PART II

AN INVESTIGATION ON THE NEUTRON PRODUCING RADIATION AT GULMARG (KASHMIR)
Soon after their discovery in 1931 neutrons were searched for in Cosmic Rays. Locher (1933) published some cloud chamber photographs which for the first time indicated the possibility of finding neutrons in Cosmic Rays. Rambaugh and Locher (1936) reported a considerable increase in the proton tracks in the plates exposed under paraffin as compared to those exposed under other materials as carbon and lead. A systematic study of the Cosmic Ray neutrons was, however, carried out by Runfer (1937) and an exponential increase in the intensity of the neutrons with altitude was obtained.

\[ \mu = \frac{6.93}{\text{atm.}} \]

with \( \mu \) as absorption co-efficient and \( p \) as pressure altitude (in atmospheres). Runfer obtained \( \mu = 6.93/\text{atm.} \) for the intensity variation from sea level upto 2650 m. Schopper (1937) extended these measurements to a height of 18000 m. A sharp increase in the intensity was obtained, though not as strong as would be expected on Runfer's law. Korff's measurements (1939 a, b), however, supported the findings of Runfer with a value \( \mu = 6.5/\text{atm.} \). Agnew, Bright & Froman (1946) using enriched \( \text{B}^{10} \) counters measured the neutron intensity upto 30,000 ft. and obtained \( \mu = 6.3/\text{atm.} \). On the basis of the observed constancy of the co-efficients
for different shields used by him a constancy in the energy spectrum of these neutrons up to the height of 30,000 ft. was inferred. In India the first Cosmic Ray neutron intensity measurements were carried out by Chatterjee (1940) and his conclusions were in broad agreement with the above law. Recently Curtiss and Gill (1952) have measured the abs. m. f. p. for fast neutrons up to a height of 13,000 ft. in Kashmir and obtained a value of 128 gms/sq.cm. of air, showing thereby that these neutrons are in equilibrium with their producers up to the mountain altitudes.

Bethe, Korff, and Placzek (hereinafter called B.K.P) have discussed the early work at some length and they have formulated the theoretical basis for these observations. The diffusion problem has been discussed by Flugge (1946). A source of definite but unknown strength has been ascribed to the atmosphere such that the density of the neutrons at the moment of their formation is a function of the atmospheric pressure at that point. These neutrons then undergo a stopping process i.e. their velocity decreases as they travel farther from the point of their origin. Besides this stopping process the diffusion phenomenon plays an important role in changing the positions of neutrons. Combining the two effects the equation governing the form of the altitude variation of the slow neutron intensity has been derived. This equation has since been completely verified by means of balloon flights made to determine the altitude variation of the slow neutrons (see
for example Yuan 1951, Davis 1950). The abs.m.r.p is known to vary with latitude (Simpson 1952). The exponential law as expected is faithfully obeyed up to a height of about 20 cms. of Hg. pressure. The intensity vs. pressure heights curves show a maxima around 8.5 cms. of Hg. pressure and a rapid falling off at higher altitudes compatible with the secondary nature of these particles. Both the existence of maximum in the intensity-height curves, as also a rapid fall of the intensity at heights above 1 m.w.e. were predicted by the calculations of Flugge. The B.K.P calculations have been revised, in the light of the added information available now, by Davis (1950) and Lattimore (1951).

Though the B.K.P theory explained the observed slow neutron intensity variation with altitude quite well, it remained incomplete in as much as no provision was made for the mechanism responsible for neutron production. That could not be done firstly because the processes contributing to the production of neutrons were not very well known and secondly because the dependence of these processes on the primary particle energy was not understood at all. Recently Messel (1951) has attempted to give a coherent picture of the entire Cosmic Ray phenomenon as it develops in the atmosphere on the basis of the facts that have come to light recently.

A mass of evidence, in the meantime, has been collecting which indicated a probable genetical relationship amongst the different Cosmic Ray phenomena observed
in the atmosphere. In particular the altitude variations of stars, penetrating showers, extensive air showers, bursts and neutrons have been known to follow similar exponential laws with the abs.m.i.p's. very close to each other. This is clearly brought out in the Table VI.

**TABLE VI**

<table>
<thead>
<tr>
<th>Cosmic Ray Phenomena</th>
<th>Absorption m.f.p in air</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetrating Showers</td>
<td>118±2 gms/cm²</td>
<td>Tinlot, T.M. (1948)</td>
</tr>
<tr>
<td>Bursts</td>
<td>173 gms/cm²</td>
<td>Rossi, B. (1948)</td>
</tr>
<tr>
<td></td>
<td>~178 gms/cm²</td>
<td>Hulsizer, R.I. (1948)</td>
</tr>
<tr>
<td></td>
<td>160 gms/cm²</td>
<td>Simpson et al (1951)</td>
</tr>
<tr>
<td>Stars</td>
<td>140 gms/cm²</td>
<td>Perkins, D.H. (1949)</td>
</tr>
<tr>
<td></td>
<td>125 gms/cm²</td>
<td>Forster, H.H. (1950)</td>
</tr>
<tr>
<td></td>
<td>150±7 gms/cm²</td>
<td>George, E.P. &amp; (1949)</td>
</tr>
<tr>
<td></td>
<td>135±4 gms/cm²</td>
<td>Jason, A.C. (1949)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bernardin et al (1949)</td>
</tr>
<tr>
<td>Neutrons</td>
<td>128 gms/cm²</td>
<td>Curtiss, L.F. &amp; (1952)</td>
</tr>
<tr>
<td></td>
<td>157±3 gms/cm² (At 53° Lat.)</td>
<td>Simpson (1952)</td>
</tr>
<tr>
<td></td>
<td>156 gms/cm²</td>
<td>Yuan, L.C. (1951)</td>
</tr>
</tbody>
</table>
Direct experimental evidence in support of the assumption of genetic relationship amongst the different Cosmic Ray phenomena has come mainly from the investigations carried out with photographic emulsions and cloud chambers. The observation of stars in photographic emulsions exposed at mountain altitudes for a few months by Blau and Wambacher (1937) provided the first evidence of nuclear disintegrations induced by Cosmic Rays. Occhialini and Powell (1947) initiated an extensive study of the stars and the star-producing radiations using improved emulsions. Cloud chamber studies of Cosmic Rays supplemented the information received from photographic emulsion plates. In particular investigations of high energy nuclear interactions and the subsequent fate of the secondaries resulting therefrom were mainly carried out with cloud chambers. Photographs which have been obtained by Gregory and Tinlot (1951), Gregory and Fretter (1946) and others provide convincing proofs of the close relationship existing between the different components of Cosmic Radiation.

Ionization bursts produced by Cosmic Rays provide yet another method of study of the Cosmic-Ray nuclear disintegrations. An extensive study of these bursts was carried out by Bridge et al. (1948) at a height of 3,500 m. An analysis of their data reveals that of the pulses larger than 7.5 MeV observed in a single chamber only 2 p.c. are due to air showers and 98 p.c. to heavily ionising particles, most of them originating presumably from nuclear disintegrat-
ions in the walls of the chamber. Bridge and his collaborators later confirmed this conclusion by placing the ionization chamber inside a cloud chamber and triggering the cloud chamber so as to observe directly the events responsible for ionization bursts.

