Beta-ray Spectra of Cs134, Hg203,W185 and Ce-compound

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Toshio AZUMA*

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Beta-ray spectra of Cs^{134}, Hg^{203}, W^{185} and Ce-compound have been measured with a double coil, magnetic lens beta-ray spectrometter. For the decay of Cs^{134}, the complex beta-ray groups of allowed type with end-points at 663-, 410-, 210- and 77-kev have been analyzed by the Fermi plot. Their relative abundance was determined to be 57, 14, 13.5 and 15.5 percent respectively. For Hg^{203} and W^{185}, one beta-ray group of the allowed and of the first forbidden transition has been found with end point at 225- and 423-kev respectively. For Ce-compound, the radioactive elements of Ce^{144}- Pr^{144}, Ce^{143} and Ce^{141} have been ascertained to exist.

1. Introduction

For the decay of Cs^{134}, considerable works have been published on the determination of the decay scheme.[1)-17)] Recently, Cork *et al*[1)] have measured the beta- and gamma-ray spectra precisely and presented the decay scheme which consisted of four beta-ray groups with end points at 657-, 410-, 210- and 80-kev, and of eleven gamma-ray groups of 202.5-, 475-, 563-, 569.7-, 605.4-, 662.7-, 796.8-, 802.6-, 1037-, 1167- and 1368-kev. In these beta-ray groups, the log (ft) value of the highest energy was 8.8 which may be classified as the first forbidden transition. But the internal conversion line of the 605-kev gamma-ray masked the highest energy part of the continuous beta-ray spectrum, and it has been difficult to classify the forbidden transition of this beta-ray group from the measured spectrum.

For Hg^{203} and W^{185}, a simple decay scheme of one beta-ray and one gamma-ray has been estimated.[18)-34)] The end-point energies of the beta-ray groups were 210- and 430-kev, whose log (ft) values were 6.2 and 7.4 respectively. The W^{185} beta-transition fell into the category of the first forbidden transition. However, the spectrum shape was of allowed type judging from the linearity of the Fermi plot. The 279-kev gamma-ray from Hg^{203} was inferred to come from the mixed interaction of E_2 and M_1.

For Ce-compound, which was chemically separated from the ash collected on board No. 5 Fukuryu Maru at the beginning of March, 1954, the identification of radioactive elements was performed by measuring the beta-ray spectrum.

In the present experiments, the continuous beta-ray spectra and the internal conversion lines of gamma-rays from these elements have been measured using the double coil, magnetic lens beta-ray spectrometer. The resolving power was 2 percent for these three radio-isotopes and 5 percent for Ce-compound. The detector consisted of a G-M counter with Zapon window which detected electrons of 5-kev and of higher energy, and also with the ordinary mica window of 2.9 mg/cm^2 thickness. The measured beta-ray spectrum was investigated by using the Fermi plot.

* Department of Physics, College of Education.

2. Experimental procedures

The beta-ray spectrometer used in the present work is the ordinary double coil, magnetic lens type. In order to reduce the scattered electrons, the spectro-chamber is equipped with the aluminium baffle system as those of Van Atta *et al*[35]. The good effect of this baffle system on the measured spectrum was studied with the internal conversion line of the 665-kev gamma-ray from Cs^{137}. The baffle system of the spectro-chamber was shown in Fig. 1 in units of cm.

