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On the Decay of ^{160}Tb

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ABSTRACT. The level structure of ^{160}Dy has been investigated from the decay of ^{160}Tb (72.4d). Single, gamma-gamma coincidence and fast-slow delayed coincidence systems have been used. Thirty seven γ-ray lines could be identified and fitted in a proposed level structure of ^{160}Dy. The positions of previously doubted transitions at energies of 98.0, 203.1, 420.3 and 1048.9 keV are confirmed. The half life time of the 86.6 keV level is found to be 2.07 $\pm$ .10 n.sec, and the reduced transition probability is calculated as:

$[0.96 \pm 0.05e^2 \times 10^{-48}\ cm^2]$.

The level structure of the doubly even nucleus ^{160}Dy has been studied by many investigators, Ewan *et al.* (1961), Boehm and Roger (1963), Fossan Herskind (1963), Kugel *et al.* (1968), Jaklevic *et al.* (1967), Hogberg *et al.* (1968), Nilsson *et al.* (1968), Ludington *et al.* (1968), Gunther *et al.* (1968), Hassan *et al.* (1981), Hasiza *et al.* (1982), Jin *et al.* (1983), Singh *et al.* (1983) and Abdulmomen *et al.* (1984). The results of these studies have led to a fairly well established decay scheme for excitation energies up to 1600 keV. The assignment of spins and parities to many of the excited states in this decay scheme has been based on directional correlation and internal conversion measurements.

However, Lederer *et al.* (1978) and recently Lee and Bunting in nulear data sheets (1985) proposed a somewhat different decay scheme in which a new level at 581 keV is included. Additional weak transitions at 203.1, 420.0 and 1048.0 keV were reported by Hassan *et al.* (1981). Moreover, Singh *et al.* (1983) suggested a new transition at 97.71 keV which could be fitted between the 1386.5 and 1288.2 keV levels.

In order to settle such proposed data, concerning the ^{160}Dy level scheme, a reinvestigation is quite needed.

Singles γ-Ray Spectrum

A radioactive ^{160}Tb point source of about 4 MBq obtained from Amersham (U.K.), is used in this work. The single γ-ray spectrum due to the decay of ^{160}Tb to ^{160}Dy has been measured using an 85.5 cm^3 hyper pure germanium γ-ray detector (FWHM = 2.1 keV for 1.33 MeV), coupled to a multichannel analyzer (4096 channels) and other associated electronics. Energy and efficiency calibration of the system were performed as reported by Farhan (1985) using standard radioactive sources at a distance of about 20 cm from the detector.

A typical single spectrum is shown in Figs. (Ia, b&c). The energies of the observed γ-ray transitions are determined by means of least square fitting. The relative intensities corresponding to these transitions have been estimated using the efficiency curve of the hyper pure germanium system and then normalized to the relative intensity of 879.4 keV γ-ray transition.

The energies and relative intensities of 37 γ-ray lines assigned to the decay of ^{160}Tb are listed in Table 1 and compared with the data published by Jin *et al.* (1983).

The accuracy in the intensity values includes the error of efficiency values and the statistical errors of the area under the photopeaks.

It should be noted that, the present results are not only in fair agreement with most of the previously established transitions but also used to confirm the new γ-ray line at 98.0 proposed by Singh *et al.* (1983) as well as those of energies at 203.1, 420.3 and 1048.0 keV observed by Hassan *et al.* (1981) as weak transitions. The γ-ray transitions at 203.1 and 420.3 keV were observed as well in the gamma-gamma coincidence measurements of this work.

The confirmation of the 1048.6 keV new transition is of value since it depopulates a well established level at 1049.1 keV of (3^+) to (0^+) ground state which suggest that such transition to have an M3 character.

In their paper, Jin *et al.* (1983) searching for well pronounced and useful data of γ-ray transitions due to the decay of ^{160}Tb to ^{160}Dy for calibration of their γ-ray spectrometer, they did not report the well known and strong γ-ray transition of 86.8 KeV as well as the weak γ-ray transitions at; 98.0, 176.6, 203.1, 237.7, 420.3 and 1048.6 keV which were reported before by different authors. The two weak γ-ray transitions at 242.5 and 432.7 keV reported by Jin *et al.* (1983) were not very clear in the present work.