Rossi (1948; 1952) has summarised the information on different Cosmic Ray phenomena on the basis of which a coherent picture of the whole phenomenon of the Cosmic Radiation as it develops in the atmosphere can be formed. At present it is presumed that all the Cosmic Ray phenomena in the atmosphere can be traced back to some nuclear disintegrations which are caused by the high energy primary Cosmic Radiation and their energetic secondaries and secondaries. The missing link to account for the electronic and the photonic components of the Cosmic Radiation has been provided by the discovery of neutral \( \pi^- \) mesons by Bjorklund, Crandall, Moyer and York (1950) which was further supported by the evidence of Steinberger, Panofsky and Steller (1950). These neutral \( \pi^- \) mesons are known to have a lifetime of the order of \( 10^{-14} \) secs., decaying into two photons.

Evidently for any complete account of the Cosmic Radiation as it develops in the atmosphere it is essential to know all the parameters that govern the production of nuclear disintegrations together with the nature and properties of the resulting disintegration products. Rossi has designated the Cosmic Ray component responsible for all the nuclear disintegrations - stars, bursts, penetrating showers
etc. - as $N$-radiation and in all the subsequent discussions below this notation is used.

A systematic study of the production of neutrons by Cosmic Rays in different elements was carried out by the Yale group. Montgomery and Tobey (1951) using the elements dispersed in the moderating medium surrounding a neutron counter have determined the neutron production rates by Cosmic Rays at sea level. They have shown that the distribution of the element in the moderator was such as to ensure a constant efficient detection of the disintegration neutrons in these elements. Their results indicated that the cross-sections for the neutron production in different elements follow a $A^{2/3}$ law.

That neutrons are produced in all nuclear disintegrations was first revealed by the study of stars using photographic emulsions. The Cornell group later produced direct experimental proof in support of this conclusion. Cocconi et al. (1950) have shown that neutrons are always associated with the locally produced penetrating showers. Besides, the multiplicity of the neutrons per event increases with the multiplicity of the ionizing particles. Up to 17 neutron counters were discharged in individual events. Considering the low efficiency of the neutron detecting system ($0.3$ according to the authors) it was concluded that an individual event is occasionally capable of producing up to a few hundred neutrons. Obviously, such an event cannot correspond to the disintegration of a single lead nucleus but must be the result of a chain of
nuclear interactions each contributing to the total number of neutrons recorded in the individual events.

The experiments demonstrating the transition effect of the $N$-radiation bring out more clearly the existence of the chain of the nuclear interactions. This transition effect has been reported by various workers for the radiation responsible for the penetrating showers, stars, the ionization bursts etc., thus providing yet another proof of the close relationship between these phenomena. Janossy and his collaborators reported the transition effect for the penetrating shower-producing radiation (Janossy 1942; Janossy and Rochester 1944; Broadbent and Janossy, 1947). This work was further extended by George and Jason (1950). These investigations exhibited the existence of a transition maximum at around 100 gms/sq. cms. of lead and a little higher for aluminium, for the penetrating shower-producing radiation. Using an arrangement of the ionization chamber, the absorption of the burst-producing radiation was studied by Lindenberger and Meyer (1954). A transition maximum at about 1 cm. of lead was obtained from these investigations. For carbon the transition maximum was shown to be at around 25 cms. The abs.m.f.p. for this radiation was calculated as 320 ± 50 gms/sq. cms. of lead. The transition effect of the star-producing radiation using photographic emulsion has been reported by Bernardini et al. (1955) and more recently by Schopper et al. (1951). A transition maximum at 1.2 cms. of lead and abs. m.f.p of 320 gms/sq. cms. above two cms. of
lead absorber has been reported by the latter workers. Simpson (1953) using neutron counters in a pile geometry has measured the absorption of the neutron-producing radiation in lead, obtaining an abs. m.f.p. of 128/sq. cms. of air and 300 gms/sq. cms. of lead. Besides, the existence of a transition effect for the radiation was also indicated.

Trieman & Fonger (1952) using a better experimental layout confirmed the existence of the transition maximum at about 15 gms/sq. cms. lead. These values are in complete agreement with those obtained for stars and ionization bursts. The penetrating showers also show the same order of abs. m.f.p. though the transition effect is rather of a different order.

The quantitative analysis of the transition effect has not been carried out so far in view of the complexity of the problems involved. Even the qualitative phenomenological explanation of this effect is beset with difficulties in view of the small value of the transition maximum together with a high abs. m.f.p.

From the above-mentioned studies it appears that the N-radiation or some part of it has got the property of releasing a large number of disintegration producing particles in individual nuclear interactions, enabling the development of nuclear disintegrations in condensed matter. Besides, the fact that the penetrating shower-production exhibits a transition maximum at greater thickness of lead than that observed for star production may arise from the difference in the mechanisms of the two phenomena or the difference in the energies of the particles that cause the nuclear disintegrat-
ions. It may be pointed out here that the transition effect for stars has been observed for the low pronged stars only, no such effect having been reported for the bigger ones.

As low energy neutrons are always emitted in all types of nuclear disintegrations they can conveniently be used for any studies of nuclear interactions of Cosmic Rays. It has been known from emulsion studies that the size frequency distribution of the stars is dependent upon the energy spectrum of the $\pi$-radiation only, at least up to mountain altitudes. As such the average number of neutrons released in a nuclear interaction of Cosmic Rays is directly proportional to the intensity of the $\pi$-radiation. With an increase in the thickness of the absorber in which the nuclear interactions are taking place not only the number of the nuclear interactions of the initial $\pi$-radiation increases but the energetic secondaries released in these interactions also produce a small but finite number of nuclear disintegrations, thus contributing to the total number of neutrons produced in the absorber. In the work reported here this increase in the neutron production rate has been studied for a lead plate by the $\pi$-radiation (i) unfiltered and (ii) filtered through 280 gms/sq. cms. It might be possible in this way, to determine the dependence of the nuclear interactions by Cosmic Rays on the energy of the $\pi$-radiations. It is known from the emulsion studies of stars that the $\pi$-radiation consists mainly of nucleons and $\pi^\pm$-mesons.
(the contribution by the photon component and the \( \mu \)-mesons, being negligibly small, will not be considered in the present work). Any difference in the interaction properties of the \( \pi^\pm \) mesons from those of the nucleons would be reflected in the neutron production rates by the filtered \( N \)-radiation. With this end in view a study has been made and the data are presented herewith for the neutron production rates in different thicknesses of lead plates by the unfiltered and filtered \( N \)-radiations. Curves have been drawn for the total production rates as a function of thickness of the lead plates for the unfiltered and filtered \( N \)-radiations. Analysis has been carried out to obtain (a) the interaction m.f.p., (b) the abs. m.f.p. of the \( N \)-radiations.

