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ON BETA DECAY OF THE ISOTOPE ^{183}Tl PRODUCED BY THE ^{147}Sm + ^{40}Ca REACTION

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Beta decay of the ground state of a very neutron-deficient isotope ^{183}Tl was investigated. The ^{183}Tl was produced via the ^{147}Sm(^{40}Ca, *p*3*n*) reaction on the SARA cyclotron at ISN, Grenoble. Gamma lines resulting from the deexcitation of ^{183}Hg levels were observed and the half-life of ^{183}Tl was determined to be 5±2 s. The known isotope ^{184}Tl was also produced and clearly identified in these experiments.

The investigations have been carried out in the framework of the JINR — IN2P3 collaboration.

О бета-распаде изотопа ^{183}Tl, образующегося в реакции ^{147}Sm + ^{40}Ca

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На циклотроне SARA в Гренобле исследовался β-распад основного состояния очень нейтронодефицитного изотопа ^{183}Tl, для получения которого использовалась ядерная реакция ^{147}Sm(^{40}Ca, *p*3*n*). Наблюдались γ-линии, соответствующие девозбуждению уровней ^{183}Hg. Период полураспада ^{183}Tl определен равным 5±2 с. В экспериментах был получен и идентифицирован также известный изотоп ^{184}Tl.

Работа выполнена в рамках соглашения между ОИЯИ и Национальным институтом физики ядра и физики частиц, Франция.

1. Introduction

During the last two decades, extensive experiments were performed to study very neutron-deficient nuclides located near the closed $Z = 82$ shell (see, e.g., Refs. [1—12]). These experiments aimed at identifying new

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isotopes, searching for the ground-state proton radioactivity and probing the limits of stability of proton-rich nuclei, studying peculiarities of α-decay in this region of nuclei, characterizing nuclear isomerism which appears to be a widespread phenomenon here, and at exploring also a variety of other aspects of nuclear structure and decay.

Our interest in studying the above nuclei is motivated mainly by findings of the recent experiments performed at Dubna where a new region of $EC(\beta^+)$-delayed fission has been revealed [13—15]. In fact, the phenomenon of $EC(\beta^+)$-delayed fission was shown to occur far outside its traditional actinide nest: it was discovered for the ultra neutron-deficient nuclei of mercury and lead. Here, a prime example of $EC(\beta^+)$-delayed fission is the fission activity of $T_{1/2} = 0.97^{+0.09}_{-0.08}$ s repeatedly detected in the $^{144}Sm + ^{40}Ca$ reaction and assigned to the $^{180}Tl \xrightarrow[0.97\,s]{EC(\beta^+)} {}^{180}Hg$ decay chain [13—15]. Another striking case of $EC(\beta^+)$-delayed fission, with $T_{1/2} \cong 0.3$ s, has been revealed in the $^{151,153}Eu + ^{40}Ca$ and $^{147}Sm + ^{45}Sc$ reactions and attributed to the decay chain $^{188}Bi \xrightarrow[0.3\,s]{EC(\beta^+)} {}^{188}Pb$ [13—15]. A quantitative analysis of the results on $EC(\beta^+)$-delayed fission will give a unique information on fission barrier heights of the cold nuclei lying extremely far off the β-stability line [13,16]. This information cannot be obtained by any traditional means. However, for this analysis it is very important to perform detailed experimental studies on the radioactive properties and structure of nuclei in this region, especially on their β decay characteristics [17].

At present, the lightest identified even-A isotope of thallium is ^{182}Tl ($T_{1/2} \approx 3$ s) known to undergo mainly $EC(\beta^+)$ decay [11,12]. For odd-A thallium isotopes, a systematic occurrence of the $1/2^+$ ground state and of a low-lying $9/2^-$ isomeric state was observed [3,7]. The first identification of the lightest odd-A thallium isotopes, ^{179}Tl, ^{181}Tl and ^{183}Tl, was based on α decay of an $9/2^-$ isomeric state [4,6,18]. The ground states of ^{179}Tl and ^{181}Tl have also been identified [6,12,18].

In this paper, we report on our experimental results concerning β decay of ^{183}Tl, which, according to systematics [3,7,18], is expected to be the main ground-state decay mode of this nucleus. The β decay of ^{183}Tl could be identified since the low-lying levels in ^{183}Hg have already been known from α-decay studies of ^{187}Pb [5], where two excited states, at 67 keV and at 275 keV, were observed, with probable spins and parities being ($3/2^-$ or $5/2^-$) and ($1/2^-$ or $3/2^-$), respectively. Then β decay of a $1/2^+$ state of ^{183}Tl can feed at least the higher level, thus providing the three γ transitions: 67 keV, 208 keV, and 275 keV.

