CONTINUOUS MEASUREMENTS OF COSMIC-RAY INTENSITY WITH MULTI-DIRECTIONAL MUON TELESCOPE 50 M.W.E. UNDERGROUND AT MATSUMOTO†

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Abstract

A multi-directional muon telescope having an area of 8 m^2 was constructed in a tunnel with a vertical depth of approximately 50 m.w.e. at Matsumoto. Continuous measurements of cosmic-ray intensity have been made since April 7, 1971. A preliminary report is presented concerning the underground site, experimental apparatus, and its arrangement, as well as some examples of experimental data obtained, and analyzed results of cosmic-ray daily variation. Counting-rates are 6×10^4/hr of vertical component for 8 m^2 area at a depth of $\sim$50 m.w.e., and 3.4×10^4/hr of N-component at $\sim$42 m.w.e., 0.85×10^4/hr of S-component at $\sim$92 m.w.e. for each of 6 m^2 area, 1.1×10^4/hr of E-component at $\sim$65 m.w.e., and 1.55×10^4/hr of W-component at $\sim$53 m.w.e. for each of 4 m^2 area, inclined at 40° to the vertical. It is found that the observed phases of diurnal and semi-diurnal vectors for five components are indicative of the extraterrestrial nature of the daily variation. The observation thus may provide an important information on the modulation of cosmic-ray intensity variation.

1. Introduction

Continuous measurements of cosmic-ray intensity have been made for a long time, extending back to 1937 (Lange and Forbush, 1948 ; 1957) through IGY, IQSY, and IASY, and have widely been acknowledged to provide an unique means for studying the electromagnetic conditions of the interplanetary medium. The measurement has been performed by means of various detectors and at different

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elevations, including that underground and in space. Neutron monitors, meson telescopes or ionization chambers are mainly used as ground-based instruments having their own energy responses. For instance, neutron monitor detects nucleons whose primary cosmic-rays have an effective response energy of about 8 *GeV*, while meson telescope or ionization chamber has its peak response at around 15 *GeV*. Measurements at different elevations also have a similar situation for energy response ; in space a direct measurement of primary cosmic-rays is attainable, thus lower energy particles ($\sim$10−100 *MeV*) predominate. And another end of higher energy response is relevant to underground measurements responding effectively to the energy in the range of 100 to 1000 *GeV* (Ahluwalia, 1971 ; Dorman, 1957 ; Peacock, 1970), which depends on the depth.

The analyses so far, on the basis of the ground-based data have mostly been made by using the world-wide neutron monitor data, because of its large intensity variation due to the lower energy responses, as well as of its precise atmospheric correction, and provided much fruitful information about the modulation of cosmic-ray intensity variation. The data of other responses, e. g., of various meson telescopes and underground detectors are also used (Underground stations are listed as follows ; Budapest in Hungary, Chacaltaya in Bolivia, Embudo in U. S. A., Hobart in Australia, Kampala in Uganda, London in England, Takeyama in Japan, Torino in Italy, and Yakutsk in U. S. S. R.). The analyses of these data revealed other aspects of the modulation, in spite of smaller magnitude of time variation due to higher energy response. Atmospheric effects, however, especially temperature corrections of muon components are still required to be debated at the present stage.

One of recent remarkable results obtained from underground data could be referred to the examination of upper limiting energy of the modulation, particularly of cosmic-ray solar anisotropy. It is shown that upper limiting energy of anisotropy fluctuates from about 50 to 100 *GeV* as solar activity changes in the 11-year solar cycle (Duggal *et al*., 1967 ; Regener *et al*., 1968 ; 1970 ; Ahluwalia *et al*., 1970 ; Kuzmin *et al*., 1970). The higher energy response of the underground results is effective to reduce large background variations in lower energy regions, and thus to reveal the prevailing features of the modulation within the interplanetary medium.

Recent analyses of solar semi-diurnal anisotropy in lower energy responses also provided important informations about the modulation, particularly of cosmic-ray density around the regions far from the plane of ecliptic (Nagashima *et al*., 1971 ; Fujii, 1971 ; Mori *et al*., 1971 ; Rao *et al*., 1970 ; Lietti *et al*., 1969 ; references are therein). Underground data might give a definitive point for determining its spectral form, especially at higher energy side of the anisotropy having a peak intensity at around 50$\sim$100 *GeV* (Krivoshapkin *et al*., 1969 ; Cini-

Castagnoli *et al*., 1968).

Also the study of so-called sidereal time variation of cosmic-rays would be made best by utilizing underground data. The observations indicated the existence of sidereal anisotropy, and also suggested the probable modulation of solar origin as well as of galactic within solar system (Sekido, 1971 ; Jacklyn, 1970 ; Nagashima *et al*., 1971 ; Nagashima *et al*., 1971 ; Swinson, 1969 ; 1970 ; Ahluwalia, 1971 ; Elliot *et al*., 1970). It is noted that internationally cooperative ten years observation proposed by Ahluwalia (1971) to measure small sidereal variation, with high counts ($\sim 10^5$/hr) muon telescope responding to higher energy ($>$200 *GeV*), will be greatly fulfiled by the underground observation. Inherent low counting-rates in underground observations can be covered by increasing the detector in size, and also inherent atmospheric effects can be removed by taking a difference among intensities for multi-directional components of the muon telescope (Nagashima *et al*,. 1971 ; Murakami *et al*., 1970). As a step, a multi-directional muon telescope having an area of 8 m^2, one of which couting-rate is about 6×10^4/hr for vertical component, was constructed in a tunnel at a vertical depth of approximately 50 m. w. e. at Matsumoto. And continuous measurements have been made since April 7, 1971. A preliminary report is presented in this work concerning the underground site, experimental apparatus, and its arrangement, as well as some examples of the data obtained, and also analyzed results of the daily variation.

2. Experimental apparatus and its arrangement

2. 1 *Description of the underground site*

(*a*) *Location*

The multi-directional muon telescope having an area of 8 m^2 was constructed in a tunnel at a vertical depth of approximately 50 m. w. e. in Iriyamabe-district. The tunnel is about 5 km southeast from our cosmic-ray laboratory of Shinshu University at Matsumoto City in Nagano Prefecture, close to Mt. Norikura as shown in Fig. 1 and in Table 1. Matsumoto City is characterized by low temperature (~ -15 °C), but less snow in winter, and also by relatively scant rainfall (1063 mm of average annual precipitation over thirty years 1931−1960), and also relatively low humidity through the year.