The interaction m.f.p. in a given material is defined as the average distance an \( N \)-ray goes through the material before giving rise to a nuclear disintegration. The abs. m.f.p., or the attenuation length is defined as the thickness of the material that reduces the intensity of the \( N \)-radiation by a factor \( 1/e \).
Production of neutrons by Cosmic Rays in different elements has been studied by several workers. Montgomery and Tobey (1951) have carried out the investigation to measure the neutron production rates in different substances. They have carried out the calculations to obtain the mode of distribution of the element under study in the moderating medium surrounding the Boron Triflouride proportional counters so as to obtain a constant efficiency of detection for all the neutrons produced in the nuclear disintegrations in the element irrespective of their energy. Cocconi et al (1950) studied the production of neutrons in lead in coincidence with the penetrating showers. They have shown that the neutrons produced in nuclear disintegrations have approximately the same spectrum as that obtained from an Ra-α-Be neutron source with the higher energy end a little higher than obtaining from Ra-α-Be source. Besides these neutrons are isotropically emitted out, showing that they are boiled off particles. The theory of low energy stars has been developed on the Bohr model of the nucleus by Le Couteur (1950 a,b) with modifications to account for the increased number of particles at the low energy end. The energy spectrum of the neutron on this model comes out to be a variant of the Maxwellian distribution with the maximum number of neutrons lying in the
energy band 5 to 10 Mev. Boron Trifluoride proportional counters being low energy neutron detectors should be surrounded by a moderating medium so as to enable them to detect the neutrons of a few Mev. Such an arrangement of the neutron counters and a moderator is termed a pile. The parameters of this pile then determine the energy band of neutrons which are efficiently detected by the pile detectors. The design parameters of the pile though only approximate are fixed with a view to detect the neutrons lying in the energy band 1-10 Mev., and these constitute the biggest fraction of the neutrons released in nuclear disintegrations.

The neutron detecting pile used in these experiments consisted of a block of paraffin wax of dimensions 24"x 22" x 11" housed in a wooden box of the same internal dimensions. The paraffin wax was selected as the moderating medium for several reasons - (i) small local production of neutrons; (ii) convenience of obtaining any geometrical pattern and (iii) easy availability and low cost. Neutrons produced in the nuclear disintegrations induced by Cosmic Rays in any substance placed over the pile detector are slowed down in the paraffin moderator before they reach the Boron Trifluoride proportional counters. The paraffin layout around the proportional counter was governed by two considerations:

1. The disintegration neutrons lying in a suitable energy band around the most probable energy of these neutrons
are slowed down to thermal energies before they enter the counter volume.

2. Neutrons present in the atmosphere and those which may find their way into the detecting system should give rise to as small number of counts as possible. The latter requirement is important as these neutrons constitute the undesirable background for the nuclear disintegration measurements. The scale diagram of the pile used in these experiments is given in Fig. 11. Extra paraffin was put on the three sides of the main detecting volume so as to reduce the background counts arising from the unwanted fast neutrons entering the detecting block from the sides and being detected by the neutron counters.

Boron Trifluoride proportional counters used in these measurements were the same as described in the earlier section of this report. Their overall dimensions were:

Length - 24"
Diameter - 1.75"
Anode wire diameter - 0.003"
Gas - Boron Trifluoride (Natural Boron) 45 cms. of Hg pressure.

Plus Argon at 5 cms. of Hg pressure.

Only two such counters were used in the pile. Both the counters used had approximately the same characteristics - the same threshold; equal plateau lengths and slopes and equal efficiencies. The two counters were connected in parallel. The E.H.T. for the counters was supplied from a battery of dry cells. The operating potential of these
counters was kept within a few volts of 2800 V as indicated by an electrostatic volt-meter. The anode of the counters connected together were coupled to the input of a cathode follower. The cathode follower and the head of the pile were shielded by a metallic box fixed to the front side of the pile and electrically earthed to the body of the cathode follower to which was also connected the outer aluminium shell of the Boron Trifluoride proportional counters. The output from this cathode follower was connected by a shielded cable to the input of a Jordan-Bell type of a linear amplifier (Model 204 C of the Atomics Instruments Company Ltd.) The power to the cathode follower was supplied from the electronically regulated power supply incorporated in the commercial amplifier through a six-wire shielded cable. The filament supply for the cathode follower was specially protected against the harmonics of the line frequency by incorporating a filter in the six-volt secondaries of the transformer. The cathode follower output from the linear amplifier was coupled to a Schmidt-Trigger type of a discriminating circuit also incorporated in the commercial amplifier unit on the same chassis. The low impedance output of the discriminator was coupled to the input of a seven stage fast scaling unit (Model 162 of the Nuclear Instruments & Chemicals Corp. Ltd.), the output of which was used to drive a mechanical register (Cyclotron Specialities). The most important precautions in these
couplings and connections are concerned with the shielding and the earthing of the different units, and the coupling lead from the counter to the input of the cathode follower. As the output pulse from the counters is of the order of a few millivolts, it was essential to have the shortest possible leads connecting the counters to the cathode follower input. Shielding needed a special attention, since slight electrical disturbances in the atmospherics or in the neighbourhood, if picked up, could give rise to false counts. This pick-up trouble was taken care of by (a) using shielded cables in all the couplings and (b) connecting the earth points of the different units in their order; cathode of the counter to the cathode follower chassis through the shield of the coupling cable, the cathode follower chassis to the linear amplifier through the shield of the connecting cable and so on.

Before starting the actual measurements of neutron production rates a thorough check up of the whole experimental layout including the neutron counters and the associated electronic equipment was carried out. The linear amplifier and the scaling unit were tested with the help of a pulser. Throughout the run of the experiment the linear amplifier worked quite smoothly without giving any trouble even once. Though the scaling unit proper functioned consistently, the incorporated electronically regulated power supply and the driver circuit for the mechanical register developed minor troubles towards the
end of the experiment. The data presented here, however, were obtained from the trouble-free working days of the experiment. The functioning of the instruments was independent of the line fluctuations to the tune of 10 p.c. as they had electronically regulated power supplies. However, the line voltage was frequently monitored and it was found never to vary beyond 2 p.c. of the normal value.

In the absence of a suitable neutron source, a check on the working of the pile was carried out by measuring the counting rate as a function of the E.H.T. across the neutron counters. The counters are known to have a plateau of about 100 volts with a slope of approximately 5 p.c. in this region. For checking the working of the detecting unit the bias and the plateau curves were frequently drawn throughout the period of the experiment. A consistency in the nature of these curves was assumed to give sufficient proof of constancy of efficiency and other characteristics of the neutron counters. A more frequent check of the operation of the arrangement resorted to every 24 hours, consisted in measuring the with- and without-Cadmium counts of the counters in the pile under exactly similar conditions of operation. Any deviation in the counter characteristics at any time would be reflected in the counting rate with- and without-Cadmium shields, as also in the ratio of these counting rates. A consistency of these two parameters within the limits of statistical deviation was taken to mean consistency in the operating
FIG. 11

BY UNFILTERED & FILTERED N-RADIATION
PILE ARRANGEMENT FOR THE PRODUCTION RATE STUDIES
characteristics of the pile.

