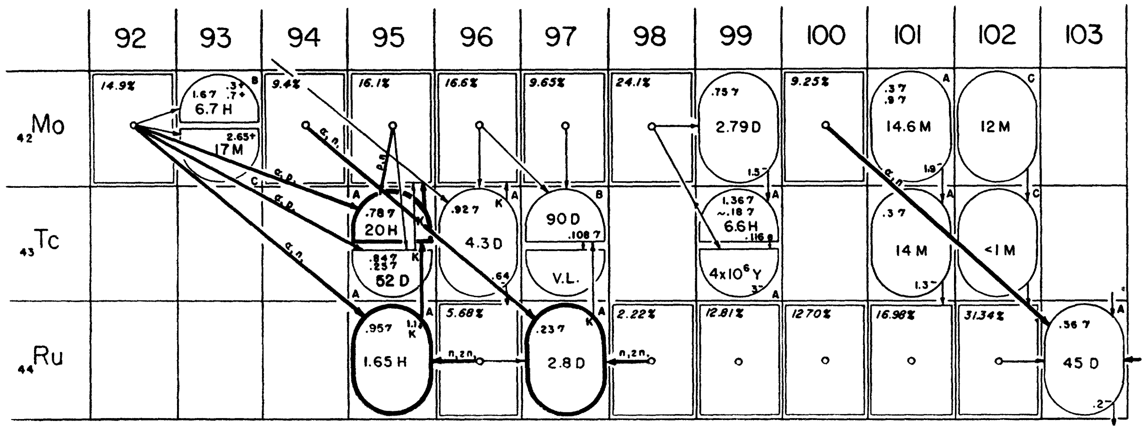

FIG. 6. The technetium region of the nuclear transmutation chart. Heavy lines and arrow indicate information reported in this paper.

Table I shows the characteristic radiations of the isotopes studied. The information reported in this paper is given in boldfaced type.

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On the Penetrating Showers of Cosmic Radiation

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Experiments have been performed on the penetrating showers of cosmic radiation accompanied and not accompanied by extensive air showers. In the accompanied showers the penetrating particles are very likely to pre-exist in the air; in the unaccompanied showers they are created in the absorbers surrounding the counters by a nucleonic component of the cosmic radiation.

1. INTRODUCTION

SEVERAL series of experiments have been performed in order to study penetrating showers associated and unassociated with the extensive cosmic-ray showers at sea level.

The experimental arrangement is shown in Fig. 1. The trays of unshielded counters a, b, c, each consisting of four counters in parallel (surface of each tray 400 cm^2), were placed in a horizontal plane at the vertices of an equilateral triangle of 4-m sides, in boxes of light material, maintained at constant temperature, on the roof of the laboratory. The three-fold coincidences $a+b+c$ ($\sim 6h^{-1}$) were due to the extensive air showers.

The penetrating particles were recorded by the six trays, A, B, C, D, E, F, each consisting of four counters in parallel (surface of each tray 400 cm^2) arranged in three telescopes, AB, CD, and EF, surrounded by lead. The thickness of the lead between A and B was 6 cm, between C and D, E and F it was 1 cm. The screens on the sides, fronts, and backs of all counters were 11 cm thick. Underneath each telescope 6 cm of lead were placed. Above the telescopes the thickness T was varied in different series of measurements from 10 to 31 cm. The axes of the telescopes AB and CD were 16 cm apart (6-cm Pb in between); the distance between the axes of AB and EF was 230 cm. The two lead boxes were placed inside the laboratory, about 3 m under the plane of the counters abc and roughly in the middle of the triangle abc.

The arrangement of the counters A, B, C, D was such that spurious coincidences $A+B+C+D$, due to a single penetrating particle crossing either AB or CD and generating a soft secondary, were avoided. In fact, the minimum amount of lead such a secondary would have had to penetrate was more than 8 cm.

2. PENETRATING SHOWERS ACCOMPANIED BY EXTENSIVE SHOWERS (PSA)

We call PSA the events in which at least two penetrating particles cross the recording system under lead, accompanied by the simultaneous discharge of the three counters a, b, and c. We recorded simultaneously the coincidences:

$$a+b+c+A+B+C+D \quad \text{(narrow PSA)},$$
$$a+b+c+A+B+E+F \quad \text{(large PSA)}.$$

The aim of the experiment was to compare the frequencies of the narrow and large PSA. Measurements have been made with different thicknesses of the lead T above the telescopes. No appreciable differences were obtained in the counting rates with the different absorbers. In Table I the results of the different series are summed up. As the table shows, the frequencies of the narrow and large PSA are about the same.