(*b*) *The tunnel*

Photograph (Fig. 2) shows a distant view of the tunnel area taken from the northern side. Over the hill above the tunnel there is nothing but low bush, and this area is designated as a forest reserve. Fig. 3 is reproduced from a contour map of the tunnel area, and also complemented by the ground survey. Two cross-sections of the tunnel are illustrated in Figs. 4 (a) and 4 (b). The

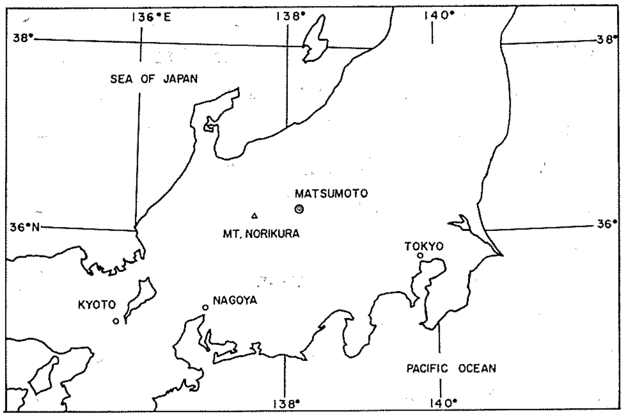


Fig. 1 Outline map of central Japan, showing the situation of Matsumoto City and Mt. Norikura.

Table 1 Locality of Matsumoto City.

Geographic		Geomagnetic		Altitude	Geomagnetic Cut-off*
Lat.	Long.	Lat.	Long.		
36°14′ N	138°00′ E	25°.7 N	203°.6 E	650 (m)	11.39 (*GV*)

* for vertical, calculated by Kondo for Mt. Norikura (1969).

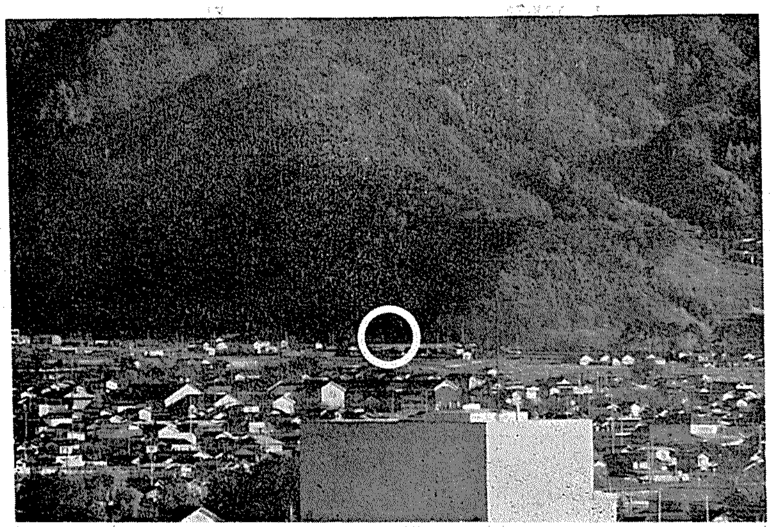


Fig. 2 Distant view of the underground site photographed from the northern side. Circle O indicates the position of underground observatory.

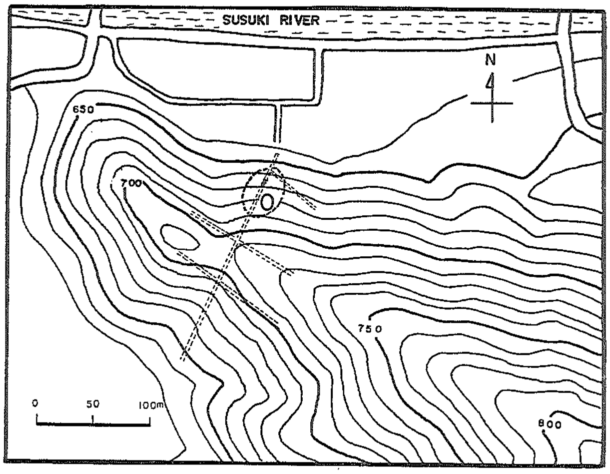
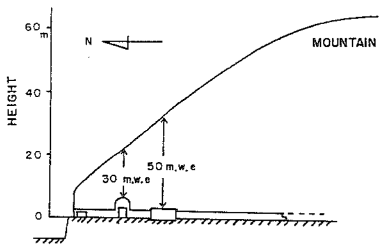
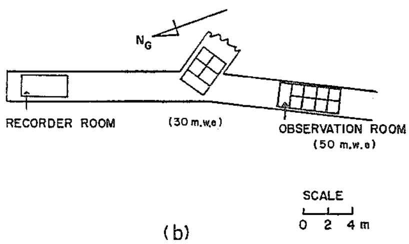


Fig. 3 Contour map of the tunnel area, demonstrating contour level at intervals of 10 m. The numbers give heights in meter above sea level. Underground observatory is situated at O inside the tunnel, which is plotted by dashed lines.



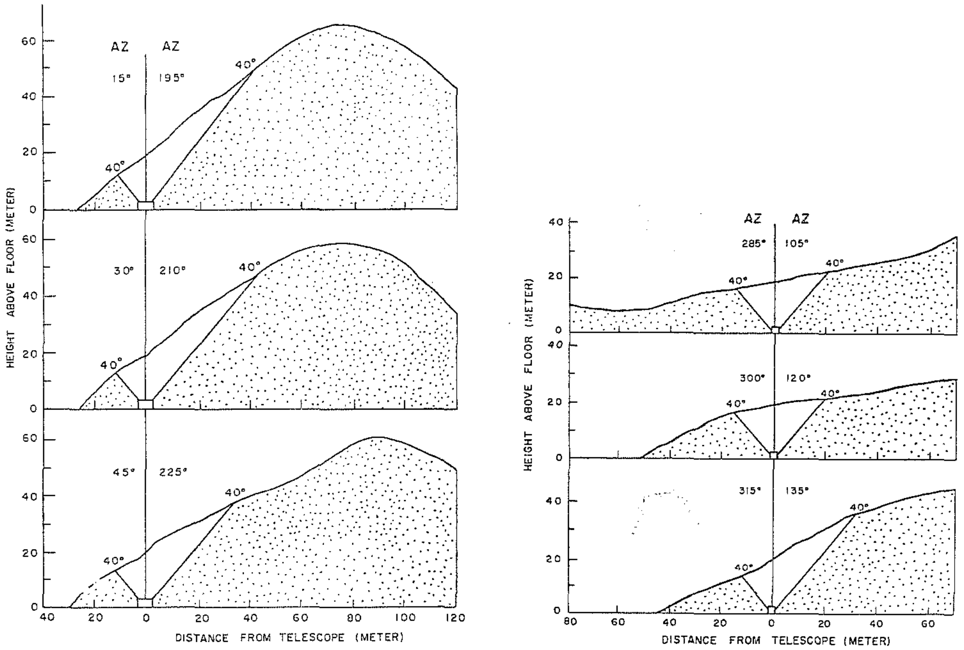
(a)



