0	0	50
29 Jul	0825	S- SSE	0.86	0	4	72	2	22	50
29 Jul	1345	SE	9.63	0	0	6	2	92	50
30 Jul	0915	SSE	18.15	0	0	0	0	100	50
30 Jul	1335	SE	23.23	0	0	6	6	88	50
30 Jul	1850	SE	24.51	0	0	2	4	94	50
31 Jul	0730	S	41.54	0	0	0	8	92	50
									1150
AVG				0.1	5.5	17.4	18.3	58.7	

TABLE C-3 SUNPHOTOMETRY DATA

JULY	TIME (EDT)	0.500 μ m (0.01 ly/min)	Op. L.	ZENITH ANGLE	Bsca ⁺ (0.0101/m)	WSPV (km)	0.3 μ m CONC. (#/cc)
26	12:00	0.6970	0.479	19	1.30	35.5	2.74
26	13:00	0.6640	0.553	10	1.77	26.0	2.36
26	14:00	0.6310	0.592	14	1.77	26.0	2.78
26	15:00	0.6310	0.543	25	1.45	31.9	2.67
26	15:40	0.5990	0.529	34	2.66	17.3	4.89
26	19:00	0.0465	0.609	77	5.31	6.7	19.55
27	8:00	0.2120	0.455	71	2.95	15.0	3.75
27	9:00	0.4910	0.415	57	0.63	55.6	1.89
27	10:00	0.6310	0.401	44	0.89	52.0	2.71
27	11:00	0.6310	0.506	31	1.18	39.0	2.70
27	13:00	0.8300	0.334	10	1.93	25.2	2.50
28	7:35	0.1730	0.349	76	2.36	19.5	27.92
28	8:00	0.3650	0.279	71	0.77	60.0	24.86
28	8:30	0.4810	0.305	64	0.62	74.3	29.71
28	9:00	0.6470	0.253	57	0.53	86.7	3.56
28	10:00	0.7300	0.296	44	0.50	91.8	0.62
28	11:00	0.8960	0.205	31	0.62	74.3	0.99
28	12:00	0.8960	0.254	19	0.56	82.2	1.18
28	13:00	0.8130	0.354	10	0.86	53.8	0.46
28	14:00	0.7300	0.451	14	1.06	43.4	0.48
28	8:00	0.3650	0.279	71	0.89	52.0	0.72
29	10:10	0.7800	0.261	42	0.71	65.0	1.83
29	11:20	0.7970	0.324	27	0.74	62.4	1.91
30	11:50	0.4320	0.911	22	1.74	26.5	24.24

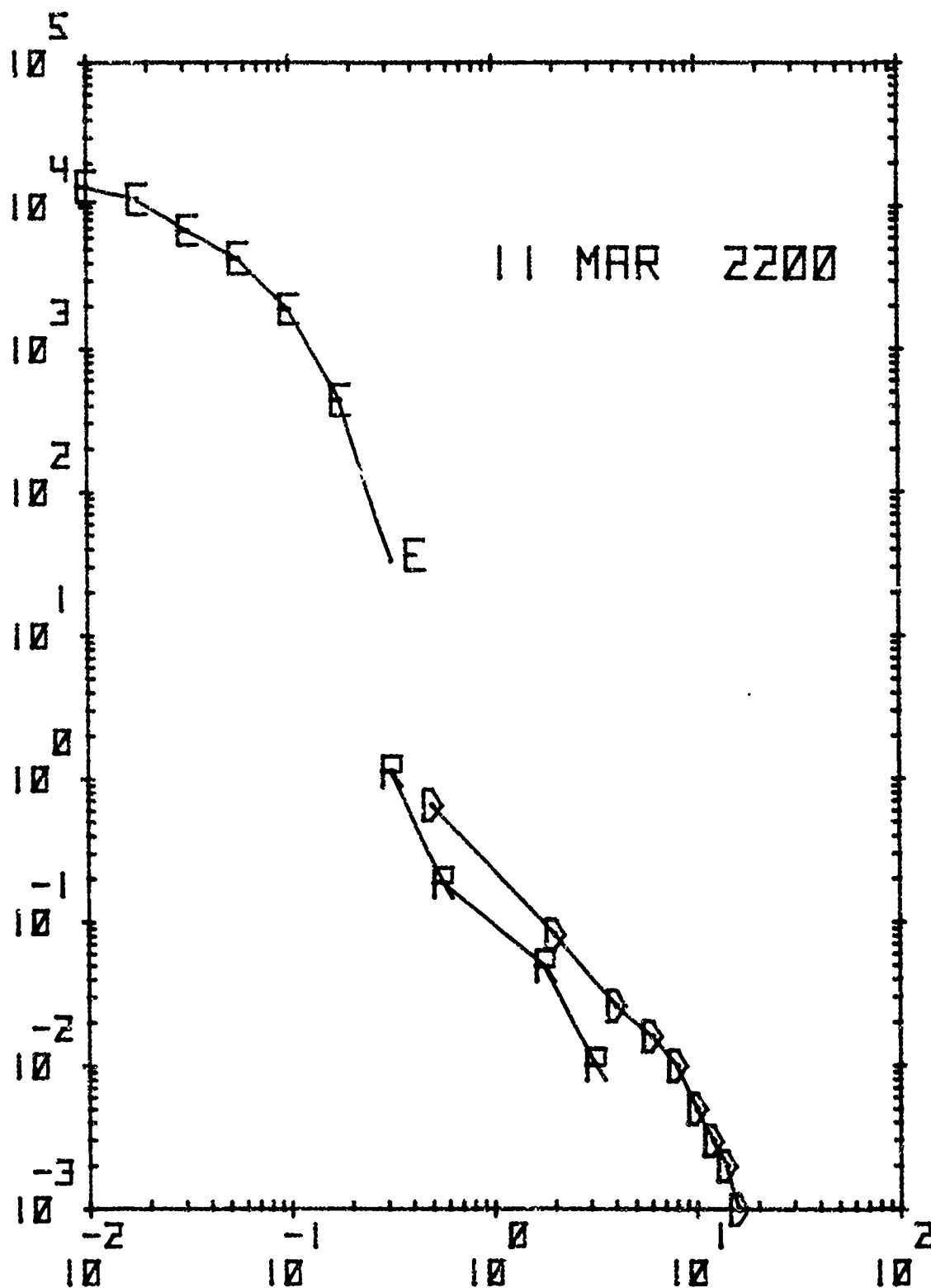
APPENDIX D

DROP SIZE DISTRIBUTIONS FOR

NRL-705-83 CRUISE 11 MARCH-17 APRIL 1983

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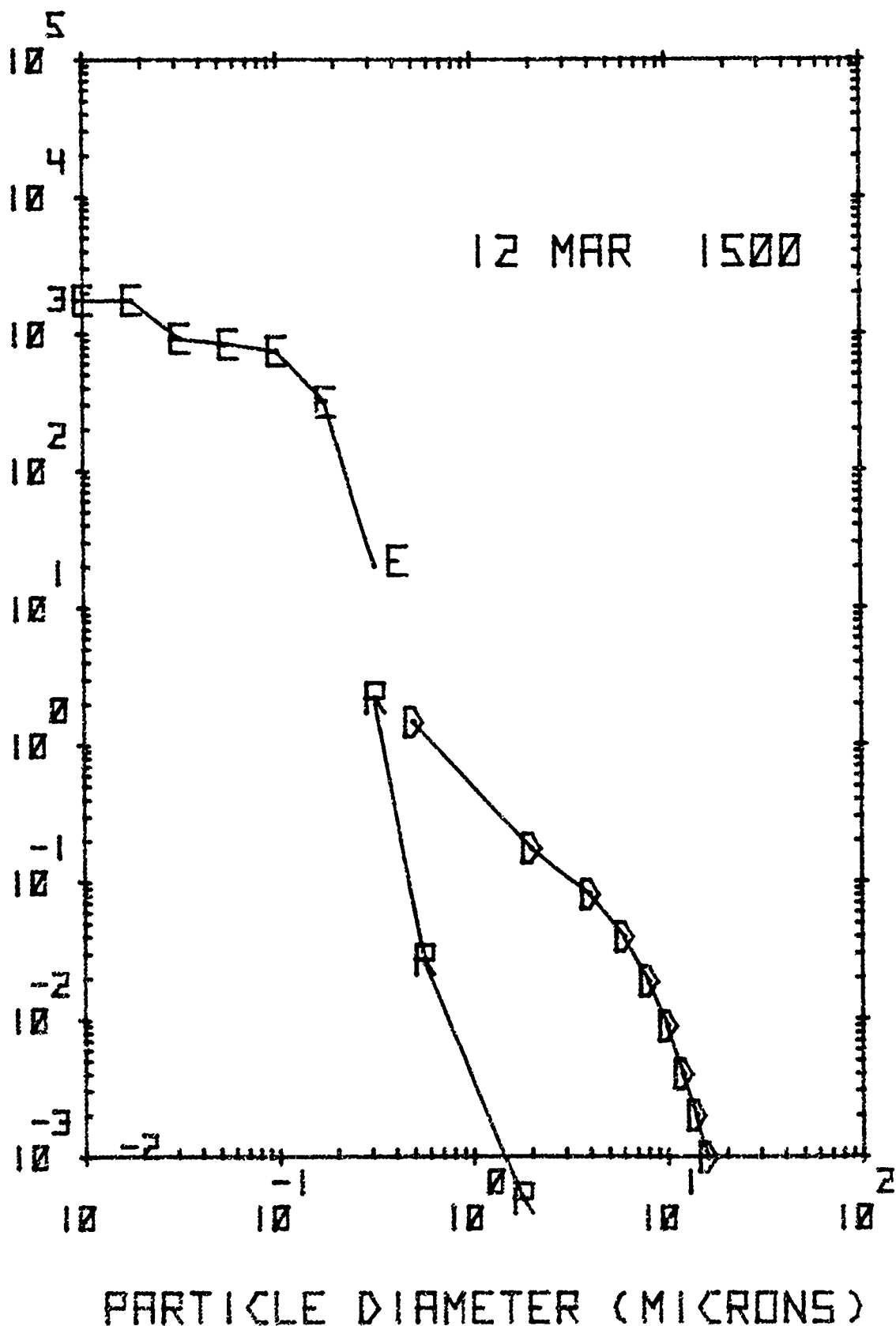
11 MAR 2200



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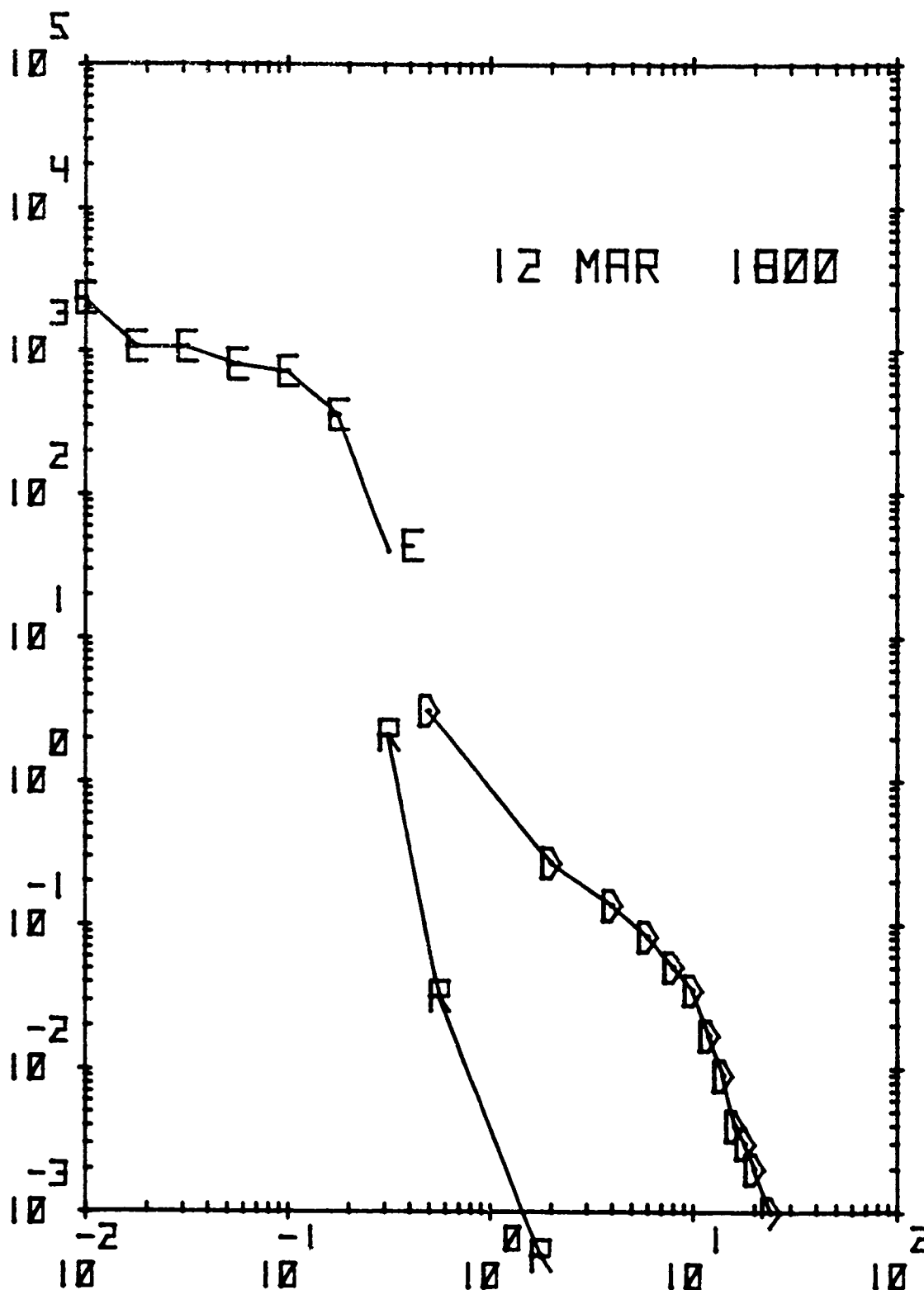
12 MAR 1500



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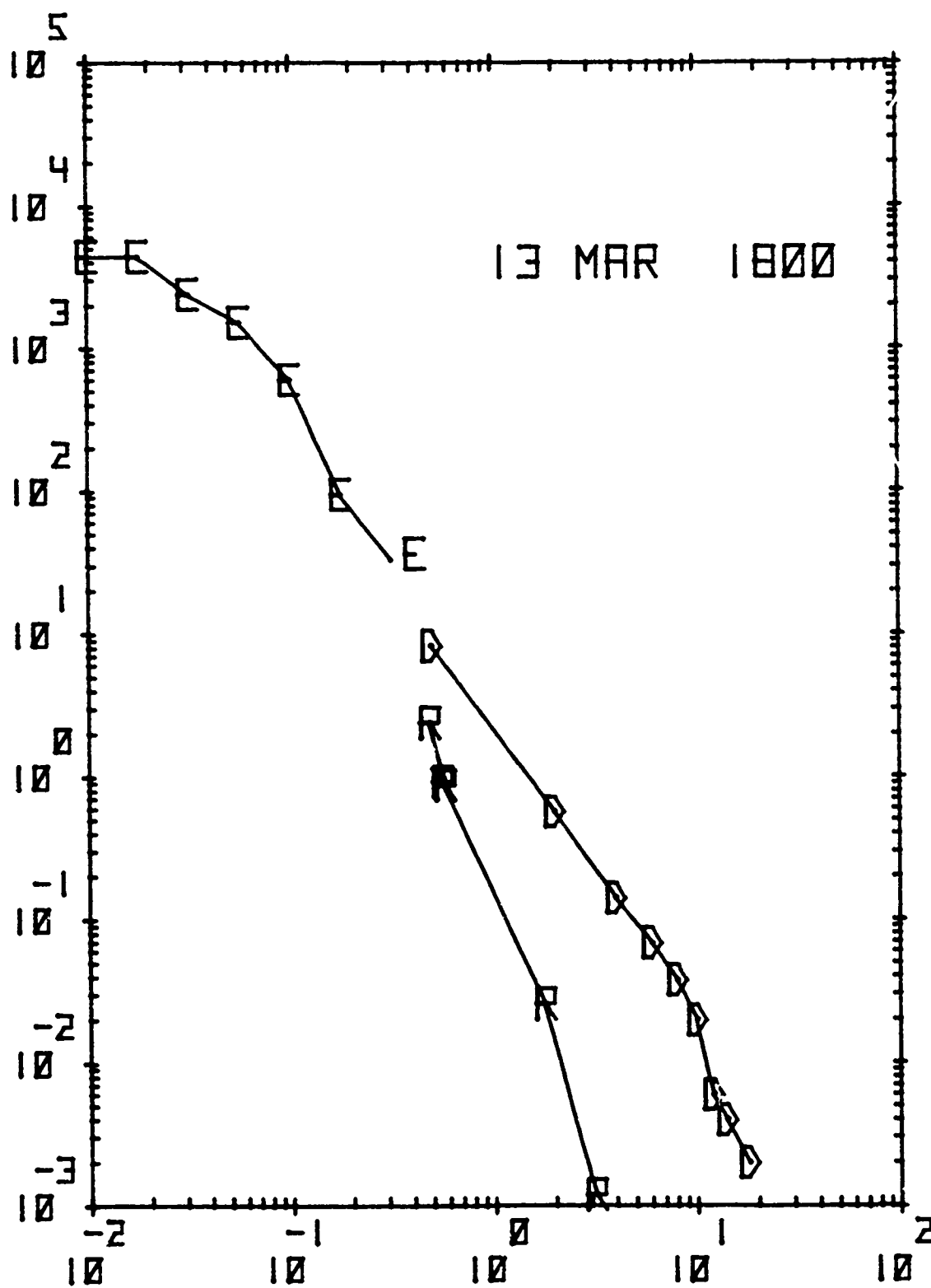
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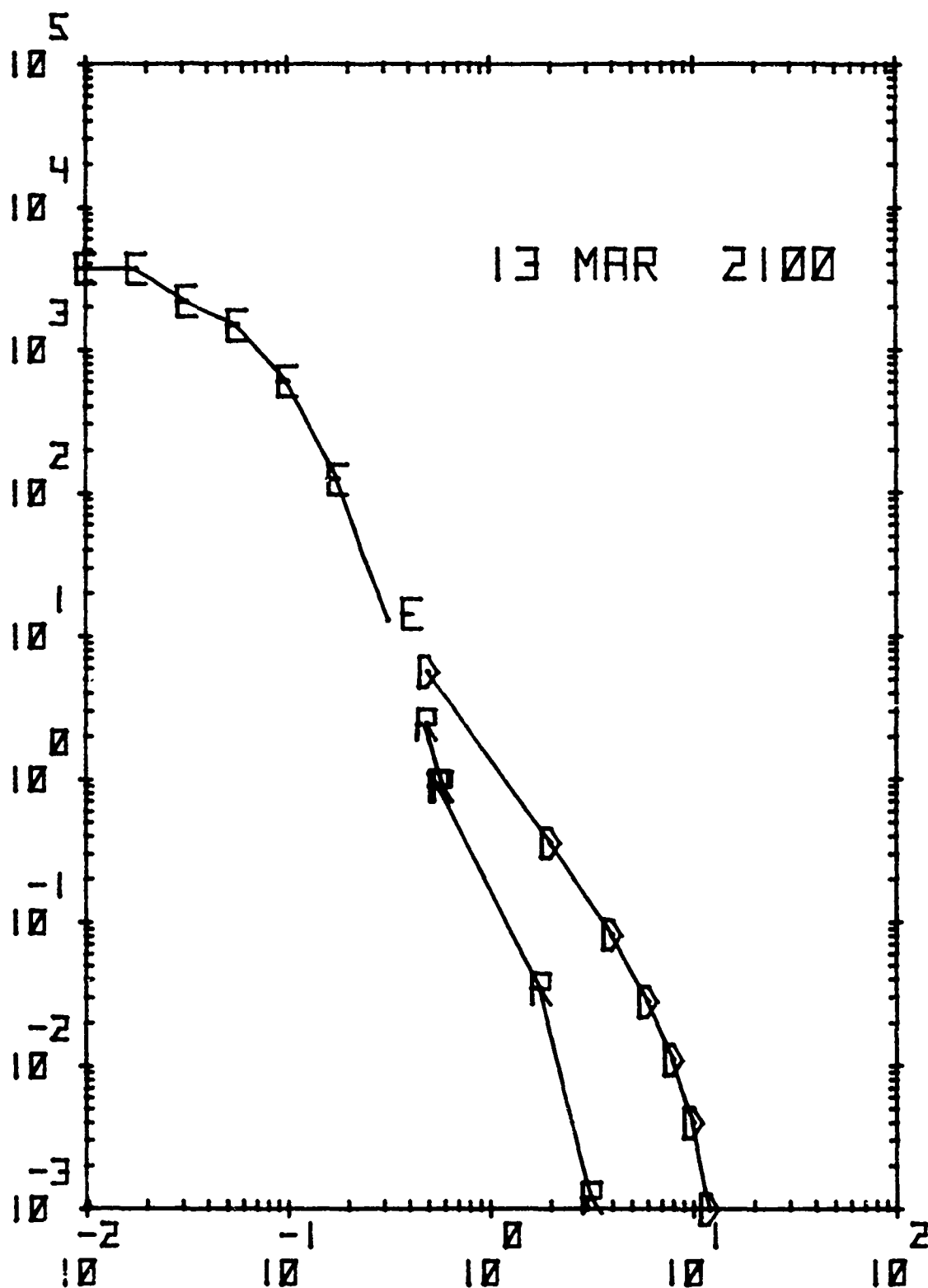
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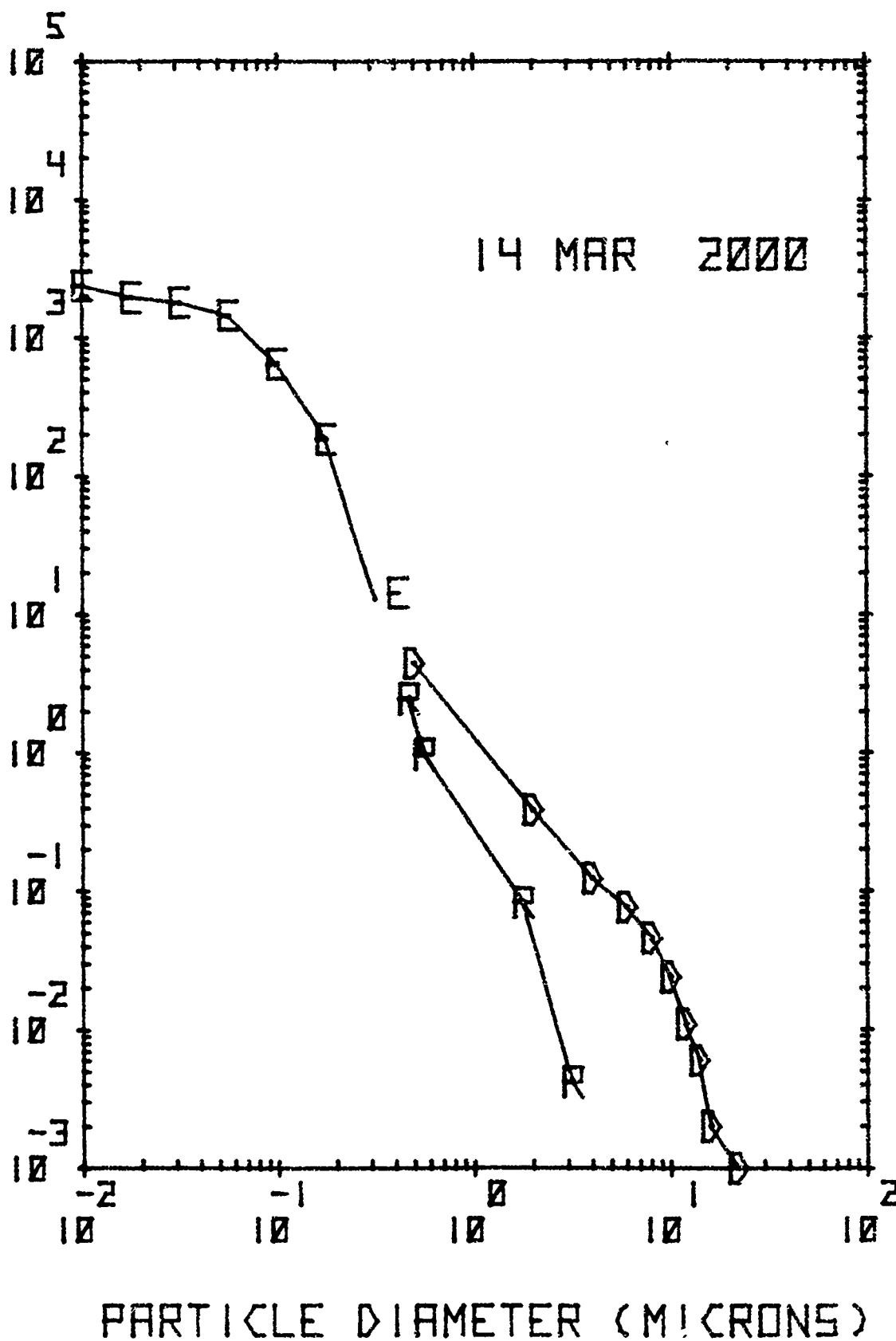
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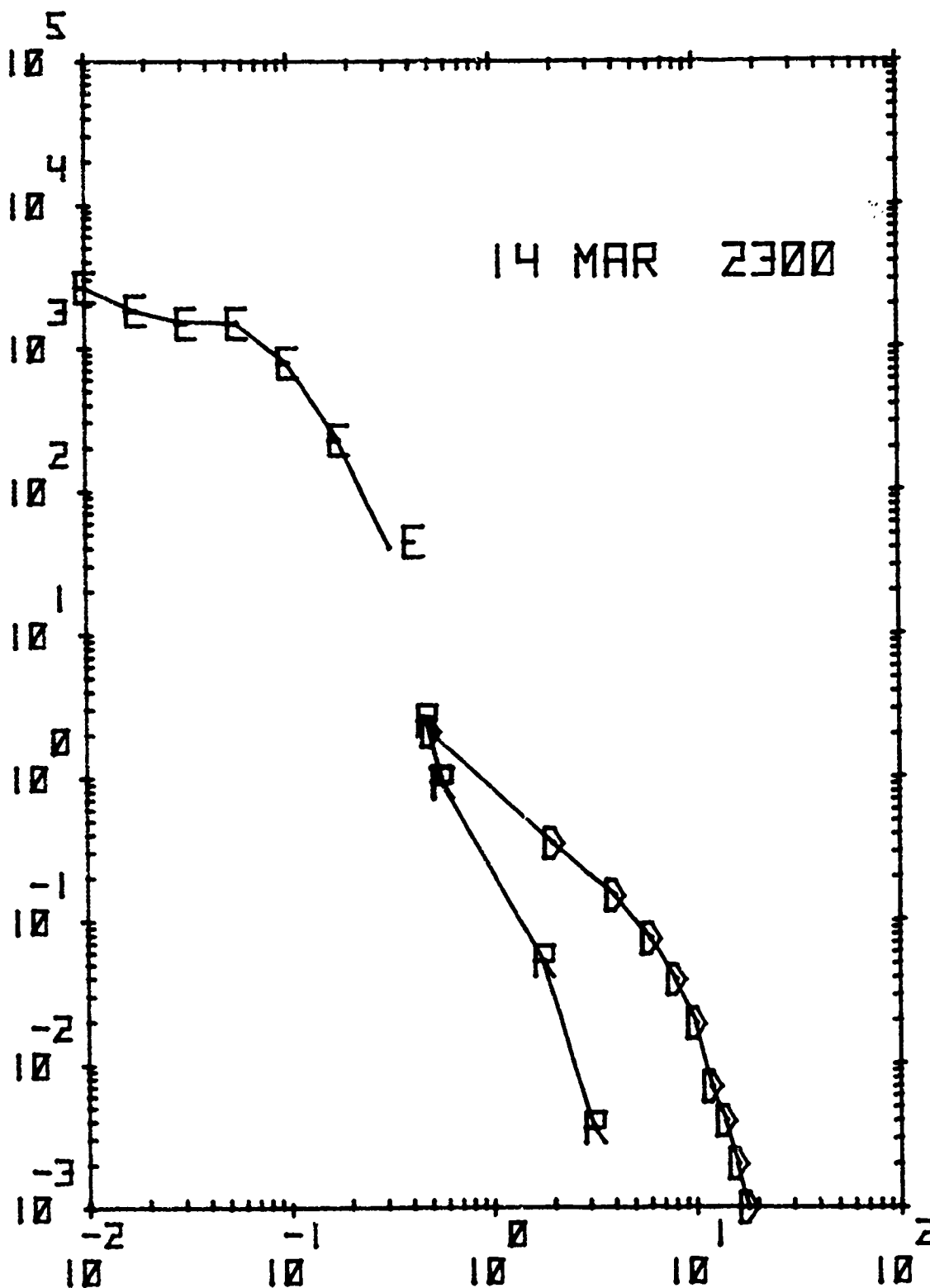
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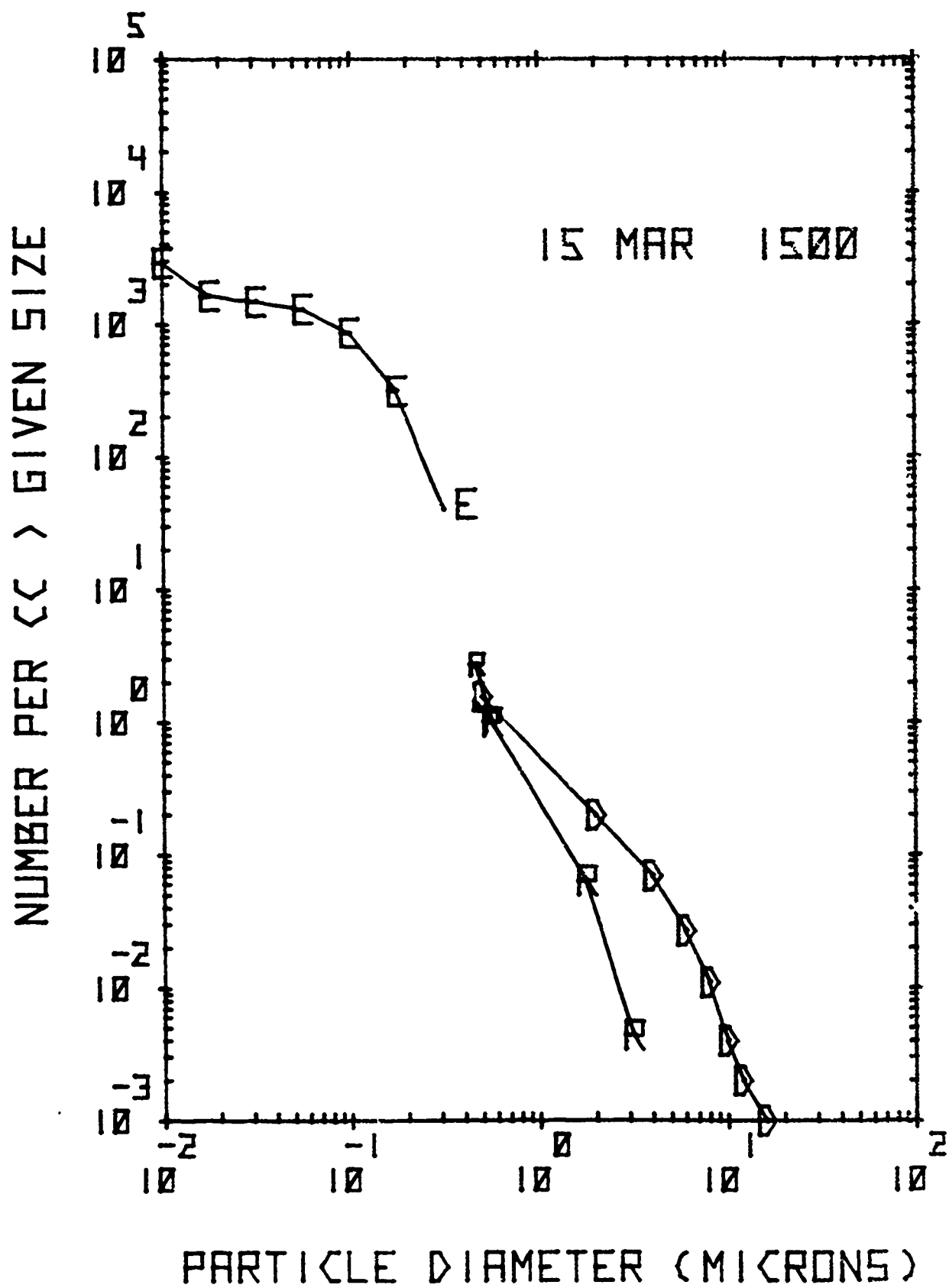


