Systematics of Absolute Gamma Ray Transition Probabilities in Deformed Odd-A Nuclei

S. G. Malmskog
SYSTEMATICS OF ABSOLUTE GAMMA RAY TRANSITION PROBABILITIES IN DEFORMED ODD-A NUCLEI

K.E.G. Löbner*, S.G. Malmskog

Abstract

All known experimentally determined absolute gamma ray transition probabilities between different intrinsic states of deformed odd-A nuclei in the rare earth region (153 ≤ A ≤ 181) and in the actinide region (A ≥ 227) are compared with theoretical transition probabilities (Weisskopf and Nilsson estimate). Systematic deviations from the theoretical values are found. Possible explanations for these deviations are given. This discussion includes Coriolis coupling, ΔK = ± 2 band-mixing effects and pairing interaction.

*) Present address:
Fysikalisches Institut der Universität, Freiburg im Breisgau, Germany.

Printed and distributed in November 1965
# LIST OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2. Compilation of experimental results</td>
<td>3</td>
</tr>
<tr>
<td>3. Results and Discussion</td>
<td>5</td>
</tr>
<tr>
<td>3.1 Electric dipole transitions</td>
<td>5</td>
</tr>
<tr>
<td>3.2 Electric quadrupole transitions</td>
<td>11</td>
</tr>
<tr>
<td>3.3 Electric octupole transitions</td>
<td>14</td>
</tr>
<tr>
<td>3.4 Magnetic dipole transitions</td>
<td>14</td>
</tr>
<tr>
<td>3.5 Magnetic quadrupole transitions</td>
<td>15</td>
</tr>
<tr>
<td>3.6 Magnetic octupole transitions</td>
<td>17</td>
</tr>
<tr>
<td>3.7 K-forbidden transitions</td>
<td>17</td>
</tr>
<tr>
<td>4. Acknowledgements</td>
<td>19</td>
</tr>
<tr>
<td>References</td>
<td>20</td>
</tr>
<tr>
<td>Tables</td>
<td></td>
</tr>
<tr>
<td>Figures</td>
<td></td>
</tr>
</tbody>
</table>
1. Introduction

The comparison of experimentally determined absolute gamma ray transition probabilities between nuclear states with theoretical predictions is one of the most fruitful methods for testing nuclear models, because the gamma matrix elements depend on the amplitudes and phases of the wave functions of the states involved.

Usually experimentally determined gamma ray transition probabilities are compared with the single particle estimate calculated by Weisskopf [We 52] or Moszkowski [Mo 55], even in cases where it is known that the assumptions underlaying these calculations do not apply to the transition probabilities to be analysed. This is done since these easily calculated transition probabilities form a convenient basis for comparison. This practice is also employed for deformed odd-A nuclei although, for the latter, the gamma ray transition probabilities can be calculated with the Nilsson model [Ni 55], which is able to describe many properties of the deformed odd-A nuclei with fair accuracy [Mo 59]. For deformed odd-A nuclei one has to distinguish between gamma ray transitions within a rotational band and those between different intrinsic states. The collective E2 gamma ray transitions between rotational states are not affected by the nuclear structure in first approximation; the transition matrix element can be expressed in terms of the static quadrupole moment and the theoretical data are in good agreement with experimental results. The M1 transitions within a rotational band, however, are affected by the intrinsic structure through the gK-values. Gamma ray transition probabilities between different intrinsic states depend on the amplitudes and phases of the wave functions of the two intrinsic states involved. Therefore the comparison of experimentally determined gamma ray transition probabilities of this type with theoretically calculated ones is a very sensitive and specific test for the Nilsson model. Details of the theory and usually used notations can be found in the original and in review papers [Ni 55], [Mo 57], [Mo 59], [Na 65]. Several authors confronted experimentally determined transition probabilities with the Nilsson model. Gnedin [Gn 61] did so in 1961 for all multipolarities, but because only very few absolute transition probabilities were known at that time no systematic behaviour could be deduced. D.R. Bès [Be 58] analysed the E1, E2 and M1 transi-
tions in $^{161}$ Dy and D. Bogdan [Bo 60] the E2 transitions in $^{153}$ Eu and $^{181}$ Ta. Several comparisons were made for E1 transitions, e.g. by D. Strominger and J.O. Rasmussen for some odd-proton nuclei in the actinide region [St 57], by I. Dutt and P. Mukherjee (in $^{153}$ Eu, $^{169}$ Tm, $^{175}$ Lu and $^{237}$ Np) [Du 59], by U. Hauser et al. (in $^{177}$ Hf, $^{175}$ Lu, $^{177}$ Lu and $^{181}$ Ta) [Hau 61a], by E.E. Berlovič et al. (in $^{173}$ Yb, $^{175}$ Lu and $^{177}$ Hf) [Be 62a], by G.A. Vartapetyan et al. (in $^{159}$ Tb and $^{173}$ Yb) [Va 61], by K.E.G. Löbner (in $^{179}$ Ta, $^{167}$ Tm, $^{161}$ Tb, $^{177}$ Yb and $^{179}$ Hf) [Lö 64b] [Lö 64c] and by S.G. Malmskog (in $^{155}$ Eu, $^{161}$ Tb, $^{177}$ Yb and $^{179}$ Hf) [Ma 65a] [Ma 65b].

The most extensive study for E1 transitions was made by Vergnes [Ve 62]. This author pointed out that there exist two well-defined groups:
a) for E1 transitions with $\Delta K = 0$ the measured transition probabilities are in agreement with theory and
b) for E1 transitions with $\Delta K = 1$ the experimentally determined transitions are delayed in comparison with the theoretical values. This delay is shown to be a smooth function of $A$. In order to confirm this trend for the E1 transition probabilities and to find perhaps similar deviations for transitions of different multipolarity, it is of general interest to measure transition probabilities between different intrinsic states of deformed odd-$A$ nuclei. On the basis of such systematic deviations from the theoretical predictions the nuclear model can perhaps be extended or refined. Very recently such a comparison was made of the known E1, E2, E3, M1, M2 and M3 transitions probabilities between different intrinsic states of deformed odd-$A$ nuclei in the rare earth region [Lö 65a]. In the present investigation known gamma ray transition probabilities in the actinide region as well are included. These transition probabilities obtained from half-life measurements, Coulomb excitation and resonance fluorescence have been compared with the theoretical transition probabilities (Weisskopf and Nilsson estimate), taking into account branching ratios, mixing ratios and total conversion coefficients selected from the recent literature (see tables I and II).

The theoretical transition probabilities calculated on the bases of the Nilsson model were obtained by using pure Nilsson states without mixing. However, mixing of states does occur, as can be deduced, for example, from the existence of K-forbidden gamma transitions. A first attempt to obtain quantitative results of such mixing was made by Kerman
[Ke 56], who introduced rotation particle coupling in the case of $^{183}$W. Very recently A. Faessler [Fa 64] started a more general study of the influence of mixing of states and analysed the three rather simple level schemes of $^{153}$Eu, $^{161}$Dy and $^{185}$Re. Substantial improvement was obtained for the analysed E2 transition probabilities with $\Delta K = 1$ [Fa 65].

In the present investigation the theoretical transition probabilities were calculated assuming pure Nilsson states, because calculations with mixing of states as performed by Faessler [Fa 64] are only possible with a computer and must be calculated for each nucleus individually. Therefore the present work may be considered as a guide for identification of the gamma ray transition probabilities which would be of most interest in conjunction with mixing of Nilsson states or with other refinements of the Nilsson model. On the other hand we hope that these systematics may also be a stimulation for experimentalists to measure additional absolute gamma ray transition probabilities. Especially measurements on transitions between the same intrinsic states in different nuclei are of great interest.

2. Compilation of experimental results

Tables I and II show the known experimental half-lives, transition energies and partial gamma ray and conversion line intensities derived from experimental data such as branching ratios, mixing ratios and conversion coefficients, from which the absolute gamma ray transition probabilities between different intrinsic states of deformed odd-A nuclei in the rare earth ($153 \leq A \leq 181$) and actinide regions ($A \geq 227$) have been deduced. Conversely, the experimental values for the quantities used for calculation of the partial gamma ray half-lives can be found from the tables; e.g. the mixing ratio $\delta^2$ can be deduced by dividing the two given relative gamma ray intensities such as $N_Y(E2)/N_Y(M1)$ of the same transition, while the total conversion coefficients for each multipolarity and each transition can be obtained by dividing the "relat. $N_e"$ by the "relat. $N_\gamma". Giving the "relat. $N_\gamma" and "relat. $N_e" has the advantage that the partial gamma ray half-life given in column 9 of tables I and II can very easily be obtained from

$$T_{1/2\gamma}(\text{exp}) = \frac{T_{1/2}(\text{level}) \sum N}{N_\gamma}$$

(1)
where $\Sigma N$ is the sum of all the relative intensities of the transitions depopulating the level and $N_{\gamma}$ is the "relat. N." for which $T_{1/2\gamma}(\text{exp})$ is calculated.

The symbols $F_W$ and $F_N$ are hindrance factors calculated relative to the theoretical single particle Weisskopf estimate

$$F_W = \frac{T_{1/2\gamma}(\text{exp})}{T_{1/2\gamma}(\text{Weisskopf})} \tag{2}$$

and the Nilsson estimate

$$F_N = \frac{T_{1/2\gamma}(\text{exp})}{T_{1/2\gamma}(\text{Nilsson})} \tag{3}$$

To obtain the Weisskopf estimate a nuclear radius constant of 1.2 fm and a statistical factor $S = 1$ are used [Wa 59]. For the calculations of the theoretical transition probabilities with the Nilsson model the formulae (35) and (36) of ref. [Ni 55] were used. The amplitudes of the eigenfunctions were chosen in accordance with the recommendations of Mottelson and Nilsson [Mo 59]. In the rare earth region the eigenfunctions with $\mu = 0.55$ for $N = 4$ and $\mu = 0.45$ for $N = 5$ and $N = 6$ were used. In the actinide region the theoretical transition probabilities were calculated using the eigenfunctions with $\mu = 0.70$ for $N = 5$ (odd-proton nuclei), $\mu = 0.45$ for $N = 6$ and $\mu = 0.40$ for $N = 7$ (odd-neutron nuclei). The deformation parameters $\gamma$ were deduced from Coulomb excitation data or interpolated from neighbouring odd-$A$ nuclei. For most of the transitions the transition probability does not change very much with deformation. If this is the case, it is mentioned in the remarks following tables I and II.

For the calculation of the theoretical magnetic transition probabilities the g-factors for the free proton and neutron

$$g_s = 5.585 \text{ and } g_L = 1 \text{ for proton transitions and}$$

$$g_s = -3.825 \text{ and } g_L = 0 \text{ for neutron transitions}$$

and effective $g_s$-factors were used.
Unless otherwise mentioned no effective charge corrections were taken into account.

The numerical values of the Clebsch-Gordan coefficients were obtained from the tables of the 3-j symbols by Rotenberg et al. [Ro 59].

The value "f" gives an estimate of the accuracy of the values \( F_W \) and \( F_N \). If the errors are symmetric one value "f" is given: multiplying and dividing the values of \( F_W \) and \( F_N \) by the factor "f" yields the estimated limits of the hindrance factors \( F_W \) and \( F_N \). If two values are given, the estimated limits of \( F_W \) and \( F_N \) are obtained by multiplying by the two values, respectively. The value "f" does not include uncertainties introduced from theory like deformation, effective charge, effective \( g_s \)-factors and \( g_R \)-factors, but it includes errors in the transition energy in addition to the errors in the partial half-life \( T_{1/2} \gamma \) for a certain multipolarity.

Sources for the experimental data used here are given in the column "references". The hindrance factors for the El transitions agree well with those calculated by Vergnes [Ve 62] and the theoretical transition probabilities of the M1 and E2 transitions with those reported by Faessler [Fa 64].

3. Results and Discussion

3.1 Electric Dipole Transitions

The comparison of the experimentally determined El gamma ray transition probabilities with the single particle Weisskopf estimate results in hindrance factors of \( F_W \approx 6 \times 10^2 \) to \( \approx 10 \). The hindrance factors \( F_N \) relative to the Nilsson estimate for the electric dipole transitions are given for \( \Delta K = 0 \) in fig. 1 and for \( \Delta K = 1 \) in fig. 2 as a function of the mass number. From these two figures the following properties can be deduced:

1) Several El transition probabilities with \( \Delta K = 0 \) are in agreement within a factor of 10 with the values theoretically calculated with the Nilsson model, which can be considered to be satisfactory. The enhancement of the 5/2 5/2\(^-\) [532] to the 5/2 5/2\(^+\) [413] and 7/2 5/2\(^+\) [413] transitions in \(^{153}\)Eu and \(^{155}\)Eu has been shown
to be due to the fact that the initial and final states of these transitions have different deformation [Ha 64] [Ma 65b]. The \( F_N \)-values of the \( 5/2^-[523] \leftrightarrow 5/2^+[642] \) transitions in \(^{237}\text{Np} \), \(^{239}\text{Np} \) and \(^{243}\text{Am} \) are found to be very small. The theoretically calculated \( G^2_{E1} \)-values (see formula 35 of ref. [Ni 55]) for these transitions are very low (at least a factor 100 lower than the other \( G^2_{E1} \)-values calculated for the present investigation). Therefore it may be expected that small admixtures from other states in this case will change the transition probabilities considerably. The large difference of the hindrance factors for the \( 7/2^-[523] \rightarrow 7/2^+[521] \) transitions in \(^{167}\text{Tm} \) and \(^{169}\text{Tm} \) cannot be explained as due to pairing interaction; these are proton-transitions and the nuclei only differ by two neutrons (see discussion on \( E1 \) transitions with \( \Delta K = 1 \)).

2) The transition probabilities of \( E1 \) transitions with \( \Delta K = \pm 1 \) to the ground state of the intrinsic state (type A, see caption of fig. 1) are delayed in comparison with the predictions of the Nilsson model. In contrast to the conclusion made by Vergnes from the data known in 1962 [Ve 62] this delay is not a smooth function of the mass number \( A \). Even for transitions between the same intrinsic states of different nuclei the hindrance factors change very rapidly for certain odd-neutron transitions as was first pointed out by Löbner [Lö 64b] [Lö 65a]. We have for

a) \( 5/2^-[642] \leftrightarrow 3/2^-[521] \) : \( F_N = 3.8 \pm 0.4 \); \( 920^{+180}_{-460} \);

\[ 28^{+14}_{-9} \text{ in } 155 \text{Gd}; 157 \text{Gd}; 161 \text{Dy} \] respectively.

b) \( 7/2^-[633] \leftrightarrow 5/2^-[512] \) : \( F_N = 36 \pm 4 \); \( 180 \pm 36 \);

\[ 880^{+440}_{-90} \text{ in } 169 \text{Yb}; 171 \text{Yb}; 173 \text{Yb}; 175 \text{Hf} \] respectively.

c) \( 7/2^-[514] \leftrightarrow 9/2^-[624] \) : \( F_N = 3000^{+3000}_{-1500} \); \( 8.0 \pm 1.0 \);

\[ 16 \pm 4 \text{ in } 177 \text{Hf}; 177 \text{Yb}; 179 \text{Hf} \] respectively.
The hindrance factors of the odd-proton $9/2^+ [514] \rightarrow 7/2^+ [404]$ transitions can be considered as a somewhat smooth behaviour as a function of the mass number: $F_N = 165 \pm 33; 207 \pm 48; 77 \pm 23; 25 \pm 6$ in $^{175}$Lu; $^{177}$Lu; $^{179}$Ta; $^{181}$Ta respectively.

3) The transition probabilities of $E1$ transitions with $\Delta K = \pm 1$ to rotational states ($I_f = K_f + 1, K_f + 2$; type B and C, see caption of fig. 1) are less delayed than the transitions to the ground state ($I_f = K_f$, type A) of the same intrinsic state; the higher the spin of the rotational state the less is the retardation of the transitions. The only exceptions found until now are for the transitions between the $5/2^- [532]$ and the $7/2, 5/2$ and $3/2^- [411]$ states in $^{155}$Tb, $^{157}$Tb and $^{159}$Tb. The absolute transition probabilities have only been determined for the transitions in $^{159}$Tb, but the relative gamma intensities in $^{155}$Tb and $^{157}$Tb show similar jumps to those in $^{159}$Tb [To 61].