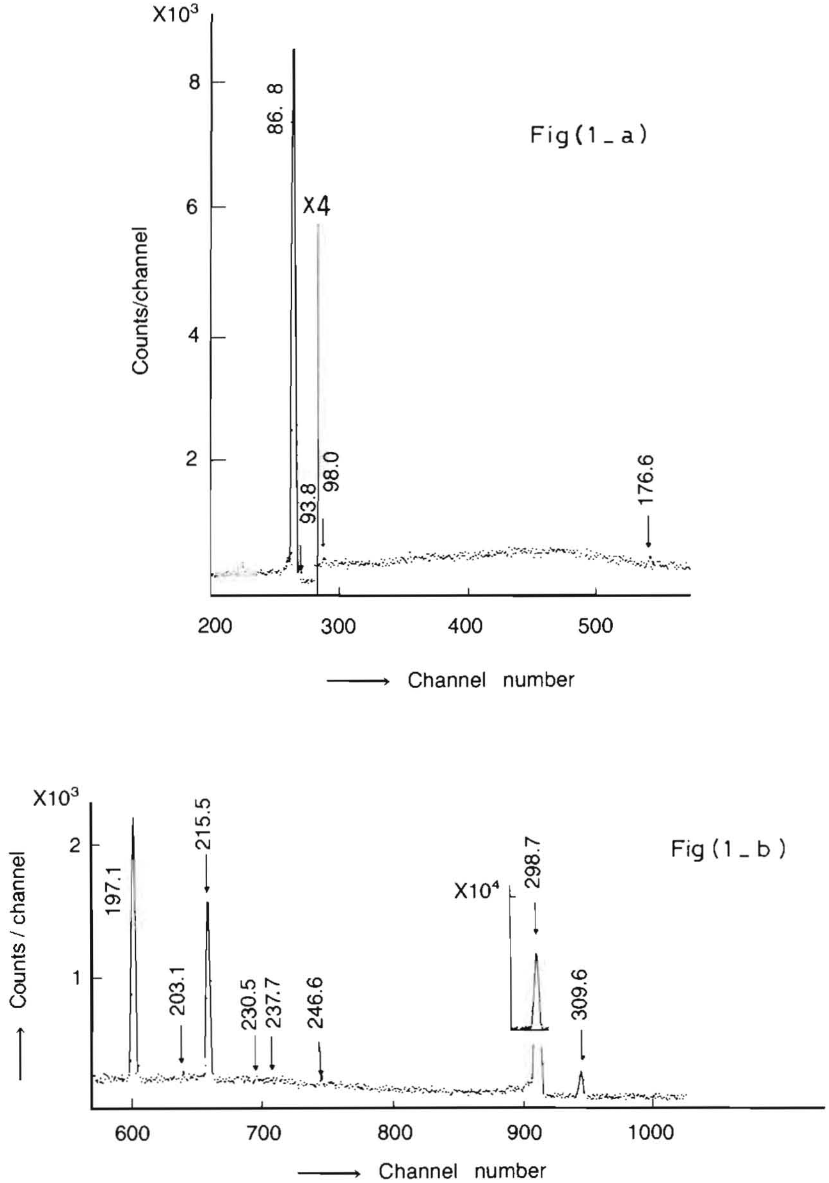

Fig. (1-a and 1-b). ^{160}Tb γ-ray singles spectrum (low energy region < 310 keV)