(b)

Fig. 4 Cross-sections of the tunnel area. (a) A plane figure in north-south plane. Height indicated in meter is measured above the floor. (b) A plane figure of the tunnel, showing two huts ; recorder room and observation room inside the tunnel.

entrance of the tunnel is facing north, and is directed along a line of about 30° with respect to the geomagnetic north. The slope of the hill is making an angle of around 35° to the horizon in this direction. Another ridge above the tunnel in east-west direction runs down in a gentle grade (~7°) to the ground as seen in Photograph (Fig. 2). The tunnel is about 2.5 m wide and 3 m high as shown in Fig. 4 (b). Simplified profiles of the absorber material above the tunnel are shown in Fig. 5 (a) and 5 (b) in six azimathal planes; 15°−195°, 30°−210°, 45°−225°, 120°−300°, and 135°−315°, respectively, with respect to the geomagnetic north. The shape of the hill above the tunnel is not so simple that precise depth for each direction such as vertical−(V), northward−(N), southward−(S), eastward−(E), and westward−direction (W), is undeterminable. This fact may yield additional complexity and ambiguity to precise determination of the energy response of cosmic-rays observed at the underground, and thus finally to better interpretation of the observed results. Here an approximate depth of 50 m.w.e. is given to a vertical depth for V−direction as shown in Fig. 4 (a), and 92 m.w.e. to the deepest depth for S−direction. The depth for each direction listed in Table 2 is determined not only by the ground survey, but also by means of cosmic-ray



(a) (b)

Fig. 5 Simplified profiles of the absorber material above the tunnel. (a) Profiles in the azimathal planes ; 15°−195°, 30°−210, and 45°−225°, with respect to the geomagnetic north. (b) Profiles in the azimathal planes ; 105°−285°, 120°−300°, and 135°−315°, with respect to the geomagnetic north.

intensity measurement. A plastic scintillator telescope of 50×50 cm^2 in area was used in the measurement, with various half opening-angles of $\pm 13°$, $+16°$ and $\pm 23°$ to deduce the vertical fluxes (counts/m^2•sec•ster). Measurements are made at various positions in the tunnel as well as at outside of the tunnel (0 m. w. e.) with zenith direction of 0°, and 30° for N-, S-, E-, and W-directions. The depth-intensity curve was utilized with the observed results to determine the effective depth as given in Table 2, and the estimated error is less than 5%. Two iron-framed huts are constructed inside the tunnel, and are roofed with thin wooden plates (3 mm thick) and also with solid styrol-faom for heat insulation.

(*c*) *Experimental conditions*

The rock above the tunnel is mostly of fine sandstones with density of about 2.5 g/cm^3, and a thickness of a soil above the rock is 10 cm at most with density of 2.0 g/cm^3 (see Fig. 5). It is not so easy to determine precisely the average amount of water contained among rocks. Some indication of the average water content at the steady state may be guessed from the following facts. Heavy rainfall of about 180 mm in total quantity was experienced over two days (120 mm in the first day and 60 mm in the second), after a long period of dry weather in the summer season in September, 1972. A decrease of about 1 % in the cosmic-ray counts was observed in the tunnel, which would be due to this rainfall. From the depth-intensity curve used, additional depth of rainfall 180 mm to 50 m. w. e. will be expected to decrease the cosmic-ray intensity as much as 0.6−0.7 %. This amount of decrease is nearly two-third of that observed in the present heavy rainfall. Above fact would suggest that some water may flow in from other area and accumlate around the region, beneath which the observation was made. This then leads to a conclusion that not appreciable amount of water is stored among rocks and soils at the steady state. Another guess about the constant contains of the water among rocks through the year is as follows. Constant but little water is coming out from the roof of the tunnel, except in the driest and frozen winter season, and this may suggest rather invariant variation of the water content among rocks with time.

The temperature in the tunnel ranges from 6 °C to 13 °C as the outside temperature changes in the range of −15 °C to 30 °C over one year. The room temperature, however, in the deeper observation room shown in Fig. 4, where the detecting apparatuses are placed, included the plastic scintillators, photo-multipliers (abbreviated to PM hereafter), and preamplifiers (also abbreviated to Preamp), is maintained at 22 ± 2 °C through the year. Similar condition is also kept in the shallower recorder room shown in Fig. 4, where the electronic circuits and the recording system are set, including mainamplifiers (abbreviated to Mainamp hereafter), coincidence circuits, mixing circuits, scalers, punch-controllers, recorders, a crystal clock, and monitoring apparatuses. The daily variation of the temperature in both rooms is less than 0.5 °C, and its time of maximum is around 18 hr. L. T. This range of the temperature change will produce an effect on the cosmic ray counts, with the observed coefficients of about −0.1 %/°C. This effect, however, can be neglected, especially for the case where differences are taken between the intensity variation for each directional component, thus the atmospheric effects result to vanish in this case. This is one of the merits in the present cosmic-ray measurement with the multi-directional telescope, which has already been demonstrated experimentally by Nagashima *et al.* (1971). The humidity inside both rooms is also controlled within 65 % by raising the room temperature higher (about 10 °C) than in the tunnel, of which humidity is almost 100 %. The temperature, and the humidity, as well as the atmospheric pressure has been recorded constantly on the pen-recorder chart in both rooms.