Deviations of the experimentally determined gamma ray transition probabilities from the theoretical values calculated with the Nilsson model can, however, be expected for electric transitions. Due to pairing interaction the gamma ray transition probabilities are modified. This modification can be expressed by a pairing factor $P$ for single particle transitions. The theoretical half-life for a single particle transition with pairing interaction $T_{1/2}^{(p)}$ is the single particle half-life $T_{1/2}$ without pairing interaction divided by the pairing factor $P$: $T_{1/2}^{(p)} = \frac{1}{P} T_{1/2}$. When the number of particles in paired states is not changed the following relations are valid [Ki 60], [Na 65]:

$$ P = (U_f U_i^* - V_f V_i^*)^2 \text{ for electric transitions} \quad (4) $$

and

$$ P = (U_f U_i^* + V_f V_i^*)^2 \text{ for magnetic transitions} \quad (5) $$

$U_i$ and $V_i$ are the probability amplitudes for the state $i$ (or $f$) being unoccupied or occupied by a pair of particles, respectively, while $i$ and $f$ denote the initial and final state of the gamma ray transition.
For levels near the Fermi surface $U_i^2$ and $V_i^2$ are $\approx 0.5$, resulting in a delay for electric transitions, because the pairing factor becomes a small value. For magnetic transitions $P$ becomes $\approx 1$, therefore the pairing interaction is expected to cause no essential modification for magnetic transitions.

Inserting the definitions [Na 65]

\[
U_i^2(f) = \frac{1}{2} \left[ 1 + \frac{\varepsilon_i(f) - \lambda}{E_i(f)} \right]  
\]

(6)

\[
V_i^2(f) = \frac{1}{2} \left[ 1 - \frac{\varepsilon_i(f) - \lambda}{E_i(f)} \right]  
\]

(7)

with

\[
E_i(f) = \sqrt{(\varepsilon_i(f) - \lambda)^2 + \Delta_i^2}  
\]

(8)

in formula (4) and making the assumption that $\Delta_i = \Delta_f = \Delta$, the following expression for the pairing factor is obtained:

\[
P = \frac{1}{2} \left[ 1 + \frac{(\varepsilon_i - \lambda)(\varepsilon_f - \lambda) - \Delta^2}{E_i E_f} \right]  
\]

(9)

To see how this pairing factor will influence the reduced electric dipole gamma ray transition probabilities a calculation with the following two simplifying assumptions were made:

a) The energy difference between adjacent single particle states is equal to 400 keV, and that

b) the Fermi surface will increase 400 keV on addition of 2 protons to an odd-proton nucleus or of 2 neutrons to an odd-neutron nucleus.

Three cases were calculated, all with $\Delta = 800$ keV:

a) the Fermi surface lies exactly between the intrinsic levels,
b) the Fermi surface lies 100 keV above the intrinsic levels, and
c) the Fermi surface is identical with the single particle levels.

In fig. 3 the different values of $\frac{1}{P}$ are given as a function of the neutron or proton number calculated on the above assumptions. This figure indicates that the sudden change of the hindrance factors $F_N$ of the E1, $\Delta K = \pm 1$ transitions between the same intrinsic states in different nuclei may be explainable by pairing interaction. The $5/2^- \leftrightarrow 3/2^-$ [521] E1 transitions reproduce this tendency of the hindrance factors quite well. In $^{155}\text{Gd}$ the Fermi surface probably lies below the final state, in $^{157}\text{Gd}$ between the initial and final state and in $^{161}\text{Dy}$ above the initial state.

The change of the hindrance factors $F_N$ of the E1 transitions $5/2^- \leftrightarrow 7/2^+$ [633] are not so easily explainable. The increase of the $F_N$ values for the E1 transitions in the three Yb isotopes ($^{169}\text{Yb}$, $^{171}\text{Yb}$ and $^{173}\text{Yb}$) could be caused by pairing interaction, but one would expect that the hindrance factors of the E1 neutron transitions in $^{173}\text{Yb}$ and $^{175}\text{Hf}$ would be about the same because the neutron number is the same in these two nuclei. Perhaps specific correlation effects, which are responsible for the creation of the giant resonance state and which may exhaust most of the E1 oscillator strength, are responsible for this irregularity [Na 65].

The hindrance factors of the E1 neutron transitions $7/2^- \leftrightarrow 9/2^+$ [624] in $^{177}\text{Hf}$ and $^{177}\text{Yb}$ and $^{179}\text{Hf}$ can be explained as being caused by pairing interaction. The interpretation may then be that in $^{177}\text{Hf}$ the Fermi surface lies between the initial and final states and in $^{177}\text{Yb}$ and $^{179}\text{Hf}$ above the initial state.

The hindrance factors of the proton transition $9/2^- \leftrightarrow 7/2^+$ [514] in $^{175}\text{Lu}$ and $^{177}\text{Lu}$ should be about the same because the proton number does not change. This is also the case for the transitions in $^{179}\text{Ta}$ and $^{181}\text{Ta}$, which is unreasonable agreement with the experimental values. Not very much more can be said about the difference of the hindrance factor between the E1 transitions in Lu and Ta, because the relative position of the two intrinsic states interchanges.

Several authors who recently made calculations to obtain numerical values for the pairing factor $P$ [Gr 61], [Mo 64a], [Mo 64b], [Ve 65],
[Ma 65a] did not find this large difference of the reduced transition probabilities because their approximations were too rough. According to these calculations the pairing interaction results in a retardation for all El transitions with $\Delta K = 0$ and $\Delta K = 1$ of about the same amount.

Another possible explanation of the disagreement of the experimentally determined El transition probabilities from the theoretical values calculated with the Nilsson model is that mixing of Nilsson states has not been taken into account. Calculations of the theoretical El transition probabilities using the Nilsson model show that selection rules forbid combination of the large components of the wave functions of initial and final states. Also the contributions of the small components to the El matrix elements tend to cancel one another out. The transition probabilities of El transitions may therefore be very sensitive to small admixtures of the Nilsson states. For rotational states the admixture from the Coriolis interaction is expected to be larger than for the corresponding ground state, which may be the explanation of the differences of the $F_N$-values for transitions of type A, B, C, D and E respectively [Be 64] [Ve 65] [Gr 65].

Very recently the following explanation for the difference of the El transitions with $\Delta K = 0$ and $\Delta K = 1$ was suggested by Faessler [Fa 65] and independently by Monsonego and Piepenbring [Mo 65]: Octupole vibrations and octupole quasiparticle interaction is taken into account. The difference for the transition probabilities of the El transitions with $\Delta K = 0$ and $\Delta K = 1$ is probably caused by the low-lying $K - \Omega = 0$ octupole vibrational band. This band will influence the transition probabilities of El transitions with $\Delta K = 0$ through mixing by particle-vibrational interaction. The El, $\Delta K = 1$ transition probabilities can only be changed by the octupole vibrational band with $K = \Omega \pm 1$. This band lies energetically much higher and has a smaller collective strength in comparison with the $K - \Omega = 0$ octupole vibrational band, therefore it can be expected that the El transitions with $\Delta K = 1$ are not very much affected by the octupole vibrational bands [Fa 65].

Monsonego and Piepenbring [Mo 65] obtained good agreement for the known El, $\Delta K = 0$ transitions in the odd-A deformed nuclei of the rare earth region by taking into account pairing interaction and octupole vibrational interaction.
M R Piepenbring [Pi 64] has also studied the influence of mixing between states with $\Delta N = \pm 2$ on E1 transition probabilities. A small improvement is obtained by this author relative to the calculations without such mixing. The large difference in the reduced transition probabilities of E1, $\Delta K = 1$ transitions between the same intrinsic states in different nuclei can, however, not be explained by such effects.

3.2 Electric Quadrupole Transitions

Although few absolute E2 transition probabilities between different intrinsic states have been determined until now, there are probably two groups of E2 transitions:

a) E2 transitions with $\Delta K = 1$ and
b) E2 transitions with $\Delta K = 2$.

a) The hindrance factors for the analysed E2 transitions with $\Delta K = 1$ in comparison with the single particle Weisskopf estimate lie between 0.08 and 57.

In comparison with the Nilsson estimate the E2, $\Delta K = 1$ transitions are enhanced by factors $1/F_N \approx 10^2$ to $\approx 10^5$. The hindrance factors $F_N$ for E2, $\Delta K = 1$ gamma ray transitions are shown in fig. 4 as a function of the mass number $A$. The considerable enhancement may be caused by mixing of states, as can be deduced from the recent calculations by A Faessler [Fa 64] [Fa 65].

The basic assumptions of the calculations by Faessler are the same as in the Nilsson model; Faessler uses the eigenvalues of the Nilsson model, but employs a rotating and vibrating core with rotation and vibration interaction. Movement of the odd-particle in this potential yields the following coupling terms: rotation-particle, vibration-particle, rotation-vibration and rotation-vibration-particle; they are obtained by an exact diagonalisation of this Hamiltonian. These terms mix states.

Faessler calculated this effect and the E2 transition probabilities including mixing of the two rotational bands (between which the "single-particle" transition takes place) and mixing with the $\beta$- and $\gamma$-vibrational bands for the known E2, $\Delta K = 1$ transitions in the odd-$A$ deformed nuclei of the rare earth region. In table III the hindrance factors
\( F_w, F_N \) and \( F_F \), (ratio of the experimentally determined half-life to the theoretical values calculated with the Weisskopf estimate, with the pure Nilsson model without mixing of states and with the calculations by Faessler including mixing of states) are given for these transitions. The closeness to unity of the values \( F_F \) are a measure of the success of Faessler's calculations. Taking into account pairing interaction probably yields a still better agreement with the experimental values.

In fig. 5 the hindrance factors \( F_N \) for \( \Delta K = 1 \) transitions are shown as a function of \( \frac{\Delta E}{A_K \sqrt{(I-K_i)(I+K_i)}} \) (\( K_i \) denotes the smaller and \( K_f \) the larger value of \( K_i \) and \( K_f \) respectively). Here \( \Delta E \) is the energy difference between the two states with the same total angular momentum \( I \), which may mix the two rotational bands involved in the \( \Delta K = 1 \) gamma ray transitions; e.g. for the \( \Delta K = 1 \) transition in \( ^{153}\text{Eu} \) \( \frac{3}{2}^+ \rightarrow \frac{5}{2}^+ \) \([411] \rightarrow 5/2 5/2^+[413] \) the \( 5/2 3/2^+[411] \) may mix with the \( 5/2 5/2^+[413] \) state and \( A_K \sqrt{(I-K_i)(I+K_i)} \) is a measure of the strength of the Coriolis coupling where \( A_K = \frac{h}{2J} \langle K | j- | K+1 \rangle \) \([Ke 56]\). The values of \( \langle K | j- | K+1 \rangle \) are taken from \([Ni 64]\). If there were no other mixing, the transition amplitude for the \( \Delta K = 1 \) transition could be written as a sum of the single particle transition amplitude and the collective part \( \frac{3}{2}^+ \rightarrow 5/2 3/2^+[411] \) with an amplitude corresponding to the admixture.

From fig. 5 it may be deduced that mixing of the two Nilsson states involved in the gamma ray transition is not the only important part for the transition probability; otherwise one would expect the hindrance factor to depend on the given parameter.

From the calculations by Faessler \([Fa 64]\) \([Fa 65]\) it follows that, besides mixing of the two intrinsic states involved in the \( \Delta K = 1 \) gamma ray transition under consideration, mixing with the \( \beta \)- and \( \gamma \)-vibrational band are important for the \( \Delta K = 1 \), \( \Delta K = 2 \) gamma ray transition probability. Mixing with other intrinsic states may be expected to have a small influence on the \( \Delta K = 1 \) transition probability since these admixtures will only yield transition probabilities with single particle strength.

b) The hindrance factors for the \( \Delta K = 2 \) transitions are given in table IV.

In fig. 6 the hindrance factors \( F_N \) of the \( \Delta K = 2 \) transitions are shown as a function of the energy difference between the \( 5/2 5/2^+ \) and
5/2 1/2 states, since these states with the same total angular momentum may mix. For the \( 3/2 \ 1/2 [530] \rightarrow 7/2 \ 5/2 [523] \) transition in \( ^{237}_{93}\text{Np} \) the energy difference between the \( 7/2 \ 1/2 [530] \) and the \( 7/2 \ 5/2 [523] \) level must be used. This figure seems to indicate the existence of this mixing depending on the energy difference of the two mixing states with \( \Delta K = 2 \). The same change of the hindrance factor of the E2, \( \Delta K = 2 \) transitions as a function of this energy difference could be caused by second order Coriolis interaction, but the amplitudes for this process are too small to account for the measured transition probabilities. Very recently Rowe \([Ro 65]\) made an attempt to find out whether the \( \Delta K = \pm 2 \) bandmixing interactions play any part in the mixing of rotational bands in \(^{183}_{\text{W}}\). This author could not decide whether such a direct mixing exists, because the absolute gamma ray transition probabilities between the intrinsic states which differ by \( \Delta K = \pm 2 \) have not yet been experimentally determined. Faessler \([Fa 64]\) obtained from his calculations terms which mix Nilsson states with \( \Delta K = 2 \). The transitions in \(^{173}_{\text{Yb}}, \ 175_{\text{Hf}} \) and \(^{181}_{\text{Ta}}\) are probably single particle transitions; mixing of the states with \( \Delta K = 2 \) is probably very slight due to the large energy difference of these states in those nuclei.

According to Kisslinger and Sorensen \([Ki 60]\) one has to use effective charges (caused by polarisation) for the calculations of the theoretical E2 single particle transition probabilities. These authors give the following effective charges:

\[
eff_p = 2 \ e_p \quad \text{for proton transitions}
\]

\[
eff_n = 1 \ e_p \quad \text{for neutron transitions}
\]

where \( e_p \) is the charge of a proton.

This effective charge correction enhances the theoretical transition probability for the odd-proton transitions by a factor of four. The retardation of the E2, \( \Delta K = 2 \) transitions in \(^{173}_{\text{Yb}}, \ 175_{\text{Hf}} \) and \(^{181}_{\text{Ta}}\) may perhaps qualitatively be explained as being caused by pairing interaction (see the discussion about E1 transitions).

Another explanation of the hindrance factors \( F_N \) might be the following. For the transitions for which the distance of the mixing states is very large, mixing with the \( \gamma \)-vibrational band of the ground state may be
important. If the phases of the single particle transition amplitude and the amplitude of the collective transition (from mixing with the $\gamma$-vibrational state) were to have opposite signs, the hindrance of the E2 transition could be caused by this admixture.

### 3.3 Electric octupole transitions

The absolute transition probabilities for eight E3 transitions of deformed odd-A nuclei with $\Delta K = 3$ are known. A comparison with the Nilsson estimate is given in fig. 7. In the case of the E3 transition probabilities with $\Delta K = 2$ these are rather uncertain, because the mixing ratio E3/M2 is not well known. 4 cases of the latter transitions are known and are compared with the Nilsson estimate in the same fig. 7. All calculations have been performed without effective charge corrections.

From fig. 7 it seems likely that there are two groups of E3 transitions:

a) E3-transition probabilities between states with $\Delta K = 3$ which are in reasonable agreement with the theoretical predictions of the Nilsson model and

b) E3-transition probabilities with $\Delta K = 2$ which are probably enhanced.

### 3.4 Magnetic dipole transitions

Comparison of the experimentally determined M1 transition probabilities between different intrinsic states with the single particle Weisskopf estimate results in hindrance factors $F_W$ between 70 and $2.6 \times 10^5$.

The hindrance factors $F_N$ in comparison with the Nilsson model are given in table V for the proton transitions and in table VI for neutron transitions, using different $g_R$-values and calculating the theoretical transition probabilities with $g_S$-values of the free proton and neutron and with effective spin g-factors. The effective spin g-factors ($g_{S_{(eff)}}$) are taken from a compilation of de Boer and Rogers [Boe 63a]. The first value of $g_R$ in table V and table VI for each transition and each nucleus corresponds to the $g_R$-value obtained by Rogers [Ro 64] for the ground state configuration derived from magnetic dipole moments and transition probabilities. The other two values of $g_R$ are arbitrarily chosen to show how the transition probability changes as a function of $g_R$. 
It is not clear at the moment how to explain the large hindrance factors for the proton transition $\frac{5}{2} - \frac{7}{2}$ in $^{181}$Ta and the neutron transition in $^{155}$Gd: $\frac{5}{2} - \frac{3}{2}$ in $^{181}$Ta by a factor of about 1000 is unexpected. Also the absolute E2 transition probability between the same intrinsic states in $^{175}$Lu and $^{181}$Ta is much lower than in $^{175}$Lu (fig. 5). A third unusual fact is that the relative position of the $\frac{7}{2} - \frac{7}{2}$ states interchanges when two protons are added to the Lu nuclei. ($\frac{7}{2} - \frac{7}{2}$ is the ground state of the Lu and Ta isotopes, see table 3a of ref. [Na 65].) The E2 transition probability in $^{155}$Gd between the $\frac{5}{2} - \frac{5}{2}$ states is also lower than one would expect (fig. 5). Probably other admixtures besides the $\frac{5}{2} - \frac{5}{2}$ state are important.