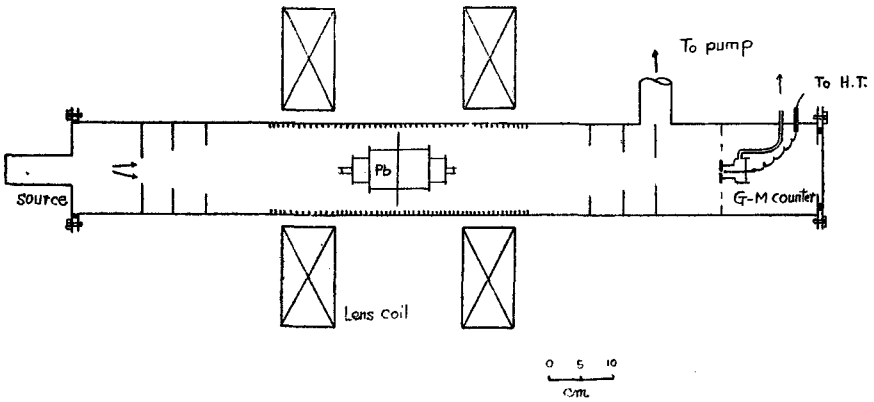

Fig. 1. The baffle system of the spectro-chamber.

The ordinary G-M counter with mica window was produced by Mitsubishi Elect. Co. Ltd. Zapon counter was made of brass and equipped with the window of the 50-mesh wire-net. Zapon film floated on the water surface was scooped by this wire-net and sandwiched in between the brass slit. This window system of about 25 $\mu g/cm^2$ thickness was strong enough to maintain the gas pressure of 30 mmHg for long time.

The radioactive sources of Cs^{134}, Hg^{203} and W^{185} were supplied from Oak Ridge National Laboratory. The sources were put on Zapon film of about 50 $\mu g/cm^2$ thickness and dried quickly under an infra-red lamp. A surface density of about 100 $\mu g/cm^2$ was obtained for Cs^{134}, but for Hg^{203} and W^{185} with weak activities surface densities of 9 mg/cm^2 and 1 mg/cm^2 were needed respectively to measure the spectrum. Therefore, the effect of source density has appeared in the observed spectra and the Fermi plots for these two sources.

For Ce-compound, the radioactive source was the ash, which fell on the fishing-boat No. 5 Fukuryu Maru near Bikini at the beginning of March, 1954, and was collected and analysed by usual method of chemical separation. The chemical procedure was reported already by H. Yamadera and Y. Nishiwaki *et al*.[36] The active material CeO_2 in power was put on a mica sheet of 3 mg/cm^2 and covered with Zapon film of about 30 $\mu g/cm^2$ to prevent its dispersion. In running the spectrometer, the resolution of 5 percent was used to increase the transmission.

The measured beta-ray spectra were investigated using the Fermi plot, namely, the plot of $(N/f(z, w))^{\frac{1}{2}}$ against the total energy, where N is the counts per minute of beta-rays per unit momentum, and $f(z, w)$ is the Fermi distribution function of transition

probability and w is the energy of emitted electron in units of mc^2. A better approximation for $f(z, w)$, especially for large z, was given by Bethe and Bacher[37] as

$$f(z, w) = f_N(z, w)\cdot[E^2(1+4\gamma^2)-1]^S,$$

where $$f_N(z, w) = (w^2-1)\cdot 2\pi y/(1-e^{-2\pi y})$$

and $$S = (1-\gamma^2)^{\frac{1}{2}}-1$$

$$\gamma = \begin{cases} \alpha z = z/137, & \text{for } \beta^- \text{ emission} \\ -\alpha z = -z/137, & \text{for } \beta^+ \text{ emission} \end{cases}$$

$$y = \gamma(1+\eta^2)^{\frac{1}{2}}/\eta$$

$$\eta = H\rho/1704$$

$$w = (1+\eta^2)^{\frac{1}{2}}$$

This approximation is accurate to about one percent for atomic numbers $z \leq 84$.

3. Beta-ray spectra

i) Cs^{134}

The momentum plot of the measured beta-ray spectrum was shown in Fig. 2 with dots. The observed internal conversion lines were tabulated in Table 1, and some of them were shown in Fig. 3, which masked the continuous beta-ray group of higher energy than 520-kev.

