DISCUSSION AND CONCLUSION

V.1 Comparison of present experimental results with results of other experiments:

Results of the experiments of Barrett et al. (1952) and Sivaprasad (1970) may be compared directly with the results of the present experiment.

Barrett et al. (1952) studied muons of energy \( \geq 560 \text{ Gev} \) in association with EAS and obtained the following dependence of the absolute number \( n_{\mu} \) of muons on the shower size \( (N_e) \),

\[
n_{\mu} (> 560, N_e) \propto N_e^{0.45 \pm 0.13} \quad \text{..(5.5.1)}
\]

Further by matching the absolute flux of the muons at observation level to the air shower flux, Barrett et al. concluded that there is one muon of energy \( \geq 560 \text{ Gev} \) in a shower of size \( \sim 400 \) electrons.

Sivaprasad (1970) gave the following relations for muons of energy \( \geq 220 \text{ Gev} \) and \( \geq 640 \text{ Gev} \) in EAS in the size range \( 10^5 \leq N \leq 10^6 \).

\[
n_{\mu} (> 220) = (16 \pm 3) \left(\frac{N}{10^5}\right)^{0.41 \pm 0.09} \quad \text{..(5.5.2)}
\]

\[
n_{\mu} (> 640) = (4.1 \pm 1.2) \left(\frac{N}{10^5}\right)^{0.41 \pm 0.15} \quad \text{..(5.5.3)}
\]
The results from the present experiment may be written as

\[ n_\mu (\geq 150) = (27 \pm 7) (N/10^5)^{0.47 \pm 0.05} \quad \ldots (5.5.4) \]

for the showers in size range \( 10^5 \leq N \leq 5 \times 10^6 \).

We note that there is a reasonable agreement between the power indices obtained in the three different experiments. As far as the absolute number of muons is concerned, there is a good agreement between the number of muons of energy \( \geq 150 \) Gev obtained on the basis of equations (5.5.2) and (5.5.3) and the results of present experiment. However, the number of muons of energy \( \geq 560 \) Gev obtained from the results of Barrett et al. (1952) appears to be much larger than expected on the basis of the energy spectrum derived using the results of Sivaprasad (1970) and the present experiment.

Greisen (1960) gave the following relation for the experimental results of Barrett et al.:

\[ n_\mu (\geq 560, N_e) = 75 (N_e/10^6)^{\alpha} \quad \ldots (5.5.4) \]

where \( \alpha = 0.7 \) decreasing towards 0.5 for small values of \( n_\mu \) and \( N_e \). Considering the other available results, Greisen (1960) also gave the energy spectrum for the muons associated with EAS. The spectrum turned out to be a power law with index \( \beta \sim -1.37 \). Though this energy
spectrum index agrees well with the one obtained in present experiment the number of muons obtained from equation (5.5.4) for \( \geq 560 \text{ Gev} \) turns out to be much higher than expected on the basis of the present results (equation 4.5.3).

It may be pointed out that the apparatus used by Barrett et al. (1952) to detect EAS consisted of four G.M. counter trays spread over a sensitive area of 30 m radius on the surface. Thus information about the size and core location of the individual showers could not be obtained in that investigation.

The validity of the argument, put forward by Barrett et al. (1952) to obtain the absolute number of muons, has been questioned by Sivaprasad (1970). The reasoning runs as follows. Assuming that every primary particle of energy \( E_p \) (corresponding to the shower size \( N_o \)) is associated with one muon of energy \( \geq 560 \text{ Gev} \), the steady state flux of these muons can be obtained by integrating over all primary energies. Because of a steep primary energy spectrum and a \( E_p^\alpha (\ll 1) \) dependence of muon number on the primary energy a dominant contribution to the muon flux will come from particles of primary energies \( \leq E_p \). Sivaprasad (1970) has recalculated the absolute value of \( n_\mu (\geq 560) \) from the data of Barrett et al. (1952). According to this calculation the results
of Barrett et al. (1952) may be rewritten as

$$n_{\mu} (\geq 560, N_e) \propto 7\left(\frac{N_e}{10^5}\right)^{0.45 \pm 0.13}$$

and the numbers obtained using this relation are in reasonable agreement with the numbers expected on the basis of equation (4.5.3).

At Hobart conference the Russian group (Asekin et al. 1971) has reported the muon spectrum, for muons associated with EAS, to be of the type

$$n_{\mu} (\geq E_{\mu}, N_e) = (3.1 \pm 1.5) \left(\frac{E_{\mu}}{0.3}\right)^{-1.58 \pm 0.2} \left(\frac{N_e}{3 \times 10^4}\right)^{0.68 \pm 0.24}$$

for $N_e > 3 \times 10^4$ and $E_{\mu} > 0.1$ Tev.

