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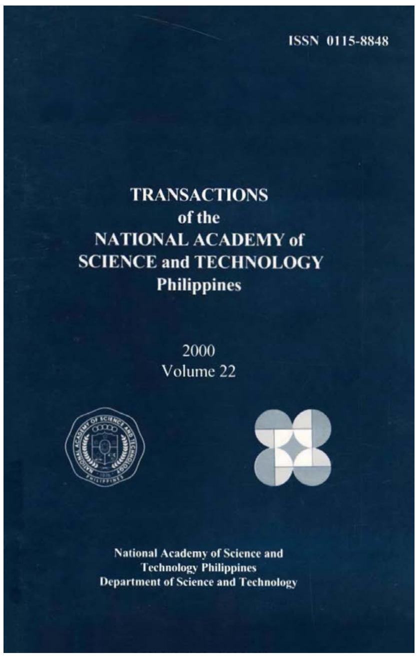

Measurement of Cosmic Ray Flux in Iligan City

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NEW MEASUREMENT OF COSMIC RAY FLUX IN ILIGAN CITY

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ABSTRACT

Sea level cosmic ray flux is measured anew in Iligan City using two plastic scintillators of area 100x10 cm2 which are stacked vertically by a spacing of 150 cm. Each scintillator is separately coupled to a Hamamatsu photomultiplier tube which when high voltage is applied, constitutes a detection-amplification system. This assembly of detectors is then connected to Nuclear Instrumentation Modules to discriminate and count coincident signals over a fixed interval of time through the months of August -- September 1999 at the MSU-IIT High Energy Physics (HEP) Laboratory. Data show that there is no significant difference between the measured average nighttime and daytime cosmic ray fluxes and that the average hourly and daily fluxes is a constant throughout the measurement period. All these results are in agreement with the first measurements of cosmic ray flux done at the same laboratory in 1999 using an entirely different detector-electronics assembly. The measured values are also shown to be consistent with Monte Carlo simulations and with the predicted, internationally accepted values.

Key words: Cosmic ray, plastic scintillator detectors, NIM modules

INTRODUCTION

Studies on cosmic rays are generally conducted at different locations, depending on the objectives of the study. High Altitude measurements offer the advantage of obtaining direct measurements of the chemical composition and energy spectra of highly energetic primary cosmic rays and allow observation of higher occurrence rate of cosmic ray events, such as atmospheric muon production processes (Maeda, 1973). Moreover measurement of horizontally incident cosmic ray muons at higher altitudes is accurate enough for studies on very high-energy muons. However, such measurement, especially if aimed at higher energies, requires huge detectors and sufficiently long exposure time (Hong, 1995). It is also susceptible to uncontrolled deviations in thermodynamic parameters of the atmosphere, such as atmospheric temperature, pressure, and particularly, vertical temperature gradient (Maeda, 1973). To compensate this limitation, sea level and underground studies are carried by measuring the extensive air showers at the surface as well as the penetrating high-energy muons to obtain indirect information on the chemical composition of the primary cosmic rays (Maeda, 1973).

Cosmic rays are high-energy subatomic particles that originate from outer space. They initiate ionization of the upper atmosphere of the earth thereby producing extensive air showers of secondary particles that, in turn, decay in flight to form the atmospheric muons. These cosmic ray fragments traverse the atmosphere in all directions and interact with surface materials. This fact made it possible for such interactions to be detected and measured using proper absorbing materials, apparatus, and method of observation.

Studies of terrestrial cosmic ray flux is a very important aspect of radiation monitoring. For instance, it has been estimated that the exposure of aircrew to cosmic radiation is 10x at plane altitudes that at sea level and health issues have been raised (New Zealand NRL, 1995). It has also been documented that cosmic rays cause soft fails in electronic logic or memory and the knowledge of local cosmic ray flux is essential in predicting electronic fail rates (Zeigler, 1996).

METHODS OF OBSERVATION

A. *Set-up*

The experimental set-up shown in Fig. 1 is composed of two plastic scintillators of area 100x10 cm^2. Each scintillator is coupled to a photomultiplier tube *(PMT)* to form a detection-amplification system. The output of the assembly of detectors is then channeled to the Nuclear Instrument Modules *(NIM)* as input for signal processing and counting of coincident signals. The two scintillation counters, together with the nuclear instrumentation modules, form the pulse-type system of counting used in the experiment.