The E.H.T for the neutron counters were obtained from a battery of dry cells put in series so as to give a total electrostatic potential of about 2800 volts. The electrostatic voltmeter, used to measure the potential difference across the counters, never showed a deviation beyond ±20 volts. The batteries did not show any temperature effect. However, in order to protect them against any deterioration due to humidity, they were wrapped in wax paper and packed in a wooden box. Besides, the place, where they were kept, was always kept warm with the help of electric heaters.

The experimental arrangement of measuring the production rates of the neutrons by the unfiltered N-radiation is given in Fig. 11a. The detector pile is placed on the floor. The lead plates of dimensions 12" x 18", were placed in the centre of the top surface of the detector block. These plates are termed 'producer plates' in the following discussion. Counting rates were obtained for different thicknesses of producer plates including 0 cms. thickness. For each thickness the counts were recorded for about four hours at a time. The thickness of the producer plates was changed in steps of 1/4" (about 7.2 gms/sq.cms.) first in the increasing order followed by a decreasing one. This constituted one cycle of measurements which took about 3 to 4 days to complete. Though no strictness was observed in keeping the time of individual measurements constant, the
readings for all the thicknesses of the producer plates were repeated several times so as to obtain the counting rates at each producer plate thickness for all the hours of the day. This method of obtaining the counting rates ensured against any substantial effect of periodic variations of Cosmic Rays. The first set of measurements of the neutron production rates by the unfiltered N-radiation as function of thickness of the producer plate was completed in the 28 working days of the month of September, 1955.

The whole detecting system - the pile plus the associated electronic instruments was then thoroughly checked for any deviation in the operating characteristics. For the measurements of the neutron production rates by the filtered N-radiation as a function of the producer plate thickness, the pile was shifted inside a pit such that its top surface was about 4 feet below the ground level. Over this pile was placed a paraffin block (22" x 24" x 5") such that it covered the pile top area completely with a free space between its underside and the pile top of about 2½". The underside of the paraffin block was fixed with a Cadmium sheet (0.5 mm.). Over this paraffin block was arranged a wooden platform for placing the lead absorber plates upto a thickness of 280 gms/sq. cms. on a surface area of 27" x 27" uniformly covering the detecting unit. This arrangement sketched in the Fig.11b ensured a low background due to the undesirable neutrons. The use of the 5 inch
### TABLE VII A. UNFILTERED N-RADIATION

<table>
<thead>
<tr>
<th>Producer Plate thickness in cms.</th>
<th>Total No. of Counts</th>
<th>Total time of observation in min.</th>
<th>Counting Rate /min.</th>
<th>Neutron-Production Rates in the plates /min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11,236</td>
<td>5,567</td>
<td>2.018 ± .019</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>7,381</td>
<td>2,926</td>
<td>2.523 ± .029</td>
<td>0.505 ± .035</td>
</tr>
<tr>
<td>1.2</td>
<td>7,600</td>
<td>2,746</td>
<td>2.770 ± .032</td>
<td>0.752 ± .037</td>
</tr>
<tr>
<td>1.9</td>
<td>10,164</td>
<td>3,170</td>
<td>3.206 ± .032</td>
<td>1.188 ± .037</td>
</tr>
<tr>
<td>2.5</td>
<td>10,057</td>
<td>2,807</td>
<td>3.583 ± .036</td>
<td>1.565 ± .040</td>
</tr>
<tr>
<td>3.2</td>
<td>11,359</td>
<td>2,851</td>
<td>3.984 ± .037</td>
<td>1.965 ± .042</td>
</tr>
<tr>
<td>3.9</td>
<td>11,844</td>
<td>2,783</td>
<td>4.256 ± .039</td>
<td>2.236 ± .044</td>
</tr>
<tr>
<td>4.5</td>
<td>7,254</td>
<td>1,712</td>
<td>4.237 ± .050</td>
<td>2.219 ± .053</td>
</tr>
</tbody>
</table>

### TABLE VII B. FILTERED N-RADIATION

<table>
<thead>
<tr>
<th>Producer Plate thickness in cms.</th>
<th>Total No. of Counts</th>
<th>Total time of observation in min.</th>
<th>Counting Rate /min.</th>
<th>Neutron-Production Rates in the producer plate /min.</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>9,999</td>
<td>5,650</td>
<td>1.768 ± .018</td>
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</tr>
<tr>
<td>0.6</td>
<td>12,718</td>
<td>6,298</td>
<td>2.019 ± .018</td>
<td>0.251 ± .025</td>
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<tr>
<td>1.2</td>
<td>10,909</td>
<td>5,000</td>
<td>2.182 ± .021</td>
<td>0.414 ± .027</td>
</tr>
<tr>
<td>1.9</td>
<td>13,962</td>
<td>5,905</td>
<td>2.364 ± .020</td>
<td>0.596 ± .027</td>
</tr>
<tr>
<td>2.5</td>
<td>10,698</td>
<td>3,855</td>
<td>2.775 ± .027</td>
<td>1.007 ± .032</td>
</tr>
</tbody>
</table>
paraffin block with the Cadmium sheet on the under-side just below the lead absorber minimises the counting rates due to the neutrons produced in the absorber plates. The neutron production rates for different thicknesses of lead were obtained as before. The measurements were made for producer plate thicknesses up to 28.8 gms/sq. cms. of lead only.

Both the measurements are present in Table VII. In the table are given the total number of the neutron counts obtained for different thicknesses of the producer plates together with the corresponding time of observation for each thickness. In the next column are given the average counting rates. The difference in the average counting rates with the producer plates in position and without it are given in the last column.
Before any information can be derived from these data certain corrections must be applied to them. These correction terms are due to (1) the change of geometry of the detecting unit with respect to the producer plates with the addition of further plates - (the displacement factor); (2) scattering of the neutrons produced in the upper layers of the producer plate by its lower layer. Because of these factors the observed counting rate for a given thickness of the producer plate is less than the actual ones. This reduction is quite marked for larger thicknesses of the producer plates. Due to the non-availability of a suitable neutron source no experimental determination of the two factors could be carried out. The correction terms can, however, be approximately evaluated from the measurements reported by other workers. The geometry correction can be applied taking advantage of Simpson's curve (1952) for the effect of the displacement of the producer plates above the detecting unit. This evaluation is carried out as follows:

Consider the thinnest producer plate 7.2 gms/sq. cms for which the observations were made. Let the whole matter be considered for the calculation of the displacement factor as concentrated at the mid surface of the producer plate. Let the observed counting rate for this
Fig. 12

DISPLACEMENT CORRECTION CURVE

SCATTERING CORRECTION CURVE

SEE TEXT ON PAGE
producer plate be \( r_1 \). The correction factor for the displacement of the plate by a distance equal to the height of its midpoint can be obtained from the curve of Simpson (Fig. 12 b). Let it be \( c_1 \), and the counting rate corrected for this displacement be \( R_1 \). Then

\[
R_1 = r_1 (1 + c_1)
\]

Let \( \frac{R_1}{r_1} = G_1 \)

Consider now the next producer plate of 14.4 gms./sq. cms. Let the observed counting rate for this producer plate be \( r_2 \) and the corresponding displacement correction term \( c_2 \). Then

Corrected counting rate due to producer plate 1 is \( R_1 \).