The values of the exponents of both energy and size spectra are larger than obtained in the present experiment, but the present results are within the error limits quoted by Asekin et al. (1971). It may be noted that the above results of the Russian group are based on the size-number spectrum of the bursts produced by muons at 40 m.w.e. associated with EAS on the surface.

We may then conclude that the variation of the number of muons of threshold energies $\geq 150$ Gev with the shower size (in the size range $10^5 - 10^6$) is a power law with the power index $\propto 0.45$. The experimental results
at lower threshold energies (upto 40 Gev) give a power law with index $\alpha \simeq 0.8$. Thus there appears to be a flattening of the muon number variation for muons of threshold energies $> 150$ Gev.

V.2 Monte Carlo Calculations:

a) Description of the Models: In order to compare the experimental results presented in preceding chapter with the predictions of some of the models of EAS development Monte Carlo calculations based on these models were carried out. Details of the models are given in Table V.1. The models are identical to the ones used by Murthy et al. (1968) for calculations of EAS characteristics, and belong to basically two different categories viz. Fire-ball models and Isobar models.

QL and QLN models are identical with each other in all respects except that in the QLN model a production of $\bar{N}N$ (nucleon-antinucleon) is envisaged along with the production of pions. Similar difference exists between IB and IBN models.

The QL and QLN models are similar to the CKP model (described in Chapter I) and the energy spectrum of the particles created in the nucleon or pion-nucleon interaction is assumed to be an exponential function of the type

$$n_s(E) \, dE = \frac{M}{T} \, \exp \left( - \frac{E}{T} \right) \, dE \quad \quad (5.1.1)$$
TABLE V.1
MODELS OF EAS DEVELOPMENT

<table>
<thead>
<tr>
<th>Model QLN</th>
<th>Model IBN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nucleon Pion</td>
<td>Nucleon Isobar</td>
</tr>
<tr>
<td>Multiplicity M</td>
<td>2.7E+1</td>
</tr>
<tr>
<td>Inelasticity K</td>
<td>0.5 1.0</td>
</tr>
<tr>
<td>Mean Free Path</td>
<td>80 120</td>
</tr>
<tr>
<td>Fraction of Nπ produced</td>
<td>(7(500/E'1+1))^{-1}</td>
</tr>
<tr>
<td>Energy spectrum of created particles</td>
<td>Exponential</td>
</tr>
</tbody>
</table>

E' is the energy of the projectile
Models QL and IB are, identical to models QLN and IBN respectively except that for QL and IB models
\( \xi = 0 \)
where $T$ is the average energy and $M$ the total number of created particles. If the NN production is involved (as in QLN model) the energy is supposed to be distributed among pions and nucleons such that their average energies are proportional to the respective masses. Thus if $m_p$ and $m_B$ represent mass of a Pion and mass of a nucleon respectively the average energy $T_p$ and $T_B$ of pions and nucleons respectively can be written as

$$T_p = \frac{E'K}{M} \left( m_p / (1-f) \right) m_p + f m_B$$

$$T_B = \frac{E'K}{M} \left( m_B / (1-f) \right) m_p + f m_B$$

where $E'$, $K$ and $M$ are the initial energy, inelasticity and multiplicity respectively.

The IB and IBN models are akin to the model proposed by Pal and Peters (1964) and the interactions in these models may be described as follows. In each interaction a fireball is assumed to be created and the constituents of this fireball share 20% of the primary energy. The fireball is then assumed to emit particles isotropically in CM system. The multiplicity for these particles is assumed to be proportional to square-root of the fireball energy and the energy spectra of the particles are governed by the same relationships as for QL and QLN.
models. The surviving nucleon, which retains 80% of the primary energy, is excited with a 70% probability into an excited isobar state of mass 2.4 GeV. Each isobar of mass $m_B = 2.4$ GeV and energy $E_B = 0.8 E'$ is assumed to decay into one of mass $m = 1.93$ GeV and energy $E$, emitting a pion of momentum $p = 400$ MeV/C isotropically in the rest system of the parent isobar. The energy distribution of the created isobar or pion may be expressed as

$$n(E) \, dE = \frac{m_B}{2} \, \frac{dE}{E_B \, p^*} \quad \ldots (5.1.3)$$

for

$$\frac{E_B}{m_B} (E^* - p^*) \leq E \leq \frac{E_B}{m_B} (E^* + p^*)$$

where $E^* = \sqrt{m^2 + p^{*2}}$; $m$ being the mass of created isobar or pion.