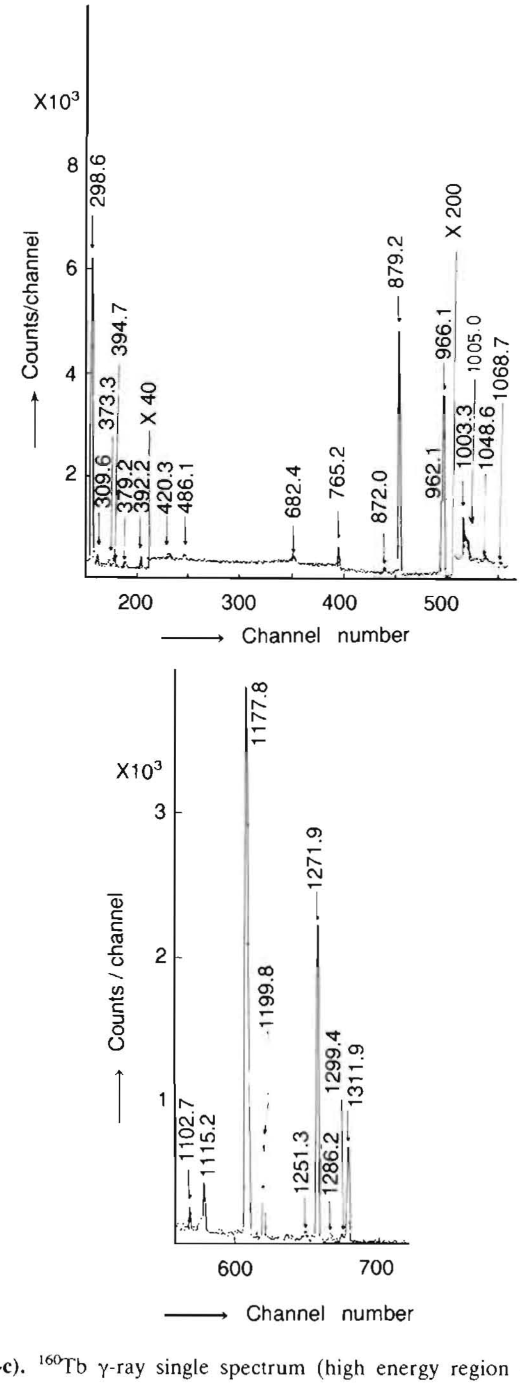

Fig. (1-c). ^{160}Tb γ-ray single spectrum (high energy region < 1320 keV)

Table 1. γ-ray energies and relative intensities of γ-ray transitions in ^{160}Dy following the decay of ^{160}Tb

Present work		Jin *et al.* (1983)	
$E_\gamma \pm \Delta E$ keV	$I_\gamma \pm \Delta I_\gamma$	E_γ keV	$I_\gamma \pm \Delta I_\gamma$
86.8 ± 0.20	45.15 ± 0.390	—	—
93.8 ± 0.30	0.21 ± 0.020	93.3	0.1810 ± 0.0100
98.0 ± 0.20	0.01 ± 0.002	—	—
176.6 ± 0.20	0.01 ± 0.002	—	—
197.1 ± 0.10	19.00 ± 0.290	197.0	17.0600 ± 0.2400
203.1 ± 0.20	0.01 ± 0.002	—	—
215.5 ± 0.10	12.03 ± 0.180	215.6	13.3700 ± 0.1400
230.5 ± 0.20	0.25 ± 0.030	230.6	0.2800 ± 0.0110
237.7 ± 0.10	0.04 ± 0.005	—	—
—	—	242.5	0.0330 ± 0.0110
246.6 ± 0.10	0.04 ± 0.008	246.5	0.0690 ± 0.0110
298.7 ± 0.02	91.35 ± 1.890	298.6	87.8000 ± 0.4000
309.6 ± 0.10	2.70 ± 0.027	309.6	2.8770 ± 0.0250
337.2 ± 0.20	1.32 ± 0.020	337.3	1.1290 ± 0.0240
349.7 ± 0.20	0.06 ± 0.008	349.9	0.0470 ± 0.0070
379.2 ± 0.10	0.06 ± 0.008	379.4	0.0400 ± 0.0070
392.2 ± 0.20	4.67 ± 0.040	392.5	4.4800 ± 0.0300
420.3 ± 0.30	0.01 ± 0.002	—	—
—	—	432.7	0.0730 ± 0.0070
486.1 ± 0.20	0.29 ± 0.029	486.1	0.2670 ± 0.0230
682.4 ± 0.30	2.01 ± 0.082	682.3	1.9700 ± 0.1600
765.2 ± 0.40	7.01 ± 0.190	765.3	7.1800 ± 0.1800
872.0 ± 0.40	0.68 ± 0.070	872.0	0.7100 ± 0.0400
879.2 ± 0.40	100.00	879.4	100.0000 ± 0.3000
962.1 ± 0.30	31.30 ± 0.300	962.3	32.0300 ± 0.1400
966.1 ± 0.40	82.33 ± 0.750	966.2	82.5700 ± 0.2900
1003.3 ± 0.40	4.01 ± 0.040	1002.9	3.5710 ± 0.0200
1005.0 ± 0.40	0.01 ± 0.001	1005.0	3.5710 ± 0.0200
1048.6 ± 0.50	0.03 ± 0.003	—	—
1068.7 ± 0.50	0.28 ± 0.020	1069.1	0.3090 ± 0.0110
1102.7 ± 0.40	1.90 ± 0.150	1102.6	0.9060 ± 0.1800
1115.2 ± 0.40	4.91 ± 0.040	1115.1	5.0990 ± 0.0230
1177.8 ± 0.30	49.98 ± 0.380	1177.9	49.2600 ± 0.1600
1199.8 ± 0.40	7.89 ± 0.070	1199.9	7.8400 ± 0.0300
1251.3 ± 0.50	0.33 ± 0.010	1251.3	0.3570 ± 0.0080
1271.9 ± 0.40	22.32 ± 0.770	1271.9	24.7200 ± 0.0080
1286.2 ± 0.50	0.05 ± 0.005	1285.6	0.0460 ± 0.0030
1299.4 ± 0.02	0.02 ± 0.002	1299.3	0.0051 ± 0.0019
1311.9 ± 0.40	9.56 ± 0.090	1312.1	9.3500 ± 0.0400

