Gamma Spectroscopy and Gamma-Ray Intensity Determination for $^{48}\text{V}$

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Abstract. The $^{48}\text{V}$ beta and electron capture decay was studied by gamma-ray spectroscopy using targets of natural metallic titanium irradiated in the IPEN/CNEN-SP Cyclotron Accelerator. The energies, in keV, and intensities, in photons per parent decay, of the observed gamma-rays are: 802.85(3) – 0.00136(12), 928.34(6) – 0.00783(3), 944.135(12) – 0.07871(7), 983.526(5) – 0.9998(3), 1312.115(5) – 0.982(3), 1437.529(15) – 0.00120(3), 2240.396(16) – 0.2333(13), 2375.20(4) – 0.000087(3), 2420.93(4) – 0.000067(3). Two lines formerly assigned to the $^{48}\text{V}$ decay, at 938 and 1063 keV, were not observed; their intensities’ upper limits determined in this experiment were $1\cdot10^{-5}$ and $6\cdot10^{-5}$ photons per parent decay, respectively.

INTRODUCTION

The nuclide $^{48}\text{V}$, which decays to $^{48}\text{Ti}$ by electron capture and $\beta^+$ with ~16 d half-life [1], is frequently found in activation analysis [2, 3, 4], and was suggested as a multigamma-ray calibration standard [5] and for NMR-ON applications [6, 7]. No new measurement of gamma-ray energies and intensities was reported after the last decay data evaluation that pointed out some inconsistencies [1]. To check the $^{48}\text{V}$ decay data, we measured the gamma-ray spectrum that follows the decay using sources produced through the $^{48}\text{Ti}(p,n)$ reaction.

EXPERIMENTAL METHOD

Natural metallic titanium samples, 99.99% purity and shaped into discs 0.6 mm thick, were irradiated in the IPEN/CNEN-SP Cyclotron Accelerator to produce the $^{48}\text{V}$ source. The proton beam with 24-MeV energy and 2-$\mu$A current had its energy degraded to 17 MeV by a thin Al foil. The samples were irradiated for a few minutes. For energy and efficiency calibration purposes, a $^{56}\text{Co}$ source with about $4\times10^5$ Bq was produced with the Cyclotron Accelerator through the $^{56}\text{Fe}(p,n)$ reaction using natural iron in the shape of the titanium target and irradiated for 15 seconds.

The gamma-ray measurements were performed with a HPGe detector (35% ORTEC, 162-cm$^3$ volume), shielded by a 20-cm-thick lead wall, using live-time counting methodology and pile-up rejection. The sources were placed in holders on the detector axis at 250 mm distance from source to detector capsule.

The gamma rays were assigned to the $^{48}\text{V}$ decay through the half-lives determined from the activity variation in the function of time, measured for about one month starting four days after irradiation. Besides $^{48}\text{V}$, activities of $^{44}\text{Sc}$, $^{46}\text{Sc}$, $^{47}\text{Sc}$, $^{48}\text{Sc}$, and $^{56}\text{Co}$ were observed in the irradiated sample. Figure 1 shows one of the obtained spectra. All peaks observed in the spectrum were identified. In addition to the lines arising from the nuclides listed above, background radiation, x-rays from the lead shielding, sum, pile-up, and annihilation gamma-escape peaks were observed.

GAMMA-RAY ENERGY AND INTENSITY ANALYSIS

The energies were determined through the procedure described in Vanin et al. [8], by simultaneous analysis of several spectra of the irradiated sample mixed with calibration sources, where each spectrum is fitted to a different curve but the energy of every gamma ray is constrained to be the same in all interpolations with the different calibration curves. The observed photon energies span the range 803 to 2375 keV, with intensities varying from 0.01% to almost 100% per decay. Three spectra were necessary to provide good energy references for all photons observed:

1. a short counting-time spectrum (a few minutes)
taken with $^{207}$Bi, $^{137}$Cs, $^{60}$Co, and the irradiated sample, all piled up on the detector axis at 250 to 254 mm from the detector capsule, to determine the precise energy of the 944-, 984-, and 1312-keV gamma rays;

2. a long counting-time spectrum of the irradiated titanium sample, where the $^{56}$Co activity already present from reactions with contaminants was used to determine the energies of the weakest peaks;

3. a spectrum of the $^{56}$Co source prepared in the Cyclotron piled on the irradiated sample at about 250 mm from the detector capsule, used both to determine the energies of the gamma rays with intermediate-emission probability and to provide common energy references between the strong and weak $^{48}$V transitions.

