may be worth while to mention that in our previous case a source prepared by condensing Po onto a palladium rod gave similar results to those on nickel strips. In any case, it is important to make a systematic experimental study starting with a support of very low atomic number.

We should like to thank Miss Sophia Wysienska and Mrs. Allen Fry for their invaluable help in examining the plates.

[1] We are thankful to Dr. M. Blau, then of the Canadian Radium Uranium Company for lending us the mesothorium source.
[2] F. Soddy, *Chemistry of Radioactive Elements* (1914), Part 2, second edition; E. Rutherford, *Radioactive Substances and Their Radiations* (1913); O. Hahn, *Applied Radioactivity* (1936).
[3] The results up to 1935 are collected in F. Rasetti's book, *Elements of Nuclear Physics* (1936).
[4] W. Y. Chang, Phys. Rev. **70**, 632 (1946).
[5] To appear in Phys. Rev. One of us would like to thank Dr. W. G. Wadey for letting him read the manuscript before publication.

Further Data Concerning the Variation of Penetrating Showers with Altitude*

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ADDITIONAL data have been obtained confirming the preliminary results recently published[1] concerning the altitude variation of the penetrating showers. It is now clear that the frequency of these showers varies exponentially with atmospheric depth from sea level to an altitude of 30,000 feet, the highest altitude investigated. The information obtained in the recent measurements also makes it possible to estimate the relative importance of penetrating showers which are, and those which are not, accompanied by atmospheric showers.

The detector of penetrating showers is described in the communication cited. Briefly, it consists of five trays of four Geiger-Mueller counters arranged in a block of lead as sketched in the inset of Fig. 1. Multiple coincident counter discharges of certain kinds are interpreted as detecting the passage of penetrating showers; these "events" are referred to by symbols of the type $A_\alpha B_\beta \cdots$, signifying simultaneous discharge of α- or more counters in tray A, β- or more counters in tray B, etc. During the experiments discussed here, an "extension" tray F was placed four inches to the side of the block of lead, at the level of the upper surface. This was used in conjunction with the detectors to investigate the correlation with atmospheric showers. The equipment in this form was operated at altitudes of 300 feet (Lexington, Massachusetts), 9500 feet (Doolittle Ranch, Colorado), and 14,300 feet (Mt. Evans, Colorado).

All of the events listed in the previous communication were recorded, in addition to events of the type $A_1B_2C_2F_\eta$, where $\eta = 1, 2, 3$, or 4.

The complete set of data giving the frequencies of the events $A_1B_1C_1D_1$, $A_2B_2C_2$, $A_1B_2C_2$, and $A_2B_2C_1$ at seven different altitudes is reproduced in the graph. The event $A_2B_2C_2$ is believed to be least affected by spurious effects and thus to represent closely the occurrence of penetrating showers at all altitudes. The experimental points for this event lie on an exponential curve within the experimental error at all points. The exponential curve chosen by the method of least mean square errors to give the best fit yields an absorption thickness of 118 ± 2 g cm^{-2}. As can be seen from the figure, the events $A_1B_2C_2$ and $A_2B_2C_1$ also follow the exponentials with the same absorption thickness down to the pressure 725 g cm^{-2} (9500 feet).

Information obtained with the extension tray is shown in Table I. Most significant is that the rate for the event $A_2B_2C_2F_1$ is at all altitudes 10 percent or less than the rate for $A_2B_2C_2$. This clearly shows that the great majority of the events recorded by the penetrating shower detector are not accompanied by dense atmospheric showers. This finding disagrees with that of Janossy and Broadbent[2] who concluded that at sea level about one-half of the penetrating showers are accompanied by atmospheric showers. It is evident, however, that the geometry of the detecting apparatus places a strong bias on the type of shower recorded.

It is interesting to note that at 14,000 feet the event $A_2B_2C_2F_4$ is about one-half as frequent as the event $A_2B_2C_2F_1$, while the frequencies of the events $A_2B_2C_2F_2$ and $A_2B_2C_2F_3$ are intermediate in value. Thus the atmospheric showers which accompany the passage of a penetrating shower through the detector appear to have a high

