Preparation of Thick Americium Targets and Synthesis of ^{259}Db*

J. S. Guo,† Z. Qin, Z. G. Gan, H. M. Fan, Y. B. Xu, J. J. He, X. G. Lei, X. L. Wu, H. Y. Liu, X. H. Zhou, S. G. Yuan, and G. M. Jin

Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, P. R. China

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A new isotope of ^{259}Db has been produced via the reaction ^{241}Am(^{22}Ne, 4*n*) at E_{lab} = 118 MeV, and its half-life of 0.51 ± 0.16 s and α-decay energy of 9.47 MeV were determined in this work. The americium targets with thickness ranged from 0.7 to 1.0 mg/cm^2 were prepared by molecular plating method through a single electrodeposition cycle. The reaction products were transported and collected using a helium-jet technique and a rotating wheel apparatus. The α decays of both the products and their daughter nuclides were detected by a series of Si(Au) surface barrier detectors arranged ingeniously. The identification of ^{259}Db was performed based on the genetic relationship between the new activity and the known ^{255}Lr established by α-recoiled milking measurement. The Q_α value of ^{259}Db derived from the present experiment is in good agreement with theoretical prediction.

1. Introduction

Since the discovery of the element 105, named Db, many isotopes from ^{255}Db through ^{263}Db, with the exception of ^{259}Db, have been identified based on the studies of genetic α-links to previously known daughter nuclides of Lr[1–5] and the measurement of characteristic x ray of element 103 in coincidence with the α-particle groups of Db isotopes.[6] According to systematics and theoretical predictions by Möller et al.[7] and Wapstra et al.,[8] the isotope ^{259}Db should be an α emitter with Q_α value of 9.61 MeV and half-life of 0.14 s with respect to α decay. Therefore it is the aim of our experiment to close this gap and to study the decay properties of ^{259}Db nuclide.

With the purpose to produce the expected nuclide by heavy-ion fusion evaporation reaction, it is of importance to prepare the thicker actinide targets. The molecular plating method is the preferred method for preparing targets of actinide elements. Its deposition efficiency is very high and the equipment needed for deposits is simple and can be handled in glove box or hoods. The molecular plating has been used for preparation of relatively thick targets. However, the deposits were very adherent as long as not more than 100 μg/cm^2 of the elements were precipitated at one time. To obtain thicker layers, the backing material with the layers was calcinated in a muffle furnace and the deposition procedure repeated several times.[9] In this work, ^{241}Am targets on aluminum foil with thickness ranged from 622 to 910 μg/cm^2 were obtained through a single molecular plating cycle.

The ^{259}Db was produced via the reaction ^{241}Am(^{22}Ne, 4*n*), and the half-life and α-decay energy of ^{259}Db were determined. Its identification was performed by recoil-milking the 21-s ^{255}Lr daughter. The Q_α value of ^{259}Db derived from the present experiment is in good agreement with theoretical prediction. Comparing with the trend for the other Z = 105 isotopes, it fits quite well for the general trend.

2. Experimental Procedure

2.1. Preparation of Thicker Americium Targets. Enriched ^{241}Am was purchased in the oxide form of a dark brown powder. $^{241}AmO_2$ (8 mg) was dissolved completely in 5 mL of 0.16 N nitric acid, and the solution of $Am(NO_3)_3$ was produced as a pink colored stock solution of ^{241}Am, with a concentration of 1.6 mg/mL. Since ^{241}Am has a characteristic γ ray of energy of 59.5 keV, it is convenient to measure the γ activities of the sample for determining the amount of americium. The concentration and isotopic composition of stock solution were assayed by measuring γ activity with HPGe detector. It was demonstrated that only the γ ray of energy of 59.5 keV could be observed, and other γ activities which could contaminate the sample were not found in the γ spectrum. Especially, the γ ray of energy of 312 keV which might arise from ^{237}Np (daughter nuclide of ^{241}Am α decay) did not appear.