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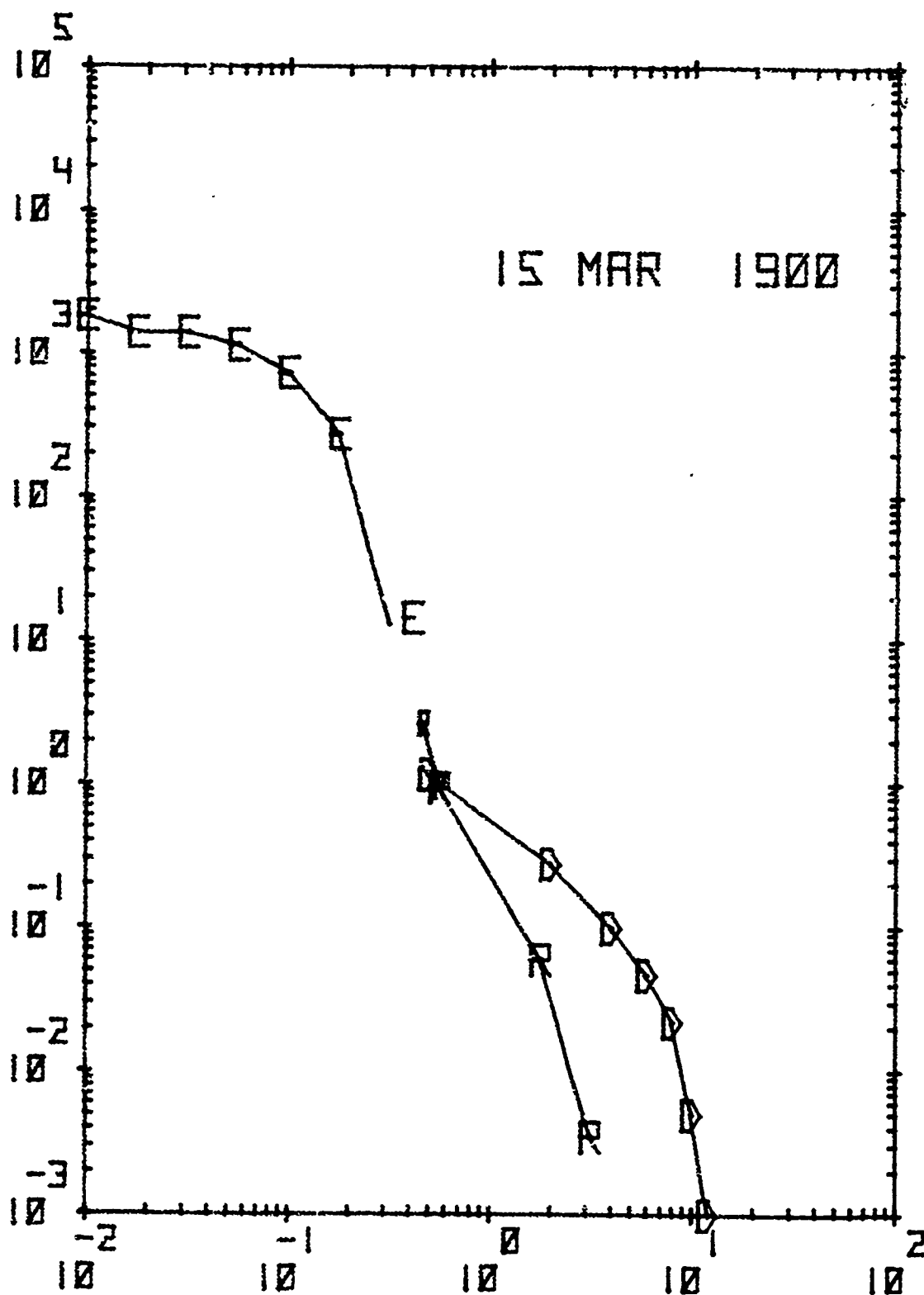


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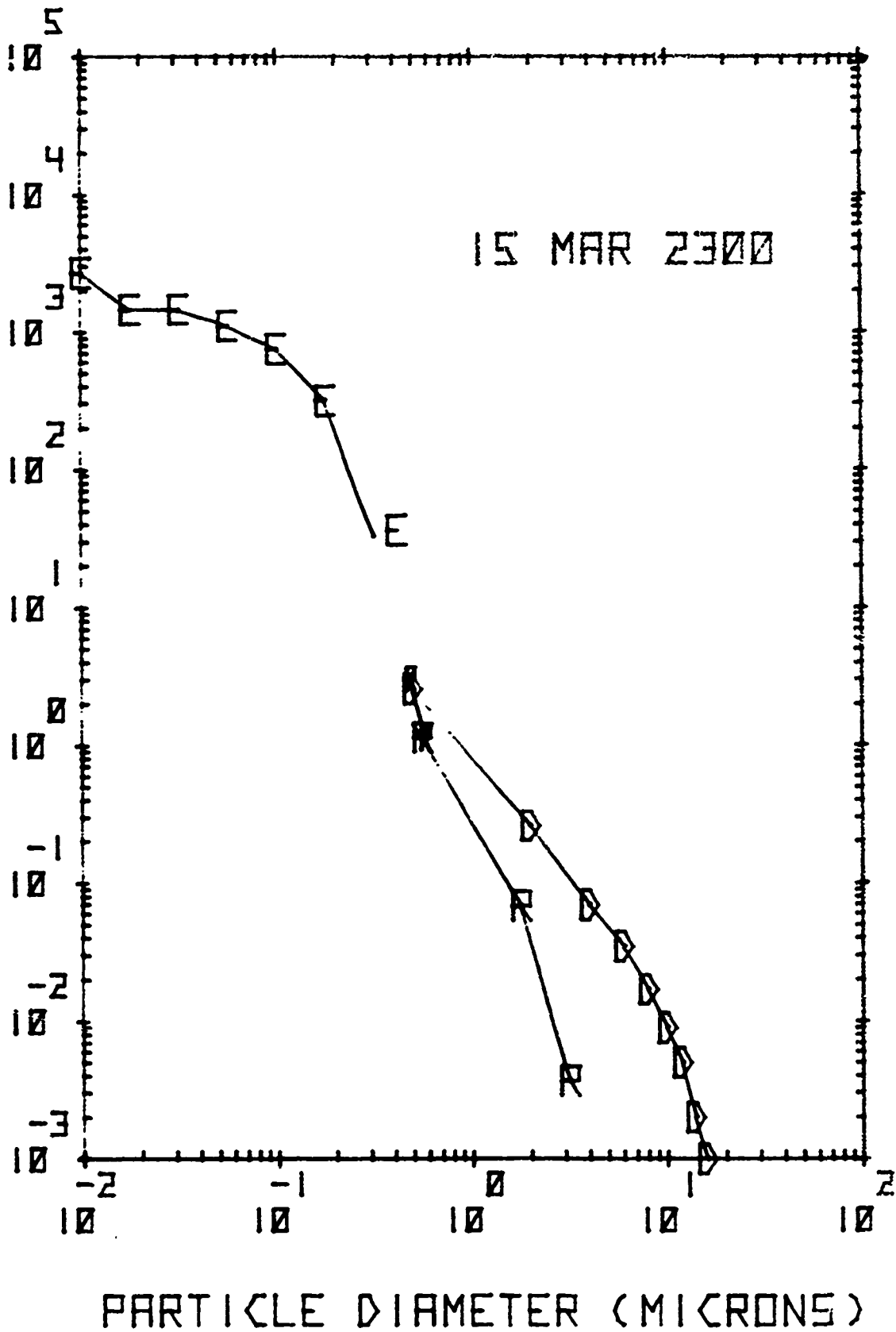
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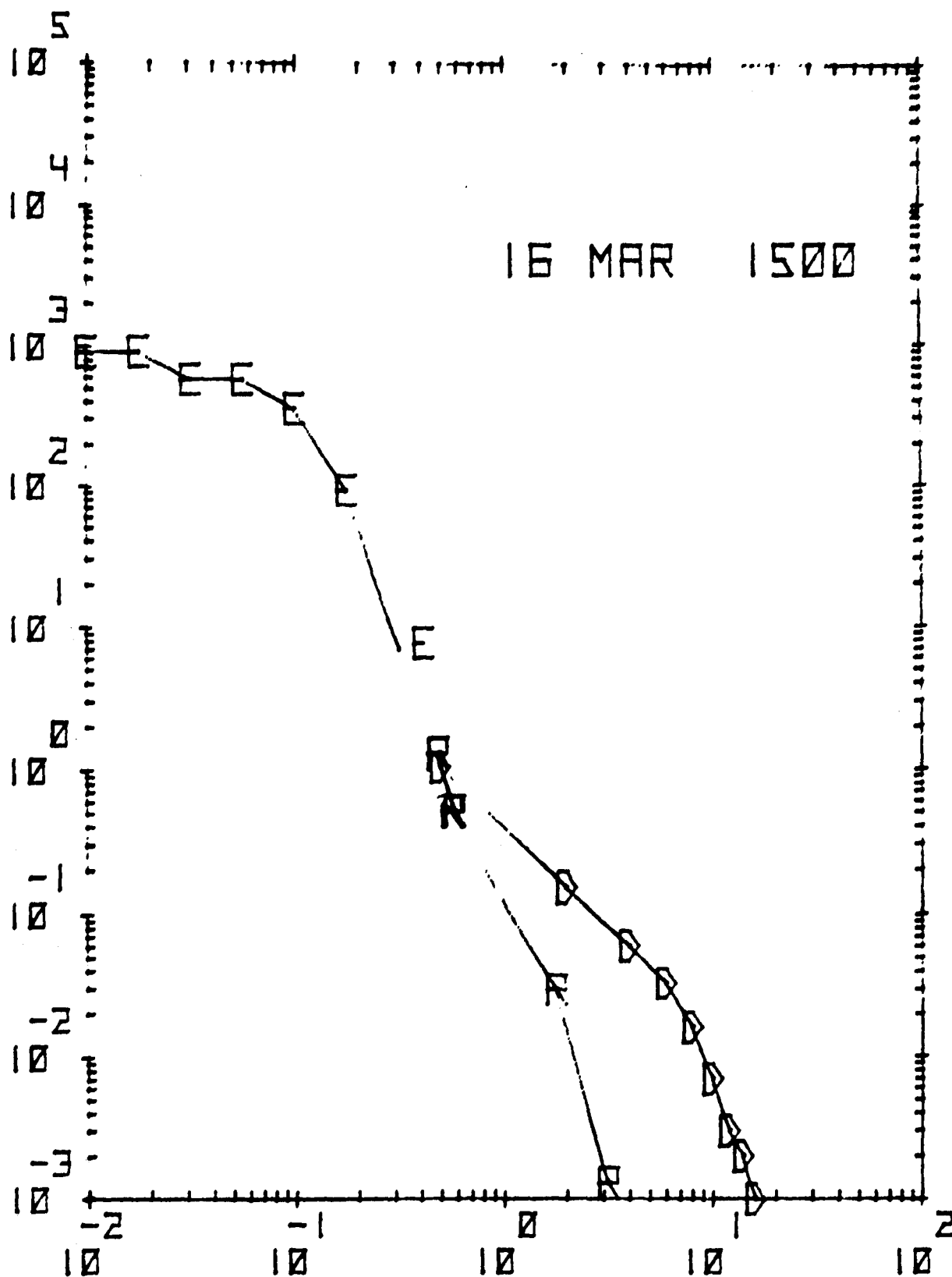
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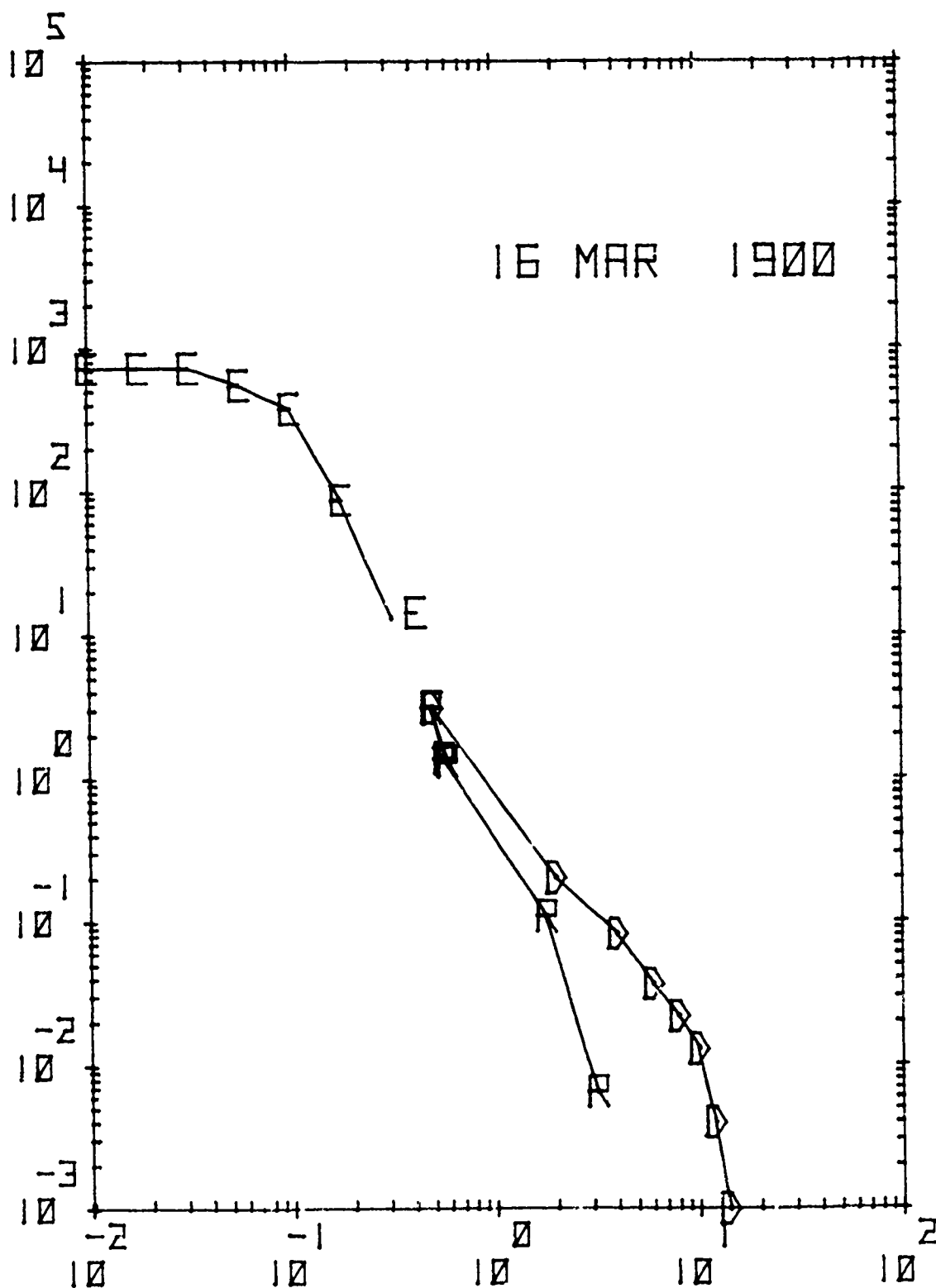
16 MAR 1500



