Revista Brasileira de Física, Vol. 3, N.° 2 , 1973

Excited Levels in ^{208}Tl

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Recebido em 21 de Fevereiro de 1973

The energies and relative intensities of gamma-rays from excited levels of ^{208}Tl populated in the alpha-decay of ^{212}Bi have been measured using coincidence techniques. These values are consistent with those obtained from alpha-particle spectroscopy data Low intensity gamma-ray transitions of 493 and 620 keV have been found which had not been detected before. An upper limit of .004% has been set for the intensities of possible transitions of 124, 145, 165 and 295 keV reported earlier. *K*-shell internal-conversion coefficients were obtained.

As energias e intensidades relativas dos raios gama dos níveis excitados do ^{208}Tl populados no decaimento alfa do ^{212}Bi foram medidas usando técnicas de coincidência Estes valores são consistentes com aqueles obtidos dos dados de espectroscopia alfa. Foram encontradas transições gama de baixa intensidade de 493 e 620 keV as quais não haviam sido detetadas antes. Um limite superior de 0,004% foi estabelecido para as intensidades de possíveis transições de 124, 145, 165 e 295 keV relatadas anteriormente. Coeficientes de conversão interna na camada K foram obtidos.

1. Introduction

Experimental studies have established[1] that a simple shell model can roughly explain all the properties of at least the low lying levels of nuclei in the region of doubly closed shell ^{208}Pb. Experimental data in this mass region is important to compare with the results of shell-model calculations using various kinds of residual interactions[2], and also to look for admixtures, to M1 and E2 transitions, of electric monopole transition which could be found in this region according to calculations of Church and Weneser[3]. The excited states of ^{208}Tl have been studied by several authors[4,5,6,7,8,9] all of which used sources of an active deposit of Thorium to obtain conversion electron and alpha particle spectra, yet some uncertainties as to the existence of the transitions, and discrepancies between intensities obtained with relation to alpha-particle feeding and intensities

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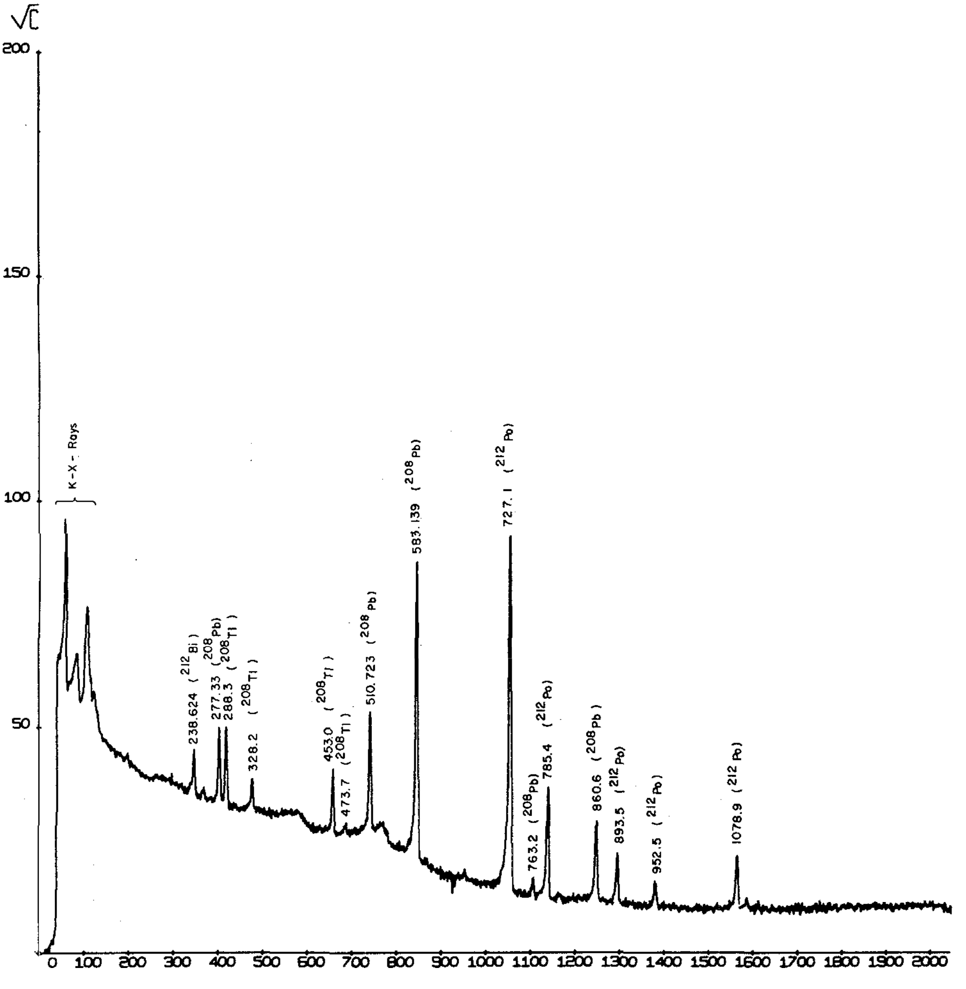
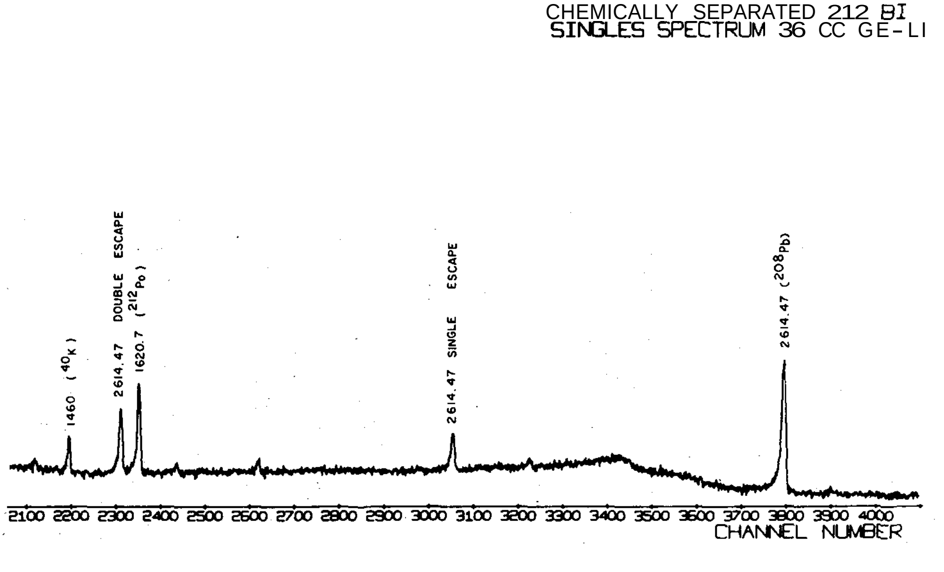