2. 2 Apparatus and its arrangement

(*a*) *Plastic scintillator*

The multi-directional muon telescope is schematically shown in Fig. 6. The telescope is constructed with 16 plastic scintillator detectors in all, each having an area of 1 m^2, made of double layers of upper and lower arrays of 8 m^2 area separated verticall by 125 cm. The telescope consists of five sub-telescopes, and

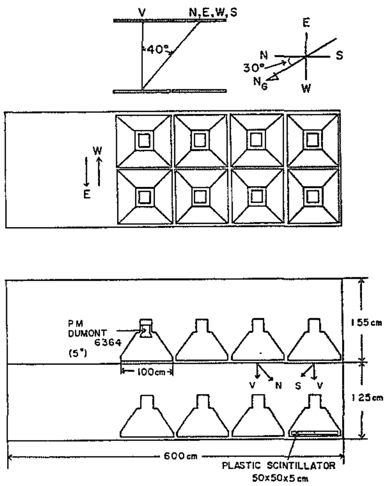


Fig. 6 Schematic diagram of the multi-directional muon telescope of 8 m^2 area. Upper left diagram shows a zenith angle extended by one unit of the detector of 1 m^2 each along a central axis for each component, and also upper right diagram shows its azimathal direction relative to the geomagnetic north N_G. Middle and bottom diagrams give plane and side views of the telescope, and plastic scintillators and photo-multiplier are also illustrated. Upper and lower arrays are separated vertically by 125 cm.

measures the cosmic-ray flux from four slant directions of north, south, east, and west, as well as from vertical, with eight vertical two-fold coincidence telescopes, six north and south, and four east and west telescopes (see Table 2). Photograph (Fig. 7) gives a side view of eight detectors of lower arrays, one-half of the telescope. One unit of the detector of 1 m^2 area contains four plastic scintillators of $50 \times 50 \times 5$ cm^3. Plastic scintillators were homemade in our laboratory*. Each detector is viewed by Du-Mont 6364 PM (5″ in diameter) mounted at the apex of the iron box (1.5 mm thick) as shown in Fig. 6. The shape of the plastic scintillator and the iron box, as well as their geometrical arrangement is almost the same as those used by Nagoya University Group (Nagashima *et al*., 1971). In order to utilize as much scintillation light as possible, emitted in the plastic by passing through charged particle, the inside surface of the box is coated with white-paint (Marine Paint) having refractive index of about 0.9. Some examples of real counts characteristics of the detector are shown in Fig. 8 (a), in which real counts per minute measured at outside the tunnel (0 m. w. e.) are plotted versus supplied high voltage. Large fluctuations are found in these characteristics, depending mostly upon PM ; for example, the over-all gain for the detector No. 1 is about three times as great as that for the detector No. 3. As uniform gains for all the detectors are desirable, the applied high voltage to each PM is adjusted to compensate this difference in characteristics. The counts at the plateau in the figure seem to indicate reasonable omni-directional counting-rates of cosmic-rays

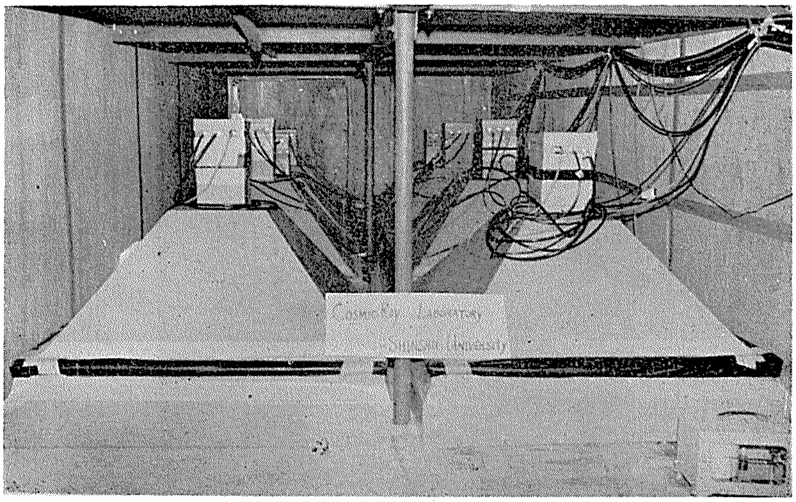


Fig. 7 Side view of eight plastic scintillator detectors of lower array, one-half of the telescope.

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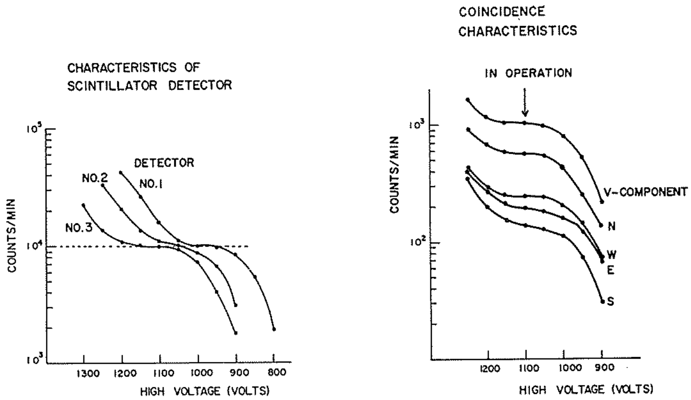
* Produding apparatus, and also producing instruction are much owed to Cosmic-ray Group in Nagoya University.



(a) (b)

Fig. 8 Real counts characteristics versus supplied high voltage. (a) Some examples of counts characteristics measured at outside the tunnel (0 m. w. e.), showing reasonable cosmic-ray counts about 10000 counts/min. m^2. (b) Coincidence characteristics for five directional components, measured at the observation room (vertical depth of 50 m. w. e.) which show different countings, depending upon each depth and area. An arrow indicates applied high volatge in operation.

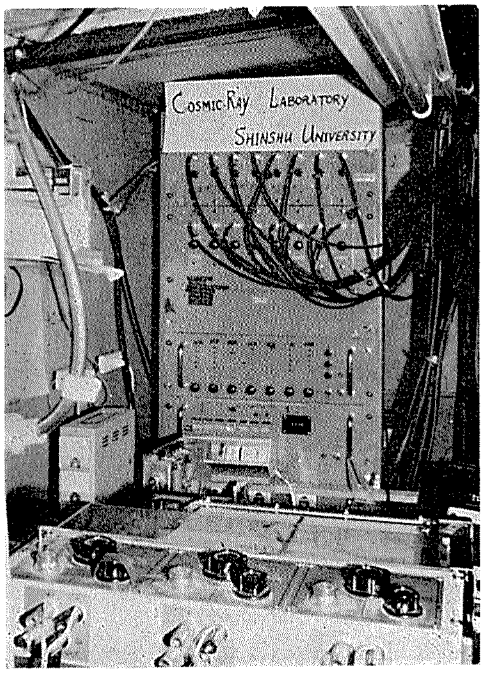


Fig. 9 Front view of one of panels of the electronic circuits.