The molecular plating was carried out in the cell with cooling-water jacket made of Pyrex glass. A rubber "O" ring of 10 mm inner diameter was used to define the area of deposition. To stir the solution, a platinum wire (anode, 1 mm diameter) was rotated continuously by a motor. An aluminum foil (cathode, 1.7 mg/cm^2 thickness) as the backing material for electrodeposition was put between the cell and the stainless-steel base. The cell was filled with 15 mL isopropyl alcohol and $300 \sim 500$ μL of the ^{241}Am stock solution. A typical electrolysis was carried out with a current of 5 mA/cm^2 at the voltage of ∼500 V, and the distance between cathode and anode was 3 cm. The efficiency of deposition of americium by molecular plating method was investigated as a function of duration of electrodeposition as shown in Figure 1. One can find that the main part (ca. 85%) of ^{241}Am had already deposited within 5 min. For plating the remaining fraction a total time of 1 h was necessary.

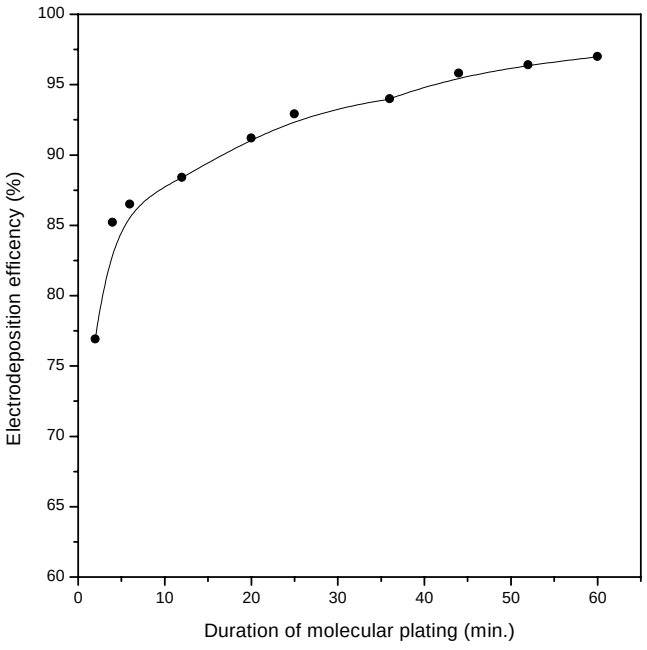

Figure 1. Efficiency of deposition of americium by molecular plating method as a function of duration of electrodeposition.

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†Corresponding author. E-mail: JSGuo@impcas.ac.cn.

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After electrodeposition, the electrolysis solution in the cell was poured into a receptacle from which any remaining Am could be recovered later. The layer on the aluminum foil was rinsed with 5 mL of isopropyl alcohol, and then placed in a muffle furnace at 773 K for 15 min. Since americium is deposited as hydrolytic species of americium which has a chemical formula of $Am(OH)_3 \cdot nH_2O$, it is necessary to convert it into an oxide form as AmO_2 which has a good thermal stability under 1273 K. Finally, three pieces of ^{241}Am targets with thickness ranged from 622 to 910 μg/cm^2 had been obtained through a single molecular plating. The procedure for preparing the thicker americium targets has been described in detail elsewhere.[10]

2.2. Experimental Setup. ^{259}Db was produced at the SFC (Sector Focus Cyclotron) of HIRFL (Heavy Ion Research Facility at Lanzhou) via the reaction of ^{241}Am(^{22}Ne, 4*n*). The beam energy was about 118 MeV in the center of target material, corresponding to the maximum of the excitation function for the ^{241}Am(^{22}Ne, 4*n*) reaction based on the statistical evaporation calculations using the Alice Code.[11] The beam of 132-MeV ^{22}Ne ions delivered from cyclotron was degraded to 118 MeV after passing through a 1.94 mg/cm^2 Havar window, 1.5 cm helium gas at 740 torr, and a 1.70 mg/cm^2 Al target backing. The typical beam current of ^{22}Ne was 0.8–1.0 μA. Three pieces of americium targets prepared above were changed at regular irradiation interval in order to avoid the irradiation damage of the target foils.

