

## **Discovery of the Mercury Isotopes**

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Forty mercury isotopes have so far been observed; the discovery of these isotopes is discussed. For each isotope a brief summary of the first refereed publication, including the production and identification method, is presented.

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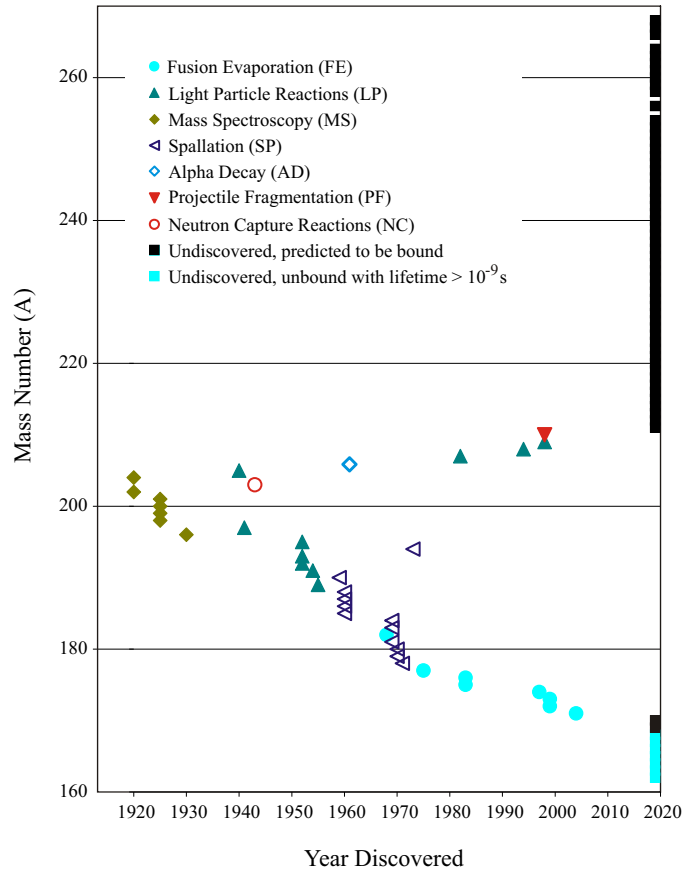
## 1. INTRODUCTION

The discovery of the mercury isotopes is discussed as part of the series of the discovery of isotopes which began with the cerium isotopes in 2009 [1]. The purpose of this series is to document and summarize the discovery of the isotopes. Guidelines for assigning credit for discovery are (1) clear identification, either through decay-curves and relationships to other known isotopes, particle or  $\gamma$ -ray spectra, or unique mass and Z-identification, and (2) publication of the discovery in a refereed journal. The authors and year of the first publication, the laboratory where the isotopes were produced as well as the production and identification methods are discussed. When appropriate, references to conference proceedings, internal reports, and theses are included. When a discovery includes a half-life measurement the measured value is compared to the currently adopted value taken from the NUBASE evaluation [2] which is based on the ENSDF database [3].

## 2. DISCOVERY OF $^{171-210}\text{HG}$

Forty mercury isotopes from  $A = 171 - 210$  have been discovered so far; these include 7 stable, 26 proton-rich and 7 neutron-rich isotopes. According to the HFB-14 model [4],  $^{268}\text{Hg}$  should be the last bound neutron-rich nucleus ( $^{265}\text{Hg}$  is predicted to be unbound). Along the proton dripline two more isotopes are predicted to be stable and it is estimated that seven additional nuclei beyond the proton dripline could live long enough to be observed [5]. Thus, there remain 66 isotopes to be discovered. Less than 40% of all possible mercury isotopes have been produced and identified so far.

Figure A summarizes the year of first discovery for all mercury isotopes identified by the method of discovery. The range of isotopes predicted to exist is indicated on the right side of the figure. The radioactive mercury isotopes were produced using fusion evaporation (FE), light-particle reactions (LP), neutron-capture (NC), spallation reactions (SP), projectile fragmentation or fission (PF), and  $\alpha$ -decay



**FIG. A.** Mercury isotopes as a function of time they were discovered. The different production methods are indicated. The solid black squares on the right hand side of the plot are isotopes predicted to be bound by the HFB-14 model. On the proton-rich side the light blue squares correspond to unbound isotopes predicted to have lifetimes larger than  $\sim 10^{-9}$  s.

(AD). The stable isotopes were identified using mass spectroscopy (MS). Heavy ions are all nuclei with an atomic mass larger than  $A=4$  [6]. Light particles also include neutrons produced by accelerators. In the following, the discovery of each mercury isotope is discussed in detail.