(~10000 counts/min•m²), which would be expected from the intensity of muons and electrons at sea level. It is also found that they have wide ranges of the plateau in the curve, about 100 volts with a slope of −5 %/50 volts. A method of two-fold coincidence is used in order to pick up the cosmic-ray signals. Coincidence between pulses from specified pair of eight detectors in upper and lower arrays, which are due to the passage of cosmic-ray particle through the plastic scintillator are recorded as shown in Fig. 6. Some coincidence characteristics of counting-rates in operation versus supplied high voltage are shown in Fig. 8 (b), with its gradient of about 0.02 %/5 volts at a certain bias voltage (2.5 volts) of the discriminator (see (c) Electronic circuits). This height of the bias voltage is chosen so as to select as many signals as possible, but to reduce the number of noises which produce accidental coincidences considerably. For simplicity in operation the bias voltage of the discriminator is set at 2.5 volts in common to all the detectors, and a little remaining difference among detectors is further complemented by fine adjustment of applied high voltage. In Fig. 8 (b), apparent differences in real counts can be seen among five directional components, having its different effective area and depth as tabulated in Table 2. Owing to low counting-rates (~100−1000 counts/min), these observed real counts are contaminated with background showers by about 10 % and also with accidental coincidences among noises by about 1 %, depending on the setting bias voltage as mentioned earlier. Long-term drift in the detecting efficiency of the detector was observed to be about −3 % during half a year, which might be dominantly due to the gain decrease of PM.

(*b*) *Mean sensitivity of the telescope*

As described in the preceding section, cosmic-ray measurements have been made for five directional components; V-, N-, S-, E-, and W-components. It is of prime necessity for the following analyses to know the effective directions, as well as the effective depths for incoming cosmic-rays to above five directions at the underground. This can be determined by considering both geometrical arrangement of the telescope as shown in Fig. 6, and geometrical shape of the absorber material above the telescope as also given in Fig. 5. Mean directional sensitivity which includes radiation sensitivity will be further calculated under an assumption of the zenith distribution of cosmic-rays observed at the underground. By using both mean sensitivity and the depth-intensity curve, the effective depth for each direction will be derived. The detailed calculations are now in progress, and the results will be presented in near future.

(*c*) *Electronic circuits*

Electronic circuits are designed in a similar fashion to those used in the multi-directional muon telescope at Mt. Norikura and at Nagoya University (Nagashima *et al.*, 1971). Front view of one of the panels of the electronic circuits is shown in Photograph (Fig. 9). Transistors are used in almost all of the circuits, and any malfunctions of the circuits can be fixed by changing a spare plug-in board. Block diagram of the electronic circuits is given in Fig. 10. Electronic pulses from the anode of PM, produced by scintillation light from the plastic, are amplified with Preamp (~10 db) adjacent to PM in the scintillator box and sent into the next stage of Mainamp in the recorder room through an emitter-follower in Preamp and a long coaxal cable (~30 m). High voltage applied to each PM is in the range of 700 to 1100 volts, depending on each PM characteristics, with coarse and fine adjustment (see Fig. 10). After amplified with Mainamp (~50 db), the output pulses are fed into the next stage of the discriminator which cuts off dominant thermal noises in PM with low pulse height (Fig. 8 (a)), and then sent into the pulse shaper. The resultant output pulses of about 10 volts high and about 0.2 microsecond in width are introduced into the coincidence circuit with resolving time ~0.3 microsecond. After mixing the outputs from the coincidence for each directional telescope, the pulse is then sent into the scaler, and finally to the recorder system. In order to get a better recording of the signals, two kinds of recording apparatuses are used and complemented with each other. One is the tape-puncher, and another the telephone-register (see Fig. 10). Cosmic-ray counts from five directions of arrivals ; V-, N-, S-, E-, and W-direction are recorded separately in four figures, together with date in six figures. Both apparatuses are controlled by the crystal clock having precision better than ± 1 second per day, through the punch-controller. For monitoring the electronic circuits, included PM and high voltage supply, three channels of the output signals ; two single counts of upper and lower arrays, and one their sum are traced constantly on the pen-recorder.

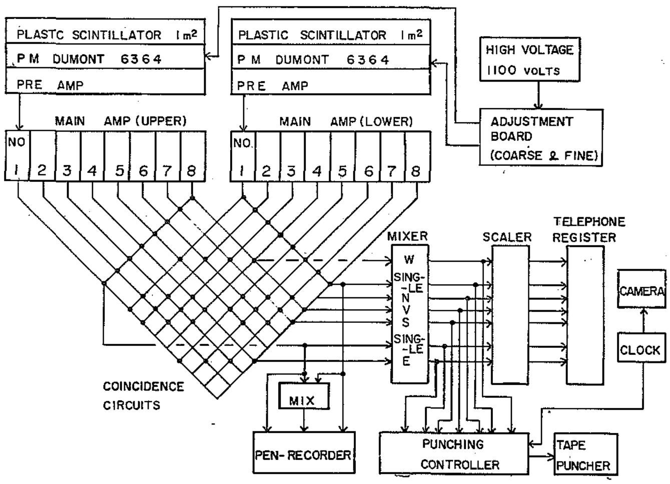


Fig. 10 Block diagram of the electronic circuits.

(*d*) *Multi-directional muon telescope*

The multi-directional muon telescope has some advantages for the elimination of contaminations from inherent atmospheric effects, background showers, noises, and also electronic disturbances. For the observation of cosmic-ray modulation the intensity variation due to atmospheric effects should be removed. However, in view of the fact that the correction for temperature variation is not so precise and practical, due to the fact that the data of the temperature in higher atmosphere is not available on the hourly basis, the following method would be one of those preferred. By taking difference between relative intensity variation in percent for any pair of five directional components, differences are regarded as the ones which are almost insensitive to atmospheric effects, under the assumption of a similar atmospheric condition between them. Also resultant differences are free from common unknown background showers, noises, and also electronic disturbances. Differences further cancel the isotropic variations common to these components. The merits of these differences have already been shown effectively and successfully in the analyses of cosmic-ray solar anisotropy (Nagashima *et al*., 1971 ; Fujii, 1971). In addition to above mentioned merits, the multi-directional telescope can further make the directional cosmic-ray measurements at the same time. Such multi-channel data thus make possible to determine the nature of the intensity variations at one station, and may provide more informations about the modulation.

The telescope of 6 m^2 area was completed on April 7, 1971, and the observa-

Table 2 Characteristics of multi-directional muon telescope 50 m.w.e. underground.