Fig. 1 - Chemically separated ^{212}Bi singles gamma-ray spectrum. Note that the square root of the number of counts is plotted on the ordinates.


CHEMICALLY SEPARATED 212 BI
SINGLES SPECTRUM 36 CC GE-LI
1460 (40K)
2614.47 DOUBLE ESCAPE
1620.7 (212Po)
2614.47 SINGLE ESCAPE
2614.47 (208Pb)
2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400 3500 3600 3700 3800 3900 4000
CHANNEL NUMBER

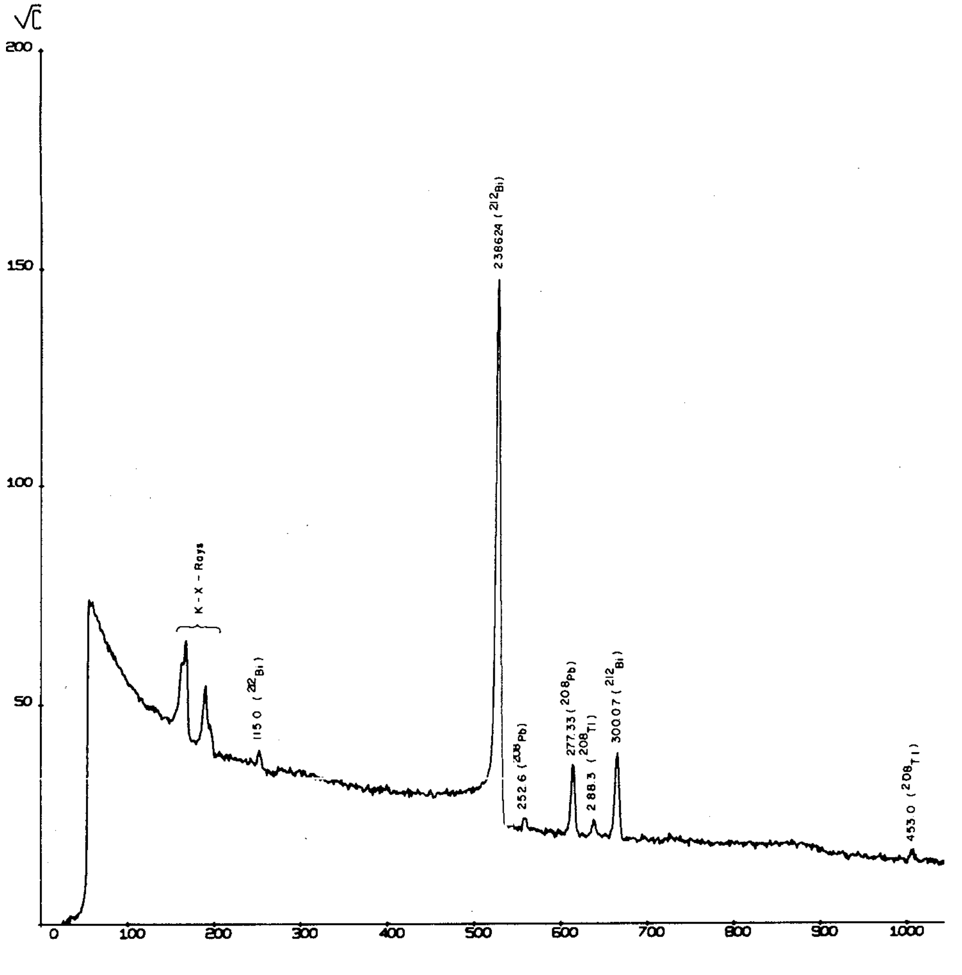
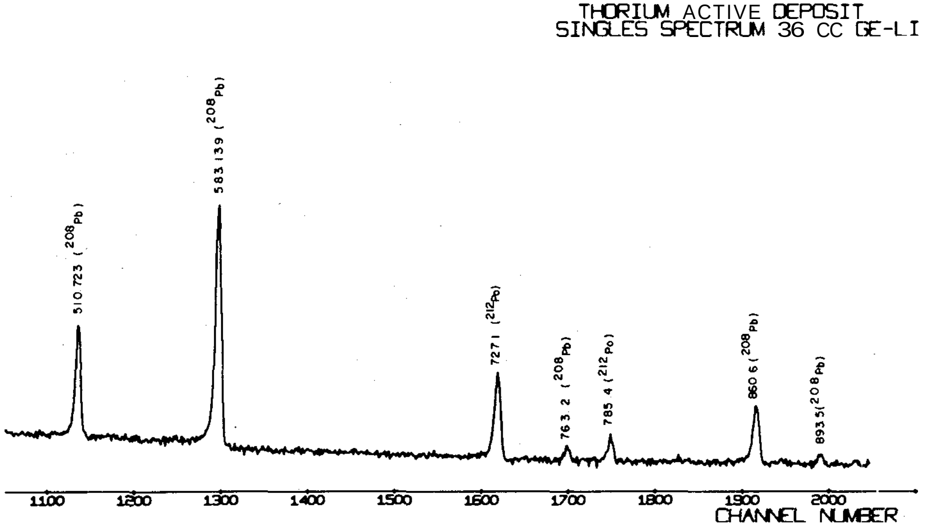


Fig. 2 - Thorium active deposit gamma-ray spectrum in the energy region of interest.



THORIUM ACTIVE DEPOSIT
SINGLES SPECTRUM 36 CC GE-LI
510 723 (208Pb)
583 139 (208Pb)
727 1 (212Po)
763 2 (208Pb)
785 4 (212Po)
860 6 (208Pb)
893 5 (208Pb)
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
CHANNEL NUMBER

relative to the 2615 keV gamma-ray transition in ^{208}Pb still exist[10]. The excited states of ^{208}Tl cannot be reached by nuclear reactions, except for (d, a) on 22 year half-life ^{210}Pb which is not easily available. In this study, gamma-ray spectra were obtained in coincidence with the alpha particles from ^{212}Bi. In order to aid the interpretation of results, gamma-ray spectra were also obtained while chemical separations were performed on the active deposit of Th to isolate ^{212}Bi from its parent and daughter. The gamma-ray spectra studied provided means of calculating internal-conversion coefficients of transitions which can now be compared with theoretical calculations.

2. Experimental

The ^{212}Pb source was collected electrostatically from the decay products of Thoron that emanated from a ^{228}Th source.

Si-Au detectors were used to count the a-particles from sources of ^{212}Pb collected on thin gold on formvar foils. The gamma-rays to be found in coincidence with the a-particles were detected by a 36 cm^3 Ge-Li detector of 4 keV half-width at 288 keV and also by an X-ray detector of 0.9 keV FWHM at 288 keV gamma-ray energy. Constant fraction timing was used on both channels. The full width at one tenth height (FWTH) was 100 nsec, using standard electronics. Details can be found elsewhere[11]. The time window was set at about 150 nsec in order not to miss true coincidences.

