INVESTIGATION OF NEUTRON-DEFICIENT ISOTOPES ^{160}Yb, ^{161}Yb, ^{163}Yb AND ^{165}Yb

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Abstract

A new isotope ^{161}Yb($T_{1/2}$ = 4.2 min) has been identified. The decay of ^{160}Yb ($T_{1/2}$ = 4.8 min), ^{163}Yb($T_{1/2}$ = 11.4 min) and ^{165}Yb($T_{1/2}$ = 9.8 min) has been investigated with Ge(Li), Si(Li) and NaI(Tl) detectors, a toroidal β-spectrometer and magnetic β-spectrographs using isobarically separated samples produced by the YASNAPP facility. A decay schemesfor ^{160}Yb, ^{163}Yb and ^{165}Yb are proposed.

1. Preparation of sources

The neutron-deficient ytterbium isotopes were produced in the spallation reaction induced by high-energy protons on a tantalum target. The external 660 MeV proton beam (current 0.1 μA) of the Dubna synchrocyclotron was employed. The metallic tantalum foils (0.05 mm thick and 0.5 g weight) were irradiated for a period ranging from 5 min to 15 min. The exposed targets were transferred pneumatically and loaded to the pipe-type surface ionization source of an electromagnetic isotope separator. Products of the spallation reaction in the tantalum target diffusing from the foil were separated by the method described in ref $^{1)}$. Measurements of isobarically separated samples started about 5 min after the end of irradiation. The ^{160}Yb and ^{161}Yb isotopes were identified using also the chemically separated samples. In this case suspensions of about 5 g of Ta_2O_5 in 0.1 M HCl were irradiated. Because of the high recoil energy of the spallation products about 40 % of those were stabilized in the liquid phase and could easily be separated from the target $^{2)}$. The rare earth spallation products were separated by cation exchange chromatography at a 2 ø x 60 mm column filled with Aminex 5. After elution of the ytterbium fraction it was deposited by electrolysis on a 5 mm^2 tungsten foil and separation of the Yb isotope was performed. The measurements started about 20 min after the end of irradiation.

2. Measurements

The spectra of γ-rays were investigated using Ge(Li) detectors with sensitive volumes 0.5, 2.4 and 3 cm^3 with system resolutions for ^{57}Co of 1.2, 0.6 and 0.9 keV, respectively and Ge(Li) detectors with volumes 27, 41 and 40 cm^3 with system resolutions for ^{60}Co of 3.5, 2.4 and 3.5 keV, respectively. The spectra were stored in 4096 channel analyzers and were analysed by means of computers. Gamma-ray energies were calibrated by measuring the investigated isotope together with several calibration sources. Calibration for efficiency of the Ge(Li) detectors was performed with an accuracy of 2-5 %; 16 different standard sources were used for this task.

The conversion electrons were investigated by means of an iron free β-spectrometer with toroidal magnetic field (the resolution was 0.65 % and the transmission 10 %), a Si(Li) detector (with volume 150 mm^2 x 3 mm and system resolution of 2.2 keV for E_e = 74 keV) and magnetic β-spectrographs operating at 0.04 % resolution.

The γ-γ-coincidence spectra were taken by two Ge(Li) detectors having sensitive volume of 27 and 41 cm^3. The resolving time of the coincidence circuits was 50 nsec. The two-dimensional coincidence spectrum (4096 x 4096 channels) was tape recorded and then further treated by the HP 2116 C computer.

The half-life of excited states was measured by the delayed γ-γ-coincidence technique with Ø4 x 4cm^3 Na(Tl) scintillation counter as a gate detector and 41 cm^3 Ge(Li) detector for recording the coincidence. The resolving time of the system was 10 nsec.

The decay energy of ^{163}Yb was determined by measuring the coincidences of positrons with 860.28 keV γ-rays. A Si(Li) detector (100 mm^2 surface, 15 mm thickness) and a Ø8 x 8cm^3 NaI(Tl) crystal were used. Corrections to the positron spectrum for the backward scattering effect in the Si(Li) detector were obtained by means of the ^{140}Pr positron spectrum.