From the calculations by Faessler [Fa 64], which explain the enhancement of E2 transitions with $\Delta K = 1$, no improvement for the MI transitions can be deduced at the moment. Faessler used $g_R = 0.31$ for calculating the MI transition probability of the $\frac{3}{2} - \frac{5}{2}$ transition in $^{153}$Eu. For this $g_R$-value the MI gamma matrix element vanishes according to our calculations, for a certain deformation between $\hbar = 4$ and $\hbar = 6$ calculating with pure Nilsson states. It is not known whether this is also the case for the calculations with mixing of states; the theoretical transition probability cannot be obtained by interpolating between the values for $\hbar = 4$ and $\hbar = 6$, which are tabulated by Faessler, and therefore a comparison with the experimental value is not possible. The transition probability calculated for the MI transition $\frac{3}{2} - \frac{5}{2}$ in $^{161}$Dy with mixing of intrinsic states according to the theory of Faessler is in good agreement with the experimental value, but this is also the case for the theoretical value calculated without mixing of Nilsson states (see table VI).

### 3.5 Magnetic quadrupole transitions

The hindrance factors $F_N$ of M2 transitions are shown in fig. 8 as a function of the mass number $A$. The $\Delta K = 1$, M2 transition probabilities are in rather good agreement with the theoretical predictions as well with the single particle Weisskopf estimate as with the calculations

---

This is deduced from the fact that $G_{M1}$ differs in sign for $\hbar = 4$ and $\hbar = 6$ (see formula 36 of ref. [Ni 55]).
of the Nilsson model, although the uncertainties of the experimentally
determined absolute transition probabilities are fairly large. These M2
transitions with ΔK = 1 compete with E1 transitions. The mixing ratio
δ^2 = M2/ΔK = 1 can for most of the cases only be deduced from experi-
mentally determined relative conversion electron intensities or from
measured conversion coefficients. Delayed E1 transitions are known
to show anomalous intensity ratios of the internal conversion electrons,
which cannot be explained as due to M2 admixture only, but must be
caused by penetration matrix elements [Ni 58], [Kr 62], [Ew 63].
Therefore for most of the analysed transitions the intensities of the
M2 admixtures between states with ΔK = 1 are uncertain.

For the ΔK = 2, M2 transitions the following hindrance factors
were obtained:

For the proton transitions:

\begin{align*}
3/2^+ & \rightarrow 7/2^- \ (165\text{Ho}) \quad F_W = 14 \pm 3; \quad F_N = \\
= & 0.28 \pm 0.04 \\
5/2^+ & \rightarrow 9/2^- \ (181\text{Ta}) \quad F_W = 93 \pm 47; \quad F_N = 1.8 \pm 0.9 \\
3/2^- & \rightarrow 7/2^- \ (237\text{Np}) \quad F_W = 21 \pm 20; \quad F_N = \\
= & (5 \pm 5) \cdot 10^{-2}
\end{align*}

and for the neutron transition:

\begin{align*}
5/2^- & \rightarrow 9/2^- \ (181\text{W}) \quad F_W = 190 \pm 60; \quad F_N = 50 \pm 20
\end{align*}

Calculating the theoretical transition probability of the M2, ΔK = 2
transition in the odd-neutron nucleus \(^{181}\text{W}\) with the Nilsson model, using
an effective \(g_s\) -factor \(g_s^{(\text{eff})} = 0.6 \ g_s^{(\text{free})}\) (see chapter 3.4), reduces
the hindrance factor \(F_N\) by a factor of 0.6, yielding \(F_N^{(\text{eff})} = 30 \pm 12\).
The theoretical transition probabilities of the M2, ΔK = 2 transitions in
the odd-proton nuclei \(^{165}\text{Ho}\) and \(^{181}\text{Ta}\) change very rapidly with deforma-
tion if effective \(g_s\) -factors are used instead of the \(g_s\) -values of the free
proton for the calculations.
3.6 Magnetic octupole transitions

The following hindrance factors were obtained for M3, \( \Delta K = 3 \) transitions:

For the \( \frac{1}{2}^+ \frac{1}{2}^+[411] \rightarrow 7/2^+ 7/2^+[404] \) proton transition

\[
\text{in } ^{181}\text{Ta: } F_W = 3.6 \pm 0.6 \quad \text{and} \quad F_N = 0.02 \pm 0.02 \quad -0.01
\]

for the \( \frac{1}{2}^+ \frac{1}{2}^-[510] \rightarrow 7/2^- 7/2^-[514] \) neutron transition

\[
\text{in } ^{175}\text{Yb: } F_W = 11 \pm 1; \quad F_N = 0.9 \pm 0.1
\]

\[
\text{in } ^{177}\text{Yb: } F_W = 25 \pm 8; \quad F_N = 2.0 \pm 0.6
\]

\[
\text{in } ^{179}\text{Hf: } F_W = 29 \pm 6; \quad F_N = 2.6 \pm 0.6 \quad \text{and}
\]

\[
\text{in } ^{179}\text{W: } F_W = (1.4 \pm 0.3) \times 10^3; \quad F_N = 180 \pm 36
\]

A better agreement of the experimental values with theory for the M3 transition probabilities is obtained when the theoretical transition probabilities are calculated with effective \( g_s \)-factors instead of the \( g_s \)-values of the free proton and neutron. According to fig. 8 of ref. [Na 65] and ref. [Boe 63a] the effective \( g_s \)-values are a factor \( \approx 0.6 \) smaller than the \( g_s \)-values of the free proton and neutron. From calculation of the theoretical transition probabilities with \( g_s(\text{eff}) = 0.6 g_s(\text{free}) \) the following hindrance factors are obtained: \( F_N(g_s(\text{eff})) = 0.45 \pm 0.03 \) for the M3 transition in \(^{181}\text{Ta} \) and \( F_N(g_s(\text{eff})) = 0.54 \pm 0.06; 1.2 \pm 0.4; 1.6 \pm 0.3 \) and \( 108 \pm 22 \) for the neutron transitions in \(^{175}\text{Yb}, \text{Yb}, ^{179}\text{Hf} \) and \(^{179}\text{W} \), respectively.

2.7 K-forbidden transitions

A Bohr and B R Mottelson [Bo 63] derived by expanding the Coriolis term a formula for the branching ratios of K-forbidden gamma ray transitions from one intrinsic state to different rotational states of another intrinsic state.

For \( K_f > K_i \), which is the usual case, the reduced transition probability is given by the following formula:
This formula was obtained from the formula given by Bohr and Mottelson [Bo 63] for \( K_f > K_i \), a 3-j symbol being used instead of the Clebsch-Gordan coefficient. \( M^2 \) gives a measure of the mixing of the states which is responsible for the transition probabilities of the \( K \)-forbidden transitions.

For the calculations of the theoretical branching ratios of \( K \)-forbidden gamma ray transitions from one intrinsic state to different rotational states of another intrinsic state it is assumed that \( M^2 \) is the same. With this assumption, theoretically and experimentally determined branching ratios of \( K \)-forbidden gamma ray transitions can be compared with one another. This comparison has been made by several authors, e.g. ref. [Al 63], [Ha 63], [Lö 64a], [Lö 64b]. The theoretical and experimental ratios they obtained cannot be compared with transitions in other nuclei.

If, however, the absolute transition probabilities of \( K \)-forbidden gamma ray transitions are known, then \( M^2 \) can be calculated using formula (10), and the experimentally determined values for \( M^2 \) can be compared for all multipolarities and for transitions in different nuclei.

In table VII the experimentally determined values \( M^2 \) for \( K \)-forbidden gamma ray transitions of odd-A nuclei in the rare earth and actinide regions are summarized. In the last column \( F_W \) is given for comparison.

\( B(\text{M1}) \) and \( B(\text{E1}) \) are given in \( 10^{-24} \text{cm}^2 \) and \( B(\text{E2}) \) in \( 10^{-48} \text{cm}^4 \), that means that \( M^2 \) has the dimension \( 10^{-24} \text{cm}^2 \) for dipole transitions and \( 10^{-48} \text{cm}^4 \) for quadrupole transitions.

The \( M^2 \) and \( F_W \) values form groups for the different degrees of \( K \)-forbiddenness for each multipolarity, respectively. Therefore this compilation may be useful for identifying the degree of \( K \)-forbiddenness of transitions between unknown states.

\[
B(\alpha; I_i, K_i \rightarrow I_f, K_f) = M^2(2l_f + 1) \left\{ \frac{I_i}{K_i(\lambda - K_i)} - \lambda \right\}^2
\]

\[
\left( \frac{I_f - K_f}{I_f + K_f} \right)! \left( \frac{I_f + K_i - \lambda}{I_f + K_i + \lambda} \right)!
\]

\[
\left( \frac{I_f + K_f}{I_f - K_i + \lambda} \right)!
\]

\text{(10)}
Absolute transition probabilities of K-forbidden gamma ray transitions have been calculated by Houchang [Ho 63] for electric dipole transitions in $^{169}$Tm, $^{173}$Lu, $^{183}$Re and $^{237}$Np. The agreement with the experimental values is reasonable (factor = 11).

Verhaar [Ve 64] calculated the absolute transition probabilities of the K-forbidden E2 transitions in $^{169}$Tm based on the generalized Peierls-Yoccoz theory. Comparing these theoretical transition probabilities with the experimental values given in table VII results in hindrance factors

\[ F_\text{V} = 0.80 \pm 0.08, \quad F_\text{V} = 0.74 \pm 0.37 \quad \text{and} \quad F_\text{V} = 0.50 \pm 0.25 \]

for the E2 transitions from the $7/2^+ [404]$ to the $3/2^+ [411]$ rotational members of the $1/2^+ [411]$ intrinsic state, respectively, which must be denoted excellent agreement.

4. Acknowledgements

The authors are indebted to Professor Dr. S G Nilsson (Lund), to Professor Dr. A H Wapstra and Dr. R van Lieshout (Amsterdam) and to Dr. A Faessler (Freiburg) for many fruitful discussions and valuable suggestions. One of the authors (K. E. G. L.) would like to extend his thanks to Dr. R van Lieshout, Professor Dr. P C Gugelot and Professor Dr. A H Wapstra for their hospitality while at the Institute for Nuclear Research in Amsterdam and to AB Atomenergi for their hospitality while at the Institute in Studsvik. He gratefully acknowledges a fellowship from the North Atlantic Treaty Organization.

We are also indebted to many authors for making available their data before publication.

This work is part of the research programme of the Institute for Nuclear Physics Research (I.K.O.), made possible by financial support from the Foundation for Fundamental Research on Matter (F.O.M.) and the Netherlands Organization for Pure Scientific Research (Z.W.O.).
References


Alb 61  ALBRIGHT, R G et al., Nucl. Phys. 27 (1961) 529.


Be 58  BÉS, D R, Nucl. Phys. 6 (1958) 645.


Be 64  BERLOVICH, E, Ye, Phys. Letters 13 (1964) 161.


Bo 56  BOEHM, F and MARMIER, P, Phys. Rev. 103 (1956) 342.


Bo 63  BOHR, A and MOTTELSUK, D, At. Energ. 14 (1963) 41.

Boe 63a BOER, J, de and ROGERS, J D, Phys. Letters 3 (1963) 304.

Br 64 BRANDI, K et al., Nucl. Phys. 59 (1964) 33.


Bu 64 BURKE, D, Private communication to C W Reich, (1964).


Fa 64  FAESSLER, A, Nucl. Phys. 59 (1964) 177.

Fa 65  FAESSLER, A, Private communication (1965).


Fu 65  FUNKE, L et al., Preprint to be publ. in Nucl. Phys (1965).


Go 62  GORODETZKY, S et al., Electromagnetic Lifetimes and Properties of Nuclear States, p. 79 (see ref. Be 62b).

Gr 51  GRAHAM, R L and BELL, R E, Phys. Rev. 83 (1951) 222.


Ha 58  HANSEN, P G et al., Nucl. Phys. 6 (1958) 630.


Ha 63 HANSEN, P G et al., Nucl. Phys. 45 (1963) 410.


Ha 65 HAMILTON, W D and DAVIES, K E, Postprint to [Ha 64] private communication, (1965).


Hau 64b HAUSER, U, Private communication (1964).


Jo 60 JOHANSSON, B and ALVÄGER, T, Arkiv Fysik 17 (1960) 163.


Kl 60 KISSLINGER, L S and SORENSEN, R A,

Kl 58 KLEMA, E D,

Ko 59 KOIČKI, S, SIMIČ, J and KUKOC, A,
Nucl. Phys. 10 (1959) 412.

Kr 62 KRAMER, G and NILSSON, S G,

Kr 63 KRACIK, B et al.,

Ku 63 KUROYANAGI, T and TAMURA, T,
Nucl. Phys. 48 (1963) 675.

La 61 LANDOLT-BÖRNSTEIN,
Zahlenwerte und Funktionen aus Naturwissenschaften und Technik.

Lö 64a LÖBNER, K E G,

Lö 64b LÖBNER, K E G and De WIT, S A,

Lö 65a LÖBNER, K E G,
Univ. of Amsterd., Diss. 1965 (unpubl.).

Lö 65b LÖBNER, K E G,
To be published.

Ma 55 MARMIER, P and BOEHM, F,

Ma 57 MANN, L G, NAGLE, R J and WEST, H I,
Bull. Am. Phys. Soc. 2 (1957) 231; see also (N.D.S.).

Ma 65a MALMSKOG, S G,

Ma 65b MALMSKOG, S G,
Nucl. Phys. 68 (1965) 517.

Mar 61 MARCHAL, A and YVON, P,

Me 59 METZGER, F R and TODD, W B,

Me 65a MEILING, W and STARY, F,
Preprint to be publ. in Nucl. Phys. 1965.
Me 65b  MEILING, W and STARY, F,  
Private communication (1965).

Mi 56  MIZE, J P, BUNKER, M E, STARNER, J W,  

Mo 55  MOSZKOWSKI, S A,  
Theory of multipole radiation. Beta- and Gamma-Ray  
Spectroscopy, ed. K Siegbahn, Amsterdam, North-Holland,  
1955 p. 373.

Mo 57  MOSZKOWSKI, S A,  
Models of nuclear structure. Handbuch der Physik, hrsg. von  

Mo 59  MOTTELSON, B R and NILSSON, S G,  

Mo 64a  MONSONEGO, G and PIEPENBRING, R,  

Mo 64b  MONSONEGO, G and PIEPENBRING, R,  
Nucl. Phys. 56 (1964) 593.

Mo 65  MONSONEGO, G and PIEPENBRING, R,  
Preprint to be publ. in Nucl. Phys. (1965).

Mu 61  MUIR, A H and BOEHM, F,  

Na 61  NAINAN, T D,  

Na 65  NATHAN, O and NILSSON, S G,  
Collective nuclear motion and the unified model. Alpha-  
Beta- and Gamma-Ray Spectroscopy, ed. K. Siegbahn,  
Amsterdam, North-Holland, 1965 p. 601.

Ni 55  NILSSON, S G,  

Ni 58  NILSSON, S G and RASMUSSEN, J O,  
Nucl. Phys. 5 (1958) 617.

Ni 64  NILSSON, S G,  
Private communication (1964).

No 64  NOVAKOV, T and HOLLANDER, J M,  
Nucl. Phys. 60 (1964) 593.

N.D.S.  Nuclear Data Sheets, National Research Council - Washington  
as available in May 1965.

Or 63  ORTH, C J, BUNKER, M E and STARNER, J W,  
Pa 55  PAUL, H.,
The influence of time-dependent electrical field gradients upon the angular correlation of gamma rays involving the 480 kev state of tantalum 181/. Lafayette, Ind. 1955. Diss. Purdue univ. 1955, reported in N.D.S.

Pe 64a  PERRIN, N,
Compt. Rend. 258 (1964) 1475; Physics Abstract 67 (1964) p. 1360, 15182.

Pe 64b  PERRIN, N N and VALENTIN, J,

Pi 64  PIEPENBRING, R,
Compt. Rend 259 (1964) 2799.

Ra 57  RASMUSSEN, J O, CANAVAN, F L and HOLLANDER, J M,

Ro 58  ROSE, M E,

Ro 59  ROTENBERG, M et al.,

Ro 64  ROGERS, J D,
Private communication (1964).