2. Experimental

Our experiments were performed at the SARA cyclotron in Grenoble. A self-supporting metallic Sm target (2.1 mg/cm^2) containing 96.5% of ^{147}Sm was irradiated by a ^{40}Ca beam with a typical intensity of $2 \cdot 10^{11}$ pps. Reaction products recoiling out of the target were stopped in 1.4-bar pressurized helium and transported on NaCl (or $PbCl_2$) aerosols through a 1-mm diameter 12-m long capillary to a programmable tape-transport system used to carry the collected activity to a low-background counting position. The tape-transport system allowed us to make also a suitable selection of collection and counting time intervals. Measurements including γ multianalysis (counting periods 8×1 s), $\gamma-X$ and $\gamma-\gamma$ coincidences were performed. Further details concerning the experimental setup are given in Ref. [19].

Two beam energies were used in the present work, 196 MeV and 210 MeV at the middle of the target. We note that prior to our work, Toth et al. [8,9] employed the $^{147}Sm + {}^{40}Ca$ reaction to produce very proton-rich isotopes of lead. In their experiments, the α activity of ^{183m}Tl was observed at bombarding energies of 194 MeV and 212 MeV, while there was no evidence for its production at 222 MeV. Thus, the beam energies used in the present work should provide an optimum yield of ^{183}Tl and ^{184}Tl via the (^{40}Ca,$p3n$) and (^{40}Ca,$p2n$) channels.This energy range selection was corroborated also by our statistical-model calculations made with the ALICE code [20].

3. Results and Discussion

•At 196 MeV

The γ spectra measured at the bombarding energy of 196 MeV give a firm evidence of the ^{184}Tl production. Two γ transitions in ^{184}Hg, 286 keV and 367 keV, known from in-beam spectroscopy studies [21] as well as from β-decay studies of ^{184}Tl [22] are clearly observed here (see Fig.1). An analysis of Hg $KX-\gamma$ coincidence data supports the assignment of these γ lines to $EC(\beta^+)$-decay of ^{184}Tl. Besides, an analysis of the time distribution of Hg KX-rays gives a half-life value of 10.0 ± 0.7 s, in a good agreement with $T_{1/2} = 11 \pm 1$ s known for ^{184}Tl [22,23]; this means also that, at the given bombarding energy, the yield of lighter (and presumably shorter-living) isotopes of Tl is low compared to that of ^{184}Tl. As the γ lines of 208 keV and, probably, 275 keV are seen in the lower spectrum on Fig.1, it indicates a production of ^{183}Tl; however, no clear coincidences between Hg KX-rays and these γ-events were obtained at this bombarding energy.