The created isobar of mass 1.93 GeV is assumed to decay into one of 1.45 GeV which in turn is assumed to decay into a nucleon, a pion of momentum $p^*$ being emitted in each decay. Expressions similar to equation (5.1.3) hold good for each decay.

b) Calculation Procedure: A primary proton of a given energy is assumed to enter the top of the atmosphere and the depth at which it suffers first collision is determined using the relation.

$$x_1 = -\lambda \ln R$$
where $R$ is a random number distributed uniformly between 0 and 1 and $\lambda$ is the mean free path of the nucleon. The depths of successive interactions of the primary as well as the secondaries is determined using the relation

$$ \chi_{n+1} = \chi_n - \lambda \ln R $$

where $\chi_n$ is the depth at which the preceding interactions took place and $\lambda$ is the relevant mean free path.

For each collision of the primary as well as each collision of the created secondaries the number of created particles of various types, their energy etc are generated by using random numbers with appropriate distribution. Number of pions decaying into muons is calculated and muons thus produced are stored along with the values of their energies. The decay of muon is considered only for muon energies less than 10 Gev. Particles having energies less than 1 Gev are not considered for further calculations.

The calculations were carried out on CDC 3600/160A computer system at TIFR, Bombay. A random number generator available with the system, was used for generating random numbers of desired distribution.

The shower size was calculated by superposing showers generated by photons resulting from the decay of $\pi^0$ meson. The following expression, given by
Greisen (1958), was used to calculate the number of electrons, at observation level, generated by a photon of given energy.

\[ N_e(E, t) = \frac{0.31}{(\log (E/\varepsilon))^2} \exp (t (1-1.5 \log \varepsilon)) \]

where \( \varepsilon \) is the critical energy, \( t \) the depth of observation level from the point of production of a gamma ray in radiation length, and \( S \) the age given by

\[ S = \frac{3t}{t + 2 \log (E/\varepsilon)} \]

V.3 Results of Monte Carlo Calculations:

The distribution of the number of muons of energy \( \geq 150 \text{ GeV} \) in the EAS initiated by a primary proton of energy \( 2.10^5 \text{ GeV} \) in the production depths is shown in Fig. V.1 for various models. All the models predict an average production heights \( \approx 11 \text{ Km} \) for the muons of energy \( \geq 150 \text{ GeV} \), though the models envisaging NN production (i.e. QLN & IBN models) predict average production heights which are smaller than those predicted by QL and IB models.

Regarding the variation of total number of muons \( n_\mu \) with the shower size \( N_e \) for various threshold
energies of muons it is seen that all the models yield a power law relationship with the exponent $\alpha$ having values in the range of 0.6 - 0.8. For muons of threshold energies up to 40 GeV QLN and IBN models predict muon numbers which are greater than the muon numbers predicted for the same threshold energies by QL and IB models respectively. However at larger threshold energies ($> 100$ GeV) the trend is reversed and the QLN and IBN models now yield numbers which are less than the corresponding numbers predicted by QL and IB models.

Fig. V.2 gives variation of the number of muons of energy $> 150$ GeV with the shower - size, in the size range $10^5 - 5 \times 10^6$ particles. The variation is well represented by a power law with power index in the range of .62 - .82. The IBN model predicts the steepest $n_\mu - N_e$ relationship.

The predictions given in Fig.V.2 are for the proton initiated showers. Calculations were also done for a mixed primary composition. The assumed composition was similar to the one established by the Balloon born emulsion experiments at $10^{12}$ ev, and may be expressed as follows:
DISTRIBUTION OF NUMBER OF MUONS OF ENERGY
\( \geq 150 \text{ GeV} \) IN PRODUCTION DEPTH

FIG. X. 1
Fig. 2 - Predictions of Monte Carlo calculations on muons of energy $\geq 150$ GeV for proton primaries & the experimental results.
Using this composition showers were simulated for the four models described in Table V.1. The primary particle was selected using random number with appropriate distribution and the showers were generated by superposing showers produced by 'Λ' protons. The predictions of the four models for above mentioned chemical composition, for muons of energy $\geq 150$ Gev are shown in Fig. V.3. It is seen that the power index for $n_\mu - N_e$ relationship in the case of the mixed composition lies in the range of 0.60 - 0.77 and the predicted number of muons for a given size and for a given model is larger than the corresponding number predicted by the model for proton primary.