Sources of ^{212}Bi were prepared by feeding the bismuth contained in a solution eluted with hydrochloric acid from a cation exchange column (Amberlite IR-120), which contained ^{212}Pb, into an anion exchange column (IRA-401) treated with Bismutiol[12] and eluting this column continuously with hydrochloric acid to extract the Tl. Details can be found elsewhere[13].

3. Experimental Results

The chemically separated ^{212}Bi singles spectra is shown in Fig. 1 while Figs. 2 and 4 shows the singles spectra of the active deposit. The coincidence spectra are shown in Fig. 3 and Fig. 5. Table 1 lists the average measured energies and relative intensities of the gamma-ray lines. All intensities were measured relative to the 288 keV y-ray transition and this one was carefully related to the 2615 keV transition in ^{208}Pb. The energy values are believed to be accurate to better than .3 keV. The gamma-ray transitions of 493 and 620 keV had not been reported before. The others agree reasonably well with the work of Benoit *et al.*[7] also shown in Table 1. An upper limit of .004% alpha decays was estimated for the intensities of the possible γ-ray transitions of 124, 145, 165 and 295 keV. From this data and using the weighted average conversion electron relative intensities reported by Benoit[7] and Nielsen[8] normalized with the K X-ray data from this work, and absolute data of Daniel[9], it was possible to calculate *K*-shell internal-conversion coefficients for the transitions shown in Table 2. The values of

Table 1. Energies and intensities of the gamma- and X-ray transitions in ^{208}Tl.

E_γ (keV)		I, (per hundred photons of 2615 keV)	
Benoit[7]	This work	Benoit[7]	This work**
—	L X-rays	—	21.5
—	39.85*	—	3 1
—	70.82'	—	.14
288	288 3	82	96
328	328 2	33	42
431	433.6	.04	.027
451	453.0	.84	.99
471	473 7	122	12
491	492.7	<.008	.017
—	620 4	—	.010

*used as an energy standard
'K_{α_2} X-ray
**Intensities aré believed to be accurate to within 10% except those of very weak lines which may be up to 30% off.

Table **2.** L- and *K*-shell internal conversion coefficients of transitions in ^{208}Tl.

		α_K		
Transition Energy (keV)	I_{e_K} [7,8,9] % alpha decay	Experimental	Theoretical[17]	
			M1	E2
39.85	54.6*	17.8†	18.5†	350†
288.3	.32	.33	.35	.068
328.2	.073	.17	.26	.050
433.6	.01	.4	.12	.027
453.0	.11	.11	.11	.025
473.7	.009	.075	.096	.023
492.7	.005	.3	.092	.021