Component	Center direction (Zenith) (°)	Observed Counting Rate ($\times 10^4$/hr)	Standard Error σ (%/hr)	Barometric Coefficient β* (%/mb)	Number of Sub-Telescope	Depth** (m.w.e.)
Upper Single	—	30	0.18	—	8	—
Lower Single	—	30	0.18	—	8	—
V	0	6.0	0.41	−0.05	8	50
N	40	3.4	0.54	−0.04	6	42
S	40	0.85	1.08	—	6	92
E	40	1.1	0.95	−0.01	4	65
W	40	1.55	0.80	−0.03	4	53

* provisional

** determined by cosmic-ray measurement. Estimated error is less than 5 % (see 2.1 (b)).

tion was started by that instrument. In August, the remaining part of the telescope was added, and continuous observations with an area of 8 m^2 have been made since August 2, 1971. Cosmic-ray intensity from five different directions; V-, N-, S-, E-, and W-directions, are punched out on the paper-tape once every hour, and simultaneously on the telephone-register which is photographed by camera. Average counting-rates for five directional components, together with their central directions of view, number of sub-telescopes contained, barometric coefficients, and effective depth are summarized in Table 2.

3. Experimental data

3. 1 Observed data

One example of the observed intensity variation for five components without corrections for atmospheric effects is plotted in Fig. 11, together with some of

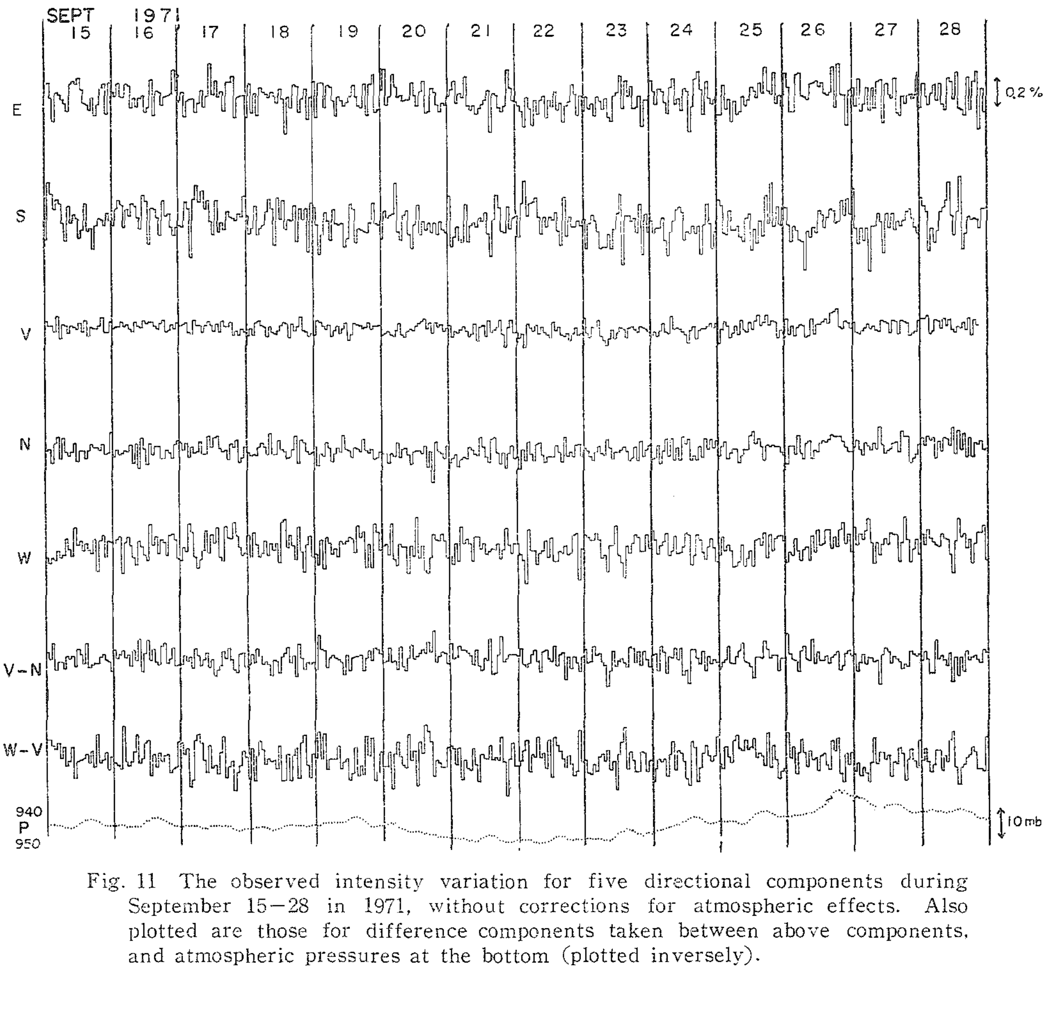
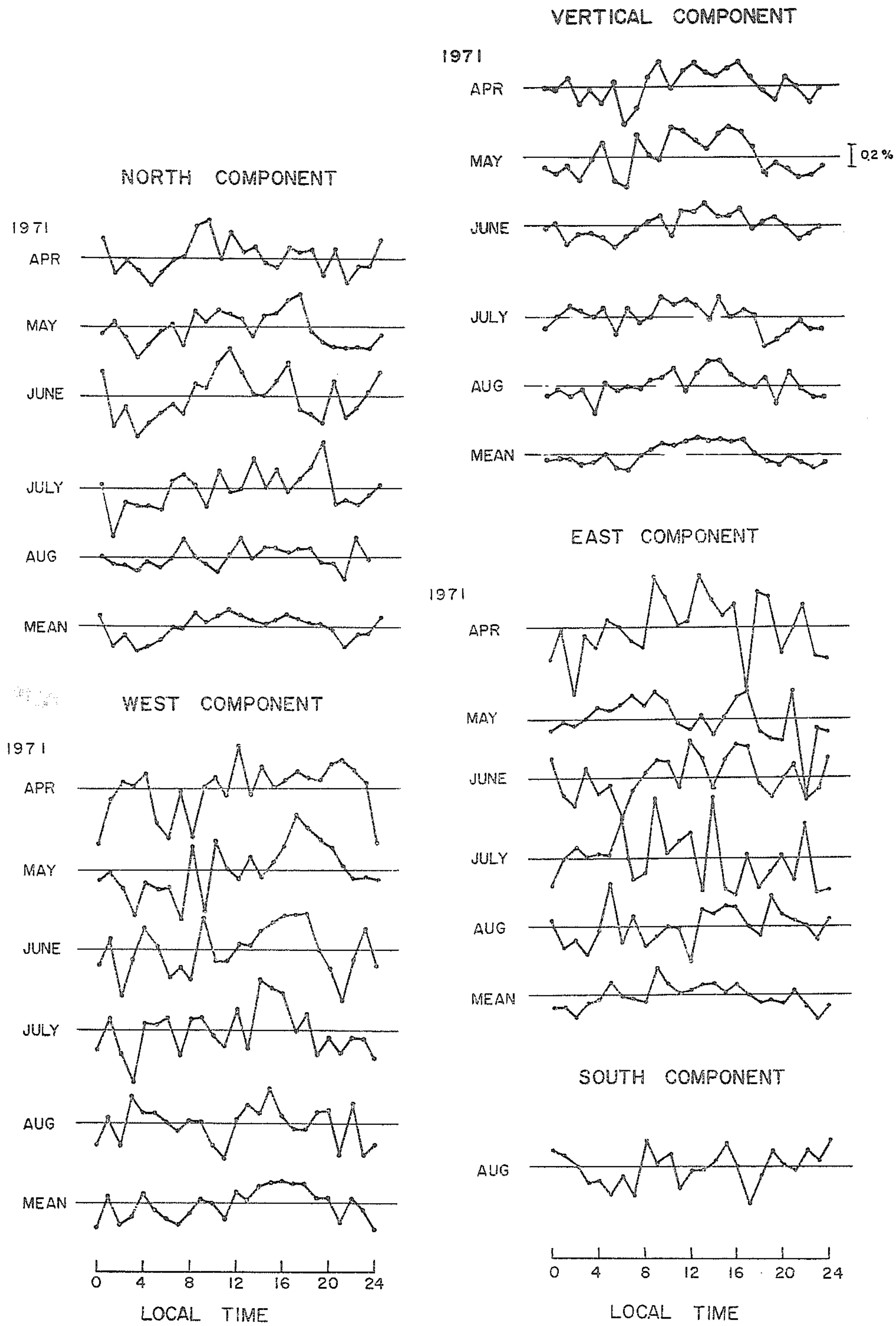