3. Results

3.1 ^{160}Yb

The decay of ^{160}Yb with a half-life of 4.8 min was observed for the first time from ^{124}Te(^{40}Ar,4n)^{160}Yb reaction $^{3)}$. The transitions with energy of 78.3, 600 and 631.7 keV were reported by de Boer et al. $^{4)}$ who determined a half-life of 4.1 ± 0.2 min for ^{160}Yb, but we established that these transitions correspond to the ^{161}Yb decay (see below). Gamma-ray spectra mesured with isobarically separated (A = 160) sources contain the thulium KX-rays, γ-transitions corresponding to the ^{160}Yb decay (see table 1) and well known γ-rays from decay of ^{160}Tm. Sources obtained by combined chemical and mass-separations (ytterbium and thulium fraction, A = 160) were measured. In the activity of ^{160}Yb γ-rays corresponding to the decay of ^{160}Yb and ^{160}Tm were observed. On the other side, the activity of ^{160}Tm contained just the γ-rays of ^{160}Tm. The half-life of ^{160}Yb was established to be $T_{1/2}$ = 4.8 ± 0.2 min. The part of our results was published in ref.$^{5)}$. It should be noted that γ-rays with energy (and relative intensity) of 173.9 keV (100) and of 215.7 keV (47) corresponding to the decay of activity with 4.6 + 0.5 min half-life were observed by de Boer et al.$^{4)}$ and identified erroneously as belonging to the ^{158}Yb decay.

Table 1.

Energies and intensities of the γ-ray transitions in the decay of ^{160}Yb

E_γ (keV)	I_γ	E_γ (keV)	I_γ
K_1 (Tm)	129	173.74 ± 0.06	100
34.18 ± 0.10	3.0	174.40 ± 0.10	13.2
42.02 ± 0.10	7.3	215.78 ± 0.06	48
62.05 ± 0.10	0.46	320.00 ± 0.15	3.6
94.29 ± 0.07	0.92	327.60 ± 0.15	5.6
98.24 ± 0.05	2.8	373.00 ± 0.10	10.0
99.46 ± 0.05	2.1	386.2 ± 0.3	3.2
116.44 ± 0.05	1.96	389.38 ± 0.15	5.7
132.23 ± 0.05	14.0	429.0 ± 0.3	1.4
140.35 ± 0.05	22.2	562.8 ± 0.3	1.9
155.76 ± 0.07	1.7	582.0 ± 0.3	2.4

Results of the γ-γ coincidence measurements used for the decay scheme construction are shown by full circles, see fig.1.

The multipolarity of following transitions was determined from internal conversion electron measurements with the toroidal magnetic spectrometer: 42.02 keV - M1 + ~ 5 % E2, 132.23 keV-E1, 140.35 keV-E1, 173.74 keV-E1 and 215.78 keV-E1. The spin of the ^{160}Tm ground state was established to be I=1 by Ekström et al. $^{6)}$, which can be explained by assuming the 1^-(p $5/2^+$[402]$\mp$n $3/2^-$[521]) assignment to this state. The measured thulium KX-ray intensity (table 1) for the ^{160}Yb decay and intensity balance of excited states of ^{160}Tm gives approximately an upper limit of 45 % for the direct population of the ground state. The decay energy Q=2.8 MeV for ^{160}Yb taken from Wapstra and Gove $^{7)}$ was used for calculation of the log ft value for β-transitions. The allowed unhindered character (log ft $\lesssim$ 4.5) was established for the β-branch to the state at 215.78 keV, which leads to unambiguous assignment 1^+(p $7/2^-$[523] -n $5/2^-$[523]) for this state. On the basis of our experimental results, the spin of the 42.03 keV state can be 2^-, 1^-, or 0^-. From energy of this state we suppose, that it is a first member of the ground-state rotational band with spin-parity 2^-.

3.2 ^{161}Yb

Single γ-ray spectra of three isobarically separated sources (A=160, 161 and 162) were measured simultaneously and decay of the transitions was followed. Besides γ-ray transitions corresponding to the decay of the well known isotopes ^{161}Tm ($T_{1/2}$ = 37 min) and of ^{161}Er($T_{1/2}$ = 3.1 h), several new transitions were identified. In table 2, these transitions of the (4.2 ± 0.2) min activity, observed in the isobarically separated sources (A=161) are listed. Additional proofs were received for correctness of mass determinations by measuring γ-ray spectra from two neighbouring mass-separated sources. In the first source, we found activity of ^{160}Yb and ^{160}Tm isotopes. In the second source, the ^{162}Yb and ^{162}Tm isotopes were established. The transitions listed in table 2 are not observed in sources of this type.