Corrected counting rate due to producer plate 2 equals \( \{ r_2 - R_1 (1-c_2) \} G_1 \).

Therefore,

the corrected counting rate for the 14.4 gms./sq. cms. plate is

\[
R_2 = \xi \gamma_2 - R_1 (1-c_2) \frac{2}{3} G_1 + R_1
\]

Let \( \frac{R_2}{r_2} = G_2 \)

Thus the general formula for the corrected counting rate due to \( n \) producer plates of thickness 7.2 gms./sq. cms. each is

\[
R_n = \xi \gamma_n - R_1 (1-c_n) \frac{2}{3} G_{n-1} + R_1
\]
$G_n$ is then the required correction term. The values of $c_n$ were obtained from Simpson's curve (1953) reproduced in Fig. 12 b.

For obtaining the correction term for the scattering by the producer plate two simplifying assumptions are made: (1) the neutrons produced in the producer plates are considered for the present calculations as coming from above the plates such that for all the neutrons the whole plate may be considered as a scatterer; (2) the neutrons produced in the disintegrations have the same spectrum as those obtained from a Ra-$\alpha$-Be neutron source. The first assumption, though not justified in toto in view of the production of the neutrons throughout the whole thickness of the producer plate, can be considered to lead to correction terms not very far from the real values particularly for the producer plate thicknesses considered in the present work. As for the second assumption Cocconi et al. (1950) have already shown that the energy spectrum of the disintegration neutrons is not very far from that obtained from a Ra-$\alpha$-Be neutron source. The emulsion studies of the stars also support the above assumption.

Using a pile of a design similar to the one described above, K.W. Gieger (1956) has measured the scattering fraction of the neutrons from a Ra-$\alpha$-Be source by lead plates of two different thicknesses (1.9 cms. and 8.3 cms.). Using these two points a curve
was drawn to give the scattering fraction as a function of thickness from 0 to 8.3 cms of lead with the assumptions that (i) it should pass through origin and (ii) and that it should be a smoothly varying function of thickness of lead absorber upto 8.3 cms of lead (Fig 12 a). In what has been discussed above the scattering fraction $s_n$ is defined simply as the fraction of neutrons removed from the detectable beam and is obtained by taking the difference of the pile counting rate for the source in a fixed position without and with a lead plate placed just above the pile between it and the source and dividing it by the counting rate with no lead present. In Table VIII, are given the different thicknesses of the producer plates above the pile in the first column. The difference of the counting rates with and without the producer plates has been considered as the production rate for the particular plate thickness. This is given in the second column. In the following columns are given the correction factors: the displacement correction factor $Q_n$ and the scattering correction factor $1/(1-s_n)$.

The most common errors that have not been taken into account in the above and subsequent calculations arise from the variations in the atmospheric conditions at Gulmarg - temperature variations and the pressure variations. The change in temperature can give rise to a variation in the counting rate in three ways:

(a) If the neutron counters exhibit any
### TABLE VIII A.

<table>
<thead>
<tr>
<th>Producer Plate thickness in gms/cm²</th>
<th>Observed Displacement correction rate / min.</th>
<th>Displacement correction Factor</th>
<th>Scattering correction Factor</th>
<th>Corrected production rate / min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2</td>
<td>0.505 ± 0.035</td>
<td>1.044</td>
<td>1.044</td>
<td>0.550 ± 0.035</td>
</tr>
<tr>
<td>14.4</td>
<td>0.752 ± 0.037</td>
<td>1.072</td>
<td>1.034</td>
<td>0.874 ± 0.037</td>
</tr>
<tr>
<td>21.6</td>
<td>1.183 ± 0.037</td>
<td>1.095</td>
<td>1.122</td>
<td>1.460 ± 0.037</td>
</tr>
<tr>
<td>28.3</td>
<td>1.565 ± 0.040</td>
<td>1.113</td>
<td>1.163</td>
<td>2.025 ± 0.040</td>
</tr>
<tr>
<td>35.0</td>
<td>1.965 ± 0.042</td>
<td>1.134</td>
<td>1.198</td>
<td>2.671 ± 0.042</td>
</tr>
<tr>
<td>43.2</td>
<td>2.338 ± 0.044</td>
<td>1.154</td>
<td>1.236</td>
<td>3.192 ± 0.044</td>
</tr>
<tr>
<td>50.4</td>
<td>2.219 ± 0.055</td>
<td>1.184</td>
<td>1.272</td>
<td>3.348 ± 0.055</td>
</tr>
</tbody>
</table>

### TABLE VIII B.

<table>
<thead>
<tr>
<th>Producer Plate thickness in gms/cm²</th>
<th>Observed production rates/ min.</th>
<th>Displacement correction Factor</th>
<th>Scattering correction Factor</th>
<th>Pressure correction Factor</th>
<th>Corrected production rate/ min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2</td>
<td>0.251 ± 0.025</td>
<td>1.044</td>
<td>1.044</td>
<td>0.9622</td>
<td>0.263 ± 0.025</td>
</tr>
<tr>
<td>14.4</td>
<td>0.414 ± 0.027</td>
<td>1.063</td>
<td>1.034</td>
<td>0.9622</td>
<td>0.462 ± 0.027</td>
</tr>
<tr>
<td>21.6</td>
<td>0.596 ± 0.027</td>
<td>1.099</td>
<td>1.122</td>
<td>0.9622</td>
<td>0.707 ± 0.027</td>
</tr>
<tr>
<td>28.3</td>
<td>1.007 ± 0.032</td>
<td>1.113</td>
<td>1.163</td>
<td>0.9622</td>
<td>1.254 ± 0.032</td>
</tr>
</tbody>
</table>
susceptibility to the temperature then the counting characteristics of the detecting system would change with temperature.

(b) With the change in the temperature of the atmosphere the average temperature of the moderating medium of the pile would also change. This in turn would mean a lowering of the average energy to which a neutron is slowed down before being detected. As the Boron Trifluoride neutron counters follow \(1/v\) law the efficiency of detection would change with temperature.

(c) A change in temperature can also give rise to a change in the \(N\)-radiation intensity.

The Boron Trifluoride neutron counters are known to show no temperature effect in the temperature region below about 30\(^\circ\) C and as such errors arising from the process (a) are ruled out. Simpson\(^1\)(1953) has made a study of the temperature effect in the lower temperature region on the pile geometries and has found that the temperature does not affect the counting rate by more than 0.00 ± 0.04 p.c. per degree C. A similar conclusion was drawn by Curtiss and Gill (1952). This eliminates the possibility of errors from the source (b). The temperature effect of \(N\)-radiation is not known to exist at all, and as such the errors due to (c) are not possible. Thus it can safely be concluded that the temperature variations do not produce any measurable effect in the measurements reported here.