Fig. 11 The observed intensity variation for five directional components during September 15—28 in 1971, without corrections for atmospheric effects. Also plotted are those for difference components taken between above components, and atmospheric pressures at the bottom (plotted inversely).


VERTICAL COMPONENT
1971
APR
MAY
JUNE
JULY
AUG
MEAN
0.2 %
NORTH COMPONENT
1971
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AUG
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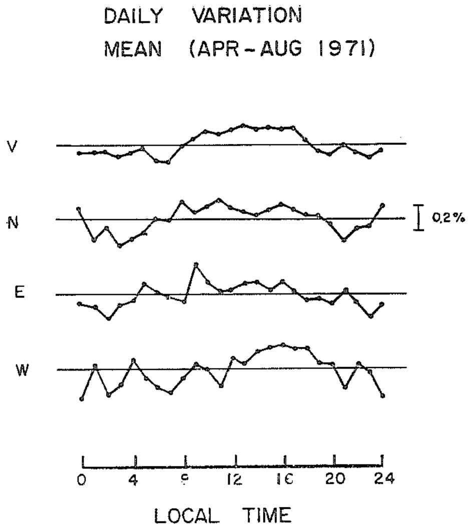
(a)



(b)

Fig. 12 The daily intensity variation for five directional components from April to August in 1971. (a) The monthly daily variation and the mean intensity for five months. (b) The averaged daily variation over five months (April-August) for four directional components, excluding S-component owing to intermittent connection failures.

those for differences taken among them for the period September 15–28, 1971. Atmospheric pressures plotted in the figure have been obtained from Matsumoto Local Meteorological Station, 3.5 km far from the underground cosmic-ray station. The monthly averages of the daily intensity variation from April to August for four directional components are given in Fig. 12 (a). In the figure for S-component only the variation in August is shown, owing to intermittent connection failures in coaxal cable and connector up to July 31. In Fig. 12 (b) the averaged daily variation over five months (April-August) is demonstrated for four directional components, which is left uncorrected for atmospheric effects.

3. 2 Analysis of data

The barometric coefficients are determined provisionally for each directional component in the present observations, and are compared with the results obatined by other authors. As shown in Table 2, the coefficients are variable, depending upon the effective depth. They seem to be reasonable, based upon a simple theoretical argument, that is, for a depth of 40～50 m.w.e. the coefficients are approximately −0.04～0.05 (%/mb), and for 60～70 m.w.e. the coefficients −0.03 ～0.02 (%/mb). The coefficient becomes smaller, the greater the depth, and is in good agreement with the results observed by other authors. For a depth of 60 ～70 m.w.e., $\beta \approx -0.037 \sim 0.045$ (%/mb) (Cini-Castagnoli *et al.*, 1968 ; Dutt *et al.*, 1965), and for ～40 m.w.e. $\beta \approx -0.04 \sim 0.06$ (%/mb) (Fenton *et al.*, 1961 ; Sandor *et al.*, 1962 ; Thomson *et al.*, 1971), suggesting the present observed data might be reliable.

The observed data during five months (April 7 – August 31, 1971) were harmonically analyzed, and the preliminary accounts of the anisotropy will be given. Monthly first and second harmonic vectors of the daily variation are derived for four directional components ; V-, N-, E-, and W-components, excluding S-component, and also for the difference intensity variation taken among them. Fig. 13 (a) gives summation harmonic-dial of the monthly diurnal vectors for V-, N-, E-, and W-components from April to August, 1971, and in Fig. 13 (b) their averaged vectors over five months (April-August) are shown. Fig. 13 (c) also demonstrates averaged difference diurnal vectors taken among vectors plotted in Fig. 13 (b), together with those observed at Mt. Norikura for the period