The reaction products recoiling out of the target were stopped in helium gas which loaded with NaCl aerosols. The products attached to aerosols were swept out of the target chamber with the helium gas, and then transported through a 1.27-mm-diameter and 20-cm-length capillary into a rough vacuum chamber to impinge upon the periphery of a vertically mounted wheel. The wheel was periodically rotated by the preset interval to place the collected recoil atoms to the position in front of a series of peripherally mounted Si(Au) surface-barrier detectors in order to measure their α-particle spectra.

In the present experiment, the detectors were divided into four groups and each group included three Si(Au) surface-barrier detectors. They were arranged around the wheel according to unequal intervals. The typical α-energy resolution for the most of detectors was 30–40 keV (FWHM) calibrated by a RdTh source. A schematic representation of the detectors arrangement is shown in Figure 2. The wheel-stepping interval is in correspondence with the arrangement of the detectors and controlled by a computer. The first collected source on the wheel was rotated 45° to the No.1-1 detector, the α decays of products and their daughters were measured, while the second source was collected. The second source was rotated 90° to the No.2-1 detector, while the first source was moved to the front of No.1-2 detector. Meanwhile, No.1-1 detector faced to no product source on the wheel, thus only records the α-particle activities from daughters which have recoiled off the wheel into the surface of No.1-1 detector. Successively the third source was rotated 75° to the No.3-1 detector, simultaneously the 2nd source is rotated to No.2-2 detector, and the 1st source goes to No.1-3 detector. In this time detectors No.1-1, No.1-2, and No.1-3 recorded the same source (1st source), thus the time sequential spectra could be obtained. When 4th source was rotated 150° to the front of No.4-1 detector, 3rd source is sent to No.3-2 position; the 2nd source is sent to No.2-3 position, and the 1st source is returned to the collection position and the 5th source will be collected there. After a cycle of the wheel a new sequential measurement will be started. By this way the measurement procedure will be repeated and continued up to the end of the experiment. In the process, the measuring time of each detector for every source is equal to the collecting time of this source. In order to measure the longer and shorter half-lives of the products, the two runs experiments, the collection time of 3 s and 10 s, were performed, respectively. The total of 9-s and 30-s time-sequential decays in each cycle for 3-s and 10-s collection, respectively, could be obtained.

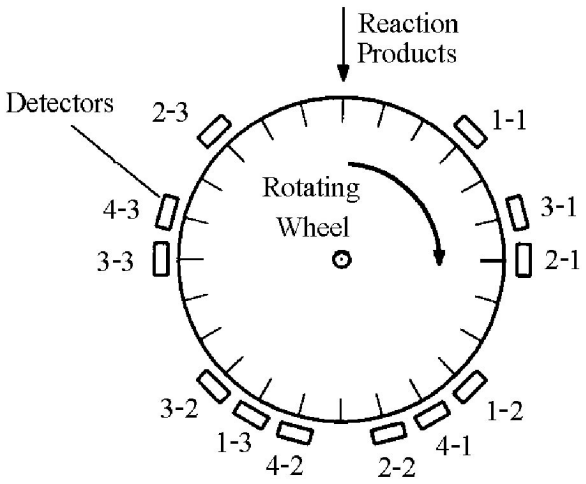

Figure 2. Scheme of the arrangement of the detectors around the rotating wheel.

In the measurement process one can see that there are one time-interval facing the source and three time-intervals facing no source for each detector. During the detector facing no source, it is recording only the decay of α-recoils (daughters) on the surface of the detectors. Furthermore, the detectors of each group are recording the time sequential decays of the products and their daughters when facing the source on the wheel. When the data are processed and analyzed we can accumulate the recorded counts for each detector in accordance with the wanted time-interval so as to obtain the time sequential spectra, such as the mother and daughter as well as the pure daughter decay spectra. In other words, the time sequential decay could be obtained both from the recorded counts of separated time intervals of each detector and from the recorded counts of the ordinal detectors of each group. This arrangement of the detectors is much simple than that with a shuttle system of detector used by Ghiorso et al.,[2] but our detector arrangement without shuttle system has a low efficiency for recording daughter decay.