The two scintillation counters are mounted horizontally on a supporting wooden stand, as shown in Fig. 1, so that one runs parallel to the other at a

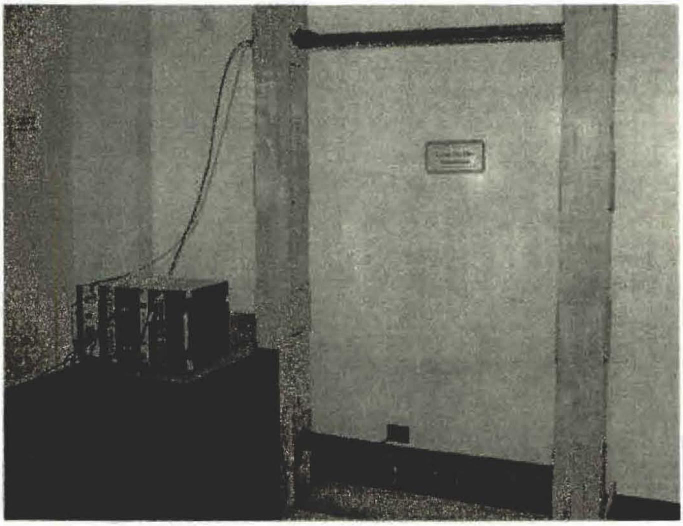


Figure 1. The Experimental Set-up

vertical distance of 150 cm. The counters are then connected to a high voltage power supply using two high voltage cables. The output terminals of the scintillation counter assembly are then connected to the *NIM* modules via small co-axial cables of the same length. The cables must be of the same length to avoid discrepancy in the delaying of signals from the counters to the coincidence circuit.

B. *The Detector*

The two detectors used in this experiment are each composed of plastic scintillators, of dimensions 100x10 cm^2, 0.50 cm thick and coupled optically to identical *PMTs* of type Hamamatsu H1161-RB9038. The scintillators are made of scintillating materials that produce sparks or scintillations of light when an ionizing radiation passes through them (Tsoulfanidis, 1983). Light from the scintillator is very weak and this necessitates a photomultiplier tube for amplification of the order of 10^6. The *PMT* then converts the amplified light into a strong electric pulse at its output.

C. *Nuclear Instrumentation Module (NIM)*

The *NIM* modules that were used in this study shown in Fig. 2 consist of a delay module, an 8-channel discriminator module, a 4-channel coincidence module, and the dual scaler or counter with an LCD display.

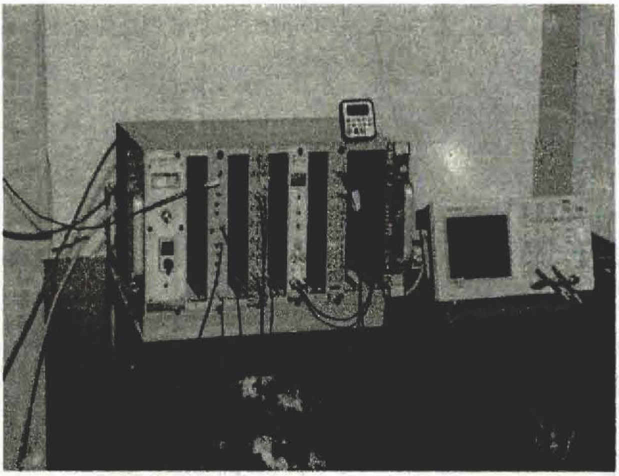


Figure 2. The Nuclear Instrumentation Module

With high voltage on, observable electric pulse from the *PMT* anodes actually represent the amplified photoemissions coming from cosmic ray particles hitting the plastic scintillators. Low-level pulses collectively called electronic noise, however, usually accompany these signals and tend to distort them. Hence, a standard logic circuit unit called the *NIM* discriminator module is used to select the desired input pulses and eliminate electronic noise by properly setting the threshold voltage level of the module. Input pulses whose corresponding energies are lower than the indicated threshold are rejected while pulses whose corresponding energies exceeded or at least equaled the threshold are allowed for subsequent counting.