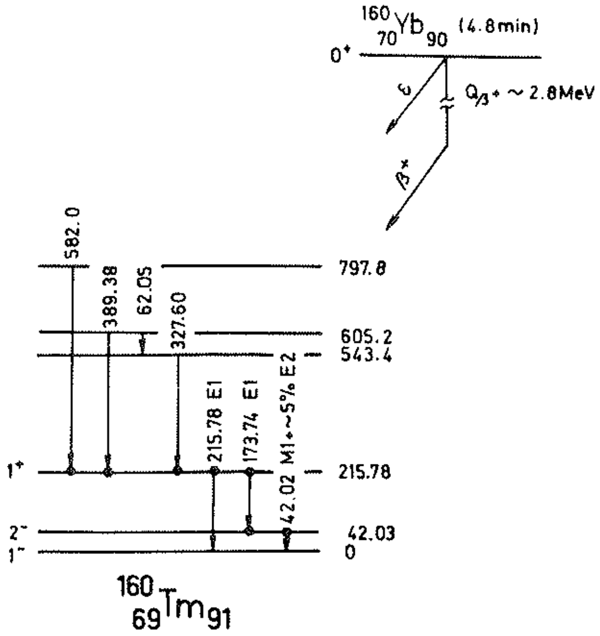

Fig. 1. The ^{160}Yb $\longrightarrow$ ^{160}Tm decay scheme.

Table 2

Energies and relative intensities of the γ-rays occuring in the ^{161}Yb $\longrightarrow$ ^{161}Tm decay

E_γ (keV)	I_γ
K_{α_1} (Tm)	100 ± 7.5
78.17 ± 0.05	48.9 ± 2.7
140.20 ± 0.20	3.3 ± 0.8
188.20 ± 0.08	4.5 ± 0.8
599.80 ± 0.30	38.8 ± 3.2
631.30 ± 0.50	21.0 ± 3.0

The 78.17 keV transition of the 4.2 min activity was identified also in the chemically (ytterbium fraction) and isobarically (A=161) separated sources. All these experimental results allowed us to determined the observed 4.2 ± 0.2 min activity as the ^{161}Yb.

De Boer et al.$^{4)}$ measured γ-rays of 78.3 keV, 600.0 keV and 631.7 keV decaying with half-lives of 4.1 ± 0.2 min and assigned them errorneously to the decay of the ^{160}Yb.

3.3 ^{163}Yb

Decay scheme of this nucleus including thirty excited levels of ^{163}Tm is shown in fig. 2. It was proposed on the basis of experimental results for γ-rays, conversion electrons and spectra of prompt and delayed coincidence. The intensity of 88 observed γ-transitions not placed in the decay scheme is about 7 %. Calculation of log ft

