In order to study the activity of Cs^{135} a mass spectrographic separation of the cesium isotopes was made with the mass spectrograph which has been described by Lewis and Hayden.[5] Photographic transfers were obtained using different intervals of exposure. With the deposit obtained, a transfer was obtained due to the 33 year Cs^{137} after 10 minutes. However, after 4 months transfer, the activity of Cs^{135} was still undetected, although the darkening due to the small amount of 1.7 y Cs^{134} present was quite pronounced. This proves that the half-life of Cs^{135} is at least 1.8×10^4 times longer than Cs^{137}, i.e., is greater than 6×10^5 years. This result is not in disagreement with the results of Sugarman in which he has detected the activity due to Cs^{135} and assigned a half-life of 2.1×10^6 years.

[1] Plutonium Project Fission Table, Rev. Mod. Phys. 18, 513 (1946).
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[3] M. G. Inghram, R. J. Hayden, and D. C. Hess, Jr., Phys. Rev. 72, 967 (1947).
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Internal Conversion Coefficient and Mass Assignment of the 57-Min. Se Isomer

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The internal conversion lines of the 57-min. Se isomer have been measured by A. C. Helmholz.[1] It was not possible, however, to calculate the internal conversion coefficient because of the contamination of other Se activities produced in the Se+d reaction. According to Seaborg's tables[2] the mass number 81 of this activity is still somewhat uncertain (class B).

The electromagnetic isotope separator of this institute has been used to separate deuteron bombarded Se. In this way it is possible to obtain carrier free activities deposited on very thin foils. As Fig. 1 shows, the ordinary isotope lines can also be focused as circular spots of a size convenient for β-spectrometer measurements. After the separation, the collector plate (Fig. 1) was cut into strips corresponding to the different mass numbers between 77 and 83. We found the complex activity of the chain $Se^{83}\rightarrow Br^{83}\rightarrow Kr^{83}$ at mass number 83. The 57-min. activity of mass number 81 (no activity at 79) was sufficient for β-spectrometer investigation. Figure 2 shows the β-spectrum of this isotope recorded 60 minutes after the separation, when transient equilibrium is practically reached. The β-spectrometer data are summarized in Table I.

TABLE I. Summary of the β-spectrometer data.

Isotope	Upper limit Fermi plot Mev	β-lines	$H\rho$	Energy kev	$h\gamma$ kev	K/L	Half-life min.
Se^{*81}		K	1060	90.5	104 ± 2	≈3.9	57 ± 1
		L	1131	102.4	104 ± 2		
Se^{81}	1.38 ± 0.05						

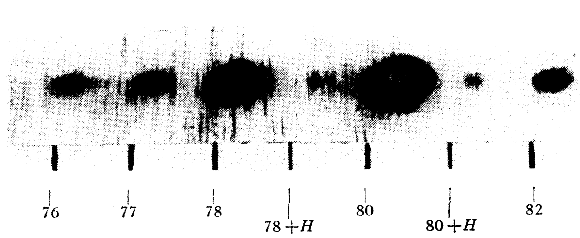

FIG. 1. Circular focused mass spectrum of Se deposited on a thin Al-plate. Spot distance 11 mm.

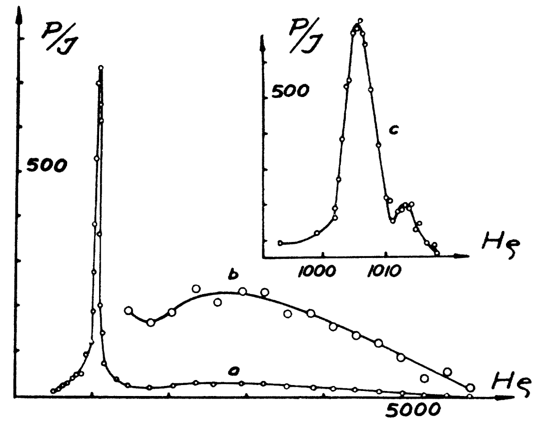

FIG. 2. a. β-spectrum of the separated activity on mass number 81. b. The continuum drawn to a five times larger P/I scale than a. c. The lines drawn to an eight times larger $H\rho$-scale than a.

To get the total internal conversion coefficient $[(Ne/(Ne+N\gamma)\cdot100)]$ the ratio of the surfaces under the lines and the continuum have to be multiplied by the factor $[\lambda Se^{81}/(\lambda Se^{81}-\lambda Se^{*81})]$, because of radioactive equilibrium requirements. If we use the values 57 and 19 min. of A. Langsdorff, Jr., and E. Segrè[3] for the half-lives, we arrive to a total impossible internal conversion coefficient of 120 percent. The half-lives 56.5 and 13.6 min. determined by H. Wäffler and O. Hirzel[4] seem, however, to fit our measurements much better and give the value 104 percent for the coefficient. We estimate the error in our measurements to be less than 10 percent. Thus the γ-ray corresponding to the isomeric transmission of Se^{81} seems to be almost completely converted.