Measuring cosmic ray flux using a single detector renders the experiment ineffective since signals from the detector represent a mixture of particles hitting the detector as mentioned. Therefore at least two detectors should be used. The particle of interest must hit both detectors coincidentally, with the signal coming from the second serving as a confirmation of its arrival at the first detector (Niñofranco, 1999). In order to ensure that signals are emanating from both detectors another standard circuit is used which is the *NIM* coincidence module. This unit is responsible for accepting two or more input pulses and conducts signals at its output only if the input pulses arrived at a specified time interval known as the resolving time. In order to register the desired coincidence, detector signals are first allowed to pass through delay lines prior to discrimination process and coincidence counting. Once proper delay is implemented (using coaxial cables and a *NIM* delay module), the signals are then guided to the discriminator, and then to the coincidence unit. Finally, pulses that are observed to be coincident are gated to the output for subsequent recording by the scaler.

Preparatory Measurement

The set-up shown in Fig. 1 cannot be used directly to have the cosmic ray flux measurement. Preparatory measurements should be done first in order that set-up is the appropriate assembly for the said measurement.

A. *The PMT Operating Voltage*

Photomultipliers can be operated over a wide range of working voltages extending over 1000 volts or more before reaching the maximum rating. The maximum high voltage ratings of the two *PMTs* used is -25000 volts. However, the actual operating voltage used in this experiment is set to -1800 volts. Figs. 3 and 4 show the actual operating voltage as determined by the plateau measurement process.

B. *The Coincidence Method*

To obtain a reasonable discriminator threshold voltage, both detectors A and B are operated one at a time and the schematic diagram shown in Fig. 5 is used. Figs. 6 and 7 show the resulting curve for threshold voltage determination. In addition, the detector (A/B) is paired to a reference detector C whose discriminator was set to minimum and the discriminator of the detector (A/B) is then varied from its minimum to maximum in steps of -100 mV. The ratio of the counts from the two scalers (N_1/N_2) is plotted against the threshold voltage of the discriminators and coincidence unit width was set to 50 ns. The very low ratio of N_1/N_2 corresponds to the noise, and the very high ratio of N_1/N_2 already neglects more significant coincidence. Based on Fig. 6 and 7, the discriminator threshold voltage is chosen at -500 mV. At this level, most of the noise are eliminated while all or most of the desired cosmic ray signals are kept.

The relative delay to be imposed on the branch of the set-up that delivers the delayed or advanced signals to the coincidence unit is measured using the schematic diagram shown in Fig. 8. This time both detectors A and B are now operated at the same time while no more reference is made to detector C. Delays on A and B are adjusted and the appropriate threshold voltage voltages were set. The ratio of the counts on the scalers (N_1/N_2) was then recorded and plotted against the relative difference of Delay A and Delay B as T_a-T_b. The correct setting for the delay must then be the value of T_a-T_b corresponding to the middle of the plateau shown in Fig. 9. For this experiment, detector A is delayed by T_a=5 nanoseconds and detector b delayed by T_b=10 nanoseconds, thus making the relative delay, T_a-T_b = -5 nanosecond.