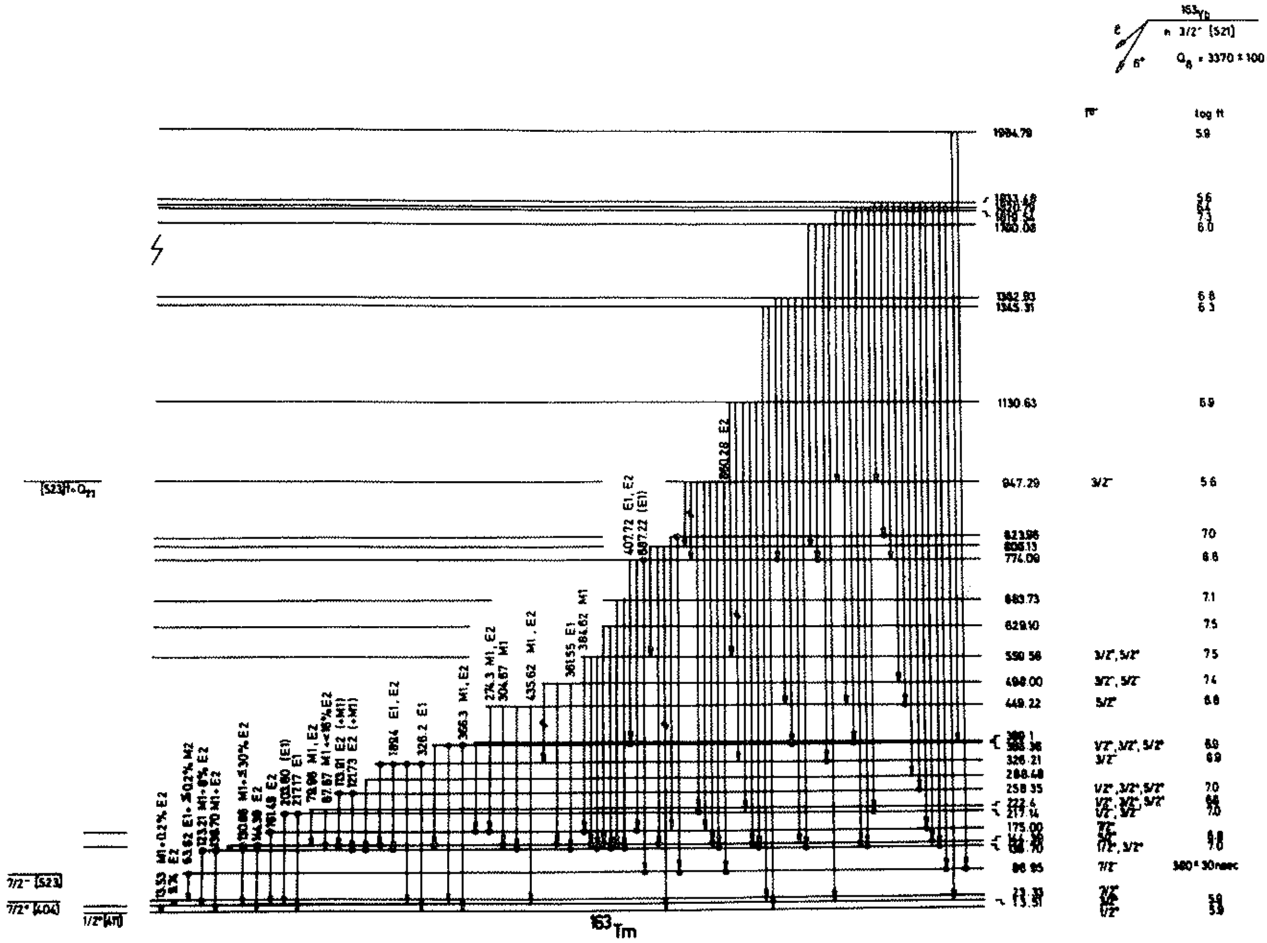

Fig. 2. The $^{163}Yb \longrightarrow {}^{163}Tm$ decay scheme.

values is based on assuming the same order of β-feeding to the first excited and ground states of ^{163}Tm in the ^{163}Yb decay. We used a Q-value of 3.37 MeV which was deduced from β^{+}-γ-coincidence measurements. Complete experimental results were recently published in ref. 8).

The spin I = 1/2 for the ground state ^{163}Tm was measured and interpreted as $1/2^{+}$[411] state 6). Conclusions for the transition multipolarity allowed assignment of the following spin and parity values to the excited levels in ^{163}Tm: 13.51 keV-$3/2^{+}$, 144.39 keV-$5/2^{+}$, 175.00 keV-$7/2^{+}$. Energies of these states are well described by the usual formula for the states of the K=1/2 rotational band with parameter A=15.36 keV and decoupling factor a = -0.707. The measured value of the admixture parameter for the transition $3/2^{+}1/2 \rightarrow 1/2^{+}1/2$ and the intensity ratios of γ-transitions from state with spin I to I-1 and I to I-2 allowed us to calculate the ratio

$$S_I^2 = (g_K - g_R)^2 \left[1+(-1)^{I+1/2}\, b_o\right]^2 / Q_o^2$$

(see table 3).

The levels at 23.33, 86.95 and 217.14 keV can be attributed to the Nilsson orbitals $7/2^{+}$[404], $7/2^{-}$[523] and $1/2^{-}$[541], respectively, by comparing them with the neighbouring Tm odd isotopes 9).

Table 3.
Calculated values of S_I^2 for states of the $1/2^{+}$[411] rotational band in ^{163}Tm and ^{165}Tm.

I	$100\ S_I^2$	
	^{163}Tm	^{165}Tm
3/2	6.45	9.4
5/2	4.2 ± 0.3	3.7 ± 0.7
9/2	-	6.4 ± 0.5

The half-life of the 86.95 keV level was measured to be $T_{1/2}$ =380±30 nsec and then the hindrance factor $F_{s.p.}$ = 1.1×10^{6} was deduced for the 63.62 keV E1 transition. It is most probable that the observed excited states of 136.70 ($3/2^{+}$) and 224.4 keV ($3/2^{+}$ or $5/2^{+}$), belong to the rotational band built on the Nilsson orbital $3/2^{+}$ 3/2 [411]. On the basis of low log ft value and from calculation of Gareev et al. 10) the structure of levels at 947.29 keV and 1833.48 keV could be interpreted as one-quasiparticle state $5/2^{-}$[532] and a three-quasiparticle state of the type

$5/2^{-}\{p\ 7/2^{-}[523],\ n\ 3/2^{-}[521],\ n\ 5/2^{-}[523]\}$,

respectively.

