end of the spectrum, in addition to the expected Compton distribution, is due to secondary electrons that are produced in the copper cap and uranium foil by the bremsstrahlung arising in the copper cap as a result of the absorption of the beta-particles.

As a check of the foregoing interpretation for the broad distribution of electrons at the low energy end of the spectrum shown in Fig. 1, a source of $Sr^{90}-Y^{90}$ was placed in a copper capsule to which was fastened the same uranium foil as that used with the Pr^{142} source. This copper capsule had the same diameter as the copper cap used with the praseodymium source. The $Sr^{90}-Y^{90}$ source, which is gamma-free and emits beta-particles with a maximum energy[6] (2.23 Mev) close to that for Pr^{142}, was found to give a secondary electron spectrum as shown by the circles and solid line in Fig. 2. The insert in Fig. 2 shows a scale drawing of the arrangement of source, copper capsule, and uranium foil. The end of the capsule on which the uranium foil was fastened had a surface density of 2.43 g/cm^2 while the sides of the capsule had a surface density of 2.12 g/cm^2. This was sufficient to absorb completely electrons with an energy of about 4 Mev.

The broken line shown in Fig. 1 was obtained from the Compton distribution produced by the Zn^{65} gamma-ray (1.12 Mev).[7] This was obtained under conditions similar to those for the Compton distribution for Pr^{142}. The scale of the Zn^{65} curve has been adjusted to match the Pr^{142} Compton distribution at the maximum ordinate and at the Compton high energy "edge." The triangles shown in Fig. 2 were obtained by substracting the two curves shown in Fig. 1 and normalizing the ordinates. It may be seen that the two secondary electron distributions produced by bremmstrahlung are in good agreement. It appears, then, that the broad distribution of electrons at the low energy end of the Pr^{142} spectrum shown in Fig. 1 is due to bremsstrahlung.

The secondary electron spectrum of Pr^{142}, shown in Fig. 1, is therefore regarded as a composite of the photoelectrons and Compton electrons arising from a single gamma-ray, plus the electrons produced by bremsstrahlung. This conclusion, accordingly, in no way alters the final results and conclusions regarding the radiations from Pr^{142} nor the decay scheme reported in the previous publication.[1]

The authors wish to express their appreciation to Messrs. Earl W. McMurry and James T. Jones, Jr. for their assistance in obtaining part of the data.

† Contribution No. 183 from the Institute for Atomic Research and Department of Physics, Iowa State College, Ames, Iowa. Work was performed in the Ames Laboratory of the AEC.

1 Jensen, Laslett, and Zaffarano, Phys. Rev. 80, 862 (1950).
2 C. E. Mandeville, Phys. Rev. 75, 1287 (1949); Cork, Schreffler, and Fowler, Phys. Rev. 74, 1657 (1948); E. R. Rae, Proc. Phys. Soc. (London) 63A, 292 (1950).
3 D. E. Alburger (private communication).
4 Jensen, Laslett, and Pratt, Phys. Rev. 75, 458 (1949).
5 Pratt, Boley, and Nichols, Rev. Sci. Instr. 22, 92 (1951); Keller, Koenigsberg, and Paskin, Rev. Sci. Instr. 21, 713 (1950).
6 E. N. Jensen and L. J. Laslett, Phys. Rev. 75, 1949 (1949).
7 Jensen, Laslett, and Pratt, Phys. Rev. 76, 430 (1949).

The Nature of Cosmic-Ray Bursts Underground*

C. N. Chou
Department of Physics, University of Chicago, Chicago, Illinois
(Received April 28, 1952)

In a previous publication,[1] size-frequency relations of cosmic-ray bursts observed underground were reported. The apparatus used was a duralumin ionization chamber of wall 1.2 cm thick, filled with argon to a pressure of 88 atmospheres at 20°. It was at least 2 to 4 meters from the wall of a tunnel under 30 meters of clay. It had a collecting volume of about 1.2 liters, and recorded bursts predominantly of sizes 10^6–10^7 ion-pairs, corresponding to about 15–150 minimum-ionizing particles. The integral size-frequency distributions [given originally in Fig. 4(c) of the previous publication] are reproduced in Fig. 1 with added indications of standard deviations. The ordinate gives the observed integral rate of bursts (except curve Pb, which has been adjusted as explained below) in number per hour. The abscissa gives the estimated energy of bursts assuming that they were produced by μ-mesons through the usual processes of knock-on, bremsstrahlung, and pair-production. The scale of the abscissa does not apply to curve S, which gives the theoretically estimated contribution of nuclear stars (presumably produced by μ-mesons) inside the chamber, based on observations by George and Evans.[2] Curve C indicates the actually observed number of bursts with the chamber unshielded (corrected for the contribution of stars as given by curve S), and hence probably produced from the clay of the wall of the tunnel. The energy of the bursts is estimated from the shower development and the geometry. Curve Pb indicates the bursts observed with lead plates of size 20×20 cm^2 and of average thickness 13 cm placed above the chamber (the correction for stars being negligible in this case). The interception efficiency (with respect to burst size) was estimated to have increased by a factor of 5, and the frequency by a factor of 30 in comparison with the observations for bursts produced from clay. This adjustment seems justified by comparing our results with those obtained recently by Driggers[3] at sea level. The dashed curve D represents his results directly. The agreement is satisfactory within experimental uncertainties.

