

<sup>239</sup>Pu(n,F $\gamma$ ) 2009Si21

| Type            | Author  | History Citation | Literature Cutoff Date |
|-----------------|---------|------------------|------------------------|
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Includes studies of delayed  $\gamma$  rays from <sup>239</sup>Pu(n,F $\gamma$ ) and from <sup>238</sup>U SF decay as well as of prompt  $\gamma$  rays from <sup>252</sup>Cf SF decay. [2009Si21](#) was compiled for XUNDL database by B. Karamy and B. Singh (McMaster).

[2009Si21](#): delayed  $\gamma$  rays from <sup>154</sup>Nd produced by <sup>239</sup>Pu(n,F $\gamma$ ) reaction were detected by two clover Ge detectors using the Lohengrin mass spectrometer of high-flux reactor of ILL, Grenoble. The mass spectrometer was used to select nuclei recoiling according to their mass-to-ion-charge and kinetic energy of the ion ratios. The time of flight through the spectrometer was  $\approx 2.7$   $\mu$ s. Measured E $\gamma$ , I $\gamma$ ,  $\gamma\gamma$ , and half-lives. Comparison with QRPM calculations.

[2009Si21](#): <sup>252</sup>Cf SF decay study, measured E $\gamma$ , I $\gamma$ ,  $\gamma\gamma$  using Gammasphere array at ANL. Prompt  $\gamma$  rays measured.

[2012YoZZ](#), [2013YoZZ](#): in-flight fission of 345 MeV/nucleon <sup>238</sup>U beam. Radioactive ion beams identified in so called PID plot by proton number (Z) versus mass-to-charge ratio (A/Q) obtained by measurement of the magnetic rigidity (B $\rho$ ), time of flight (TOF), and energy loss (dE) in the BigRIPS separator. Used total kinetic energy (TKE) detector (20 layers of Si detectors) in the F12 focal plane at the end of the BigRIPS beamline, in order to identify heavier elements with different atomic charge states. Measured delayed  $\gamma$  rays 135.5, 162.1, 270.0, 294.6, 794.0, 894.7, 931.0, 957.2 (with no uncertainty) and deduced T<sub>1/2</sub>.

No evidence was found by [2009Si21](#) for a (5<sup>-</sup>) isomer with T<sub>1/2</sub>>1  $\mu$ s reported in [1998Ga12](#).

<sup>154</sup>Nd Levels

| E(level) <sup>†</sup>     | J $\pi$ <sup>‡</sup> | T <sub>1/2</sub> | Comments   |
|---------------------------|----------------------|------------------|--|
| 0.0 <sup>#</sup>          | 0 <sup>+</sup>       |                  |  |
| 70.8 <sup>#</sup> 3       | 2 <sup>+</sup>       |                  |  |
| 233.3 <sup>#</sup> 4      | 4 <sup>+</sup>       |                  |  |
| 481.6 <sup>#</sup> 5      | 6 <sup>+</sup>       |                  |  |
| 809.4 <sup>#</sup> 6      | 8 <sup>+</sup>       |                  |  |
| 961.9 <sup>&amp;</sup>    | (1 <sup>-</sup> )    |                  |  |
| 1002.7 <sup>@</sup> 4     | (2 <sup>-</sup> )    |                  |  |
| 1027.7 <sup>&amp;</sup> 4 | (3 <sup>-</sup> )    |                  |  |
| 1128.2 <sup>@</sup> 4     | (4 <sup>-</sup> )    |                  |  |
| 1162.9 <sup>&amp;</sup> 5 | (5 <sup>-</sup> )    |                  |  |
| 1209.8 <sup>#</sup> 7     | 10 <sup>+</sup>      |                  |  |
| 1297.9 <sup>a</sup> 4     | (4 <sup>-</sup> )    | 3.0 $\mu$ s 3    | T <sub>1/2</sub> : weighted average of 3.2 $\mu$ s 3 ( <a href="#">2009Si21</a> ); 2.7 $\mu$ s 3 ( <a href="#">2013YoZZ</a> , superseding 2.7 $\mu$ s 5 from <a href="#">2012YoZZ</a> ). All studies done by fitting the summed time spectra of the most intense delayed $\gamma$ rays.<br>Dominant configuration= $\nu 5/2[642] \otimes \nu 3/2[521]$ . |
| 1325.4 <sup>@</sup> 5     | (6 <sup>-</sup> )    |                  |  |
| 1384.2 <sup>b</sup> 5     | (5 <sup>-</sup> )    |                  |  |
| 1488.0 <sup>a</sup> 6     | (6 <sup>-</sup> )    |                  |  |
| 1593.7 <sup>@</sup> 6     | (8 <sup>-</sup> )    |                  |  |
| 1608.7 <sup>b</sup> 6     | (7 <sup>-</sup> )    |                  |  |
| 1676.2 <sup>#</sup> 7     | 12 <sup>+</sup>      |                  |  |
| 1746.7 <sup>a</sup> 7     | (8 <sup>-</sup> )    |                  |  |
| 1902.3 <sup>b</sup> 7     | (9 <sup>-</sup> )    |                  |  |
| 1931.8 <sup>@</sup> 7     | (10 <sup>-</sup> )   |                  |  |
| 2074.5 <sup>a</sup> 8     | (10 <sup>-</sup> )   |                  |  |
| 2201.5 <sup>#</sup> 8     | 14 <sup>+</sup>      |                  |  |
| 2263.7 <sup>b</sup> 8     | (11 <sup>-</sup> )   |                  |  |
| 2337.4 <sup>@</sup> 8     | (12 <sup>-</sup> )   |                  |  |