†Normalized as explained in the text
*I_{e_L} present work
† α_L

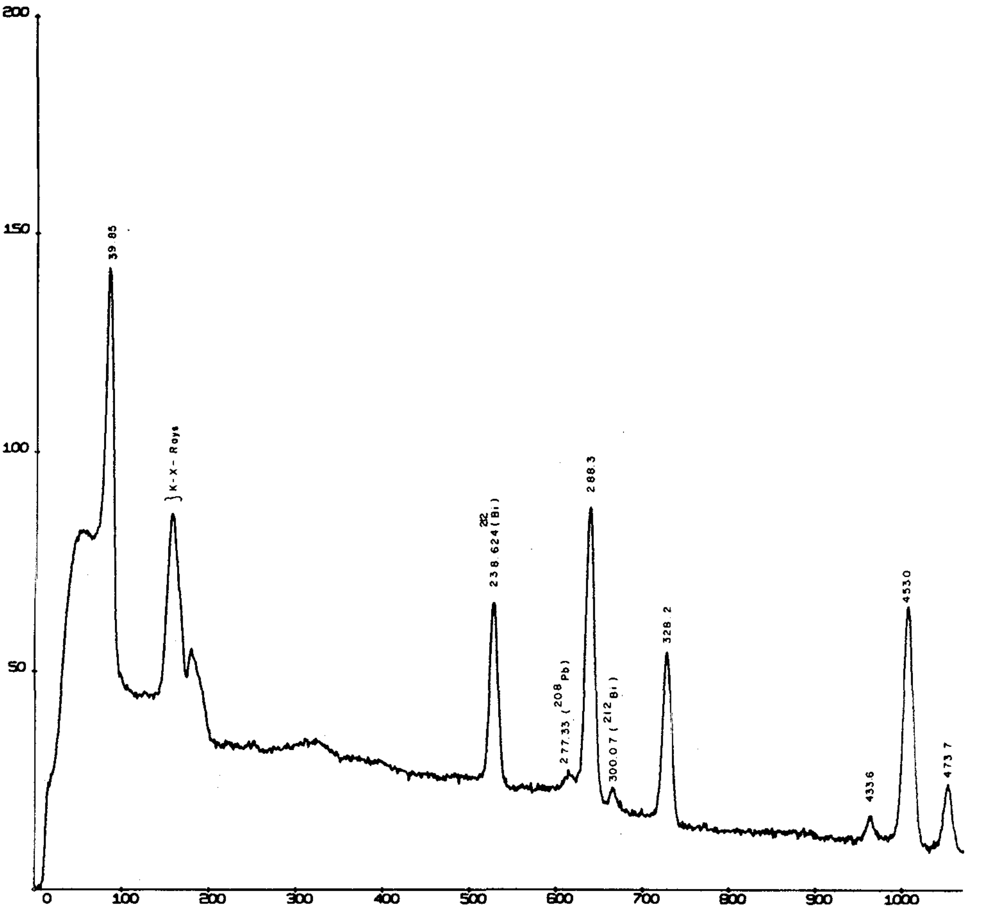
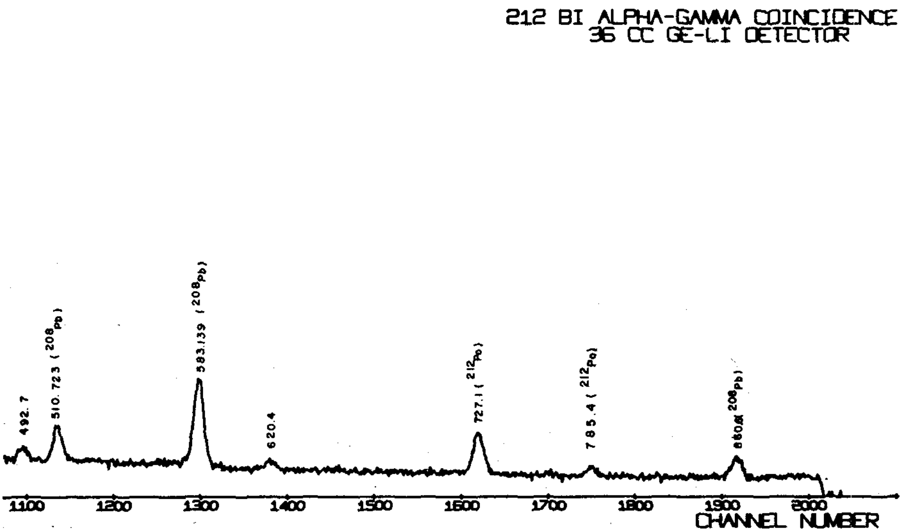


Fig. 3 - Gamma-ray spectrum in coincidence with the alpha particles from ^{212}Bi. Impurities shown were used for calibrating purposes.


212 BI ALPHA-GAMMA COINCIDENCE
36 CC GE-LI DETECTOR
492.7
510.723 (208Pb)
583.139 (208Pb)
620.4
727.1 (212Po)
785.4 (212Po)
208Pb)
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
CHANNEL NUMBER