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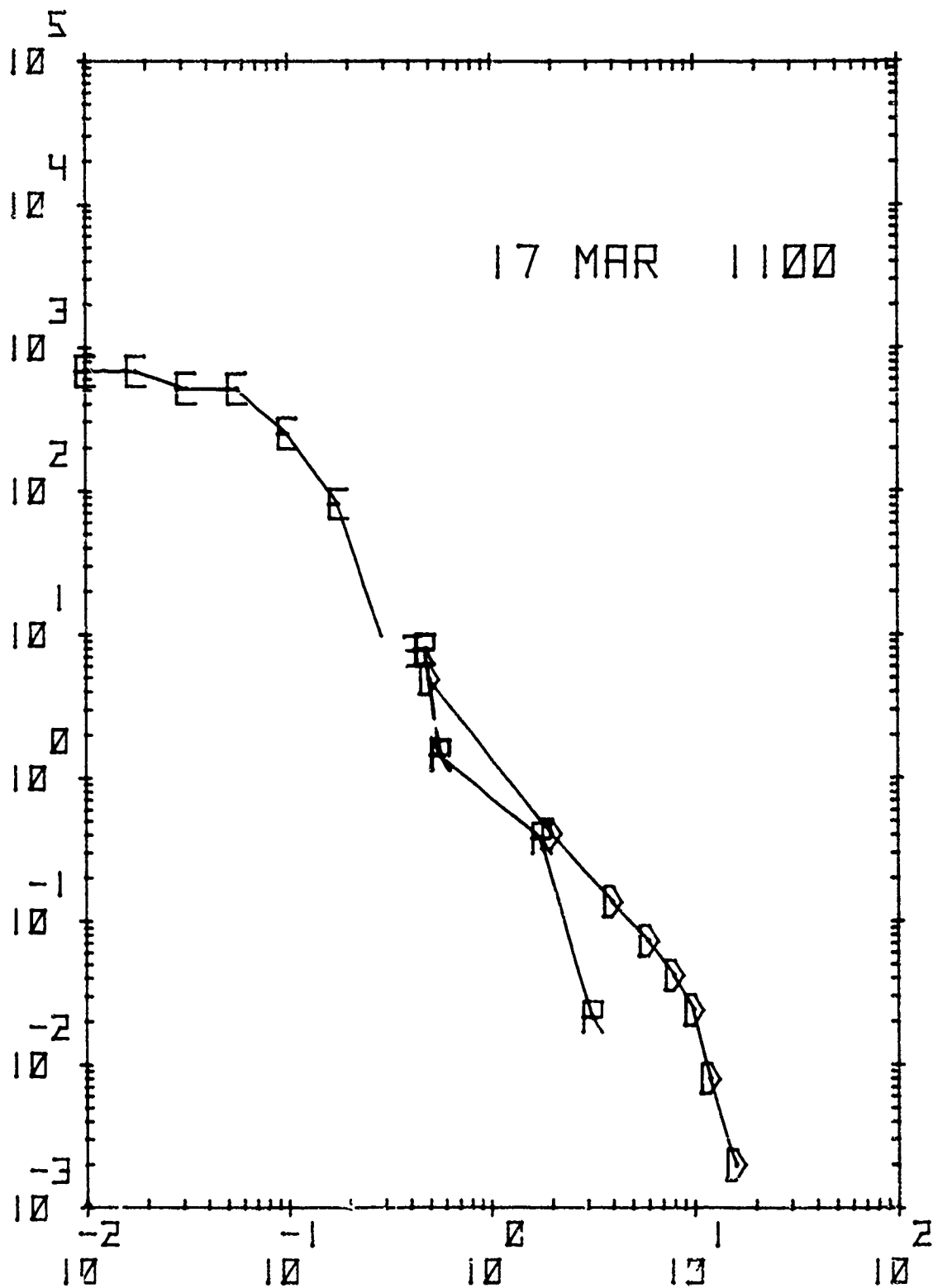
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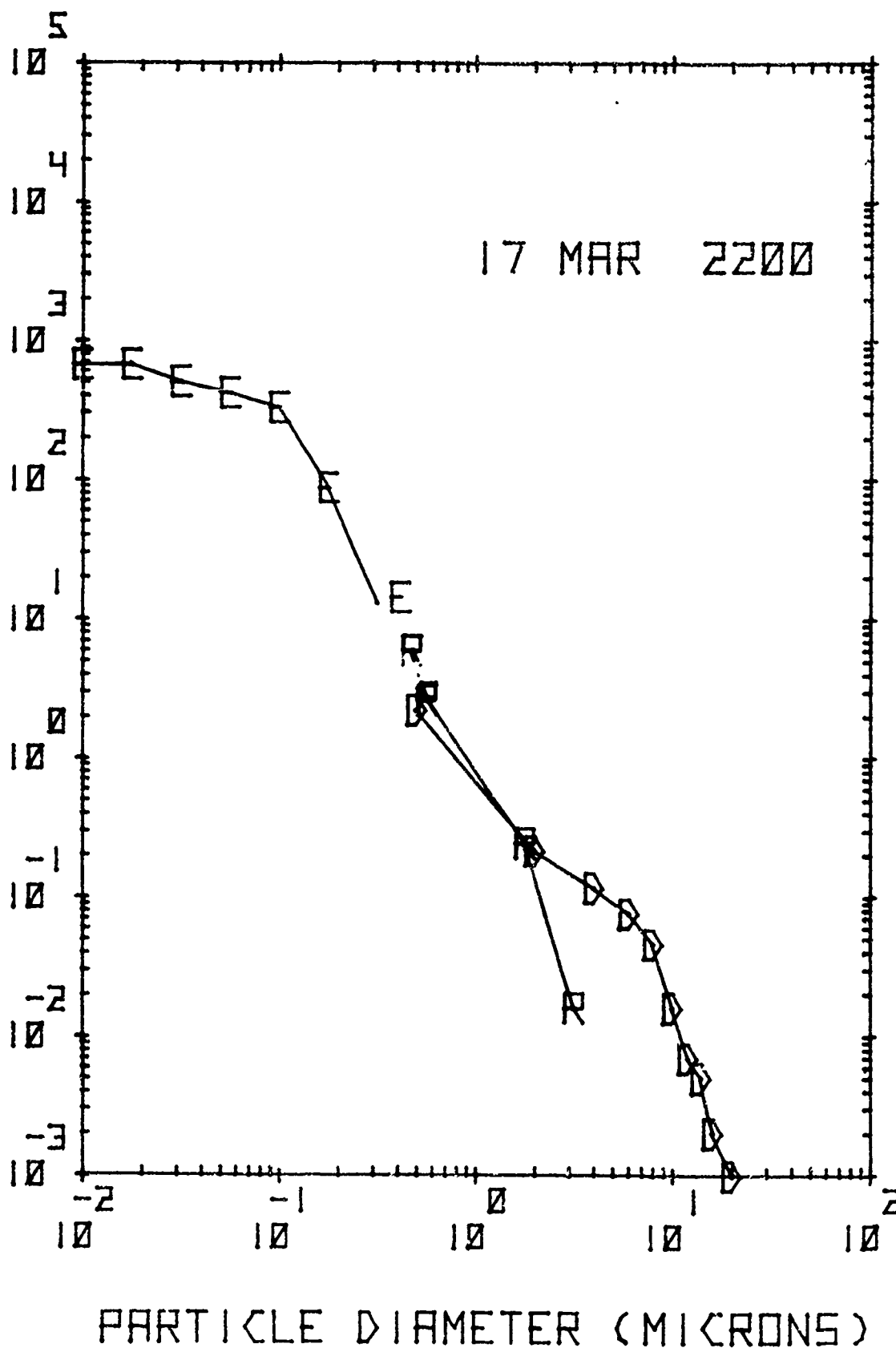
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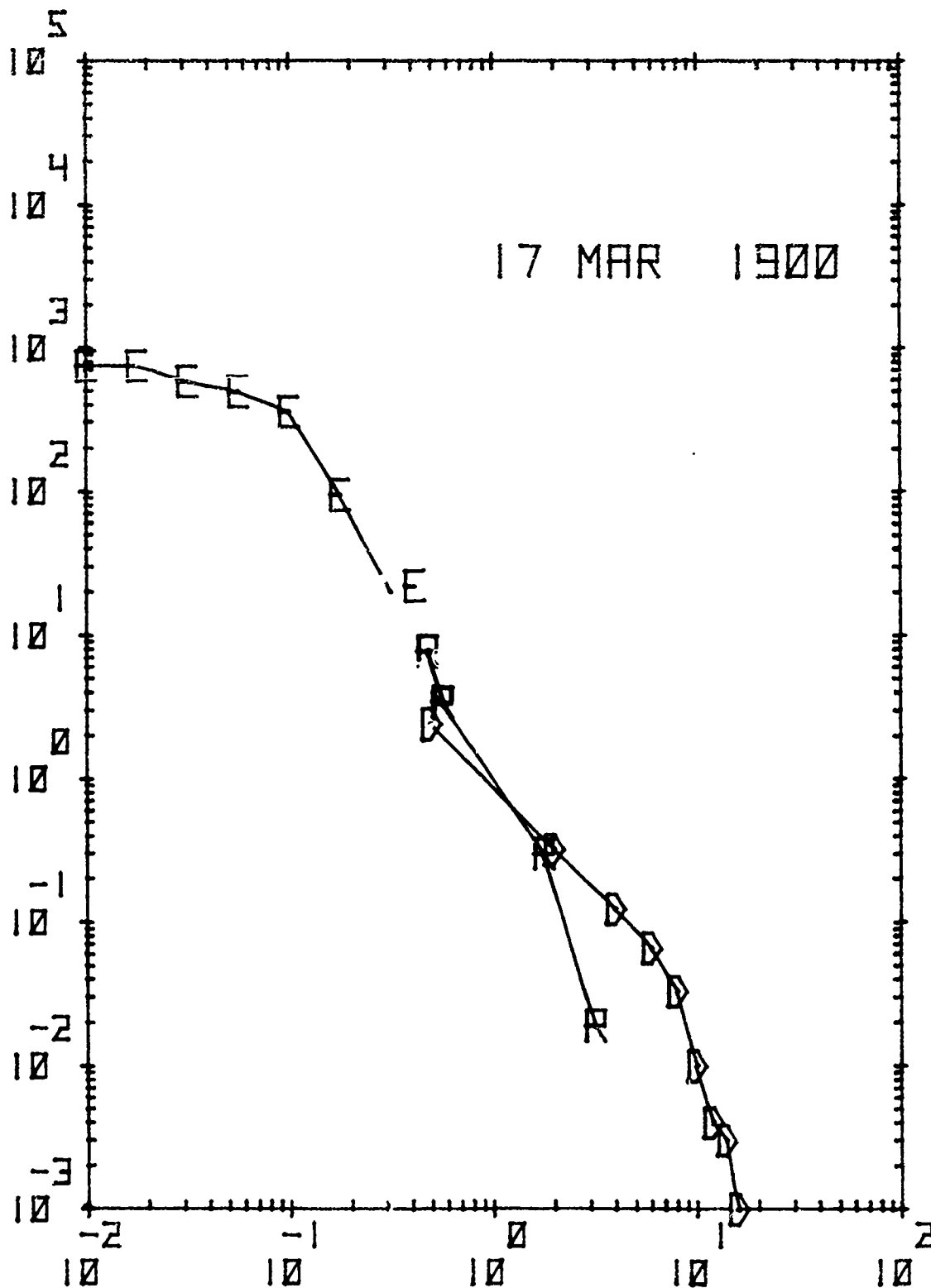
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17 MAR 2200



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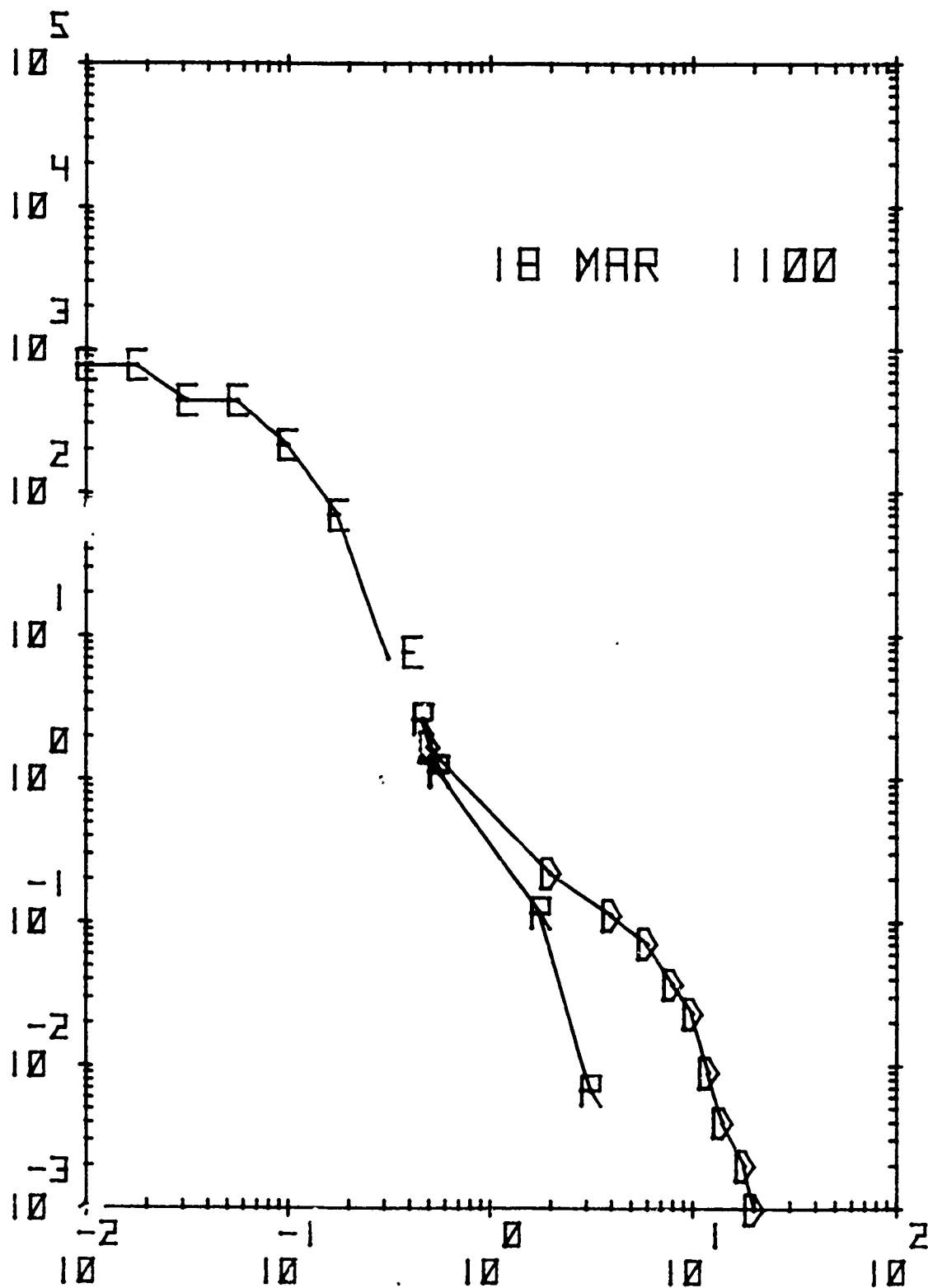
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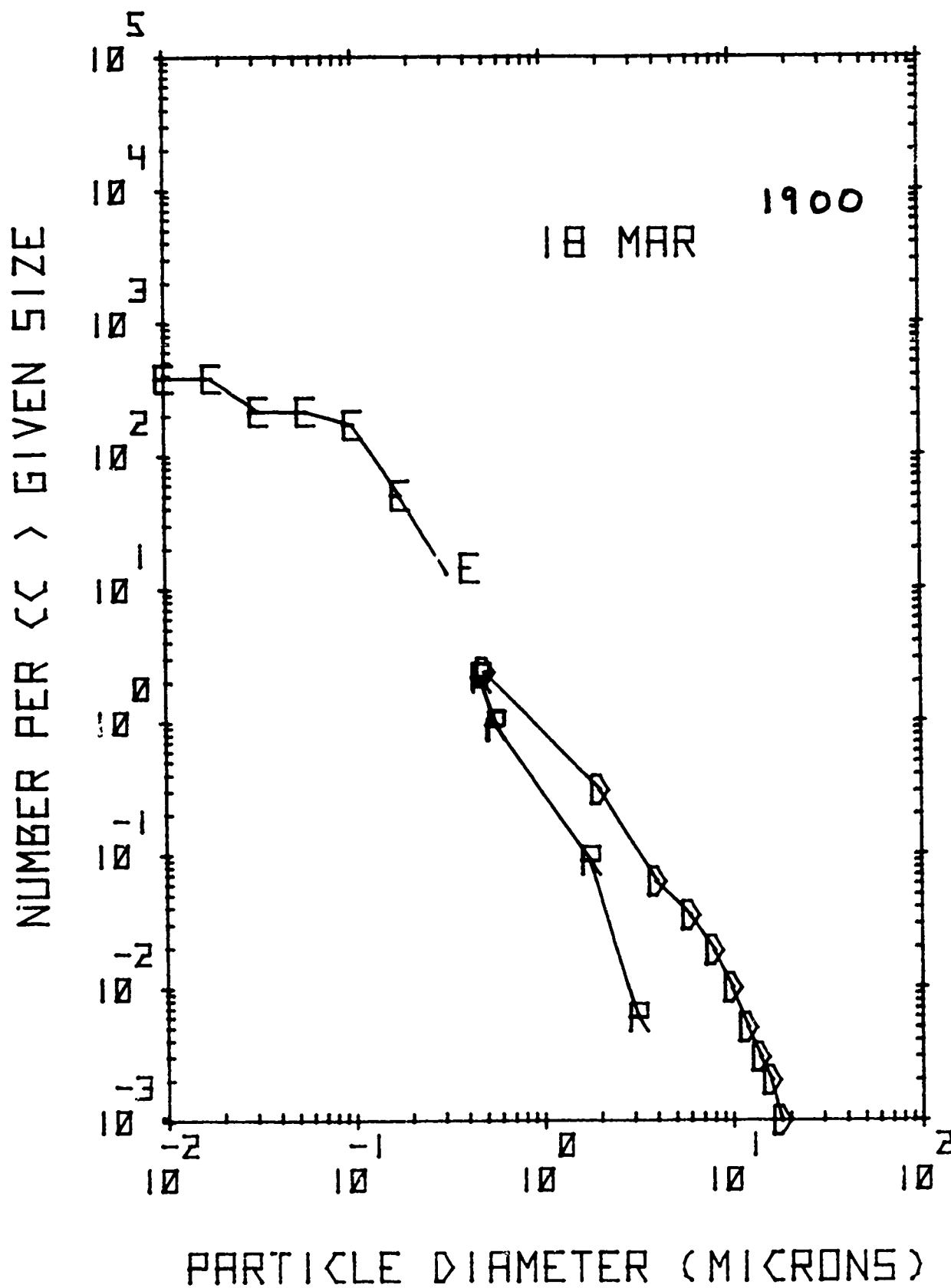
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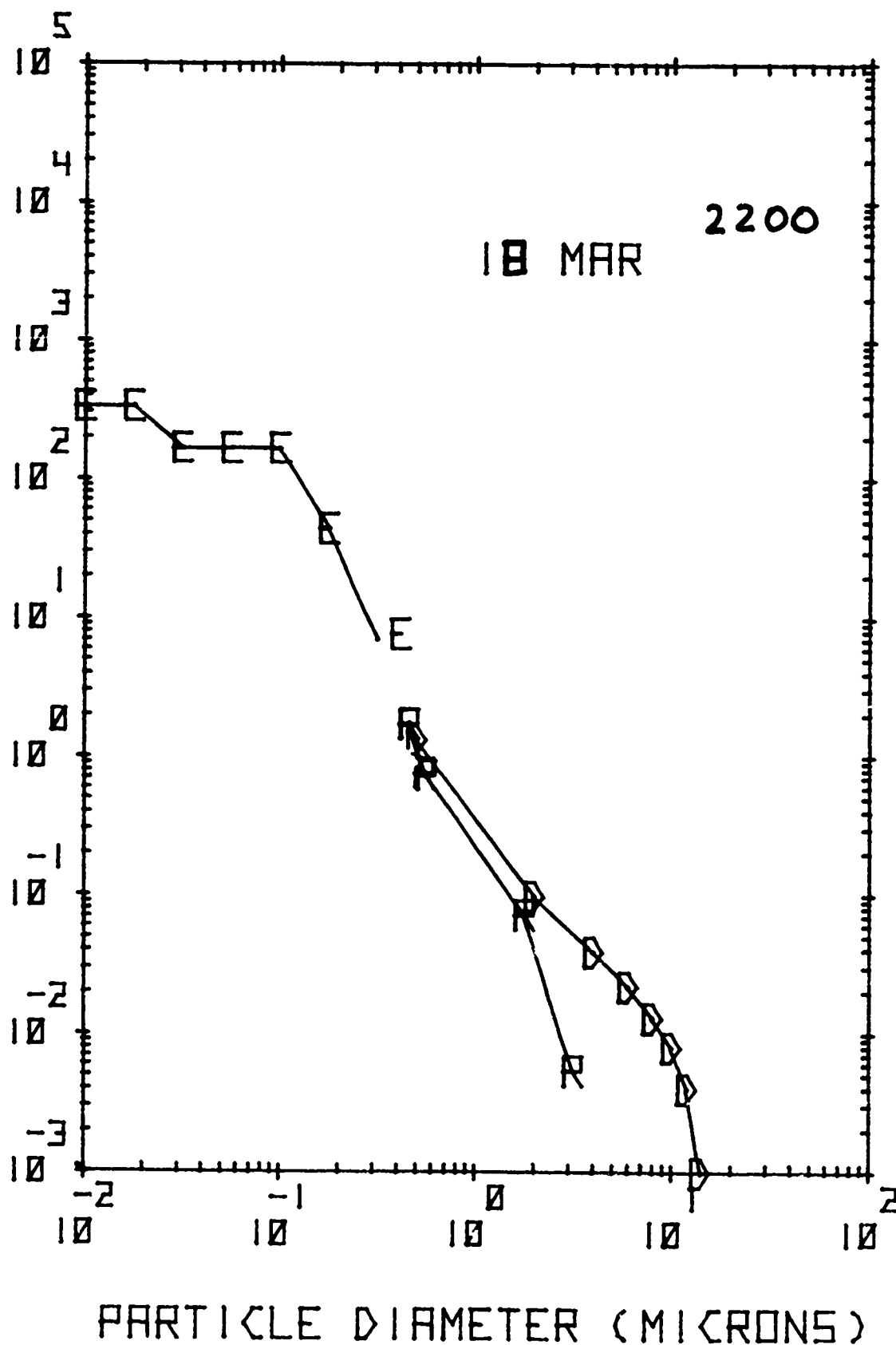
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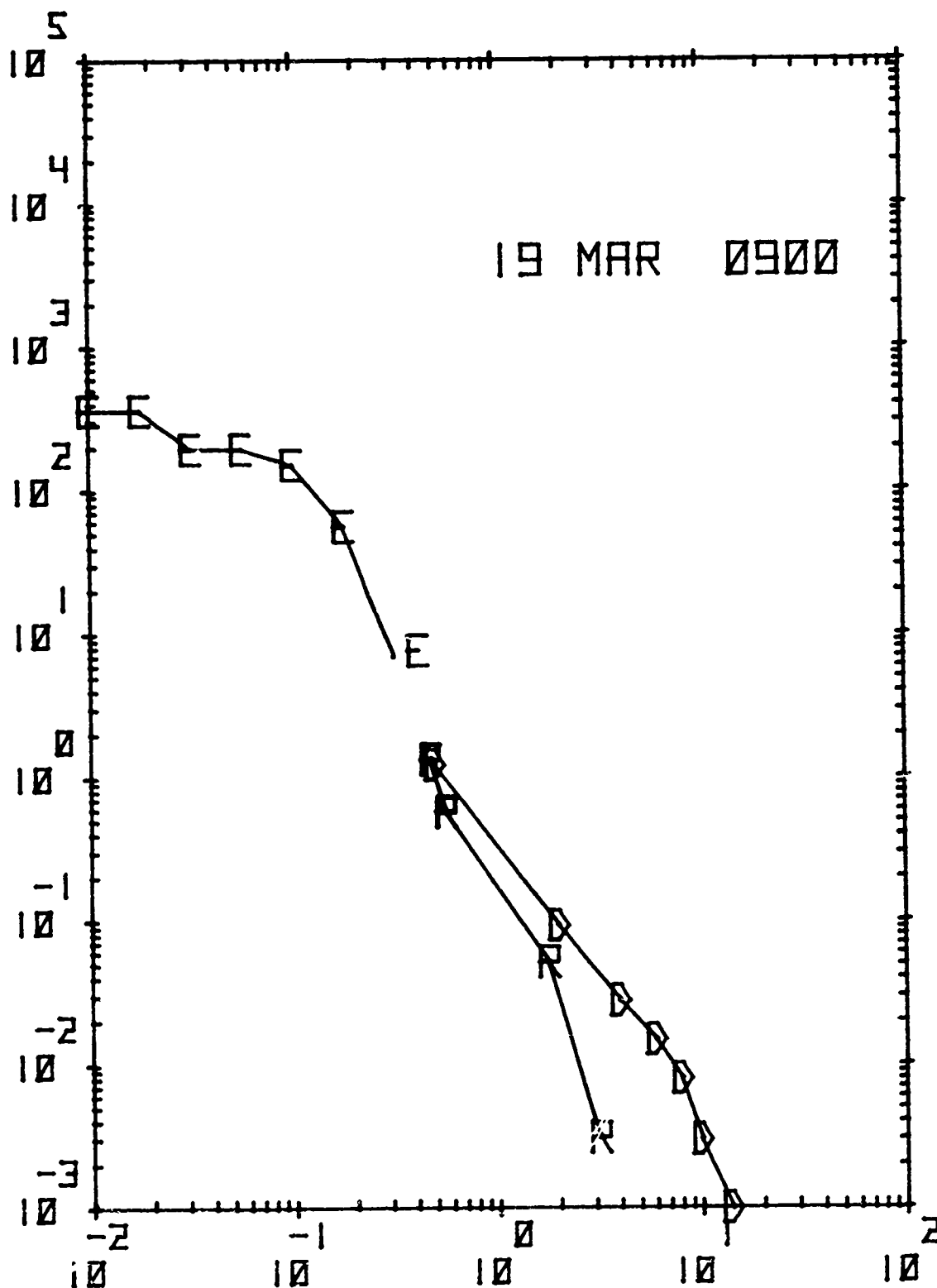


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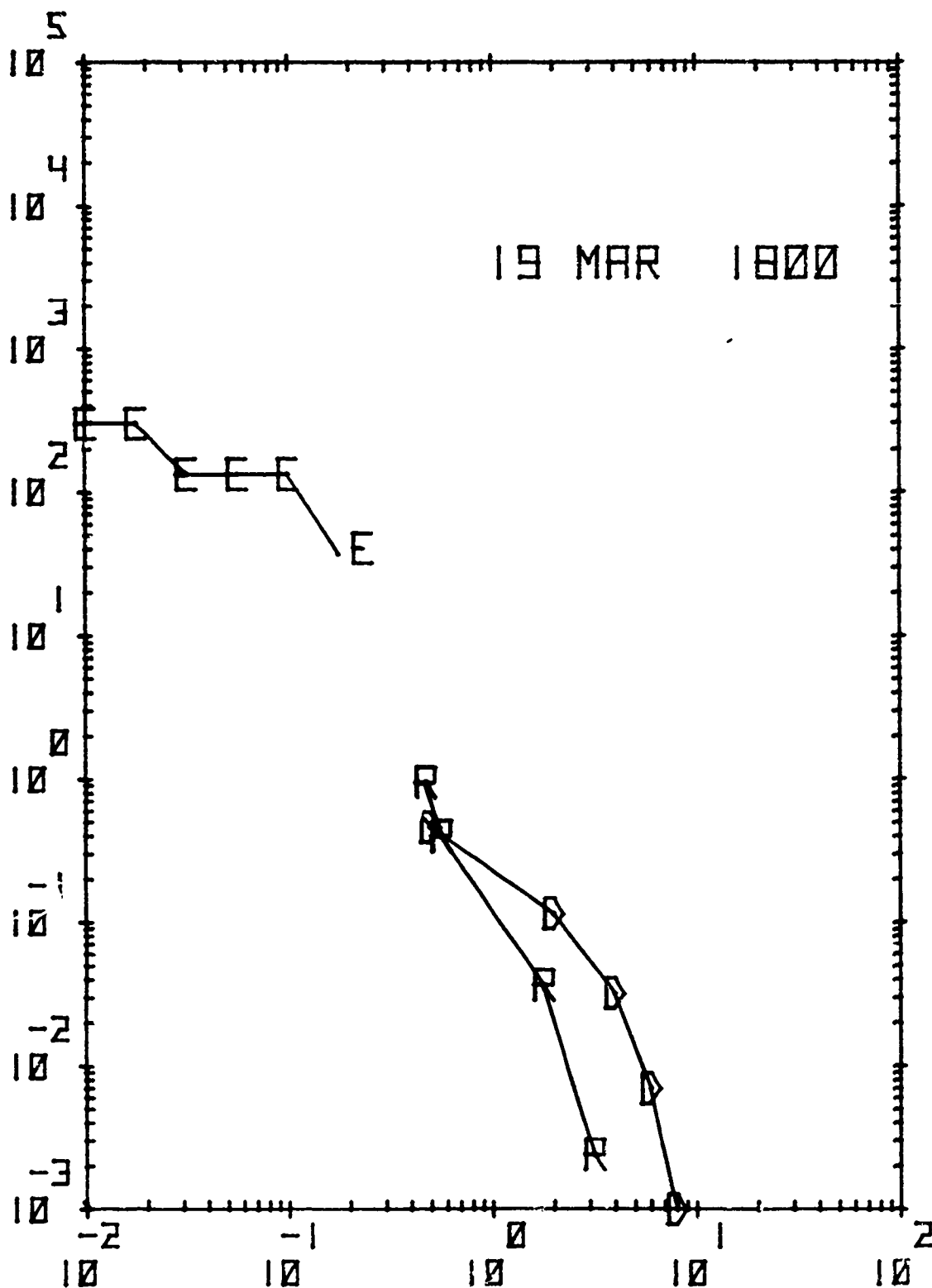
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PARTICLE DIAMETER (MICRONS)