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<sup>239</sup>Pu(n,Fγ) 2009Si21 (continued)

<sup>154</sup>Nd Levels (continued)

| E(level) <sup>†</sup> | J <sup>π</sup> <sup>‡</sup> | E(level) <sup>†</sup> | J <sup>π</sup> <sup>‡</sup> | E(level) <sup>†</sup>  | J <sup>π</sup> <sup>‡</sup> |
|-----------------------|-----------------------------|-----------------------|-----------------------------|------------------------|-----------------------------|
| 2468.0 <sup>a</sup> 9 | (12 <sup>-</sup> )          | 2778.0 <sup>#</sup> 9 | 16 <sup>+</sup>             | 2950.2 <sup>a</sup> 10 | (14 <sup>-</sup> )          |
| 2691.5 <sup>b</sup> 9 | (13 <sup>-</sup> )          | 2807.3 <sup>@</sup> 8 | (14 <sup>-</sup> )          | 3337.8 <sup>@</sup> 9  | (16 <sup>-</sup> )          |
|                       |                             |                       |                             | 3397.6 <sup>#</sup> 9  | (18 <sup>+</sup> )          |

<sup>†</sup> From least-squares fit to the E<sub>γ</sub>'s.

<sup>‡</sup> Adopted by 2009Si21 based on band structure and theoretical calculations.

<sup>#</sup> Band(A): K<sup>π</sup>=0<sup>+</sup> band.

<sup>@</sup> Band(B): K<sup>π</sup>=(1<sup>-</sup>) band, α=0.

& Band(b): K<sup>π</sup>=(1<sup>-</sup>) band, α=1.

<sup>a</sup> Band(C): K<sup>π</sup>=(4<sup>-</sup>) band, α=0.

<sup>b</sup> Band(c): K<sup>π</sup>=(4<sup>-</sup>) band, α=1.

γ(<sup>154</sup>Nd)