The Fermi plot of the beta-ray of the highest energy was investigated with the correction factors of the higher forbidden transitions. The correction factors tried in the work were C_1T[38] and $C_{1S}T$[39] for the first forbidden and C_2T[38] for the second forbidden transition, where

$$C_1T \sim \frac{1}{12}K^2L_0+\frac{3}{4}L_1$$

$$C_{1S}T \sim \frac{1}{3}KL_0+N_0$$

$$C_2T \sim \frac{1}{15}K^4L_0+2K^2L_1+15L_2.$$

Table 1. Internal conversion lines of Cs^{134}.

photo-electron		gamma-ray	
(gauss-cm)	(kev)	energy (kev)*	Shell
1478	165	202	K
3004	525	562	K
3162	567	604	K
3282	598	604	L
3335	611	611	M
3862	758	795	K
3928	764	800	K
4747	1001	1038	K
5238	1142	1179	K
5921	1340	1377	K

* The binding energies were 37.4-, 5.99- and 1.29-kev for K, L and M electrons respectively.

The notation of Konopinski and Uhlenbeck's article[38] was used here. The numerical calculations for these correction factors were performed on the assumption that $\gamma^2 \ll 1$, which was a fairely good approximation in our case.

The Fermi plot of the allowed type deviated from a straight line at the energy of 410-kev. Those corrected with C_1T and C_2T deviated from it at the energy of 490-kev, and it was difficult to decide the order of the forbidden transition from a few points on a straight line as those shown in Fig. 4. But the Fermi plot corrected with $C_{1S}T$ gave

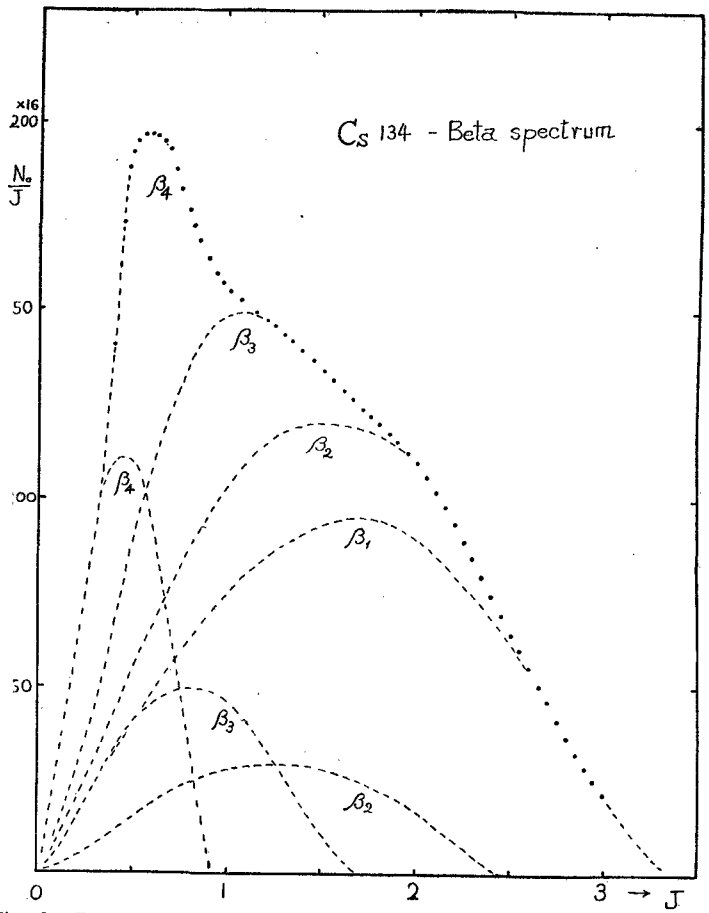

Fig. 2. Beta-ray spectrum of C_s^{134}. Dots show the observed values and broken lines those constructed from the Fermi plot.

