AN INVESTIGATION OF COSMIC RAY SCINTILLATIONS IN MUONS NEAR SEA LEVEL

A Dissertation

by

ROBERT HENRY BENSON

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Approved as to style and content by:

Nelson M. Duller

(Chairman of Committee)
Nelson M. Duller

(Head of Department)
Robert E. Tribble

George W. Kattawar

(Member)
George W. Kattawar

Philip J. Green

(Member)
Philip J. Green

Davis A. Fahlquist

(Member)
Davis A. Fahlquist

August 1985

ABSTRACT

An Investigation of Cosmic Ray Scintillations
in Muons Near Sea Level
(August 1985)
Robert Henry Benson,
B.S., Southwest Texas State University
Chairman of Advisory Committee: Dr. N. M. Duller

An investigation of scintillations in ground-level cosmic ray muons has been conducted using a muon telescope constructed at Texas A&M University. The power density spectrum of the muon counting rate was calculated and the resultant slope of -1.36 is in excellent agreement with accepted theory.

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to Professor Nelson M. Duller for his unfailing support during my years at Texas A&M. I would also like to thank Professors Philip Green and Dr. George W. Kattawar for their help and guidance during this project. This work could not have been done without the support and encouragement of my wife Ramona and my children Debra, Eric, and Michael.

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CHAPTER I

INTRODUCTION

Background

A considerable body of research has been done on the subject of intensity variations in the primary and secondary cosmic rays arriving at the earth. Unlike photon astronomy, cosmic ray astronomy utilizes charged particles as information carriers, and consequently cosmic ray observations are subject to the influences of magnetic fields and to a smaller degree, electric fields. In many ways this dependence on fields complicates the study of cosmic rays. Conversely, this very dependence can be used as a tool with which to investigate the electromagnetic structure of interplanetary space.

Until quite recently, most investigators were concerned with large-amplitude periodic variations or conspicuous discrete events found in the cosmic radiation (Kohlhorster et al. 1923; Lindholm 1928; Compton et al. 1932; Hess et al. 1936; Schonland et al. 1937; Lange and Forbush 1948; Alfven and Malmfors 1943; Elliot and Dolbear 1950; Sandstrom and Lindgren 1959; Pomerantz et al. 1962; and Kane 1962. However, inspection of a record of

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The citations in this dissertation follow the style of the Astrophysical Journal.

cosmic ray intensity as a function of time invariably reveals a continuous spectrum of statistically significant smaller-amplitude variations. These fluctuations have a broad-band spectrum and are not directly connected with regular periodic variations such as the diurnal anisotropy. These aperiodic fluctuations are best characterized by their power spectral density function (PSDF). The PSDF (also called the autospectral density function) of random data (e.g., intensity data) describes the frequency composition of an intensity-time record in terms of the spectral density of the mean square value of the record. The PSDF of a record of cosmic ray intensity as a function of time shows a broad continuum of variations from the mean value on all scales from minutes to weeks. These variations are called "cosmic ray scintillations" and are believed to be related to magnetic fluctuations and cosmic ray gradients in the interplanetary medium.

In the nineteen-seventies, J. R. Jokipii and A. J. Owens developed a body of theory which sought to explain cosmic ray scintillations by bringing together modern particle diffusion theory and the hypothesis that the phenomenon was due to the interactions of cosmic ray particles with various magnetic fields (Owens and Jokipii 1972; Owens 1974; Owens and Jokipii 1974; Jokipii and Owens 1976). The theory successfully predicts results obtained with certain low-energy components of the cosmic ray flux but has not been carefully tested in higher-energy ranges such as the secondary muon component or extensive air showers. The subject of this thesis is to report the results of one such experimental study done at Texas A&M University. In the A&M study, cosmic ray scintillations were observed using ground-level muons in an energy range above that used by Jokipii and Owens and below the range of extensive air showers.

A short history of cosmic ray physics

The discovery of cosmic rays came by chance, as did the discovery of many other physical phenomena. The beginning of the science is marked by the early observation in Germany by Elster (1900) and Geitel (1900) of a strange source of ions in the air while they were investigating atmospheric electricity. Independently, C. T. R. Wilson (1900) discovered an ionizing agency capable of penetrating thick layers of earth. Wilson speculated that the new radiation might emanate from extraterrestrial sources, but no investigation to test the idea was done for at least a decade.

Hess (1912) carried pressurized electroscopes to altitudes of five kilometers. Hess found a rapid increase in the intensity of the radiation as a function of altitude. Shortly after Hess' work, Kolhorster (1913), using improved equipment, confirmed Hess' results to an altitude of nine kilometers.

After the First World War, advances in technology improved the data considerably. While on a voyage from Amsterdam to Java, Clay (1927) noticed a systematic variation in the intensity of cosmic radiation with changes in latitude. This variation was called the latitude effect. The latitude effect was not explained until Störmer (1930) undertook detailed theoretical calculations of the trajectories of charged particles in the earth's magnetic field. His calculations indicated that there were disallowed orbits for incoming particles and that the resulting selection of orbits by the earth's magnetic field could explain the latitude effect.

Quantum theory was being developed at this time, but few people believed the new theory could possibly apply to cosmic rays. The startling discovery of the positron (Andersson 1932) increased interest in cosmic rays as a tool for studying sub-atomic particles.

Two important developments in the early thirties advanced cosmic ray research. Bruno Rossi invented the fast coincidence counting method and for the first time was able to gather directional information about the radiation. He used two Geiger-Müller tubes separated spatially and required that pulses occur in both tubes simultaneously to signal the passage of a single particle.

Blackett and Occhialini (1933) improved the Wilson

He used a Geiger-Müller counter to trigger the expansion of the chamber thus synchronizing chamber expansion to allow observation of individual cosmic ray particle tracks. Earlier cloud chambers were expanded at random and, once they were expanded, the sensitive times for track formation were short. Sometimes many expansions were required before a track happened to appear. Blackett was able to improve the data collection process by this method.

Rossi (1935) discovered that the cosmic radiation was characterized by a soft and a hard component. The soft component had far less penetrating power than the hard component. He reported to the amazed scientific world that some cosmic rays could penetrate as much as three feet of lead.

Rossi (1933) also discovered cosmic ray air showers. An air shower is a cascade process in the atmosphere where many secondary particles are produced. These particles come streaming down after high-energy collisions between the primary cosmic ray particles and atoms in the upper atmosphere.

The cascade problem was analyzed in detail by several theorists, a few of which were Bhabha (1937), Heitler (1937), Carlson and Oppenheimer (1937), and Oppenheimer and Serber (1937). Cascade theory successfully explained the soft component of the cosmic radiation as electrons and photons in self-regenerative equilibrium.

Once it was realized that most of the particles seen at the surface of the earth are secondaries, researchers turned their attention to the study of the primary radiation. Rossi (1934) and Johnson (1938) discovered an east-west asymmetry in the ground-level radiation. This was a clue that the primary particles were positively charged. The asymmetry was found to be greater for the hard component than for the soft component.

The meson was first predicted by Yukawa (1935) in Japan. He worked out a model of the nuclear force in which the meson played the role of the photon in electromagnetic theory. The mass of a newly discovered particle suspected to be that hypothesized by Yukawa (but later found not to be) was determined to be about 200 times the mass of the electron. This mass information was gathered from particle tracks in the Wilson cloud chamber. The experimental work was done by Street and Stevenson (1937) and Nishina, Takeuchi, and Ichimiya (1937).

Euler and Heisenberg (1938) and Heisenberg (1938) pieced together an over-all picture of the cosmic radiation as it was understood at that time. They pointed out a conspicuous problem associated with the meson theory. A large nuclear interaction cross section was expected when, in fact, the observed cross section was very small.

To resolve the problem with the meson theory, Sakata (1940) and later Tanikawa devised a two-meson theory. The two became known as the pi meson and the mu meson, later shortened to pion and muon. This work resolved most of the problems associated with the meson theory but because of World War II, the work was not well known outside of Japan. The eventual "two-meson" picture emerged clearly after the discovery of the pion in nuclear emulsion studies (Powell et al. 1946).

A fairly complete picture of cosmic rays and their interaction with the earth's atmosphere could now be drawn from the preceding work. The primary radiation is extra-terrestrial and is composed of mostly protons. The primary radiation strikes the top of the atmosphere with extremely high energy setting off a cascade of complex secondary interactions which result in three main components at ground level. These are the electromagnetic or "soft" component, the meson or "hard" component, and the nucleonic component.

One product resulting from the interaction of the primary cosmic rays with the upper atmosphere is the neutral pion, which decays into gamma rays. These photons give rise to fast positrons and electrons which in turn create by bremsstrahlung additional positrons and electrons. As a result, a cascade or shower occurs in the atmosphere and this is called the soft component. The soft component can generally be absorbed completely by 10 cm of lead.

Another product from the initial primary interaction is the charged pion. Charged pions decay into positive and negative muons. Muons interact weakly with the atmosphere and can travel quite easily to the ground. Muons constitute most of what is called the hard component. The experiment discussed here is concerned with the hard component of the ground-level cosmic radiation.

The primary interaction may also produce disintegration fragments and neutrons. These fragments and slow neutrons are called the nucleonic component.

Brief description of the problem

Owens and Jokipii (1974) completed a theory that sought to explain cosmic ray scintillations based on purely field-aligned diffusion of primary cosmic ray particles and predicted that the cosmic ray PSDF would simply be a constant times the magnetic-field PSDF. This theory was in conflict with observation in that it predicted a flat spectrum while observation indicated the spectrum was an inverse power law. By including cosmic ray particle drifts in their model, Jokipii and Owens (1976) were able to predict the required spectrum at least in the primary particle energy range detected indirectly by ground-based neutron monitors. The same conclusion regarding the importance of particle drift terms and the shape of the PSDF was reached by Toptygin and Vasilejev (1976).

Most of the experimental work done thus far has used data recorded with long-running neutron monitor stations. The theory seems to be in good agreement with these observations; however, the nucleonic component of the cosmic rays is only part of the secondary radiation arriving on earth. As has been explained, another important part of the ground-level cosmic radiation is the muon component. Very little has been done to test the Owens and Jokipii scintillation theory using the hard component of cosmic rays. Most work with muons utilizes data from deep-underground stations (Attolini 1978) where the energy range is much higher than the range of neutron monitors. Some work has been done in Hungary (Erdos et al. 1977) using "extensive air shower" (EAS) data but these data are statistically so poor that any conclusions drawn are quite tenuous.

It appeared that no experiment utilizing the cosmic ray hard component at ground-level had been designed and built with the express purpose of testing the scintillation theory. The implementation and completion of such an experiment would result in testing the theory in an energy range not previously investigated, and such an experiment is the subject of this work.

CHAPTER II

THE EXPERIMENT

Description of the detector

In order to test the Owens-Jokippi theory using the hard component of the cosmic radiation, it was necessary to design and build an instrument which could efficiently detect ground-level muons while rejecting the photon-electron cascade or soft component. The experiment required high counting rates which meant relatively large detectors were needed. The entire system had to be electronically stable over periods of several weeks. Organic plastic scintillators were chosen as the primary detectors in this experiment because they combine many favorable properties. Plastic scintillators have extremely fast response times and they are easy to cast into large-area detectors.

Two large slabs of plastic scintillator were placed in light-tight wooden boxes (see page 14). The slabs were 182.9 cm X 91.5 cm X 2.54 cm in size and were of the highest quality clear plastic casting. The slabs were doped with organic materials that emit UV light when struck by high energy cosmic ray particles. A wavelength shifter was also included in the plastic which shifted the UV radiation to the optical. These two detectors were separated in the vertical dimension by 51.5 cm. Each scintillator was viewed by four 12.7 cm photomultiplier (PM) tubes optically coupled to the scintillators by acrylic light pipes. The boundaries between the scintillator and the light pipes and the surface of the PM tubes and the light pipes were cemented with a silicon rubber compound which properly matched the respective indices of refraction.

The pulse output from each PM was fed into a low-noise preamplifier attached directly to the base of each tube. Aluminum foil was wrapped around the surfaces of both the scintillator and the light pipes. To some degree, the foil reflected escaping light back into the scintillator, thus improving the efficiency of the system. Each box was sealed and carefully checked to assure there were no light leaks.

One box was placed directly on the floor of the laboratory and then covered with a layer of lead 10 cm thick. This thickness of lead is sufficient to shield the bottom detector from well over 99% of all cosmic ray electrons found in the soft component. The second detector was placed on top of the lead shield and was aligned to cover over the bottom detector. In order to register an event as the passage of a cosmic ray muon, it was required that a particle be detected first in the top scintillator, pass through the lead shield, and then be detected in the bottom detector within the small resolving time of 0.2 microseconds.

The output signals from the four preamplifiers in each box were fed through RG-58 coaxial cable to an 8-input voltage adder. The four signals from the bottom detector were added and the four signals from the top detector were added, yielding two pulses, one from each box. These two signals were then passed to pulse shaping amplifiers with discriminators. After pulse shaping and discrimination, the output signals were fed to a high-speed coincidence module which gave an output pulse only when a pulse from the bottom and the top detectors arrived within 0.2 microseconds. The output pulse from the coincidence module was accepted as a muon event and the time of its occurrence was recorded.

A multichannel analyzer (MCA) with 1024 channels was set to operate in the scaler mode so that counts could be accumulated in each channel for preset times. The data discussed in this thesis were muon counts accumulated over one hour periods for 1024 hours. With this arrangement, data can be collected for more than 42 days. After collection, the data were transferred to the disk storage device of a microcomputer. Subsequent data analysis was accomplished using only microcomputer technology. Fig. 2 is a block diagram of the experiment.

Fig. 1. A diagram showing a top and side view of the telescope.

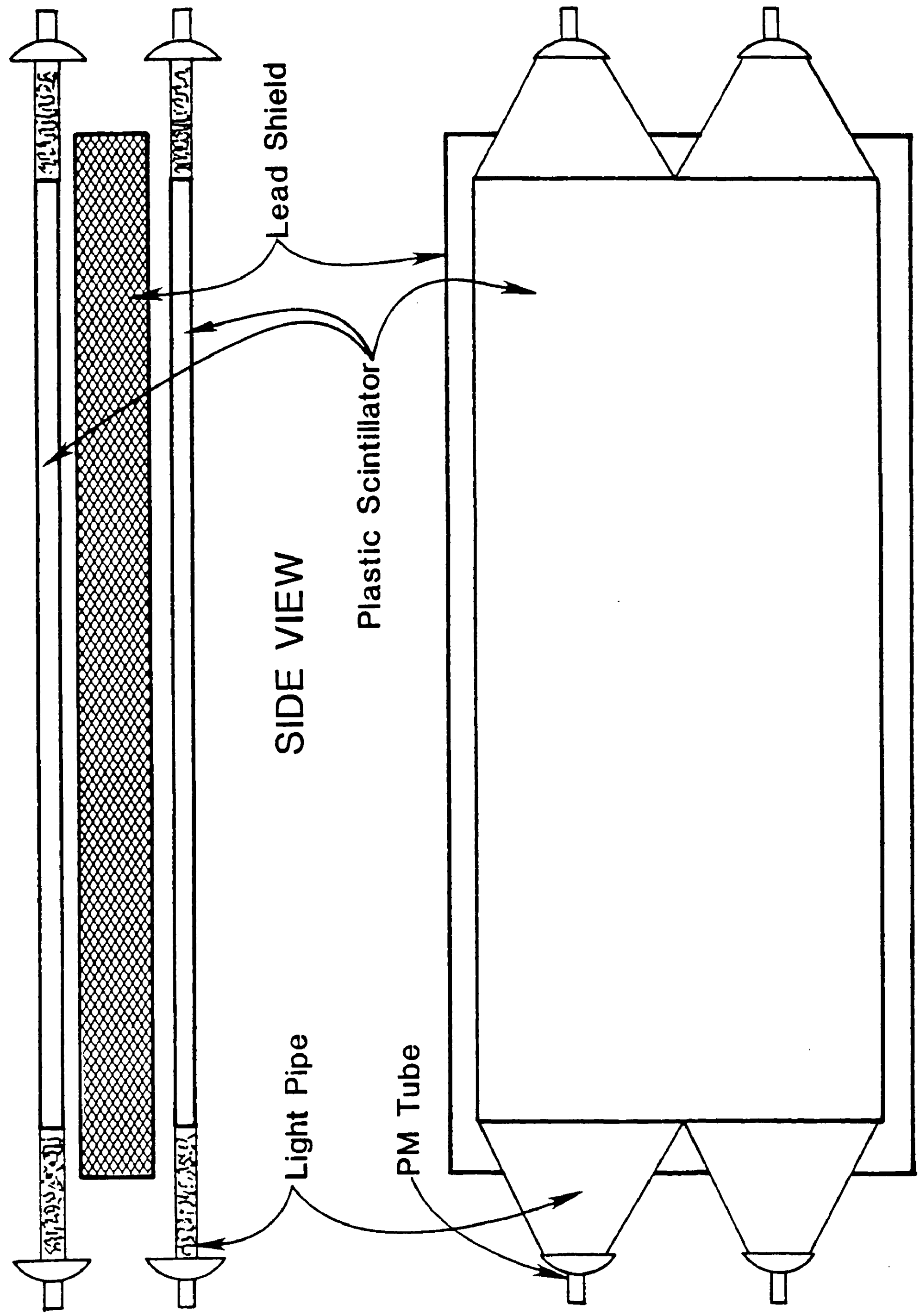
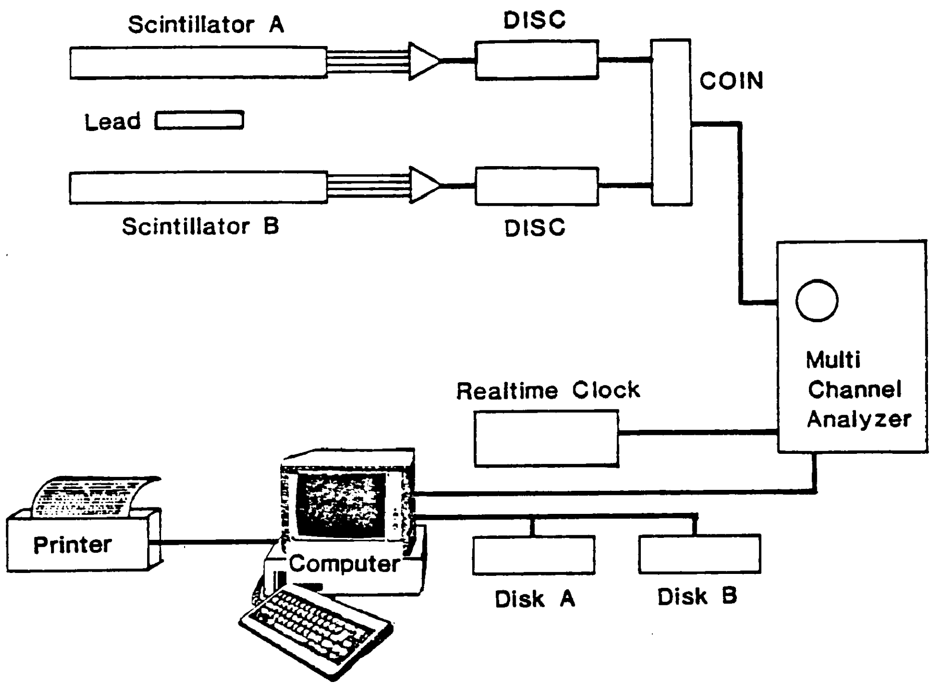

Lead Shield
Plastic Scintillator
SIDE VIEW
TOP VIEW
Light Pipe
PM Tube

Fig. 2. A schematic diagram of the telescope showing major electronic parts.