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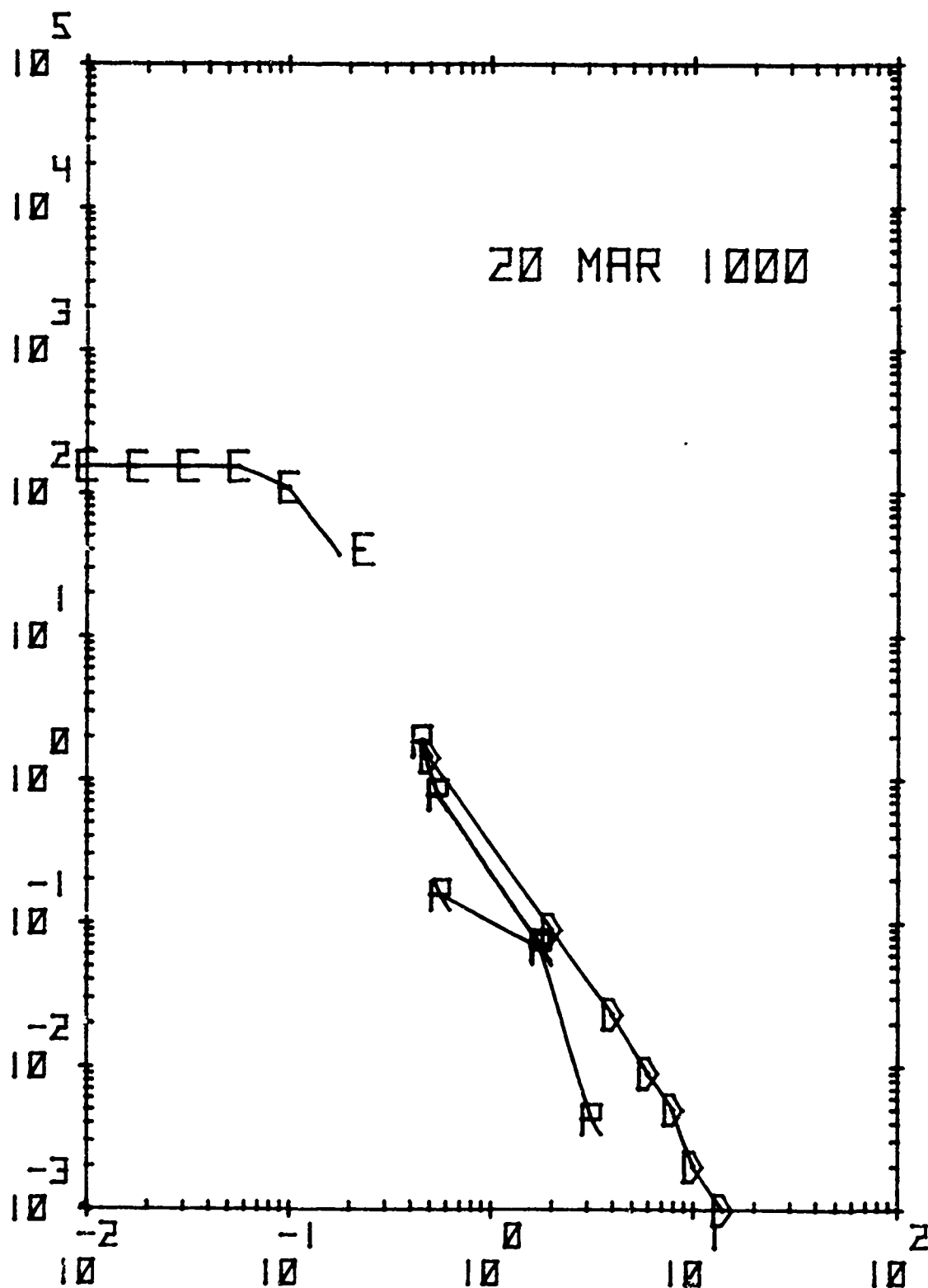
19 MAR 1800



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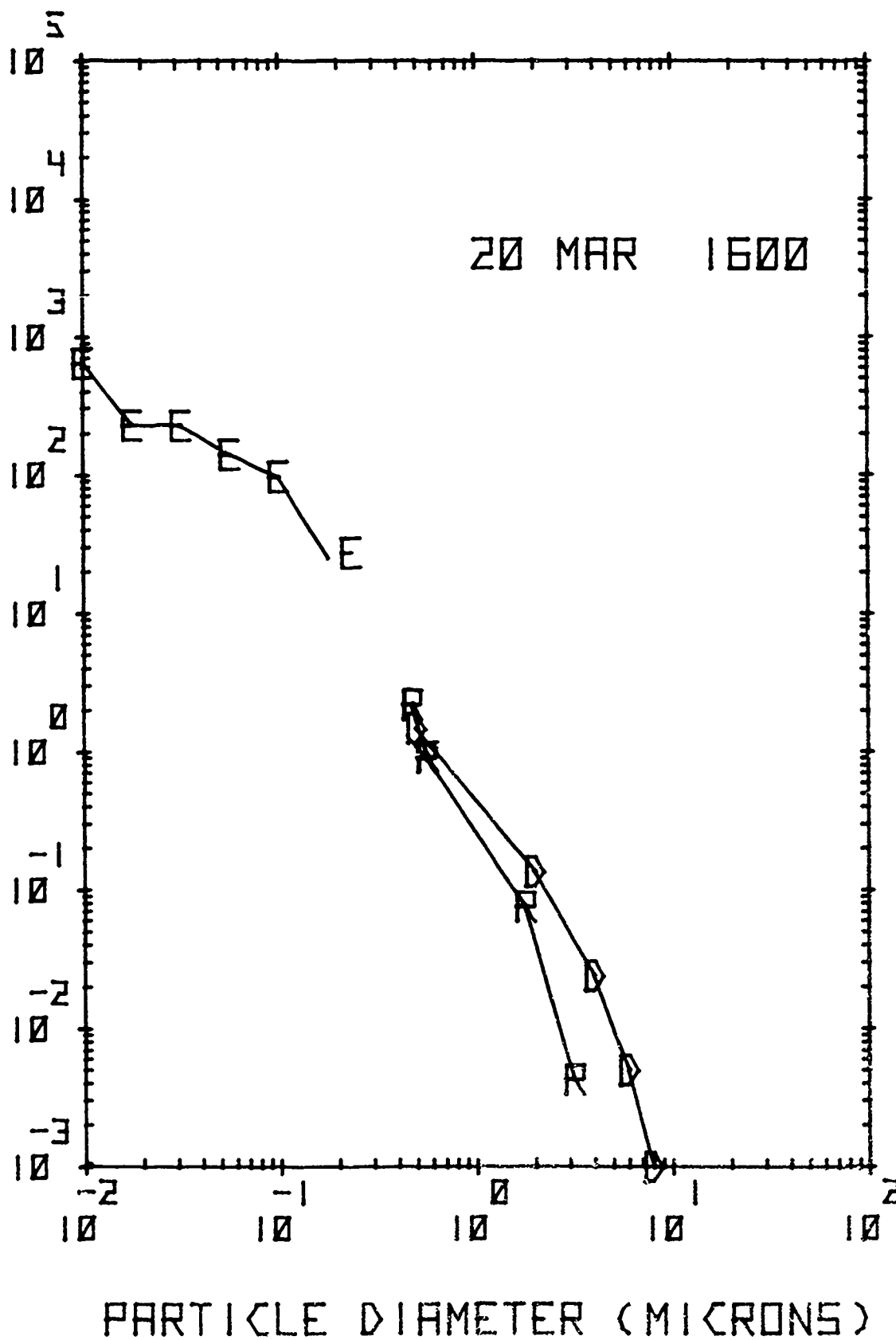
20 MAR 1000



PARTICLE DIAMETER (MICRONS)

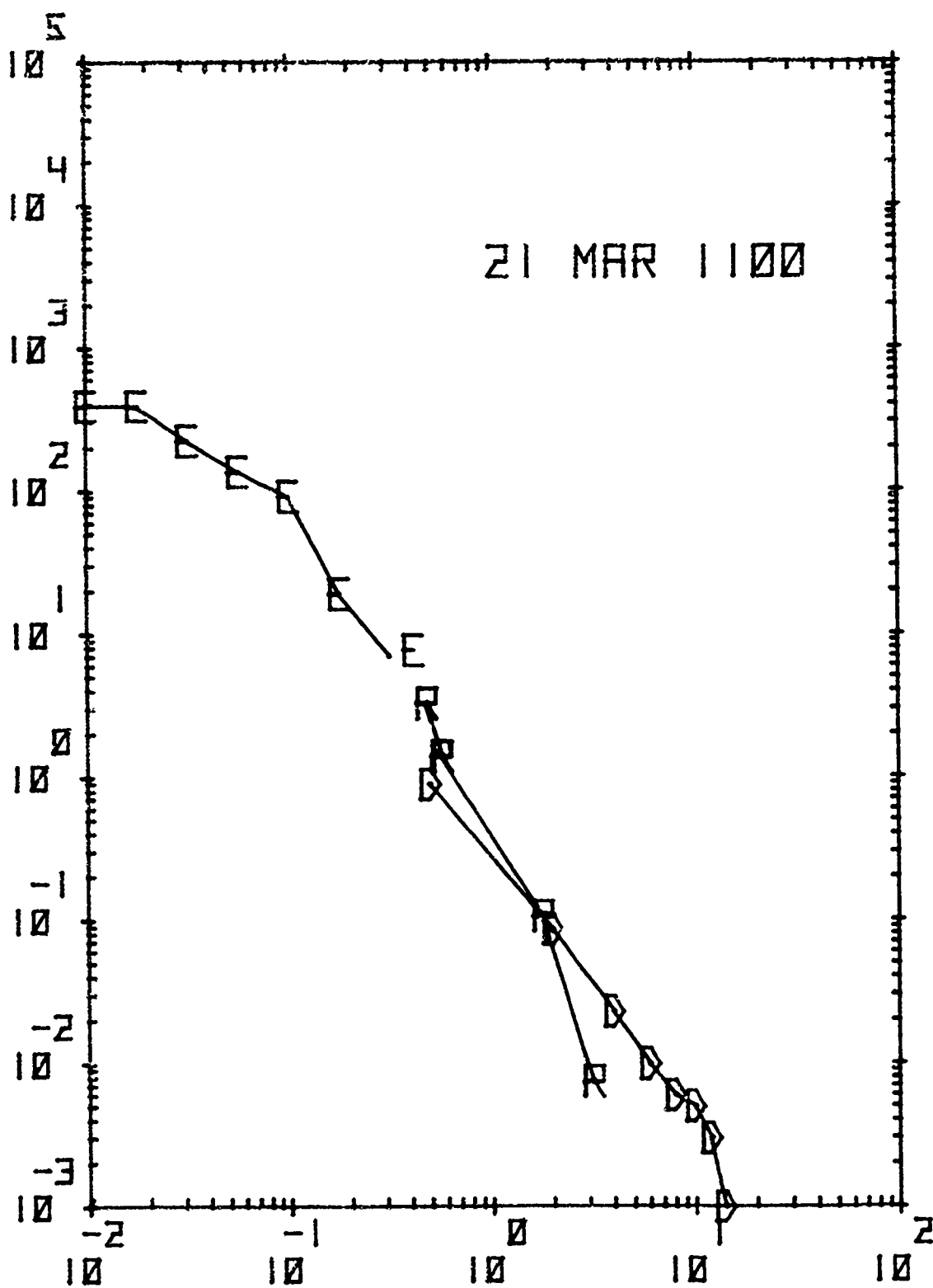
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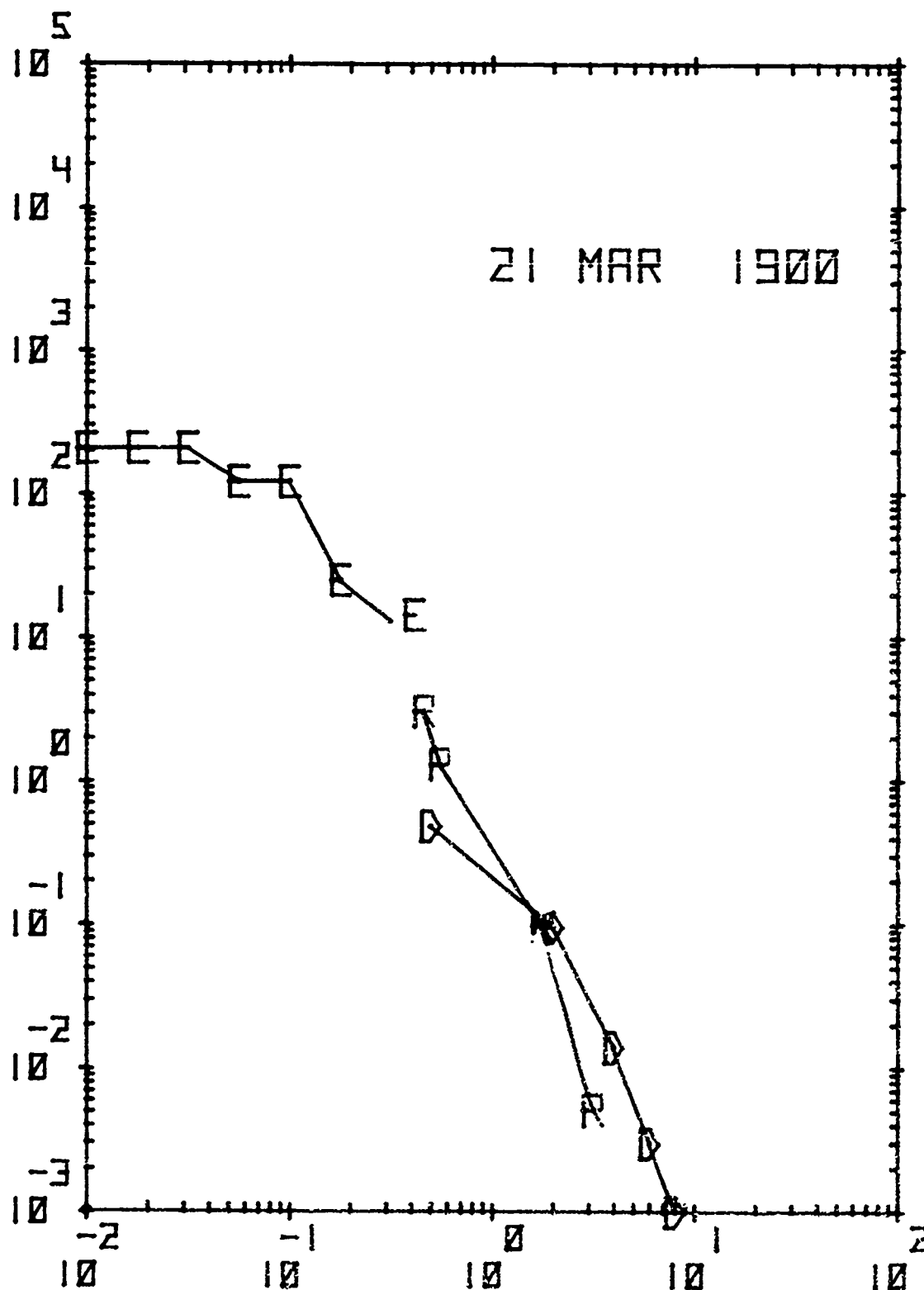
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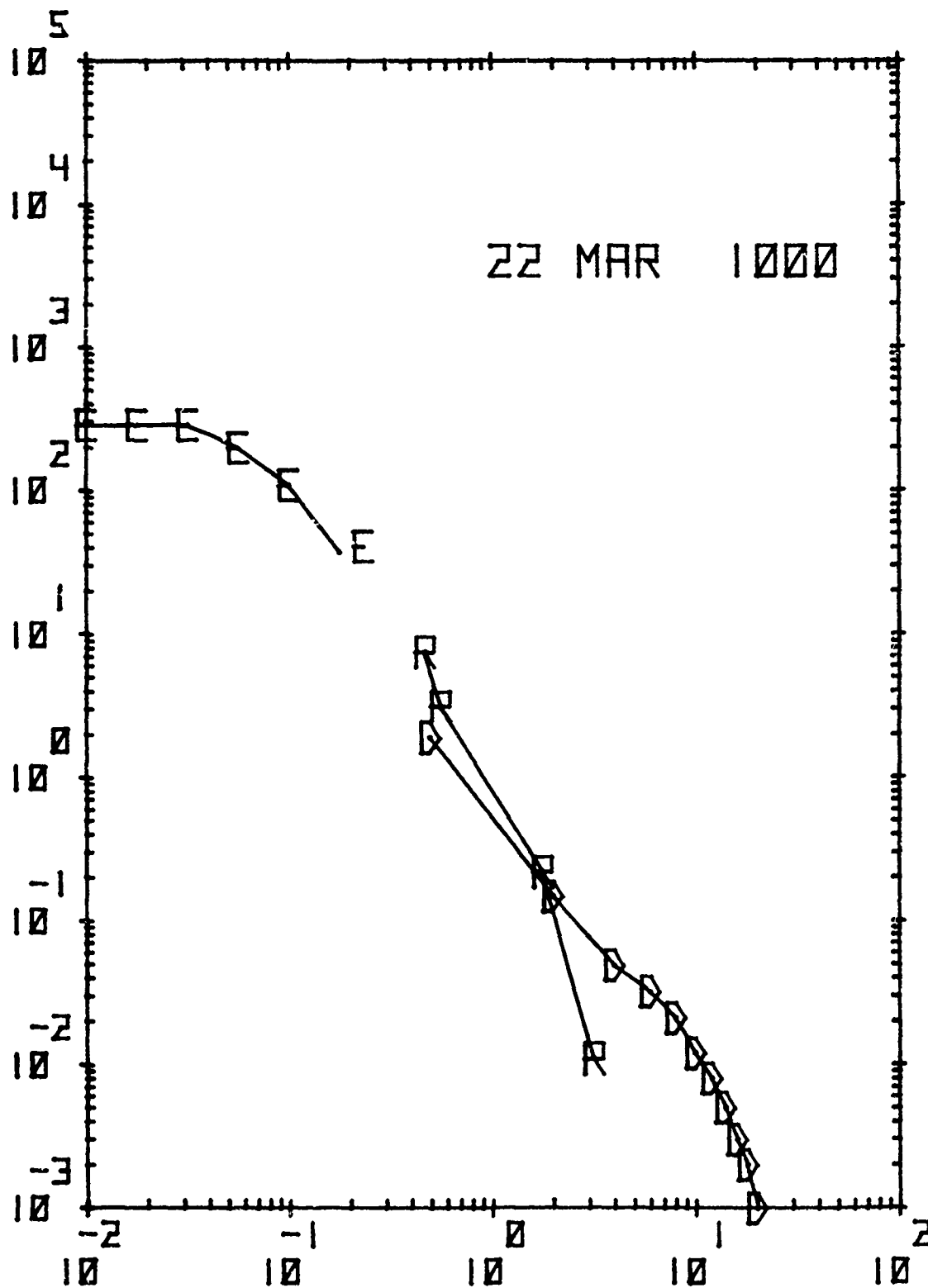
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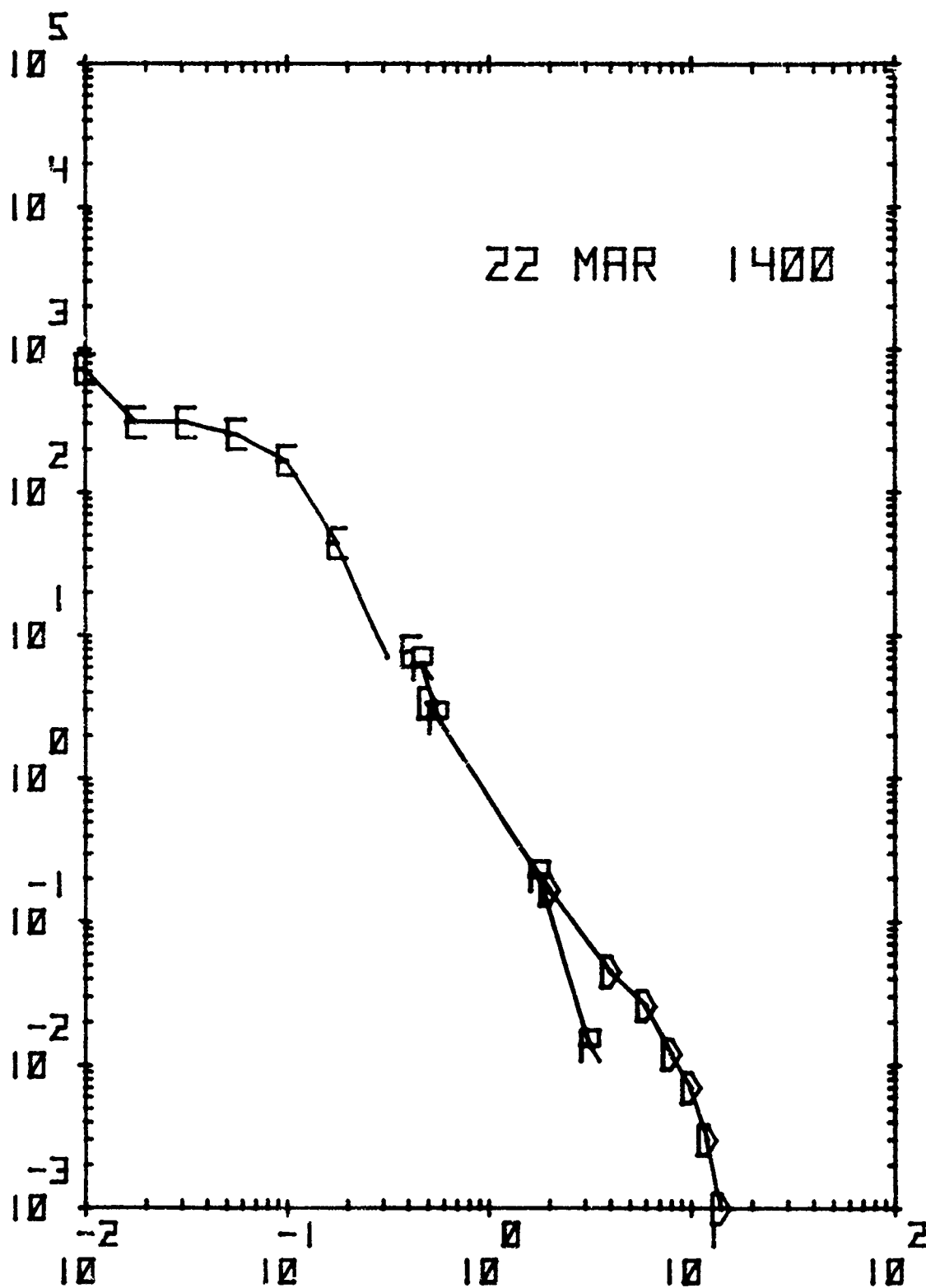
22 MAR 1000



PARTICLE DIAMETER (MICRONS)