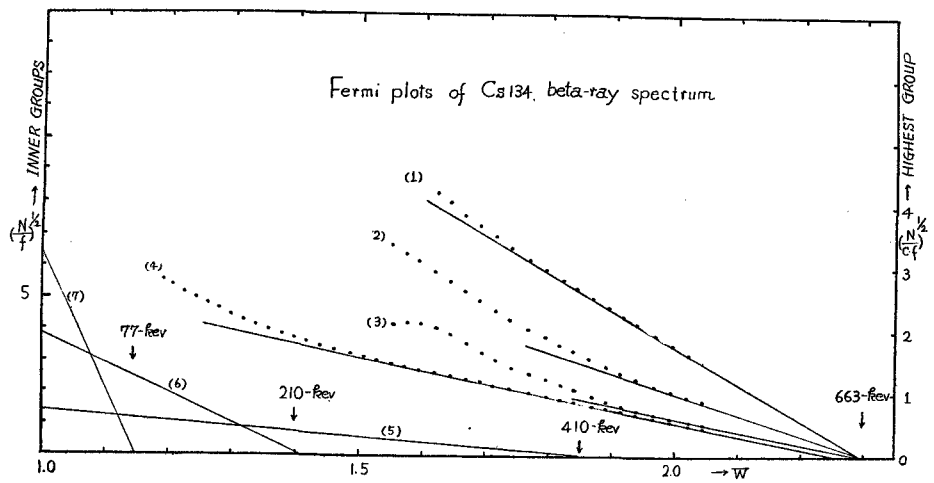

Fig. 3. Fermi plots of C_s^{134} beta-ray spectrum. In the highest group, (1) allowed, (2) corrected with C_{1T}, (3) corrected with C_{2T}, (4) corrected with C_{1ST}. In the inner groups of the allowed type, (5) 410-kev, (6) 210-kev, (7) 77-kev.

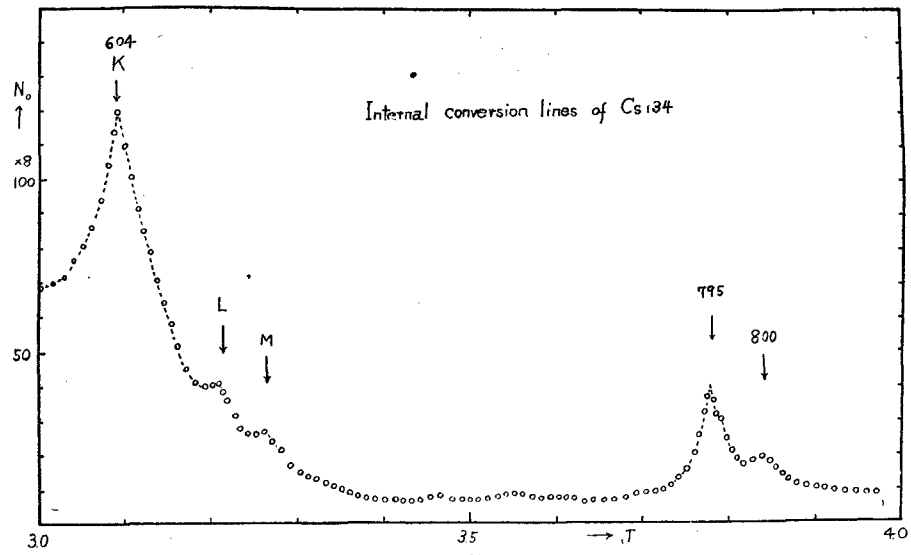

Fig. 4. Internal conversion lines of Cs^{134} gamma-rays, which masked the highest energy end of the continuous beta-ray spectrum.

a straight line up to 280-kev.

Assuming that the beta-ray group of the highest energy was the first forbidden mixed interaction and that the inner groups were of the allowed type, four groups with end points at 663-, 280-, 173- and 66-kev have been analyzed. But the decay scheme which accomodated with the observed gamma-ray energies was not constructed.