Scintillator A
DISC
COIN
Lead
Scintillator B
DISC
Multi
Channel
Analyzer
Realtime Clock
Printer
Computer
Disk A
Disk B

Optics of the instrument

The coincidence counting rate of any particle telescope depends upon the effective dimensions and relative positions of the telescope particle detectors as well as the incident intensity of radiation and the sensor efficiencies. The factor of proportionality relating the counting rate C to the isotropic intensity I is defined by the geometric factor G (Sullivan 1971). That is

$$C = GI.$$

In order to have confidence that the telescope is functioning correctly, it is necessary to calculate the expected counting rate of the instrument. In the absence of the earth's atmosphere and magnetic field, the trajectories of cosmic ray particles can be modeled as straight lines stretching from their origins isotropically to a ground-based cosmic ray telescope. In this idealistic approximation, the optics of the instrument would be determined by simple geometry because of the purely random directions of incidence characteristic of isotropic radiation.

With the introduction of the earth's and other magnetic fields, particles with sufficient momentum would continue to reach the instrument. However, certain anisotrophies would now appear because of the interaction of the cosmic rays with these fields.

When the earth's atmosphere is added to make the model more nearly complete, the primary cosmic radiation is also transformed into secondary components, a process which involves a spatial distribution of abrupt changes in directions of particle trajectories. It becomes clear that a ground-based cosmic ray telescope must involve a complex set of factors consisting of the pure geometry of the instrument, the atmosphere, and the various magnetic fields present along the particle trajectories.

A completely analytical description of a ground-based cosmic ray telescope is very complicated in all but the simplest configurations (e.g., extremely small total solid angle), and it is necessary to resort to numerical methods for large telescope arrays. A numerical calculation to determine the geometric factor of the wide-angle telescope used in this experiment is described below.

A computer program was written which computed the counting rate contributed by each 5 cm square block of detector surface in the lower sensitive area. A block was chosen on the bottom detector and all the contributions from the 5 cm blocks in the top detector were added to an accumulator after which another block was chosen on the bottom and the process continued until all the blocks on the bottom were taken into account. The vertical intensity I of cosmic ray muons at sea-level is approximately 0.008 particles/cm^2/sec/sterad and the zenith angle

T dependence is approximately $\cos^{2.6}$ T. This directional intensity was used in the calculation. Refer to page 22 for details.

In the analysis the following notation is convenient:

r = radius from exit of cosmic ray at the bottom detector to the entrance at the top detector.

X_t, Y_t = position of entry block on top detector

X_b, Y_b = position of exit block on bottom detector

l = normal distance between the two large detectors

The following relations result from application of simple geometry:

$$X = X_t - X_b$$

$$Y = Y_t - Y_b$$

$$R = (X^2 + Y^2)^{1/2}$$

$$r = (R^2 + l^2)^{1/2}$$

$$T = \arctan (R / l)$$

$$A = \arctan (X / l)$$

$$B = \arctan (Y / l)$$

The projected area of the block is given by

$$S = ab \cos(A) \cos(B)$$

where a and b are the horizontal linear dimensions of the block.

The solid angle Γ is then

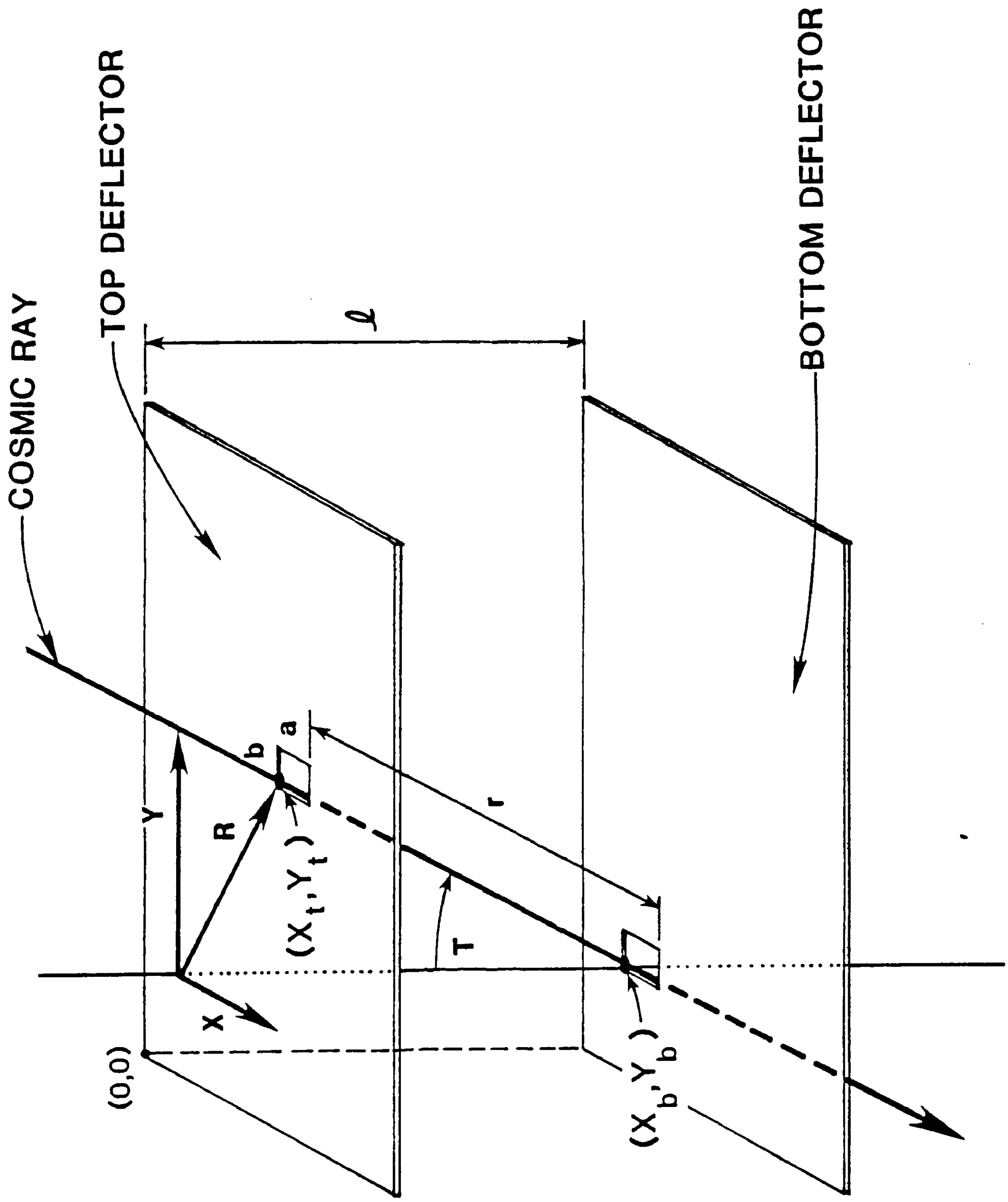
$$\Gamma = S/r^2$$

and the contribution to the counting rate C' from one pair of blocks is

$$C' = \Gamma Iab$$

where I is the vertical intensity of the cosmic radiation. The total counting rate is the sum of the contributions over the entire detector surface multiplied by the zenith angle dependence. The calculated result for this experiment is 137.2 per second. This is in excellent agreement with the observed average counting rate of 119.7 per second. A listing of program GFACTOR.BAS, which was written to make this calculation, is given in Appendix A.

Fig. 3. A diagram illustrating the geometry used in the calculation of the G factor.


COSMIC RAY
TOP DEFLECTOR
BOTTOM DEFLECTOR
ℓ
a
b
r
Y
R
X
T
(0,0)
(X_t,Y_t)
(X_b,Y_b)

Meteorological data collection

The influence of atmospheric pressure and temperature changes on the cosmic ray counting rate as seen in a ground-level instrument such as the one described here are factors that cannot be ignored. Since muons are the only particles which are detected in the present experiment, it is important, at least in principle, to take account of the fact that they result from the decay of pions produced by primary cosmic ray particles as they interact at various depths in the earth's atmosphere. The height of production of pions and the competition between decay and nuclear interaction of these pions make the structure (density vs. altitude) of the atmosphere relevant to the ground-level muon intensity.

The Federal Aviation Administration maintains a Flight Service Station on the Texas A&M campus. This station is part of the data collection system of the National Weather Service. Several meteorological measurements, including temperature and atmospheric pressure, are made each hour. Temperature and pressure readings over the data collection period were obtained from this reporting station. For aviation purposes, atmospheric pressures recorded at the station are reported as equivalent sea-level pressures. It was necessary to convert these sea-level readings to true pressures at the laboratory elevation. The conversion was done using a standard isothermal model for the atmosphere.

Calibration of the instrument

The output of a cosmic ray telescope using thin detectors and photomultiplier tubes exhibits a complex pulse height distribution. The area under a typical output pulse is proportional to the quantity of light received by the photomultipliers from the scintillator. The amount of light received from the scintillator depends on factors like the coupling between the photomultiplier tubes and the scintillator, Landau fluctuations, and inhomogeneities in the light-transmitting materials. When the pulse height distribution of such a system is observed with a pulse height analyzer, the result is the superposition of the noise output from the photomultiplier tubes and the pulses generated by cosmic ray muons. Because the muons are essentially all at kinetic energies well in excess of several times their relativistic rest energy, this pulse height distribution is called the minimum ionization curve. The task of calibrating the instrument involved adjusting the outputs from each of eight photomultiplier tubes so that the muon minimum ionization curves were similar. This calibration was accomplished in the following way. Each slab of scintillator was viewed by four photomultiplier tubes. The output of the first tube was fed to the low-voltage input of a CANBERRA Series

30 multichannel analyzer. The remaining three tubes were summed with a pulse adder. The output from the pulse adder was fed to an ORTEC Model 463 constant-factor discriminator where it was shaped and used to gate the multichannel analyzer. The minimum ionization curve of the first tube was then plotted and the channel number in which the curve had a maximum was noted.

The arrangement was then changed to observe the second tube's minimum ionization curve. The peak of the second curve was adjusted to fall in the same channel as the peak of the first tube by adjusting the high voltage on the second tube. This procedure was carried out for all four tubes in the top detector. Once the top detector was completed, the output of all four tubes was used to gate the multichannel analyzer while the tubes in the bottom detector were adjusted in the same fashion.

In actual operation of the telescope during data collection, the four outputs from the top detector and the four outputs from the bottom detector were fed to two separate pulse adders, yielding one pulse from the top detector and one pulse from the bottom detector. These two pulses were then fed to the input of two ORTEC Model 463 discriminators and the discrimination level adjusted to block most of the noise from the photomultiplier tubes but accepting most pulses generated by the passage of muons through the telescope.

CHAPTER III

THEORY

Theoretical predictions

During the first half of the 1970's, two researchers developed a theory of cosmic ray scintillations in a series of 4 papers (Owens and Jokipii 1972; Owens 1974; Owens and Jokipii 1974; Jokipii and Owens 1976).

In the first paper, a simplified approach called the "Thin-Slab" model was presented. The idea was to model the earth's magnetosheath as a thin slab of irregular magnetic field. This model followed earlier reasoning used to study scintillations or "twinkling" in the optical and radio spectrum. The model was tested using low-energy (1 to 40 MeV) particle data from experiments aboard satellites, and the predictions were in fair agreement with theory. However, when the model was tested using data from neutron monitors in the range of 1 GeV, the model failed.

The failure of the thin-slab model gave rise to speculations that the scintillations observed in neutron monitor data were related to irregularities in the interplanetary magnetic fields. In paper 2, Owens presents the General Theory of Interplanetary Scintillations in which a quasi-linear expansion of Liouville's equation is used. The general result requires relating cosmic ray scintillations to magnetic field fluctuation and to cosmic ray gradients in interplanetary space. This general theory was in fair agreement with observation from at least one neutron monitor.

In paper 3, Owens and Jokipii develop a simplified solution to the general equation for the special case of the low-frequency limit. They also took into account the modulating effect of the earth's rotation.

Finally, in paper 4 Owens and Jokipii discuss the effects of non-field aligned diffusion. Predictions of PSDF made with the model were in good agreement with observations at several neutron monitors. The theory developed in the series of papers referred to above is used below to predict the PSDF of cosmic ray scintillations at a location on the Texas A&M campus.

The normalized PSDF for a polar observing station, where the earth's rotation does not play a part, is given by

$$P_{pol.}(f) = a^2 P_B,$$

where P_B = normalized power spectrum of the magnetic field

a = cosmic ray anisotropy.

For the case of an equatorial station, the result is

$$P_{eq.} = a^2/4[P_B(f - f_e) + P_B(f + f_e)]$$

where f_e = rotational frequency of the earth.

The PSDF for a station at some viewing latitude L is then given by

$$P(f) = P_{pol.}(f)\sin^2 L + P_{eq.}(f)\cos^2 L$$

The PSDF of the interplanetary magnetic field has been empirically determined by at least two groups (Hedgecock 1975; Quenby and Sear 1971) and those results are

$$P_B(f) = 1.55 \text{ X } 10^4 / (1 + (f/10^{-5})^{1.5}) \text{ after}$$

Hedgecock, and

$$P_B(f) = 4.10^{-3}\ f^{-1.2} \text{ after Quenby and Sear.}$$

Fig. 4 is a plot of the PSDF predicted for a polar observing station and Fig. 5 is the PSDF for an equatorial observing station. Fig. 6 is the prediction for an observing station at geographic latitude 30 N using the Hedgecock determination of $P_B(f)$. The present experiment can be regarded as 75% equatorial and 25% polar. This assumption is justified because at very high rigidity, cosmic rays arrive at the earth at about the same angle as would be the case in the absence of a geomagnetic field.

Fig. 4. Predicted PSDF for a purely polar telescope.
Frequency is in Hz.