The detector efficiency was calibrated according the method described in Tramontano and Vanin [9] using the uncalibrated $^{56}$Co source specially produced for this purpose, as described above, and a $^{207}$Bi activity-calibrated source (Amersham, 200 kBq). Two different $^{56}$Co spectra were input into the calibration, one taken for a few minutes for the strong peaks and another with one day’s duration, where only the weak gamma-ray transitions were analyzed. The $^{48}$V decay gamma-ray peak-areas in the emission-intensity calculation were obtained from different counting-time spectra to match the order of magnitude of standard source peak areas used in the efficiency calibration.

It was difficult to determine the 803-keV gamma-ray transition energy and intensity due to the contribution of the 1332-keV $\gamma$-ray single-escape peak to the spectral line observed at 803 keV. The ratio between the intensities of single-escape (SE) and full energy peaks from the 1332-keV $\gamma$-ray is about $1 \cdot 10^{-3}$, which makes the observed 1332 SE + 803 $\gamma$ line an unresolved doublet. In order to resolve this peak, the full width at the half maximum of spectral lines in the function of energy was calibrated using the values fitted to the peaks from the strong transitions using the expression

$$FWHM(x) = \sqrt{a + bx + cx^2}$$

where $x$ is the channel number, $a$, $b$, and $c$ are the fitting parameters. Then, the peak parameters of the line assigned to the 803-keV gamma transition were obtained in a fit where the width of the line was fixed to the calibrated value and the width of the SE peak was left as a free parameter.
TABLE 1. Energies and relative intensities of the gamma rays following $^{48}$V decay obtained in this work and evaluated [1]. The stars * in the first column were placed for gamma rays that were not observed in this work. For absolute intensity per 100 decays, multiply by 0.099981.

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>Relative intensity</th>
</tr>
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<tbody>
<tr>
<td>This work</td>
<td>NDS [1]</td>
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<td>-------------</td>
<td>--------------------</td>
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<tr>
<td>802.85(3)</td>
<td>1.36(12)</td>
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<tr>
<td>928.34(6)</td>
<td>7.83(3)</td>
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<td>944.135(12)</td>
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<td>983.526(5)</td>
<td>1000.0(3)</td>
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<td>*</td>
<td>1063.9(1)</td>
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<tr>
<td>1312.115(5)</td>
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<tr>
<td>1437.529(15)</td>
<td>1.20(3)</td>
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<td>2240.396(16)</td>
<td>23.33(13)</td>
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<td>2375.20(4)</td>
<td>0.087(3)</td>
</tr>
<tr>
<td>2420.93(4)</td>
<td>0.067(3)</td>
</tr>
</tbody>
</table>

RESULTS

The gamma-ray energies and relative intensities compared to the Burrows evaluation [1] are given in Table 1. Figure 2 shows the decay scheme where the level energies were calculated from a least-squares fit to the gamma-ray transition energies, taking into account the recoil energies. The transition-intensity normalization assumed no direct beta feeding to the $^{48}$Ti ground state, a very likely hypotheses considering the involved spins. The internal conversion coefficients given by Burrows [1] were used.

DISCUSSION AND CONCLUSION

The energies and gamma-ray transition intensities obtained in this work are in general more precise than previously known. There are a few discrepancies between the results presented here and the previous evaluation. The energy of the 803-keV transition is somewhat different from the previously adopted value; the value obtained in this work is in better agreement with the level energies and took into account the interference due to the 1312-keV annihilation single-escape peak.
The 1064-keV gamma transition from the 3359-keV level was not observed in this work. As pointed out by Burrows [1], the branching ratio of 1064 to 2375 keV gamma transitions in the $^{48}$V decay previously published by Meyer [5] was in disagreement with that observed in the ($\alpha$,p$\gamma$) inelastic scattering experiment [10], where the 3359-keV level is fed with reasonable intensity. Assuming the experimental branching ratio from Linard et al. [10] and using the known 2375-keV gamma-ray intensity in the $^{48}$V beta-decay, the expected 1064-keV gamma-ray intensity is almost one order of magnitude smaller than reported by Meyer [5]. Even if the upper limit obtained in this work does not rule out the value previously quoted in the $^{48}$V beta decay, this new evidence lends support to the adoption of the ($\alpha$,p$\gamma$) branching ratio as in [1] instead of the previously reported value from $^{48}$V beta decay.

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REFERENCES