Barometric effects of the \(N\)-radiation have been
known to exist. Cocconi-Tongiorgi (1949) have obtained the barometric eo-efficient for the neutrons as
\[ \beta = (11.2 \pm 0.6) \text{ p.c. per cm. of Hg. pressure.} \]
In the measurements reported here no pressure corrections have been applied. The hourly pressure data for the period of observation does not show any abrupt change in the pressure on any day of the month; and further, the difference between the maximum and the minimum pressure during the entire period of observation of each set was only 10 millibars. The average pressures during the period of two measurements were 726 mbs. and 731 mbs. respectively. The variations during each set of observations were within \( \pm 5 \) mbs. The correction term due to this change in pressure would amount to only a few p.c. of the production rate (which is less than the statistical deviation of the production rate). Besides, the mode of taking the observations ensured that the pressure effects would be minimum.
CHAPTER IV

ANALYSIS OF THE DATA

The production rates after being corrected have been plotted as a function of the thickness of the producer plate for both the unfiltered and the filtered N-radiations on a semi-logarithmic graph in Figs. 13 & 14. The curves smoothly passing through the points have also been drawn for the two measurements. The initial parts of these curves may be represented by an equation of the form:

\[ N_x = A + B \left\{ 1 - \exp\left( -x/l \right) \right\} \]

Where \( N_x \) is the counting rate for the producer plate of thickness \( x \), ‘\( A \)’ is the value of \( N \) for \( x = 0 \); \( B \) would then be a constant to be given by the product of the intensity of the N-radiation and the efficiency of the detecting system including the geometry of the producer plates with respect to the detecting unit. \( l \) is interpreted as the interaction mean free path of the N-radiation in lead. To obtain the best values of \( B \) and \( l \) the following procedure was adopted:

‘\( A \)’ was obtained by producing the curve backwards and obtaining the ordinate of its interaction with the y-axis. This background rate \( A \) was then subtracted from the counting rates for different thicknesses of the producer plates obtained from the curves. Let the resultant be \( N'_x \) given by
FOR FILTERED N-RADIATION
TRANSITION & PRODUCTION CURVES

THICKNESS OF THE PRODUCER PLATES IN GMS/CM²
0 10 20 30 40 50

CORRECTED COUNTING RATE/HOUR
0 1 2 3 4 5

CURVE I

CURVE II

(ABSTRACT SCALE)

X/N

X/N
Assuming certain values for \( B \) and \( l \) the values of 
\[
C_x = B \left[ 1 - \exp \left( -x/l \right) \right]
\]
were calculated for each thickness \( x \) of the producer plates. The value of the \( \chi^2 \) was then evaluated for the entire set of points as follows:

\[
\chi^2 = \sum_x \frac{(C_x - \gamma_x')^2}{C_x}
\]

For a fixed value of \( l \), \( B \) was varied and the \( \chi^2 \) was calculated for different values of \( B \). The \( \chi^2 \) values so obtained were then plotted as a function of \( B \). The curve shows a minimum corresponding to a particular value of \( B \) which then is the optimum value of \( B \) for the given value of \( l \). The calculations were then made for other values of \( l \) and a family of curves of \( \chi^2 \) versus \( B \) with \( l \) as the parameter were obtained. For each assumed value of \( l \) an optimum value of \( B \) was thus obtained. The optimum value of \( l \) was then fixed by the consideration of getting the best fit of the calculated points with the initial part of the observed curve I. This assumption may be considered valid only approximately as the indications are (from the present experiment also) that the secondaries do contribute to the observed counting rates. The results of these calculations lead to a value of the interaction m.f.p. equal to 200 gms./sq.cms. For comparison the interaction lengths of the \( N \)-radiation are given in the Table IX. The int. m.f.p. for the filtered \( N \)-radiation is \( \approx 250 \) gms./sq.cms.

From the \( N \) versus \( x \) curves I and II the \( (\delta N / \delta x)_x \) versus \( x \) curves III and IV have been
<table>
<thead>
<tr>
<th>Cosmic Ray Phenomena</th>
<th>Int. m. f. p. of the N-radiation</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>76, 984</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1949 b.</td>
</tr>
<tr>
<td></td>
<td>196 - 13 gm/cm$^2$ Lead</td>
<td>Sitte, K. Phy. Rev. 78, 714, 19</td>
</tr>
<tr>
<td>$\pi$ - mesons</td>
<td>82 - 35 gm/cm$^2$ emulsion</td>
<td>Camirin et. al. Phil. Mag. 41, 418, 1950</td>
</tr>
<tr>
<td>Stars</td>
<td>102 - 27 gm/cm$^2$ emulsion</td>
<td>Camirin et. al. Phil. Mag. 41, 413, 1950</td>
</tr>
<tr>
<td>Neutron-producing Radiation</td>
<td>200 gms/cm$^2$ Lead</td>
<td>Present work</td>
</tr>
</tbody>
</table>
obtained with the help of the well known graphical and tabular methods (Treatment of Statistical Data—by Worringer Geffener). From the curves III and IV it is evident that the production rate per unit thickness of the producer plate is very much dependent upon the amount of the condensed matter the $N$-radiations has already passed through. The curve III shows an increase in its early part up to about 25 gms./sq. cms. where it exhibits a broad maximum. After this point the curve shows an exponential decrease with thickness.

The curve for the filtered $N$-radiation, however, continues to show an increasing trend up to 30 gms./sq. cms. (the last point of observation on the $N$ versus $x$ curve II corresponds to 28.8 gms./sq. cms.). This curve has a slope greater than that of the previous one, indicating that the interaction mean free path for the filtered $N$-radiation is greater than that for the unfiltered one. The curves III & IV, thus establish the transition phenomena for filtered and unfiltered $N$-radiation.

The transition curve for the unfiltered $N$-radiation above 25 gms./sq. cms. can lead to an estimation of the absorption mean free path of the $N$-radiation. This curve leads to a value of absorption mean free path of 330 (±30) gms./sq. cms. of lead, the errors being due to the shortness of the available range.

Yet another method of obtaining the absorption mean free path lies in the comparison of the production rates in
the producer plates of the same thickness by the unfiltered \( N \)-radiation and by the radiation filtered through 280 gms./sq. cms. of lead. As is seen in the Fig. 15, in their initial parts the two curves do not run exactly parallel to each other, i.e. the ratio of the production rate by the unfiltered \( N \)-radiation to that due to the filtered radiation is seen to be a function of the thickness of the producer plate. This ratio varies from about 2.32 for 5 gms./sq. cms. producer plates to about 2.00 for 20 gms./sq. cms. and about 1.63 for 30 gms./sq. cms. producer plates. Then the intensity - equation

\[
T_2 = T_1 \exp\left(-\frac{x}{\lambda}\right)
\]

can be used to give the abs. m.f.p. of the \( N \)-radiation. Assuming that the secondaries do not contribute materially to the neutron production rate in the small thickness of the producer plates in both the cases of production by the filtered and the unfiltered \( N \)-radiation, and further, that the average multiplicity of the neutron production for the filtered and the unfiltered radiation remains constant the intensity can be considered to be directly proportional to the production rates, so that

\[
\frac{T_1}{T_2} = \exp\left[\frac{(x_2 - x_1)}{\lambda}\right] = \frac{I_1}{I_2}
\]

where \( x_2 - x_1 \) = 280 gms./sq. cms. of lead absorber, \( \lambda \) is the absorption mean free path of the \( N \)-radiation and \( N_1 \) and \( N_2 \) are the production rates in producer plates of the
same thickness by the unfiltered and the filtered $N$-radiations respectively. Corresponding to the ratio of $N_1$ to $N_2$, the absorption mean free path ranges from 330 gms./sq.cms. of lead for 5 gms./sq.cms. lead producer plates to 410 gms./sq.cms. of lead for the 20 gms./sq.cms. producer plates. The average value may, therefore, be taken as 365 ± 35 gms./sq.cms. The production rate in producer plates thicker than about 20 gms./sq.cms. cannot be used directly for the above calculations since the contribution due to the secondaries to the total nuclear disintegrations in the producer plate is no more negligible. Because of the contribution from the secondaries to the total nuclear disintegrations the value of the absorption mean free path obtained by comparing the production rates in the 5 gms./sq.cms. producer plates would be nearer to the actual absorption mean free path value.
CHAPTER V