3.4 ^{165}Yb

The decay of 9.8 min ^{165}Yb has been studied. Nearly 140 γ-transitions were assigned surely and 15 tentatively to the decay of ^{165}Yb. In comparison with the results of ref.11) 34 new transitions were observed and 13 transitions were not confirmed. The transition energies determined in our measurements are more precise than those reported in ref. 11).

The multipolarity of the transitions with energy 11.56 keV - M1 +$\lesssim$ 0.1 % E2, 30.80 keV - E1, 68.86 keV - E2 and 80.11 keV - E1 +$\lesssim$ 0.2 % M2 were deduced from a comparison of the L-or M-subshell ratios of the conversion electron intensities with theoretical values. Relative intensities of K-conversion electrons, γ-rays and deduced multipolarity of transition are given in table 4.

Table 4.

Transition intensities and multipole orders. The decay of ^{165}Yb.

E_γ (keV)	I_K	I_γ	Multipole order
91.97	16	2.64	M1+E2
104.26	10	1.21	M1
118.06	45	18.4	E2,M1+E2
147.29	11	7.95	E2,M1+E2
156.51	2	1.05	M1
170.25	1.5	4.45	E1(E2)
185.88	2.5	4.45	E2
203.32	3	2.81	M1
232.61	0.5	1.87	E2
235.21	0.6	0.73	M1
275.53	0.2	1.50	E1
304.03	1.6	8.29	E2,M1+E2
320.68	0.2	1.70	E1,(E2)
332.30	0.2	1.00	E2,E1

The decay scheme in fig. 3 is based on the results obtained from γ-γ-coincidence measurements. We do not introduce levels 275.5 keV, 369.8 keV, 609.5 keV, 950.0 keV, 1100.5 keV, 1129.1 keV, 1352.6 keV and 1424.8 keV proposed in ref.11). New levels at 797.34 keV, 830.98 keV, 889.85 keV, 921.37 keV, 1790.40 keV, 1846.56 keV, 1919.40 keV and 2194.91 keV are placed in our decay scheme. Calculation of log ft values was performed using Q-value equal to 2.76 MeV obtained in ref. 12). The assignment of levels corresponding to the rotational bands above Nilsson states 1/2$^+$[411], 7/2$^+$[404], 7/2$^-$[523], 1/2$^-$[541], 5/2$^+$[402], and 3/2$^+$[411] was made following conclusions from ref. 11) and ref.13). The multipolarities of transitions deexciting the above mentioned levels confirm their spin-parity determination. The spins and parities for other levels were proposed provided that