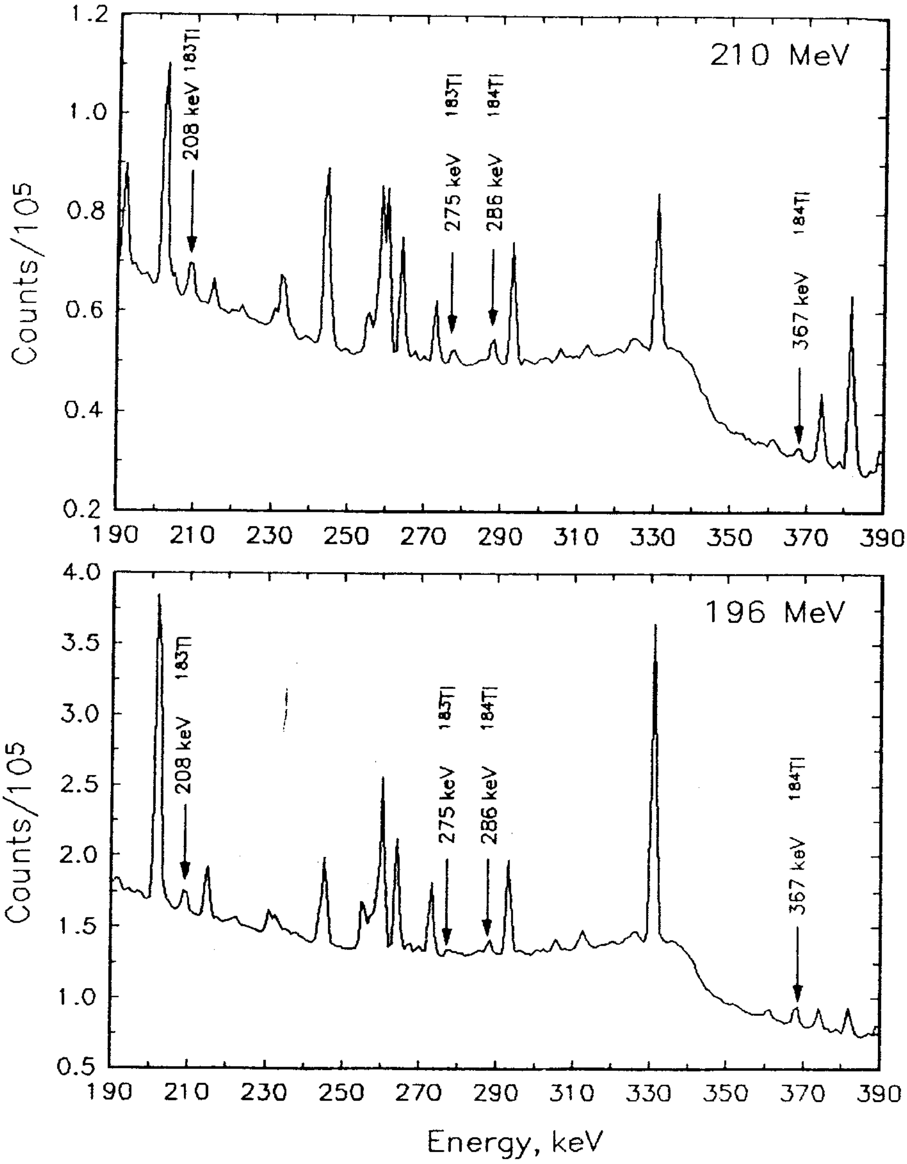

Fig.1. Comparison of the γ spectra measured at the ^{40}Ca beam energies of 210 MeV (upper spectrum) and 196 MeV (lower spectrum)

***At 210 MeV**

As it could be expected, here the relative intensity of the 208 keV and 275 keV γ-lines has increased compared to that of the 367 keV γ-line of