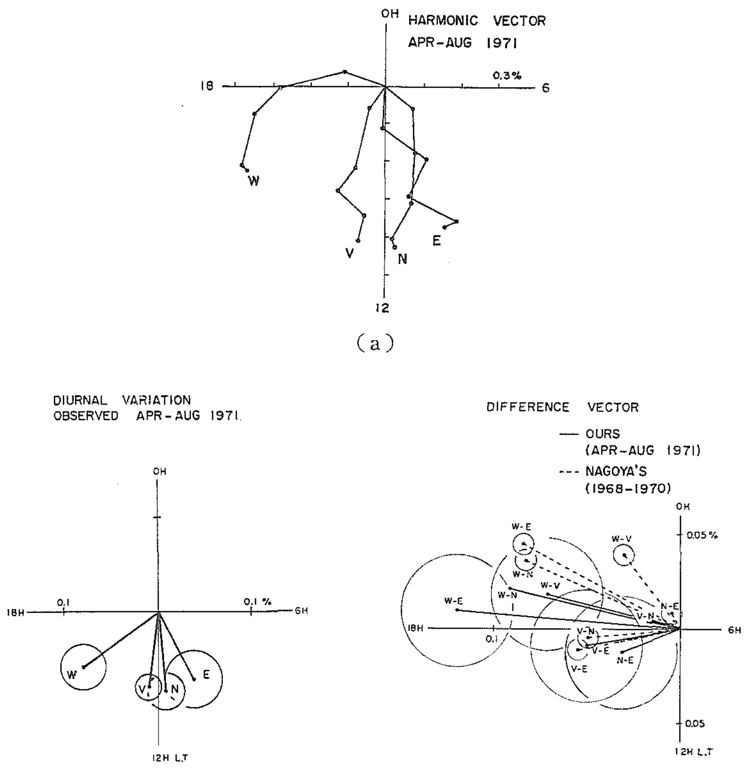
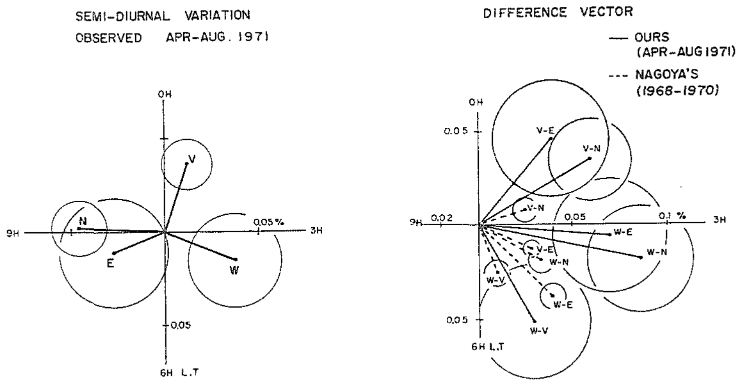


Fig. 13 The diurnal vector of the intensity variation. (a) Summation harmonic-dial of the monthly mean vectors for four components from April to August in 1971. (b) Averaged diurnal vectors over five months (April-August) for four directional components. Attached errors are taken from each counting-rates. (c) Difference diurnal vectors, for six components derived from above four vectors, and also shown difference vectors observed at Mt. Norikura for the period 1968–1970.

1968−1970 (Fujimoto, 1971). Figs. 14 (a) and 14 (b) also give the semi-diurnal, and the differences between semi-diurnal vectors for four directional components, together with those at Mt. Norikura (Fujii, 1971). Error circles attached in the figures are taken from counting-rates for each component. The data are corrected for atmospheric pressures, using common coefficient −0.03 (%/mb), but left uncorrected for the temperature. Difference vectors, of course, are free from such atmospheric effects as mentioned earlier.



(a) (b)

Fig. 14 The semi-diurnal vectors of the intensity variation. (a) Averaged semi-diurnal vectors over five months (April-August) for four directional components. Attached errors are taken from each counting-rates. (b) Difference semi-diurnal vectors for six components derived from above four vectors, and also shown difference vectors observed at Mt. Norikura for the period 1968−1970.

First, as for the cosmic-ray solar diurnal variation, it is found that each monthly vector moves persistently from month to month as shown in Fig. 13 (a). And averaged vectors are statistically significant, in which each vector has an amplitude more than two times of the standard error as plotted in Fig. 13 (b). Further, difference vectors in Fig. 13 (c) can be clearly seen to be in good agreement with those observed at Mt. Norikura for the period 1968−1970. Second, Figs. 14 (a) and 14 (b) show that the observed vectors for the semi-diurnal variation are also consistent with those observed at Mt. Norikura. At a glance in these figures, observed phase relations among components are reasonable, in view of their asymptotic directions. Observed phases for both diurnal and semi-diurnal variations of W-component are latest among them, which are 15.5 hr and 3.8 hr L. T., respectively. And V is next for both variations, observed at 12.4 hr and 0.6 hr L. T. Phases for N and E, however, are obtained at 11.5 hr and 9 hr for N, and 10 hr and 8.3 hr L. T. for E, respectively. This relation between them is found to be rather inverse, but within error, based upon a simple account of asymptotic directions, and this is probably due to poor statistics as shown in Figs. 13 (b) and 14 (a). It is noted that these observed phases are indicative of the extraterrestrial nature of the daily variation.

A preliminary examination has been made concerning with the nature of solar anisotropy in space, which would be responsible for the observed underground variations. Least squares method and also χ^2-test (chi-square test) were utilized in a similar manner already used in the previous analysis of the neutron monitor data (Mori *et al.*, 1971). In the present case the standard error is taken from those for counting-rates. The expected variations were calculated by assuming the power-type spectrum $P^{-\gamma}$ for the anisotropy, with Dorman's response function (Dorman, 1957), and also with asymptotic directions calculated by Kondo (1966). One case was obtained provisionally, where $\gamma \sim -0.5$ and the source direction is about 12.5 hr L. T. for the diurnal anisotropy. And $\gamma \sim 0.0$ and its direction lies at around 0.7 hr L. T. for the semi-diurnal anisotropy, respectively, which give minimal χ^2 values or minimal sum of the residuals for the differences between the observed and expected variations. These results are still required to be examined, because both anisotropies are somewhat different from, but do not appear to be inconsistent with, those which have already been obtained by the telescope with lower energy responses (Nagashima *et al.*, 1971 ; Fujii, 1971 ; Fujimoto, 1971). Final analyses will be made by determining precise effective depth and direction for each component, and further by accumlating the observed data as much as possible, at least one full year.

4. Conclusions

A multi-directional muon telescope having an area of 8 m^2 was constructed in a tunnel with a vertical depth of approximately 50 m. w. e. at Matsumoto, and continuous observations have been made since April 7, 1971.

From the above results and discussions it may be concluded that,

(1) Reliable data are obtained, and the derived barometric coefficients are in good agreement with those obtained by other authors.

(2) Preliminary accounts of solar anisotropies suggest that the observed phases for diurnal and semi-diurnal vectors might indicate the extraterrestrial nature of the variation. The spectral dependence, determined by the present underground data is found to be somewhat different from, but does not appear to be inconsistent with, those which already obtained by the telescopes with lower energy responses.

Further investigations, especially of spectral determinations for semi-diurnal anisotropy are now in progress, and the results will be presented elsewhere.

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