Ro 65  ROWE, D J,
Nucl. Phys. 61 (1965) 1.

Sc 59  SCHMID, L C, BURSON, S B and CORK, J M,

Sn 57  SNYDER, E S and FRANKEL, S,

St 55  STROMINGER, D and RASMUSSEN, J O,

St 56  STROMINGER, D,

St 57  STROMINGER, D and RASMUSSEN, J O,
Nucl. Phys. 3 (1957) 197.

St 59  STROMINGER, D,

Ste 57  STEPHENS, F S, Jr., et al.,
Su 57   SUNYAR, A W,  
         (Reported by Sn 57.)
Ta 65   TAMURA, T,  
         Nucl. Phys. 62 (1965) 305.
To 61   TOTH, K S and NIELSEN, O B,  
Un 60   UNIK, J P,  
         Coincidence measurements in nuclear decay scheme studies.  
Un 64   UNIK, J P,  
Va 61   VARTAPETJAN, G A, PETROSJAN, Z A and CHUDAVERDJAN, A G,  
         JETP 14 (1962) 1213.
Va 63   VALENTIN, J and SANTONI, A,  
Ve 57   VERGNES, M N,  
Ve 60   VERGNES, M N,  
Ve 61   VERGNES, M N and JASTRZEBSKI, J,  
Ve 62   VERGNES, M N,  
Ve 63   VERGNES, M N,  
Ve 64   VERHAAR, B J,  
         Nucl. Phys. 54 (1964) 641.
Ve 65   VERGNES, M N and RASMUSSEN, J O,  
Vo 60   VOROBEV, A A, KOMAR, A P, and KOROLEV, V A,  
Wa 59   WAPSTRA, A H, NIJGH, G J and LIESHOUT, R, VAN,  
We 52   BLATT, J M and WEISSKOFP, V F,  
Wi 60  WILSON, R G and POOL, M L,

Wi 65  WIEN, K,
Private communication (1965).

Zy 64  ZYLICZ, J, YOUNG, F and CHRISTENSEN, P R,
Private communication (reported in ref. Ja 64).
<table>
<thead>
<tr>
<th>Nucleus (level in keV)</th>
<th>T₂ (exp) of level in sec</th>
<th>Transition energy in keV</th>
<th>Initial state</th>
<th>Final state</th>
<th>Multipolarity</th>
<th>Relative N₀</th>
<th>Relative N₀ 1/2 (γ) in sec</th>
<th>F₀</th>
<th>Fₙ</th>
<th>f</th>
<th>n</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>153⁴Eu⁶3 (172.95)</td>
<td>1.4x10⁻¹⁰</td>
<td>172.95</td>
<td>3/2 5/2⁺ [413]</td>
<td>5/2 5/2⁺ [413]</td>
<td>M₁</td>
<td>1000</td>
<td>1500</td>
<td>8.9x10⁻⁵</td>
<td>4.5x10⁻⁵</td>
<td>0.24</td>
<td>1.3</td>
<td>4.8 Tₜ : (Na 64) (Na 65) N₀ : (N,D,S,) N₀ : (Ro 58) (N,D,S,)</td>
</tr>
<tr>
<td>153⁴Eu⁶3 (103.2)</td>
<td>3.5x10⁻⁹</td>
<td>103.2</td>
<td>3/2 3/2⁺ [413]</td>
<td>5/2 5/2⁺ [413]</td>
<td>M₁</td>
<td>1000</td>
<td>1500</td>
<td>2.0x10⁻⁴</td>
<td>3.2⁺</td>
<td>1.8</td>
<td>4.8 Tₜ : (N,D,S,) (Na 65a) 6² : (N,D,S,) (Na 65) N₀ : (Ro 58)</td>
<td></td>
</tr>
<tr>
<td>153⁴Eu⁶3 (104.335)</td>
<td>1.2x10⁻¹⁰</td>
<td>104.335</td>
<td>5/2 5/2⁻ [513]</td>
<td>5/2 5/2⁺ [413]</td>
<td>E₁</td>
<td>100</td>
<td>26</td>
<td>2.6x10⁻⁵</td>
<td>2.3x10⁻³</td>
<td>4.1x10⁻³</td>
<td>4.9 Tₜ : (Na 65b) 6² : (N,D,S,) N₀ : (Ro 58)</td>
<td></td>
</tr>
<tr>
<td>155⁴Eu⁶₃ (246)</td>
<td>1.3x10⁻⁹</td>
<td>246</td>
<td>3/2 3/2⁺ [413]</td>
<td>5/2 5/2⁺ [413]</td>
<td>M₁</td>
<td>1040</td>
<td>160</td>
<td>5.1x10⁻⁹</td>
<td>3.4x10⁻³</td>
<td>1.8⁺</td>
<td>2.0</td>
<td>4.9 Tₜ : (Na 61) (Na 65b) N₀ : (N,D,S,) (Na 63) N₀ : (Ro 58)</td>
</tr>
<tr>
<td>Nucleus (level in keV)</td>
<td>(T_2^0) (exp) of level in eV</td>
<td>Transition energy in eV</td>
<td>Initial state</td>
<td>Final state</td>
<td>Multipolarity</td>
<td>Relative (N_\gamma)</td>
<td>Relative (N_e)</td>
<td>(T_2^0) (exp) in sec</td>
<td>(F_N)</td>
<td>(f)</td>
<td>(\eta)</td>
<td>References</td>
</tr>
<tr>
<td>------------------------</td>
<td>---------------------------------</td>
<td>------------------------</td>
<td>--------------</td>
<td>------------</td>
<td>--------------</td>
<td>----------------</td>
<td>----------------</td>
<td>-----------------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>----------------</td>
</tr>
<tr>
<td>(^{159})Tb (65) (363)</td>
<td>(1.0 \times 10^{-10})</td>
<td>363</td>
<td>(5/2)</td>
<td>(5/2)</td>
<td>(5/2) (3/2^+) ([532])</td>
<td>(5/2)</td>
<td>(3/2^+) ([411])</td>
<td>(3/2)</td>
<td>100</td>
<td>1,06</td>
<td>(1.7 \times 10^{-9})</td>
<td>(3.5 \times 10^{-4})</td>
</tr>
<tr>
<td>(^{161})Tb (65) (418)</td>
<td>(8.7 \times 10^{-10})</td>
<td>361</td>
<td>(7/2)</td>
<td>(7/2)</td>
<td>(5/2) (3/2^+) ([523])</td>
<td>(5/2)</td>
<td>(3/2^+) ([411])</td>
<td>(3/2)</td>
<td>100</td>
<td>1,1</td>
<td>(1.2 \times 10^{-9})</td>
<td>(2.4 \times 10^{-5})</td>
</tr>
<tr>
<td>(^{161})Tb (65) (432)</td>
<td>(&lt; 2 \times 10^{-10})</td>
<td>482</td>
<td>(5/2)</td>
<td>(5/2)</td>
<td>(5/2) (3/2^+) ([552])</td>
<td>(3/2)</td>
<td>(3/2^+) ([411])</td>
<td>(5/2)</td>
<td>690</td>
<td>(&lt; 17)</td>
<td>(&lt; 3.6 \times 10^{-10})</td>
<td>(&lt; 1.5 \times 10^{-9})</td>
</tr>
<tr>
<td>(^{159})No (67) (206)</td>
<td>(6.9)</td>
<td>206</td>
<td>(1/2)</td>
<td>(1/2^+) ([411])</td>
<td>(7/2)</td>
<td>(5/2^+) ([523])</td>
<td>(7/2)</td>
<td>100</td>
<td>140</td>
<td>16.6</td>
<td>330</td>
<td>5.5</td>
</tr>
<tr>
<td>(^{161})No (67) (211.1)</td>
<td>(6.5)</td>
<td>211.1</td>
<td>(1/2)</td>
<td>(1/2^+) ([411])</td>
<td>(7/2)</td>
<td>(5/2^+) ([523])</td>
<td>(7/2)</td>
<td>100</td>
<td>124</td>
<td>14.6</td>
<td>360</td>
<td>5.8</td>
</tr>
<tr>
<td>(^{163})No (67) (309.6)</td>
<td>(0.8)</td>
<td>309.6</td>
<td>(1/2)</td>
<td>(1/2^+) ([411])</td>
<td>(7/2)</td>
<td>(7/2^+) ([523])</td>
<td>(7/2)</td>
<td>100</td>
<td>2.7</td>
<td>1.0</td>
<td>370</td>
<td>6.4</td>
</tr>
<tr>
<td>(^{165})No (67) (361)</td>
<td>(1.5 \times 10^{-6})</td>
<td>361</td>
<td>(3/2)</td>
<td>(3/2^+) ([411])</td>
<td>(7/2)</td>
<td>(7/2^+) ([523])</td>
<td>(7/2)</td>
<td>100</td>
<td>(2.9)</td>
<td>(1.9 \times 10^{-6})</td>
<td>(2.2 \times 10^{-6})</td>
<td>(11)</td>
</tr>
</tbody>
</table>
Table 3 (continued)

<table>
<thead>
<tr>
<th>Nucleus (level in keV)</th>
<th>I_g (exp) of level in sec</th>
<th>Transition energy in keV</th>
<th>Initial state</th>
<th>Final state</th>
<th>Multipolarity</th>
<th>Relative N_Y</th>
<th>Relative N_e</th>
<th>T_0/2 Y (exp) in sec</th>
<th>F_Y</th>
<th>F_N</th>
<th>f</th>
<th>n</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>^{167}Tm (179.4)</td>
<td>6.4x10^-7</td>
<td>7/2 1/2^+ [403]</td>
<td>5/2 1/2^+ [411]</td>
<td>M1</td>
<td>476</td>
<td>54</td>
<td>6</td>
<td>5.4x10^-5</td>
<td>8.3x10^-6</td>
<td>8.3x10^-6</td>
<td>130</td>
<td></td>
<td></td>
</tr>
<tr>
<td>^{167}Tm (232.7)</td>
<td>198.0</td>
<td>5/2 1/2^+ [411]</td>
<td>3/2 1/2^+ [411]</td>
<td>E2</td>
<td>280</td>
<td>19</td>
<td>6.5x10^-6</td>
<td>1.8x10^-3</td>
<td>K-forb.</td>
<td>1.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>^{167}Tm (316.2)</td>
<td>308.0</td>
<td>3/2 1/2^+ [411]</td>
<td>2</td>
<td>238</td>
<td>1270</td>
<td>8</td>
<td>2.6x10^-6</td>
<td>2.0x10^-8</td>
<td>2K-forb.</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>^{169}Tm (379)</td>
<td>2</td>
<td>2/2 1/2^+ [411]</td>
<td>5/2 1/2^+ [411]</td>
<td>E1</td>
<td>940</td>
<td>442</td>
<td>1.9x10^-6</td>
<td>6.7x10^-5</td>
<td>2K-forb.</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>^{171}Tm (425.1)</td>
<td>2</td>
<td>5/2 1/2^+ [411]</td>
<td>5/2 1/2^+ [411]</td>
<td>E1</td>
<td>1022</td>
<td>442</td>
<td>3.4x10^-5</td>
<td>2.2x10^-9</td>
<td>2K-forb.</td>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>^{169}Lu (29)</td>
<td>160</td>
<td>2/2 1/2^+ [405]</td>
<td>1/2 1/2^- [405]</td>
<td>E3</td>
<td>1</td>
<td>9.3x10^-4</td>
<td>1.5x10^-7</td>
<td>380</td>
<td>1.0</td>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>^{169}Lu (70.4)</td>
<td>76</td>
<td>1/2 1/2^- [405]</td>
<td>7/2 1/2^+ [405]</td>
<td>E3</td>
<td>1</td>
<td>610</td>
<td>4.6x10^-4</td>
<td>590</td>
<td>1.9</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