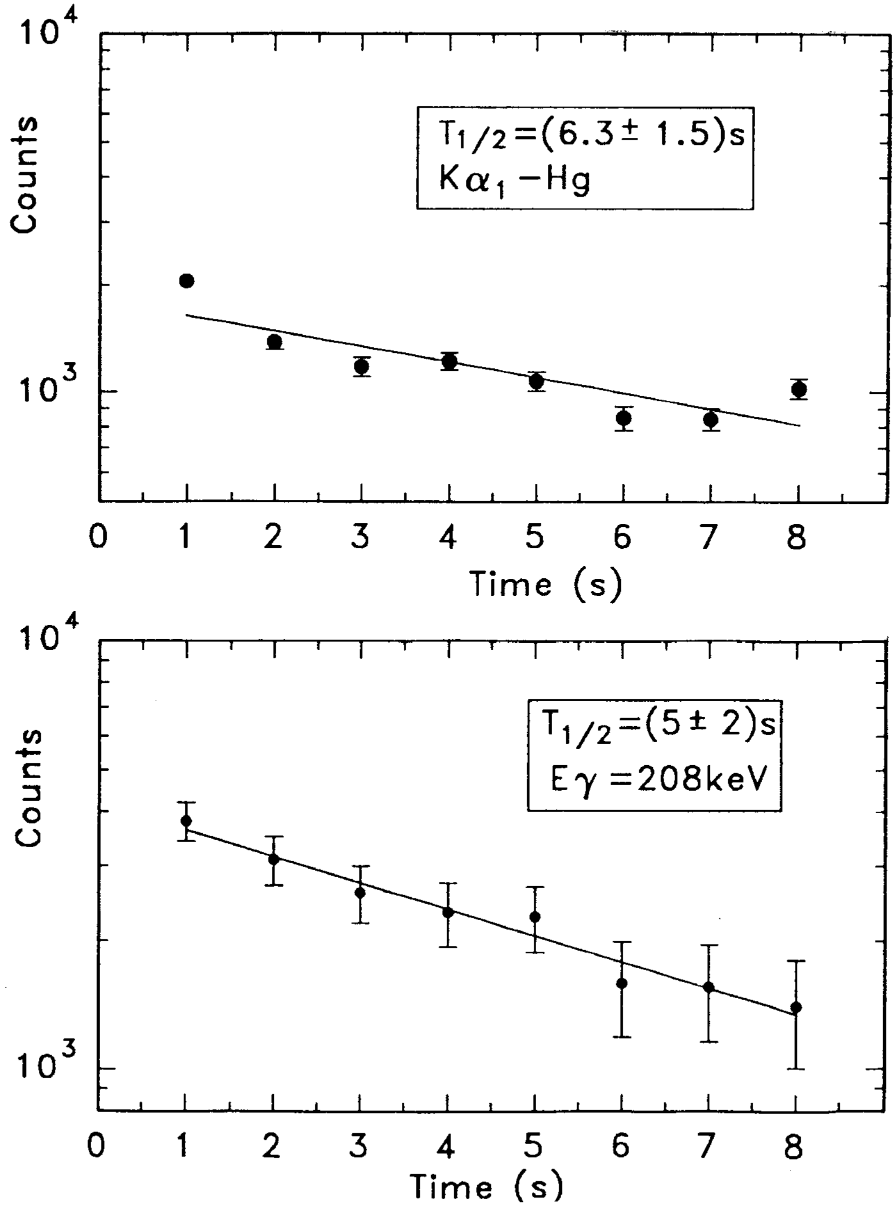

Fig.2. Decay curves of the $K_{\alpha 1}$−Hg X-rays and of the 208 keV γ-rays measured at the ^{40}Ca beam energy of 210 MeV

^{184}Tl (see Fig.1). A time analysis of the 208 keV γ-line and that of Hg *KX*-rays gives half-life values of 5 ± 2 s and 6.3 ± 1.5 s, respectively (Fig.2). These values are in agreement with the «gross» theory predictions of Takahashi et al. [24] for ^{183}Tl and also with the $T_{1/2}$ value of 6.9 ± 1.4 s obtained for ^{183}Tl in a parallel investigation [12] performed by using a mass-separator facility and 1 GeV proton-induced spallation reactions on uranium and thorium targets.

To conclude, the ^{183}Tl isotope with $T_{1/2} = 5 \pm 2$ s was clearly produced in the ^{147}Sm(^{40}Ca,$p3n$) reaction and characterized via measuring its ground-state β decay. Yet the isotope of principal interest for us is the still unknown ^{180}Tl — the precursor of the $EC(\beta^+)$-delayed fission of ^{180}Hg — which can be produced by the ^{144}Sm(^{40}Ca, $p3n$) reaction. The sensitivity of the experiment to identify ^{180}Tl can be essentially improved by involving the detection of α particles and $\alpha - X$ coincidences. Whereas for ^{182}Tl and ^{184}Tl the α-decay branches are quite small, $b_\alpha < 5\%$ [11,12] and $b_\alpha \approx 2\%$ [23], respectively, ^{180}Tl is expected to show comparable branches for α and $EC(\beta^+)$ decays. Again, to increase the selectivity of the ^{180}Tl experiment, it is highly desirable to use a mass-separation technique, e.g., the IGISOL technique [25]. However, when applying this technique to heavy-ion-induced fusion-evaporation reactions, a serious difficulty arises due to the so-called «plasma effect» which causes a dramatic reduction of the efficiency [26]. A way out of this difficult situation can be provided by taking advantage of a huge difference between the angular distribution of beam particles and that of evaporation residues (EVRs) after passing a moderately thick target of a few mg/cm^2. This «shadow» method with a beam stop previously used by Sprouse et al. [27] for laser spectroscopy studies was applied in our recent IGISOL experiments at SARA with the ^{154}Sm + ^{40}Ar (217 MeV) reaction [28]. The beam stop allowed us to catch more than 96% of the ^{40}Ar particles whereas some 40% of EVRs missed the beam stop by virtue of their transverse momenta and could enter the He pressurized IGISOL chamber separated from the target/beam-stop chamber by a thin Havar window. In this way it was possible to decrease the «plasma effect» significantly and thus mass-separate the Hg-Au-Pt isotopes in the 188-189-190 mass chains. It is this combination of the «shadow» method with the IGISOL technique that shall be applied in our forthcoming studies of ^{180}Tl.

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