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*Short note*

# Identification of $^{209}$Hg

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**Abstract.** The new neutron-rich nuclide $^{209}$Hg has been identified for the first time. An on-line, gas-thermochromatographic technique was developed for rapidly separating the Hg-element products from 600-MeV $^{18}$O+$^{nat}$Pb(thick target) reaction system. A special detection arrangement was used in order to detect the weak $\gamma$-activities of the neutron-rich Hg isotopes. The half-life of $^{209}$Hg was determined to be $35^{+9}_{-6}$ s.

**PACS.** 25.70.Hi Transfer reactions – 27.80.+w $190 \leq A \leq 219$

The known, heaviest, neutron-rich isotopes have so far not been extended far enough from the $\beta$-stability line for the mass region of $A > 170$. In the present work the new neutron-rich mercury isotope $^{209}$Hg was produced in 600-MeV $^{18}$O+$^{nat}$Pb reaction system. The $^{18}$O beam was provided by the intermediate-energy heavy ion accelerator SSC of the Heavy-Ion Research Facility located Lanzhou (HIRFL) in China . The nature lead target in molten state had a thickness of 5 mm.

The mercury element products produced during the 600-MeV $^{18}$O bombardment were continuously released, transported and separated by using an on-line, gas-thermochromategraphic separation device, which was developed for rapidly separating the mercury-element products at on-line condition from note only the molten lead target material but also the other volatilized products. Its work principle is similar to that of the off-line, gas-thermocromatography one[1,2]. Due to the use of a specially designed graphite target box the maximum diffusion depth for the volatilizable products was limited to 5 mm, hence a short delay time may be achieved. The separated mercury products were collected on a 10 mg/cm$^2$ gold foil. By means of a radioactive $^{203}$Hg-isotope label test [1,2] the collection efficiency for the Hg-element products was determined to be, on average, of $80^{+13}_{-5}$ %. The possible element contaimination was tested to be much lower than 1% [3]. Such a low contamination level excluded our direct detection of the $\gamma$ rays from directly produced $^{209}$Tl.

A weak 2.2 particle-nA $^{18}$O beam was used. Every sample was irradiated for 120 s. Every collected sample was automatically transported to a low-background area within 18-25 s, and measurement start at 45 s after irradiation stop. The measurement lasted 420 s for every sample. The data were recorded in a time-succession, multispectrum mode. A total of 143 such cycles were performed.

The gamma activities of the collected sample were measured by using a specially detection arrangement. It consisted of a coincidence of the $\gamma$-ray energy signals from a HPGe $\gamma$-ray detector with the $\beta$-ray energy loss signals from a plastic scintillator $4\pi\Delta E_\beta$ detector, and a combined anticoincidence with the time-logic signals of the 511 keV $\gamma$-rays detected by a large BGO detector. The P-type HPGe detector had an efficiency 25% with an excellent resolution of 1.9 keV(FWHM) at the 1.33-MeV $\gamma$ -ray energy. The size of the BGO detector was about $140\times70\times$ 50 mm$^3$, and its largest surface faced the sample with a distance of 5 cm. Every gold-foil sample was put into the 1.6-mm gap between the two 0.5-mm-thick, 25 mm-diameter plastic scintillator of the $4\pi\Delta E_\beta$ detector. The HPGe and the BGO detector were placed on opposite sides of the scintillator pair. For the $\gamma$-ray spectra filtered by the coincident and the anticoincident condition, the Compton background level was reduced by about one order of magnitude and the intensities of those $\gamma$-rays from neutron-deficient mercury isotopes were reduced by the factors of about 15 and 3 for EC- and $\beta^+$-delayed $\gamma$ rays respectively. However, those $\gamma$ ray following only $\beta^-$ decay may be detected with a high efficiency of 46±3 %, compared to the corresponding efficiency in the single $\gamma$-ray spectra [4]. A typical, partial, filtered the $\gamma$-ray spectra is shown in Fig. 1. Obviously, the $\gamma$-ray lines of neutron-rich mercury isotopes became conspicuous. For example, the 305-keV $\gamma$ ray being the most intense characteristic $\gamma$ ray of the neutron-rich isotope $^{206}$Hg [5], was appeared just

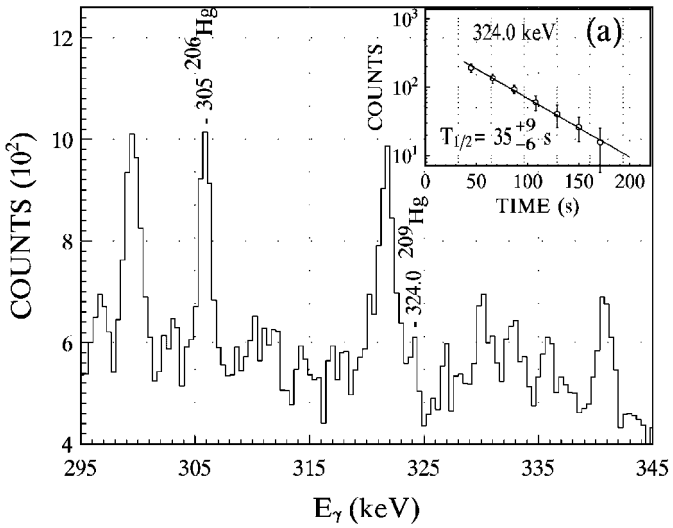


**Fig. 1.** The filtered $\gamma$ spectrum obtained for beginning 40-s measurement and 143 sample. (a)-the 324.0-keV $\gamma$-ray decay and fitting curve