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Interpretation of Underground Cosmic-Ray Data

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October 13, 1949

This letter is intended to put on record some remarks made verbally by the writer and others within the last year, regarding the interpretation of underground experiments.

It is well known that the vertical cosmic-ray intensity follows the depth as a power law with exponent ≈1.9 down to a depth of about 300 meters water equivalent (when correction is made at the smaller depths for the decay of mu-mesons in the atmosphere), and with exponent ≈2.9 at depths beyond about 400 meters. On the other hand, the extensive air showers have a power-law energy spectrum with exponent ≈1.8 continuing to energies 10^5 times greater than the energy which a meson must have to penetrate to the greatest depth at which they have been detected (3000 m). The explanation of this anomaly in terms of increased energy loss of high energy mesons has been rejected.[1-3] Barnothy and Forro[3,4] have explained it on the hypothesis that the rays that penetrate great depths are not mesons but their neutral decay products, which occasionally produce short-range charged secondaries in or near the detecting apparatus. The writer[1] and Hayakawa[2] have offered the suggestion that mu-mesons are the penetrating particles, but are themselves decay products of pi-mesons produced high in the atmosphere. The original estimate of the lifetime of the pi-meson necessary to fit this picture was rather crude, but more refined calculations by Hayakawa and Tomonaga[5] and by Eyges and Greisen[6] have verified that the mean life measured in Berkeley[7] has about the best value to fit the underground intensity curve.

We wish to remark that the hypotheses of Barnothy and Forro and of the writer are exactly equivalent in respect to the means of obtaining the proper form of the vertical intensity *vs.* depth relation, and to point out that the necessary parts of both hypotheses are the following: (1) An unstable particle of type A is produced high in the atmosphere with an energy spectrum $\sim E^{-1.5}$, and decays into a particle of type B that is capable of penetrating to great depths; (2) essentially no particles of type A are capable of penetrating to great depths—or $I_A\epsilon_A \ll I_B\epsilon_B$, where I and ϵ represent respectively the intensity and the efficiency of detecting the components at large depths; (3) particles of type B lose energy at an approximately constant rate in traversing matter—mainly in small units instead of transferring large fractions of their energy in single interactions; and (4) $\gamma c\tau_0 = kL$, where γ is the Lorentz factor for particles of type B just capable of penetrating to the depth where the kink occurs, τ_0 is the mean life at rest of particles of type A, L is the distance (6.4×10^5 cm near the top of the atmosphere) in which the atmospheric pressure decreases by a factor e, and k is a factor varying from about $\frac{1}{2}$ to 1.5 depending on the cross section for absorption of particles of type A by processes other than decay.

All conditions 1 to 4 are met by the pi-mu-meson explanation, provided that pi-mesons of high energy have cross sections for nuclear interaction greater than 1/1000 of the geometric cross section of the nucleons. The hypothesis of neutral penetrating particles can of course be made to account for conditions 1, 3, and 4 because we have practically no independent information about the energy loss of the neutral particles in the ground. However, it is also necessary in this case to explain the absence of mu-mesons at great depths; i.e., one must assume either that the meson spectrum is sharply cut off at high energies, or that a new process of energy loss sets in. The cut-off must be so complete that the mesons become less than 1/400 as abundant as is predicted by extrapolation of the known part of the meson energy spectrum with the assumption of no new absorption processes.

Further information on the origin of the penetrating particles is obtainable from the zenith angle dependence of the underground intensity, but here again the hypotheses of Barnothy and Forro and of the writer predict identical results, again with the necessary assumptions 1 to 4 listed above. In inclined directions, the unstable component A is produced at greater altitudes than in the vertical direction, so that the probability of decay is greater by a factor $\sec\theta$ (because of the reduced density of the air, in case A is subject to other strong absorption processes, or because of the longer path to sea level in case A is not a strongly interacting particle). Therefore, if the dependence on depth h goes as $h^{-\gamma}$ above the kink and $h^{-(\gamma+1)}$ below the kink in the curve, the zenith dependence underground should go as $(\cos\theta)^\gamma$ both above *and* below the kink.* This is in agreement with the experimental results of Barnothy and Forro.[3] If they are indeed correct, they constitute clear proof not that the hypothesis of Barnothy and Forro or that of the writer is correct, but that the conditions 1 to 4 listed above are met by the penetrating particles and their parents.