| E <sub>γ</sub> <sup>†</sup> | I <sub>γ</sub> <sup>#</sup> | E <sub>i</sub> (level) | J <sub>i</sub> <sup>π</sup> | E <sub>f</sub> | J <sub>f</sub> <sup>π</sup> | Mult.   | Comments  |
|-----------------------------|-----------------------------|------------------------|-----------------------------|----------------|-----------------------------|---------|---|
| 70.8 3                      | 11 2                        | 70.8                   | 2 <sup>+</sup>              | 0.0            | 0 <sup>+</sup>              |         |   |
| 86.3 2                      |                             | 1384.2                 | (5 <sup>-</sup> )           | 1297.9         | (4 <sup>-</sup> )           |         |   |
| 103.8 2                     |                             | 1488.0                 | (6 <sup>-</sup> )           | 1384.2         | (5 <sup>-</sup> )           |         | I <sub>γ</sub> (103.8γ)/I <sub>γ</sub> (190γ)=14.5 75.  |
| 120.7 2                     |                             | 1608.7                 | (7 <sup>-</sup> )           | 1488.0         | (6 <sup>-</sup> )           |         | I <sub>γ</sub> (120.7γ)/I <sub>γ</sub> (224γ)=12.5 64.  |
| 125.5 3                     | 6 1                         | 1128.2                 | (4 <sup>-</sup> )           | 1002.7         | (2 <sup>-</sup> )           | [E2]    |   |
| 134.8 3                     | 8 1                         | 1297.9                 | (4 <sup>-</sup> )           | 1162.9         | (5 <sup>-</sup> )           | [M1+E2] |   |
| 138.1 2                     |                             | 1746.7                 | (8 <sup>-</sup> )           | 1608.7         | (7 <sup>-</sup> )           |         | I <sub>γ</sub> (138.2γ)/I <sub>γ</sub> (259γ)=5.6 21.   |
| 155.6 2                     |                             | 1902.3                 | (9 <sup>-</sup> )           | 1746.7         | (8 <sup>-</sup> )           |         | I <sub>γ</sub> (155.6γ)/I <sub>γ</sub> (293γ)=1.4 4.  |
| 162.4 3                     | 55 9                        | 233.3                  | 4 <sup>+</sup>              | 70.8           | 2 <sup>+</sup>              |         |   |
| 169.8 3                     | 45 7                        | 1297.9                 | (4 <sup>-</sup> )           | 1128.2         | (4 <sup>-</sup> )           | [M1+E2] |   |
| 172.2 2                     |                             | 2074.5                 | (10 <sup>-</sup> )          | 1902.3         | (9 <sup>-</sup> )           |         | I <sub>γ</sub> (172.2γ)/I <sub>γ</sub> (328γ)=4.0 13.   |
| 189.2 2                     |                             | 2263.7                 | (11 <sup>-</sup> )          | 2074.5         | (10 <sup>-</sup> )          |         | I <sub>γ</sub> (189.2γ)/I <sub>γ</sub> (361γ)=1.8 8.  |
| 190 <sup>@</sup>            |                             | 1488.0                 | (6 <sup>-</sup> )           | 1297.9         | (4 <sup>-</sup> )           |         |   |
| 197.2 3                     |                             | 1325.4                 | (6 <sup>-</sup> )           | 1128.2         | (4 <sup>-</sup> )           |         |   |
| 204.2 2                     |                             | 2468.0                 | (12 <sup>-</sup> )          | 2263.7         | (11 <sup>-</sup> )          |         | E <sub>γ</sub> : 204.3 listed in table II of 2009Si21.<br>I <sub>γ</sub> (204.2γ)/I <sub>γ</sub> (394γ)=7.0 36.<br>I <sub>γ</sub> (223.5γ)/I <sub>γ</sub> (428γ)=1.0 4. |
| 223.5 2                     |                             | 2691.5                 | (13 <sup>-</sup> )          | 2468.0         | (12 <sup>-</sup> )          |         |   |
| 224                         |                             | 1608.7                 | (7 <sup>-</sup> )           | 1384.2         | (5 <sup>-</sup> )           |         |   |
| 248.4 3                     | 15 3                        | 481.6                  | 6 <sup>+</sup>              | 233.3          | 4 <sup>+</sup>              |         |   |
| 258.7 2                     |                             | 2950.2                 | (14 <sup>-</sup> )          | 2691.5         | (13 <sup>-</sup> )          |         |   |
| 259 <sup>@</sup>            |                             | 1746.7                 | (8 <sup>-</sup> )           | 1488.0         | (6 <sup>-</sup> )           |         |   |
| 268.3 3                     |                             | 1593.7                 | (8 <sup>-</sup> )           | 1325.4         | (6 <sup>-</sup> )           |         |   |
| 270.3 3                     | 21 4                        | 1297.9                 | (4 <sup>-</sup> )           | 1027.7         | (3 <sup>-</sup> )           | [M1+E2] |   |
| 293                         |                             | 1902.3                 | (9 <sup>-</sup> )           | 1608.7         | (7 <sup>-</sup> )           |         |   |
| 295.3 3                     | 15 3                        | 1297.9                 | (4 <sup>-</sup> )           | 1002.7         | (2 <sup>-</sup> )           |         |   |
| 327.8 3                     |                             | 809.4                  | 8 <sup>+</sup>              | 481.6          | 6 <sup>+</sup>              |         |   |
| 328                         |                             | 2074.5                 | (10 <sup>-</sup> )          | 1746.7         | (8 <sup>-</sup> )           |         |   |
| 338.1 3                     |                             | 1931.8                 | (10 <sup>-</sup> )          | 1593.7         | (8 <sup>-</sup> )           |         |   |
| 361 <sup>@</sup>            |                             | 2263.7                 | (11 <sup>-</sup> )          | 1902.3         | (9 <sup>-</sup> )           |         |   |
| 394                         |                             | 2468.0                 | (12 <sup>-</sup> )          | 2074.5         | (10 <sup>-</sup> )          |         |   |
| 400.4 3                     |                             | 1209.8                 | 10 <sup>+</sup>             | 809.4          | 8 <sup>+</sup>              |         |   |
| 405.6 3                     |                             | 2337.4                 | (12 <sup>-</sup> )          | 1931.8         | (10 <sup>-</sup> )          |         |   |
| 428                         |                             | 2691.5                 | (13 <sup>-</sup> )          | 2263.7         | (11 <sup>-</sup> )          |         |   |
| 466.4 3                     |                             | 1676.2                 | 12 <sup>+</sup>             | 1209.8         | 10 <sup>+</sup>             |         |   |
| 469.9 3                     |                             | 2807.3                 | (14 <sup>-</sup> )          | 2337.4         | (12 <sup>-</sup> )          |         |   |
| 525.3 3                     |                             | 2201.5                 | 14 <sup>+</sup>             | 1676.2         | 12 <sup>+</sup>             |         |   |