We think that this result is understandable only by assuming one of the following hypotheses:

(a) PSA consist of particles pre-existing in the extensive showers, i.e., not locally generated in the lead.

(b) PSA consist of particles locally generated in the lead in a *non-multiple* process by some component of the extensive showers.

In fact, were the penetrating particles generated in the lead above the counters in multiple processes, the probability of coincidences $a+b+c+A+B+C+D$ would have been much larger than that of the coincidences $a+b+c+A+B+E+F$.

This result, in agreement with data obtained by Greisen and Treat at Echo Lake,[1] leads us to a conclusion about the origin of the PSA in complete disagreement with the previous view based on experiments performed by one of us,[2] as well as on experiments of Janossy[3] and Salvini and Tagliaferri;[4] all these experiments have been interpreted as indicating local multiple processes of generation of PSA.

We think that our present experiment faces the problem in a more direct way than our previous experiment[2] so that the present results have surely more weight than the previous ones. As for the experiments of Janossy[3] and of Salvini and Tagliaferri,[4] we want to note that their arrangement for detecting the penetrating showers probably did not completely avoid the penetrating showers not accompanied by extensive showers, which, as we shall see, are locally generated in the absorber.

On the basis of our experiment there is no way of discriminating between hypotheses (a) and (b). However, an indication in favor of hypothesis (a) may be derived from the fact that, as shown by reference 2 and confirmed by references 3 and 4, the frequency of PSA is independent of the atomic number Z of the absorber above the counters. Ferretti has shown[5] that if the penetrating particles are locally produced by the electrons and photons of the extensive showers, the independence of Z of their rate of production would indicate a cross section for the process proportional to Z^2, which would be hardly understandable. The independence of Z is instead to be expected in the case of hypothesis (a), since the absorption of the

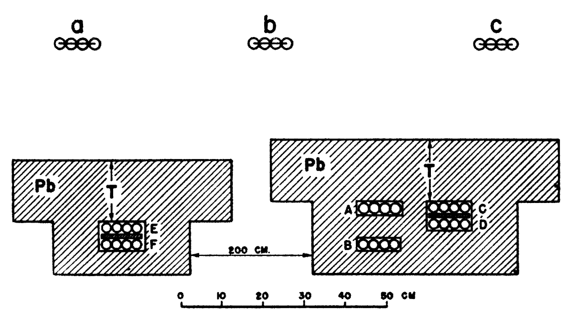

FIG. 1. Arrangement of the counters and the absorbers.

[1] J. Treat and K. Greisen, Phys. Rev.

[2] G. Cocconi and C. Festa, Nuovo Cimento **3**, 293 (1946).

[3] L. Janossy and Broadbent, Proc. Roy. Soc. **190**, 497 (1947).

[4] G. Salvini and G. Tagliaferri, Phys. Rev. **73**, 261 (1948).

[5] B. Ferretti, Nuovo Cimento **3**, 301 (1946).

TABLE I.

hours	$a+b+c+A+B+C+D$ (narrow PSA)	$a+b+c+A+B+E+F$ (large PSA)
1640	52	50

penetrating particles pre-existing in the shower is mass proportional.

3. PENETRATING SHOWERS NOT ACCOMPANIED BY EXTENSIVE SHOWERS (PSNA)

We call PSNA the events in which at least two penetrating particles cross the detecting system under lead, without simultaneous discharge of the counters *abc*.

While performing the PSA experiments, we also recorded the coincidences: $A+B+C+D$ and $A+B+E+F$. The PSNA were given by the differences:

$$(A+B+C+D)-(a+b+c+A+B+C+D) \quad \text{(narrow PSNA)},$$

and

$$(A+B+E+F)-(a+b+c+A+B+E+F) \quad \text{(large PSNA)}.$$

While in PSA experiments the chance coincidences were completely negligible, in the PSNA experiments the chance coincidences due to two incoherent mesons crossing AB and one of the telescopes CD or EF are quite troublesome. In order to minimize their number, a coincidence circuit (blocking oscillators and crystal diode coincidences) was used with resolving time 1.2 μsec. The rate of chance coincidences $A+B+C+D$ or $A+B+E+F$ was $0.08h^{-1}$.

The results obtained with various thicknesses of the lead T above the telescopes are collected in Table II.

From the data of Table II it appears that the behavior of PSNA is completely different from that of PSA. PSNA are practically all narrow

TABLE II.