3. Results and Discussion

The α-particle spectra shown in Figure 3 resulted from bombardment of the ^{241}Am target with 118 MeV ^{22}Ne ions in 3-s collection and measurement time interval by No.1 detector of each

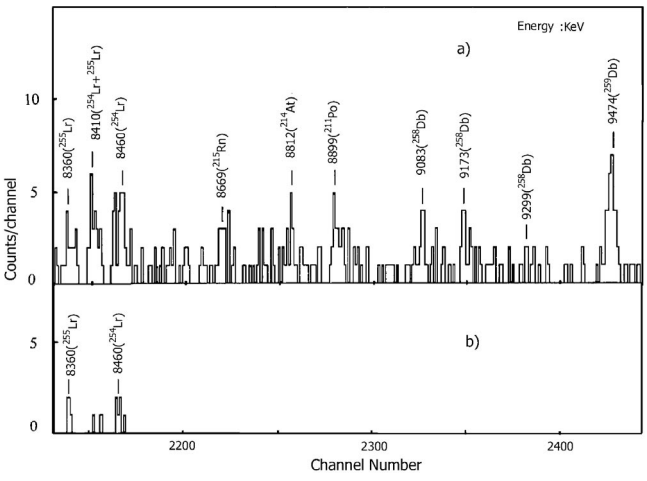

Figure 3. The α-particle spectra produced by bombardments of ^{241}Am with 118-MeV ^{22}Ne ions. It is the sum counts recorded by No.1 detector of each group in 3-s collection and measurement time for each cycle. (a) The α-particle spectrum recorded by the detectors facing the product source. (b) The α-particle spectrum recorded by the detectors not facing the product source (the α spectrum of the recoil daughter).

group. The α spectra recorded by the detectors in facing the product source on the wheel, combined with the α spectra from the same detectors but not facing the product source, are shown in Figure 3(a) and (b), respectively. In other words, Figure 3(a) represents the α spectra of the products (including mother and daughter nuclides) on the wheel, and Figure 3(b) is the α spectra from the decay of α-recoil-daughter nuclides embedded in the surface of detectors.

An α peak with the energy of 9.47 MeV observed clearly in Figure 3(a) is assigned to ^{259}Db in the present work. Its half-life is measured to be 0.51 s (as shown in Figure 4). In addition, an α peak with an energy of 8.36 MeV has a measured half-life of 21 s and thus could be assigned to the previous known nuclide ^{255}Lr. Its second α peak of 8.40 MeV is just overlapped with another peak of 8.41 MeV. We believe that the nuclide ^{255}Lr is α decay daughter of ^{259}Db nuclide, and it could exclude the contribution of ^{255}Lr produced directly in the bombardment due to rather small production cross section of ($\alpha 4n$) reaction according to Alice Code calculation.

A complex group of peaks with the energies of 9.08, 9.17, and 9.30 MeV in the Figure 3(a) could be assigned to ^{258}Db based on the whole complex group decays with a measured half-life of 4.3 s. This nuclide arose from the reaction ^{241}Am(^{22}Ne, 5*n*). The α-decay daughter ^{254}Lr of ^{258}Db nuclide presented in Figure 3(a) has an α peak with an energy of 8.46 MeV. And another 8.41 MeV α peak of ^{254}Lr nuclide is inter-overlapped with an 8.40 MeV α peak of ^{255}Lr. The decay curve of ^{254}Lr has a growth-decay phenomenon, thus it proved that the ^{254}Lr nuclide arose from the decay of the mother nuclide ^{258}Db not from the reaction directly. The half-lives of 4.3 and 13.4 s deduced from the decay curves of ^{254}Lr are in coincidence quite well with the known values of ^{258}Db and ^{254}Lr, respectively. Therefore, the nuclide ^{258}Db and its daughter ^{254}Lr have also been clearly observed from the same projectile-target combination, thus, proving the reliability of our assignment of ^{259}Db.