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**$^{239}\text{Pu}(n,\text{F}\gamma)$  2009Si21 (continued)** $\gamma(^{154}\text{Nd})$  (continued)

| $E_\gamma$ † | $I_\gamma$ # | $E_i(\text{level})$ | $J_i^\pi$          | $E_f$  | $J_f^\pi$          | $E_\gamma$ † | $I_\gamma$ # | $E_i(\text{level})$ | $J_i^\pi$         | $E_f$ | $J_f^\pi$      |
|--------------|--------------|---------------------|--------------------|--------|--------------------|--------------|--------------|---------------------|-------------------|-------|----------------|
| 530.5 3      |              | 3337.8              | (16 <sup>-</sup> ) | 2807.3 | (14 <sup>-</sup> ) | 895.0 3      | 34 6         | 1128.2              | (4 <sup>-</sup> ) | 233.3 | 4 <sup>+</sup> |
| 576.5 3      |              | 2778.0              | 16 <sup>+</sup>    | 2201.5 | 14 <sup>+</sup>    | 929.4 ‡ 3    | <36          | 1162.9              | (5 <sup>-</sup> ) | 233.3 | 4 <sup>+</sup> |
| 619.6 @ 3    |              | 3397.6              | (18 <sup>+</sup> ) | 2778.0 | 16 <sup>+</sup>    | 932.0 ‡ 3    | <36          | 1002.7              | (2 <sup>-</sup> ) | 70.8  | 2 <sup>+</sup> |
| 682 @        |              | 1162.9              | (5 <sup>-</sup> )  | 481.6  | 6 <sup>+</sup>     | 956.9 3      | 12 4         | 1027.7              | (3 <sup>-</sup> ) | 70.8  | 2 <sup>+</sup> |
| 794.5 3      | 13 3         | 1027.7              | (3 <sup>-</sup> )  | 233.3  | 4 <sup>+</sup>     |              |              |                     |                   |       |                |

† Delayed  $\gamma$ -ray energies are from  $^{239}\text{Pu}(n,\text{F}\gamma)$  and prompt  $\gamma$ -ray energies are from  $^{252}\text{Cf}$  SF decay (2009Si21).

‡ 929.4 and 932.0  $\gamma$  rays are observed as an unresolved doublet. Combined intensity is 36 9.

# Delayed  $\gamma$  intensities. Prompt  $\gamma$  ray branching ratios are given under comments for  $\gamma$  rays from levels above the 3.0- $\mu\text{s}$  isomer.