NUMBER PER CC > GIVEN SIZE

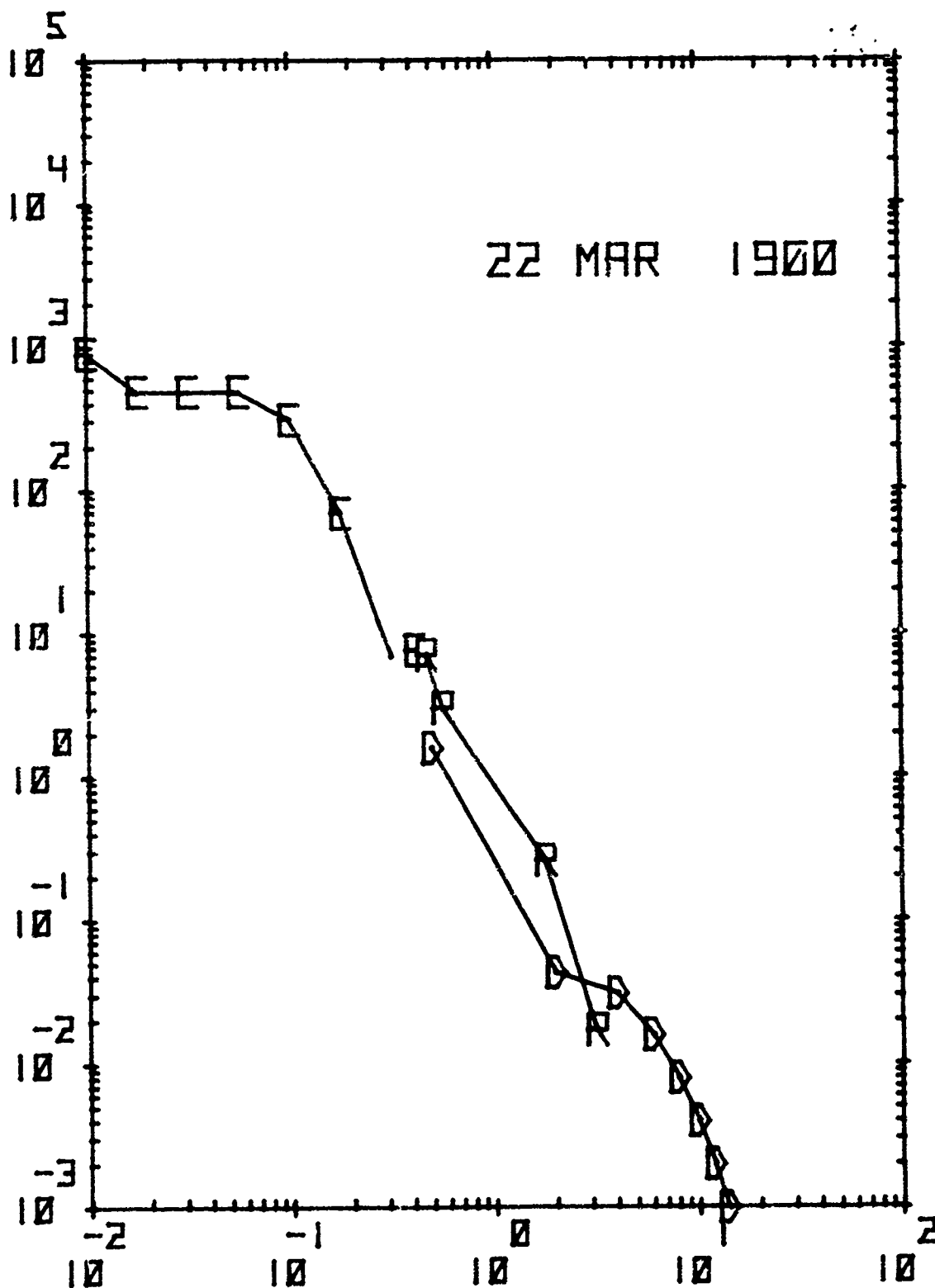
22 MAR 1400



PARTICLE DIAMETER (MICRONS)

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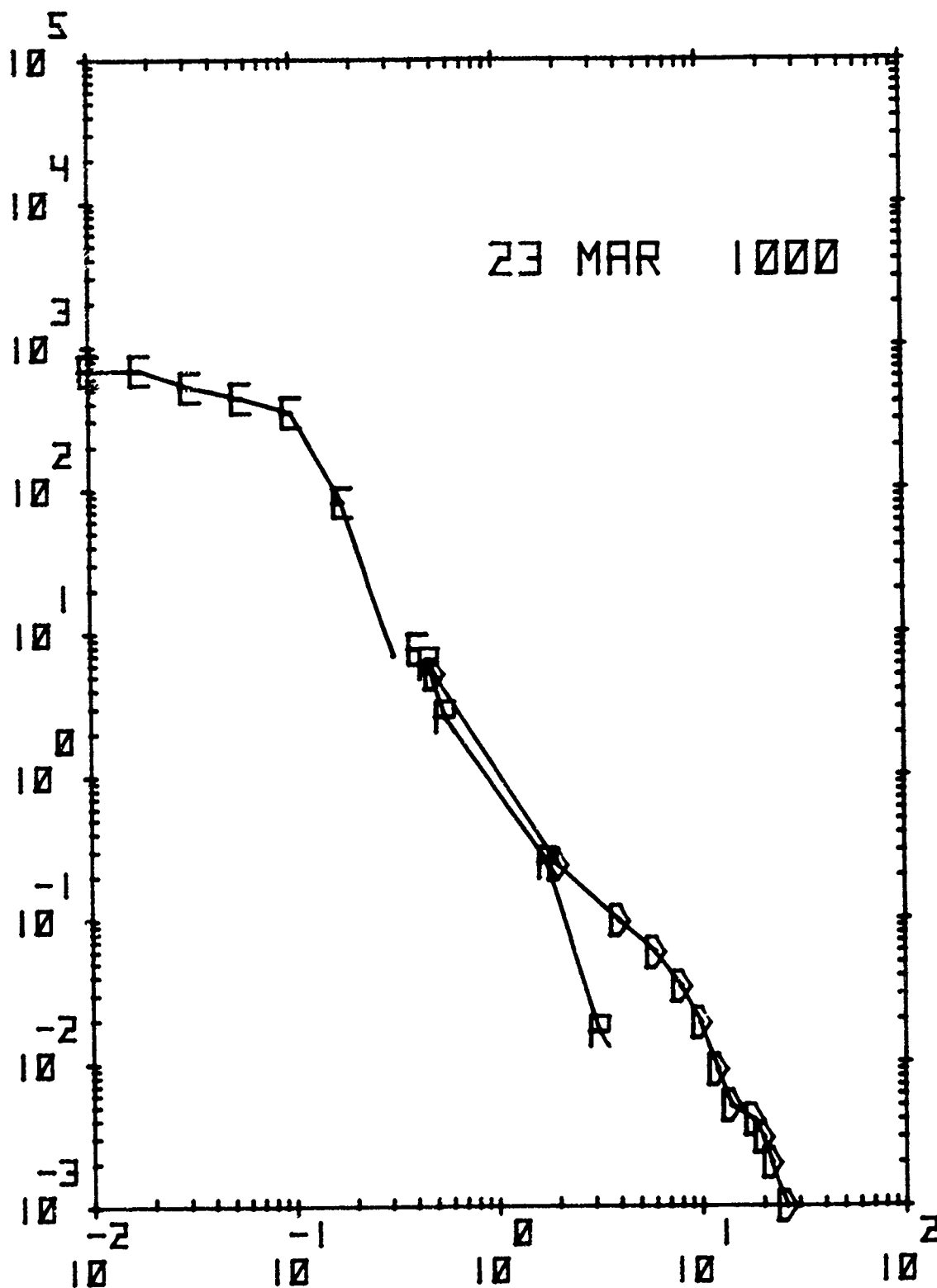
22 MAR 1900



PARTICLE DIAMETER (MICRONS)

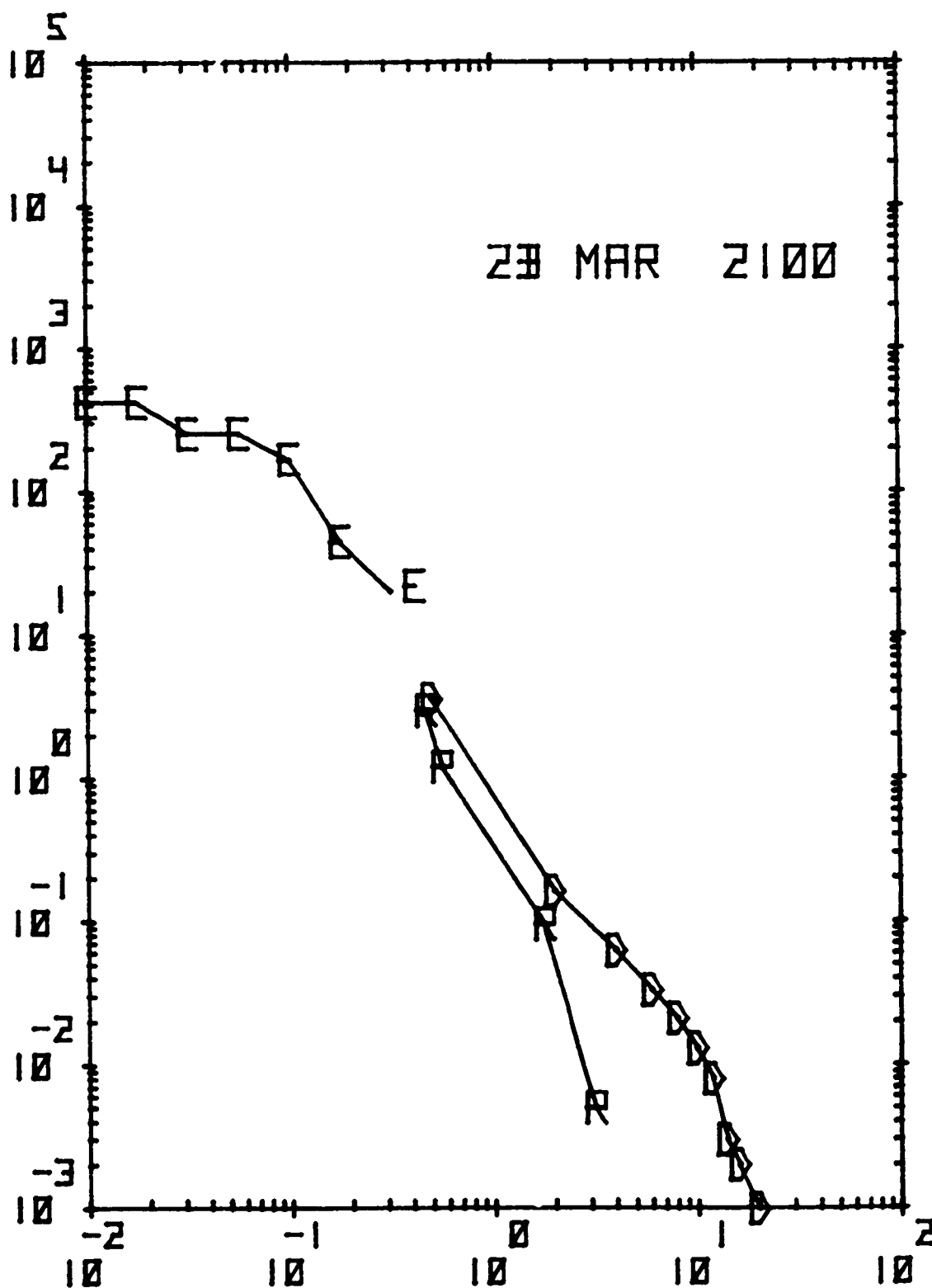
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23 MAR 1000



NUMBER PER CC > GIVEN SIZE

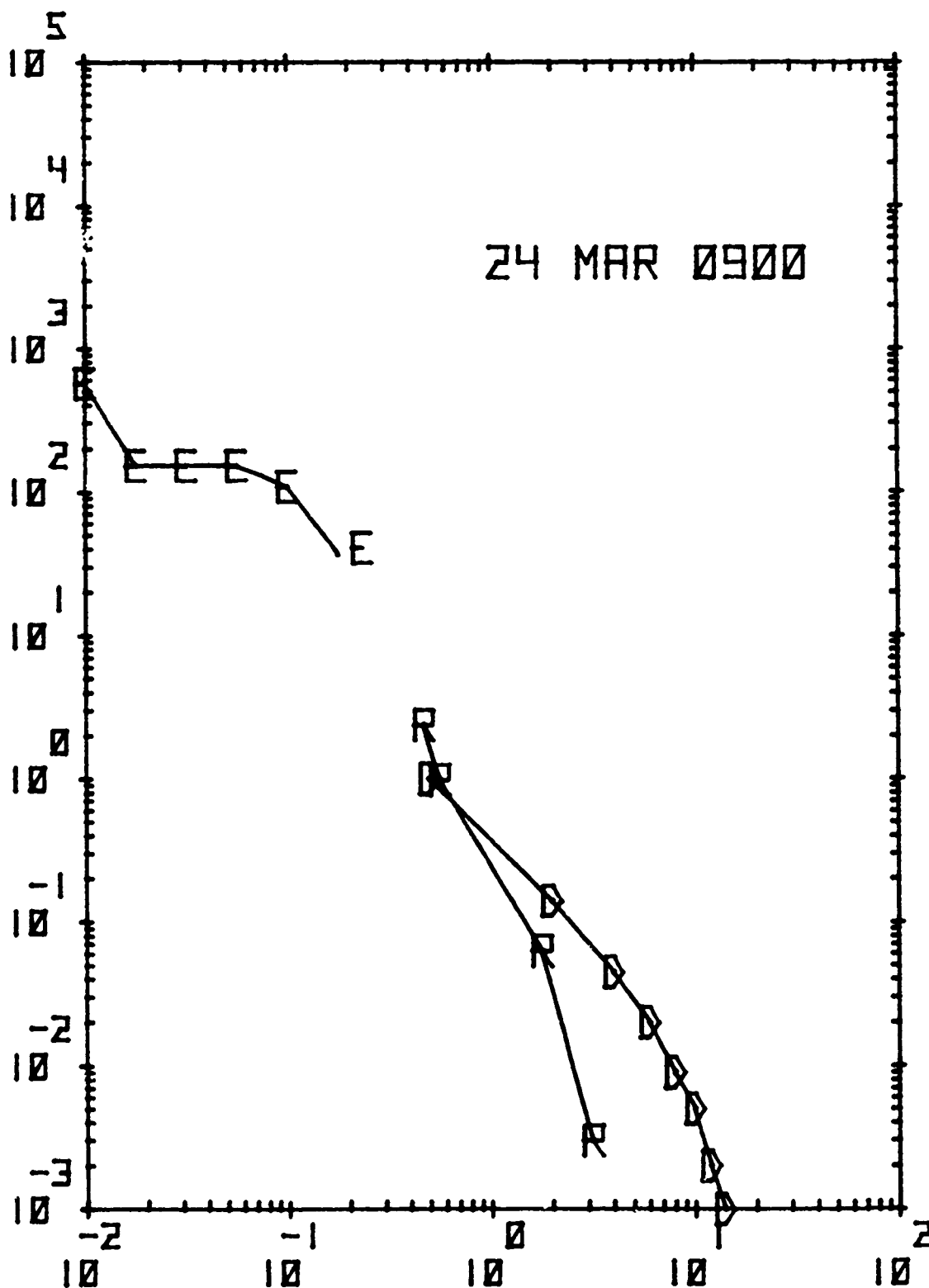
23 MAR 2100



PARTICLE DIAMETER (MICRONS)

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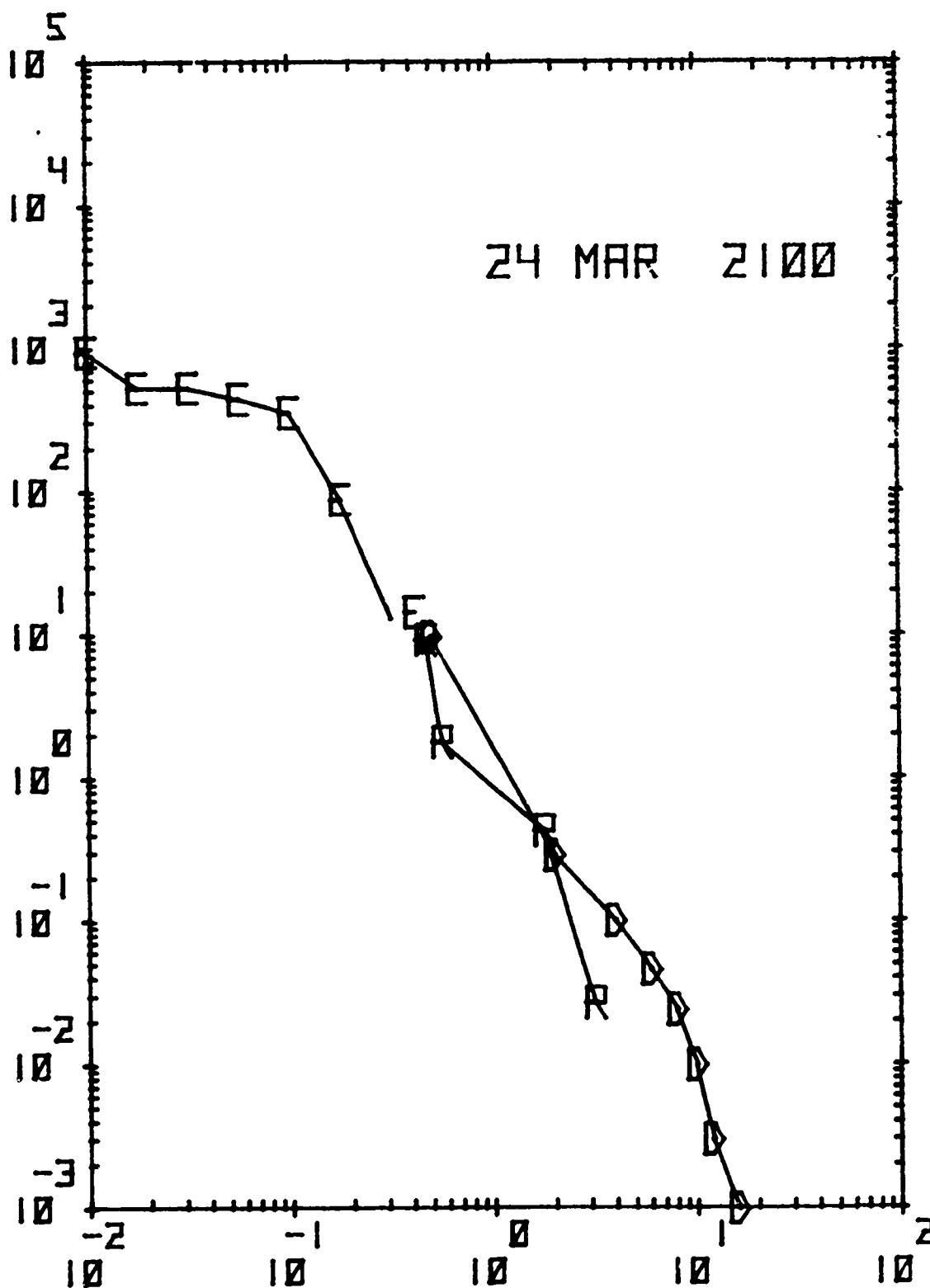
24 MAR 0900



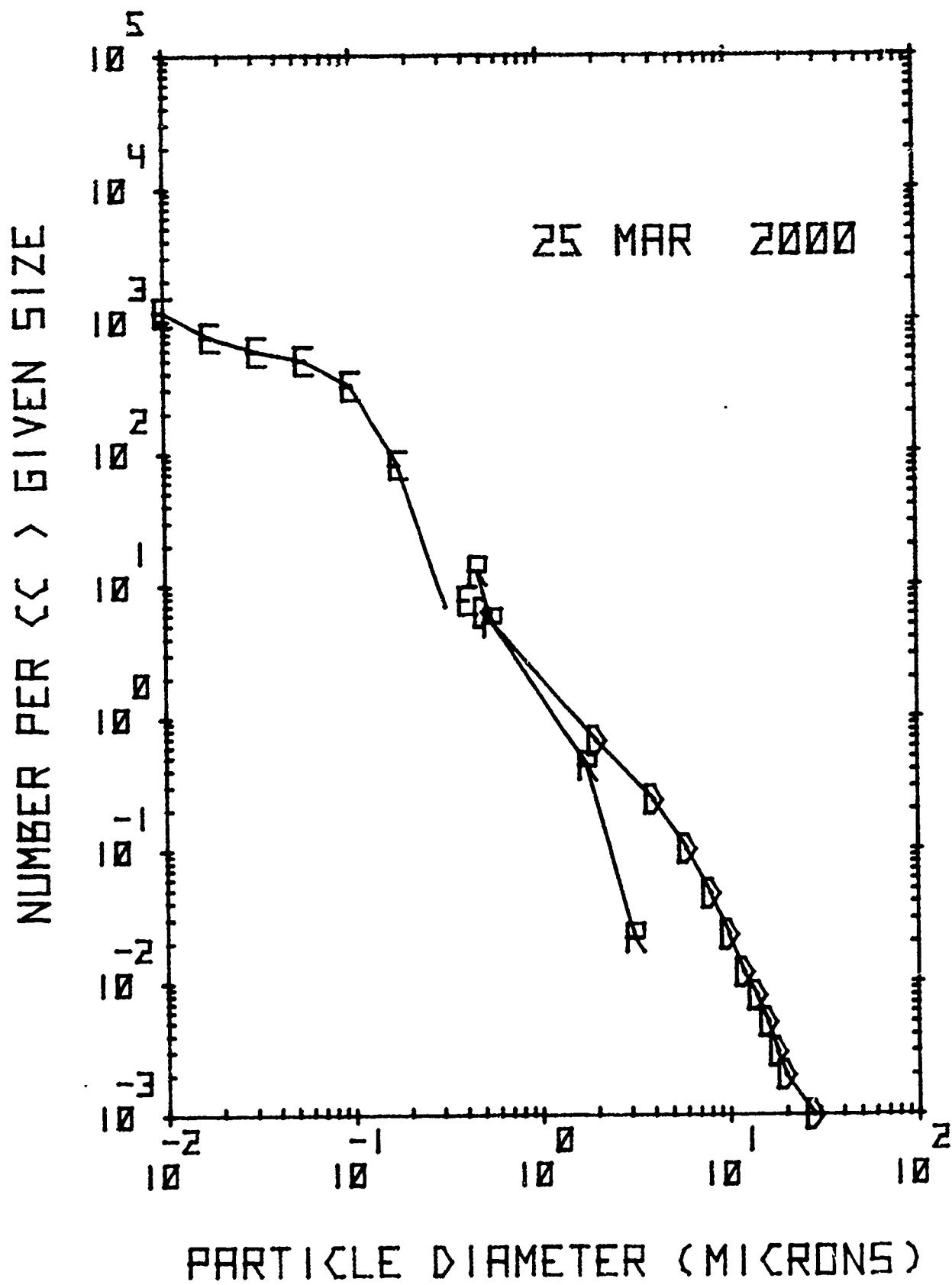
PARTICLE DIAMETER (MICRONS)

NUMBER PER $\langle C \rangle$ GIVEN SIZE

24 MAR 2100

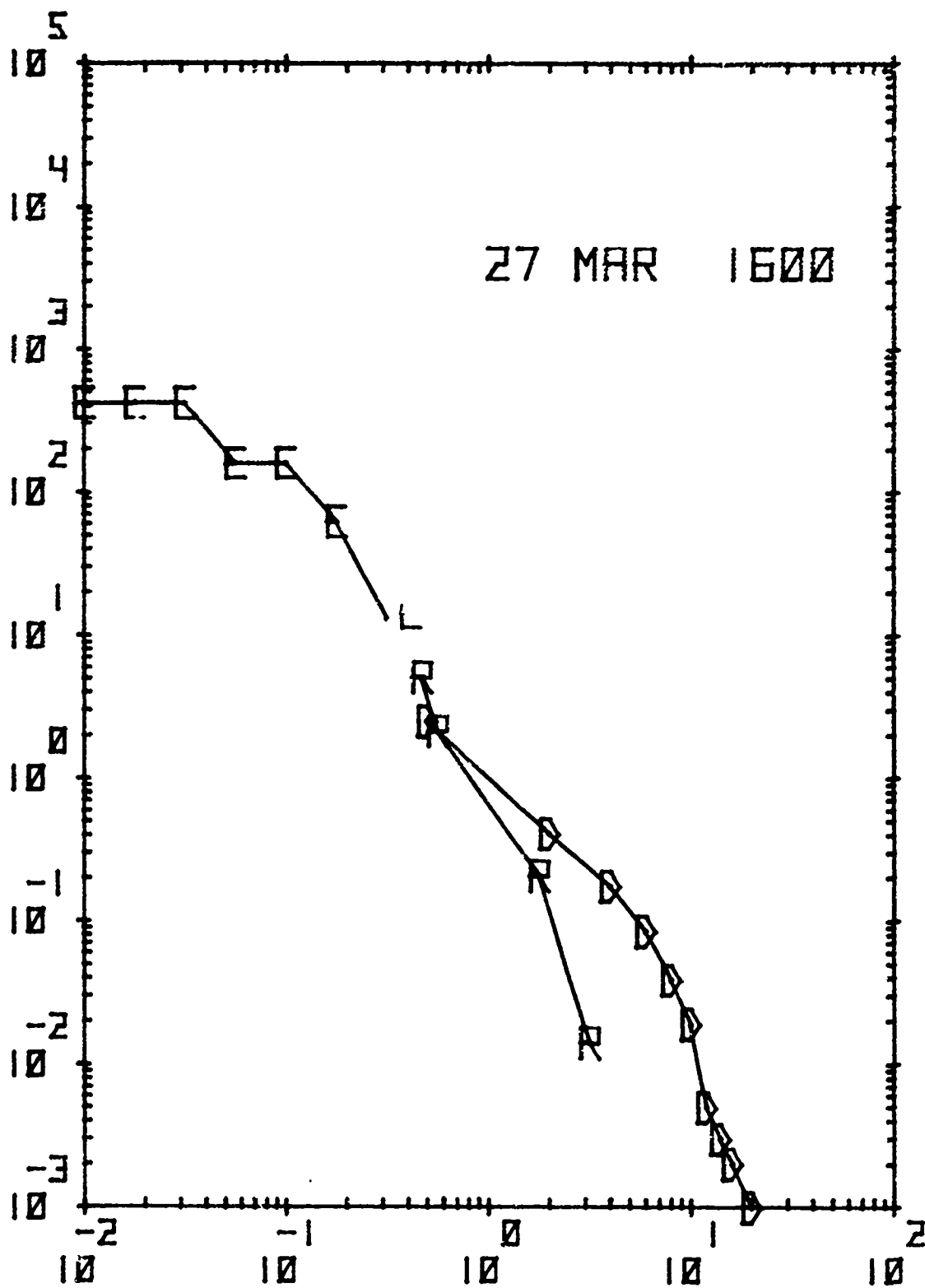


PARTICLE DIAMETER (MICRONS)