Gamma-Gamma Coincidence Spectra

In order to establish the decay scheme of ^{160}Tb, gamma-gamma coincidence measurements have been carried out using the HPGe-HPGe gamma-gamma coincidence spectrometer described and calibrated by Farhan (1985). The spectrometer consists of two hyper pure germanium detectors (HPGe) of 85.5 and 67.5 cm^3 active volumes, a fast coincidence unit (50-100 n.sec resolving time), 4096 channels analyzer and associated electronic units.

A set of gamma-gamma coincidence measurements have been carried out to tentatively place the following new weak transitions at energies 98.0, 203.1, 420.3 and 1048.0 keV, as well as to check other doubtful interband transitions in the decay scheme.

Figure 2 shows a typical coincidence spectrum gated with the 86.8 keV γ-transition. A total of 26 γ-ray transitions were observed and labelled by their energy values. The analysis of the coincidence data can indicate the following:

i) The presence of the 203.1 and 420.3 keV transitions is supported since they have been identified as members feeding possible coincidences, *i.e.* 872.0 - 197.1 - 86.8 keV and 1068.7-86.8 keV for the former transition while the latter can lead to the 879.2 - 86.8 keV coincidence.

ii) The absence of the 1048.0 transition in this coincidence spectrum is in accordance with the expected location of this transition between the 1049.1 level and the ground state.

iii) Although the false coincidence background in the low energy region prevented the detection of the 98.0 keV transition, yet it may nevertheless act as a member feeding the coincidence 1005.0 - 197.1 - 86.8 which has been identified.

It has to be noted that all the transitions observed in both single and coincidence measurements have been applied in deducing a decay scheme of ^{160}Tb as presented in Fig. 3. The 581 keV level have been observed in the decay of ^{160}Ho to levels in ^{160}Dy and confirmed by inelastic neutron scattering (Lederer *et al.* 1978). Some other authors reported this level when studying the decay of ^{160}Tb, which populated by a 681 keV, and depopulated by 297 keV γ-ray transitions. Unfortunately, it was not easy to resolve the 681 keV from 682.2 keV, and the 297 from the 298.7 keV. Accordingly, we could not claim the presence of this level in the present work. This scheme can incorporate the four weak transitions under discussion as shown by dotted lines.