References:
- T_{1/2} : (UO 64b) (Ta 55)
- N_Y : (Na 59) (Ro 58)
- N_Y/N_e : (Na 59) (Ro 58)
- N_Y : (Ro 58)
- N_e : (Ro 58)
- N_Y : (Ro 58)
- N_e : (Ro 58)
- N_Y : (Ro 58)
- N_e : (Ro 58)
- N_Y : (Ro 58)
- N_e : (Ro 58)
- N_Y : (Ro 58)
- N_e : (Ro 58)
- N_Y : (Ro 58)
- N_e : (Ro 58)
- N_Y : (Ro 58)
- N_e : (Ro 58)
<table>
<thead>
<tr>
<th>Nucleus (level in keV)</th>
<th>$T_2$ (exp) of level in sec</th>
<th>Transition energy in keV</th>
<th>Initial state</th>
<th>Final state</th>
<th>Multi-polarity</th>
<th>Relative $N_\gamma$</th>
<th>Relative $N_\alpha$</th>
<th>$T_2$ (exp) in sec</th>
<th>$F_N$</th>
<th>$F_\gamma$</th>
<th>$f$</th>
<th>$n$</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{173}$Tm (123.8)</td>
<td>7.7x10^-5</td>
<td>123.8</td>
<td>5/2 1/2 $^{[54]}_2$</td>
<td>7/2 7/2 $^{[40]}_2$</td>
<td>E1</td>
<td>100</td>
<td>19</td>
<td>9.2x10^-5</td>
<td>8.1x10^8</td>
<td>2K-forb.</td>
<td>1.1</td>
<td></td>
<td>$T_2$ : (N,D,S) (Pn 64a)</td>
</tr>
<tr>
<td>$^{175}$Tm (343.4)</td>
<td>3x10^-10</td>
<td>343.4</td>
<td>5/2 5/2 $^{[32]}_1$</td>
<td>7/2 7/2 $^{[40]}_2$</td>
<td>E1</td>
<td>417</td>
<td>50</td>
<td>7.6x10^-10</td>
<td>1.4x10^3</td>
<td>2.5</td>
<td>2.0</td>
<td>4.5</td>
<td>$T_2$ : (Oe 62)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$N_\gamma$ : (N,D,S)</td>
</tr>
<tr>
<td>$^{177}$Tm (545)</td>
<td>1,3x10^-6</td>
<td>345</td>
<td>5/2 1/2 $^{[54]}_2$</td>
<td>7/2 7/2 $^{[40]}_2$</td>
<td>E1</td>
<td>100</td>
<td>1.5</td>
<td>1.3x10^-6</td>
<td>2.5x10^8</td>
<td>2K-forb.</td>
<td>1.1</td>
<td></td>
<td>$T_2$ : (Bj 65)</td>
</tr>
<tr>
<td>$^{179}$Tm (396.3)</td>
<td>3,25x10^-9</td>
<td>396.3</td>
<td>9/2 9/2 $^{[54]}_2$</td>
<td>7/2 7/2 $^{[40]}_2$</td>
<td>E1</td>
<td>965</td>
<td>9</td>
<td>6.6x10^-9</td>
<td>1.9x10^6</td>
<td>165</td>
<td>1.2</td>
<td>4.5</td>
<td>$T_2$ : (N,D,S) (Hau 61a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Hau 62)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Be 62a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Be 62b)</td>
</tr>
<tr>
<td>$^{177}$Tm (147)</td>
<td>1,25x10^-7</td>
<td>147</td>
<td>9/2 9/2 $^{[54]}_2$</td>
<td>7/2 7/2 $^{[40]}_2$</td>
<td>E1</td>
<td>100</td>
<td>13</td>
<td>1.7x10^-7</td>
<td>2.5x10^6</td>
<td>207</td>
<td>1.3</td>
<td>4.2</td>
<td>$T_2$ : (N,D,S)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\delta$ : (Mit 56)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$N_\alpha$ : (Ro 58)</td>
</tr>
<tr>
<td>$^{179}$Tb (30.7)</td>
<td>1.45x10^-6</td>
<td>30.7</td>
<td>9/2 9/2 $^{[54]}_2$</td>
<td>7/2 7/2 $^{[40]}_2$</td>
<td>E1</td>
<td>100</td>
<td>400</td>
<td>7.3x10^-6</td>
<td>10^6</td>
<td>77</td>
<td>1.3</td>
<td>4.0</td>
<td>$T_2$ : (Po 64b) (L8 64a) (Hau 64a) (Ta 64b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$N_\alpha$ : (Va 65)</td>
</tr>
<tr>
<td>Nucleus</td>
<td>$T_1$(exp) of level in sec</td>
<td>Transition energy in keV</td>
<td>Initial state</td>
<td>Final state</td>
<td>Multipolarity</td>
<td>Relative $N_1$</td>
<td>Relative $N_0$</td>
<td>$\gamma$ (exp) in deg</td>
<td>$F_N$</td>
<td>$F_W$</td>
<td>$f$</td>
<td>$\eta$</td>
<td>References</td>
</tr>
<tr>
<td>---------</td>
<td>---------------------------</td>
<td>-------------------------</td>
<td>---------------</td>
<td>------------</td>
<td>--------------</td>
<td>--------------</td>
<td>--------------</td>
<td>----------------------</td>
<td>------</td>
<td>------</td>
<td>-----</td>
<td>------</td>
<td>------------</td>
</tr>
<tr>
<td>$^{181}$Ta $^{73}$ (6,3)</td>
<td>$6.6 \times 10^{-6}$</td>
<td>6.3</td>
<td>$9/2^- [413]$</td>
<td>$7/2^- [408]$</td>
<td>E1</td>
<td>10</td>
<td>440</td>
<td>$3.1 \times 10^{-4}$</td>
<td>$3.7 \times 10^4$</td>
<td>25</td>
<td>1.3</td>
<td>3.7</td>
<td>$T_2$ : (Hu 61) (Cl 61)</td>
</tr>
<tr>
<td>$^{181}$Ta $^{73}$ (482)</td>
<td>$1.0 \times 10^{-2}$</td>
<td>482</td>
<td>$5/2^- [402]$</td>
<td>$7/2^- [404]$</td>
<td>M1</td>
<td>200</td>
<td>12</td>
<td>$5.1 \times 10^{-7}$</td>
<td>$2.5 \times 10^6$</td>
<td>8500</td>
<td>-</td>
<td>3.7</td>
<td>$T_2$ : (N.D.S.) (Ha 61) (Go 62) (La 65a) (La 65b) $N_2$ : (N.D.S.)</td>
</tr>
<tr>
<td>346</td>
<td>$9/2^- [404]$</td>
<td>E2</td>
<td>1300</td>
<td>74</td>
<td>$7.9 \times 10^{-8}$</td>
<td>$4.2 \times 10^1$</td>
<td>9.2 \times 10^{-3}</td>
<td>1.2</td>
<td>$\delta^2$ (482 keV) = 40 from angular correlation ($N.D.S.$) and in brackets</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>476</td>
<td>$9/2^- [514]$</td>
<td>M2</td>
<td>28</td>
<td>55</td>
<td>$3.7 \times 10^{-6}$</td>
<td>$9.3 \times 10^4$</td>
<td>1.8</td>
<td>1.5 \times 10^{-3}</td>
<td>$\delta^2$ (482 keV) = 8 from conversion electron measurements $^{M}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{181}$Ta $^{73}$ (615)</td>
<td>$1.7 \times 10^{-5}$</td>
<td>615</td>
<td>$1/2^- [411]$</td>
<td>$7/2^- [404]$</td>
<td>M3</td>
<td>23</td>
<td>3</td>
<td>$7.0 \times 10^{-5}$</td>
<td>$3.6 \times 10^4$</td>
<td>2.0</td>
<td>3.7</td>
<td>$T_2$, $N_2$, $\delta^2$ : (N.D.S.)</td>
<td></td>
</tr>
<tr>
<td>133</td>
<td>$5/2^- [502]$</td>
<td>E2</td>
<td>400</td>
<td>3040</td>
<td>$4.0 \times 10^{-5}$</td>
<td>$130$</td>
<td>7</td>
<td>1.1</td>
<td>$N_2$, $N_2$ : (Ro 58)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{227}$Ac $^{90}$ (27,3)</td>
<td>$3.7 \times 10^{-8}$</td>
<td>27.3</td>
<td>$1/2^- [530]$</td>
<td>$3/2^- [857]$</td>
<td>E1</td>
<td>110</td>
<td>500</td>
<td>$2.2 \times 10^{-7}$</td>
<td>$2.5 \times 10^4$</td>
<td>10</td>
<td>1.4</td>
<td>3.9</td>
<td>$T_2$ : (Fo 56)</td>
</tr>
<tr>
<td>$^{231}$Pa $^{81}$ (84,2)</td>
<td>$4.1 \times 10^{-8}$</td>
<td>84.2</td>
<td>$5/2^- [642]$</td>
<td>$3/2^- [530]$</td>
<td>E1</td>
<td>77</td>
<td>214</td>
<td>$5.7 \times 10^{-7}$</td>
<td>$1.9 \times 10^6$</td>
<td>K-forb.</td>
<td>1.4</td>
<td>4.5</td>
<td>$T_2$ : (St 55)</td>
</tr>
<tr>
<td>25.7</td>
<td>$7/2^- [530]$</td>
<td>E1</td>
<td>130</td>
<td>625</td>
<td>$3.3 \times 10^{-7}$</td>
<td>$3.0 \times 10^4$</td>
<td>K-forb.</td>
<td>1.4</td>
<td>$N_2$, $N_2$ : (As 60)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{233}$Pa $^{91}$ (88,6)</td>
<td>$3.7 \times 10^{-8}$</td>
<td>86.6</td>
<td>$5/2^- [642]$</td>
<td>$3/2^- [530]$</td>
<td>E1</td>
<td>140</td>
<td>266</td>
<td>$2.7 \times 10^{-7}$</td>
<td>$8.7 \times 10^5$</td>
<td>K-forb.</td>
<td>1.5</td>
<td>4.6</td>
<td>$T_2$ : (Eng 54) (Har 61)</td>
</tr>
<tr>
<td>29.2</td>
<td>$7/2^- [530]$</td>
<td>E1</td>
<td>120</td>
<td>360</td>
<td>$2.5 \times 10^{-7}$</td>
<td>$3.8 \times 10^4$</td>
<td>K-forb.</td>
<td>1.5</td>
<td>$N_2$, $N_2$ : (As 60)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{237}$Np $^{92}$ (59,6)</td>
<td>$6.3 \times 10^{-8}$</td>
<td>59.6</td>
<td>$5/2^- [523]$</td>
<td>$5/2^- [542]$</td>
<td>E1</td>
<td>8100</td>
<td>7450</td>
<td>$1.6 \times 10^{-7}$</td>
<td>$1.9 \times 10^5$</td>
<td>$9.6 \times 10^{-3}$</td>
<td>1.3</td>
<td>4.8</td>
<td>$T_2$ : (Un 60)</td>
</tr>
<tr>
<td>26.4</td>
<td>$7/2^- [542]$</td>
<td>E1</td>
<td>810</td>
<td>4400</td>
<td>$1.6 \times 10^{-8}$</td>
<td>$1.7 \times 10^{-6}$</td>
<td>$9.4 \times 10^{-4}$</td>
<td>1.3</td>
<td>$N_2$, $N_2$ : (Jaf 55)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isotope</td>
<td>$T_1$ (exp)</td>
<td>Transition energy</td>
<td>Initial state</td>
<td>Final state</td>
<td>Multipolarity</td>
<td>Relative $N_Y$</td>
<td>Relative $N_0$</td>
<td>$1/2 \gamma$ (exp)</td>
<td>$F_N$</td>
<td>$f$</td>
<td>$\eta$</td>
<td>References</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>------------------</td>
<td>--------------</td>
<td>------------</td>
<td>--------------</td>
<td>---------------</td>
<td>---------------</td>
<td>-----------------</td>
<td>------</td>
<td>-----</td>
<td>------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>$^{237}\text{Np}$</td>
<td>$5.2 \times 10^{-9}$</td>
<td>267.2</td>
<td>$3/2$ $1/2^{+}$ [330]</td>
<td>$5/2$ $5/2^{+}$ [642]</td>
<td>$E1$</td>
<td>80</td>
<td>80</td>
<td>$5.9 \times 10^{-7}$</td>
<td>$5.4 \times 10^{-7}$</td>
<td>K-forb.</td>
<td>1.5</td>
<td>4.8</td>
<td>$T_2$ : (Un 60)</td>
</tr>
<tr>
<td>(267.2)</td>
<td>234.2</td>
<td>207.9</td>
<td>$5/2$ $5/2^{+}$ [325]</td>
<td>$E1$</td>
<td>2</td>
<td>20</td>
<td>$2.5 \times 10^{-5}$</td>
<td>21</td>
<td>$3 \times 10^{-2}$</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{239}\text{Pu}$</td>
<td>$1.4 \times 10^{-9}$</td>
<td>74.6</td>
<td>$5/2$ $5/2^{+}$ [320]</td>
<td>$5/2$ $5/2^{+}$ [642]</td>
<td>$E1$</td>
<td>720</td>
<td>195</td>
<td>$1.9 \times 10^{-6}$</td>
<td>$4.9 \times 10^{-3}$</td>
<td>$1 \times 10^{-4}$</td>
<td>1.2</td>
<td>5.6</td>
<td>$T_2$ : (Chr 63) (Un 60) (Anl 51)</td>
</tr>
<tr>
<td>(74.6)</td>
<td>45.1</td>
<td>42</td>
<td>$7/2$ $5/2^{+}$ [320]</td>
<td>$E1$</td>
<td>40</td>
<td>45</td>
<td>$3.5 \times 10^{-8}$</td>
<td>$1.6 \times 10^{-4}$</td>
<td>$2 \times 10^{-4}$</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{243}\text{Am}$</td>
<td>$2.0 \times 10^{-9}$</td>
<td>83.9</td>
<td>$5/2$ $5/2^{+}$ [642]</td>
<td>$5/2$ $5/2^{+}$ [320]</td>
<td>$E1$</td>
<td>2100</td>
<td>420</td>
<td>$2.5 \times 10^{-6}$</td>
<td>$9.0 \times 10^{-3}$</td>
<td>$4 \times 10^{-4}$</td>
<td>1.2</td>
<td>5.2</td>
<td>$T_2$ : (Am 60)</td>
</tr>
<tr>
<td>(83.9)</td>
<td>42</td>
<td>7/2 $5/2^{+}$ [320]</td>
<td>$E1$</td>
<td>100</td>
<td>140</td>
<td>$5.5 \times 10^{-3}$</td>
<td>$2.4 \times 10^{-3}$</td>
<td>$5 \times 10^{-3}$</td>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table I. (continued)
Remarks to Table I

$^{153}$Cu and $^{155}$Cu: The theoretical M1 transition probabilities of the

\[ \frac{3}{2}^{+} \rightarrow \frac{5}{2}^{+} \]

\[ \frac{5}{2}^{+} \rightarrow \frac{7}{2}^{+} \]

transitions change very rapidly with deformation (a factor \( \sim 100 \) between \( \eta = 4 \) and \( \eta = 6 \)).

$^{155}$Cu: The highest \( \alpha_{K} \) measured by (Kr 63) yields \( \delta^{2} = 0.013 \pm 0.008 \) for the 104.35 keV transition. This M2 admixture does not change \( \alpha_{N} \) (El) very much, and for the determination of the partial M2 transition probability it is too uncertain; therefore it was omitted.

$^{159}$Tb: The partial gamma ray half-life for the 363 keV transition is in agreement with the value obtained from resonance fluorescence by Metzger and Todd (Ma 58): \( T_{1/2}^{\gamma} = (1.4 \pm 0.2) \times 10^{-10} \) s.

$^{161}$Tb: The theoretical \( \alpha_{K} \) values for the 361.0 and 283.8 keV transitions used here differ from those given in (N.D.S.).

$^{167}$Tm: The branching ratios for the two transitions depopulating the 179.4 keV level were deduced from measured conversion electron intensities by Harmatz et al. (Ha 59). This procedure introduces large uncertainties, because the theoretical K-conversion coefficient of the 82.9 keV transition is not well known and has not been measured, and because the measured conversion electron ratios do not seem to be in agreement with the theoretical predictions.

$^{169}$Tm: The E2 admixtures for the 108.0 and 177.2 keV transitions were taken from the angular correlation measurements by Koloki et al. (Ko 59), which are lower than the admixtures obtained from the measurements of the conversion electron ratios,
The theoretical transition probabilities of the E3 transitions $\frac{1}{2}^+ \rightarrow \frac{1}{2}^+ \left[ \frac{5}{4}^+ \right] \rightarrow \frac{7}{2}^+ \left[ \frac{9}{2}^+ \right] \left[ \frac{3}{2}^+ \right]$ change very rapidly with deformation (a factor $\approx 50$ between $\eta = 4$ and $\eta = 6$).

The mixing ratio of the 482 keV transition is very uncertain. From gamma-gamma angular correlation measurements $2.7 \leq \delta^2 \leq 6.1$ was obtained (Pa 50), (Ge 56), (Gra 61) and gamma-K-conversion electron angular correlations yielded $7.8 \leq \delta^2 \leq 23$ (Ge 56), while from the measurements of the K-conversion coefficient it follows that $2.3 \leq \delta^2 \leq 15$ (Ge 56), (Sn 57), (Su 59) and from measurements of the K/L ratio $\delta^2 \geq 7.0$ (K/L ratios reported in N.O.S.) can be deduced. The last value differs from that deduced in (N.O.S.). The discrepancies are probably caused partially by the $\frac{5}{2}^+ \rightarrow \frac{3}{2}^+$ transition of 476 keV depopulating the same level as the 482 keV transition; besides the 482 keV M1 transition probably shows anomalous conversion coefficients caused by penetration effects, see e.g. ref. (Ch 60) and (Gra 61). Because of these uncertainties the hindrance factors were calculated with $\delta^2 = 40$ and in brackets with $\delta^2 = 8$ for the 482 keV transition.

The theoretical M3 gamma ray transition probability of the $\frac{1}{2}^+ \frac{1}{2}^+ \left[ \frac{5}{4}^+ \right] \rightarrow \frac{7}{2}^+ \frac{7}{2}^+ \left[ \frac{3}{2}^+ \right]$ transition changes very rapidly with deformation. The gamma matrix element becomes zero between $\eta = 2$ and $\eta = 4$.

The theoretical E1 transition probability for the $\frac{5}{2}^+ \left[ \frac{5}{4}^+ \right] \rightarrow \frac{3}{2}^+ \left[ \frac{3}{2}^+ \right]$ transition changes by a factor of 100 between $\eta = 4$ and $\eta = 6$.
<table>
<thead>
<tr>
<th>Nucleus (level in keV)</th>
<th>$I^J$ (exp) of level (n sec)</th>
<th>Transition energy in keV</th>
<th>Initial state $I K^L M$</th>
<th>Final state $I K^L M$</th>
<th>Multipolarity</th>
<th>Relative $K_Y$</th>
<th>Relative $N_e$</th>
<th>$T_{1/2}$ (Y) (exp)</th>
<th>$F_N$</th>
<th>$F_H$</th>
<th>$f$</th>
<th>$\eta$</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>156 &amp; 156 (86,54)</td>
<td>6.7x10^{-9}</td>
<td>86.54</td>
<td>3/2 3/2$^*$ [58]</td>
<td>3/2 3/2$^*$ [58]</td>
<td>$\ell 1$</td>
<td>4110</td>
<td>1912</td>
<td>4.0^{-8}</td>
<td>2.6x10^{4}</td>
<td>3.6</td>
<td>1.2</td>
<td>6.2</td>
<td>$T_2$: (Ve 60a) (Ha 62) (Ha 64b) (Ro 64) (Le 65a) (Le 65b) (Ve 65b)</td>
</tr>
<tr>
<td>156 &amp; 156 (105,32)</td>
<td>1.09x10^{-9}</td>
<td>105.3</td>
<td>5/2 5/2$^*$ [54]</td>
<td>3/2 3/2$^*$ [58]</td>
<td>$\ell 1$</td>
<td>4545</td>
<td>1239</td>
<td>1.7x10^{-9}</td>
<td>8.7x10^{3}</td>
<td>3.8</td>
<td>1.1</td>
<td>5.2</td>
<td>$T_2$: (Ve 60b) (Ha 62) (Te 64)</td>
</tr>
<tr>
<td>156 &amp; 156 (64,0)</td>
<td>4.6x10^{-7}</td>
<td>64.0</td>
<td>5/2 5/2$^*$ [54]</td>
<td>3/2 3/2$^*$ [58]</td>
<td>$\ell 1$</td>
<td>50</td>
<td>50</td>
<td>1.8x10^{-6}</td>
<td>2.1x10^{6}</td>
<td>920</td>
<td>1.2x10^{-5}</td>
<td>6.2</td>
<td>$T_3$: (Ve 60b) (Ha 62) (Te 64) (Nds)</td>
</tr>
<tr>
<td>181 &amp; 181 (25,7)</td>
<td>2.75x10^{-9}</td>
<td>25.7</td>
<td>5/2 5/2$^*$ [54]</td>
<td>5/2 5/2$^*$ [54]</td>
<td>$\ell 1$</td>
<td>1000</td>
<td>228</td>
<td>9.0x10^{-6}</td>
<td>6.7x10^{3}</td>
<td>0.84</td>
<td>1.2</td>
<td>6.0</td>
<td>$T_4$: (Ve 59) (Ha 56) (St 59) (Ve 60) (Ve 65a)</td>
</tr>
<tr>
<td>161 &amp; 161 (74,5)</td>
<td>3.0x10^{-9}</td>
<td>74.5</td>
<td>3/2 3/2$^*$ [54]</td>
<td>5/2 5/2$^*$ [54]</td>
<td>$\ell 1$</td>
<td>1000</td>
<td>666</td>
<td>2.9x10^{-6}</td>
<td>2.2x10^{4}</td>
<td>31</td>
<td>1.5</td>
<td>6.0</td>
<td>$T_5$: (Ve 59) (Ha 56) (St 59) (Ve 60) (Ve 65a)</td>
</tr>
<tr>
<td>185 &amp; 185 (108)</td>
<td>72</td>
<td>108</td>
<td>1/2 1/2$^*$ [54]</td>
<td>7/2 7/2$^*$ [54]</td>
<td>$\ell 3$</td>
<td>100</td>
<td>666</td>
<td>570</td>
<td>1.3x10^{2}</td>
<td>3.0</td>
<td>1.3</td>
<td>6.0</td>
<td>$T_5$: (Ve 59) (Ha 56) (St 59) (Ve 60) (Ve 65a)</td>
</tr>
</tbody>
</table>

