HALF-LIFE MEASUREMENTS OF THE ^{154}Tb ISOTOPE

G.Rastrepina[1]

Institute of Nuclear Research, Hun. Acad. Sci.,
Bem tér 18/c, Debrecen H-4026, Hungary
e-mail: gannar@atomki.hu

The adopted half life of the 9.4 h isomeric state of ^{154}Tb has a relatively high uncertainty and ambiguous values can be found in the literature. Therefore the half-life of the m1 isomer of ^{154}Tb has been measured with high precision. The result is $T_{1/2}$ = 9.994±0.039 *h*. With the careful analysis of the systematic errors, the uncertainty of this half-life value has been significantly reduced.

1. Introduction

Most of the elements heavier than iron are built up in stars via neutron capture in the s- and/or r-processes. There are, however, 35 nuclei on the proton-rich side of the valley of stability, which cannot be produced by neutron capture, because the path of these processes are blocked by stable isotopes. These are the so-called p-nuclei and their synthesis is the p-process. The proton-rich nuclei are produced by a combination of the (γ,n), (γ,p) and (γ,α) reactions on existing s- or r-nuclei at stellar temperatures around a few GK, characteristic of explosive environments. To adequately describe the p-process nucleosynthesis, one needs reliable information on the thousands of reaction rates involved. In this respect, there is a considerable lack of experimental data on the relevant cross sections in the p-process energy range, because most γ-induced reactions are very difficult to measure directly [1]. To overcome this difficulty, the charged particle induced reaction cross sections are measured and their inverse photodisintegration reaction cross sections are calculated using the detailed balance theorem [2]. Experimental data for charged particle induced reaction cross sections are scare above Fe: the energies of relevant α-particles are well below the Coulomb barrier for nuclei with Z > 28 making the cross section very small and thus difficult to measure.

p-Process studies are based mostly on the Hauser-Feshbach statistical model to predict the reaction rates. Although the (p,γ) measurements generally agree with the statistical model prediction within a factor of less than 2, (α, γ) measurements show considerable underestimation of cross-sections in comparison with a frequently used model prediction [3]. Therefore it is important to investigate the α-induced reaction cross sections experimentally to test the reliability of the statistical model prediction. Reaction cross section can be determined by measuring activity of the reaction product using the activation technique. The resulting cross section is directly correlated with the half-life of the reaction product; deviations, ambiguities, and uncertainties of available half-life data translate directly into uncertainties of experimental cross-section results.

The aim of this work is to check the reliability of the adopted half-life value of $^{154\,m1}$Tb as a source of uncertainty at future reaction cross-section measurements by activation technique.

The currently adopted half-live of ^{154m1}Tb is $T_{1/2}$=9.4±0.4 *h* [4] and is based on 5 experiments [5-9] which were fulfilled many years ago. To check the half-life value and to reduce its error are presented to be reasonable.

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2. Experimental technique

2.1. Source preparation

The experiment was carried out at the cyclotron laboratory in ATOMKI, Debrecen, Hungary. Five sources of the ^{154}Tb isotope were produced in the ^{151}Eu(α, n)^{154}Tb reaction by bombarding the ^{151}Eu targets with the α-beam energies between 13.5 and 17 MeV. The targets were prepared evaporating few quantities of enriched oxides $^{151}Eu_2O_3$ (99.2 % enrichment) onto thin Al foils. The thicknesses of the targets were between 100 μg/cm^2 and 180 μg/cm^2. Irradiations of the targets were lasted from 5 to 12 hours. The typical α-beam current was 2 μA. The size of the beam spot was roughly 8 mm in diameter.

2.2. Gamma counting

The irradiated sample was placed in front of a 40% relative efficiency HPGe detector in a holder fixed rigidly onto the end of the detector cap. The system was shielded by 5 cm thick lead to reduce the laboratory background. The signals from the detector preamplifier have been shaped and amplified by an ORTEC model 671 spectroscopic amplifier. The signals were then fed into an ORTEC model ASPEC A65-B32 MAESTRO software. This data acquisition system has a built-in dead time correction, but in order to check the dead time which is crucial for a precise half-life experiment, a pulse generator has been included in the system.

The spectra were stored in every hour and the total length of the counting was varied between 21 and 62 hours (more than 6 half-lives) depending on the source activity.

The decay of the ground state and two long-lived isomeric states of ^{154}Tb (Fig.1) involves emission of a large number of different energy γ-radiations. Fig.2 shows a typical γ-spectrum taken 5 h after the start of counting for the α-beam energy E_α = 15 *MeV*.

The strongest γ-radiation following the β-decay of ^{154m1}Tb is the 540.2 keV line, which has a relative intensity 20% [4]. This line was used for analysis of the ^{154m1}Tb decay curve. Its intensity reduced from 370,000 counts/hour to 4,000 counts/hour during 61 hours for 17-MeV α-beam source. We also observed γ-lines corresponding to the β-decays of the ^{24}Na, ^{57}Ni, ^{66}Ga radioisotopes.