NUMBER PER CC > GIVEN SIZE

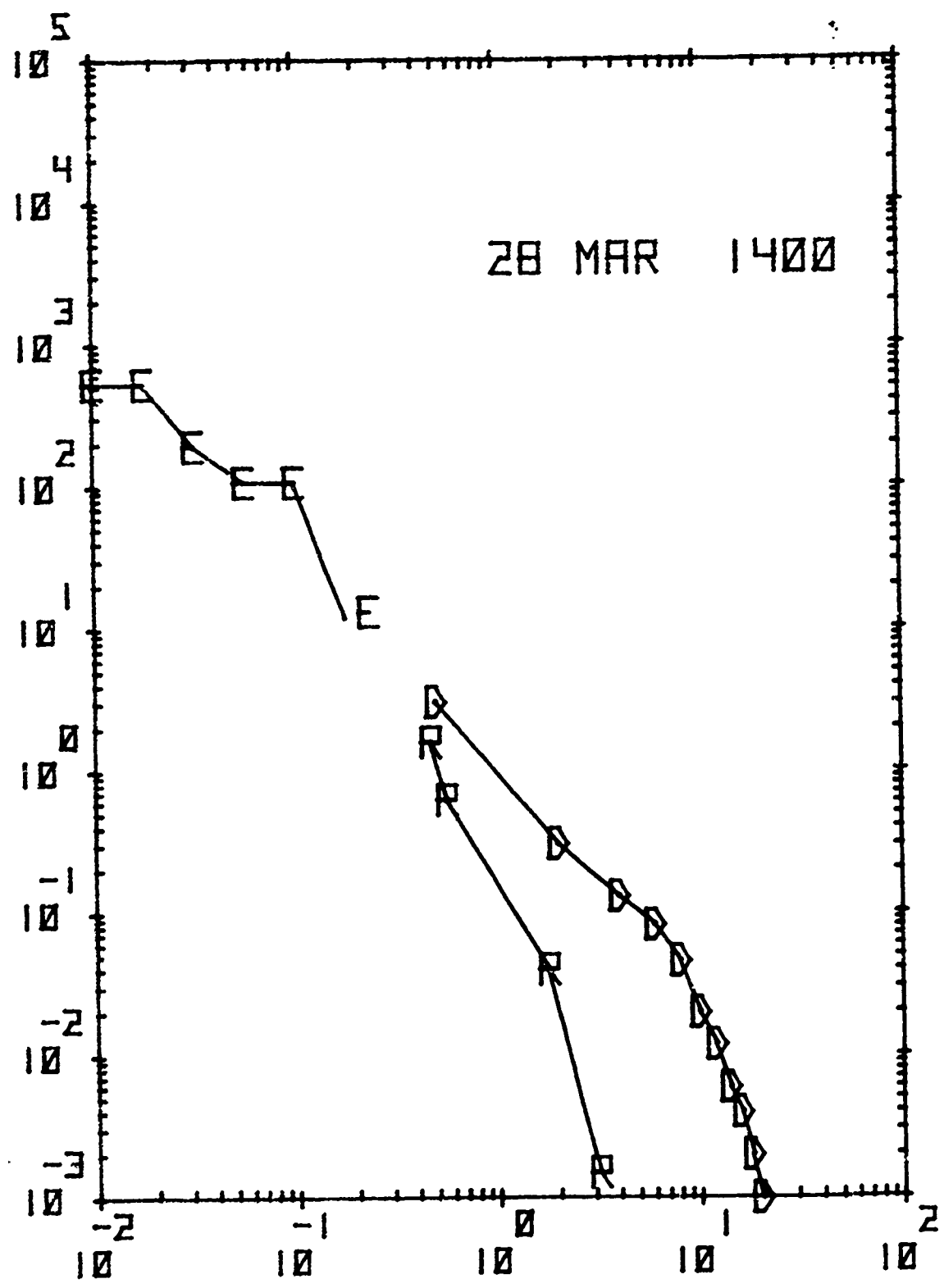
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PARTICLE DIAMETER (MICRONS)

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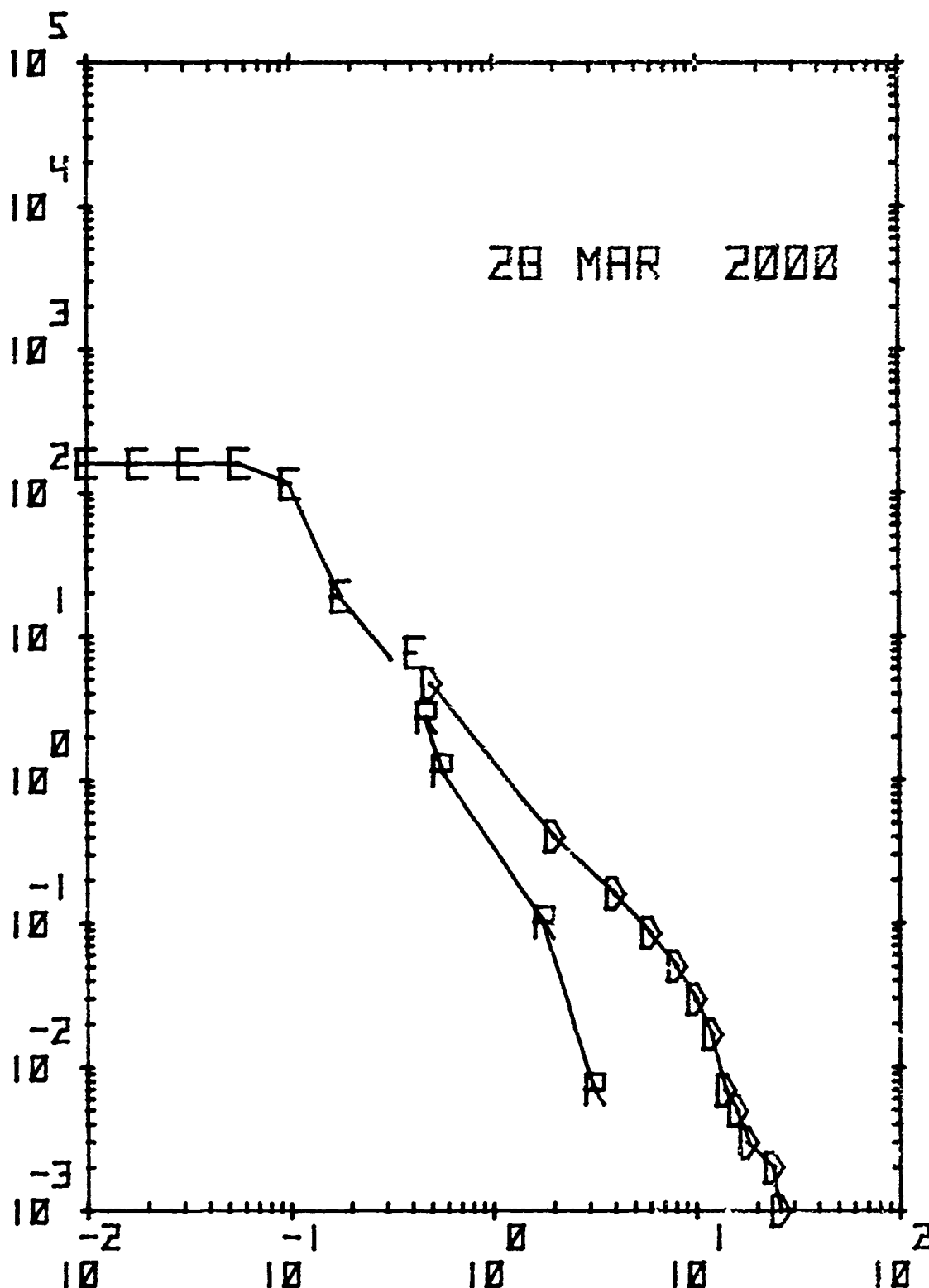
28 MAR 1400



PARTICLE DIAMETER (MICRONS)

NUMBER PER CC > GIVEN SIZE

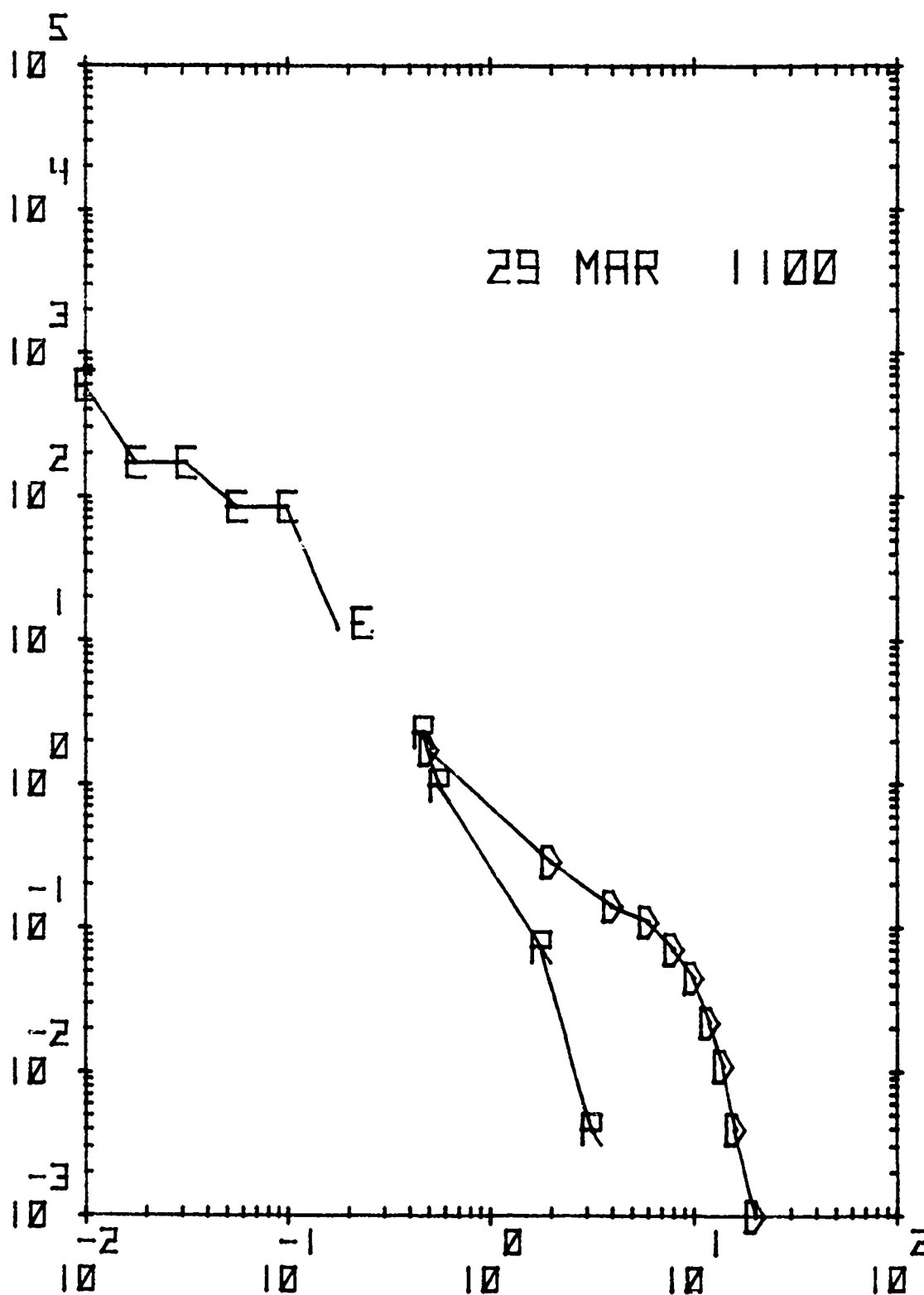
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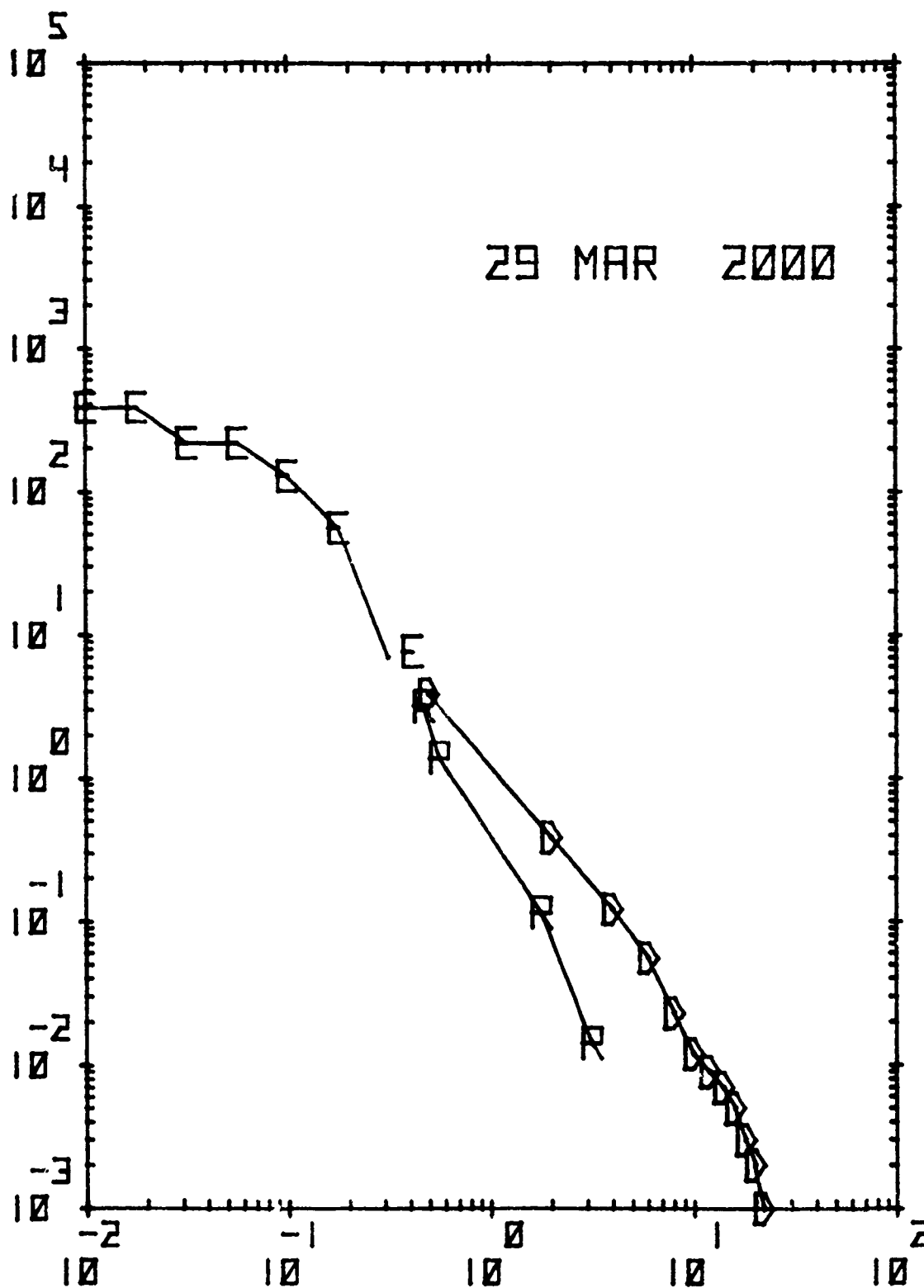
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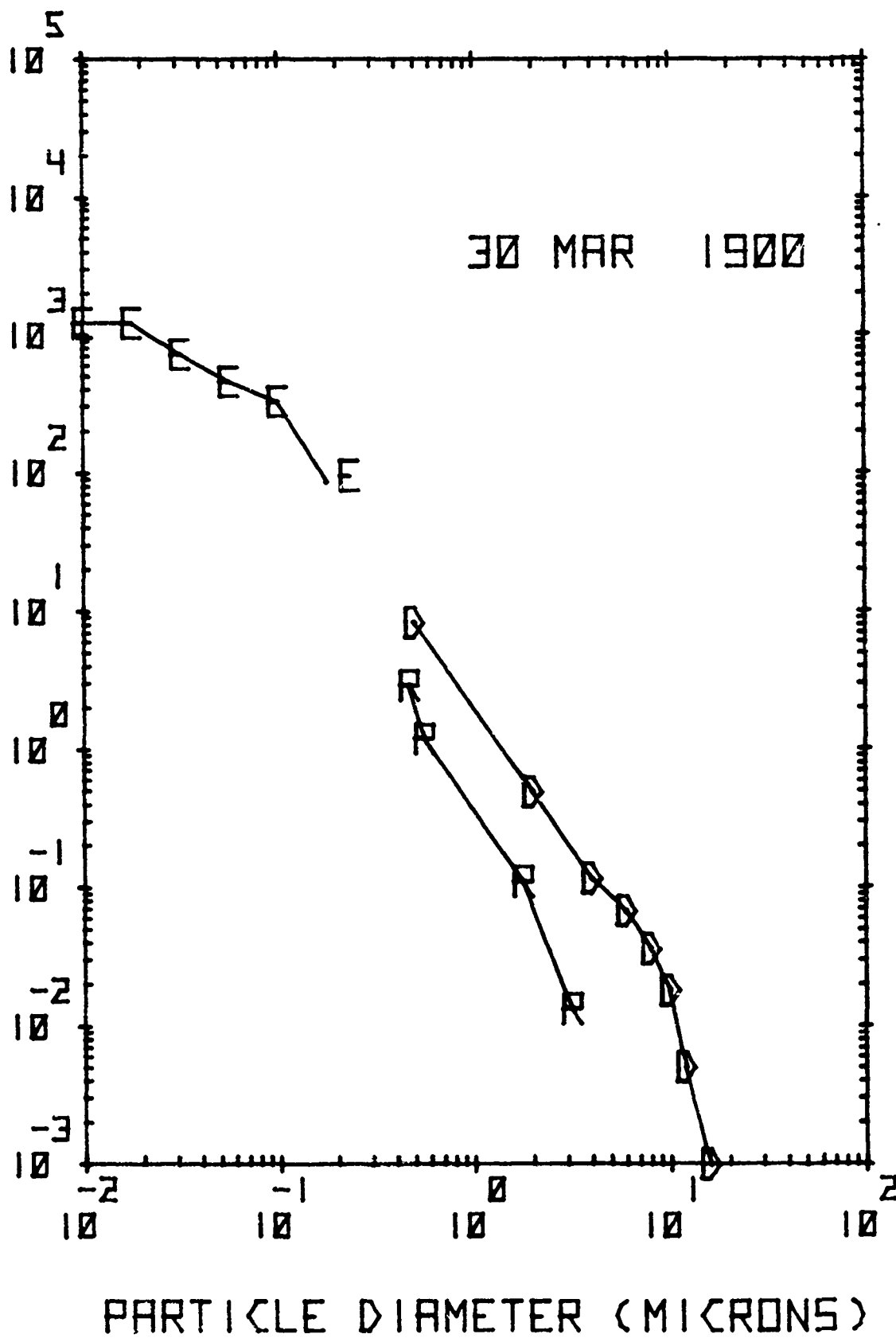
29 MAR 2000



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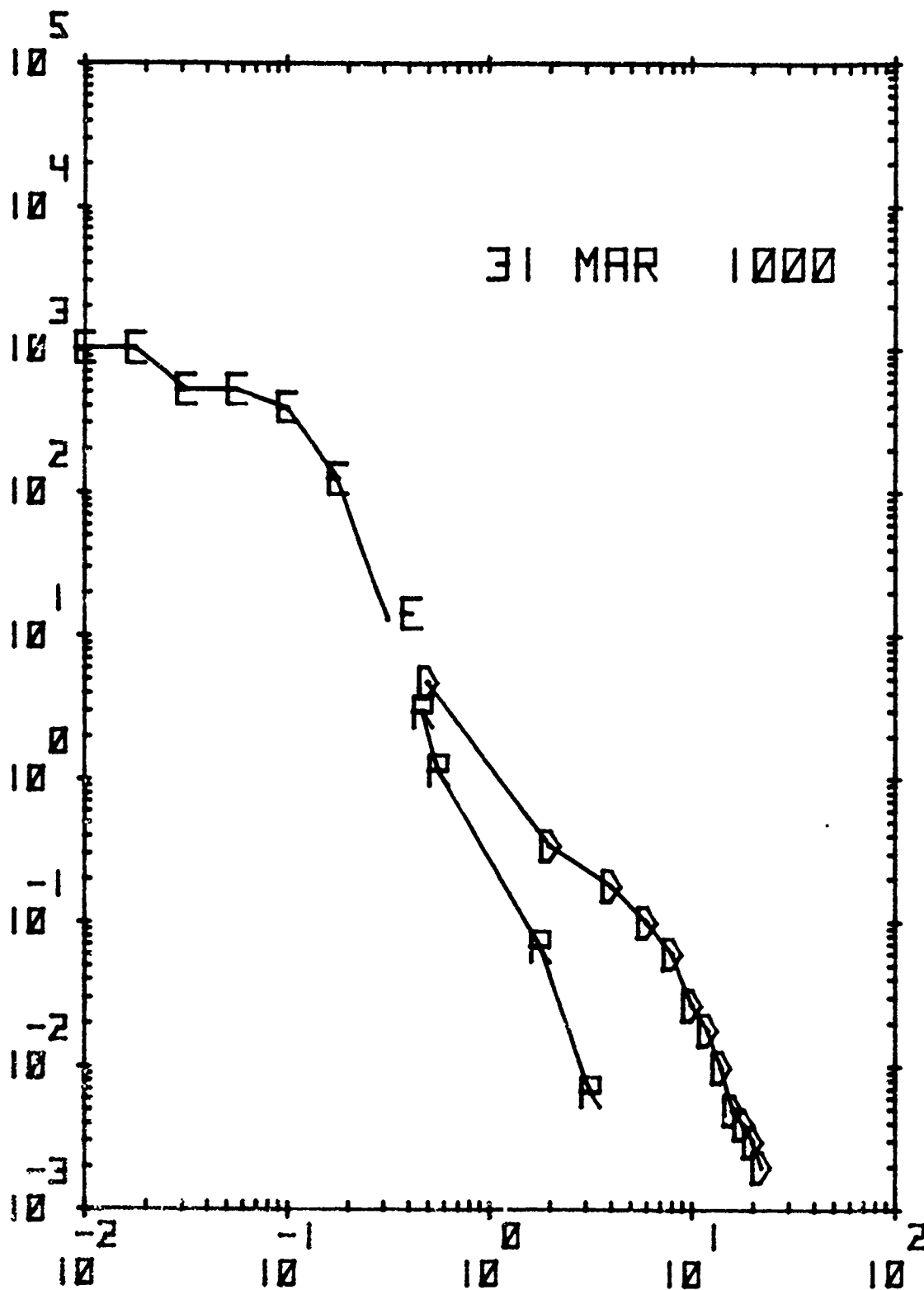
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30 MAR 1900



NUMBER PER CC > GIVEN SIZE

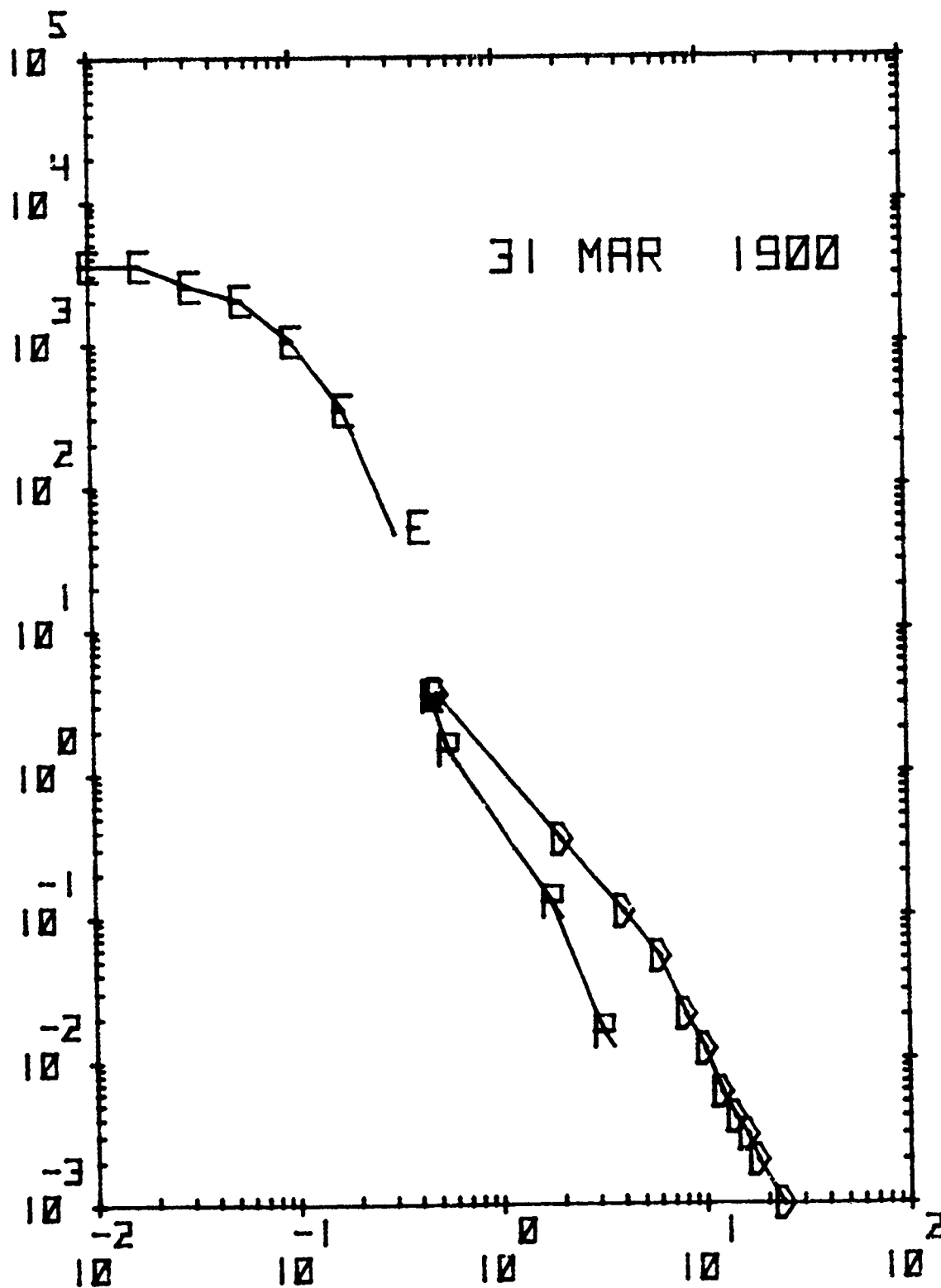
31 MAR 1000



PARTICLE DIAMETER (MICRONS)