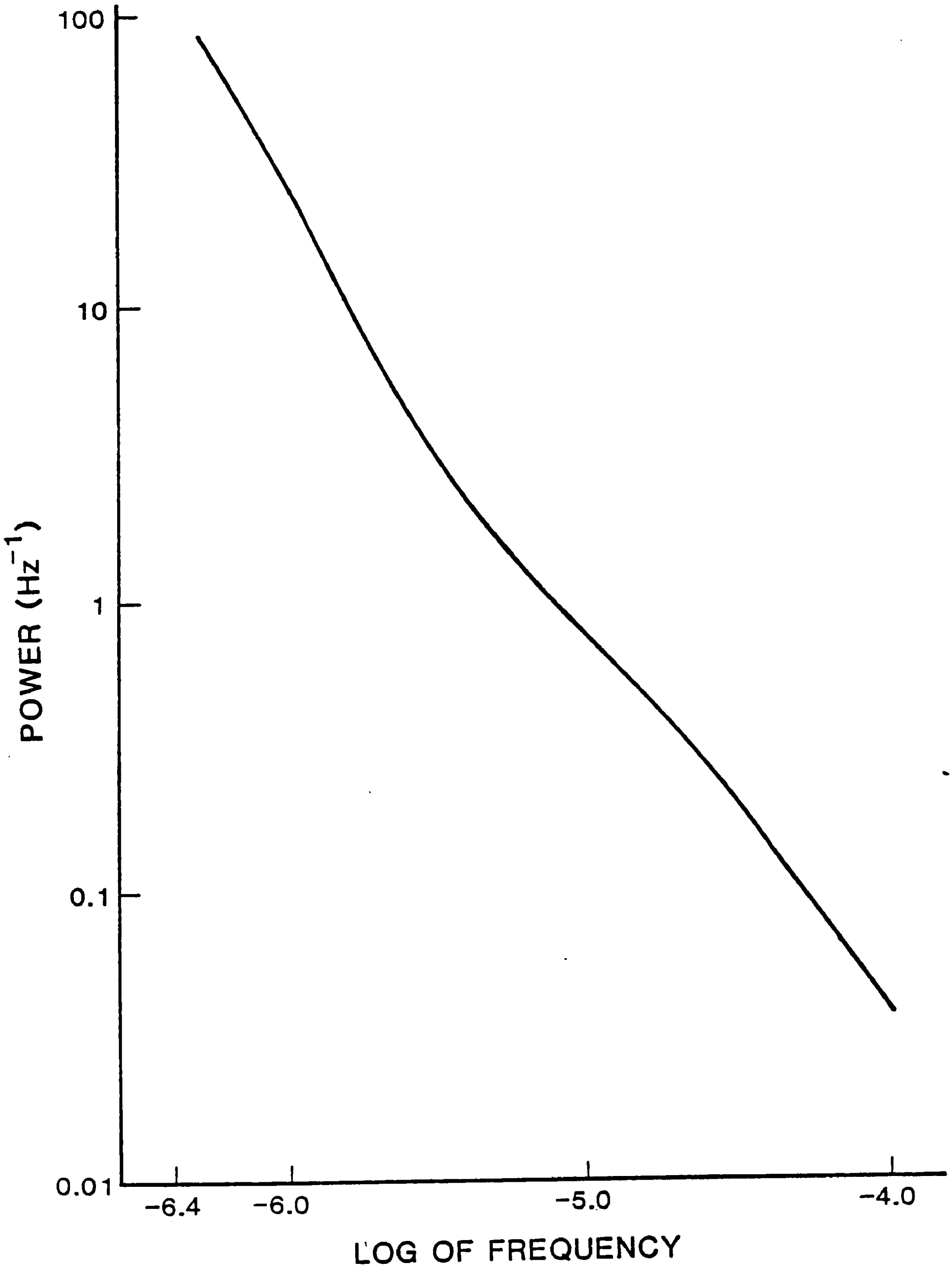

100
10
1
0.1
0.01
POWER (Hz^{-1})
-6.4
-6.0
-5.0
-4.0
LOG OF FREQUENCY

Fig. 5. Predicted PSDF for a purely equatorial telescope. Frequency is in Hz.

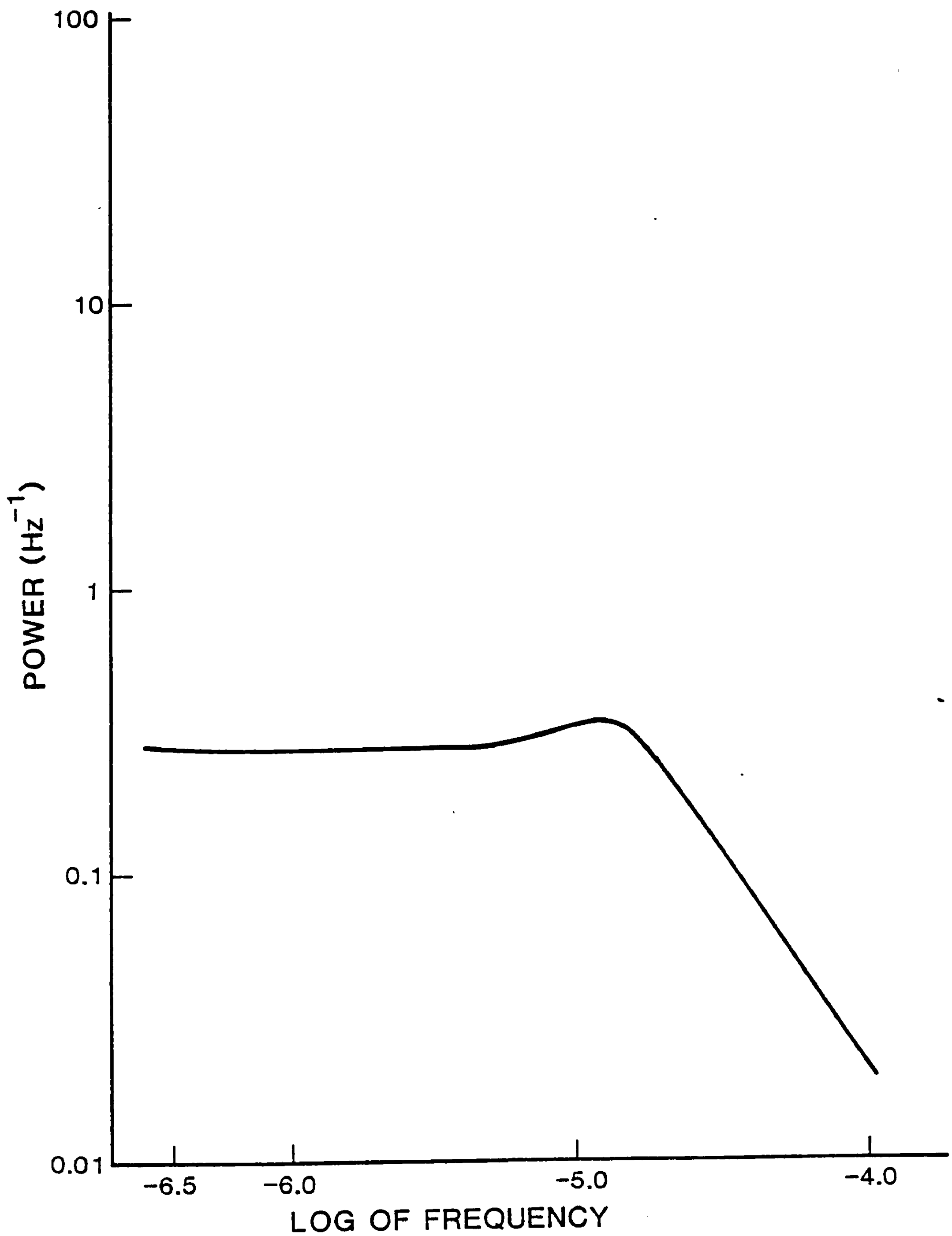
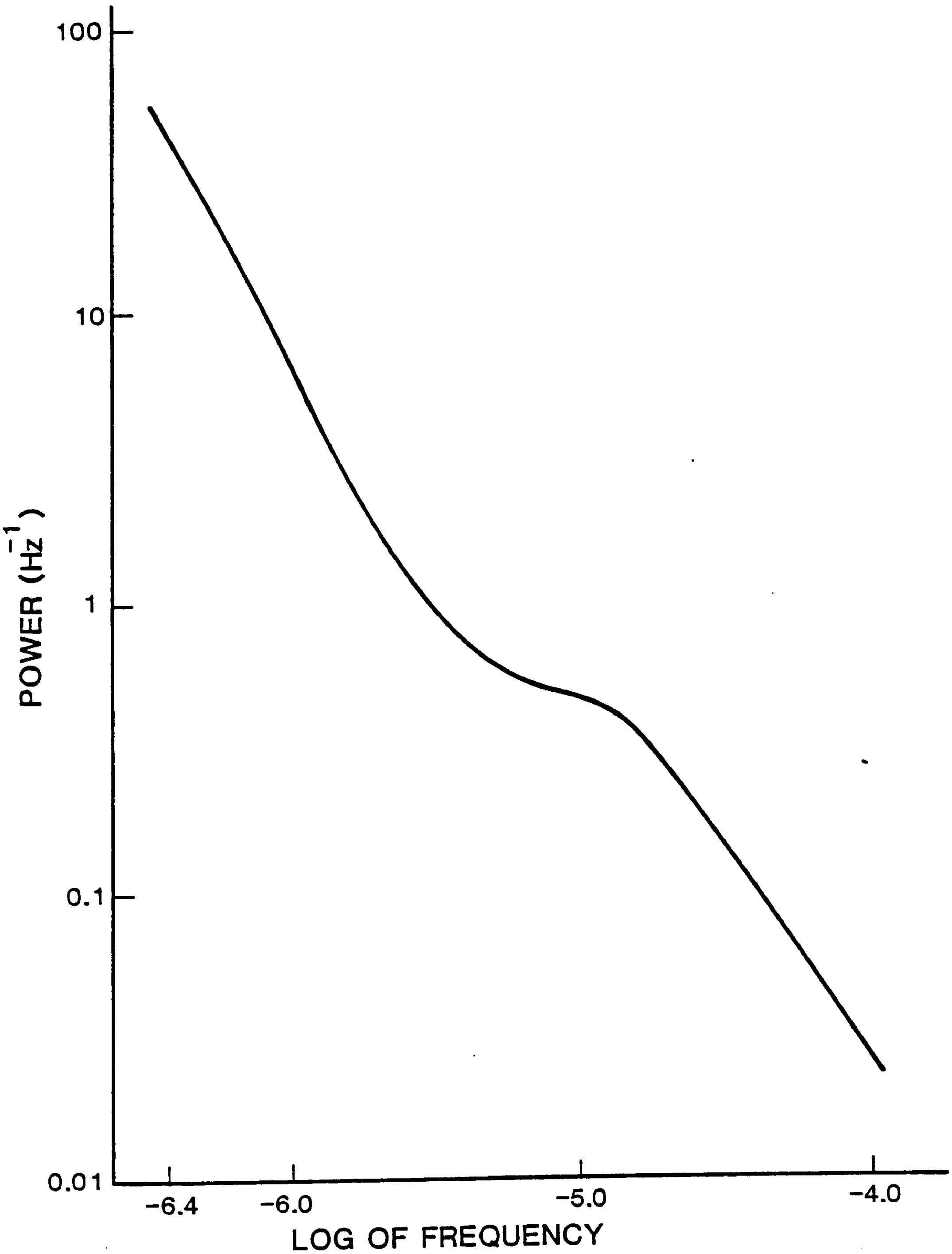

100
10
1
0.1
0.01
POWER (Hz^{-1})
-6.5
-6.0
-5.0
-4.0
LOG OF FREQUENCY

Fig. 6. Predicted PSDF for the Texas A&M University campus. Frequency is in Hz.


100
10
1
0.1
0.01
POWER (Hz^{-1})
-6.4
-6.0
-5.0
-4.0
LOG OF FREQUENCY

CHAPTER IV

ANALYSIS

Description of data

The data collection phase of the experiment was started on March 22, 1983, at 18:00 hours. Cosmic ray muons were counted for one hour periods and stored in ascending channels of the Canberra Series 30 Multichannel Analyzer. Care was taken to control all photomultiplier supply voltages at constant levels. The data collection was continued for 1024 hours, or until May 4, 1983. At the end of the collection period, the data were transferred to a microcomputer floppy disk.

Since the data taken in this experiment do not constitute a continuous random record but a sampling at interrupted one-hour intervals, it is not possible to retain information in the frequency domain beyond the Nyquist folding frequency. The Nyquist folding frequency is defined as

$$f_c = 1/2h$$

where h is the sampling interval (Bendat and Piersol 1971). The Nyquist folding frequency for data taken in this experiment is 1.39×10^{-4} Hz.

Atmospheric data collected at the Federal Aviation Administration, Flight Service Station at Easterwood

Airport on the Texas A&M University campus, consisting of pressure and temperature readings, were entered into the computer and organized in such a way as to be associated with the hourly muon counting data.

Correcting atmospheric pressure values

Atmospheric pressure readings reported from the Flight Service Station are given after being corrected to sea level. This means the reported values for pressure are values that would be read by a barometer placed in a local well at a depth equal to sea level. In order to determine the effects of the changes in atmospheric pressure on the cosmic ray counting rate, it was first necessary to convert the sea-level pressures to equivalent pressures at the altitude of the laboratory. A simple isothermal model was use to obtain the corrections (Haymes 1971).

$$P = P_0 e^{-h/H}$$

h = height of lab above sea-level

H = scale height of earth's atmosphere

P_0 = sea-level pressure

P = laboratory pressure

The scale height is defined as

$$H = kT/mg,$$

where k = Boltzmann's constant

T = temperature in degrees Kelvin

m = average mass of air (29 amu)

g = acceleration due to gravity.

For each hour during the experiment, the temperature at the beginning of the hour was used to determine the scale height and each pressure reading was then corrected to laboratory elevation.

Removal of long-term trend

Many times a special correction is needed to remove a long-term trend in the data, defined as any frequency component whose period is longer than the record length (Bendat & Piersol 1971). In particular, this type of component cannot be removed by highpass digital filtering. Hence some special trend removal technique must be applied. The counting data taken in this experiment contained a very gradual linear trend toward lower counting rates over the collection period probably caused by slowly changing values for the electrical components in the circuits. It was necessary to remove this trend before further analysis was possible because the trend would have biased the results at low frequencies. The two generally accepted methods used to remove trends from counting rate data are the average slope method and the least squares method. The least squares method was chosen here because it is the more accurate. Fig. 7 shows a plot of counting rate vs. time before trend removal. The least squares method involved finding the slope of the best straight line through the points by a least squares fit and then adjusting all points relative to a line with zero slope. Fig. 8 shows a plot of the counting rate vs. time after the removal of the long-term trend.

Trend removal is an important intermediate step in the digital processing of random data and should be given due consideration. If trends are not eliminated in data, large distortions can occur in the later processing of correlation and spectral quantities. In particular, trends in data can completely mullify the estimation of low frequency spectral content.

Fig. 7. Counting rate vs. time before trend removal.

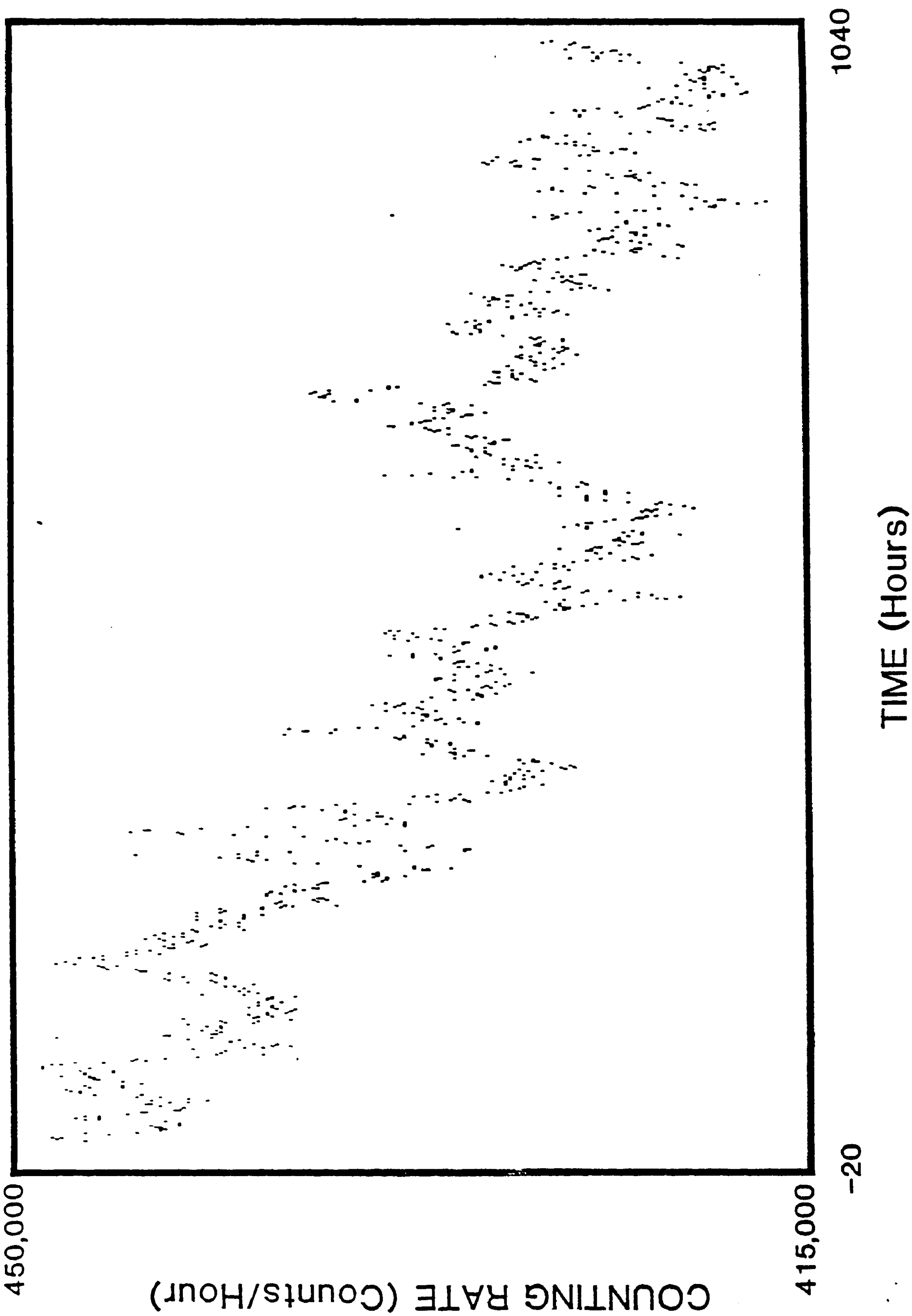
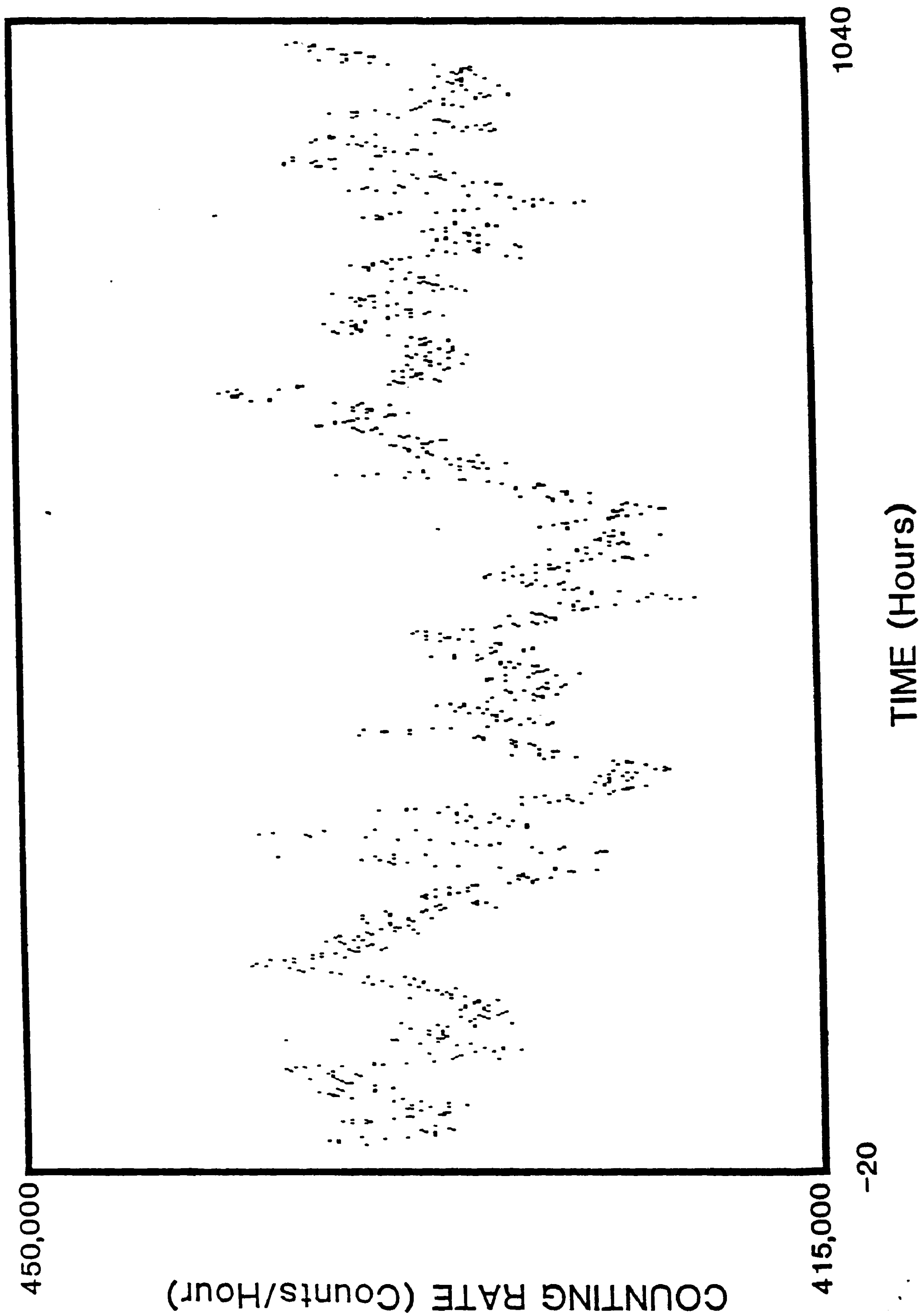