Table II: Experimental data and transition factors for gamma-ray transitions between different intrinsic states of odd-mass nuclei in the rare earth and actinide regions. The references are provided next to each entry.
<table>
<thead>
<tr>
<th>Nucleus (level in keV)</th>
<th>$T_1$(exp) of level in sec</th>
<th>Transition energy in keV</th>
<th>Initial state $I_h$[N $\bar{L}$, $\Lambda$]</th>
<th>Final state $I_h$[N $\bar{L}$, $\Lambda$]</th>
<th>Multipolarity</th>
<th>Relative $N$</th>
<th>Relative $N_0$</th>
<th>$T_1/2$(exp) in sec</th>
<th>$F_M$</th>
<th>$F_N$</th>
<th>$f$</th>
<th>$n$</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>165 Er 69 (47.15)</td>
<td>3.5x10^{-5}</td>
<td>47.15</td>
<td>5/2 5/2$^+[54]$</td>
<td>5/2 5/2$^-[50]$</td>
<td>E1</td>
<td>100</td>
<td>40</td>
<td>4.8x10^{-9}</td>
<td>2.5x10^{-3}</td>
<td>0.3</td>
<td>1.2</td>
<td>5.9</td>
<td>$T_1$: (Ja 64)</td>
</tr>
<tr>
<td>167 Er 69 (207.8)</td>
<td>2.3</td>
<td>207.8</td>
<td>1/2 1/2$^-[52]$</td>
<td>7/2 7/2$^-[53]$</td>
<td>E3</td>
<td>100</td>
<td>138</td>
<td>1.3x10^{-2}</td>
<td>2.4</td>
<td>1.2</td>
<td>5.8</td>
<td>$T_2$: (La 65a)</td>
<td></td>
</tr>
<tr>
<td>169 Yb 70 (191.4)</td>
<td>3.35x10^{-5}</td>
<td>191.4</td>
<td>5/2 5/2$^-[51]$</td>
<td>7/2 7/2$^-[53]$</td>
<td>E1</td>
<td>28600</td>
<td>1800</td>
<td>4.2x10^{-9}</td>
<td>1.3x10^{-5}</td>
<td>38</td>
<td>1.4</td>
<td>5.6</td>
<td>$T_3$: (La 65a) (La 65b)</td>
</tr>
<tr>
<td>171 Yb 70 (122.2)</td>
<td>2.65x10^{-7}</td>
<td>122.2</td>
<td>1/2 1/2$^-[52]$</td>
<td>5/2 5/2$^-[51]$</td>
<td>E2</td>
<td>weak</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.6</td>
<td>$T_3$: (La 65a) (La 65b)</td>
<td></td>
</tr>
<tr>
<td>173 Yb 70 (351.2)</td>
<td>4.5x10^{-10}</td>
<td>351.2</td>
<td>5/2 5/2$^-[51]$</td>
<td>7/2 7/2$^-[53]$</td>
<td>E1</td>
<td>32^d</td>
<td>0.7</td>
<td>2.3x10^{-8}</td>
<td>4.6x10^{-6}</td>
<td>880^a</td>
<td>1.5j0.9</td>
<td>5.6</td>
<td>$T_4$: (Be 61) (Va 61)</td>
</tr>
</tbody>
</table>

$^a$: N from middle K-observation; $^b$: K-forb. (from Ro 58); $^c$: K-forb. (from Ro 58)
<table>
<thead>
<tr>
<th>Nucleus (level in keV)</th>
<th>( T_2 ) (exp) or level in s</th>
<th>Transition energy in keV</th>
<th>Initial state</th>
<th>Final state</th>
<th>( I K^T [\text{p} N L] )</th>
<th>Multipolarity</th>
<th>( N^o Y )</th>
<th>Relative ( N^o e )</th>
<th>( T_2 \gamma ) (exp) in s</th>
<th>( F_N )</th>
<th>( F_N )</th>
<th>( f )</th>
<th>( n )</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>( {^{173}\text{Yb}} ) ( 70 ) ( (397) )</td>
<td>( 3.0 \times 10^{-6} )</td>
<td>397</td>
<td>( 1/2 ) ( 1/2^* ) ( ^{321} )</td>
<td>( 5/2 ) ( 5/2^* ) ( ^{312} )</td>
<td>E2</td>
<td>100</td>
<td>3</td>
<td>( 3.1 \times 10^{-6} )</td>
<td>3.1</td>
<td>32</td>
<td>1.1</td>
<td>5.6</td>
<td>( T_2 \gamma ) (( \text{K} ) 65) (( \text{Cr} ) 65) (( \text{W} ) 65)</td>
<td></td>
</tr>
<tr>
<td>( {^{173}\text{Yb}} ) ( 70 ) ( (465) )</td>
<td>( 5.5 \times 10^{-10} )</td>
<td>465</td>
<td>( 3/2 ) ( 1/2^* ) ( ^{321} )</td>
<td>( 5/2 ) ( 5/2^* ) ( ^{312} )</td>
<td>M1</td>
<td>3.6</td>
<td>0.49</td>
<td>( 1.6 \times 10^{-9} )</td>
<td>7.5</td>
<td>10</td>
<td>1.2</td>
<td>-</td>
<td>( T_2 \gamma ) (( \text{W} ) 65)</td>
<td></td>
</tr>
<tr>
<td>( {^{175}\text{Yb}} ) ( 70 ) ( (500) )</td>
<td>0.07</td>
<td>500</td>
<td>( 1/2 ) ( 1/2^* ) ( ^{310} )</td>
<td>( 7/2 ) ( 7/2^* ) ( ^{314} )</td>
<td>M3</td>
<td>100</td>
<td>33</td>
<td>( 9.5 \times 10^{-2} )</td>
<td>11</td>
<td>0.9</td>
<td>1.1</td>
<td>5.6</td>
<td>( T_2 \gamma ) ( \delta^2 ) : (( \text{Ca} ) 59) (( \text{Ha} ) 60) (( \text{Fe} ) 62)</td>
<td></td>
</tr>
<tr>
<td>( {^{177}\text{Yb}} ) ( 70 ) ( (104) )</td>
<td>( 4.7 \times 10^{-9} )</td>
<td>104</td>
<td>( 7/2 ) ( 7/2^* ) ( ^{314} )</td>
<td>( 9/2 ) ( 9/2^* ) ( ^{324} )</td>
<td>E1</td>
<td>1000</td>
<td>311</td>
<td>( 6.6 \times 10^{-9} )</td>
<td>3.5</td>
<td>10</td>
<td>1.1</td>
<td>5.6</td>
<td>( T_2 \gamma ) (( \text{L} ) 646) (( \text{M} ) 65a)</td>
<td></td>
</tr>
<tr>
<td>( {^{177}\text{Yb}} ) ( 70 ) ( (322) )</td>
<td>6.3</td>
<td>228</td>
<td>( 1/2 ) ( 1/2^* ) ( ^{310} )</td>
<td>( 7/2 ) ( 7/2^* ) ( ^{314} )</td>
<td>M3</td>
<td>100</td>
<td>718</td>
<td>( 5.2 \times 10^{-4} )</td>
<td>25</td>
<td>2.0</td>
<td>1.3</td>
<td>5.6</td>
<td>( T_2 \gamma ) ( \delta^2 ) : (( \text{Ca} ) 59) (( \text{Ha} ) 60) (( \text{Fe} ) 62)</td>
<td></td>
</tr>
<tr>
<td>( {^{175}\text{Hf}} ) ( 72 ) ( (125.9) )</td>
<td>( 4.9 \times 10^{-5} )</td>
<td>125.9</td>
<td>( 1/2 ) ( 1/2^* ) ( ^{321} )</td>
<td>( 5/2 ) ( 5/2^* ) ( ^{312} )</td>
<td>E2</td>
<td>100</td>
<td>137</td>
<td>( 1.2 \times 10^{-4} )</td>
<td>390</td>
<td>4</td>
<td>1.2</td>
<td>5.5</td>
<td>( T_2 \gamma ) (( \text{Br} ) 64)</td>
<td></td>
</tr>
<tr>
<td>( {^{175}\text{Hf}} ) ( 72 ) ( (207.4) )</td>
<td>( 1.55 \times 10^{-9} )</td>
<td>207.4</td>
<td>( 7/2 ) ( 7/2^* ) ( ^{323} )</td>
<td>( 5/2 ) ( 5/2^* ) ( ^{312} )</td>
<td>E1</td>
<td>375</td>
<td>21</td>
<td>( [2.1-2.6] \times 10^{-10} )</td>
<td>( 0.07-1.06 )</td>
<td>16-20</td>
<td>1.2</td>
<td>5.5</td>
<td>( T_2 \gamma ) (( \text{Un} ) 64)</td>
<td></td>
</tr>
</tbody>
</table>

\( N^o \gamma \) (lower limit given by (\( \text{Ha} \) 60))

\( N^o \gamma \) (upper limit from intensity balance of 81.5 keV level)
<table>
<thead>
<tr>
<th>Nucleus</th>
<th>$T_j^{\text{exp}}$ (sec)</th>
<th>Transition energy</th>
<th>Initial state</th>
<th>Final state</th>
<th>Multipolarity</th>
<th>Relative $N_{\gamma}$</th>
<th>Relative $N_{\alpha}$</th>
<th>$\tau_{\gamma}$ (sec)</th>
<th>$F_W$</th>
<th>$F_N$</th>
<th>$f$</th>
<th>$n$</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{177}_{72}$Hf (321.4)</td>
<td>$6.7 \times 10^{-10}$</td>
<td>6.72</td>
<td>9/2 $9/2$ $^m[824]$</td>
<td>7/2 $7/2$ $^m[314]$</td>
<td>E1</td>
<td>14</td>
<td>0.3</td>
<td>$1.2 \times 10^{-7}$</td>
<td>1.9x10$^{-7}$</td>
<td>3.0x10$^{-3}$</td>
<td>2.0</td>
<td>5.4</td>
<td>$T_2$ : (Hau 61a) (Hau 62) (Be 62a)</td>
</tr>
<tr>
<td>$^{179}_{72}$Hf (215)</td>
<td>$1.6 \times 10^{-9}$</td>
<td>215</td>
<td>7/2 $7/2$ $^m[314]$</td>
<td>9/2 $9/2$ $^m[624]$</td>
<td>E1</td>
<td>1000</td>
<td>49</td>
<td>$1.6 \times 10^{-9}$</td>
<td>7.4x10$^{-4}$</td>
<td>16</td>
<td>1.2</td>
<td>5.2</td>
<td>$T_2$ : (Vo 63) (La 64b) (Ma 65a)</td>
</tr>
<tr>
<td>$^{179}_{72}$Hf (215)</td>
<td>18.6</td>
<td>18.6</td>
<td>1/2 $1/2$ $^m[310]$</td>
<td>7/2 $7/2$ $^m[514]$</td>
<td>M3</td>
<td>100</td>
<td>3500</td>
<td>6.7x10$^{-3}$</td>
<td>29</td>
<td>2.6</td>
<td>1.2</td>
<td>3.2</td>
<td>$T_2$ : (Ha 59)</td>
</tr>
<tr>
<td>$^{179}_{74}$W (221.8)</td>
<td>312</td>
<td>312</td>
<td>1/2 $1/2$ $^m[310]$</td>
<td>7/2 $7/2$ $^m[514]$</td>
<td>K3</td>
<td>10</td>
<td>105</td>
<td>3.6x10$^{-3}$</td>
<td>1.4x10$^{-3}$</td>
<td>180$^a$</td>
<td>1.2</td>
<td>4.3</td>
<td>$T_2$ : (N,D,S.)</td>
</tr>
<tr>
<td>$^{181}_{74}$W (565.5)</td>
<td>0.45x10$^{-6}$</td>
<td>365.5</td>
<td>5/2 $5/2$ $^m[312]$</td>
<td>9/2 $9/2$ $^m[624]$</td>
<td>M2</td>
<td>1000</td>
<td>480</td>
<td>2.2x10$^{-5}$</td>
<td>150</td>
<td>41</td>
<td>1.2</td>
<td>4.3</td>
<td>$T_2$ : (Bu 57) (Du 58)</td>
</tr>
<tr>
<td>$^{231}_{90}$Th (186)</td>
<td>$7.7 \times 10^{-10}$</td>
<td>7.72</td>
<td>5/2 $5/2$ $^m[722]$</td>
<td>5/2 $5/2$ $^m[335]$</td>
<td>E1</td>
<td>820</td>
<td>93</td>
<td>$1.0 \times 10^{-9}$</td>
<td>3.6x10$^{-4}$</td>
<td>0.80</td>
<td>1.4</td>
<td>4.5</td>
<td>$T_2$ : (St 59)</td>
</tr>
</tbody>
</table>

$^a$ N.E. from N. E. (Bu 60) $Y_{\gamma}$, $N_{\gamma}$ from $N_{\alpha}$ $Y_{\alpha}$ $K$ (Ha 60) $Y_{\gamma}$ Without admixture and with upper limit of admixture deduced from $\alpha_{\gamma}$ (Bu 57)
<table>
<thead>
<tr>
<th>Nucleus (level in keV)</th>
<th>$T_1^{\text{(exp)}}$ of level in sec</th>
<th>Transition energy in keV</th>
<th>Initial state</th>
<th>Final state</th>
<th>Multi-polarity</th>
<th>Relative $N_y$</th>
<th>Relative $N_o$</th>
<th>$T_1^{\text{(exp)}}$ (mp) in sec</th>
<th>$F_W$</th>
<th>$F_N$</th>
<th>$\gamma$</th>
<th>$N$</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>233U (311.9)</td>
<td>2.0x10^{-10}</td>
<td>311.9</td>
<td>3/2 3/2^+ [533]</td>
<td>5/2 5/2^+ [533]</td>
<td>E2</td>
<td>3400</td>
<td>3350</td>
<td>4.0x10^{-10}</td>
<td>5.4x10^{-2}</td>
<td>36</td>
<td>1.2</td>
<td>4.8</td>
<td>$T_2^+$ : (Jo 60)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$N_y, N_o$ : (Alb 61)</td>
</tr>
<tr>
<td>237U (145)</td>
<td>3.3x10^{-9}</td>
<td>145</td>
<td>5/2 5/2^+ [533]</td>
<td>1/2 1/2^+ [533]</td>
<td>E2</td>
<td>100</td>
<td>270</td>
<td>9.0x10^{-2}</td>
<td>9.0x10^{-2}</td>
<td>1.8x10^{-4}</td>
<td>2.0</td>
<td>5.0</td>
<td>$T_2^+$ : (Anl 61)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$N_y, N_o$ : (Ro 58)</td>
</tr>
<tr>
<td>237Pu (145)</td>
<td>0.18</td>
<td>145</td>
<td>1/2 1/2^+ [533]</td>
<td>7/2 7/2^ [743]</td>
<td>E3</td>
<td>1</td>
<td>45</td>
<td>8.3</td>
<td>32</td>
<td>20</td>
<td>1.3</td>
<td>5.1</td>
<td>$T_2^+$ : (Ste 57)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$N_y, N_o$ : (Ro 58)</td>
</tr>
<tr>
<td>239Pu (285,5)</td>
<td>1.1x10^{-9}</td>
<td>285.5</td>
<td>5/2 5/2^+ [522]</td>
<td>1/2 1/2^+ [531]</td>
<td>E2</td>
<td>37</td>
<td>10</td>
<td>5.0x10^{-7}</td>
<td>1.7x10^{-2}</td>
<td>0.39</td>
<td>1.4</td>
<td>5.2</td>
<td>$T_2^+$ : (Ge 51)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$N_y, N_o$ : (Ev 57) (Ev 59)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$N_y, N_o$ : (Ev 57) (Ev 59)</td>
</tr>
<tr>
<td>239Pu (391.6)</td>
<td>1.9x10^{-7}</td>
<td>334.4</td>
<td>7/2 7/2^ [743]</td>
<td>5/2 1/2^+ [531]</td>
<td>E1</td>
<td>117</td>
<td>3</td>
<td>3.4x10^{-6}</td>
<td>7.2x10^{-8}</td>
<td>2K-forb.</td>
<td>1.2</td>
<td>5.2</td>
<td>$T_2^+$ : (Eng 53)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$N_y, N_o$ : (Ev 57) (Ev 59)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$N_y, N_o$ : (Ev 57) (Ev 59)</td>
</tr>
<tr>
<td>245Ca (394)</td>
<td>&lt; 8x10^{-10}</td>
<td>394</td>
<td>9/2 9/2^ [754]</td>
<td>7/2 7/2^+ [524]</td>
<td>E1</td>
<td>6500</td>
<td>200</td>
<td>&lt;1.0x10^{-6}</td>
<td>&lt;5.6x10^{-8}</td>
<td>&lt;44</td>
<td>-</td>
<td>5.2</td>
<td>$T_2^+$ : (St 56)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$N_y, N_o$ : (Ro 58)</td>
</tr>
<tr>
<td>257Cf (103)</td>
<td>3.7x10^{-8}</td>
<td>81.1</td>
<td>7/2 7/2^ [613]</td>
<td>3/2 1/2^ [820]</td>
<td>E2</td>
<td>88</td>
<td>5700</td>
<td>3.8x10^{-5}</td>
<td>2.2</td>
<td>K-forb.</td>
<td>1.4</td>
<td>5.4</td>
<td>$T_2^+$ : (As 64)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$N_y, N_o$ : (As 64) (Ro 58)</td>
</tr>
</tbody>
</table>
Remarks to Table II