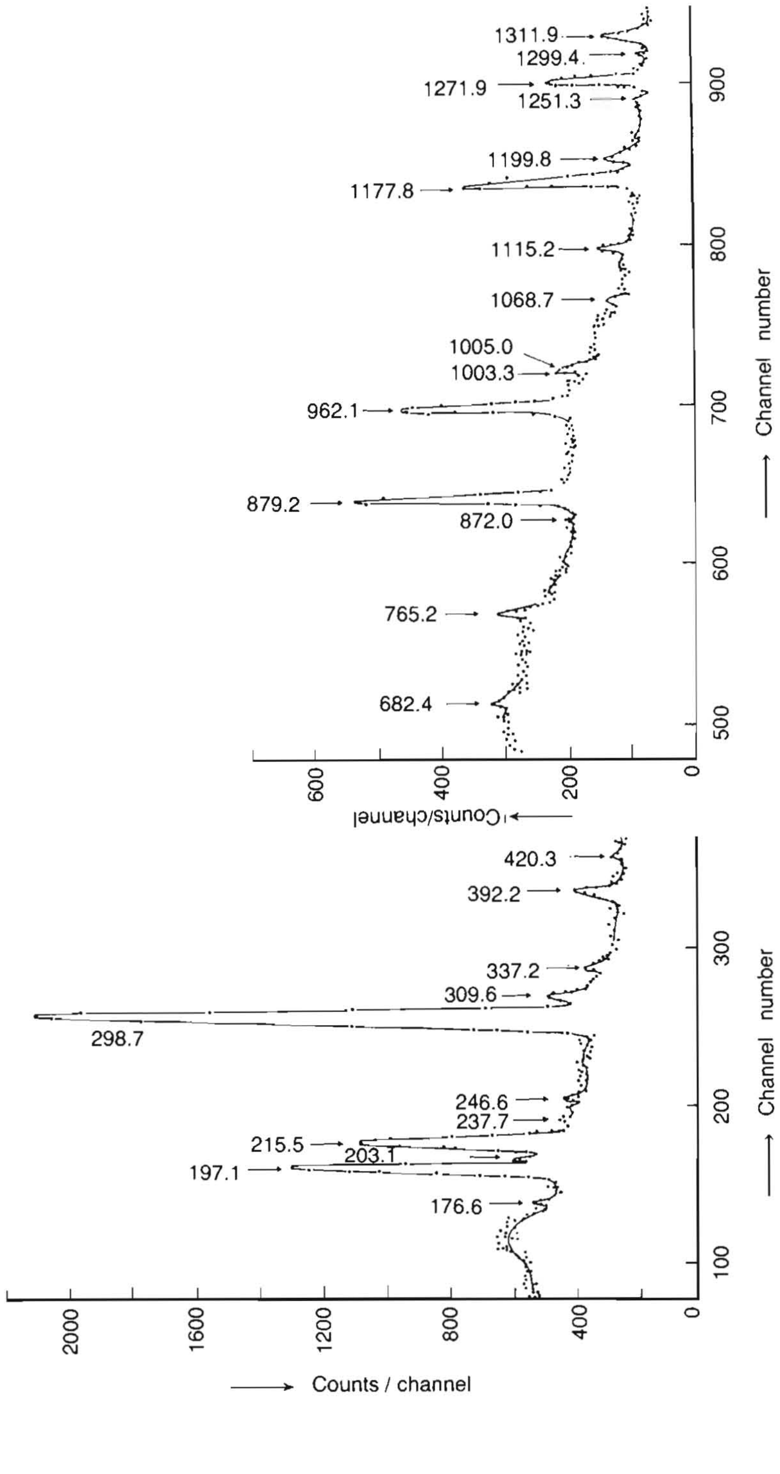

Fig. 2. Gamma-gamma coincidence spectrum [using 86.8 keV in gate]