450,000
415,000
COUNTING RATE (Counts/Hour)
-20
1040
TIME (Hours)

Fig. 8. Counting rate vs. time after trend removal.


COUNTING RATE (Counts/Hour)
450,000
415,000
TIME (Hours)
-20
1040

Pressure coefficient

Early measurements concerning the variation of the cosmic ray intensity with altitude (Pfotzer 1936) indicated that the number of particles increased with altitude to a maximum called the Pfotzer maximum. After passing this maximum, the intensity decreased and finally became constant at the top of the atmosphere. This structure is a consequence of the production of secondary particles in the atmosphere and the Pfotzer maximum is associated with the altitude in the atmosphere below which the loss of secondary particles through various interactions with the atmosphere dominates production.

The number of secondary particles lost by nuclear reactions and electromagnetic scattering depends on the cross sections for these processes in the atmosphere. The spatial rates of these losses, as well as losses due to ionization, are functions of the air density. The counting rate is correlated to the integrated effect of the density variations in the atmosphere above the instrument. Consequently the counting rate will correlate with atmospheric pressure. According to empirically determined relations, the intensity as a function of atmospheric pressure can be described by an exponential law (Sandstrom 1965). The counting rate N recorded at a given altitude, can be corrected for variations of pressure by the formula

$$N_C = Ne^{-aB},$$

where B = is the deviation from the mean barometric pressure.

N = uncorrected counting rate

N_C = corrected counting rate

a = pressure coefficient.

If this equation is cast in linear form by taking logarithms on both sides, the pressure coefficient can be identified as the slope and is found by a least squares method. By this procedure, the pressure coefficient at the laboratory site was found to be $-1.132 \times 10^{-3} \pm 0.055$ %/mbar.

Fig. 9 is a plot of the uncorrected counting rate vs. pressure. Fig. 10 is a plot of the counting rate after trend removal vs. pressure. That variations in atmospheric pressure have a major influence on cosmic ray counting rates is obvious in this graph. Fig. 11 shows a plot of counting rate after trend removal and after pressure correction vs. time. Fig. 12 shows a plot of the counting rate after trend removal and after pressure correction vs. pressure.

Fig 9. A plot of uncorrected counting rate vs. atmospheric pressure.

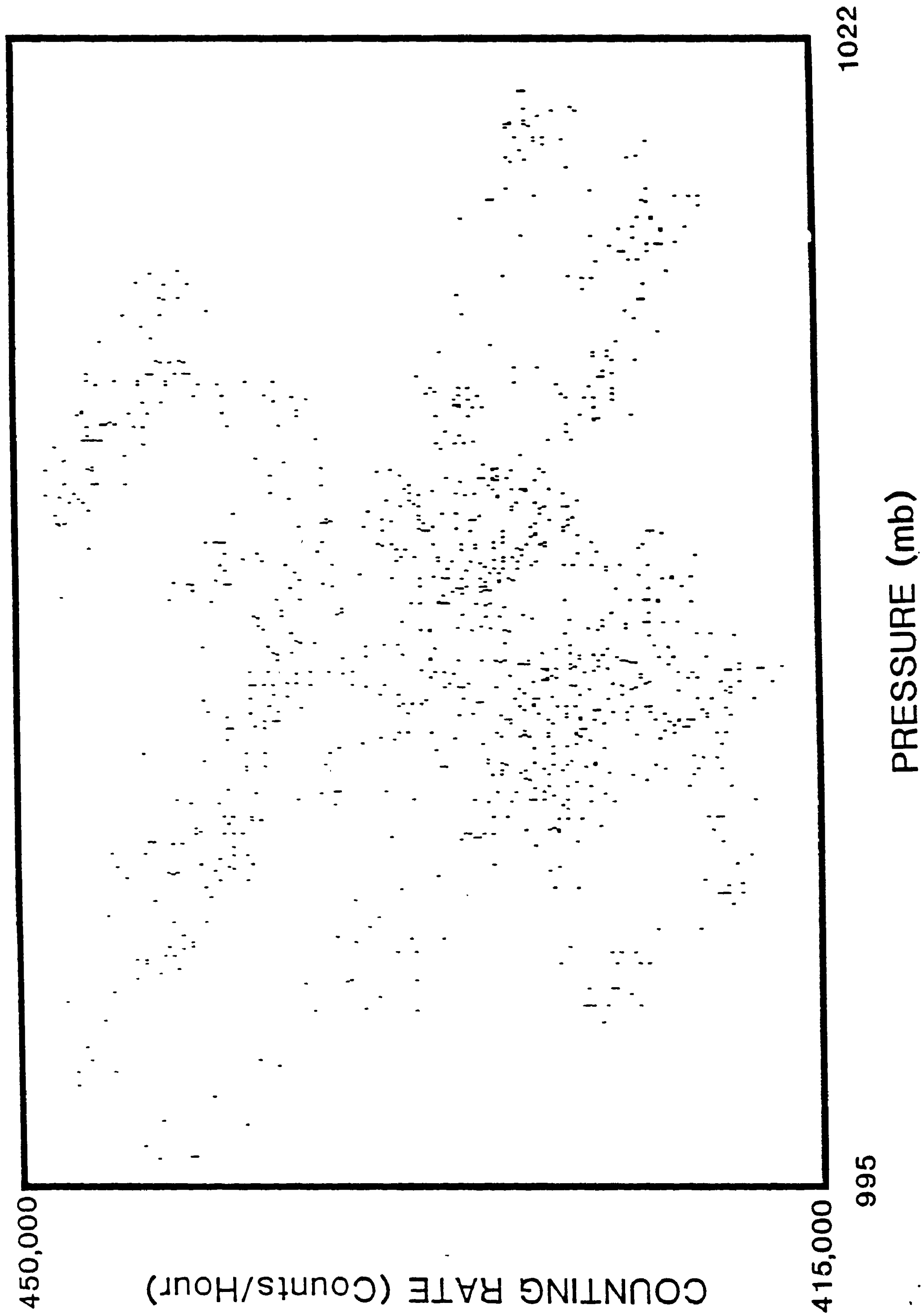
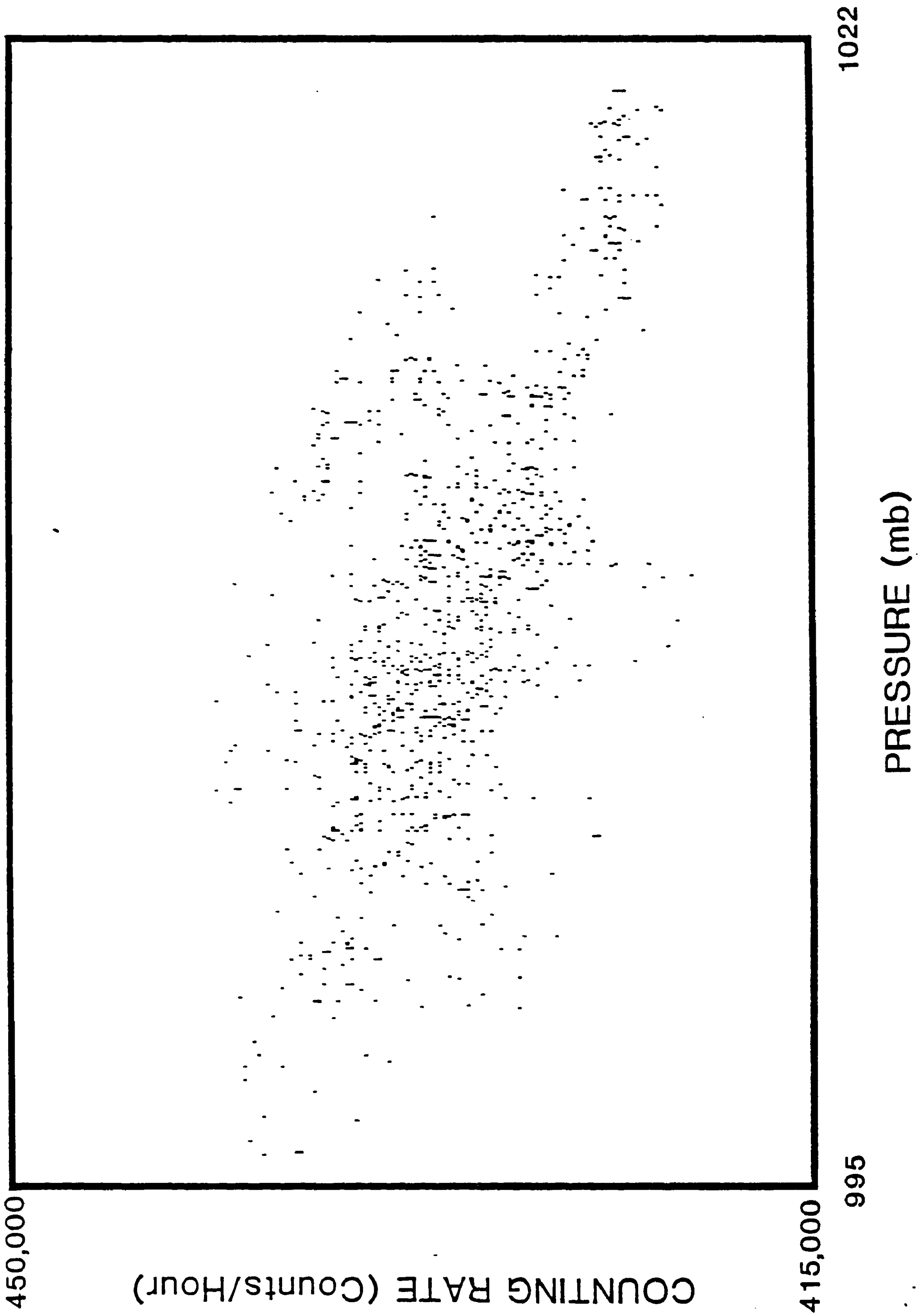

COUNTING RATE (Counts/Hour)
450,000
415,000
PRESSURE (mb)
995
1022

Fig. 10. A plot of counting rate after trend removal vs. atmospheric pressure.



450,000
415,000
COUNTING RATE (Counts/Hour)
995
1022
PRESSURE (mb)

Fig. 11. A plot of counting rate after trend removal and after pressure correction vs. time.

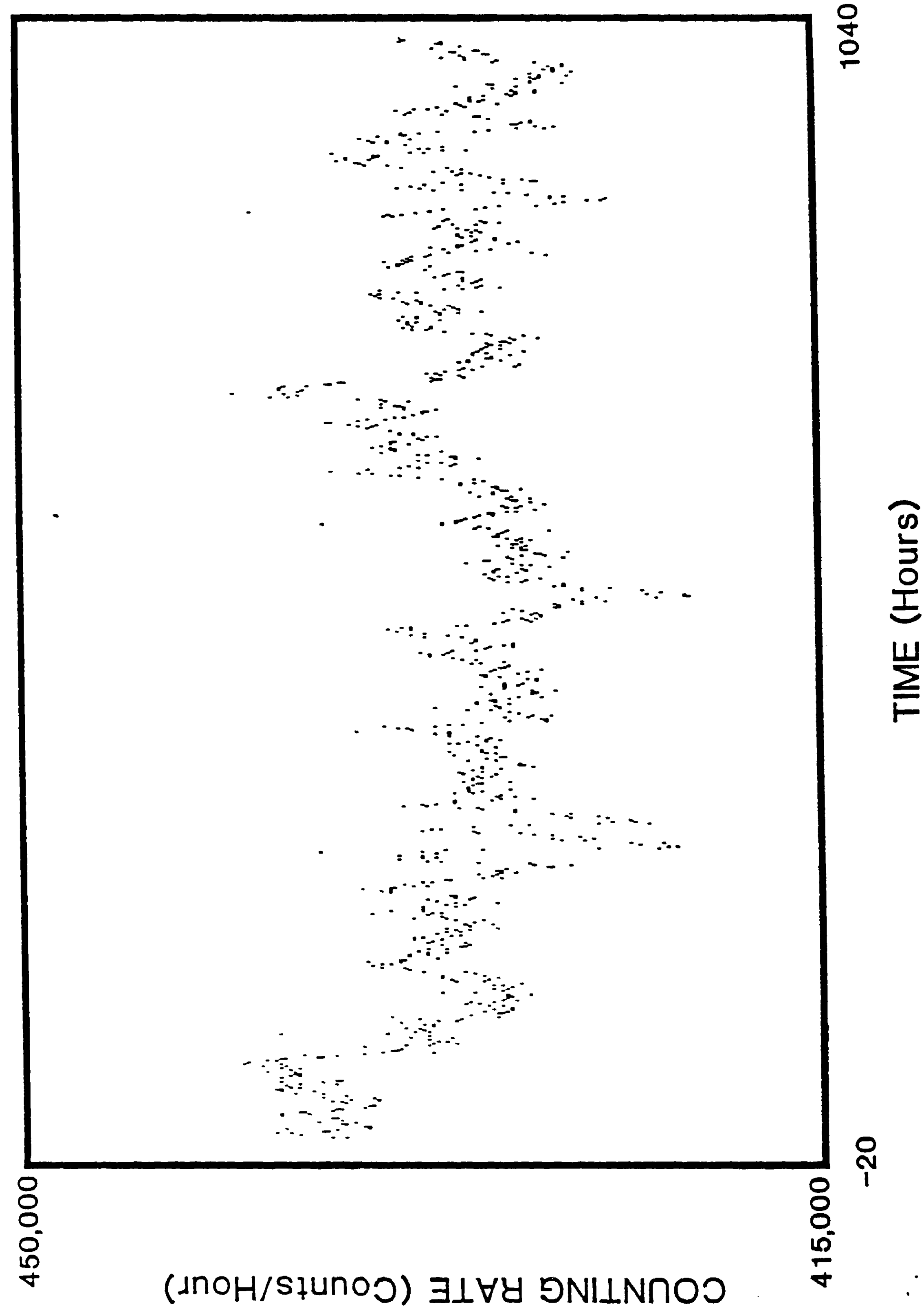
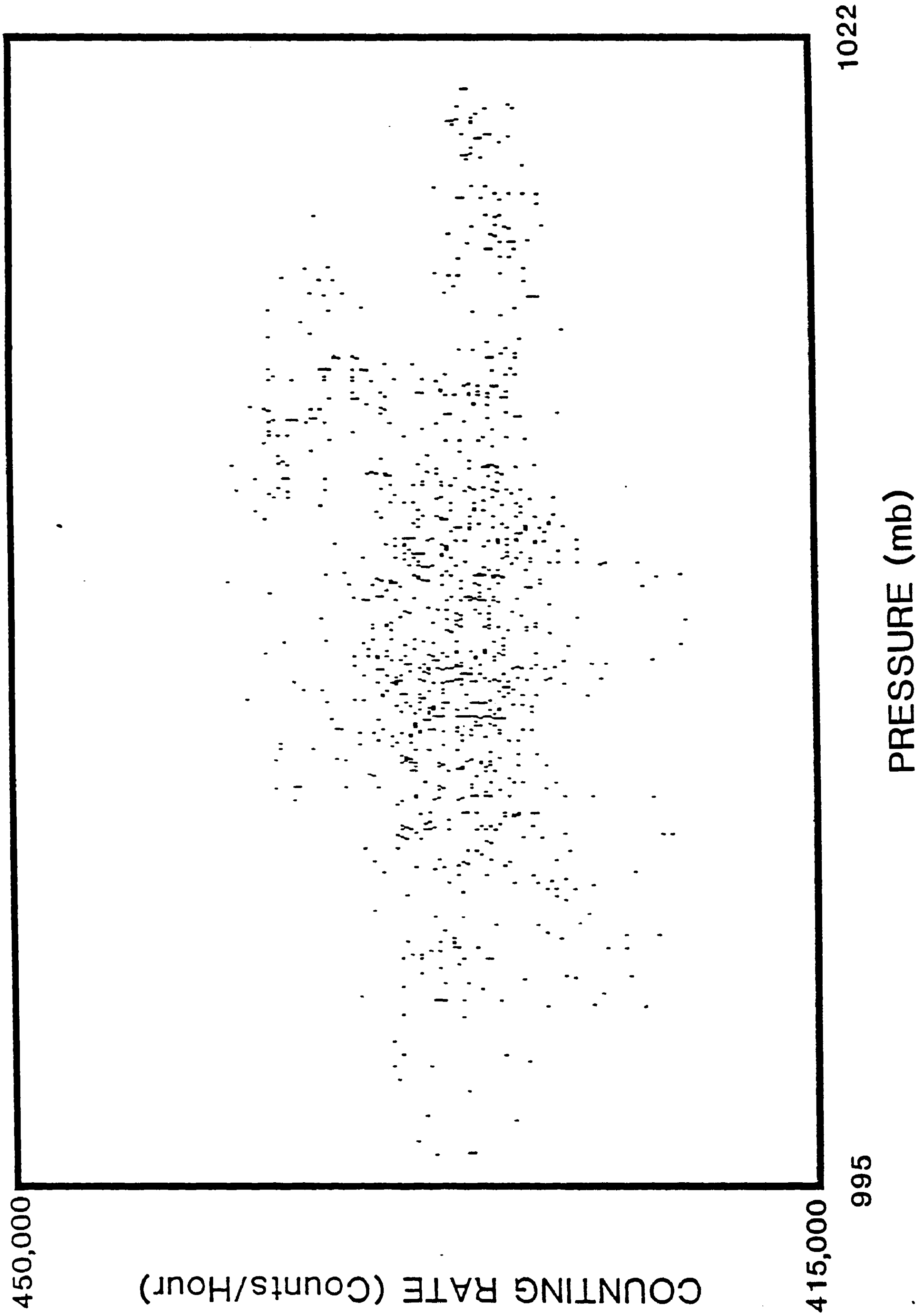