If we assume that the complex beta-ray groups are all of allowed type, four groups can be analyzed with end points at 663-, 410-, 210- and 77-kev respectively. The momentum plots constructed from the Fermi plots are shown in Fig. 3 as β_1, β_2, β_3 and β_4 respectively. Their relative abundances were estimated to be 57, 14, 13.5 and 15.5 percent respectively. These results are almost the same as those of Cork *et al*[1] and accomodated with the gamma-ray energies, except the small difference of their relative abundances.

ii) Hg^{203}

One beta-ray group of allowed type with end point at 225-kev was ascertained from the Fermi plot as shown in Fig. 5. The observed peak value of the internal conversion line of the 278-kev gamma-ray was shown in Table 2 and Fig. 5.

Table 2. The internal conversion line of the Hg^{203} gamma-ray.

photo-electron		Binding energy (kev)	Gamma-ray energy (kev)	Shell
(gauss-cm)	(kev)			
1624	195	82.9	278	K
1954	264	14.8	278.8	L

The observed ratio $K/(L+M)$ was 2.80, and α_K was 0.16. This was assumed to be the mixed interaction of E_2- and M_1-transition.[27]

iii) W^{185}

One beta-ray group with end point at 423-kev was ascertained from the Fermi plot.

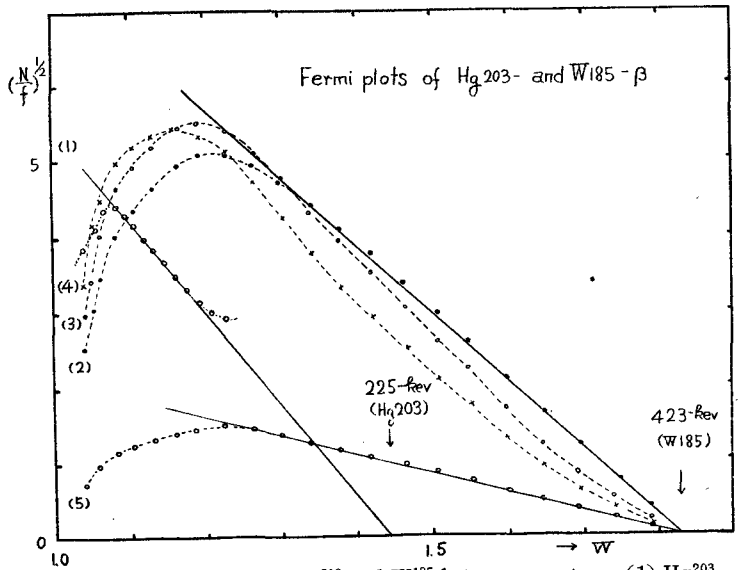

Fig. 5. Fermi plots of Hg^{203} and W^{185} beta-ray spectra. (1) Hg^{203}, allowed plot. For W^{185}, (2) allowed, (3) corrected with C_{1T}, (4) corrected with C_{2T}, (5) corrected with C_{1ST}.

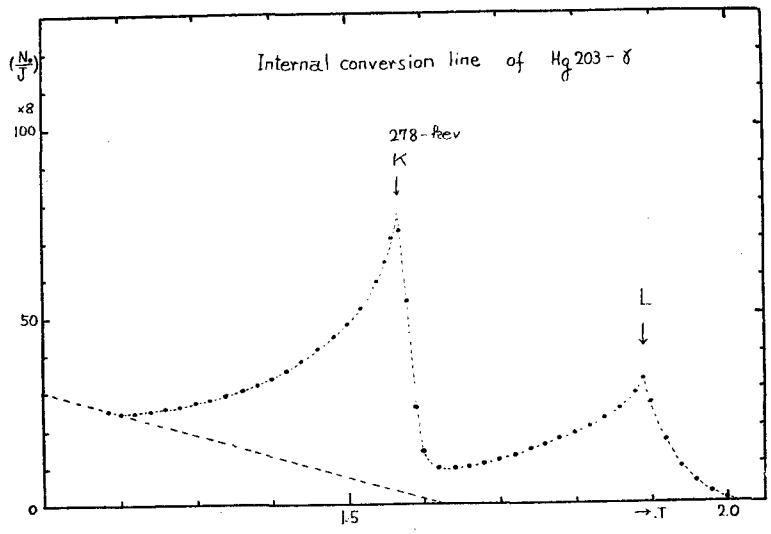

Fig. 6. Internal conversion line of Hg^{203} gamma-ray.