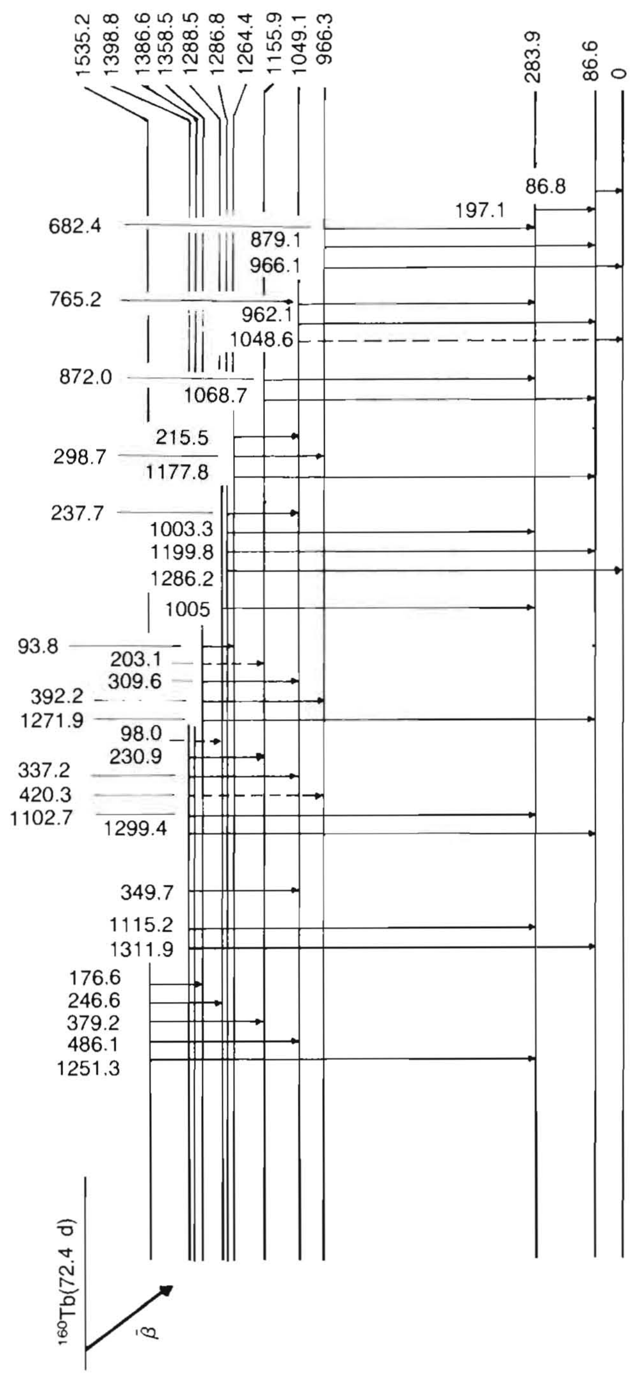

Fig. 3. ^{160}Dy level structure

Half-Life Time Measurements

In this work, the fast-slow coincidence technique is used to remeasure the half-life time of the 86.8 keV level. The spectrometer contains mainly, two NaI (T ℓ) scintillation detectors with dimensions of 5 cm $\phi \times$ 5cm L., coincidence units, 1024 channels analyzer and the other associated electronic units. The fast-slow coincidence system used is as described and calibrated by Al-Khateeb (1984). The prompt time spectrum has been measured with ^{22}Na standard radioactive source with the start and stop window settings as in the delayed time spectrum. The prompt resolution curve is characterized by a FWHM (Full Width at Half Maximum) of 4.35 n.sec. The time calibration has been done by using a set of calibrated units.

Although the 86.8 keV level is populated by nine γ-ray transitions from which the most intense ones are of energies 197.1, 879.2, 962.1, 1177.8 and 1271.9 keV, yet it is depopulated by a single transition of energy at 86.6 keV. Accordingly two window settings of an energy range (879 - 962 keV) and (1177 - 1271 keV) have been chosen for the start channel unit, while the stop channel has been set at 86.8 keV as shown in Fig. 4. One of the prompt and delayed time spectra from the fast-slow timing system is shown in Fig. 5.

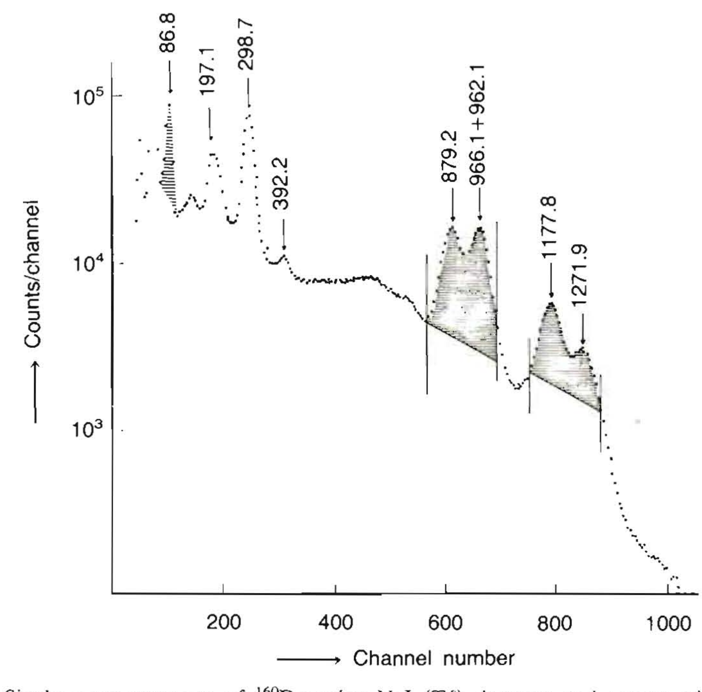

Fig. 4. Single γ-ray spectrum of ^{160}Dy using NaI (Tℓ) detector and energy window setting