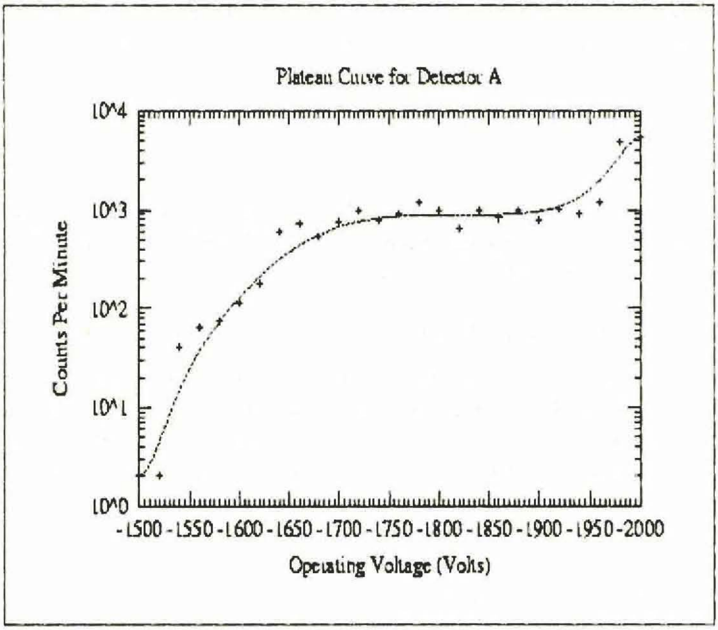


Figure 3. Plateau Curve for Detector A

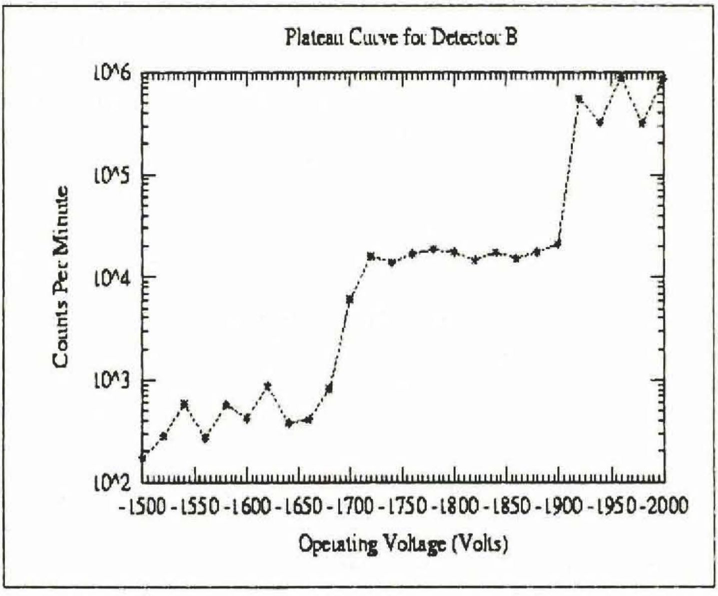


Figure 4. Plateau Curve for Detector B

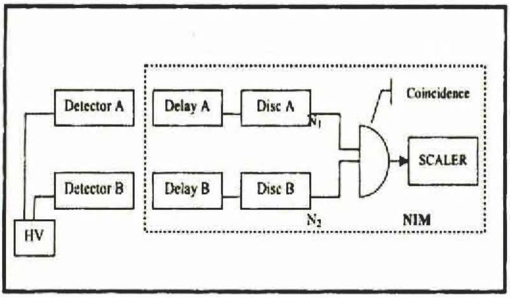


Figure 5. Schematic diagram of the connection for the determination of the threshold voltage

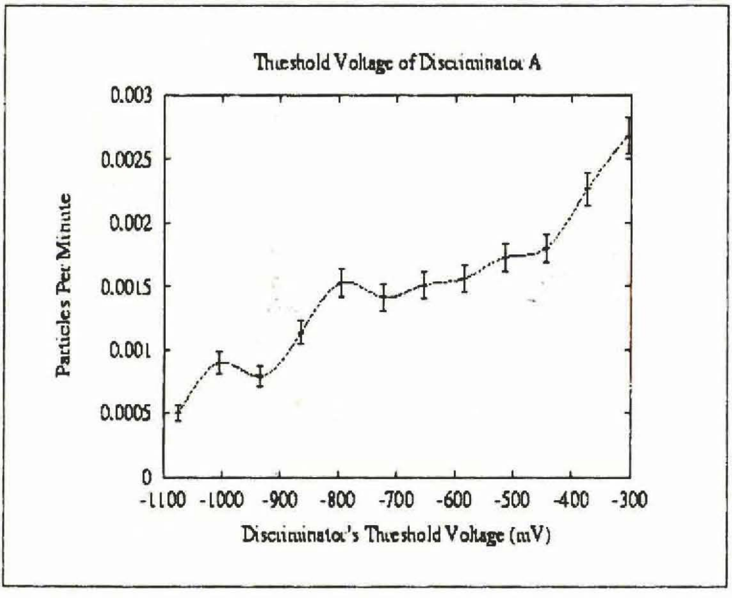


Figure 6. Threshold Curve for Discriminator A

RESULTS

Once the proper settings for the discriminator and delay are done we can then proceed to the measurement of cosmic ray flux. The set-up is then made to operate from 8:00 AM to 4:00 PM during daylight and from 8:00 PM to 4:00 AM during the night. The counts taken directly from the coincidence circuit are recorded on an hourly basis, which means that for daytime and for the nighttime we obtain 8 samples each.