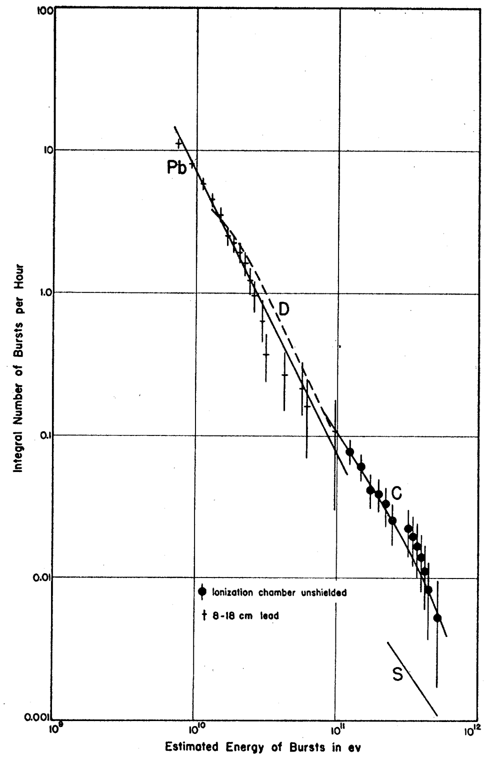

FIG. 1. Integral size—frequency relations of bursts.

The curves Pb and C should be compared with the well-known underground intensity vs depth relation actually observed.[2] The slope of curve C agrees well with the slope of the intensity vs depth curve at depth greater than about 200 m water equivalent. Hence if we assume that the conclusion is valid that the efficiency of burst production under similar geometrical conditions remained the same at ground level as underground, our experimental results show that either (a) fewer μ-mesons of energy higher than about 10^{11} ev or/and (b) more μ-mesons of energies in the range 10^{10}–10^{11} ev exist under 60 m water equivalent than at ground level.

Explanation based on alternative (a) has been given independently by Greisen[4] and by Hayakawa[5] in 1948. Due to the relativistic increase of the lifetime of the high-energy π-mesons, the probability of their undergoing interaction before decay increases, and hence it results in the reduction of the number of μ-mesons of energies greater than about 10^{11} ev. Since the experimental information we possess regarding the number of μ-mesons underground is not too precise, some contribution of the type (b) cannot be ruled out entirely. Recently Hayakawa[6] discussed the possible effects of κ-mesons underground. He assumed that κ^0-mesons should interact in the earth crust according to the scheme

$$\kappa^0+P(N)\rightarrow N(P)+\kappa^+(\kappa^-),$$

and that the mean free path of all κ-mesons should be of the order of several tens of meters of water equivalent. Most of the $\kappa^{\pm}$-mesons[7] of energies more than about 10^{11} ev would survive since their mean life is about 10^{-9} sec. On the other hand, most of those of energies less than about 10^{11} ev should decay possibly into μ-mesons. Hayakawa suggested the following decay scheme:

$$\kappa^{\pm}\rightarrow\kappa^0+\mu^{\pm}+\mu^0.$$

Formerly only processes of type (a) seemed to be responsible for the results observed here; recently, however, the comparatively large abundance of the production of κ-mesons at high energies[8] may mean that the contribution of process (b) is considerable and cannot be neglected in explaining the frequency of bursts underground.

The author is greatly indebted to Professor Marcel Schein for the use of the facilities of the Cosmic-Ray Laboratory and for valuable and stimulating discussions. He also wishes to thank the Department of State for a grant.

* Supported in part by the joint program of the ONR and AEC.

[1] C. N. Chou, Phys. Rev. **74**, 1659 (1948).
[2] J. G. Wilson, *Progress in Cosmic-Ray Physics* (North-Holland Publishing Company, Amsterdam, Holland, 1952), p. 395.
[3] F. E. Driggers, private communication to Professor Marcel Schein (1952).
[4] K. I. Greisen, Phys. Rev. **73**, 521 (1948).
[5] S. Hayakawa, Prog. Theor. Phys. (Japan) **3**, 199 (1948).
[6] S. Hayakawa, Proc. Phys. Soc. (London) **A65**, 215 (1952).
[7] C. O'Ceallaigh, Phil. Mag. (London) **42**, 1032 (1951).
[8] Proc. Rochester Conference on Meson Physics (University of Rochester, Rochester, 1952), p. 58.