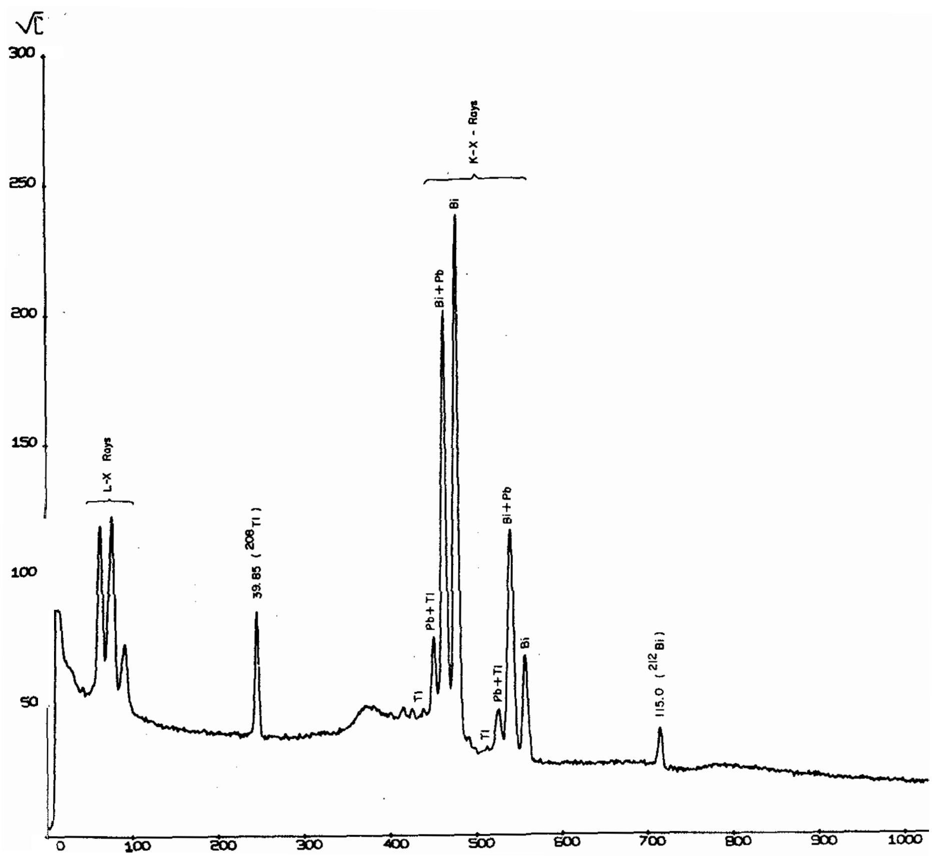
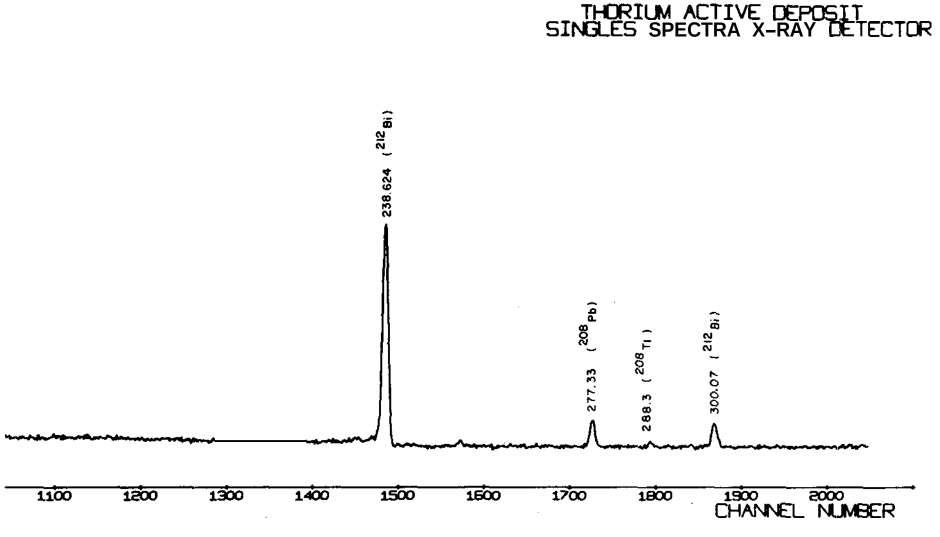


Fig. 4 - Thorium active deposit singles gamma-ray spectrum below 330 keV.


THORIUM ACTIVE DEPOSIT
SINGLES SPECTRA X-RAY DETECTOR
238.624 (212Bi)
277.33 (208Pb)
288.3 (208Tl)
300.07 (212Bi)
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
CHANNEL NUMBER

the K-shell fluorescent yields and relative intensities of Ka and $K\beta'$ lines were taken from Wapstra *et al.*[14].

To obtain the L-shell internal-conversion electron intensity of the 40 keV transition, use was made of the relative intensities of K- and L-shell conversion electrons given by Siegbahn[15], rather than using the L-shell X-ray data and the uncertain values of the L-shell fluorescent yield ω_L reported in the literature and the efficiency ε_L of the detector in this energy region. From the L-shell X-ray data, it was possible to obtain a value of .38 for ω_L. This value may be considered as an upper limit, because the K absorption edge of Ge changes the extrapolation trend of the efficiency calibration curve.

The values of the L-shell internal-conversion electron intensity, together with the ratio of intensities of L- to M- N- and O-shell internal-conversion electrons from the 40 keV level given by Siegbahn[15] and absolute intensities of gamma-rays and K-shell internal-conversion electrons feeding the 40 KeV level taken from Tables 1 and 2, yielded an alpha particle feeding of 72% for that level, relative to photons of 2615 keV, in excellent agreement with the value of 69.9% of the alpha decay of ^{212}Bi obtained by means of alpha-particle spectroscopy[16].