COUNTING RATE (Counts/Hour)
450,000
415,000
TIME (Hours)
-20
1040

Fig. 12. A plot of counting rate after trend removal and after pressure correction vs. atmospheric pressure.



450,000
415,000
COUNTING RATE (Counts/Hour)
995
1022
PRESSURE (mb)

Temperature coefficient

The number of muons lost in the atmosphere by decay is a function of the distances they have travelled from their points of origin. The same applies to the parent pions. Consequently the counting rate of an instrument at ground level will vary with the average height of pion production. The height of the pion producing layer depends on the average atmospheric depth to which the primary protons penetrate. If it is assumed that the primary spectrum does not vary, this depth is a constant when expressed in g/cm^2. From the thermodynamics of the atmosphere it follows that the height of the pion producing layer is temperature dependent and is given by the following expression (Sandstrom 1965).

$$dH = (1/g) R_o \log_e (B_1/B_2)\ dT$$

where H = the height to be considered in the earth's atmosphere

T = the mean absolute temperature of a layer between the levels defined by the pressures.

R_o = the specific gas constant of air

B_1 = pressure at bottom of layer

B_2 = pressure at top of layer

The total cross section per unit volume for the capture of pions decreases with increasing temperature. Thus, at this stage, the number of parent particles for negative muons increases with temperature.

As can be seen, the effect of temperature on counting rate is complicated. Modern theory predicts a slight positive coefficient for muons; experimental results vary from about 0.04% per degree C to -0.05% per degree C. (Sandstrom 1965). It is generally accepted that the proper form of the required correction is linear.

A linear regression was performed on the pressure corrected data and the temperature coefficient was found to be -.017 $\pm$ 0.0062% per degree C for this experiment. Using this value, the data were corrected using a least squares fit method similar to that discussed in the section on trend removal. The final corrected counting rate data vs. temperature is shown in Fig. 13. Fig. 14 is a plot of the final corrected counting rate vs. time. A listing of the data is given in appendix C.

Fig. 13. Final corrected counting rate vs. temperature.

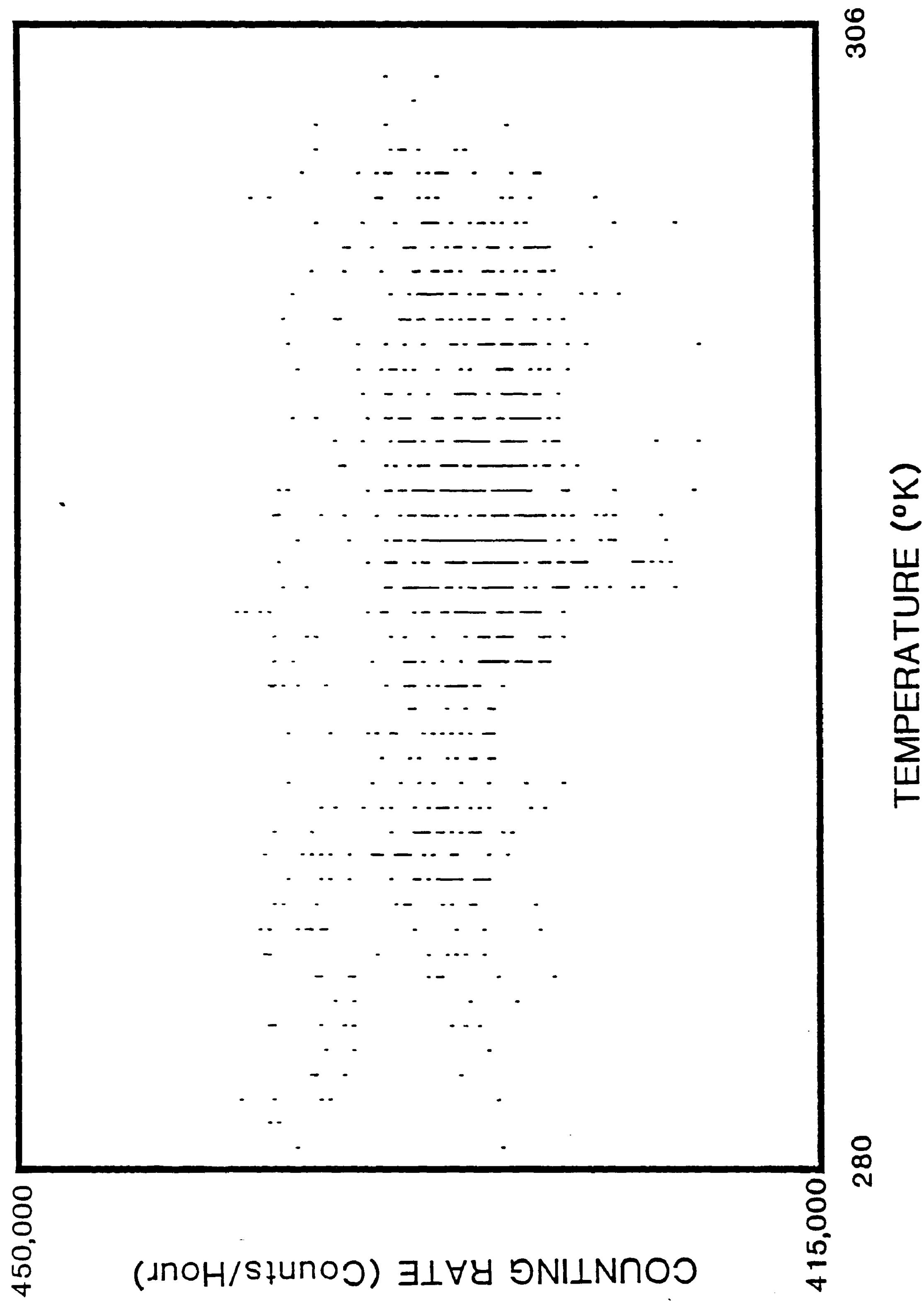
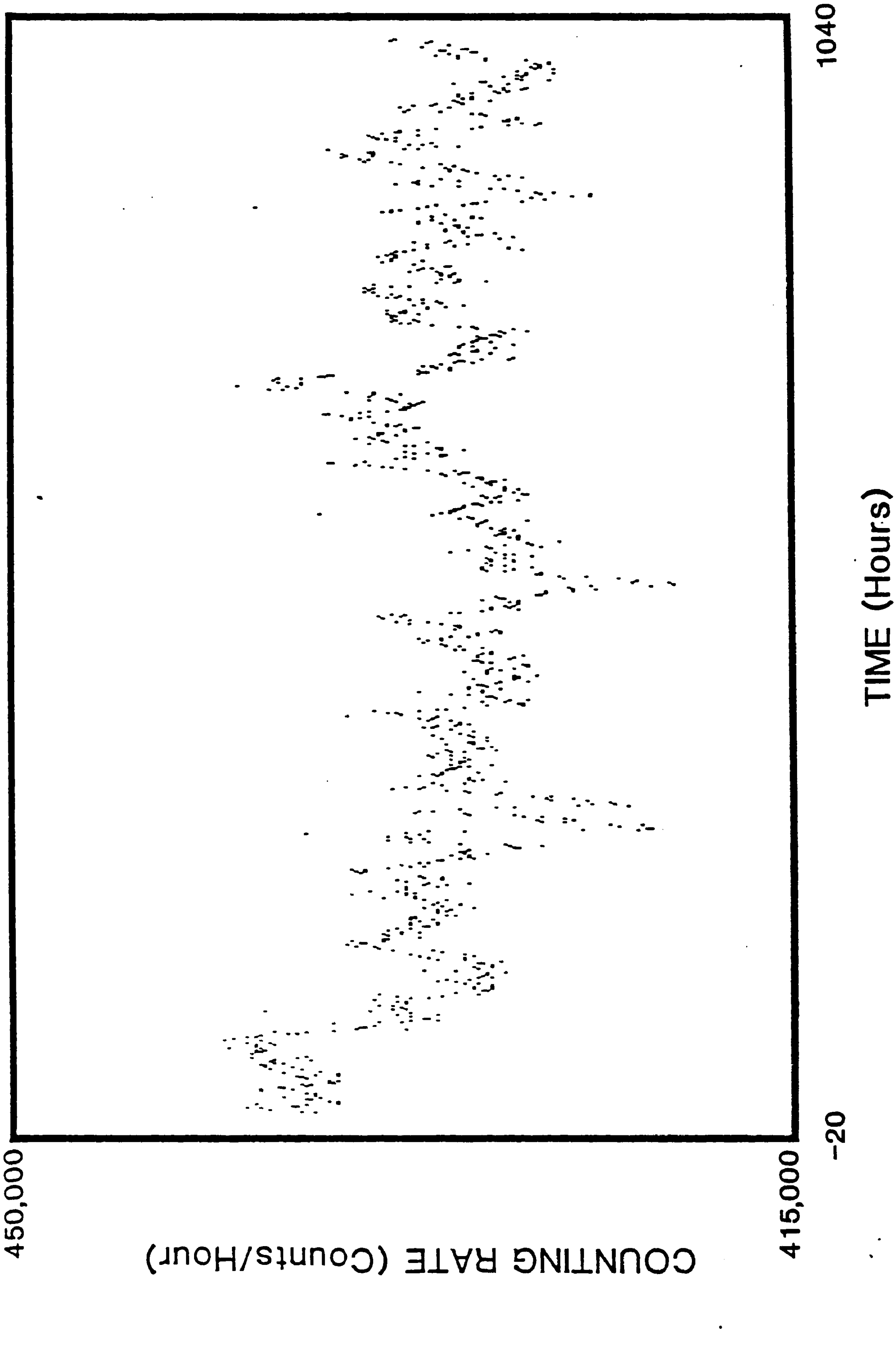

306
280
TEMPERATURE (°K)
450,000
415,000
COUNTING RATE (Counts/Hour)

Fig. 14. Final corrected counting rate vs. time.



450,000
415,000
COUNTING RATE (Counts/Hour)
-20
1040
TIME (Hours)

Statistical information

The Poisson distribution represents an approximation to the binomial distribution for the special case when the average number of events is very much smaller than the possible number of events and is generally appropriate for counting experiments such as a cosmic ray telescope. With high counting rates, the shape of the Poisson distribution is similar to the normal distribution.

It is interesting to compare the observed frequency distribution with the normal distribution. One way of achieving a comparison is by determining curve type criteria after Pearson (Arkin and Colton, 1970). Parameters calculated for this experiment were mean, standard deviation, kurtosis, and skewness.

The kurtosis of a frequency distribution is a measure of its peakedness. If kurtosis is greater than 3, then the curve is said to be leptokurtic or more peaked than the normal curve. If kurtosis is less than 3, then the curve is said to be platykurtic or more flat-topped than the normal curve.

Skewness is a term for the degree of distortion from symmetry exhibited by a frequency distribution. It is a measure of the difference between the mean and the mode of a distribution. When a distribution is perfectly symmetrical, the skewness is zero.

The results found for these counting data are:

Mean	=	430730.7 counts/hr
Standard deviation	=	3367.5 counts/hr
Kurtosis	=	0.12899
Skewness	=	0.1437.

Power spectral density analysis

Although power spectral analysis has been a tool in engineering for years (Blackman and Tukey 1958), its use in cosmic ray research has closely followed the development of the digital computer. With both high-energy and low-energy cosmic rays, the PSDF tends to be broadbanded and featureless and is well approximated by a power law of the form

$$P(f) = Af^{-a} \tag{1}$$

where

A = a constant

a = a constant

f = frequency.

For this kind of spectrum, a log-log graph gives the best representation. However, spectra calculated by the commonly used correlation function (CF) or the Fast Fourier transform (FFT) techniques (Blackman and Tukey 1958; Bendat and Piersol 1971) give estimates linearly spaced in frequency. For this reason, most recent investigators has chosen the lesser known Nested Variance (NV) method (Owens 1977). The Nested Variance algorithm for calculating the PSDF is superior to the CF and FFT methods for cosmic ray time series because it gives spectral estimates spaced logarithmically in frequency, it takes less computing time, and it easily accommodates data gaps. For these reasons, this method of analysis was chosen for this investigation.

Consider a time series of a stationary Gaussian random variable x(t) with zero mean. The average value of x(t), calculated over a time t, is

$$\bar{X}_t = (1/t)\int_0^t x(t')dt' \qquad (2)$$

and the variance of the sample mean is

$$V_t = \langle \bar{X}_t{}^2 \rangle \qquad (3)$$

where brackets indicate an ensemble average. Let x(t') be represented by a Fourier-Stieltjes integral of the form (Yaglom 1962)

$$x(t') = \int_{-\infty}^{\infty} e^{iwt'} \mathfrak{X}(w)\, dw/6.283 \qquad (4)$$

After replacing x(t') in (2) with (4) one obtains $\bar{X}_t$ in terms of $\mathfrak{X}(w)$. Putting this result into (3) and using the Wiener-Khintchine theorem (Bendat and Piersol 1971) we have

$$\langle \mathfrak{X}(w)\mathfrak{X}^*(w')\rangle = 6.283\ (w - w')P(w) \quad (5)$$

where P is the PSDF of x(t). The resulting variance is

$$V_t = \int_{-\infty}^{\infty} P(w)G(w;t)\,dw/6.283 \quad (6)$$

where the filter G(w;t) in the frequency domain is given by

$$G(w;t) = \sin^2(wt/2)/(wt/2)^2 \quad (7)$$

Now consider the variance calculated over some time T greater than t. Since (6) is linear in P, the difference $V_t - V_T$ will be a relation similar to (6) with the filter $G'(w't,T) = G(w;t) - G(w;T)$. Choosing $T = 2t$ and defining the PSDF as a function of positive frequency $f = w/6.283$, we have

$$V_t - V_{2t} = \int_{0}^{\infty} P(f)h(f;t)\,df \quad (8)$$

where

$$h(f;t) = \sin^4(3.145ft)/(3.145ft)^2 \quad (9)$$

The filter h(f;t) gives a fair representation of an ideal band pass filter with limits 1/4t and 1/2t. Since the integral of h(f;t) over frequency is $(4t)^{-1}$, we have the estimate

$$P[(1/4t) \leq f \leq (1/2t)] = 4t[V^{t} - V^{2t}] \qquad (10)$$

Equation (10) is the basis of the nested variance method. During calculation, the estimates are obtained over the range 1/4t to 1/2t for times t and 2t. Next the variance of data averaged over 4t is obtained and subtracted from the variance over 2t. Equation (10) is applied and this process is continued until the final variance is obtained with an averaging time that is half the record length. The estimates are over ranges decreasing by powers of 2 starting at the Nyquist folding frequency.