T (cm Pb)	hours	narrow PSNA ob-served	narrow PSNA cor-rected*	narrow PSNA rate h^{-1}	large PSNA ob-served	large PSNA cor-rected	large PSNA rate h^{-1}
6	122	224	214	1.75±0.12	—	—	—
10	313	638	613	1.95±0.08	38	13	0.04 ±0.02
15	713	1475	1418	1.99±0.05	62	5	0.007±0.015
22	471	989	951	2.02±0.07	33	0	0 ±0.02
31	143	294	282	1.97±0.12	20	3	0.02 ±0.04

* "Corrected" figures refer to coincidences corrected for the chance coincidences.

TABLE III.

T	hours	narrow PSNA ob-served	narrow PSNA cor-rected**	narrow PSNA rate h^{-1}
Permanent 6-cm Pb	61	224	214	3.5 ±0.23
6-cm Pb+72-g cm^{-2} Pb	207	852	820	3.97±0.14
6-cm Pb+72-g cm^{-2} C	243	1561	1521	6.25±0.16

** The correction indicated is for chance coincidences.

showers, which indicates that they are created locally in multiple processes in the lead above the detecting system. All the recorded $A+B+E+F$ coincidences may be accounted for by chance coincidences.

The frequency of the narrow PSNA remains practically constant ($\sim 2h^{-1}$) when the thickness T is varied from 10 to 31-cm Pb; from this the conclusion may be derived that either the primary radiation generating the PSNA or the particles of which PSNA consist have high penetrating power; but one has to remember that the variation of T causes a change in the angular spread of the recorded showers, so that a possible absorption may be masked.

An experiment has been performed in order to study the dependence of PSNA on the atomic number Z of the material in which their production take place. The frequencies of the PSNA have been compared under equivalent amounts of lead and carbon, placed above a permanent layer of 6-cm Pb.

In order to avoid the geometrical effect due to the different densities of these materials, the measurements with lead were performed with the permanent Pb always close above the telescopes, and the other 6-cm Pb arranged in 5 layers evenly distributed in the same space as that occupied by the equivalent amount of graphite (42 cm). In order to increase the counting rate, the telescope EF was placed inside the absorber, near AB, in the symmetrical position of CD. Coincidences $a+b+c+A+B+C+D$ and $a+b+c+A+B+E+F$ were recorded, as well as coincidences $A+B+C+D$ and $A+B+E+F$, in order to allow the discrimination of the PSNA.

The results are collected in Table III.

From these data it follows that (coinc. under C/coinc. under Pb)$=1.58\pm0.07$. This remarkable difference between the frequencies of the showers under carbon and lead may be considered as a confirmation of the hypothesis formulated by several authors,[3,6,7] that the PSNA are generated by a nucleonic radiation, presumably the primary protons; the lower efficiency of Pb in producing PSNA would be due to the condensation effect of many nucleons in the heavy nucleus, as pointed out by Janossy.[8]

Following this interpretation, from our data it is possible to state that the cross section for the production of PSNA must not be much smaller than the geometrical cross section of the nucleons ($\sim 7.10^{-26}$ cm^2). This is in agreement with the cross section ($\sim 2.10^{-26}$ cm^2) required to explain the variation of the frequency of the PSNA with altitude above sea level.[6,7]

Finally, a test experiment has been made with all the counters of the trays *a*, *b*, *c* connected in parallel and acting as a single counter of 1200-cm^2 surface. With $T=15$ and 31-cm Pb, penetrating showers were recorded both accompanied and unaccompanied by at least one particle on the tray *abc*.

The counting rates obtained were practically the same as those recorded during the experiments described above. This demonstrates that the discrimination between PSA and PSNA did not depend on the particular arrangement of unshielded counters chosen for detecting the extensive showers.

[6] G. Wataghin, Nature **161**, 91 (1948).
[7] E. P. George and P. T. Trent, Nature **161**, 248 (1948).
[8] L. Janossy, Phys. Rev. **64**, 345 (1943).

4. CONCLUSIONS

Penetrating showers not accompanied by extensive showers and penetrating showers accompanied by extensive showers differ sharply in local behavior. The first ones are mostly generated locally in the absorber above the detecting system and their rate of production is weakly Z dependent (larger for smaller Z). The second ones, instead, are mostly generated in the air and their rate under absorbers of equal weight does not depend on Z.

We wish to emphasize that this distinction between the two kinds of showers rests on an experimental basis and does not imply any more fundamental difference between the showers than a difference in their place of origin, whether it is in the absorber or in the air far above the absorber.

With counter arrangements designed to detect narrow penetrating showers, the frequency of PSNA is much bigger than that of the PSA (with our arrangement 70 times). Therefore, most of experiments on penetrating showers in which no discrimination has been made between showers accompanied and not accompanied by extensive showers concern the PSNA. Hence, we want to emphasize that the conclusions derived therefrom refer to this type of shower.

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