173 Yb:

The relative gamma ray intensities depopulating the 351.2 level were taken from the measurements by Bichard et al. (Bi 59), which are in reasonable agreement with the results obtained by (Go 59), (Di 59) and (Ha 59). Using the relative gamma intensities of the latter authors yields still higher values of the hindrance factor \( F_N \) for the 351.2 keV El transition.

For the 397 keV level there exist two interpretations of the spin:

1) Orth et al. (Or 63) \( 1/2^+ 1/2^- [521] \)
2) Kuroyanagi et al. (Ku 63) \( 3/2^+ 3/2^- [651] \)

According to Table XXXI of (Ha 62) or Table 3b of (Ma 64) the intrinsic state \( 1/2^+ 1/2^- [521] \) is expected to lie in \( \text{Yb} \) at \( \leq 400 \) keV. If the 397 keV level were not identical with the \( 1/2^+ 1/2^- [521] \) state, one would expect this level to lie lower than 400 keV, requiring a pretty strong beta branch from \( \text{Ta} \) \( 1/2^- 1/2^+ [411] \) to this level.

If the 397 keV level were the \( 3/2^+ 3/2^- [651] \) intrinsic state, the El transition to the ground state would be hindered by \( F_N \approx 7 \times 10^3 \) if there were no M2 admixture. But a high M2 admixture must be expected (the theoretical partial M2 gamma half-life corresponds to \( \approx 1.4 \times 10^{-5} \) sec and the M2 transitions with \( \Delta K = 1 \) are usually in agreement with the theoretical values), which would increase the hindrance factor \( F_N \) for the El transition. This would yield the highest hindrance factor yet determined for an El transition.

Also from \( (d, p) \) and \( (d, t) \) reactions it must be deduced that the 397 keV level is the \( 1/2^- 1/2^+ [521] \) state (Bu 64).

For these reasons the interpretation by Orth et al. (Or 63) was used in the present investigation. The E2 reduced transition probability to the ground state is then in good agreement with that of the E2 transition \( 1/2^- 1/2^+ [411] \) to \( 5/2^- \) in \( \text{Ta} \) (see the discussion about E2 transitions).
173\textsuperscript{Yb}: The half-life of the 536.8 keV level in \textsuperscript{173}Yb measured by delayed coincidences between the KX rays and gamma rays (Be 61) from the decay of \textsuperscript{173}Lu omitted. According to Wilson and Wool (Wi 60), Jastrzebski et al. (Ja 64) and Zylicz et al. (Zy 64), the 636.8 keV level is only populated by L, M, N capture in this decay.

177\textsuperscript{Hf}: For the used mixing ratio \(\delta^2 = 0.78\) of the 321.4 keV transition, the relative conversion electron intensities of Harmatz et al. (Ha 60) are in agreement with the relative gamma intensities measured by Marmier and Boehm (Ma 55) and Mann et al. (Ma 57) for the 321.4 and 208.4 keV transitions. Harmatz et al. give \(\delta^2 = 1.25\) and the measured \(Q_K\)-value by Marmier and Boehm yields \(\delta^2 = 0.64\).

179\textsuperscript{W}: If the 221.8 KeV level were to be interpreted as the \(1/2^+ \ [521]\) intrinsic state instead of the \(1/2^- \ [510]\), the M3 transition to the ground state would be still more delayed; the hindrance factor would be \(F_N \approx 360\).
Table III: Hindrance factors of E2 gamma ray transitions with $\Delta K = 1$ relative to the Weisskopf estimate ($F_W$), the pure Nilsson model without mixing ($F_N$) and to the calculations by Paessler with mixing of Nilsson states ($F_F$).

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>Transition</th>
<th>$F_W$</th>
<th>$F_N$</th>
<th>$F_F^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{153}$Eu $^{63}$</td>
<td>$3/2 \to 3/2^+ [411] + 5/2 \to 5/2^+ [413]$</td>
<td>$0.6 \pm 0.3$</td>
<td>$(3.0 \pm 1.5) \times 10^{-5}$</td>
<td>$6.8 \pm 3.4$</td>
</tr>
<tr>
<td></td>
<td>$5/2 \to 5/2^+ [411] + 5/2 \to 5/2^+ [413]$</td>
<td>$2.0 \pm 0.3$</td>
<td>$(9.7 \pm 9.1) \times 10^{-5}$</td>
<td>$22 \pm 11$</td>
</tr>
<tr>
<td></td>
<td>$5/2 \to 5/2^+ [411] + 7/2 \to 5/2^+ [413]$</td>
<td>$0.5 \pm 0.3$</td>
<td>$(9.1 \pm 13.7) \times 10^{-6}$</td>
<td>$18 \pm 27$</td>
</tr>
<tr>
<td>$^{155}$Eu $^{63}$</td>
<td>$3/2 \to 3/2^+ [411] + 5/2 \to 5/2^+ [413]$</td>
<td>$0.27 \pm 0.27$</td>
<td>$(1.0 \pm 1.0) \times 10^{-5}$</td>
<td>$0.9 \pm 0.9$</td>
</tr>
<tr>
<td>$^{155}$Gd $^{64}$</td>
<td>$5/2 \to 5/2^+ [642] + 3/2 \to 3/2^+ [651]$</td>
<td>$57 \pm 114$</td>
<td>$(1.3 \pm 2.6) \times 10^{-3}$</td>
<td>$56 \pm 112$</td>
</tr>
<tr>
<td>$^{161}$Dy $^{66}$</td>
<td>$3/2 \to 3/2^+ [521] + 5/2 \to 5/2^+ [523]$</td>
<td>$(9.1 \pm 1.9) \times 10^{-5}$</td>
<td>$(6.6 \pm 6.6) \times 10^{-5}$</td>
<td>$3.1 \pm 3.1$</td>
</tr>
<tr>
<td>$^{175}$Lu $^{71}$</td>
<td>$5/2 \to 5/2^+ [402] + 7/2 \to 7/2^+ [404]$</td>
<td>$0.28 \pm 0.28$</td>
<td>$(5.1 \pm 5.1) \times 10^{-5}$</td>
<td>$0.30 \pm 0.30$</td>
</tr>
<tr>
<td></td>
<td>$5/2 \to 5/2^+ [402] + 9/2 \to 7/2^+ [404]$</td>
<td>$2.5 \pm 1.3$</td>
<td>$(3.7 \pm 1.9) \times 10^{-4}$</td>
<td>$2.2 \pm 1.1$</td>
</tr>
<tr>
<td>$^{181}$Ta $^{73}$</td>
<td>$5/2 \to 5/2^+ [402] + 7/2 \to 7/2^+ [404]$</td>
<td>$37 \pm 8$</td>
<td>$(1.0 \pm 0.2) \times 10^{-2}$</td>
<td>$23 \pm 5$</td>
</tr>
<tr>
<td></td>
<td>$5/2 \to 5/2^+ [402] + 9/2 \to 7/2^+ [404]$</td>
<td>$42 \pm 8$</td>
<td>$(9.2 \pm 1.9) \times 10^{-3}$</td>
<td>$22 \pm 5$</td>
</tr>
<tr>
<td>$^{233}$M $^{92}$</td>
<td>$3/2 \to 3/2^+ [631] + 7/2 \to 5/2^+ [633]$</td>
<td>$10.9 \pm 3.0$</td>
<td>$(3.4 \pm 1.0) \times 10^{-2}$</td>
<td></td>
</tr>
</tbody>
</table>

* calculated with effective charges for the single-particle part: $e_{eff} = (2 + \frac{Z}{A^2})$ for odd-proton nuclei

and $e_{eff} = (1 + \frac{Z}{A^2})$ for odd-neutron nuclei.
Table IV: Hindrance factors of E2 gamma ray transitions with $\Delta K = 2$

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>Transition</th>
<th>$F_W$</th>
<th>$F_N$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{169}_{70}$Yb</td>
<td>$5/2 \ 5/2^- [512] \rightarrow 1/2 \ 1/2^- [521]$</td>
<td>4.1 ± 1.2</td>
<td>0.015 ± 0.005</td>
</tr>
<tr>
<td>$^{171}_{70}$Yb</td>
<td>$5/2 \ 5/2^- [512] \rightarrow 5/2 \ 1/2^- [521]$</td>
<td>18 ± 4</td>
<td>0.039 ± 0.008</td>
</tr>
<tr>
<td>$^{173}_{70}$Yb</td>
<td>$1/2 \ 1/2^- [521] \rightarrow 5/2 \ 5/2^- [512]$</td>
<td>3100 ± 310</td>
<td>32 ± 3</td>
</tr>
<tr>
<td>$^{175}_{72}$Hf</td>
<td>$1/2 \ 1/2^- [521] \rightarrow 5/2 \ 5/2^- [512]$</td>
<td>390 ± 78</td>
<td>4.0 ± 0.8</td>
</tr>
<tr>
<td>$^{181}_{73}$Ta</td>
<td>$1/2 \ 1/2^+[411] \rightarrow 5/2 \ 5/2^+[402]$</td>
<td>180 ± 18</td>
<td>7.0 ± 0.7</td>
</tr>
<tr>
<td>$^{237}_{92}$U</td>
<td>$5/2 \ 5/2^+[622] \rightarrow 1/2 \ 1/2^+[631]$</td>
<td>0.09 ± 0.09</td>
<td>(1.8 ± 1.8) x 10^{-4}</td>
</tr>
<tr>
<td>$^{237}_{93}$Np</td>
<td>$3/2 \ 1/2^- [530] \rightarrow 7/2 \ 5/2^- [523]$</td>
<td>2.6 ± 1.0</td>
<td>(1.6 ± 0.6) x 10^{-3}</td>
</tr>
<tr>
<td>$^{239}_{94}$Pu</td>
<td>$5/2 \ 5/2^+[622] \rightarrow 1/2 \ 1/2^+[631]$</td>
<td>170 ± 60</td>
<td>0.39 ± 0.12</td>
</tr>
</tbody>
</table>
Table V: Hindrance factors $F_N$ of $\alpha$ transitions in odd-proton nuclei

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>initial state</th>
<th>final state</th>
<th>deform. $\eta$</th>
<th>hindrance factor $F_N = F_N(g_R, g_s)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{153}_{63}Eu$</td>
<td>$3/2 \ 3/2^+[411]$</td>
<td>$5/2 \ 5/2^+[413]$</td>
<td>4.8</td>
<td>$g_s = g_s(\text{free})$&lt;br&gt;$g_s(\text{eff}) = 0.61 g_s(\text{free})$&lt;br&gt; $\sigma_R = 0.475$ $\sigma_R = 0.42$ $\sigma_R = 0.50$&lt;br&gt;0.24 0.066 0.37 0.37 0.67 0.26</td>
</tr>
<tr>
<td>$^{155}_{63}Eu$</td>
<td>$3/2 \ 3/2^+[411]$</td>
<td>$5/2 \ 5/2^+[413]$</td>
<td>4.8</td>
<td>$g_s = g_s(\text{free})$&lt;br&gt;$g_s(\text{eff}) = 0.61 g_s(\text{free})$&lt;br&gt; $\sigma_R = 0.37$ $\sigma_R = 0.31$ $\sigma_R = 0.40$&lt;br&gt;3.2 0.86 4.9 4.8 8.8 3.4</td>
</tr>
<tr>
<td>$^{175}_{71}Lu$</td>
<td>$5/2 \ 5/2^+[402]$</td>
<td>$7/2 \ 7/2^+[404]$</td>
<td>4.5</td>
<td>$g_s = g_s(\text{free})$&lt;br&gt;$g_s(\text{eff}) = 0.60 g_s(\text{free})$&lt;br&gt; $\sigma_R = 0.321$ $\sigma_R = 0.31$ $\sigma_R = 0.40$&lt;br&gt;2.5 4.8 3.3 4.6 8.4 5.9</td>
</tr>
<tr>
<td>$^{181}_{73}Ta$</td>
<td>$5/2 \ 5/2^+[402]$</td>
<td>$7/2 \ 7/2^+[404]$</td>
<td>3.7</td>
<td>$g_s = g_s(\text{free})$&lt;br&gt;$g_s(\text{eff}) = 0.51 g_s(\text{free})$&lt;br&gt; $\sigma_R = 0.305$ $\sigma_R = 0.31$ $\sigma_R = 0.40$&lt;br&gt;1700- 3100* 1900- 8600* 1200- 5600* 3600-17000* 3700-17000* 2600-12000*</td>
</tr>
</tbody>
</table>

* The two values of $F_N$ correspond to the two experimental partial half-lives $T_{1/2\alpha}(\alpha \gamma)$ given in table I (for $Q^2 = 8$ and $Q^2 = 40$).
Table VI: Hindrance factors $F_N$ of M1 transitions in odd-neutron nuclei

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>Initial state</th>
<th>Final state</th>
<th>$g(R)$</th>
<th>$g_S$ (free)</th>
<th>$g_S$ (eff)</th>
<th>Hindrance factor $F_N = F_R(g_R, g_S)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{155}_{64}$Gd</td>
<td>$5/2^- 5/2^+ [642]$</td>
<td>$5/2^- 5/2^+ [651]$</td>
<td>6.2</td>
<td>$g_S = g_S$ (free)</td>
<td>$g_S$ (eff) = 0.61 $g_S$ (free)</td>
<td>$g_R = 0.31 \quad g_R = 0.25 \quad g_R = 0.35$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>300 240 340</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>200 150 230</td>
</tr>
<tr>
<td>$^{161}_{66}$Dy</td>
<td>$3/2^- 3/2^- [521]$</td>
<td>$3/2^- 3/2^- [523]$</td>
<td>6.0</td>
<td>$g_S = g_S$ (free)</td>
<td>$g_S$ (eff) = 0.52 $g_S$ (free)</td>
<td>$g_R = 0.22 \quad g_R = 0.20 \quad g_R = 0.30$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.4 1.6 1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.16 0.19 0.06</td>
</tr>
<tr>
<td>$^{233}_{92}$U</td>
<td>$3/2^- 3/2^+ [631]$</td>
<td>$3/2^- 3/2^+ [633]$</td>
<td>4.8</td>
<td>$g_S = g_S$ (free)</td>
<td>$g_S$ (eff) = 0.6 $g_S$ (free)</td>
<td>$g_R = 0.27 \quad g_R = 0.22 \quad g_R = 0.32$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>36 40 32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.5 10.0 5.6</td>
</tr>
</tbody>
</table>
Table VII: Experimentally determined values of $M^2$ according to formula (10) and $F_w$-hindrance factors of K-forbidden gamma ray transitions.