The internal-conversion coefficients obtained are shown in Table 2 together with theoretical values for M1 and E2 transitions taken from Hager and Seltzer[17]. All K-conversion coefficients are compatible with M1 transitions with perhaps E2 admixtures, except for the 434 and 493 keV transitions whose K-conversion coefficients are larger by a factor of three to fifteen than the expected theoretical values. These are very low intensity conversion electron transitions and the data significant to one figure are not reliable. The K-conversion electron intensity for the 493 keV transition has only been reported by Dzelepov[18], but Nielsen[8] reports half that value as an upper limit for the K-shell electron intensity and neither of the most recent works of Benoit *et al.*[7] nor Daniel and Luhrs[9] report it. If the absolute internal-conversion electron data for the 434 keV transition reported by Daniel and Luhrs alone is used, its intemal-conversion coefficients drops to the value of 0.15; however the work of Benoit *et al.*[7] and Nielsen[8] would raise that number by a factor of 4 and 2 respectively and there is no apparent reason to discard the data from these authors. A possible explanation for the high value of a, is given in the discussion of results. The decay scheme shown in Fig. 5 is consistent with data of the present experiment.

4. Discussion

The best summary of the information available up to 1963 about the levels of ^{208}Tl is the one given by Cobb[6]. The work of Klein[5], Benoit *et al.*[7] and Daniel and Luhrs[8] is consistent with that summary, and so is this work. There are however some reported transitions which are not consistent with data presented here. The 146 keV intemal-conversion electron transition[15] would have such a high conversion coefficient (> 9) that it would have to be of EO character (M2 would be too slow to compete) which is inconsistent with the scheme. The 580 keV (576 keV[5]) gamma-ray transition was not detected but it could be hidden under the 583 keV random peak and the intensity balance of the 620 keV level yields a value of .005% ± ± .003 for its intensity.

The anomalously high intemal-conversion coefficient of the 434 keV transition, can perhaps be explained by electric monopole admixture to M1 and E2, as predicted by Church and Weneser[3], for transitions between equal spin-parity states, for this mass region. According to the shell-model calculations of Kim and Rasmussen[2], there is some configuration mixing in the excited states of ^{208}Tl. This would allow the EO single proton transition. According to the results of α-γ angular correlations work by Klein[5], the 434 keV transition is from 87 to 75% E2. These values are not very reliable, because the NaI detector used could not resolve the 474 from the 434, 453 and 493 keV lines. Using Klein's values and those of Table 2, the contribution of EO conversion electron component relative to the E2 gamma-ray component, ε^2 can be estimated to be between .38, .42. Even using the conversion-electron data reported by Daniel and Luhrs[8] alone would indicate some EO contribution to the transition. This type of admixture would not be detectable in the 288 keV transition simply on the basis of conversion coefficients measurements because the almost pure M1 character of that transition would mask the possible EO contribution unless δ^2 and a, were known very accurately.

The high conversion coefficient found for the 474 keV transition which indicates it to be almost pure M1 does not agree with the α-γ angular correlation data of Klein[5] which atributes to it more than 98.5% E2-character.

Our thanks are due to J. C. Sobreiro da Silva and C. J. de Almeida for the graphs and to Mrs. M. L. dos Reis Nogueira and *G.* C. Paraguassú for the expert typing.