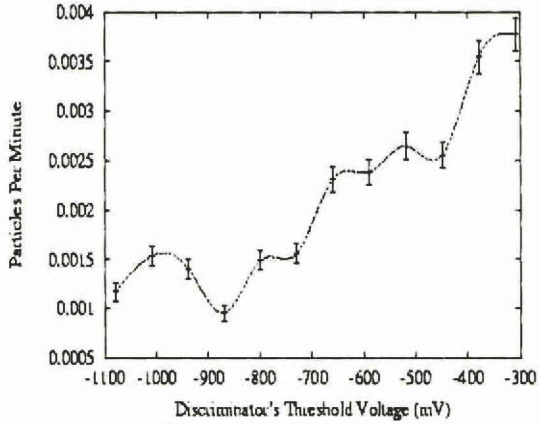


Figure 7. Threshold Curve for Discriminator 9

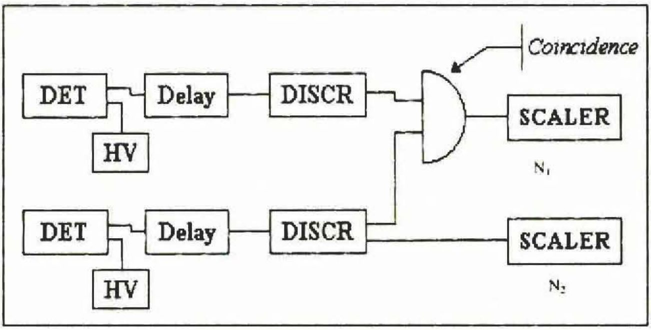


Figure 8. Schematic diagram of the connection used in the determination of the appropriate delay

A. *Measured Flux*

The flux measurement on a per hour basis are converted to a per minute basis of measurement. They are then grouped by eight, which corresponds to the number of per hour measurement from 8:00 AM to 4:00 PM during daytime and from 8:00 PM to 4:00 AM during nighttime. For each group of eight we get averages and corresponding errors. The average *n* of each group of eight were computed using equation,

$$\bar{n} = \left(\frac{1}{N}\right)\sum_{i=1}^{N} n_i \qquad (1)$$

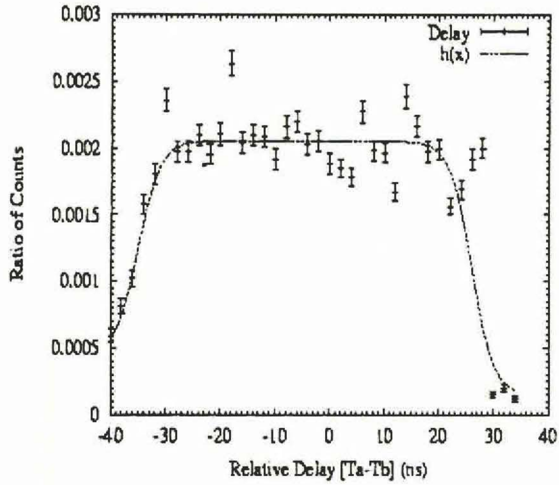


Figure 9. Relative Delay Curve

and the corresponding error σ computed according to,

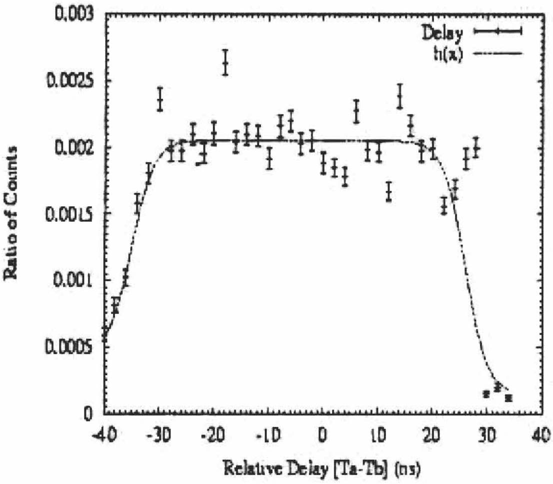
$$\sigma^2 = \left(\frac{1}{N-1}\right)\sum_{i=1}^{N}(n_i - \bar{n})^2 \tag{2}$$

where N=8 for both equations. Equation 2 is used in the computation for error since N=8 is relatively a small number of sample per day or night. The average and error computations are done separately for the data during daytime and nighttime.