V.4 Comparison of Experimental Results with the Predictions of the models:

The experimental results, presented in Chapter IV, are shown along with the predictions of the Monte Carlo Calculations in Fig. V.2 and V.3. Whereas the experiment gives a power index of $(0.47 \pm 0.05)$ for the $n_\mu - N_e$ variation for muons of energy $\geq 150$ Gev, the models
SHOWER SIZE
PREDICTIONS OF THE MONTE CARLO CALCULATION ON MUONS OF ENERGY $\geq 150$ GeV. FOR A MIXED PRIMARY COMPOSITION & EXPERIMENTAL RESULTS.

FIG. 3.3
predict power indices which are much larger than the experimental value. The absolute value of the number of muons is closer to the predicted value for showers of $10^5$ particles and the discrepancy increases with the increasing shower size because of the difference in the power indices. Thus we see that the models under consideration cannot reproduce the experimentally observed variation of $n_\mu$ with $N_e$ for the proton as well as the mixed composition primaries as ... found at energy $\lesssim 10^{12}$ ev. We shall discuss this aspect further in a later section.

V.5 Consequences of observed $n_\mu - N_e$ relation:

As seen in the proceeding sections the variation of the muon number with the size, for muons of energy $\gtrsim 150$ Gev, in size range $10^5$ to $5\times10^6$ particles, is flatter than observed for muons of lower threshold energies and the models examined do not reproduce the observed variation. Two possible explanations may be envisaged for this flat $n_\mu - N_e$ variation.

The first explanation is to invoke an energy dependent change in some characteristic of the interaction, in the relevant energy region, which may lead to a decrease in the fraction of energy going into the production of the parent particles of muons. This
will lead to a relative reduction in the muon number for higher shower sizes and will result in a flatter $n_{\mu} - N_e$ variation. An alternative explanation is to invoke a change in the mass-composition of the primary cosmic rays in the relevant energy region ($10^{14} - 10^{15}$ eV) such that the average mass number $A$ of the primaries decreases from a high value at low energies to a lower value at higher energies. This will result in an enhancement in the muon number of small size showers leading to a flatter $n_{\mu} - N_e$ variation. Possibility of both the effects operating simultaneously may also be considered.

In light of the existing results and model calculations by various authors we have examined the second possibility in the following section.

V.6 Primary Mass Composition and the $n_{\mu} - N_e$ relation:

The chemical composition of primary cosmic rays has been well established at energies $\lesssim 10^{10}$ eV. Studies, using large emulsion stacks flown in Balloons, indicate that the composition remains unaltered upto energies $\lesssim 10^{12}$ eV. At very high energies $10^{17}$ eV, the smallness of the fluctuations in the characteristics of the EAS,
indicates a pure protonic nature of the primaries as discussed by Linsley and Scarci (1962) and K. Suga et al. (1970). A change in the primary chemical composition may then be expected in the intervening energy interval \((10^{14} - 10^{16} \text{ eV})\). It has long been considered that the primary cosmic rays over a certain threshold of magnetic rigidity may not be retained in our galaxy and there may exist a galactic rigidity cut-off, for the primary cosmic rays, beyond which the cosmic rays may be of extra-galactic origin. Peters (1961) envisaged such a rigidity cut-off on the basis of certain irregularities in the air shower characteristics.

Using an "Isobar-cum-Fireball" model, similar to the model of Pal and Peters (1964), and assuming a changing chemical composition due to galactic rigidity cut-off, Cowsik (1967) calculated the size dependence of the average shower characteristics. He assumed a rigidity cut-off at \(10^5 \text{ Gv}\) and a chemical composition same as at low energies upto the cut-off. Beyond the cut-off a pure extra-galactic proton primary component was assumed. A comparison of the results from present experiment with the calculations of Cowsik (1967) is shown in Fig.V.4. The heavy lines are the calculated curves at two threshold
energies, viz. 100 Gev. and 200 Gev. Besides the disagreement with the absolute values, the observed variation is not reproduced under the assumptions and the model used by Cowsik (1967). Chatterjee (1964) also proposed a similar model for the primary energy spectrum using the galactic cut-off for protons at $3 \times 10^{14}$ eV and $Z$ times higher for the heavier particles. The cut-off was assumed to be sharp. Sivaprasad (1970) has modified this model slightly by introducing a gradual cut-off starting at $10^{14}$ eV for the protons. The flux was assumed to drop-off to 1% of the pre-cut-off value within an energy equal to 2.5 times the cut-off energy. Using this model Sivaprasad studied the $n^\mu - Ne$ variations as predicted by various models of nucleon-nucleon interactions as used by Murthy et al. (1967). The results of the calculations may be summarised as follows:

The calculations predict a flattening in $n^\mu - Ne$ variations at high energies and the predicted variations, for threshold energies 220 Gev and 640 Gev in the size range $10^5 - 10^6$ particles are in better agreement with the experimental results of Sivaprasad (1970). The predictions are not in conflict with the experimental results for muons of threshold energies upto 40 Gev and the models envisaging NN production are in better agreement with the experimental results.
COMPARISON OF EXPERIMENTAL RESULTS WITH THE CALCULATIONS OF COWSIK (1967).

FIG IV. 4
The effect of the magnetic rigidity cut-off on the \( n_\mu - N_e \) relation can be understood as follows. For a given level of observation, the average size of the showers initiated by a heavy primary will be different from the size of the shower initiated by a proton of same energy. Thus the primary energy, required to produce shower of a given size, will be different for the primaries of different 'A' values. It is this difference in the primary energy, for producing showers of a given size, coupled with the existence of the rigidity-cut-off that leads of a decrease in \( <A> \) with the increase in shower size, even though there is an increase in \( <\Lambda> \) with increasing primary energy. This in turn leads to a rather flatter \( n_\mu - N_e \) relation than obtained on the basis of a constant composition.

Calculations of Sivaprasad (1970) for muons of energy \( \gtrsim 220 \) Gev are shown in Fig. V.5 along with the results from the present experiment for muons of energy \( \gtrsim 150 \) Gev. The trend of the \( n_\mu - N_e \) variation, predicted by the calculations, is not in disagreement with the observed trend.

The Durham group (J. F. de Beer et al. 1968; C. Adcock et al. 1968) has carried out a theoretical study of the possible consequences, of a primary compo-
SHOWER SIZE
COMPARISON OF THE EXPERIMENTAL RESULTS WITH CALCULATIONS OF SIVAPRASAD (1970)

FIG Y-5
sition subjected to a magnetic rigidity cut-off, on various parameters of EAS which can be measured above ground at sea-level. If the primary composition changes as a result of the magnetic modulation the authors anticipate a highly characteristic oscillation effect in the value of $\alpha = \frac{\Delta \ln n_p}{\Delta \ln N_e}$ as a function of $N_e$. Catz et al. (1970) have observed a somewhat similar oscillation in experimentally obtained values of $\alpha$ in the size range predicted by the Durham group. Though there are significant errors on the values of $\alpha$ as measured by Catz et al. (1970) and though the fluctuation in values of $\alpha$ is not as great as anticipated by the Durham group, the results of Catz et al. (1970) appear to support a changing primary composition subjected to magnetic rigidity cut-off. However, Thompson et al. (1970), from an examination of recent data on muons in EAS, conclude that the majority of the primaries are still protons above $10^{15}$ eV.

V.7 Change in the nature of the characteristics of the nuclear interaction and the $n_\mu$-Ne relation:

A flatter variation of $n_\mu$ with size, than the one predicted by the above discussed models may be brought about by envisaging an energy dependent change in the characteristics of nuclear interaction such that the
fraction of energy going to the pion production decreases gradually in the relevant energy range. One of the possible changes which may be envisaged, is an energy dependent increase in the $\bar{\text{NN}}$ production. As seen earlier the production of $\bar{\text{NN}}$ results in the reduction in muon number for muons of threshold energies beyond 40 Gev. Thus in the energy range, relevant to the sizes $10^5 - 10^6$ at the observation level, an energy dependent increase in the production of $\bar{\text{NN}}$ may result in a flatter $n^- - N_e$ variation than predicted by usual models.

There is no experimental evidence against the increased $\bar{\text{NN}}$ production at high energies. Tonwar et al. (1971) have shown, from their experimental observations of the time structure of the hadrons in EAS, that the $\bar{\text{NN}}$ production at energies $\gtrsim 10^{12}$ eV is as high as 14%. Thus a rather rapid increase in the cross-section of the $\bar{\text{NN}}$ pairs at energies beyond 100 Gev is implied. However, to fit the observational data above the size range $10^6$, this effect of increase in $\bar{\text{NN}}$ production with increasing primary energy must saturate at an energy region in the neighbourhood of $10^{16}$ eV.