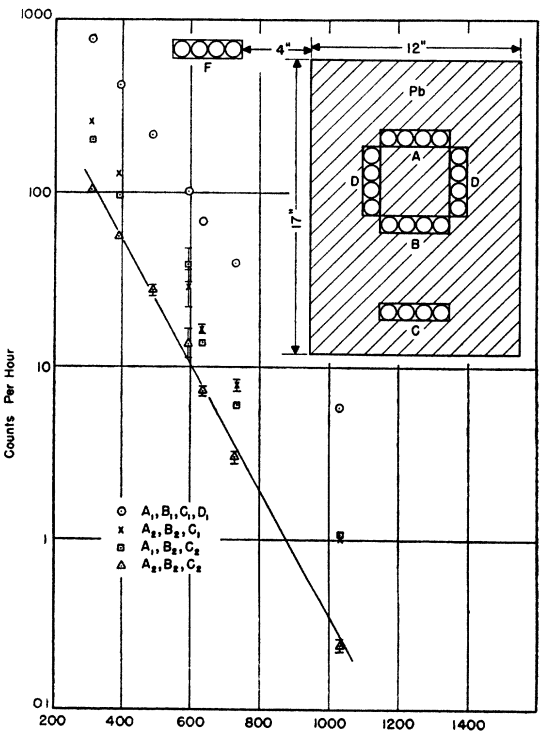

FIG. 1. Complete set of data giving the frequency of the events $A_1B_1C_1D_1$, $A_2B_2C_1$, $A_1B_2C_2$, and $A_2B_2C_2$ at seven different altitudes.

TABLE I.

Altitude (feet)	Pressure (g cm^{-2})	Time (hour)	$A_1B_2C_2$ (counts)	$A_1B_2C_2F_1$ (counts)	$A_2B_2C_2$ (counts)	$A_2B_2C_2F_1$ (counts)	$A_2B_2C_2F_2$ (counts)	$A_2B_2C_2F_3$ (counts)	$A_2B_2C_2F_4$ (counts)
250	1030	308	309	16					
		113.5			25	3			
9500	725	58			174	17	12	10	6
14,000	625	41.5			.293	15	10	9	8

density. The area of each counter is 67.5 cm^2. If one assumed that all of the showers striking tray F had the same average density, one would calculate this density as being about 220 particles per square meter.

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[2] D. Broadbent and L. Janossy, Proc. Roy. Soc. **A192**, 364 (1948).

Development of Thick Emulsions by a Two-Bath Method*

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THE increased use of thick emulsions in nuclear physics has made it desirable to find a satisfactory technique of uniformly developing them. Dilworth, Occhialini, and Payne[1] have described the so-called temperature development method. We are using an alternate method of development on Ilford, C2, 200 u plates, which is probably applicable to even thicker emulsions. The results we have obtained to date might be helpful to others who are using these emulsions.

The method we adapted for our purpose is essentially that described by Crabtree *et al.*[2] which was used for the uniform development of large quantities of motion picture film. In this method the developer is divided into two baths. The first bath contains the developing agent, part of the sodium sulfite and the potassium bromide, but no alkali. The second bath contains all the necessary constituents of an ordinary developer plus an additional amount of alkali. In the first bath the developer diffuses into the emulsion. However, the rate of development is very low because of the lack of alkali. In the second bath the actual development takes place because of the presence of the alkali. It was necessary to add developing agent to the second bath, because not enough can be absorbed from the first bath.

After trying various combinations of the constituents and different times of development we find the following procedure to give the best results.

Step 1: Soak in water for 10 min.
Step 2: Solution A for 30 min. (slight agitation).
Step 3: Solution B for 30 min. (no agitation).
Step 4: 2 percent acetic acid 15 min. (agitation).
Step 5: Fix in F-5 at 74°F with constant agitations 6–8 hours.
Step 6: Wash in running water 2 hours.

Solution A:

Elon	1.1 g.
Na_2SO_3	24.0 g.
Hydroquinone	4.4 g.
KBr	2.0 g.
H_2O to make	2000 cc

Solution B:

Stock D-19	400 cc
H_2O	1600 cc
Additional Na_2CO_3	16 g.

For different batches of the same emulsion, slight adjustments of the developing times and the composition of the solutions may be necessary. The temperatures of the solutions in the Steps 1–4 were all kept constant at 68°F. The temperature of the fixer could also be kept at 68°F. However, it was increased to 74°F to shorten the fixing time.

Because the temperature is kept constant the danger of reticulation is avoided. None of our plates showed any sign of reticulation. Proton tracks in the emulsion had their normal grain density while the background fog was very low. The plates appeared to be uniformly developed throughout the emulsion.

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[1] C. C. Dilworth, G. P. S. Occhialini, and R. H. Payne, Nature **162**, 102 (1948).
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Thermonuclear Reactions in the Expanding Universe

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IT has been shown in previous work[1–3] that the observed relative abundances of the elements can be explained satisfactorily by consideration of the building up of nuclei by successive neutron captures during the early stages of the expanding universe. Because of the radioactivity of the neutron, and also because neutrons are used in forming the elements, the building up process must have been completed essentially in a time of the order of several neutron decay periods, i.e., about 10^3–10^4 sec. It should be noted that following the essential completion of the main element forming process, the temperature prevailing