The spectral estimates have a chi-squared distribution with N/2 degrees of freedom where N is the number of observations. This result gives good statistical accuracy at high frequencies and less accuracy at lower frequencies. The standard error for the k^{th} estimate is given by (Bendat and Piersol 1971) as

$$p^{k} = [1 + (2/f)^{0.5}] \qquad (11)$$

A listing of the computer program used to do Nested Variance analysis is given in Appendix B.

CHAPTER V

DISCUSSION

Discussion of results

The PSDF for the data obtained in this experiment was calculated by the Nested Variance methods outlined in Chapter IV. The maximum number of estimates possible by this method is nine and the results are listed in Table I below.

TABLE I

Log of frequency	Log of power
-3.982	-1.555
-4.283	-1.209
-4.584	-0.706
-4.885	-0.294
-5.186	0.293
-5.487	0.493
-5.788	0.920
-6.089	1.260
-6.390	2.026

The average counting rate during the data collection phase of the experiment was 400730.72 counts/hour. The standard deviation was calculated to be 3362.28 counts/hour. The expected power level from a purely random Poisson noise is $10^{-1.777}$ Hz^{-1}. In order to avoid the effects of aliasing, calculation of the spectrum was terminated at the Nyquist folding frequency. For an experiment with a sampling rate of 1/hour, the Nyquist folding frequency is $10^{-3.857}$. A regression analysis was performed on logarithms of the estimates of the PSDf with the resultant slope and Y-intercept being -1.360 and -6.951 respectively.

Fig. 15 and Fig. 16 are graphs of the estimates to the PSDF as described above. The vertical bars represent standard errors based on the degrees of freedom for each estimate (Bendat and Piersol 1971). Horizontal bars indicate the width of each frequency band from which estimates were derived. The bold dashed line is the result of the linear regression analysis and the solid curve is the predicted cosmic ray muon PSDF for the Texas A&M University campus site. The horizontal dashed line shows the power due to Poisson noise and the vertical dotted line shows the Nyquist folding frequency. Fig. 15 uses interplanetary magnetic field data by Hedgecock (1975) and Fig. 16 uses interplanetary magnetic field data by Quenby and Sear (1971). As can be seen from the two graphs, the results of this experiment are in better agreement with the work of Hedgecock. Even though the resolution of this analysis is low, there is little indication of a sharp peak in the PSDF at the earth's rotational frequency as is predicted using the Quenby and Sear data. Also the slope of the Quenby and Sear data is steeper than the slope calculated in this experiment. This is not to say that the Quenby and Sear result should be disregarded. Their prediction is never more than one order of magnitude from the estimates obtained in this experiment. In astrophysics, that is still a good fit. Implications of these results are discussed in Chapter VI.

Fig. 15. A comparison of the muon PSDF at TAMU with the theory using data by Hedgecock. Frequency is in Hz.

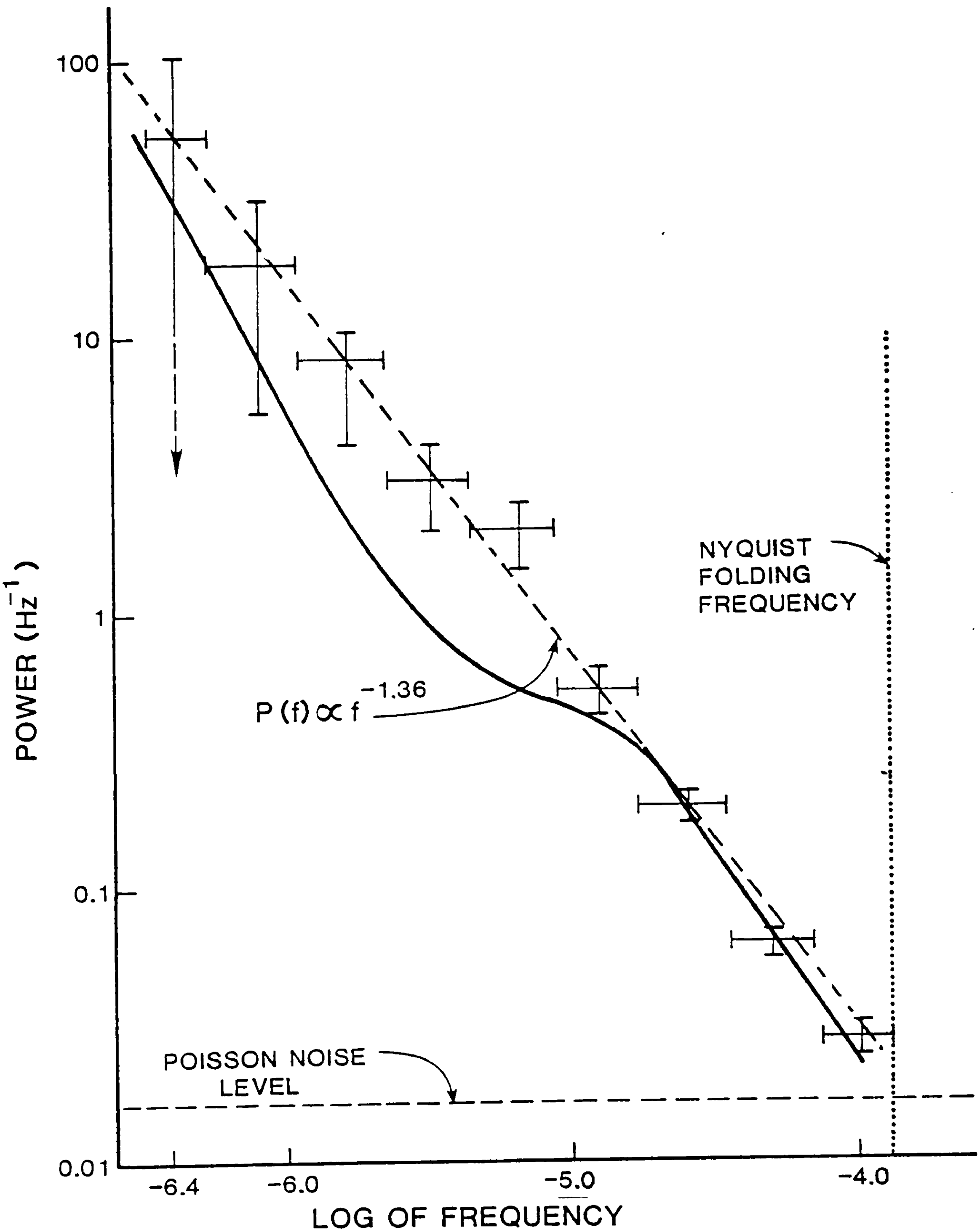
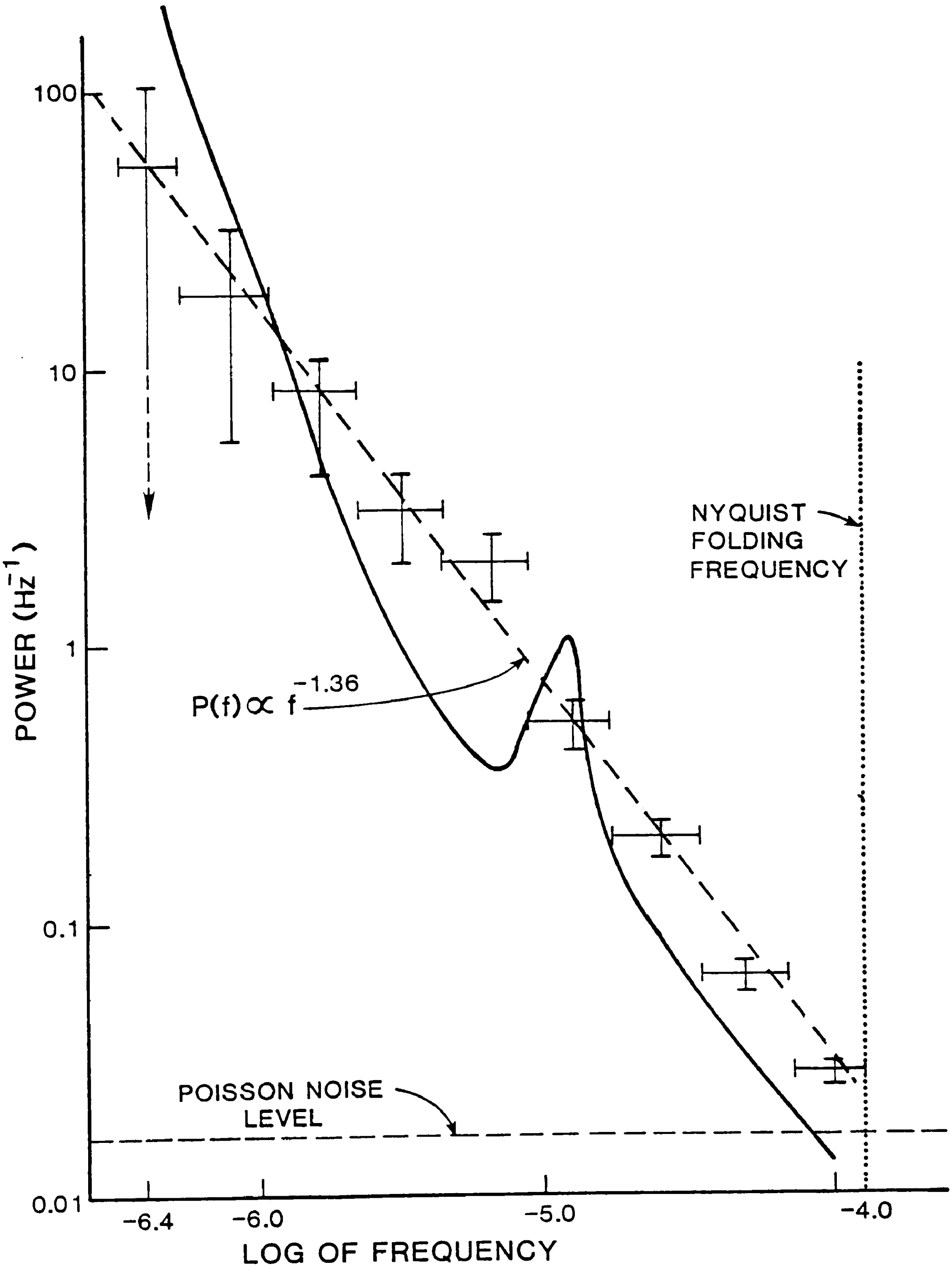

100
10
1
0.1
0.01
POWER (Hz^{-1})
NYQUIST
FOLDING
FREQUENCY
P(f) ∝ f$^{-1.36}$
POISSON NOISE
LEVEL
-6.4
-6.0
-5.0
-4.0
LOG OF FREQUENCY

Fig. 16. A comparison of the muon PSDF at TAMU with the theory using data by Quenby and Sear. Frequency is in Hz.



100
10
1
0.1
0.01
POWER (Hz^{-1})
$P(f) \propto f^{-1.36}$
NYQUIST FOLDING FREQUENCY
POISSON NOISE LEVEL
-6.4
-6.0
-5.0
-4.0
LOG OF FREQUENCY

CHAPTER VI

CONCLUSIONS

Summary

During the last decade, A. J. Owens and J. R. Jokipii along with several other researchers, developed a theory which sought to explain recently observed scintillation in the secondary cosmic radiation. After several years, the theory developed to the extent that predictions drawn from the work were in good agreement with observations using ground-level neutron monitors. The theory had not been tested using the "hard" component of the secondary cosmic radiation.

A cosmic ray muon telescope was designed, built, and calibrated at Texas A&M University with the aim of testing the theory using the hard component of cosmic radiation.

Counting data were collected between March 22, 1983, and May 4, 1983. In addition, atmospheric pressure and temperature data were obtained from the Federal Aviation Administration's Flight Service Station at Easterwood Airport on the Texas A&M campus.

The output of the experiment was an hourly record of cosmic ray muon counting rate and, therefore, the output constituted a time series. Long-term trends were removed from the time series. Corrections were made to compensate for the effects of atmospheric pressure and temperature.

Certain statistical parameters were calculated for the time series.

Estimates of the PSDF were calculated by the Nested Variance method and results of this analysis were compared to predictions of the Owens and Jokipii theory using two different empirical formulas for the PSDF of the interplanetary magnetic field. The PSDF for the time series recorded at Texas A&M was in good agreement with both predictions. Agreement was better for the formula published by Hedgecock.

Conclusions

The Owens and Jokipii theory is in very good agreement with observations made in the 5.6 GV range at Texas A&M University with the cosmic ray muon telescope described here.

Muon telescopes can be used to observe changes in the PSDF of the interplanetary magnetic field through which the primary cosmic ray must pass.

With independent data on the interplanetary magnetic field PSDF, a cosmic ray muon telescope can be used to measure the cosmic ray anisotropy.

Large improvements in the resolution and frequency range could be expected by increasing the effective sensitive area of the telescope. This is especially important for underground telescopes which operate in higher energy ranges with much lower average counting rates.

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APPENDIX A

PROGRAM GFACTOR

```
'*********************************************************
'*
'*   Program - GFACTOR.BAS
'*
'*   Written by - ROBERT BENSON
'*
'*
'*   Last Modified - 11/3/84
'*   Purpose
'*   To calculate, by numerical integration, the
'*   geometric factor of a simple retangular cosmic
'*   ray telescope
'*
'*   Description of parameters
'*   a          - length of detector
'*   b          - width of detector
'*   l          - vertical spacing of detectors
'*   intensity  - vertical intensity
'*   exponent   - zenith angle dependence
'*   inc        - step size
'*
'*********************************************************
'
'
       cls
       a = 180
       b = 90
       l = 50.1
       intensity = 8.0e-3
       exponent = 2.6
       inc = 5

       for i% = 1 to a step inc
       for j% = 1 to b step inc
       for k% = 1 to a step inc
       for n% = 1 to b step inc

       x = k% = I%
       y = n% - j%
       rsq = x^2 + x^2
       r = sqr(rsq)
       the = atn(r/l)
       xp = cos(atn(x/l))
       yp = cos(atn(y/l))
       area = xp * yp * inc^2
       roe = sqr(r^2 + l^2)
       sang = area/roe^2
```

```
totang = totang + sang
count = count + sang * intensity * cos(the)_
        ^exponent*inc^2
next n%,k%,j%,i%

print "Solid Angle = ";totang
print "Count rate  = ";count

stop
```