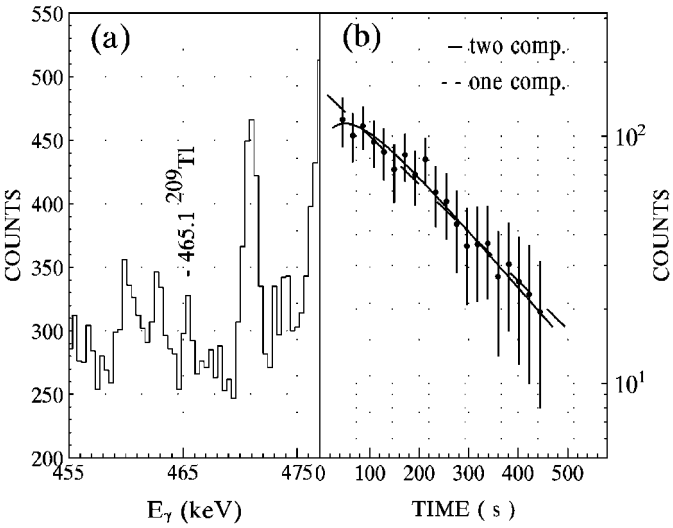


**Fig. 2.** **a** The observed $^{209}$Tl 465.1-keV $\gamma$ peak. **b** Its time-vaeying intensities and fitting curves

as one peak quite common in the single $\gamma$ ray spectrum, but it became almost the most intense $\gamma$-ray line in the corresponding filtered spectrum shown in Fig. 1.

In the series of the cumulative, filtered $\gamma$-ray spectra the characteristic 465.1-keV $\gamma$ ray lines [5] of the neutron-rich nuclide $^{209}$Tl, as the $\beta^-$-decay daughter nucleus of the expected new neutron-rich nuclide $^{209}$Hg, were observed. A typical 465.1-keV $\gamma$ ray peak was pointed in Fig. 2(a). And its time-varying intensities as well as the curves least-square-fitted respectively to both mother-daughter (two-components) and direct decay (single component) are shown in Fig. 2(b).

The extracted fitting parameters are listed in Table 1. Obviously, the two-component model can give a reasonable interpretation for the growth and decay of the 465.1-keV $\gamma$ activity , in which one component with half life

**Table 1.** The extracted parameters: $T_1/2$–half life; Y0-primary yields, corrected for the efficiency factors

| $E\gamma$ | *Two-comp.* | | *Single-comp.* | |
|---|---|---|---|---|
| (keV) | $T_{1/2}$(s) | Y0($10^5$)$^{(1)}$ | $T_{1/2}$(s) | Y0($10^5$)$^{(1)}$ |
| 465.1 | $35^{+27}_{-10}$ | 4.06±0.61 | | |
| | 132 | 4.51±0.77 | $154^{+33}_{-23}$ | |
| 324.0 | | | $35^{+9}_{-6}$ | 4.65±1.3$^{(2)}$ |

(1)-unit is atom
(2)-obtained for supporsed 100% branching ratio

about 132 s was assigned to the daughter nucleus $^{209}$Tl and another short-loved component with half life about 35 s to the mother nucleus $^{209}$Hg.

But the count measurements began at 45 s after irradiation stop, resulting large uncertainties in the extracted $^{209}$Hg half life. Because the 324.0-keV energy level corresponding to the $3/2^+$ state of $^{209}$Tl nucleus has been known [6,7], the 324-keV $\gamma$ ray may relate to the $\gamma$-ray transition between the level $3/2^+$of $^{209}$Tl and its $1/2^+$ ground state. And it should be observable as one of the $^{209}$Hg $\beta$-delayed $\gamma$ rays if this new neutron-rich isotope $^{209}$Hg was really produced. A positive result was obtained. This 324.0-keV $\gamma$-ray line is clearly visible in the spectrum shown in Fig. 1 due to the big decrease of $\gamma$-ray measurement background and the strong detection suppression for the 322.9-keV $\gamma$ ray following 100% EC decay of $^{187}$Hg [8]. The observed decay of the 324.0-keV $\gamma$ ray intensities as well as the fitting curves are shown in Fig. 1(a). The fitting parameters extracted for the decay of 324.0 $\gamma$ ray are also listed in Table 1. It can be found that not only the half life of $^{209}$Hg $\beta^-$ decay but also the $^{209}$Hg primary yield, extracted from fitting the 324.0-keV $\gamma$ ray decay, were consistent with that from the 465.1-keV $\gamma$ rays. The $^{209}$Hg half life determined by the decay of the 324.0-keV $\gamma$ ray is $35^{+9}_{-6}$ s. It is in agreement with the microscopic calculation given by H. V. Klapdor et al. [9].

Up to now the new neutron-rich nuclide $^{209}$Hg has unambiguously been identified. In the $^{18}$O+$^{nat}$Pb reaction system the nucleus $^{209}$ Hg may be produced only in a very exotic multinucleon transfer reaction process, in which the removal of two protons from a target nucleus $^{208}$ Pb must be accompanied by its capture of three neutrons. Such an exotic multinucleon transfer process was also observed for the first time.

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