The gamma-ray of 134-kev reported hitherto could not be detected owing to the weak activity of the source. The effect of the source thickness appeared in the measured spectrum at energies lower than $W=1.25$ in units of mc^2.

The correction factors studied in the present work were C_{1T} and C_{1ST} for the first forbidden and C_{2T} for the second forbidded transition. For these correction factors, the same functional forms as those for Cs^{134} were used. The Fermi plots corrected with C_{1T} and C_{2T} gave no fit to a straight line, but C_{1ST} gave good result as those of allowed plot. The first forbidden transition, $\Delta j=\pm 1$, yes, coincided with the classification of the log (ft)- value.

iv) Ce-compound

The observed beta-ray spectrum was shown in Fig. 7. The insert showed the internal conversion line of the 134-kev gamma-ray. The allowed Fermi plot of the higher energy part of the beta-ray group was shown in Fig. 8, which gave the end-point energy of 2.97-Mev. This beta-ray group was subtracted and the remaining beta-ray groups were analysed also using the Fermi polt. It can be seen that the remaining beta-ray group was complex consisting of six components with end points at 1.377-,

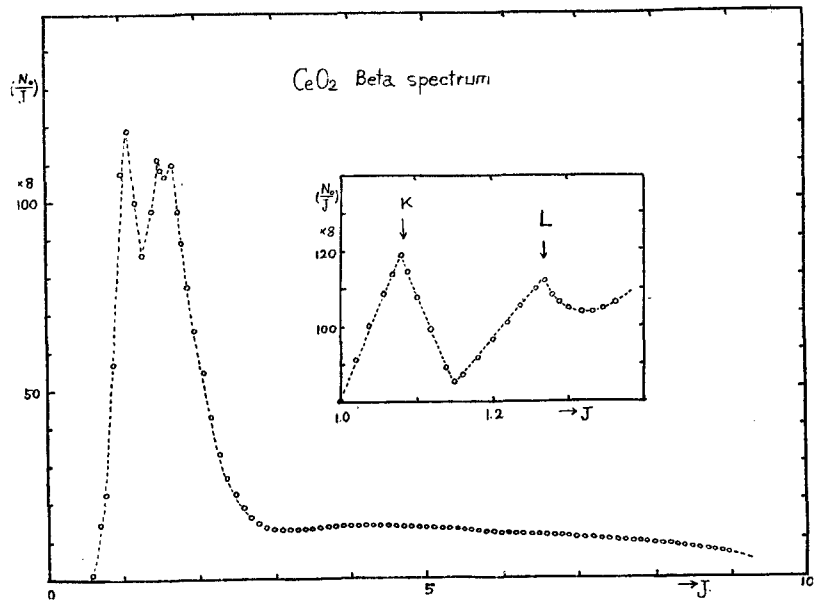

Fig. 7. Beta-ray spectrum of CeO_2.