NUMBER PER CC > GIVEN SIZE

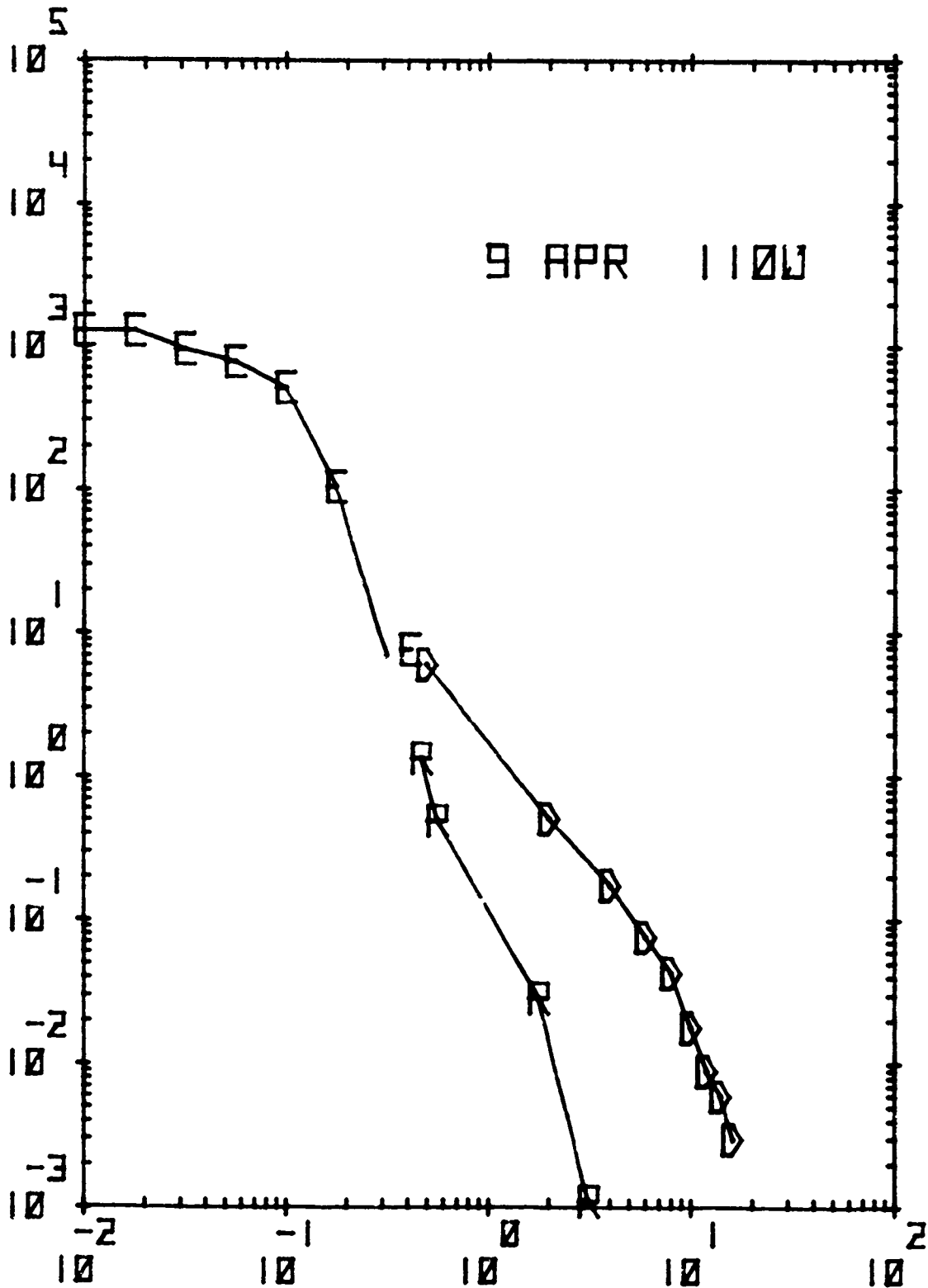
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NUMBER PER CC > GIVEN SIZE

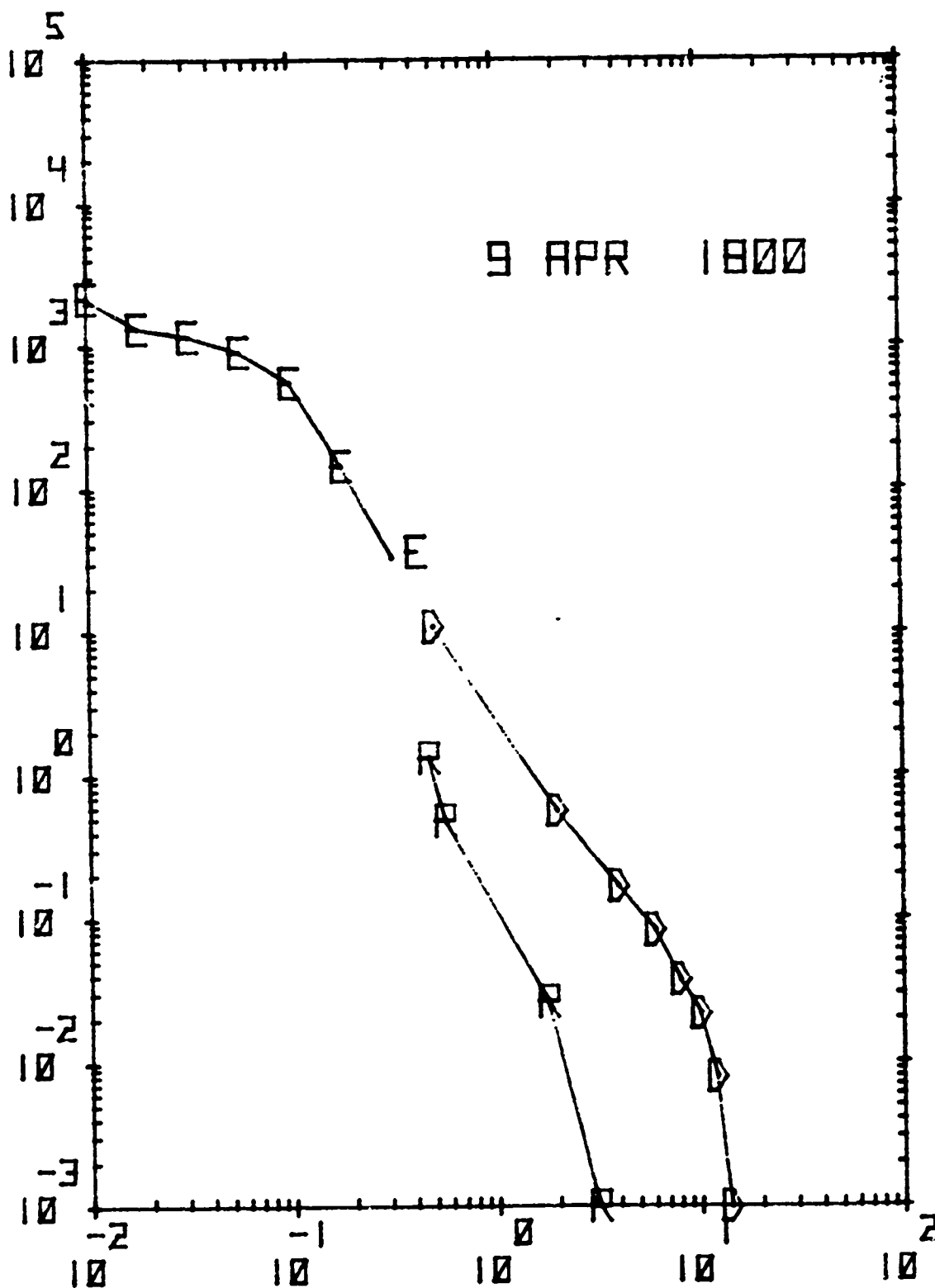
9 APR 1100



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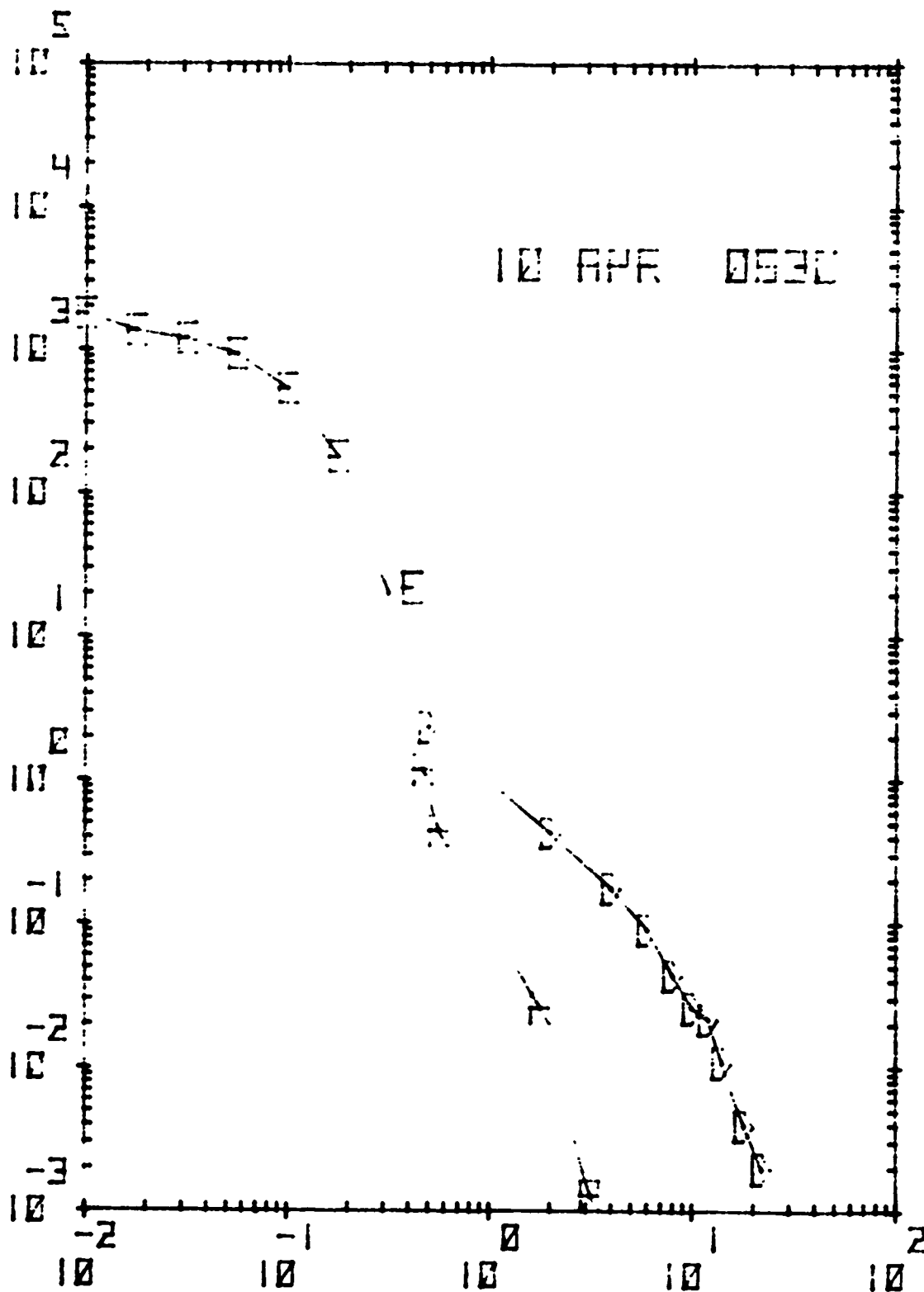
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9 APR 1800



NUMBER PER CC > GIVEN SIZE

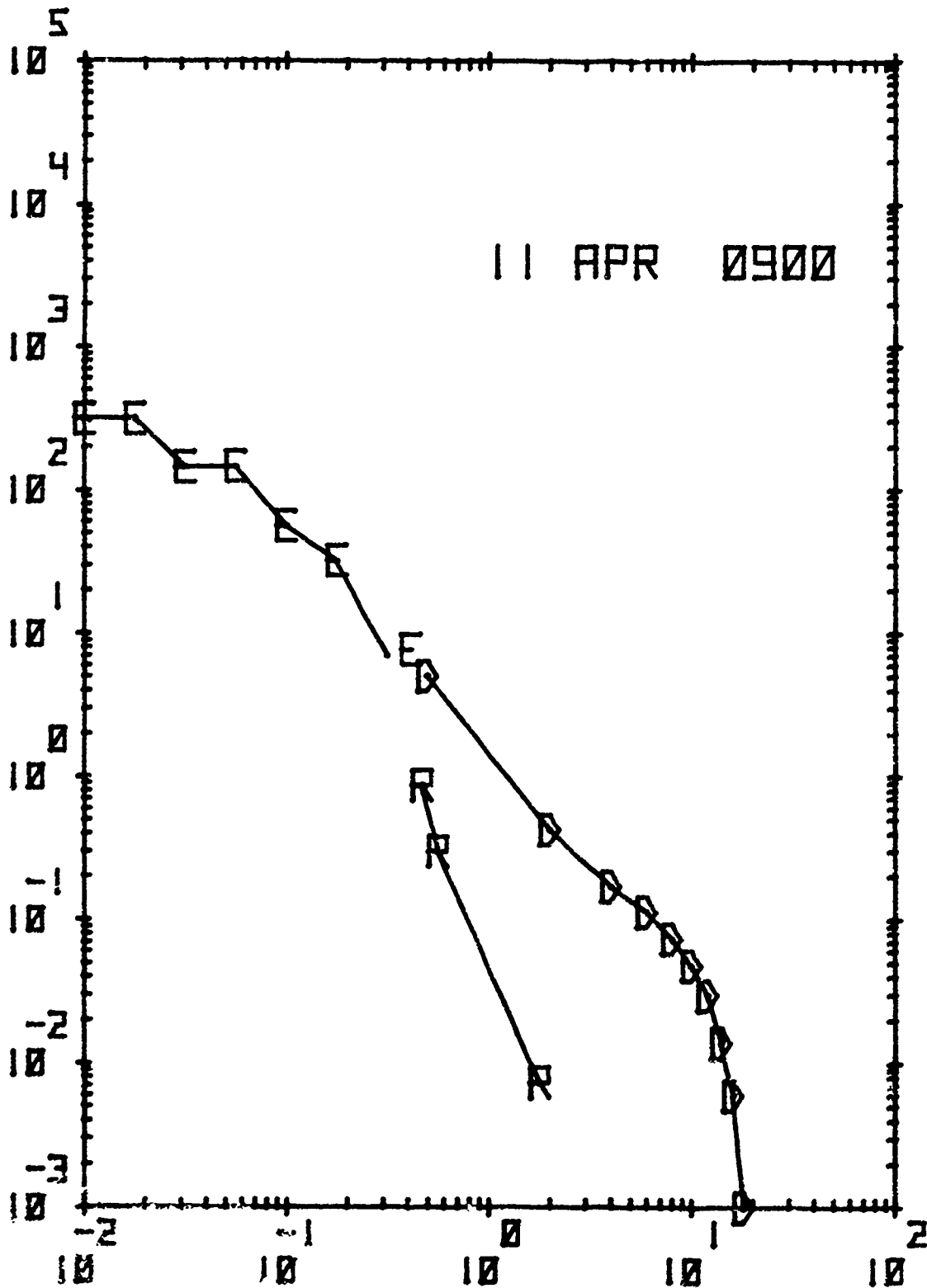
10 APR 0530



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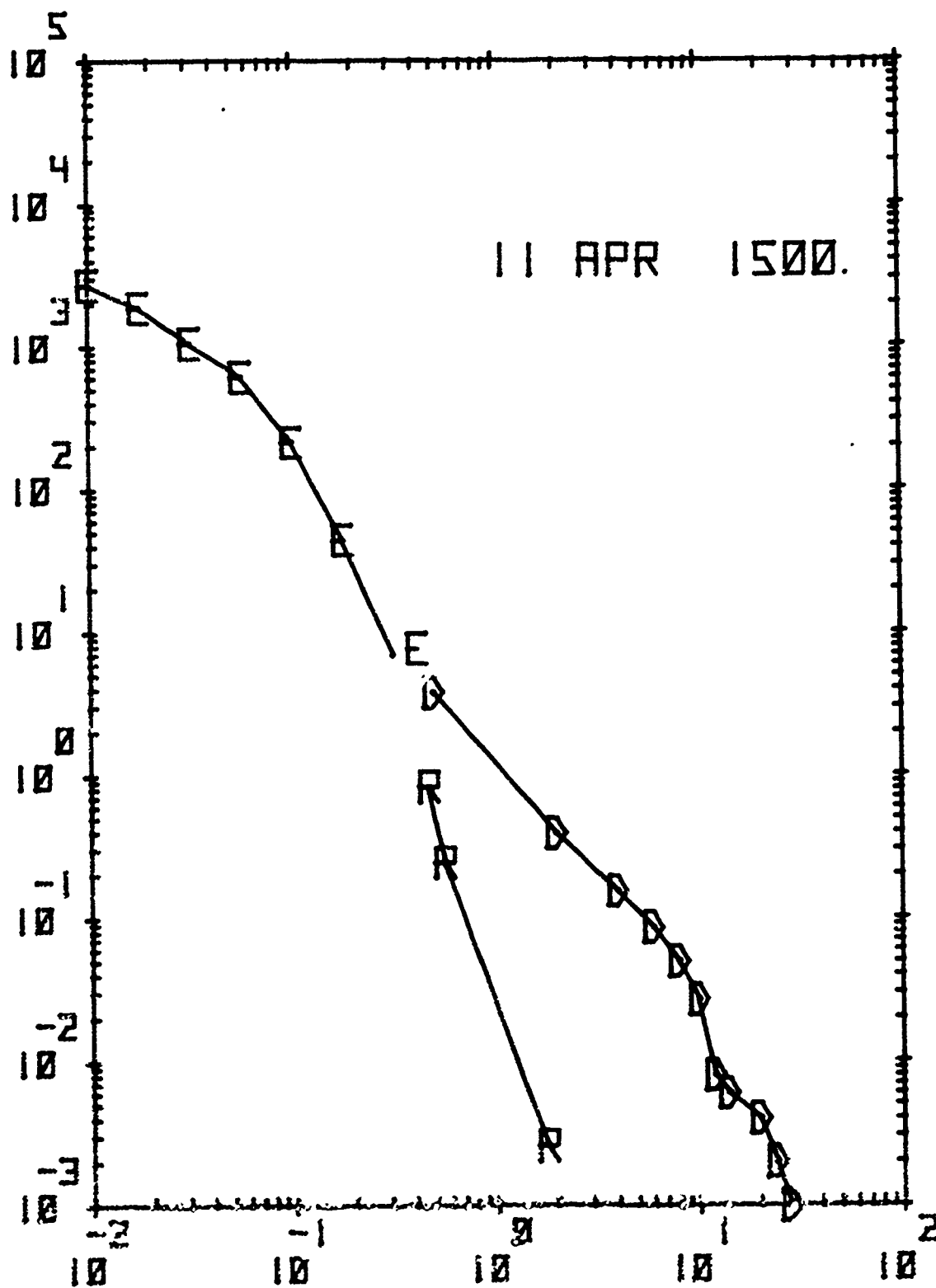
11 APR 0900



PARTICLE DIAMETER (MICRONS)

NUMBER PER CC > GIVEN SIZE

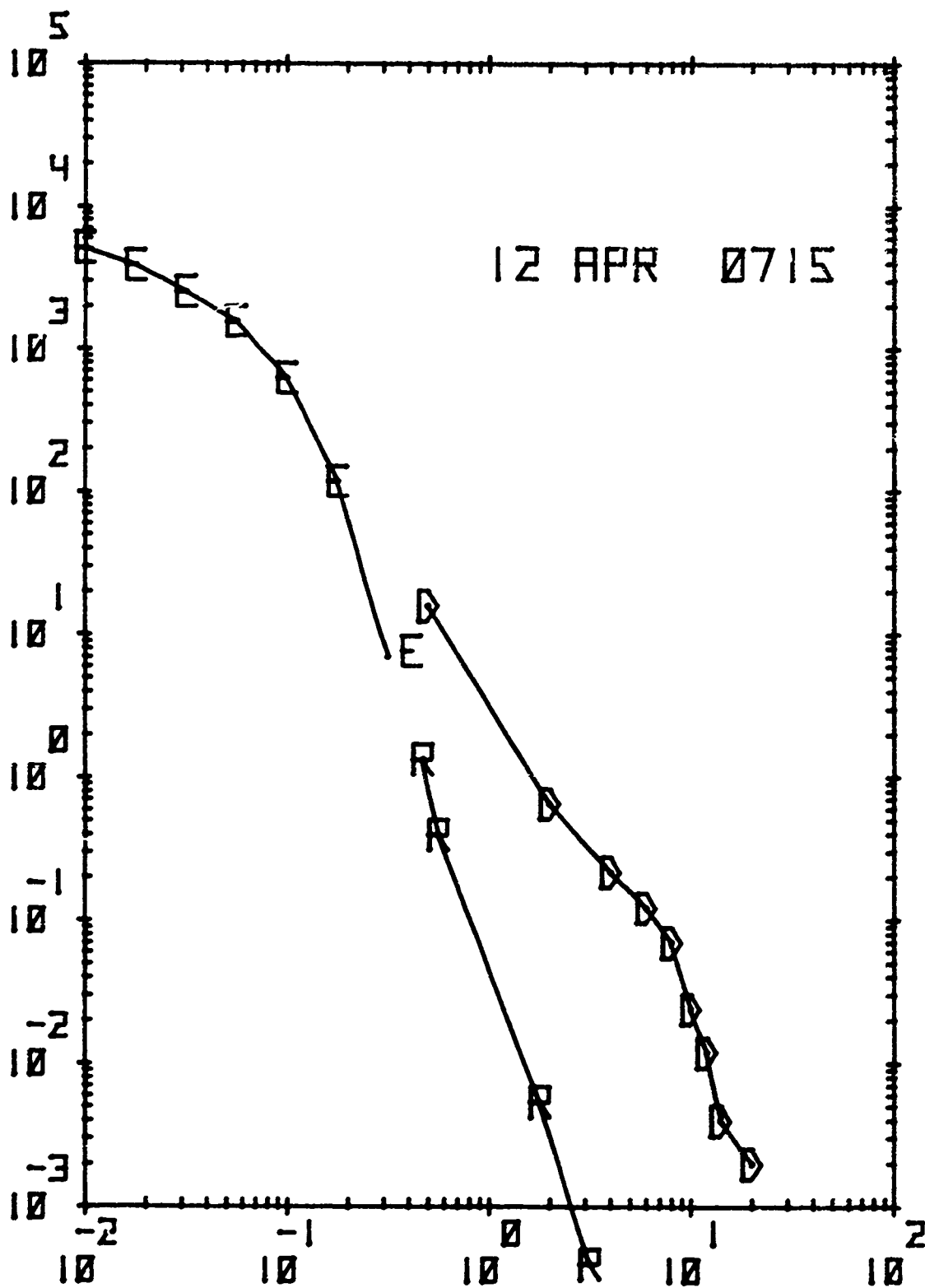
11 APR 1500.