V.8 Energy Spectrum of Muons in Extensive Air Showers:

As mentioned earlier (Chapter I) Greisen (1960), on the basis of the available experimental results gave...
an energy spectrum of muons of the type \( (2/ \sqrt{E_{\mu}^2})^{1.37} \).

In the present experiment (Chapter IV) we have obtained an energy spectrum for muons with threshold energies in the range 150 GeV - 640 GeV. The spectrum goes as \( E_{\mu}^{-1.30} \) and there appears to be a fair agreement in the two power indices. However, as seen in Fig. V.6, there appears to be some discrepancies between the experimental results at low threshold energies (upto 40 GeV) and at higher threshold energies. It is seen that though the slope at low threshold energies is in good agreement with the slope at higher energies the number of muons at higher energies do not agree with the ones expected on the basis of extrapolation of the results at lower energies. This can be understood on the basis of the difference in the power index

\[
\alpha = \frac{\partial \ln N_{\mu}}{\partial \ln N_{E}} \text{ for muons of lower threshold energies and higher threshold energies which results in a gap on the number-energy diagram as seen in Fig. V.6.}
\]

The experimental results of Earnshaw et al. (1968) stand out as the highest muon numbers for the respective threshold energies. The result of Barrett et al. (1952) also does not confirm to the picture at higher threshold energies as obtained from the results of Sivaprasad (1970) and the present experiment. However, if the result of Barrett et al. is modified as suggested by Sivaprasad the
INDEX

- BARRETT et al. (1952)
- EARL (1959)
- ANDRONIKASHVILI & KAZAROV (1960)
- KHRENOV (1961)
- BENNETT & GREISEN (1961)
- HASSEGAWA et al. (1962)
- BARNEVELLI et al. (1964)
- EARNshaw et al. (1968)
- VERNov et al. (1968)
- SIVAPRASEDA (1970)
- PRESENT EXPERIMENT

MUON ENERGY IN GeV
INTEGRAL ENERGY SPECTRUM OF MUONS IN EAS ($N_e = 10^5$)

FIG. IX. 6
picture becomes more consistent. For muon threshold energies \( < 10 \text{ Gev} \) there appears to be a flattening in the energy spectrum.

V.9 Conclusions:

From the considerations of the preceding sections we conclude that the \( n_{\mu} - \text{Ne} \) variation as observed in the present experiment for high energy muons \( (\geq 150 \text{ Gev}) \) is flatter than one predicted by the "present-day-known" models using a constant primary composition.

The possibility of a changing primary composition resulting in a \( n_{\mu} - \text{Ne} \) variation similar to the observed one is examined and it is seen that a primary composition subjected to a gradual galactic rigidity-cut-off may reproduce the observed variation. At this point it may be pointed out that if the observed \( n_{\mu} - \text{Ne} \) variation in this size range is due to the rigidity cut-off in the relevant primary energy range \( (10^{14} - 10^{15} \text{ ev}) \) then outside this range the \( n_{\mu} - \text{Ne} \) variation for muons of higher energies (beyond threshold energies of 40 Gev) should be a power law with index \( \lambda \sim 0.6 - 0.8 \). This is expected because outside the cut-off region a constant primary composition exists and such a composition will result in a power law index \( \lambda \sim 0.6 - 0.8 \).
The possibility of a change in the characteristic of the nuclear interaction with energy cannot be ruled out.

V. Suggestions for future investigations:

Two possible explanations for the observed $n^\mu$ -Ne variations in the size range $10^5 - 10^6$ particles have been given in preceding sections. If the primary composition changes with energy in the energy interval $10^{14}$ eV to $10^{15}$ eV and remains constant outside this region the expected $n^\mu$ -Ne variation for muons of energy $\gtrsim 150$ Gev, will have a power index $\sim 0.6 - 0.8$ for shower sizes $<10^5$ particles and $>10^6$ particles. This aspect of the $n^\mu$ -Ne variation should be looked-for in the extended measurement on muons of energy $\gtrsim 150$ Gev in showers over a wide size range. Moreover, it is necessary to have narrower grouping in the shower sizes than obtained in the present experiment.

It is also desirable to study the behaviour of the other components of EAS as a function of the size in the region $10^5 - 10^6$. Specially an investigation on charged to neutral ratio of hadrons of energy $\gtrsim 100$ Gev in the region $10^5 - 10^6$ may be helpful to understand the different models of muon production.
Study of the fluctuations in the various characteristics of the EAS in different size range will also be useful in understanding the composition of the primary cosmic rays at high energies (\( \geq 10^{14} \text{ eV} \)).