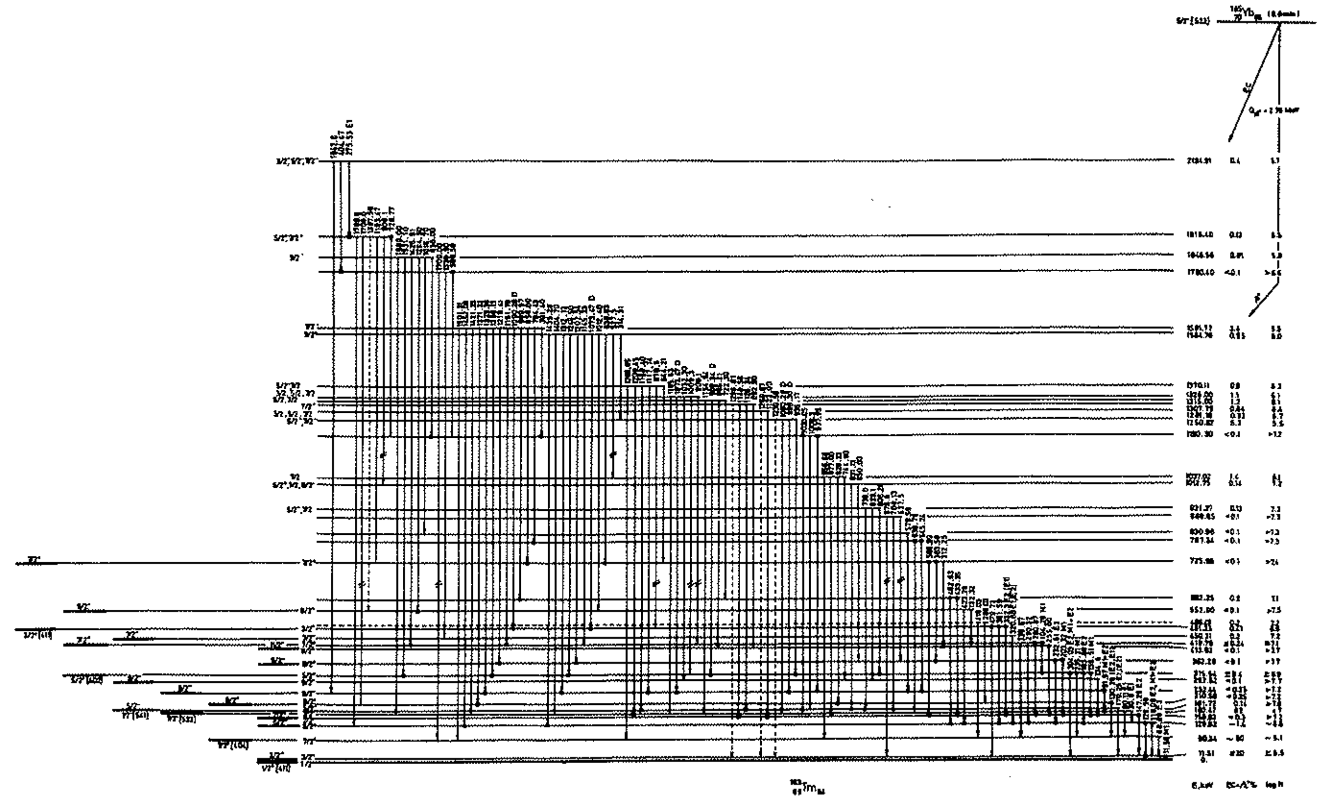

Fig. 3. The ^{165}Yb $\rightarrow$ ^{165}Tm decay scheme

unknown multipolarity of transitions can be M1 or E1 or E2. Next restrictions for spin and parity of levels follow from the range of log ft values. The interpretation of the levels situated above ~800 keV is rather complicated task and is in progress.

References

1) A.Latuszynski, K.Zuber, A.Potempa, J.Zuber W.Zuk, Preprint JINR, E6-7780, Dubna 1974

2) Z.Malek, G.Pfrepper Preprint JINR, 12 - 4013, Dubna 1968

3) M.Neiman, D.Ward, UCRL - 18667 (1968), p.59

4) F.W.N. de Boer, M.H.Cardoso, P.F.A.Goudsmit, P.Koldewijn, J.Konijn, B.J.Meijer CERN-70-30 (1970), p.939

5) G.Beyer, M.Honusek, H.U.Siebert, K.Zuber, J.Zuber, A.Latuszynski, I.Penev, A.Potempa, H.Strusny, M.Jachim Acta Physica Polonica vol.B6(1975),p.427

6) C.Ekström, M.Olsmats, B.Wannberg, Nucl.Phys. A170 (1971) 649

7) A.H.Wapstra, N.B.Gove, Nuclear Data Tables 9 (1971) nos 4,5

8) J.Adam, K.Ya.Gromov, M.Honusek, T.A.Islamov, A.Sh.Khamidov, V.V.Kuznetsov, H.G.Ortlepp, H.U.Siebert Nucl.Phys. A254 (1975) 63

9) K.Ya.Gromov, H.U.Siebert, V.G.Kalinnikov, G.Musiol, H.Strusny, Particles and Nuclei 6, no.4 (1975) 971

10) F.A.Gareev, V.G.Soloviev, S.I.Fedotov, Yad.Fiz. 14 (1971) 1165

11) T.Tamura, I.Rezanka, S.Iwata, J.O.Rasmussen, J.Alonso, Phys.Rev. C 8 (1973) 2425

12) P.Paris, J.Phys. (Paris), 28, (1967) 388

13) J.Gizon, A.Gizon, S.A.Hjorth, D.Barneoud, S.Andre, J.Treherne Nucl.Phys. A193 (1972) 193