Comparison of the 34 averages and corresponding errors from the graph revealed that for daytime measurements no significant day-to-day variations of flux are observed. The same observation holds for nighttime measurement of fluxes. Figs. 10 and 11 typify this insignificance of daytime and nighttime variations of cosmic ray flux.

Fig. 12 shows a flat or constant value for the measured average flux which means that there is no significant variation between the daily averages of the cosmic flux for the entire measurement period. The horizontal dashed line drawn across the plot in Fig. 12 represents the overall average computed using Eq. 1 with N = 592, the total number of per hour measurements done during the data gathering period. The overall average flux n_m, is calculated to be 26.86 particles/min with an error of ± 0.69 particles/min, or

$$Flux_{measured)}, \bar{n}_m = 26.86 \pm 0.69 \text{ particles/min} \tag{3}$$



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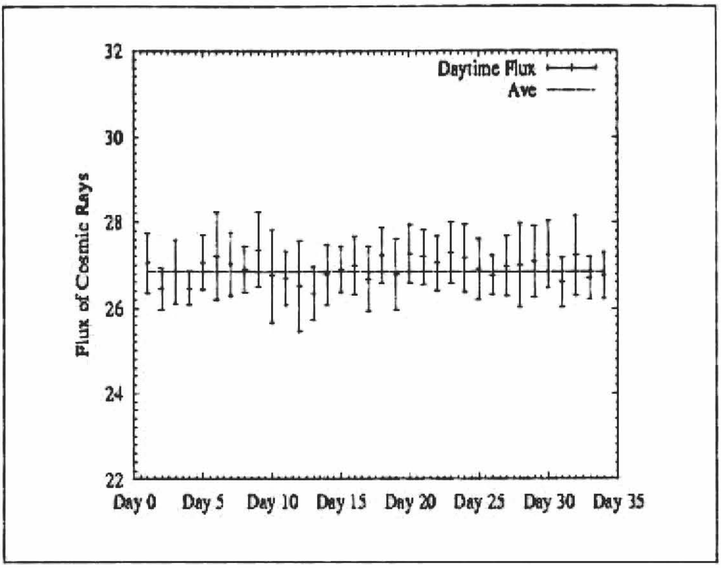