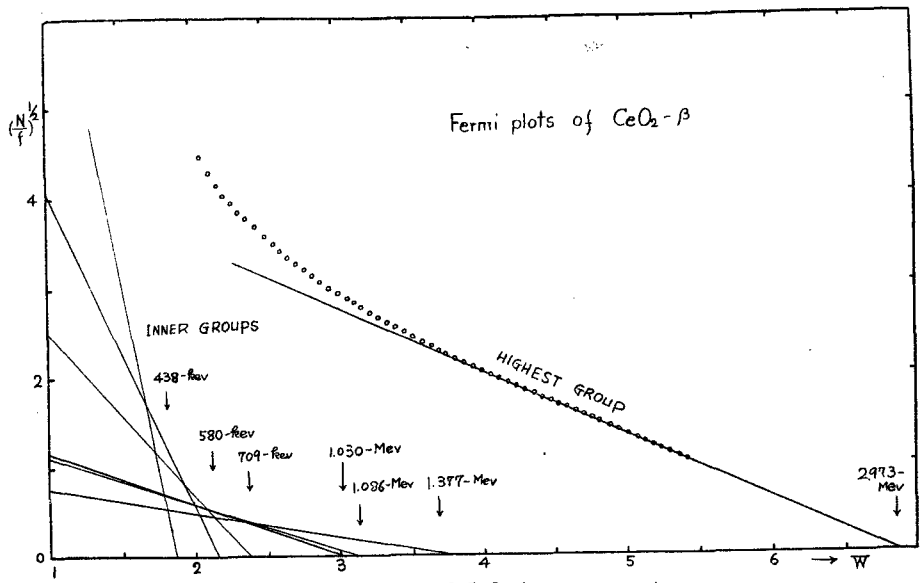

Fig. 8. Fermi plot of CeO_2 beta-ray spectrum.

1.086–, 1.030–, 0.709–, 0.580– and 0.438–Mev respectively.

The data obtained in the present work were compared with the momentum spectra of pure Ce-isotopes which have been reported hitherto. Porter and Cook and others[40)-42)] have measured the beta-ray spectrum of pure Ce^{144} (289d)–Pr^{144} isotope with a lens coil spectrometer and observed the beta-ray groups of 2.97–, 0.30– and 0.17–Mev, and the gamma-ray groups of 134–, 100–, 80.7–, 54– and 33.7–kev. For Ce^{141}, Feedman and Engelkemsir and others[43)-45)] have reported the beta-ray groups of 581– and 442–kev, and the gamma-ray of 145–kev. For Ce^{143}, Burgus and others[46)-48)] have measured the beta-ray groups of 1.39–, 1.09– and 0.71–Mev, and the gamma-ray groups of 720–, 660–, 356–, 289–, 160–, 126– and 35–kev.

In the present experiment, Ce^{144}– Pr^{144} was ascertained to exist in the sample, when we compared the beta-ray spectrum of the highest energy and the internal conversion line of the 134–kev gamma-ray. The half-life of Ce^{141} was short compared to that of Ce^{144}, but the small contamination of the former element was inferred from the beta-ray groups of 580– and 438–kev. The energies of the internal conversion lines of Ce^{144} and Ce^{143} were different from each other by only 10–kev and have similar shape of spectrum, so that these could not be distinguished from each other because of the low resolving power of the beta-ray spectrometer used in the present work and of its small contamination. But its existence was inferred from the beta-ray groups of 1.377–, 1.086– and 0.709–Mev.

Since it will be difficult to separate the elements Ce and Yt by the usual method of chemical separation described above[33)], these elements will contaminate within the sample used in the work. But the identification of the 1.537–Mev beta-ray group of Yt^{91} was difficult.

Summarizing the results, we may conclude that Ce^{144}– Pr^{144}, Ce^{143} and Ce^{141} were found to exist in the radioactive sample CeO_2 which was chemically separated from the ash collected on board No. 5 Fukuryu Maru. The other compounds were chemically separated, but the Fermi analysis could not be performed owing to the weak radioactivities.

In conclusion, the auther wishes to express his sincere gratitude to Prof. K. Kimura of Kyoto University for his kind encouragement and discussion throughout the work. Acknowledgement should also be made to Dr. Y. Nishiwaki of Osaka City University for the measurement of Ce-compound separated from his collected ash, and also to Mr. K. Tsumori for his assistances with the operation of the spectrometer throughout the work.

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