APPENDIX B

PROGRAM PILOTA - Nested Variance Method

```
'*********************************************************
'*
'*        PILOTA.BAS
'*
'*
'*        Written by Robert Benson  02/06/85
'*
'*        Last Revision - 02/15/85
'*
'*
'*
'*        PROGRAM DESCRIPTION
'*
'*        This program calculates the power density
'*        spectrum by the "Nested Variance Method"
'*
'*        The user must setup the following items
'*
'*        x( ) = array of input data
'*        t    = time between observations
'*        n%   = number of observations
'*
'*        if iave = 0 then the power spectrum of
'*                    x - <x> is calculated
'*
'*        if iave = 1 then the power spectrum of
'*                    (x - <x>)/<x> is calculated
'*
'*        for details of method see:
'*        (Owens, A. J.,J. Geophys. Res.,82,3315,1977)
'*
'*
'*        ::::::::::::::::::::
'*        :: INCLUDE FILES ::
'*        ::::::::::::::::::::
'*
'*              NONE
'*
'*********************************************************

     dim x(1024),xig(1024)
     def  fnlg(z)=log(z)/2.30259

     f$ = "##.###"

     t=3600
```

```
     n%=1024
     iave%=1

     gosub 1100 : '<----- Routine to read in data

     xave=0
     sig2=0
     rn=0
     fc=1/(2*t)
     for  i%=1 to n%
     xig(i%)=0
     if abs(x(i%))<.000001 then 10
     xig(i%)=1
     rn=rn+1
     xave=xave+x(i%)
     sig2=sig2+x(i%)^2
10   next i%
     j%=2^(int(log(n%)/log(2)+.99))
     for i%=n%+1 to j%
     x(i%)=0
     xig(i%)=0
     i%

     xave=xave/rn
     sig2=sig2/rn-xave^2
     sig=sqr(sig2)

     log.pnoise = fnlg(2/(xave/t))
     log.nyquist = fnlg(1/(2*t))

     gosub 1400 : '<----- Print routine


     for i%=1 to n%
     x(i%)=x(i%)-xave
     if iave%<=0 then 20
     x(i%)=x(i%)/xave
20   next i%


     if iave%<=0 then 30
     sig2=sig2/xave^2
30   l%=1
     n%=j%

1000 rnn=0
     sig2n=0

     for i%=2 to n% step 2
     j%=i%/2
     xig(i%)=.5*(xig(i%-1)+xig(i%))
     if xig(j%)<=.000001 then 40
```

```
    x(j%)=.5*(x(i%-1)*xig(i%-1)+x(i%)*xig(i%))/xig(j%)
40  rnn=rnn+xig(j%)
    sig2n=sig2n+xig(j%)*x(j%)^2
    next i%

    sig2n=sig2n/rnn
    fl=fc/2^l%
    fu=fl*2
    p=(sig2-sig2n)/(fu-fl)
    d=rn-rnn
    pe=p*sqr(2/d)

    gosub 1200 : '<----- Go do calculations

    l%=l%+1
    n%=n%/2
    rn=rnn
    sig2=sig2n
    if n%>3 then 1000

    gosub 1300 : '<----- Print routine

    end

1100 '=====================================================
     '                 Routine to read in data
     '=====================================================

     input"Enter the file name for data ";filename$
     open"i",1,filename$
     for i%=1 to 1024
     input#1,x(i%)
     next i%
     close
     return

1200 '=====================================================
     '                 Routine to calculate power
     '=====================================================

     low.freq = fl
     high.freq = fu
     cent.freq = fl + (fu-fl)/2
     log.low.freq = fnlg(low.freq)
     log.high.freq = fnlg(high.freq)
     log.cent.freq = fnlg(cent.freq)

     low.pow = p-pe
     high.pow = p+pe
     cent.pow = p
```

```
    if low.pow = 0 then log.low.pow = 0 : goto 100
    log.low.pow = fnlg(low.pow)
100 log.high.pow = fnlg(high.pow)
    log.cent.pow = fnlg(cent.pow)

    count% = count% + 1
    sum.freq.pow = sum.freq.pow + log.cent.pow * _
         log.cent.freq
    sum.freq = sum.freq + log.cent.freq
    sum.pow = sum.pow + log.cent.pow
    sum.freq.sqr = sum.freq.sqr + log.cent.freq * _
         log.cent.freq

    lprint using f$; log.low.freq;  : lprint tab(10);
    lprint using f$; log.cent.freq; : lprint tab(19);
    lprint using f$; log.high.freq; : lprint tab(30);
    lprint using f$; log.low.pow;   : lprint tab(39);
    lprint using f$; log.cent.pow;  : lprint tab(48);
    lprint using f$; log.high.pow;  : lprint tab(67);

    lprint using"####"; d

    return


1300 '==================================================
     '               Print routine
     '==================================================

    lprint:lprint:lprint

    lprint "Mean value of data is ";tab(35)_
           :lprint using"#######.##";xave

    lprint "Standard deviation is ";tab(35)_
           :lprint using"#######.##";sig

    lprint "Log of Poisson noise level is ";tab(40)_
           :lprint using f$;log.pnoise

    lprint "Log of Nyquist folding frequency is "; _
         tab(40) : lprint using f$;log.nyquist

    slope = (count% * sum.freq.pow - sum.freq * _
         sum.pow)/(count% * sum.freq.sqr - _
         (sum.freq)^2)

    yint = sum.pow/count% - slope * sum.freq/count%
    lprint
    lprint "Slope is ";tab(40);:lprint using f$;slope
    lprint "Y intercept is ";tab(40);: _
```

```
          lprint using f$;yint

     lprint chr$(12)

     return

1400 '==================================================
     '              Print routine
     '==================================================

     cls
     "    Frequency Band";tab(38);"Power"
     lprint " Low     Center    High ";tab(31);_
     "Low     Center    High ";tab(60);_
     "Degrees of Freedom"

     lprint " ---     ------    ---- ";tab(31);_
             "---     ------    ---- ";tab(60);_
             "------- -- -------"
     lprint

     return
```

APPENDIX C

SCINTILLATION DATA

DATE	HOUR	TEMP	PRESS CORR	COUNT RAW	COUNT DT	COUNT PCTC
03-22-83	18	286.49	1010.09	446821	435127	436375
03-22-83	19	285.94	1010.97	446916	435245	437043
03-22-83	20	285.94	1011.27	448104	436456	438432
03-22-83	21	285.94	1012.16	448028	436402	438892
03-22-83	22	285.38	1012.45	448411	436808	439511
03-22-83	23	285.38	1013.05	445948	434368	437402
03-22-83	24	285.38	1013.05	445848	434291	437324
03-23-83	1	285.38	1014.04	446964	435430	439044
03-23-83	2	284.27	1014.03	444732	433221	436896
03-23-83	3	284.27	1013.53	443556	432068	435445
03-23-83	4	283.72	1013.53	443521	432055	435474
03-23-83	5	283.16	1014.02	443459	432016	435759
03-23-83	6	282.60	1014.51	443925	432505	436576
03-23-83	7	283.16	1015.60	443519	432122	436775
03-23-83	8	283.72	1016.01	442712	431338	436176
03-23-83	9	285.38	1016.62	444037	432686	437765
03-23-83	10	287.05	1016.64	442859	431531	436481
03-23-83	11	288.16	1016.35	443494	432188	436894
03-23-83	12	289.83	1015.98	443397	432114	436479
03-23-83	13	290.94	1015.00	446350	435090	438833
03-23-83	14	290.94	1014.20	446931	435694	438979
03-23-83	15	290.94	1013.21	447371	436157	438872
03-23-83	16	292.05	1013.02	446215	435024	437537
03-23-83	17	291.49	1012.62	446987	435819	438149
03-23-83	18	290.94	1013.01	446381	435236	437830
03-23-83	19	288.16	1013.28	445050	433927	436880
03-23-83	20	285.38	1013.55	444424	433324	436638
03-23-83	21	284.27	1014.23	444267	433190	436979
03-23-83	22	284.27	1014.23	442898	431844	435621
03-23-83	23	283.16	1014.51	442739	431708	435729
03-23-83	24	283.16	1014.21	442511	431503	435350
03-24-83	1	282.05	1014.50	442632	431647	435746
03-24-83	2	281.49	1014.49	443570	432607	436752
03-24-83	3	282.05	1014.20	443971	433031	436970
03-24-83	4	282.05	1014.20	444269	433352	437294
03-24-83	5	282.60	1014.21	442329	431435	435324
03-24-83	6	281.49	1014.49	443226	432355	436498
03-24-83	7	280.38	1015.08	444054	433206	437781
03-24-83	8	283.16	1015.70	441490	430665	435359
03-24-83	9	288.16	1016.35	442335	431532	436230
03-24-83	10	290.94	1016.38	444628	433848	438377
03-24-83	11	292.05	1016.00	443524	432767	436981
03-24-83	12	293.16	1015.32	444364	433630	437376
03-24-83	13	293.72	1013.94	446509	435798	438721

03-24-83	14	294.83	1013.25	447138	436450	438893
03-24-83	15	294.83	1012.66	447190	436525	438627
03-24-83	16	295.38	1011.38	447554	436911	438232
03-24-83	17	294.27	1011.16	447207	436587	437865
03-24-83	18	293.16	1011.15	447759	437162	438520
03-24-83	19	290.94	1011.62	445326	434752	436542
03-24-83	20	289.83	1011.91	446731	436180	438229
03-24-83	21	287.60	1012.28	445357	434829	437253
03-24-83	22	287.05	1012.97	446882	436377	439252
03-24-83	23	286.49	1012.96	444417	433934	436829
03-24-83	24	285.38	1012.55	444480	434020	436764
03-25-83	1	284.83	1015.62	445261	434824	439390
03-25-83	2	283.16	1012.63	446232	435818	438789
03-25-83	3	283.16	1012.63	446446	436055	439027
03-25-83	4	280.94	1012.01	446603	436235	439019
03-25-83	5	280.94	1011.61	446561	436216	438768
03-25-83	6	281.49	1011.62	446784	436461	438978
03-25-83	7	281.49	1011.62	448025	437725	440249
03-25-83	8	284.83	1011.95	446880	436603	439058
03-25-83	9	288.72	1012.99	445691	435437	438190
03-25-83	10	290.94	1012.71	446826	436595	439023
03-25-83	11	293.16	1014.03	445730	435522	438537
03-25-83	12	292.60	1013.33	447088	436903	439565
03-25-83	13	292.05	1012.63	446700	436537	438834
03-25-83	14	292.60	1011.94	448709	438569	440433
03-25-83	15	292.60	1011.34	448786	438669	440186
03-25-83	16	292.60	1010.85	448277	438183	439414
03-25-83	17	292.60	1010.65	447982	437911	439025
03-25-83	18	291.49	1011.23	447313	437265	438798
03-25-83	19	287.60	1012.98	446143	436118	438954
03-25-83	20	287.05	1012.97	444780	434778	437642
03-25-83	21	287.05	1013.27	444255	434275	437308
03-25-83	22	286.49	1013.95	444649	434692	438163
03-25-83	23	287.05	1013.96	443319	433385	436809
03-25-83	24	287.05	1013.96	442047	432136	435551
03-26-83	1	287.05	1013.96	441125	431237	434644
03-26-83	2	287.05	1013.66	439035	429170	432391
03-26-83	3	287.05	1013.66	440901	431059	434293
03-26-83	4	287.05	1013.27	440926	431106	434117
03-26-83	5	286.49	1012.96	440751	430954	433829
03-26-83	6	286.49	1012.96	440710	430936	433811
03-26-83	7	286.49	1013.66	442095	432344	435630
03-26-83	8	288.72	1013.68	439166	429438	432547
03-26-83	9	289.83	1013.99	440005	430300	433508
03-26-83	10	290.94	1014.00	438723	429041	432161
03-26-83	11	292.60	1013.63	437772	428112	430890
03-26-83	12	294.27	1012.95	438568	428931	431203
03-26-83	13	295.94	1012.18	439409	429795	431508
03-26-83	14	295.38	1010.88	440569	430978	431996
03-26-83	15	296.49	1009.80	440042	430474	430793
03-26-83	16	295.38	1009.09	442335	432790	432790
03-26-83	17	295.38	1008.90	448234	438712	438602

03-26-83	18	294.83	1009.29	441445	431945	432101
03-26-83	19	293.16	1008.87	443358	433881	433923
03-26-83	20	292.60	1009.26	443179	433725	434032
03-26-83	21	291.49	1009.65	441146	431715	432327
03-26-83	22	290.38	1010.23	441316	431908	432934
03-26-83	23	289.27	1010.22	440862	431477	432580
03-26-83	24	289.27	1010.22	441140	431778	432882
03-27-83	1	289.83	1010.22	441728	432388	433451
03-27-83	2	289.83	1009.53	440960	431643	432311
03-27-83	3	289.83	1009.23	441022	431728	432225
03-27-83	4	288.16	1008.82	441612	432341	432730
03-27-83	5	287.05	1009.20	440903	431655	432344
03-27-83	6	287.60	1009.21	442301	433076	433731
03-27-83	7	288.16	1009.21	440713	431511	432122
03-27-83	8	289.27	1009.92	439430	430250	431179
03-27-83	9	291.49	1009.94	441036	431879	432656
03-27-83	10	293.16	1009.76	439329	430195	430742
03-27-83	11	294.83	1009.48	437754	428643	428905
03-27-83	12	295.94	1009.20	442616	433528	433549
03-27-83	13	297.60	1008.42	439601	430536	429989
03-27-83	14	298.16	1007.44	438737	429695	428554
03-27-83	15	298.72	1006.85	439254	430234	428716
03-27-83	16	298.72	1006.85	439782	430785	429264
03-27-83	17	297.05	1006.83	438823	429849	428445
03-27-83	18	295.94	1007.61	438981	430030	429149
03-27-83	19	294.27	1007.59	438096	429168	428402
03-27-83	20	293.16	1007.88	437809	428904	428385
03-27-83	21	292.05	1008.46	438537	429655	429547
03-27-83	22	291.49	1008.85	437745	428886	429041
03-27-83	23	290.94	1008.85	438619	429782	429978
03-27-83	24	290.94	1008.45	439605	430791	430760
03-28-83	1	290.94	1008.15	439391	430600	430399
03-28-83	2	291.49	1007.56	438682	429914	429338
03-28-83	3	292.05	1006.58	438358	429613	428442
03-28-83	4	292.05	1005.98	439287	430565	429052
03-28-83	5	292.60	1005.99	438949	430250	428702
03-28-83	6	292.05	1005.98	438846	430169	428657
03-28-83	7	292.05	1005.98	438707	430053	428541
03-28-83	8	292.60	1006.29	437735	429104	427729
03-28-83	9	293.16	1006.19	438724	430116	428640
03-28-83	10	294.27	1006.21	441684	433099	431541
03-28-83	11	293.72	1006.50	439880	431318	429972
03-28-83	12	293.16	1005.80	439199	430660	428961
03-28-83	13	293.72	1004.81	440117	431600	429295
03-28-83	14	296.49	1004.25	439663	431169	428343
03-28-83	15	295.94	1003.74	439865	431394	428320
03-28-83	16	296.49	1003.65	439908	431460	428293
03-28-83	17	295.38	1003.34	440743	432318	429052
03-28-83	18	294.27	1003.33	440296	431894	428709
03-28-83	19	294.27	1003.63	439441	431062	428053
03-28-83	20	294.27	1003.33	441091	432734	429543
03-28-83	21	293.72	1003.32	442313	433979	430815

03-28-83	22	293.72	1002.73	441345	433034	429542
03-28-83	23	293.72	1002.43	443135	434847	431170
03-28-83	24	290.94	1002.40	443440	435175	431686
03-29-83	1	293.16	1003.02	440641	432399	429118
03-29-83	2	293.72	1003.72	440716	432497	429569
03-29-83	3	287.60	1004.05	442547	434350	432057
03-29-83	4	286.49	1003.74	441167	432993	430615
03-29-83	5	286.49	1004.04	441376	433225	431015
03-29-83	6	285.94	1004.13	443135	435007	432882
03-29-83	7	285.94	1003.14	444401	436296	433598
03-29-83	8	287.05	1003.15	444324	436242	433467
03-29-83	9	288.16	1002.87	444732	436673	433651
03-29-83	10	288.72	1002.57	445820	437783	434539
03-29-83	11	288.16	1002.87	446112	438098	435066
03-29-83	12	288.16	1002.27	445523	437532	434160
03-29-83	13	289.83	1001.40	446378	438410	434406
03-29-83	14	292.60	999.34	448164	440219	434808
03-29-83	15	294.27	998.27	447358	439436	433295
03-29-83	16	294.83	997.68	447744	439845	433320
03-29-83	17	295.38	997.39	447732	439855	433121
03-29-83	18	294.83	997.68	446042	438188	431687
03-29-83	19	292.05	997.95	447063	439232	433078
03-29-83	20	290.94	998.93	446505	438697	433193
03-29-83	21	288.72	999.60	446115	438330	433381
03-29-83	22	288.72	999.90	445131	437369	432600
03-29-83	23	287.60	1000.28	444742	437003	432540
03-29-83	24	288.16	1000.68	443619	435903	431638
03-30-83	1	285.94	1000.36	445102	437408	433113
03-30-83	2	285.38	1000.36	444716	437045	432795
03-30-83	3	284.27	1000.05	444093	436445	432108
03-30-83	4	284.83	1000.15	443181	435556	431242
03-30-83	5	284.27	1000.64	443064	435462	431470
03-30-83	6	284.83	1001.24	443397	435818	432122
03-30-83	7	285.38	1001.84	441852	434296	430912
03-30-83	8	288.16	1002.47	441630	434096	430864
03-30-83	9	292.60	1003.11	442904	435393	432182
03-30-83	10	296.49	1003.45	442433	434945	431639
03-30-83	11	299.83	1003.39	442203	434738	431148
03-30-83	12	301.49	1003.11	443514	436072	432186
03-30-83	13	301.49	1002.42	443536	436117	431838
03-30-83	14	302.60	1001.73	444297	436901	432138
03-30-83	15	303.16	1000.95	442955	435581	430347
03-30-83	16	302.60	1000.74	442598	435247	429940
03-30-83	17	303.16	1000.45	443764	436436	430907
03-30-83	18	300.94	1000.43	443498	436193	430823
03-30-83	19	295.38	1000.66	442614	435332	430519
03-30-83	20	295.94	1001.26	441932	434673	430167
03-30-83	21	294.83	1002.05	442049	434813	430837
03-30-83	22	292.60	1002.62	442145	434931	431444
03-30-83	23	291.49	1002.60	439852	432661	429265
03-30-83	24	288.72	1002.57	440996	433828	430614
03-31-83	1	287.60	1002.26	441412	434267	430956