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>Initial state</th>
<th>Final state</th>
<th>Multipolarity</th>
<th>Degree of forbiddenness</th>
<th>$M^2$</th>
<th>$F_w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{161}\text{Tb}$</td>
<td>$7/2^- \ 7/2^-[523]$</td>
<td>$5/2^+ \ 3/2^+[411]$</td>
<td>E1</td>
<td>$1K$</td>
<td>$(2.1 \pm 0.2) \times 10^{-8}$</td>
<td>$(2.4 \pm 0.3) \times 10^5$</td>
</tr>
<tr>
<td>$^{161}\text{Tb}$</td>
<td>$7/2^- \ 7/2^-[523]$</td>
<td>$7/2^+ \ 3/2^+[411]$</td>
<td>E1</td>
<td>$1K$</td>
<td>$(7.5 \pm 4.5) \times 10^{-9}$</td>
<td>$(1.0 \pm 0.6) \times 10^6$</td>
</tr>
<tr>
<td>$^{231}\text{Pa}$</td>
<td>$5/2^- \ 5/2^+[642]$</td>
<td>$3/2^- \ 1/2^-[530]$</td>
<td>E1</td>
<td>$1K$</td>
<td>$(6.5 \pm 2.6) \times 10^{-9}$</td>
<td>$(1.9 \pm 0.7) \times 10^6$</td>
</tr>
<tr>
<td>$^{233}\text{Pa}$</td>
<td>$5/2^- \ 5/2^+[642]$</td>
<td>$7/2^- \ 1/2^-[530]$</td>
<td>E1</td>
<td>$1K$</td>
<td>$(9.5 \pm 3.8) \times 10^{-7}$</td>
<td>$(3.0 \pm 1.2) \times 10^4$</td>
</tr>
<tr>
<td>$^{233}\text{Pa}$</td>
<td>$7/2^- \ 5/2^+[642]$</td>
<td>$5/2^- \ 1/2^-[530]$</td>
<td>E1</td>
<td>$1K$</td>
<td>$(1.3 \pm 0.6) \times 10^{-8}$</td>
<td>$(8.7 \pm 4.3) \times 10^5$</td>
</tr>
<tr>
<td>$^{237}\text{Np}$</td>
<td>$3/2^- \ 1/2^-[530]$</td>
<td>$5/2^- \ 5/2^+[642]$</td>
<td>E1</td>
<td>$1K$</td>
<td>$(1.3 \pm 0.7) \times 10^{-10}$</td>
<td>$(6.4 \pm 3.2) \times 10^7$</td>
</tr>
<tr>
<td>$^{167}\text{Tm}$</td>
<td>$7/2^- \ 7/2^-[523]$</td>
<td>$5/2^- \ 1/2^+[411]$</td>
<td>E1</td>
<td>$2K$</td>
<td>$(4.4 \pm 1.4) \times 10^{-12}$</td>
<td>$(1.5 \pm 0.4) \times 10^8$</td>
</tr>
<tr>
<td>$^{167}\text{Tm}$</td>
<td>$7/2^- \ 7/2^-[523]$</td>
<td>$7/2^- \ 1/2^+[411]$</td>
<td>E1</td>
<td>$2K$</td>
<td>$(6.0 \pm 3.0) \times 10^{-13}$</td>
<td>$(8.3 \pm 4.2) \times 10^8$</td>
</tr>
<tr>
<td>$^{169}\text{Tm}$</td>
<td>$7/2^- \ 7/2^-[523]$</td>
<td>$5/2^- \ 1/2^+[411]$</td>
<td>E1</td>
<td>$2K$</td>
<td>$(3.4 \pm 3.4) \times 10^{-12}$</td>
<td>$(2.0 \pm 2.0) \times 10^8$</td>
</tr>
<tr>
<td>$^{169}\text{Tm}$</td>
<td>$7/2^- \ 7/2^-[523]$</td>
<td>$7/2^- \ 1/2^+[411]$</td>
<td>E1</td>
<td>$2K$</td>
<td>$(2.3 \pm 4.6) \times 10^{-13}$</td>
<td>$(2.2 \pm 4.4) \times 10^9$</td>
</tr>
</tbody>
</table>

\(^{a)} \) 1K = Once K-forbidden transition
<table>
<thead>
<tr>
<th>Nucleus</th>
<th>Initial state</th>
<th>Final state</th>
<th>Multipolarity</th>
<th>Degree of forbiddenness</th>
<th>$M^2$</th>
<th>$F_W$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{171}_{69}Tm$</td>
<td>$7/2 7/2^{-}[523]$</td>
<td>$5/2 1/2^+[411]$</td>
<td>E1</td>
<td>2K</td>
<td>$(1.4 \pm 0.2) \times 10^{-12}$</td>
<td>$(4.8 \pm 0.5) \times 10^{8}$</td>
</tr>
<tr>
<td>$^{171}_{69}Tm$</td>
<td>$7/2 7/2^{-}[523]$</td>
<td>$7/2 1/2^+[411]$</td>
<td>E1</td>
<td>2K</td>
<td>$(4.4 \pm 0.8) \times 10^{-13}$</td>
<td>$(1.2 \pm 0.2) \times 10^{9}$</td>
</tr>
<tr>
<td>$^{173}_{71}Lu$</td>
<td>$5/2 1/2^{-}[541]$</td>
<td>$7/2 7/2^+[404]$</td>
<td>E1</td>
<td>2K</td>
<td>$(6.3 \pm 0.6) \times 10^{-13}$</td>
<td>$(8.1 \pm 0.8) \times 10^{8}$</td>
</tr>
<tr>
<td>$^{175}_{71}Lu$</td>
<td>$5/2 1/2^{-}[541]$</td>
<td>$7/2 7/2^+[404]$</td>
<td>E1</td>
<td>2K</td>
<td>$(2.1 \pm 0.2) \times 10^{-12}$</td>
<td>$(2.5 \pm 0.3) \times 10^{8}$</td>
</tr>
<tr>
<td>$^{239}_{94}Pu$</td>
<td>$7/2 7/2^{-}[743]$</td>
<td>$5/2 1/2^+[631]$</td>
<td>E1</td>
<td>2K</td>
<td>$(1.2 \pm 0.3) \times 10^{-12}$</td>
<td>$(7.2 \pm 1.4) \times 10^{8}$</td>
</tr>
<tr>
<td>$^{239}_{94}Pu$</td>
<td>$7/2 7/2^{-}[743]$</td>
<td>$7/2 1/2^+[631]$</td>
<td>E1</td>
<td>2K</td>
<td>$(7.8 \pm 2.4) \times 10^{-13}$</td>
<td>$(6.2 \pm 2.4) \times 10^{8}$</td>
</tr>
<tr>
<td>$^{169}_{70}Yb$</td>
<td>$5/2 5/2^{-}[512]$</td>
<td>$3/2 1/2^{-}[521]$</td>
<td>M1</td>
<td>1K</td>
<td>$(7.5 \pm 3.7) \times 10^{-9} - 2.5 \times 10^{-9}$</td>
<td>$(1.3 \pm 0.7) \times 10^{4}$</td>
</tr>
<tr>
<td>$^{169}_{70}Yb$</td>
<td>$5/2 5/2^{-}[512]$</td>
<td>$5/2 1/2^{-}[521]$</td>
<td>M1</td>
<td>1K</td>
<td>$(1.1 \pm 1.7) \times 10^{-8} - 0.7 \times 10^{-8}$</td>
<td>$(7.6 \pm 11.4) \times 10^{3}$</td>
</tr>
<tr>
<td>$^{171}_{70}Yb$</td>
<td>$5/2 5/2^{-}[512]$</td>
<td>$3/2 1/2^{-}[521]$</td>
<td>M1</td>
<td>1K</td>
<td>$(8.5 \pm 1.5) \times 10^{-9}$</td>
<td>$(1.2 \pm 0.2) \times 10^{4}$</td>
</tr>
<tr>
<td>$^{171}_{70}Yb$</td>
<td>$5/2 5/2^{-}[512]$</td>
<td>$5/2 1/2^{-}[521]$</td>
<td>M1</td>
<td>1K</td>
<td>$(1.3 \pm 0.4) \times 10^{-9}$</td>
<td>$(6.7 \pm 2.0) \times 10^{4}$</td>
</tr>
<tr>
<td>$^{173}_{70}Yb$</td>
<td>$3/2 1/2^{-}[521]$</td>
<td>$5/2 5/2^{-}[512]$</td>
<td>M1</td>
<td>1K</td>
<td>$(9.0 \pm 1.8) \times 10^{-9}$</td>
<td>$(7.5 \pm 1.5) \times 10^{3}$</td>
</tr>
<tr>
<td>$^{237}_{93}Np$</td>
<td>$3/2 1/2^{-}[530]$</td>
<td>$5/2 5/2^{-}[523]$</td>
<td>M1</td>
<td>1K</td>
<td>$(7.8 \pm 1.6) \times 10^{-9}$</td>
<td>$(8.4 \pm 1.7) \times 10^{3}$</td>
</tr>
<tr>
<td>$^{239}_{94}Pu$</td>
<td>$5/2 5/2^{+}[522]$</td>
<td>$3/2 1/2^{+}[631]$</td>
<td>M1</td>
<td>1K</td>
<td>$(4.0 \pm 0.8) \times 10^{-8}$</td>
<td>$(2.6 \pm 0.5) \times 10^{3}$</td>
</tr>
<tr>
<td>Nucleus</td>
<td>Initial state</td>
<td>Final state</td>
<td>Multipolarity</td>
<td>Degree of forbiddenness</td>
<td>$M^2$</td>
<td>$F_W$</td>
</tr>
<tr>
<td>---------</td>
<td>---------------</td>
<td>-------------</td>
<td>---------------</td>
<td>------------------------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>$^{239}_{94}$Pu</td>
<td>5/2 5/2$^+$[622]</td>
<td>5/2 1/2$^+$[631]</td>
<td>M1</td>
<td>1K</td>
<td>$(8.6 \pm 1.7) \times 10^{-8}$</td>
<td>$(1.0 \pm 0.2) \times 10^3$</td>
</tr>
<tr>
<td>$^{239}_{94}$Pu</td>
<td>5/2 5/2$^+$[622]</td>
<td>7/2 1/2 [631]</td>
<td>M1</td>
<td>1K</td>
<td>$(1.1 \pm 0.3) \times 10^{-8}$</td>
<td>$(2.6 \pm 0.8) \times 10^4$</td>
</tr>
<tr>
<td>$^{167}_{69}$Tm</td>
<td>7/2 7/2$^+$[404]</td>
<td>5/2 1/2$^+$[411]</td>
<td>M1</td>
<td>2K</td>
<td>$(3 \text{ to } 11) \times 10^{-11}$</td>
<td>$(0.6 \text{ to } 2.1) \times 10^5$</td>
</tr>
<tr>
<td>$^{167}_{69}$Tm</td>
<td>7/2 7/2$^+$[404]</td>
<td>7/2 1/2$^+$[411]</td>
<td>M1</td>
<td>2K</td>
<td>$(0.9 \text{ to } 8.8) \times 10^{-11}$</td>
<td>$(0.6 \text{ to } 6.0) \times 10^5$</td>
</tr>
<tr>
<td>$^{169}_{69}$Tm</td>
<td>7/2 7/2$^+$[404]</td>
<td>5/2 1/2$^+$[411]</td>
<td>M1</td>
<td>2K</td>
<td>$(9.7 \pm 2.0) \times 10^{-12}$</td>
<td>$(6.7 \pm 1.3) \times 10^5$</td>
</tr>
<tr>
<td>$^{169}_{69}$Tm</td>
<td>7/2 7/2$^+$[404]</td>
<td>7/2 1/2$^+$[411]</td>
<td>M1</td>
<td>2K</td>
<td>$(6.2 \pm 1.2) \times 10^{-12}$</td>
<td>$(7.8 \pm 1.5) \times 10^5$</td>
</tr>
<tr>
<td>$^{251}_{98}$Cf</td>
<td>7/2 7/2$^+$[613]</td>
<td>5/2 1/2$^+$[620]</td>
<td>M1</td>
<td>2K</td>
<td>$(2.0 \pm 0.7) \times 10^{-10}$</td>
<td>$(3.4 \pm 1.3) \times 10^4$</td>
</tr>
<tr>
<td>$^{169}_{69}$Tm</td>
<td>7/2 7/2$^+$[404]</td>
<td>3/2 1/2$^+$[411]</td>
<td>E2</td>
<td>1K</td>
<td>$(2.1 \pm 0.2) \times 10^{-6}$</td>
<td>$(1.8 \pm 0.2) \times 10^3$</td>
</tr>
<tr>
<td>$^{169}_{69}$Tm</td>
<td>7/2 7/2$^+$[404]</td>
<td>5/2 1/2$^+$[411]</td>
<td>E2</td>
<td>1K</td>
<td>$(2.3 \pm 2.3) \times 10^{-6}$</td>
<td>$(9.2 \pm 9.2) \times 10^2$</td>
</tr>
<tr>
<td>$^{169}_{69}$Tm</td>
<td>7/2 7/2$^+$[404]</td>
<td>7/2 1/2$^+$[411]</td>
<td>E2</td>
<td>1K</td>
<td>$(3.4 \pm 3.4) \times 10^{-6}$</td>
<td>$(8.4 \pm 8.4) \times 10^2$</td>
</tr>
<tr>
<td>$^{251}_{98}$Cf</td>
<td>7/2 7/2$^+$[613]</td>
<td>3/2 1/2$^+$[620]</td>
<td>E2</td>
<td>1K</td>
<td>$(2.9 \pm 1.7) \times 10^{-3}$</td>
<td>$2.2 \pm 0.9$</td>
</tr>
</tbody>
</table>
The hindrance factors $F_N$ of $E1, \Delta K = 0$ transitions are given as a function of the mass number. The following symbols are used in this and all succeeding figures:

- $\otimes$ denotes proton transitions
- $\otimes$ denotes neutron transitions

A: transition from $I_i = K_i$ to $I_f = K_f$
B: transition from $I_i = K_i$ to $I_f = K_f + 1$
C: transition from $I_i = K_i$ to $I_f = K_f + 2$
D: transition from $I_i = K_i + 1$ to $I_f = K_f$
E: transition from $I_i = K_i + 1$ to $I_f = K_f + 1$

where the subscripts $i$ and $f$ denote the initial and final state, respectively.

Transitions between the same states in different nuclei are connected by lines.

Transitions in the same nucleus to different rotational members of the same intrinsic state are connected by broken lines.

Estimated errors are given by bars; arrows indicate upper limits.
Fig. 2 The hindrance factors $F_N$ of $E1, \Delta K = 1$ transitions are shown as a function of the mass number. See caption of fig. 1 for notation.
The change of reciprocal value of the pairing factor $P$ defined by eq. 9 as a function of the proton or neutron number for a nucleus with 400 keV equally spaced single particle levels is given where the Fermi surface is situated a) exactly between the intrinsic levels, b) 100 keV above the intrinsic level, and c) is identical with the single particle levels. Giving the reciprocal value $P$ shows how the hindrance factors $F_N$ (given in the other figures) should change due to the pairing factor.
Fig. 4 The hindrance factors $F_N$ of $E2$, $\Delta K = 1$ transitions are shown as a function of the mass number. See also caption of fig. 1.
The hindrance factors $F_N$ of E2, $\Delta K = 1$ transitions are shown as a function of $A_K \sqrt{(I-K_<) (I+K_>)}$ where $\Delta E$ is the energy difference between the two states which are responsible for mixing of the two rotational bands involved in the E2 gamma ray transition and $A_K \sqrt{(I-K_<) (I+K_>)}$ is a measure of the strength of the Coriolis coupling. See captions of fig. 1 for notation.
The hindrance factors $F_N$ of $E2, \Delta K = 2$ transitions are shown as a function of the energy difference between the two states with the same total angular momentum which mix the two rotational bands. See caption of fig. 1. The two values of $F_N$ for the proton transitions correspond to the hindrance factors obtained with (the upper) and without (the lower) effective charge correction (see text).
Fig. 7 The hindrance factors $F_N$ for all E3 transitions are shown as a function of the mass number. See caption of fig 1 for notation.
Fig. 8 The hindrance factors $F_N$ of M2 transitions are given as a function of the mass number. See caption of fig. 1 for notation.