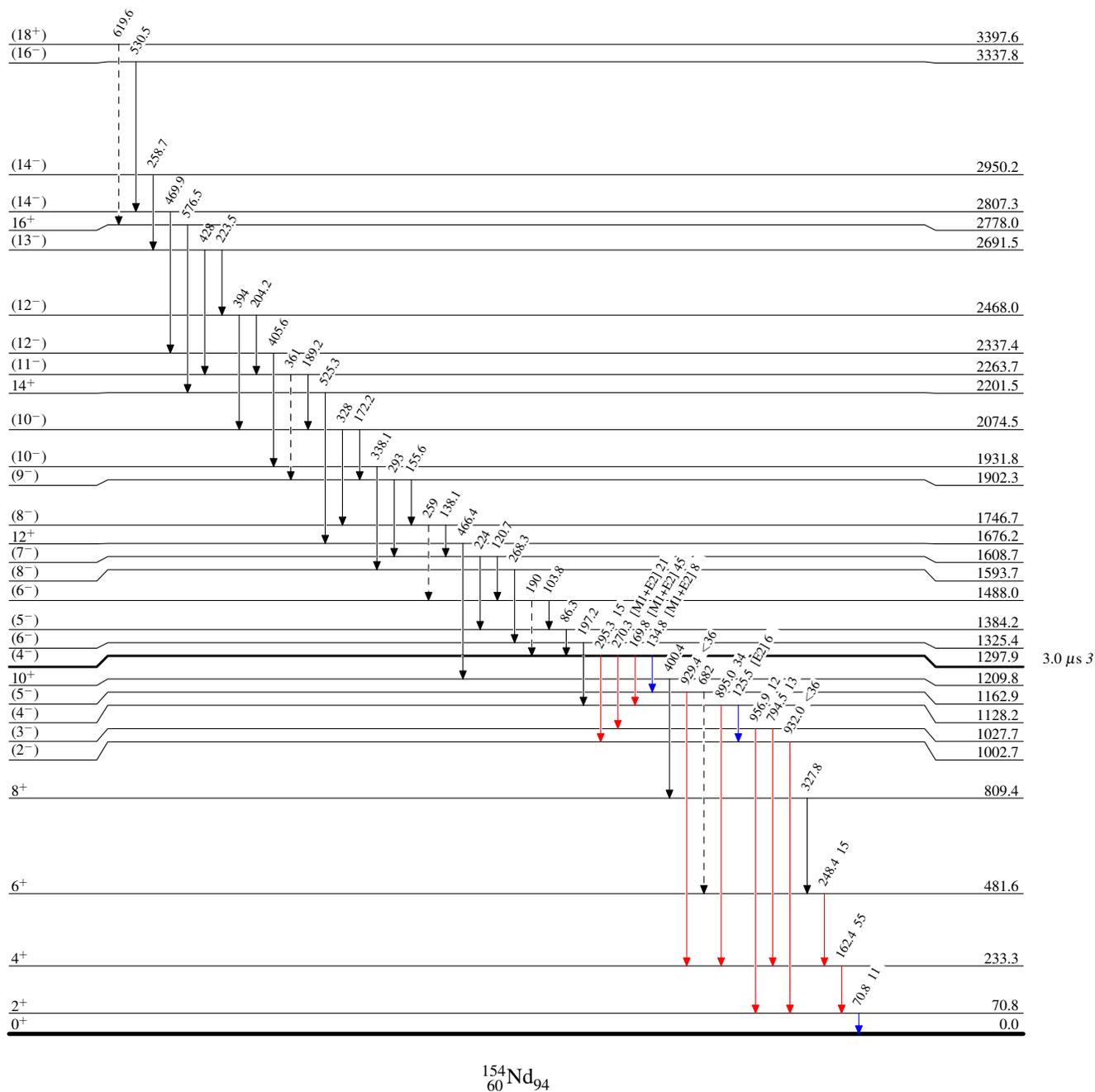
@ Placement of transition in the level scheme is uncertain.

$^{239}\text{Pu}(n,\text{F}\gamma)$  2009Si21

Legend

Level Scheme  
Intensities: Relative  $I_\gamma$

- $I_\gamma < 2\% \times I_\gamma^{\text{max}}$
- $I_\gamma < 10\% \times I_\gamma^{\text{max}}$
- $I_\gamma > 10\% \times I_\gamma^{\text{max}}$
- - - -  $\gamma$  Decay (Uncertain)



$^{154}_{60}\text{Nd}_{94}$

$^{239}\text{Pu}(n,\text{F}\gamma)$  2009Si21