Double Beta-Decay of Sn^{124}†

R. M. PEARCE AND E. K. DARBY
Department of Physics, University of British Columbia, Vancouver, Canada
(Received April 23, 1952)

SEVERAL attempts have been made to detect the double beta-decay of Sn^{124}.[1–3] Fireman[1] has obtained a positive result from which he concluded that the half-life of the process is 0.4×10^{16} years. Lawson[2] and very recently Kalkstein and Libby[3] came, however, to the conclusion that if the double beta process exists at all, its half-life must be much longer ($>2\times10^{17}$ years).

We have carried out another experiment with the view of detecting the double beta-decay of Sn^{124}. The experiment gave a negative result, thus confirming Lawson's, and Kalkstein and Libby's findings. However, our experiment was quite different in nature from the experiments quoted above, and we feel, should lead to a more reliable identification of the double beta-decay, should it exist.

According to the existing theories, the double beta-decay of a nucleus may, in principle, take place in two different manners, one in which the beta-particles are accompanied by two neutrinos and the other in which only the two beta-particles are emitted.

The predicted half-life from the different theories is rather uncertain; there is, however, no doubt that the half-life should be several orders of magnitude longer for a four-particle process than for a two-particle process. In addition to the predicted difference in half-life, the two-particle process possesses another distinguishing feature: since no neutrinos are emitted the sum of the energies of the two beta-particles must be equal to the total energy carried away and thus must be constant.

It follows from these considerations that if the double beta-

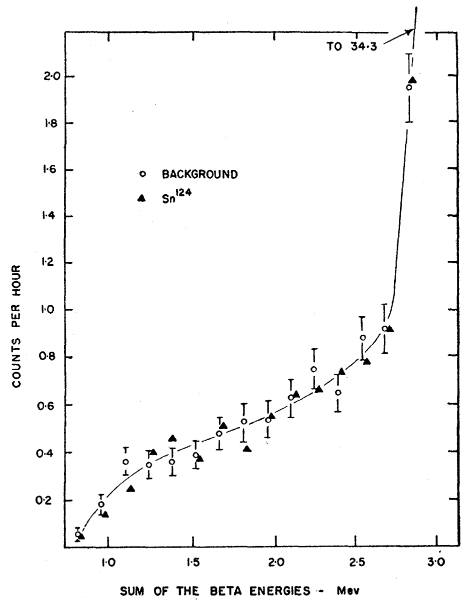

FIG. 1. Coincidence spectra for tin sample and for background as obtained on an 18-channel kicksorter.

decay is observable at all, it will very likely be a two-particle process, so that the sum of the beta energies will be constant. Consequently, we have devised an experiment with Sn^{124} in which the sum of the energies of coincident events in the tin was displayed on a "kicksorter." The energy spectrum of the double beta-process recorded with the kicksorter should then consist of the background with a "peak" at an energy corresponding to the sum of the two beta-energies. It is difficult to imagine another process in which such a sharp peak could occur, so a positive identification should be possible.

A source consisting of a 200-mg tin foil (100 mg/cm²) containing 95 percent Sn^{124} was placed between two scintillation counters. (The source was made at Oak Ridge National Laboratory and supplied through the cooperation of the Atomic Energy Project, Chalk River.) Coincident beta-particles were detected in the thick anthracene crystals ($1\times1\times\frac{1}{2}$ in.) which were separated by 1 cm. The background rate was obtained by replacing the tin foil with an aluminum foil of equal weight. (An aluminum "dummy" was used because available natural tin foils showed some slight contamination.) The amplitudes of two coincident pulses from the detectors were added electronically. The pulse representing this sum was then displayed on an 18 channel "kicksorter" of Chalk River design. A "gate" controlled by the coincidence mixer allowed the output from the pulse adder to reach the kicksorter only in the case of a coincident event.

Since the amplitudes of the detector pulses are proportional to the energy of the beta-particles,[4] the added pulses from double beta-events were expected to have constant amplitude. This would result in a "peak" on the graph of the number of coincidences *versus* the sum of energies of the two beta-particles. The counters were calibrated and adjusted to have identical graphs of pulse height *versus* energy by using the 2.4 Mev beta-particle group from Sb^{124}.

Figure 1 shows the coincidence spectrum obtained with the Sn^{124} in place, and also the background coincidence spectrum. The data were obtained over a period of 264 hours, the background being taken every second day. The counters were shielded by 16 cm of lead from above and by 8 cm of lead in other directions. The large number of counts in channel 18 (energies >3.0 Mev) is the result of cosmic radiation. A large liquid scintillator placed above the counters and connected in anti-coincidence reduced the number of counts in channel 18 by 40