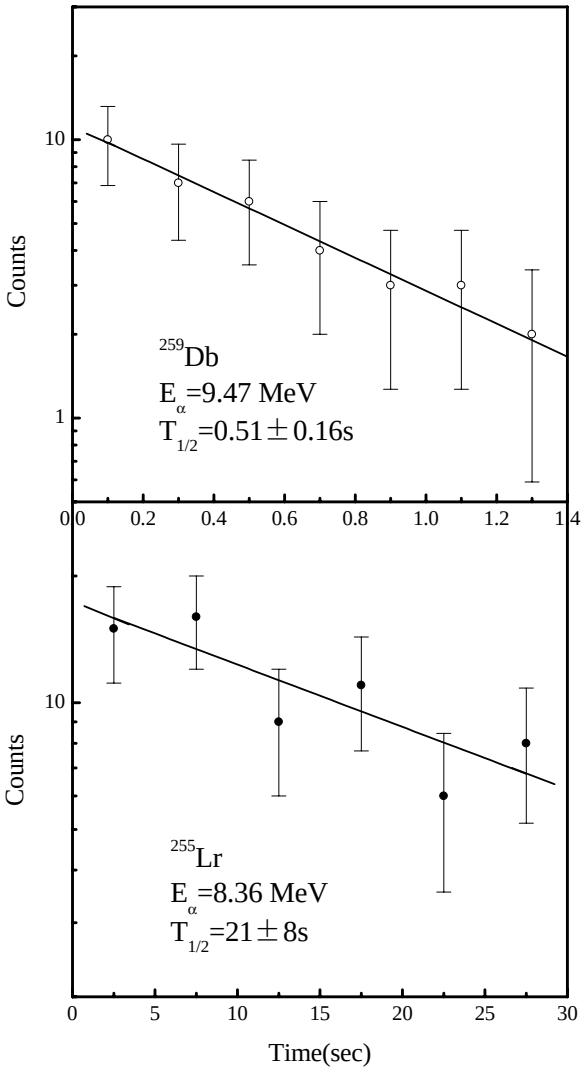

Figure 4. The decay curves for α decays of ^{259}Db with α energy of 9.47 MeV and ^{255}Lr with α energy of 8.36 MeV when the detectors were facing the product source. For ^{259}Db decay (upper portion) the counts were obtained from the sum counts by No.1 detector of each group for 3-s collection and measurement time in each cycle, and for ^{255}Lr (lower portion) the decay was obtained from the sequential detectors of each group for 10-s collection and measurement time in each cycle.

Figure 3(b) represented only α spectra of the recoil-daughter nuclides when the detectors were not facing the products source. In these "daughter" spectra the presented α peaks have the same energies of 8.36, 8.41, and 8.46 MeV and same half-lives of 13.4 and 21.3 s, respectively, as the values of ^{254}Lr and ^{255}Lr in the "parent" spectra (Figure 3(a)), thus confirming the assignment of the ^{254}Lr and ^{255}Lr, and hence their precursors of ^{258}Db and ^{259}Db.

The production cross sections are estimated from the yields of the ^{259}Db and ^{258}Db α decays to be 1.6 ± 1.2 nb and 3.6 ± 1.8 nb, respectively. These values result from an assumed $60 \pm 10\%$ He-jet transport efficiency, a detection efficiency of $40 \pm 10\%$, and a transport time of 0.2 s for the products from the target chamber to the collection wheel system. The Q_α value of 9.62 MeV for new isotope ^{259}Db derived from the present experiment is in good agreement with the values of 9.61 and 9.60 MeV theoretically predicted by Möller et al.[7] and Wapstra et al.[8] We compared the Q_α of new isotope ^{259}Db to the values of the known isotopes in a "Q_α systematics" for isotopes with $Z \geq 98$, and it shows that the Q_α value of ^{259}Db fitted well to the general trend.

4. Conclusion

Three pieces of ^{241}Am targets with thickness ranged from 622 to 910 μg/cm^2 had been obtained by a single molecular plating. A new nuclide ^{259}Db has been produced by bombarding ^{241}Am with ^{22}Ne ions. The identification of this nuclide has been performed by measuring the α-particle emission of the mother and daughter nuclides. ^{259}Db has a 0.51 ± 0.16 s half-life and decays by α emission with the energy of 9.47 MeV. The Q_α value for new isotope ^{259}Db derived from the present experiment is in good agreement with the theoretical prediction.

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