The half-life time has been determined by means of the centriod shift method, and the average of several measurements gave a half-life time of 2.07 ± 0.10 n.sec which is found to be in good agreement with the previously reported values of Fossan and Herskind (1963) and Kugel *et al.* (1968). The adopted error covers that due to time calibration and that which can arise from the non-linearity of the TAC (Time to Amplitude Converter). This value of half-life time has been used to calculate the reduced transition probablity, Kugel *et al.* (1968) applying the relation.

$$B\,(E2 : I_i \rightarrow I_f = \frac{56.34}{E^5} \; \frac{1}{(1+\alpha_T)T_{\frac{1}{2}}}$$

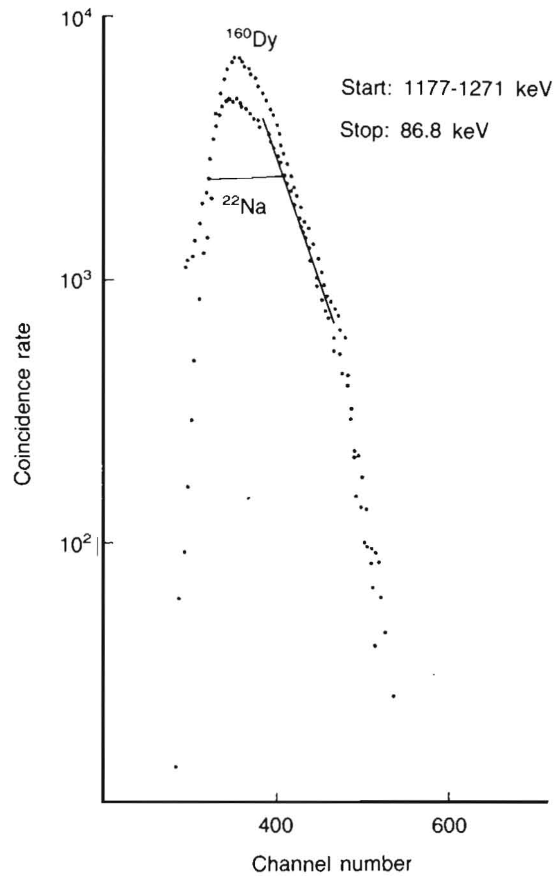

Fig. 5. Prompt and delayed time spectra for fast-slow timing system

where E is keV, $T_{\frac{1}{2}}$ is seconds and $\alpha_T = 4.75$ taken from Hager and Seltzer Tables (1967).

The B(E2) value for the 86.8 keV transition between 2^+ to 0^+ levels is found to be [0.96 (5) $e^2 \times 10^{-48}$ cm^2] which is in a good agreement with the value reported by Kugel *et al.* (1968).

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References

Abdulmomen, M.A. and **Morsy, M.** (1984) *Study of level structure of some deformed nuclei.* Final Rep., Phys. Dept., Faculty of Science, King Abdulaziz University.

Al-Khateeb, W.F. (1984) *Meausrement of half-life time of the 81 keV level in ^{133}Cs*, M.Sc. Thesis, Phys. Dept. Faculty of Science, King Abdulaziz University.

Boehm, F. and **Roger, H.** (1963) Properties of some states in ^{160}Dy, *Nucl. Phys.* **41:** 553-560.

Ewan, G.T., Graham, R.L. and **Geiger, J.S.** (1961) Negative parity levels in the even-even nucles ^{160}Dy, *Nucl. Phys.* **22:** 610-628.

Farhan, A.S. (1985) *Spectral studies on the decay of ^{133}Ba nuclei using high resolution semiconductor detectors.* M.Sc. Thesis, Phys. Dept., Faculty of Science, King Abdulaziz University.

Fossan, D.B. and **Herskind, B.** (1963) Half-lives of first excited 2^+ states ($150<A<190$), *Nucl. Phys.* **40:** 24-33.