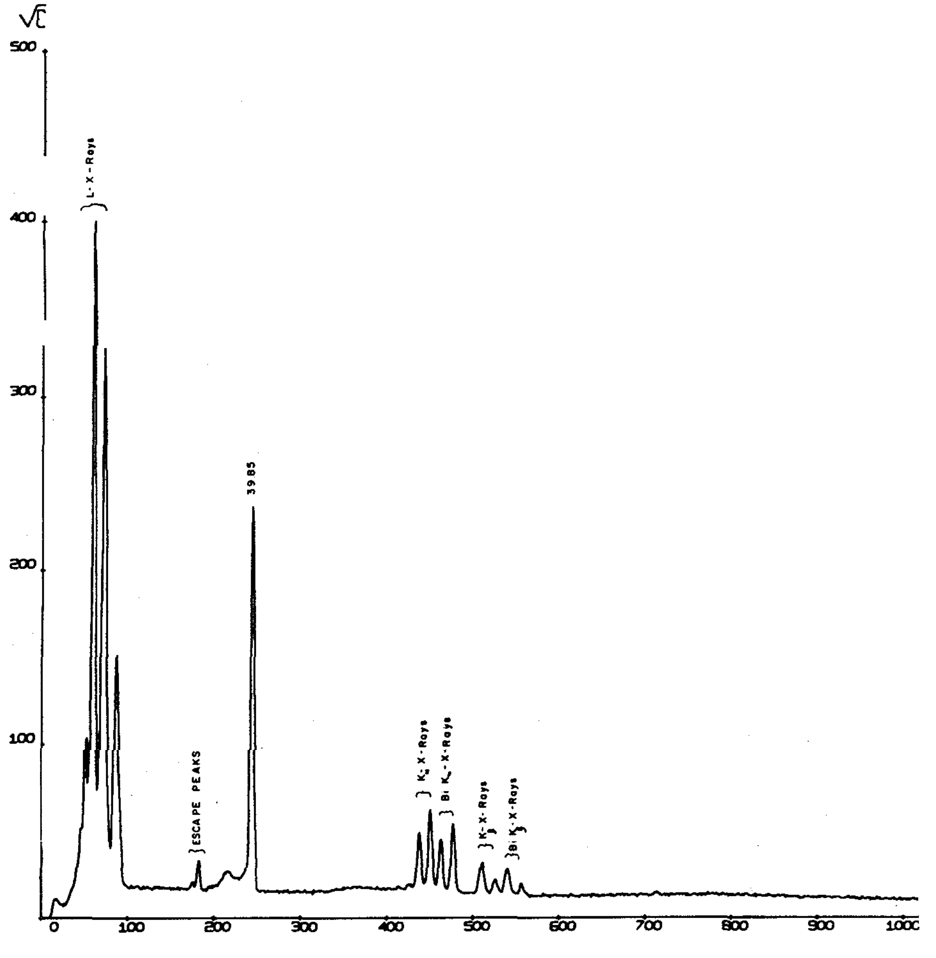
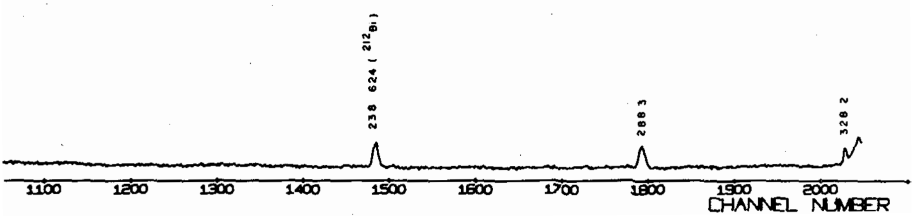


Fig. 5 - Gamma-rays below 330 keV in coincidence with ^{212}Bi alpha particles.

212 BI ALPHA-GAMMA COINCIDENCE
X-RAY DETECTOR



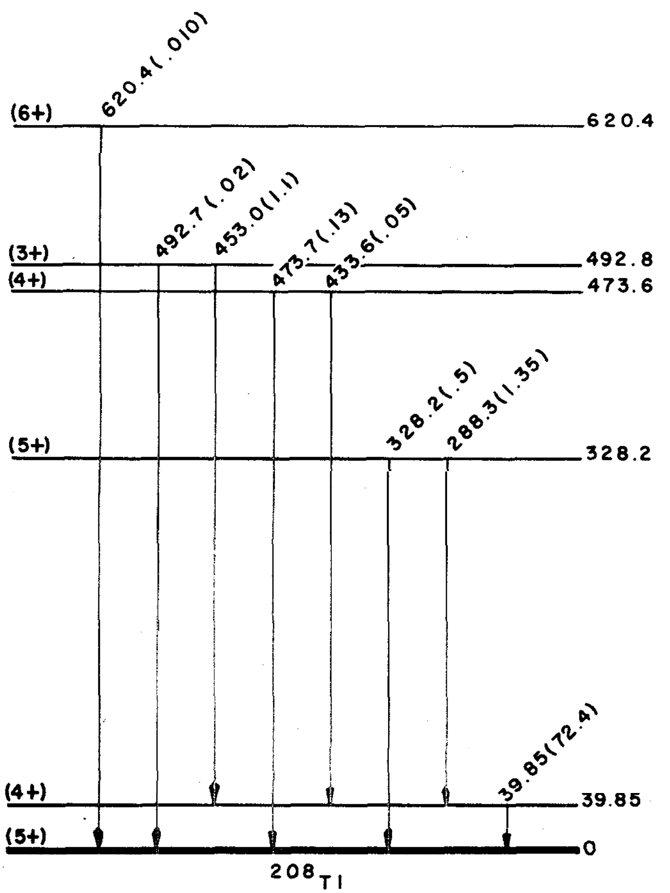


Fig. 6 - *Levels* of ^{208}Tl populated by the α-decay of ^{212}Bi. Energies of levels are weighied average of gamma-ray energies. Numbers in parenthesis refer to transitions per 100 α-decays of ^{212}Bi.

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