PARTICLE DIAMETER (MICRONS)

NUMBER PER CC > GIVEN SIZE

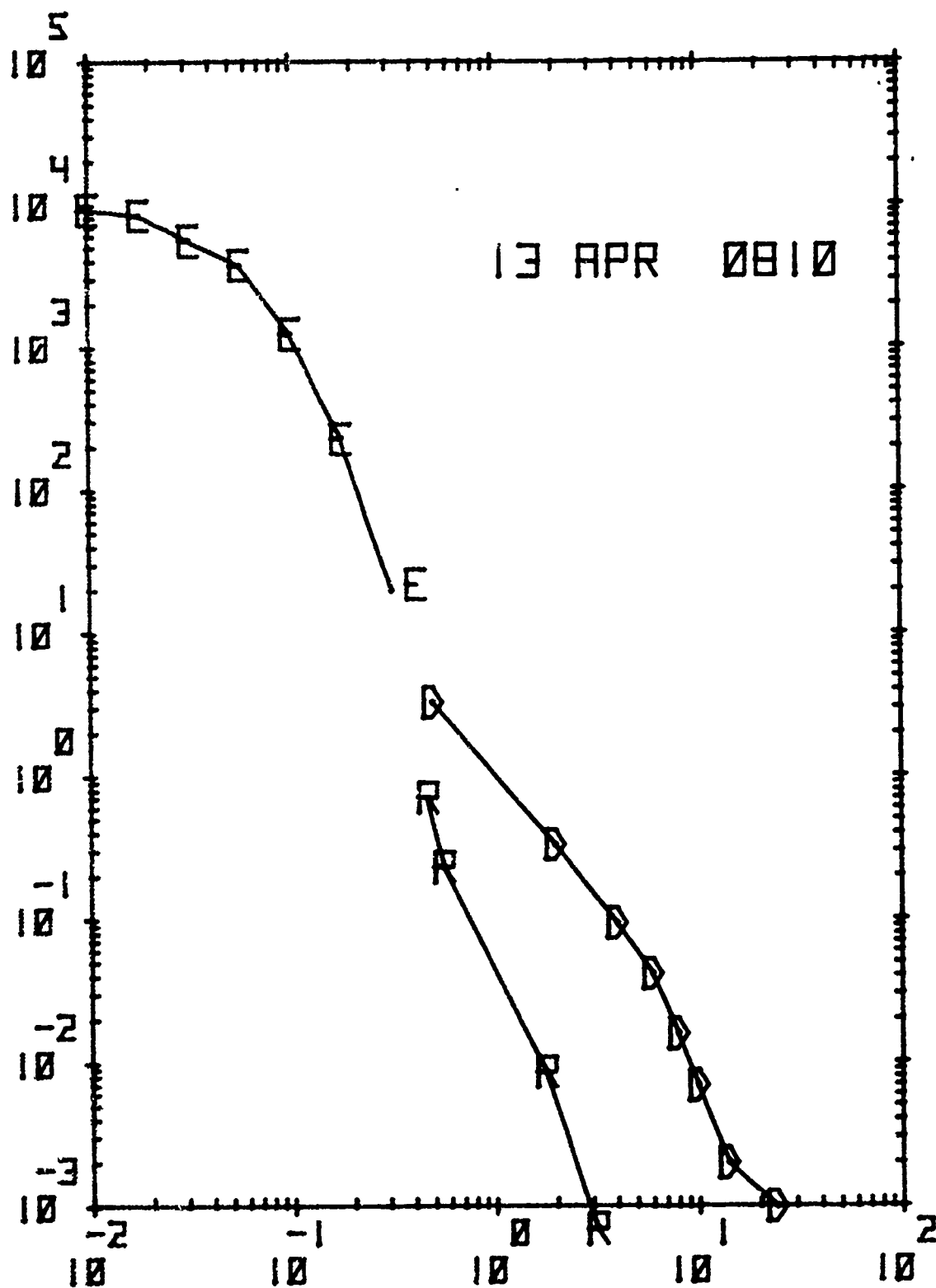
12 APR 0715



PARTICLE DIAMETER (MICRONS)

NUMBER PER $\llcorner$ > GIVEN SIZE

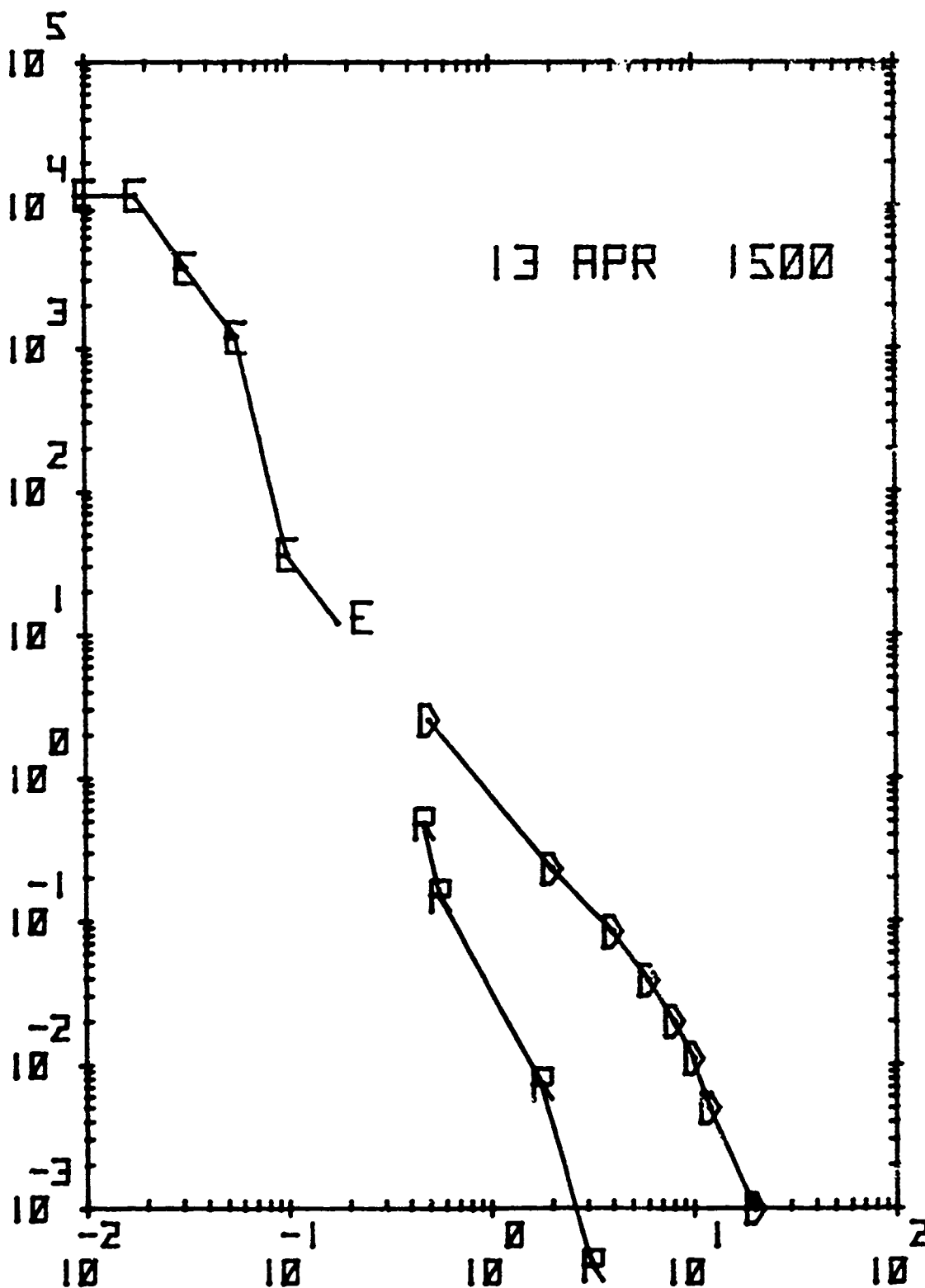
13 APR 0810



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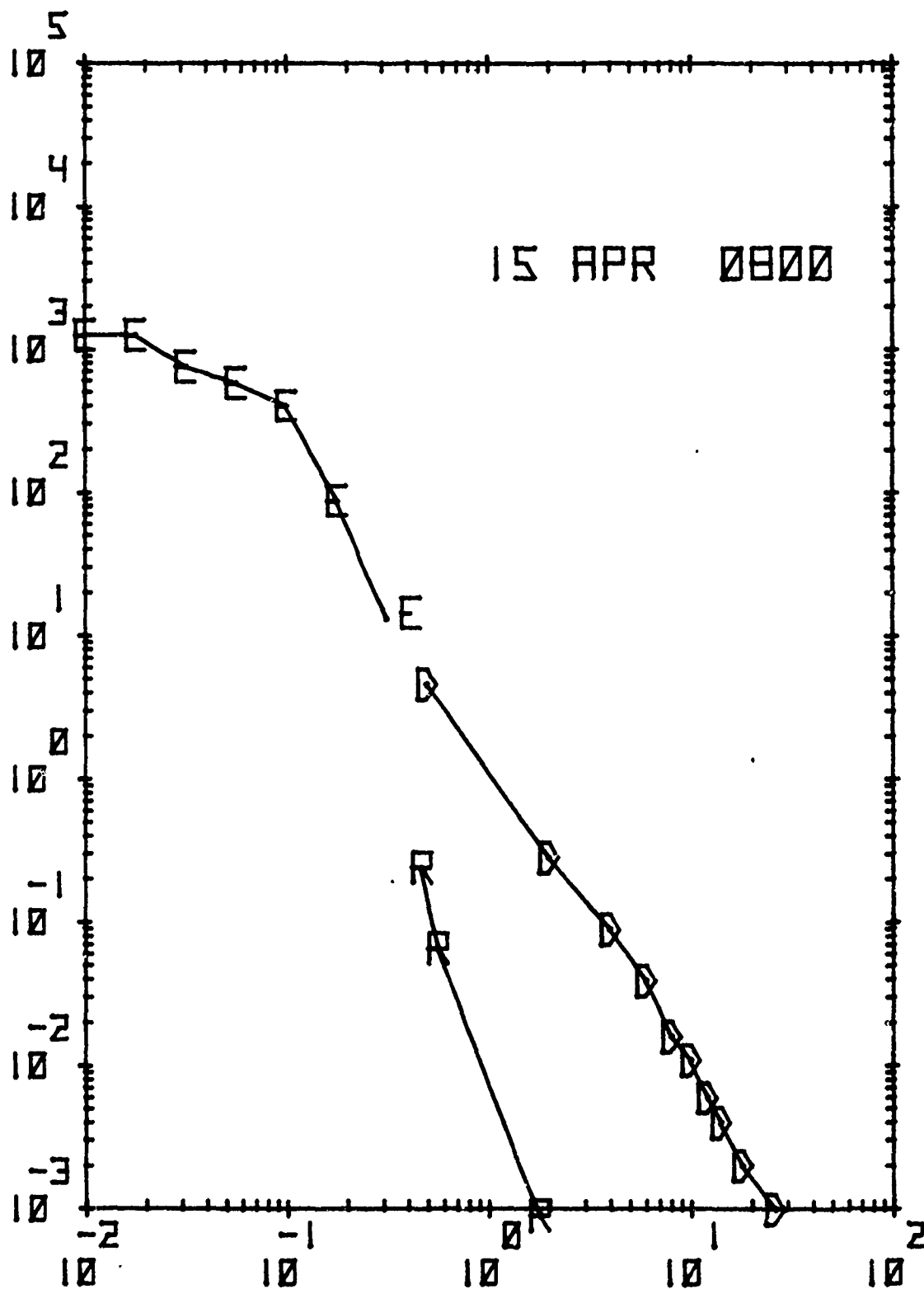
13 APR 1500



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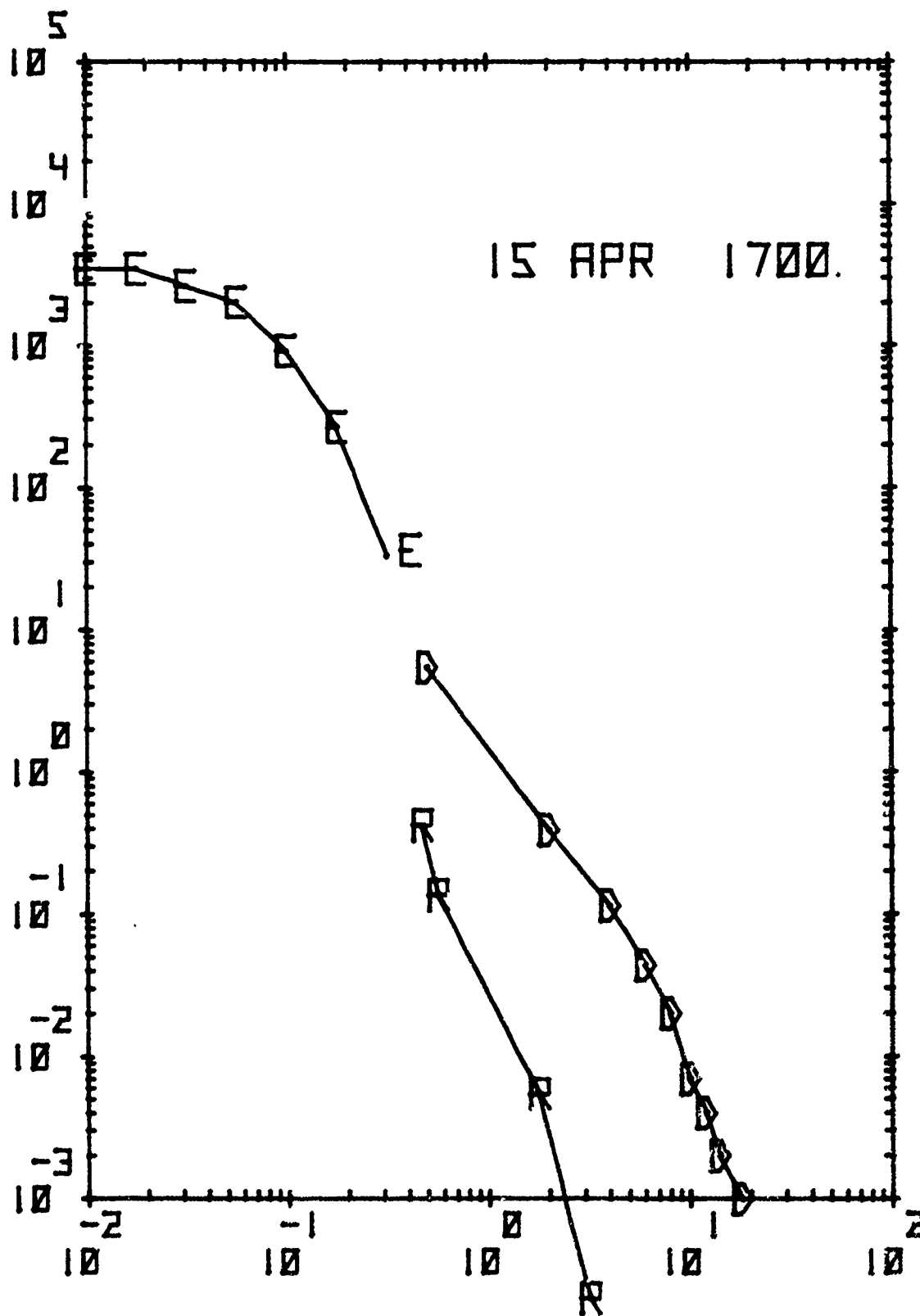
15 APR 0800



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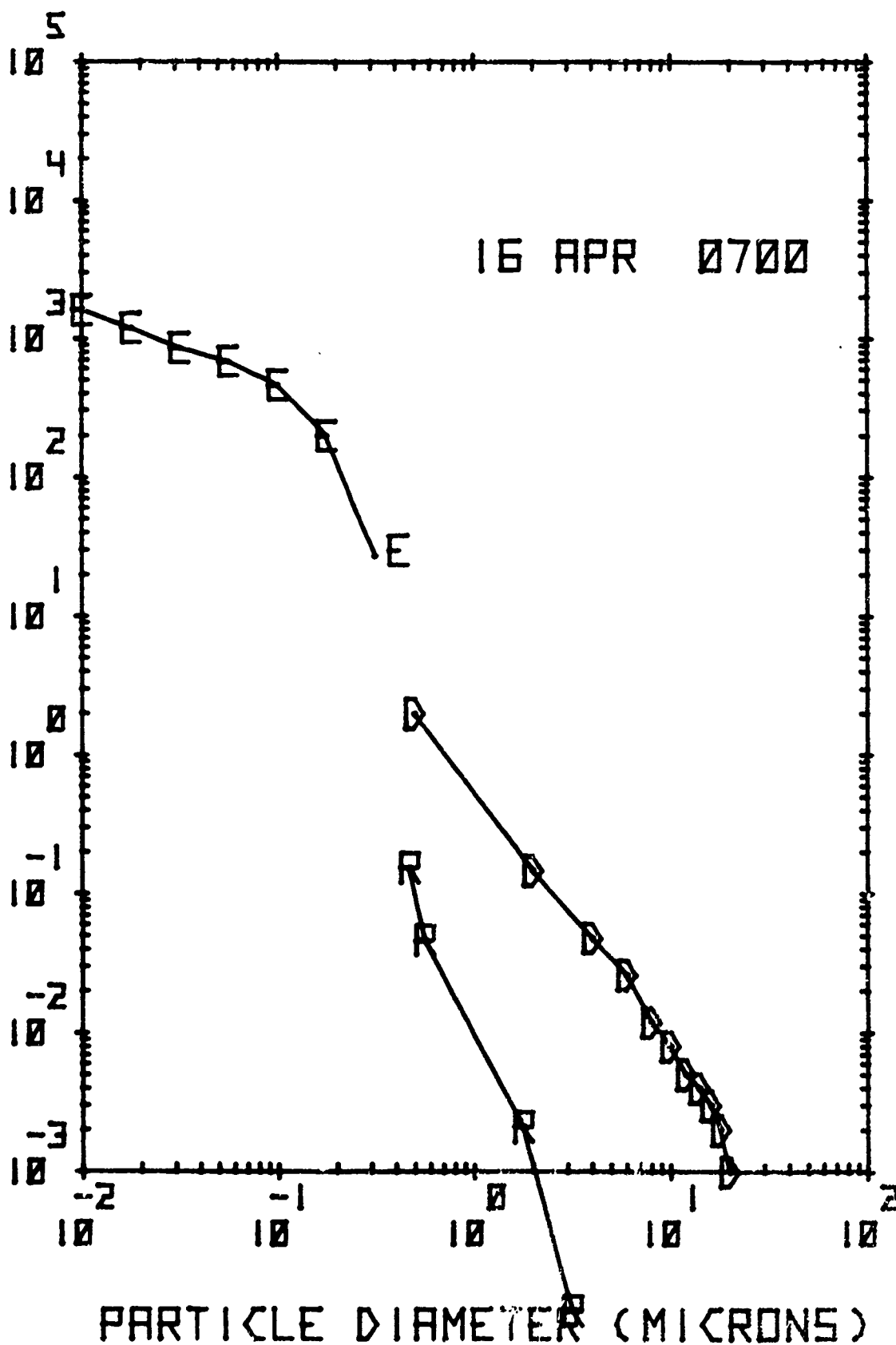
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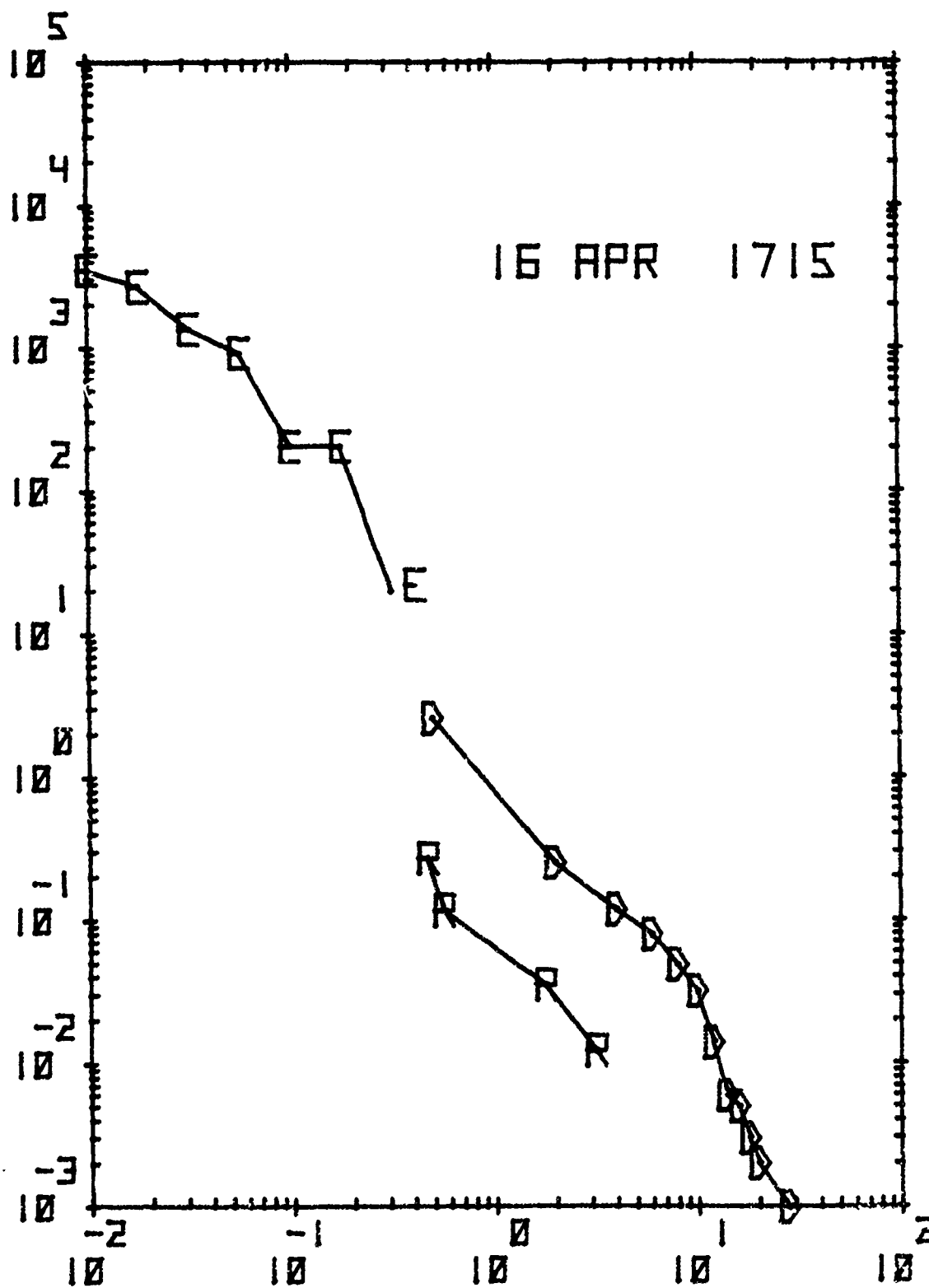
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16 APR 0700



NUMBER PER CC > GIVEN SIZE

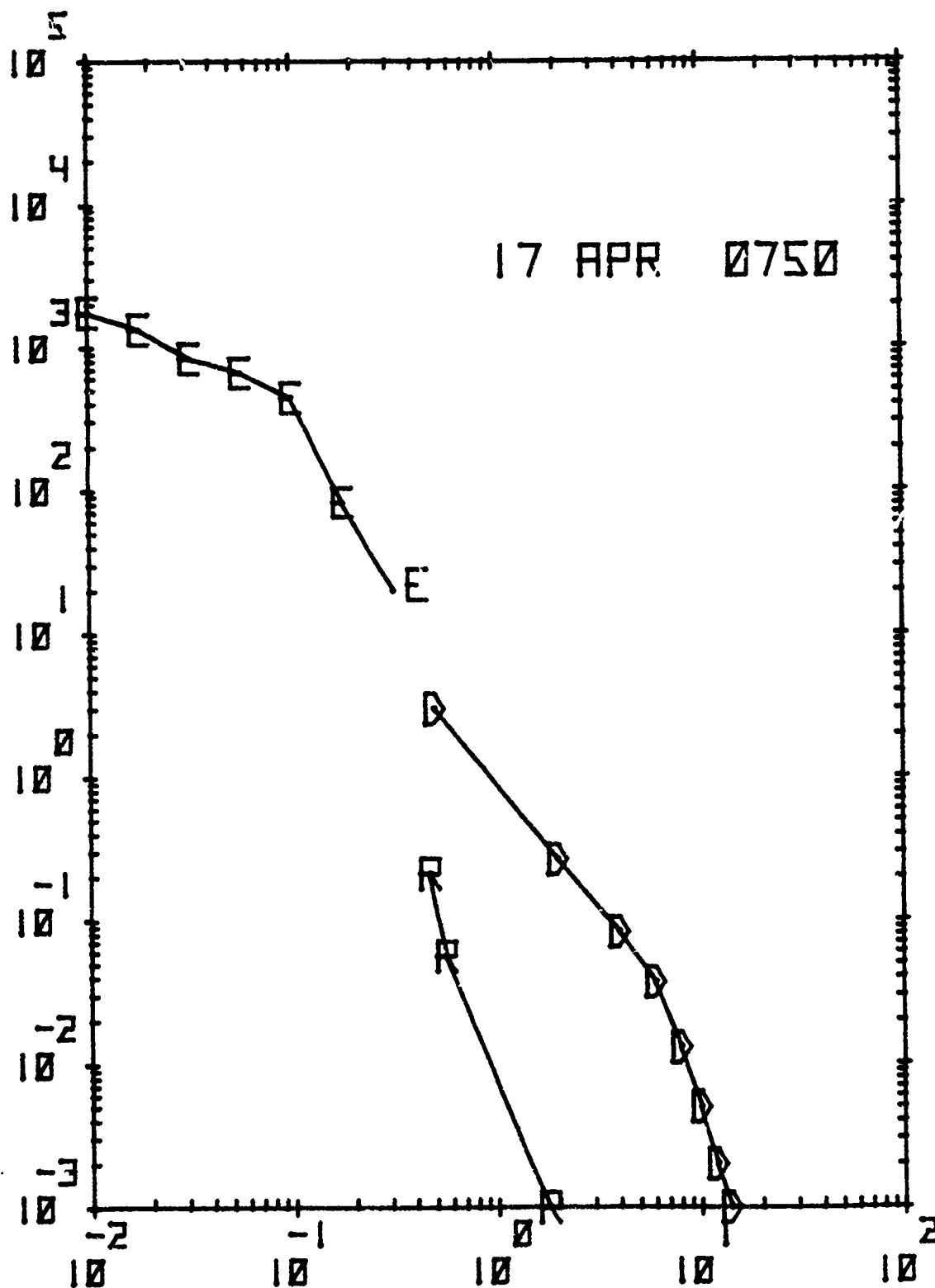
16 APR 1715



PARTICLE DIAMETER (MICRONS)

NUMBER PER CC > GIVEN SIZE

17 APR 0750



PARTICLE DIAMETER (MICRONS)