DISCUSSION

The curves I and II when extrapolated backwards lead to a finite value of the production rates for the 0 cms. thick producer plate. This is most surprising in view of the fact that only the production rate in different thicknesses of the producer plates have been plotted. It may be noted that the curves have been drawn on a semi-logarithmic graph and as such the extrapolation of the curve to obtain the counting rate for the 0 cms. thick absorber may be questioned. This extrapolated value is very much dependent upon the way the curve is drawn, more so on a semi-log graph. However, some guidance can be taken from the curves III and IV to obtain the correct value. From the transition curves it is seen that the rate of production per unit thickness for any thickness is more than the similar quantity for smaller thicknesses and less than that for greater thicknesses in the range 0 < 25 gm/cm² of producer plate thicknesses.

On this consideration the extrapolated value of 'A' has been obtained. It remains to account for the existence of 'A'. This may be understood as follows: For obtaining the production rate for different thicknesses of lead, the difference of the counting rates with the producer plates in position over the pile top and without them have been obtained. This procedure implicitly assumes that the background counts - the counting rate obtained without the
producer plate - is not very much affected by placing the producer plate above the pile. Though the scattering of the neutrons produced in the moderator, and the absorption of the N-radiation producing the neutrons in the paraffin have not been considered, the correction term due to these processes are likely to be quite small, and since the sign of the two effects are opposite to each other they might even cancel each other. The possibility that the producer plate may give rise to neutrons through mechanisms other than those due to the N-radiation passing down through it, is discussed below and it is probable that these processes may contribute materially to account for the existence of 'A'.

The interaction mean free path obtained from the above calculations is significantly different from the geometrical value of 160 gms./sq.cms. of lead. While the interaction length reported by some workers are not very different from the one obtained above, the other reported values are quite far from it as is clear from table IX. Walker (1950) has shown that the interaction mean free path of the N-radiation is a function of energy of the events being studied, such that the higher energy events correspond to lower values of interaction mean free paths and vice versa. For example, the interaction mean free path for showers of particles greater than 5 in number, was 150 ± 8 gms./sq.cms. lead, whereas for showers of 3 particles, it was 208 gms./sq.cms. This conclusion was initially doubted because of the alternative explanation of
the change in counting rates as a result of the possible contributions from the secondaries of the nuclear interactions. However, Sitte's measurements (1950) confirmed the above conclusions of Walker. Besides, Boehmer and Bridge (as reported in High Energy Particles - By Rossi, P.) have obtained an interaction length of the neutral N-radiation equal to 220gms./sq. cms. of lead absorber. This is in close agreement with the value reported here.

The interaction mean free path for the filtered N-radiation seems to be slightly different from the one obtained for the unfiltered N-radiation.

That the interaction mean free path is not the same thing as the absorption length for Cosmic Ray events due to nucleons has been emphasized by Rossi (1948). Janossy and Heitler have even shown on theoretical consideration that the absorption mean free path of the N-radiation should be equal to 2 times the interaction mean free path which is given by the geometrical cross section for the nucleus. The ratio of the interaction mean free path to the absorption mean free path obtained from the present experiments lies in the range 1.6 to 2. Values of this ratio have been reported by several workers and they all lie in the above range. For example, whereas George and Jason (1950) reported a value 2, Rosser and Swift (1951) obtained a value $1.8 \pm 0.3$ for the shower stars. The average value from the present experiment may be taken as 1.8 - a value quite close to 2, as predicted by Janossy and Heitler.
The value of the absorption mean free path obtained from a comparison of the curves I and II is slightly higher than the one obtained from curve III. The difference may be quite significant inspite of the large error in the earlier value. Barton, George and Jason (1951) working with photographic nuclear emulsion plates found the absorption mean free path of the star producing radiation in Carbon as $166 \pm 8$ gms./sq.cms. This figure is much more than that expected on the basis of the geometrical cross section for the nuclear interactions. The absorption mean free path of the N-radiation in air which has an atomic weight greater than that of Carbon is less than that for Carbon as reported by Barton et.al. Curtiss and Gill (1952) obtained the absorption mean free path of fast neutrons, which are in equilibrium with their producers upto a height of 20,000 ft. (Bernardini et.al, 1949) as $128$ gms./sq.cms. of air. The large difference in the observed and the expected values has been ascribed by Barton et.al. to the behaviour of the $\pi$-mesons in air as compared to that in condensed matter. The $\pi$-mesons in air have a greater probability for $\pi\rightarrow\mu$ decay than for a nuclear interaction with air nuclei. Compared with this, the $\mu$-mesons have a greater probability of producing nuclear disintegrations in dense material. It has been shown by Barton et.al. that if the contribution of $\pi$-mesons to the total nuclear disintegrations is subtracted from the observed star rates the value obtained for the absorption mean free path of the star producing radiation comes out to be $143 \pm 10$ gms./sq.cms.
of Carbon - a value nearer to the geometrical one. The attenuation of the star-producing radiation has been measured by Rosser and Swift (1951) at Pic du Midi (altitude 2800 m.), and they show that the ratio of the star intensities above and under 30 cms. of lead is dependent upon the type of the stars that are being studied - a phenomenon similar to the one observed in the present experiments for the production rate ratios as a function of the thickness of the producer plates. The values of the attenuation length in lead as obtained by Rosser and Swift are:

\[(305 \pm 7) \text{ gms./sq.cms.} \text{ for all stars.}\]
\[(380 \pm 65) \text{ -do- for penetrating showers (} n > 2 \text{)}\]
\[(405 \pm 31) \text{ -do- for events with charged relativistic primaries}\]
\[(260 \pm 34) \text{ -do- for events with uncharged primaries (excluding simple evaporation stars)}\]

Fujimoto and Hayakawa (1949) have suggested a division of the nuclear disintegration-producing radiation into two components viz. (1) the component responsible for the stars with relativistic secondaries - i.e. the shower primaries or the A-component; (2) the component giving rise to evaporation stars low energy star primaries or the B-component.