Gunther, C., Ryde H. and **Krien, K.** (1968) Mixing of rotational bands in the ^{160}Dy, *Nucl. Phys.* **A-122:** 401-416.

Hager, R.S. and **Seltzer, E.C.** (1967) *Internal Conversion Tables*, California Inst. of Tech. Report CALT63.

Hasiza, M.L., Singh, K. and **Sahota, H.S.** (1982) The decay of ^{170}Tb, *Indian J. Phys.* **56A:** 221-226.

Hassan, A.M., Abou Zeid, M.A. and **Mekhamer, M.** (1981) Studies on the decay of ^{160}Tb to levels in ^{160}Dy by Ge(Li)– Ge(Li) coincidence system, *AREAEE. Rep.* 264.

Hogberg, S., Begmark, J.E., Malmsten, G. and **Nilsson, O.** (1968) Determination of relative intensities of M Internal conversion lines in pure E2 transitions, *Nucl. Phys.* **A-120:** 569-575.

Jaklevic, J.M., Funk, E.G. and **Mihelich, J.W.** (1967) Coincidence and directional correlation measurements, on the decay of ^{160}Tb employing a Ge(Li) detector, *Nucl. Phys.* **A-99:** 83-99.

Jin, J. Takada, Iwata, Y. and **Yoshizawa, Y.** (1983) Precision measurements of gamma-ray intensities, V, ^{160}Tm and ^{182}Ta, *Nucl. Instr. and Meth.* **212:** 259-271.

Kugel, H.W., Funk, E.G. and **Mihelich, J.W.** (1968) Half-lives of 4^+ and 2^+ rotational states in several rare earth nucle, *Phys. Rev.* **165:** 1352-1360.

Lederer, C.M. and **Virginia, S. S.** Eds. (1978) *Table of isotopes*, Lowerence Berkley Lab., John Wiley and Sons Inc., p. 939.

Lee, M.A. and **Bunting, R.L.** (1985) *Nuclear Data Seets*, edited by National Nuclear Center, Brookhaven National Lab., UPTON, N.Y., USA. **46:** 239-285.

Ludington, M.A., Reidy, J.J., Wiedenbeck, M.L., McMillan, D.J., Hamilton, J.H. and **Pinajian, J.J.** (1968) The decay of ^{160}Tb to levels of ^{160}Dy, *Nucl. Phys.* **A-119:** 398-416.

Nilsson, O., Thoren, I., Malsten, G. and **Hogberg, S.,** (1968) K/L, Lm/Mm and M/ (N+O+P) ratios in Pure E2 transitions, *Nucl. Phys.* **A-120:** 561-568.
Singh, J.,Gary, M.L., Singh, N. and **Terhan, P.N.** (1983) The level structure of ^{160}Dy, *Proc. Intern. Conf. Nuclear Physics*, Florence, August 29-Sept. 3, V.I.

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اضمحلال نواة التربيوم^{١٦٠}

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المملكة العربية السعودية

تم في هذا البحث دراسة اضمحلال نواة التربيوم^{١٦٠} إلى الديسبروزيوم^{١٦٠} ذات عمر النصف (٧٢,٤) يوم.

استخدم لذلك الغرض مطياف جاما المفرد، ومطياف جاما - جاما التطابقي، ونظام التطابق (سريع بطىء)، حيث استعملت كواشف الجرمانيوم بالغ النقاوة وكواشف أيوديد الصوديوم المنشط بالثاليوم. أمكن التعرف على سبعة وثلاثين من الخطوط الجامية الواضحة والتي استخدمت لبناء هيكل مناسيب الطاقة المقترح لنواة الديسبروزيوم^{١٦٠}.

أوضحت النتائج إمكانية إزالة اللبس الذي كان يحيط بالانتقالات الجامية الجديدة للطاقات: ٩٨,٠، ٢٠٣,١، ٤٢٠,٣، ١٠٤٨,٩ ك. أ. ف.

كما تضمن البحث تعيين عمر النصف للمستوى ٨٦,٦ ك. أ. ف عند (٢,٠٧ ± ٠,١٠)×١٠$^{-٩}$ ثانية. كما تم حساب الاحتمال المنحسر للانتقال الجامي منه، والذي بلغت قيمته [$0.96\pm0.05 e^2\times10^{-48} Cm^2$] مما يتفق مع النتائج المعلومة في هذا المجال.