03-31-83	2	286.49	1002.25	440129	433007	429783
03-31-83	3	284.83	1002.83	440693	433594	430820
03-31-83	4	284.83	1002.53	440784	433708	430763
03-31-83	5	284.83	1002.83	440181	433127	430356
03-31-83	6	285.94	1003.54	440963	433932	431476
03-31-83	7	287.05	1004.34	440874	433866	431782
03-31-83	8	287.05	1005.04	441965	434980	433290
03-31-83	9	288.72	1006.14	439938	432976	431795
03-31-83	10	289.83	1007.15	440004	433065	432376
03-31-83	11	289.83	1007.74	442066	435150	434796
03-31-83	12	289.83	1007.74	439074	432180	431829
03-31-83	13	289.83	1006.85	440010	433139	432279
03-31-83	14	290.94	1006.47	442000	435152	433987
03-31-83	15	290.94	1006.07	440859	434034	432643
03-31-83	16	294.27	1005.81	440793	433991	432202
03-31-83	17	294.83	1005.82	440932	434153	432327
03-31-83	18	295.38	1006.32	439160	432404	430827
03-31-83	19	294.27	1006.90	438322	431588	430426
03-31-83	20	291.49	1007.17	439002	432291	431490
03-31-83	21	290.38	1008.05	438125	431437	431221
03-31-83	22	289.27	1008.63	435895	429230	429426
03-31-83	23	287.60	1008.61	438562	431920	432231
03-31-83	24	287.60	1009.21	436628	430009	430659
04-01-83	1	286.49	1009.69	438274	431678	432688
04-01-83	2	286.49	1009.69	436198	429625	430630
04-01-83	3	286.49	1009.99	436825	430274	431452
04-01-83	4	286.49	1010.68	436645	430117	431687
04-01-83	5	284.27	1010.66	436442	429937	431661
04-01-83	6	284.83	1011.36	438827	432345	434438
04-01-83	7	287.05	1012.08	438322	431863	434198
04-01-83	8	287.05	1011.78	438900	432464	434630
04-01-83	9	289.27	1013.19	437694	431281	434080
04-01-83	10	295.38	1013.56	438702	432311	434866
04-01-83	11	298.72	1013.59	437245	430877	433189
04-01-83	12	300.94	1013.32	437560	431215	433207
04-01-83	13	302.05	1012.64	436845	430523	432041
04-01-83	14	302.60	1011.95	436638	430339	431422
04-01-83	15	302.60	1011.26	438113	431837	432530
04-01-83	16	302.60	1010.56	437620	431367	431660
04-01-83	17	302.60	1011.55	436691	430460	431315
04-01-83	18	300.94	1010.74	436498	430290	430809
04-01-83	19	298.16	1010.71	436202	430017	430728
04-01-83	20	292.60	1010.95	434652	428490	429750
04-01-83	21	290.38	1011.22	433723	427584	429160
04-01-83	22	289.83	1011.91	433614	427498	429505
04-01-83	23	290.38	1011.92	433439	427346	429317
04-01-83	24	288.16	1011.89	434205	428134	430258
04-02-83	1	287.05	1011.38	432754	426706	428617
04-02-83	2	285.38	1010.77	433876	427851	429546
04-02-83	3	284.83	1010.46	434020	428018	429579
04-02-83	4	283.16	1010.15	434240	428261	429773
04-02-83	5	282.60	1010.14	433876	427920	429466

04-02-83	6	285.38	1010.17	431736	425803	427152
04-02-83	7	285.94	1010.48	431867	425956	427439
04-02-83	8	288.72	1010.51	430639	424751	426040
04-02-83	9	291.49	1010.54	432337	426472	427578
04-02-83	10	293.16	1010.86	432397	426555	427717
04-02-83	11	294.27	1010.57	434729	428910	429831
04-02-83	12	295.94	1010.19	436551	430755	431339
04-02-83	13	295.38	1009.29	437647	431874	431988
04-02-83	14	297.05	1008.22	439441	433690	433067
04-02-83	15	296.49	1006.63	438780	433052	431566
04-02-83	16	295.94	1005.83	439710	434005	432101
04-02-83	17	295.38	1005.52	440894	435212	433168
04-02-83	18	295.38	1005.23	440078	434419	432213
04-02-83	19	294.83	1005.22	444562	438926	436734
04-02-83	20	294.83	1005.22	439366	433753	431587
04-02-83	21	294.83	1004.92	440155	434564	432223
04-02-83	22	294.83	1004.92	439218	433650	431313
04-02-83	23	294.83	1004.13	437895	432350	429573
04-02-83	24	294.83	1004.13	432608	427086	424342
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04-03-83	2	293.16	1003.22	429740	424264	421155
04-03-83	3	293.72	1003.22	429957	424504	421353
04-03-83	4	293.72	1002.33	431773	426343	422682
04-03-83	5	294.27	1000.85	431522	426114	421591
04-03-83	6	293.16	1000.84	432873	427488	423026
04-03-83	7	293.72	1001.14	434859	429497	425141
04-03-83	8	293.72	1001.74	435428	430089	426064
04-03-83	9	294.83	1001.35	434308	428992	424677
04-03-83	10	297.05	1000.88	436300	431007	426242
04-03-83	11	298.72	999.81	435767	430497	425013
04-03-83	12	299.27	999.12	437238	431990	426058
04-03-83	13	300.38	997.84	438852	433627	426870
04-03-83	14	300.94	996.46	440225	435023	427423
04-03-83	15	300.94	995.66	442603	437424	429333
04-03-83	16	300.38	995.66	442824	437668	429610
04-03-83	17	299.83	995.95	444915	439782	431893
04-03-83	18	298.72	995.64	444149	439039	431071
04-03-83	19	297.05	996.52	444093	439005	431661
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04-03-83	21	295.38	997.99	439605	434563	428247
04-03-83	22	294.83	999.77	437688	432669	427423
04-03-83	23	294.27	999.16	435051	430055	424545
04-03-83	24	293.72	999.16	432657	427684	422241
04-04-83	1	293.72	999.85	432796	427846	422788
04-04-83	2	294.27	1000.55	433461	428533	423817
04-04-83	3	293.72	1000.55	432619	427714	423047
04-04-83	4	294.27	999.46	434378	429496	424159
04-04-83	5	294.27	999.86	435629	430770	425640
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04-04-83	7	293.16	1002.03	433221	428408	424602
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04-04-83	9	293.16	1004.31	433868	429100	426569

04-04-83	10	295.38	1005.42	434926	430181	428104
04-04-83	11	295.94	1006.82	434001	429279	427954
04-04-83	12	296.49	1006.83	435457	430758	429393
04-04-83	13	297.05	1007.13	435440	430764	429527
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04-04-83	15	297.60	1006.84	438907	434277	432823
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04-04-83	18	295.94	1007.81	437598	433036	432264
04-04-83	19	299.27	1008.54	435719	431180	430575
04-04-83	20	290.94	1009.44	435017	430501	431033
04-04-83	21	289.83	1011.12	432553	428060	429622
04-04-83	22	289.27	1012.40	431285	426815	429137
04-04-83	23	288.72	1012.59	429805	425357	427820
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04-05-83	1	287.60	1013.57	430009	425607	428709
04-05-83	2	286.49	1013.86	430339	425960	429311
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04-05-83	4	284.27	1014.13	432323	427990	431677
04-05-83	5	283.16	1014.71	431233	426923	431014
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04-05-83	8	286.49	1018.32	429091	424849	430717
04-05-83	9	290.38	1020.15	428044	423825	430426
04-05-83	10	293.16	1020.87	427537	423341	430134
04-05-83	11	294.27	1020.88	427468	423295	430010
04-05-83	12	294.83	1020.89	427270	423120	429796
04-05-83	13	295.94	1020.21	427389	423262	429472
04-05-83	14	295.94	1020.01	428267	424162	430272
04-05-83	15	296.49	1019.62	426539	422457	428281
04-05-83	16	295.94	1019.32	428231	424172	429891
04-05-83	17	295.38	1018.32	428758	424722	429922
04-05-83	18	294.27	1018.60	428156	424143	429578
04-05-83	19	291.49	1019.27	427327	423337	429349
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04-05-83	21	286.49	1019.81	426935	422990	429675
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04-05-83	23	285.94	1020.10	427278	423379	430276
04-05-83	24	286.49	1020.10	428247	424371	431243
04-06-83	1	284.83	1019.79	427809	423956	430770
04-06-83	2	284.83	1019.79	426563	422733	429527
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04-06-83	4	283.72	1019.08	425425	421640	428098
04-06-83	5	283.16	1019.47	427525	423763	430517
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04-06-83	7	280.38	1020.43	425019	421303	428767
04-06-83	8	287.60	1020.51	425195	421502	428476
04-06-83	9	289.83	1020.44	426133	422463	429248
04-06-83	10	292.60	1020.47	427397	423750	430364
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04-06-83	15	297.05	1016.06	430427	426894	430710
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04-06-83	19	293.72	1013.74	431813	428371	431131
04-06-83	20	292.60	1013.43	430562	427143	429802
04-06-83	21	291.49	1013.42	430504	427108	429845
04-06-83	22	291.49	1013.42	429864	426491	429224
04-06-83	23	289.83	1013.69	429599	426249	429257
04-06-83	24	288.16	1013.68	430487	427160	430293
04-07-83	1	287.60	1013.77	431552	428247	431481
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04-07-83	23	292.05	1009.16	429467	426665	426952
04-07-83	24	291.49	1009.25	429320	426541	426920
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04-08-83	5	291.49	1006.87	431124	428460	427497
04-08-83	6	291.49	1007.17	431703	429061	428266
04-08-83	7	292.05	1007.47	431905	429286	428618
04-08-83	8	292.05	1007.67	431596	429000	428446
04-08-83	9	292.05	1008.16	432287	429714	429436
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04-08-83	11	293.16	1008.77	431326	428799	428784
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04-08-83	23	294.83	1009.48	429286	427033	427294
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04-09-83	7	294.27	1010.87	430607	428537	429627
04-09-83	8	294.83	1011.27	428791	426744	428013
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04-09-83	14	300.94	1009.75	428645	426735	426693
04-09-83	15	300.94	1009.35	430458	428571	428303
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04-11-83	19	297.05	1008.12	428568	427870	427199
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04-12-83	1	292.60	1010.45	427159	426598	427570
04-12-83	2	291.49	1010.14	426788	426250	427130
04-12-83	3	292.60	1009.76	427156	426640	427223
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04-12-83	17	301.49	1007.28	425520	425324	423859
04-12-83	18	301.49	1007.38	422805	422632	421231
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04-12-83	21	296.49	1009.11	422213	422109	422038
04-12-83	22	295.38	1009.39	420330	420249	420415
04-12-83	23	293.72	1009.37	421510	421452	421729
04-12-83	24	293.16	1009.66	422126	422090	422571
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04-13-83	3	293.72	1009.97	424544	424577	425193
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04-13-83	5	293.16	1009.66	425514	425593	426078
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04-13-83	13	300.94	1011.04	426878	427140	427825
04-13-83	14	302.05	1009.37	428344	428629	428289
04-13-83	15	303.72	1008.79	429103	429410	428617
04-13-83	16	302.60	1008.48	427804	428134	427252
04-13-83	17	302.60	1008.18	429143	429496	428442
04-13-83	18	300.94	1008.46	428874	429250	428478
04-13-83	19	297.60	1008.42	427442	427841	427298
04-13-83	20	297.60	1009.32	428148	428570	428533
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04-13-83	23	294.27	1010.47	425928	426418	427277
04-13-83	24	293.72	1011.06	426013	426526	427759
04-14-83	1	294.27	1012.26	427740	428276	430153
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04-14-83	3	293.16	1012.64	426569	427151	429321
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04-14-83	6	292.05	1013.22	422926	423576	426136
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04-16-83	7	291.49	1017.88	421860	423630	428859
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04-17-83	16	300.38	1009.74	431564	434089	434083
04-17-83	17	300.38	1009.35	429534	432082	431854
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04-18-83	22	292.60	1009.86	428535	431746	432393
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04-25-83	18	295.94	1006.52	428182	435142	433628
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04-25-83	20	291.49	1007.07	426503	433508	432648
04-25-83	21	291.49	1006.97	427033	434061	433143
04-25-83	22	290.94	1007.26	426643	433694	432983
04-25-83	23	290.38	1007.25	426302	433376	432702
04-25-83	24	289.83	1007.25	425745	432842	432211
04-26-83	1	289.83	1007.45	425329	432449	431932

04-26-83	2	288.16	1007.13	420440	427583	427015
04-26-83	3	288.16	1007.13	421059	428224	427655
04-26-83	4	288.16	1007.43	424528	431716	431314
04-26-83	5	287.60	1007.42	423220	430431	430065
04-26-83	6	288.72	1008.33	422194	429428	429496
04-26-83	7	290.94	1009.14	423589	430846	431207
04-26-83	8	292.05	1009.55	424093	431373	431885
04-26-83	9	292.05	1010.15	422378	429681	430532
04-26-83	10	294.27	1010.47	422101	429426	430292
04-26-83	11	296.49	1010.49	422164	429512	430222
04-26-83	12	296.49	1009.90	420169	427540	427914
04-26-83	13	299.27	1010.43	421632	429026	429494
04-26-83	14	298.72	1008.83	420319	427736	427341
04-26-83	15	294.83	1007.80	422064	429504	428816
04-26-83	16	300.94	1007.37	422986	430449	429058
04-26-83	17	300.38	1006.87	422384	429869	428239
04-26-83	18	299.83	1006.86	423812	431320	429721
04-26-83	19	297.05	1006.83	423420	430951	429544
04-26-83	20	295.94	1007.51	423743	431297	430357
04-26-83	21	294.27	1008.19	423193	430770	430342
04-26-83	22	294.27	1008.88	421847	429447	429411
04-26-83	23	293.72	1008.88	422269	429892	429897
04-26-83	24	292.60	1008.87	422353	429998	430081
04-27-83	1	292.05	1008.56	422242	429910	429859
04-27-83	2	291.49	1008.26	423167	430858	430678
04-27-83	3	290.94	1008.25	424192	431906	431761
04-27-83	4	290.94	1008.55	423816	431553	431579
04-27-83	5	290.94	1008.85	423014	430774	430970
04-27-83	6	289.27	1008.83	421890	429673	429983
04-27-83	7	292.05	1009.16	420728	428533	428821
04-27-83	8	293.72	1009.37	421190	429018	429300
04-27-83	9	295.38	1009.39	421212	429063	429233
04-27-83	10	295.94	1010.09	422564	430438	430964
04-27-83	11	298.72	1009.43	422647	430544	430487
04-27-83	12	299.27	1008.84	425872	433792	433355
04-27-83	13	299.83	1008.05	425909	433852	432922
04-27-83	14	299.27	1007.35	425784	433749	432462
04-27-83	15	300.94	1006.97	426635	434623	432990
04-27-83	16	302.05	1006.39	433216	441227	439149
04-27-83	17	301.49	1006.09	425884	433918	431745
04-27-83	18	300.38	1006.07	425330	433387	431289
04-27-83	19	297.60	1006.04	424733	432813	430909
04-27-83	20	296.49	1006.33	423092	431195	429546
04-27-83	21	295.94	1006.92	422292	430417	429145
04-27-83	22	295.94	1007.51	421843	429991	429055
04-27-83	23	295.94	1007.51	419675	427846	426914
04-27-83	24	295.38	1007.51	421272	429466	428572
04-28-83	1	295.38	1007.21	418814	427031	425973
04-28-83	2	295.38	1007.21	418785	427025	425967
04-28-83	3	284.27	1006.79	418698	426961	426492
04-28-83	4	295.38	1006.91	416886	425172	423952
04-28-83	5	294.83	1006.51	417709	426017	424611

04-28-83	6	294.83	1006.91	419048	427379	426193
04-28-83	7	294.83	1007.30	416418	424772	423812
04-28-83	8	295.94	1007.31	418236	426613	425571
04-28-83	9	296.49	1008.02	418527	426927	426242
04-28-83	10	297.60	1008.03	419500	427923	427160
04-28-83	11	298.72	1008.04	420176	428622	427780
04-28-83	12	299.27	1007.35	421286	429754	428479
04-28-83	13	299.83	1006.76	423084	431575	429918
04-28-83	14	300.38	1006.27	424522	433036	431053
04-28-83	15	300.38	1005.68	425507	434044	431721
04-28-83	16	300.94	1005.39	426626	435186	432648
04-28-83	17	300.94	1005.39	425927	434510	431977
04-28-83	18	299.83	1004.78	424000	432606	429821
04-28-83	19	298.16	1004.46	425812	434440	431586
04-28-83	20	297.60	1005.35	424358	433009	430712
04-28-83	21	298.72	1005.96	421354	430028	428008
04-28-83	22	296.49	1006.23	419973	428670	426974
04-28-83	23	295.94	1006.52	419617	428337	426846
04-28-83	24	295.38	1006.52	420212	428955	427504
04-29-83	1	295.94	1006.72	420883	429649	428267
04-29-83	2	295.38	1006.02	421968	430756	429016
04-29-83	3	295.94	1006.32	422156	430967	429354
04-29-83	4	297.60	1006.04	423263	432097	430196
04-29-83	5	295.38	1006.32	422432	431289	429717
04-29-83	6	295.38	1007.01	422543	431423	430241
04-29-83	7	295.94	1007.41	423494	432397	431399
04-29-83	8	296.49	1008.02	422142	431068	430377
04-29-83	9	297.05	1008.32	421548	430496	429935
04-29-83	10	298.16	1008.33	422312	431283	430642
04-29-83	11	299.83	1008.35	424196	433190	432433
04-29-83	12	300.94	1007.57	425229	434246	432957
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04-29-83	14	302.60	1006.40	427341	436404	434311
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04-29-83	16	302.60	1005.01	428883	437991	435093
04-29-83	17	303.16	1004.62	427688	436819	433663
04-29-83	18	301.49	1004.30	428958	438112	434891
04-29-83	19	299.83	1004.58	427525	436702	433777
04-29-83	20	298.72	1004.96	428546	437746	435116
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04-29-83	22	297.05	1005.94	426450	435696	433764
04-29-83	23	295.94	1005.93	428449	437717	435854
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04-30-83	3	295.94	1006.22	422170	431530	429858
04-30-83	4	295.38	1006.22	423754	433137	431500
04-30-83	5	294.83	1006.51	424061	433467	432037
04-30-83	6	294.27	1006.80	422778	432207	430987
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04-30-83	9	299.27	1008.14	424440	433937	433100

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04-30-83	11	302.60	1007.59	425632	435175	433768
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04-30-83	14	304.83	1005.33	427297	436908	434032
04-30-83	15	303.16	1004.32	426965	436599	433274
04-30-83	16	300.38	1003.99	426187	435844	432546
04-30-83	17	296.49	1003.35	426299	435979	432608
04-30-83	18	300.38	1003.40	426395	436098	432462
04-30-83	19	299.83	1003.69	425317	435043	431622
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04-30-83	21	298.72	1004.57	422313	432084	429266
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04-30-83	24	297.60	1004.85	419022	428862	426306
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05-04-83	6	293.72	999.26	425077	436700	431200
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