The average energy of the B-component of the Cosmic Radiation is about 1000 Mev. and this is in the main, secondary to the A-component. The fact that the present experiment leads to two different values of the
absorption mean free path has probably this division as its basis. Whereas in the unfiltered $N$-radiation the two components are in equilibrium, their ratio in the $N$-radiation filtered through 280 gms./sq.cms. is no more the same. Rosser and Swift (1951) have shown that the percentage of the stars produced by the charged relativistic primaries increases from 13.1 ± 0.9 p.c. for unshielded plates to 17.0 ± 1.0 p.c. for plates under 30 cms. of lead and this has been ascribed to the fast $\pi^-$-mesons created in the lead absorber. Barton et al. have even shown that the $\pi^-$-mesons give rise to a transition effect for Carbon at around 100 gms./sq.cms. a value reported by other workers for the penetrating showers.

In the present work the existence of the transition effect for the neutron-producing radiation has also been obtained. The transition curve III for the unfiltered $N$-radiation shows an initial rise up to about 25 gms./sq.cms at which point it enters a region of a broad maximum before decreasing exponentially. The transition curve IV for the filtered $N$-radiation on the other hand, shows a comparatively steeper rise than for the unfiltered one. Besides, the curve IV shows an increasing trend right upto 30 gms./sq.cms. This change in the behaviour of the $N$-radiation after passing through 280 gms./sq.cms of lead can come about because of either (1) a change in the average energy of the $N$-radiation, (2) a change in the composition
of the N-radiation or (3) both. It may be noted that the
transition maximum reported by Simpson for the neutron
producers occurs at 15 gms./sq. cms. of lead. It is
probable that the transition phenomenon is latitude
sensitive.

Any process invoked to explain the increase of
\( \frac{\delta N}{\delta x} \) should also be able to explain the saturation
that sets in around 25 gms./sq. cms. of lead as also the
shift in the saturation point for the N-radiation
filtered through 280 gms./sq. cms. of lead. The
transition effect for the star has been obtained by
Malasipna et al. (Nuovo 1950) with a maxima around 1 cms.
of lead. Dallaporta Merlin and Puppi (1950) have tried
explain the increase in the star rates on the assumption
of the evaporation neutrons capable of producing nuclear
disintegrations. The results of Malasipna et al. (1950)
showed a higher rate of stars in plates placed on top of
a lead absorber than in the plates not placed on the
absorber suggesting that there is a larger backward
emission of secondary neutrons capable of producing 3- and
4- pronged stars than in an equivalent thickness of air.
The results of Bernardini et al. (1950) also show that
there is a much larger proportion of 3- and 4- pronged
stars under 2 cms. of lead; under 30 cms. of lead this
transition effect vanishes. In the present work the
nature of the transition effect is such that it persists
even after the N-radiation has been filtered through 280
Besides the maxima of the transition curve appears to be shifted for the filtered $N$-radiation. Barton et al. have shown that the increase in the $\pi$-mesons under the absorber cannot contribute to the order of the change observed. Considering the long interaction length it is difficult to imagine a fast development of the nucleon cascade so as to reach its maximum within the 25 gms./sq.cms. of lead. It seems more probable, therefore, that the secondaries from the nuclear interactions taking place in the material placed just below the producer plates contribute materially to the observed increased production rates. A tentative mechanism explaining the transition effect is discussed below.

It is known from the emulsion studies that in the energetic nuclear interactions, besides the release of the relativistic particles in the forward direction, the isotropic low energy particles are also emitted. This isotropic class of particles consists of the $\pi$-mesons of a few hundred Mev. energies of nucleons of 100-200 Mev. energies. These particles are capable of producing nuclear disintegrations. In the present work the difference of the counting rates with- and without- producer plates in position has been taken to give the counting rate proportional to the nuclear disintegrations produced by the $N$-radiation in the lead producer plates. This implicitly assumes that the background counting rate represented by the rate obtained without the producer plate in position is not disturbed when a producer plate of any
thickness is placed over the detecting unit. This background counting rate consists of two parts only:
(i) the fast neutrons of Cosmic Rays that enter the pile from outside and get detected by the detecting unit, and
(ii) the neutrons arising from the nuclear disintegrations taking place in the pile moderator. The effect of the producer plate on the first is a very small reduction for the range of thicknesses of the producer plates for which the transition effect is observed. The effect on the latter however, is expected to be quite marked. The change in this comes out because of (a) the absorption of the N-radiation that gives rise to the nuclear interaction in paraffin (a reduction) (b) the back-scattering of the neutrons produced in the moderator so as to get detected in the neutron counters (an addition) (c) a possible increase of the nuclear interaction in the paraffin because of the increase in the energetic secondaries due to the nuclear interactions in the producer plates, (d) the interactions of the energetic isotropic secondaries of the nuclear interactions of paraffin in the producer plate above. The contributions from (a) and (b) are definitely quite small for the thickness of the producer plates in question and being opposite in sign, they are likely to minimise the total effect due to them. However, the processes (c) and (d) are important for the present considerations. Barton et al. have shown that it is the isotropic class of the secondaries which is important for accounting for
any increase in the star frequency. They have shown that the frequencies of the $\eta$-mesons directed downwards increase up to about 100 gms./sq. cms. of Carbon and decrease afterwards, whereas those directed up show a monotonic decrease right from the beginning. Either of the two processes or a suitable combination of the two can, it appears, account for the transition curve, with the position of the maxima being taken care of by the range of the average secondary particle. This explanation incidently, may also be able to explain the presence of an apparent production rate for 0 cms. lead producer. As the efficiency of the pile is not known, the effect of the two mechanisms cannot be estimated. This theory can, however, be put to test by changing the moderating medium and by putting some elements other than lead as producers so as to change the effect of the back-radiation.
SUMMARY

Investigations have been carried out on the properties of $\alpha$-radiations by a detection of the neutrons produced in the nuclear disintegrations. The results of the present studies are:

(i) the interaction mean free path of the $\alpha$-radiation comes out to be 200 gms./sq.cms., a value much higher than the geometrical one. The interaction length of the filtered $\alpha$-radiation is slightly higher than this value (about 250 gms./sq.cms.)

(ii) the absorption mean free path of the $\alpha$-radiation is obtained as $320 \pm 40$ gms./sq.cms. a value expected on the basis of the geometrical cross section.

(iii) the absorption mean free path obtained by comparing the nuclear disintegration rates by the filtered and unfiltered $\alpha$-radiations leads to an absorption length of 360 gms./sq.cms. of lead. This value is considerably higher than the geometrical one and probably the secondaries produced in the nuclear interactions might account for the difference.

(iv) The transition effect of the $\alpha$-radiation had been observed for the unfiltered as also for the filtered $\alpha$-radiation. The transition curve III for the former shows a broad maximum around 25 gms./sq.cms. compared to the transition maximum reported by Simpson at 15 gms./sq.cms of lead. The present value as compared to Simpson's
indicates a latitude effect for the transition phenomena. Besides, for the $N$-radiation filtered through 280 gms/sq.cms. the transition maximum appears to be shifted up. Both these may be accounted for on the basis of the average energy of the $N$-radiation. A tentative explanation for the phenomenon is discussed.