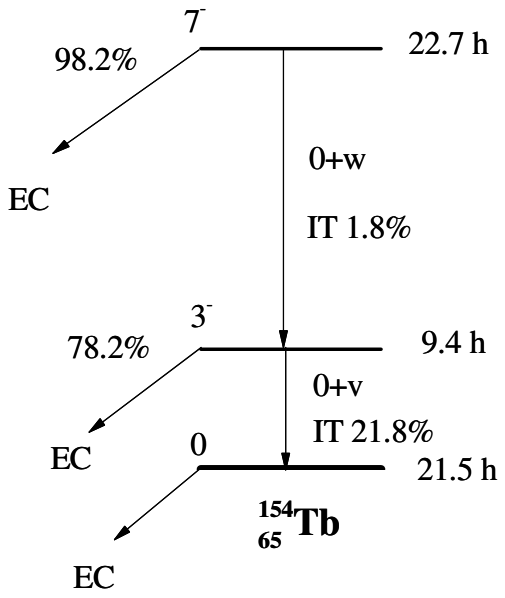

Figure 1. Simplified decay scheme of ^{154}Tb isomers.

3. Results and conclusion

The half-life of the ^{154m1}Tb isomer was determined by fitting of the time dependence of the 540-keV peak to the exponential law by the least square method [10]. Fig.3 shows one of the decay curves of the ^{154m1}Tb. The results of the fits for five α-beam energies are listed in Table 1. The adopted value of the ^{154m1}Tb isomer and its statistical uncertainty was calculated as the weighted average of the five measured samples. This gives $T_{1/2}$=9.994±0.006 *h*. The total uncertainty is the quadratic sum of the statistical uncertainty and the following partial systematic uncertainties: detection efficiency (0.24%), dead-time determination (0.1%), m2 isomer feeding (0.1%) and ground state decay contribution (0.27%). The final result is $T_{1/2}$=9.994±0.039 *h* with a total uncertainty of 0.4%.

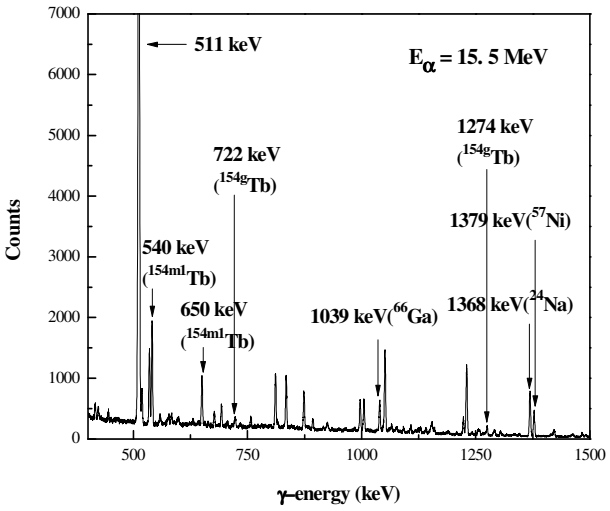

Figure 2. γ-spectrum taken 5 h after the start of counting for the α-beam energy E_α = 15 *MeV*. The 540.2 keV line was used for analysis.

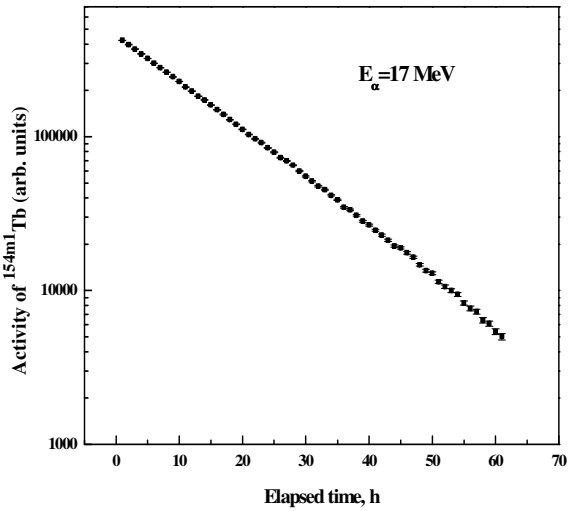

Figure 3. Decay curve of ^{154m1}Tb measured during 61 hours for the 17-MeV α-beam source.

The half-value obtained in the present work is significantly higher than the recommended value in the literature (9.4±0.4 h [4]) and its uncertainty is one order of magnitude lower. It should be pointed out that our value is in agreement with the results [5-7], in marginal agreement with [8], but in serious disagreement with [9]. Since our value is more precise than any of the previous results and it is in agreement with the available most precise values, the result of our these measurements is recommended as the adapted value.

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Table 1. Half-life results of ^{154m1}Tb

E_α, MeV	**$T_{1/2}$(^{154m1}Tb), h**	**χ^2_{red}**
13.5	9.993±0.106	0.88
14	10.008±0.033	0.85
15	9.984±0.019	0.98
15.5	10.008±0.029	0.90
17	9.994±0.006	1.31
final result	**9.994.±0.039**	
literature value	9.4.±0.04	

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ВИМІРЮВАННЯ ПЕРІОДУ НАПІВРОЗПАДУ ІЗОТОПУ ^{154ml}Tb

Г.Растрепіна

Інститут ядерних досліджень Угорської академії наук,
Bem tér 18/c, Debrecen H-4026, Hungary
e-mail: gannar@atomki.hu

Виміряно період напіврозпаду ізомеру ^{154ml}Tb, який складає $T_{1/2}$ = 9.994±0.039 год. Внаслідок ретельного аналізу систематичних похибок, загальна похибка періоду напіврозпаду нами зменшена в 10 разів порівняно з прийнятою сучасними базами ядерних даних.