Direct information about the ionizing or neutral nature of the rays found underground, and about the penetrating character or local origin of the charged rays observed, can be obtained in principle from accurate absorption curves. The data available at this date are however somewhat confusing. Barnothy and Forro have presented evidence that most of the rays are neutral. Miesowicz, Jurkiewicz, and Massalski,[8] however, have apparently shown that the neutral rays are simply low energy gamma-rays of local radioactive origin. The absorption curves that have been measured of the ionizing component underground[3, 9–11] contain large statistical errors, irregularities that have required artificial explanations, and disagreements with each other. If the charged particles are those that have traversed all the earth above the counters, a meter of lead should only succeed in stopping 6 percent of the particles at 300 m.w.e., $2\frac{1}{2}$ percent at 1000 m.w.e., and one percent at 3000 m.w.e. The absorption measured by Wilson[9] at 300 m.w.e. is small enough (though the statistical errors are large); but the absorption measured by Nishina and Miyazaki[11] at 3000 m.w.e. is much too great; and the ups and downs of the curves of Barnothy and Forro at 1000 m.w.e., if not due to statistical and unknown systematic errors, are also too great.

It seems impossible, therefore, to draw a specific and reliable conclusion about the nature and origin of the rays underground from the data now available.

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[3] J. Barnothy and M. Forro, Phys. Rev. **74**, 1300 (1948).
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[5] S. Hayakawa and S. Tomonaga, Phys. Rev. **75**, 1958 (1949).
[6] Unpublished.
[7] J. R. Richardson, Phys. Rev. **74**, 1720 (1948). The uncertainties in the underground data, in the exponent γ of the spectrum, in the range-energy curve of mu-mesons and in the nuclear interaction of pi-mesons prevent attributing much precision to the agreement. The more recent Berkeley value of 1.7×10^{-8} sec. gives just as good a fit as Richardon's value of 0.9×10^{-8} sec. Mean life values greater than 4×10^{-8} or less than 0.4×10^{-8} do not fit the data well.

* Of course, for particles of type A with low energy, the probability of decay is practically 1 regardless of the zenith direction. The factor $\sec\theta$ applies only to high energy particles that have small probabilities of decaying.

[8] Miesowicz, Jurkiewicz, and Massalski, Phys. Rev. (to be published); see also J. Barnothy and M. Forro, Phys. Rev. **55**, 870 (1939).
[9] V. C. Wilson, Phys. Rev. **55**, 6 (1939).
[10] J. Barnothy and M. Forro, Phys. Rev. **55**, 870 (1939); Phys. Rev. **58**, 844 (1940).
[11] Y. Nishina and Y. Miyazaki (private communication).

Radiation from Zn^{65}

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SOME preliminary measurements have been made in this laboratory on the energies of the beta- and gamma-radiations from Zn^{65}, using a beta-ray spectrometer of the thin lens type. The spectrometer has been equipped with a spiral baffle placed in the center of the spectrometer tube. A proper choice of the focusing magnet's current direction thus makes possible the selection for analysis of either positrons or negatrons. The source was in the form of a small square of zinc metal of surface density 25 milligrams/cm², irradiated with slow neutrons in the pile at Chalk River, Ontario. The total activity was one millicurie. Positron, negatron, and gamma-ray spectra were run. In the latter case, measurements were made of the energies of photoelectrons expelled from a uranium radiator of density 50 milligrams/cm². The resolution of the instrument is of the order of 3.5 percent in momentum. The energy calibration used both the F line of thorium B and the annihilation radiation of Zn^{65}. The estimated error on the basis of this calibration is thought to be about 0.5 percent in momentum. No corrections have been made for the finite thickness of the source or radiator, the importance of which has been discussed recently by Jensen, Laslett, and Pratt[1] and by Hornyak, Lauritsen, and Rasmussen.[2]

The results are shown in the accompanying figures. In all cases, the "normal" background, measured with the source in position in the spectrometer, and zero current in the focusing coils, averaged about 20 counts per minute, and this has been subtracted before plotting. Figure 1, (a) and (b), shows the positron distribution obtained and the calculated Fermi plot. Extrapolation of the latter leads to an end point of 0.325 ± 0.002 Mev which is in good agreement with the spectrometer measurements of Peacock.[3] Only one recognizable positron group is evident, although the effects of source thickness and scattering in the spectrometer would make difficult the detection of weak positron groups below say 0.15 Mev. Figure 2 shows the result obtained with the magnet