Figure 10. Day Time Flux

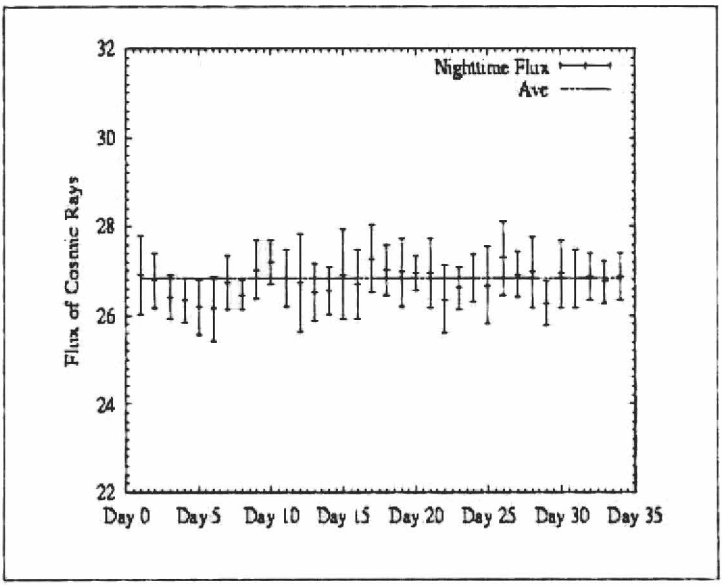

Figure 11. Night Time Flux

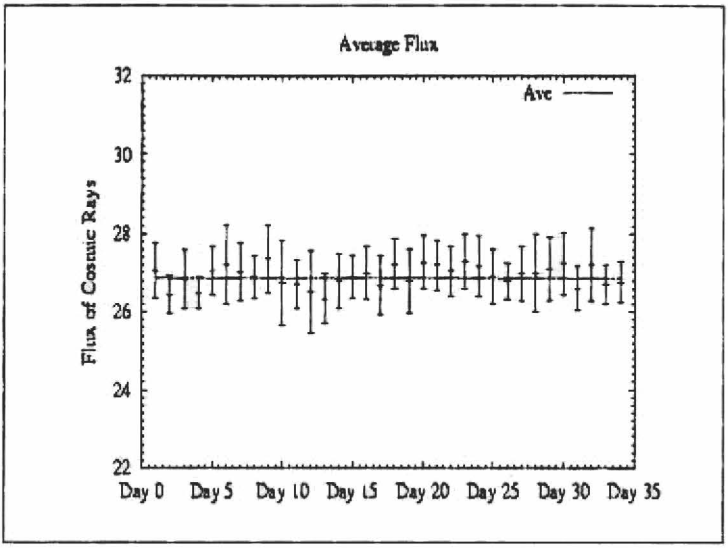

Figure 12. Average Flux

B. Comparison with Measured Values

Previous measurement of cosmic ray flux done in the same location gave an average flux equal to 10.52 particles/min with an error ± 0.43 particles/min, or $\text{Flux}_{(\text{measured})} = \bar{n}_m = 10.52 \pm 0.43$ particles/min using plastic scintillators of size 20x20 cm^2 and different sets of *NIM* electronic modules.

To obtain an exact comparison between the 1999 and present measurements, the fluxes are converted into the units of number of particles per square meter per minute, by dividing the raw data with the scintillator areas. This gives a flux of 0.0269 ± 0.0007 particles/m^2/min for the 100x10cm^2 scintillator while it is 0.0263 ± 0.0004 particles/m^{2}min for the 20x20cm^2 scintillator. These results are again shown in Table 1 to emphasize that the two independent measurements are entirely consistent with each other.

Table 1. Comparison of Fluxes for different dimensions of scintillators.

Scintillator used	**Flux**	
	# of particles min-1	**# of particles cm-2 min-1**
100 x 10 x 0.5 cm3	26.86 ± 0.69	0.0269 ± 0.0007
20 x 20 x 1.0 cm3	10.52 ± 0.43	0.0263 ± 0.0004

C. Estimated Flux

A straightforward way to check the measured flux is by using a rough measurement of solid angle. This estimate is done by considering the set-up to be enclosed by a sphere of radius equal to the distance from the center of the top counter to one corner of the bottom counter. It can only subtend a fraction of the 4π-geometry called $\Delta\Omega$, the fractional solid angle and is equal to the ratio of the area of the detector opening to the area enclosing the space where the events to be detected takes place multiplied by 4π:

$$\Delta\Omega = \frac{100\text{x}10}{4\pi R^2} 4\pi = 0.039 \text{ sterad} \tag{4}$$

where we have measured R = 158.20 cm in our set-up. The standard reference put up by the Particle Data Group (PDG) lists typical values of sea level cosmic ray flux in terms of the flux I_v per unit solid angle per unit horizontal area per unit time about the vertical direction and this is equal to 110 particlesm^2/sec/sterad (PDG, 1988, 1994). This is equivalent to 0.66 particles/cm^2/min/sterad. Hence our measured values agrees with

$$Flux_{(\text{estimate})} = \Delta\Omega\, x I_v x (100x10\text{cm}^2) = 26.37 \text{ particles/min.}$$

Thus this crude estimate agrees with our measured average value as given in Eq. 3.

D. *Simulated Flux*

A more accurate way, and the standard practice, is to test our measurements by doing a Monte Carlo simulation of cosmic radiation hitting the detector assembly. A computer program in high level language is written that uses a random number generator to simulate cosmic rays hitting the specified detector geometry. Again using the reference values given by PDG for the solid angle flux, I_v, the computer simulation program outputs a result which gives the average flux to be 26.183 ± 0.262 particles/min which is again consistent with our measured values.

CONCLUSIONS

From the results obtained in the experiment, daytime and nighttime variation of flux is negligible. Fluxes measured in the same location though of different scintillator dimensions gave consistent measurements of the flux in terms of number of particles per square cm per min. For the 20x20 cm^2 scintillator detector assembly, the average measured flux is 0.0263 ± 0.0004 particles/cm^2/min and for the 100x10 cm^2 scintillator detector assembly the value is 0.0269 ± 0.0007 particles/cm^2/min. Both the estimated and the Monte Carlo generated flux are consistent with these actual measurements.

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