### $^{171}\text{Hg}$

$^{171}\text{Hg}$  was discovered by Kettunen *et al.* in 2004, and published in *Decay studies of  $^{170,171}\text{Au}$ ,  $^{171-173}\text{Hg}$ , and  $^{176}\text{Tl}$*  [7]. The cyclotron of the Accelerator Laboratory of the University of Jyväskylä in Finland was used to produce the isotopes by the  $^{96}\text{Ru}(^{78}\text{Kr},3n)$  fusion evaporation reaction. The isotopes were separated by the gas-filled recoil separator RITU, and implanted into a position sensitive silicon strip detector. “A new  $\alpha$ -decaying isotope  $^{171}\text{Hg}$  and the previously known  $^{172}\text{Hg}$  isotope were produced via 3n- and 2n-fusion evaporation channels in the bombardment of the  $^{96}\text{Ru}$  target with the

$^{78}\text{Kr}$  ion beam.” The reported half-life of  $53_{-16}^{+36}$   $\mu\text{s}$  is currently the only measurement.

### $^{172,173}\text{Hg}$

The discovery by Seweryniak *et al.* of  $^{172}\text{Hg}$  and  $^{173}\text{Hg}$  was published in *Decay properties of the new isotopes  $^{172}\text{Hg}$  and  $^{173}\text{Hg}$*  in 1999 [8]. The isotopes  $^{172}\text{Hg}$  and  $^{173}\text{Hg}$  were produced by the ATLAS superconducting linear accelerator at Argonne National Laboratory by the fusion evaporation reactions,  $^{78}\text{Kr}(^{96}\text{Ru},2\text{n})$  and  $^{80}\text{Kr}(^{96}\text{Ru},3\text{n})$ , respectively. To identify the mass, the isotopes were separated using the Argonne Fragment Mass Analyzer. Three strong lines “are also present in decays followed within 100 ms by  $\alpha$  particles corresponding to the decay of  $^{168}\text{Pt}$  ( $E_\alpha \approx 6.83$  MeV), and thus are assigned to the decay of the previously unknown isotope  $^{172}\text{Hg}$ .” The observation of  $\alpha$ -radiation populating  $^{169}\text{Pt}$  “leads to an unambiguous assignment of this group to the decay of a new isotope  $^{173}\text{Hg}$ .” The  $0.25_{-0.09}^{+0.35}$  ms measured half-life of  $^{172}\text{Hg}$  agrees with the adopted value of  $0.29_{-0.08}^{+0.23}$  ms, while the  $^{173}\text{Hg}$  half-life of  $0.9_{-0.3}^{+0.6}$  ms corresponds to the only measurement at the present time.

### $^{174}\text{Hg}$

Uusitalo *et al.* published the discovery of  $^{174}\text{Hg}$  in *Alpha decay of the new isotope  $^{174}\text{Hg}$*  [9] in 1997.  $^{174}\text{Hg}$  was produced in the fusion-evaporation reaction  $^{144}\text{Sm}(^{36}\text{Ar},6\text{n})$  with beam energy between 180 and 230 MeV at the University of Jyväskylä in Finland. The isotopes were separated by the gas-filled recoil separator RITU, and implanted into a position sensitive silicon strip detector. “The measured decay properties of the daughter activity are compatible with those of  $^{170}\text{Pt}$  for which  $T_{1/2} = 6_{-2}^{+5}$  ms and  $E_\alpha = 6545 \pm 8$  keV were reported. The mother activity can then be assigned to the new mercury isotope  $^{174}\text{Hg}$ .” The reported half-life of  $2.1_{-0.7}^{+1.8}$  ms is currently the only measurement.

### $^{175,176}\text{Hg}$

*Alpha Decay of New Neutron Deficient Gold, Mercury and Thallium Isotopes* reported the discovery of  $^{175}\text{Hg}$  and  $^{176}\text{Hg}$  by Schneider *et al.* in 1983 at the Gesellschaft für Schwerionenforschung (GSI) in Germany [10]. The isotopes were produced in fusion-evaporation reactions of a  $^{92}\text{Mo}$  beam with energies between 4.5 A·MeV and 5.4 A·MeV and separated with the velocity filter SHIP. “The decays of the new isotopes  $^{173}\text{Au}$ ,  $^{175,176}\text{Hg}$  and  $^{179}\text{Tl}$  could be correlated to the known  $\alpha$ -decays of their daughters”. The half-life of  $^{175}\text{Hg}$  was measured to be  $20_{-13}^{+40}$  ms, while the half life of  $^{176}\text{Hg}$  was measured to be  $34_{-9}^{+18}$  ms. Both half-lives are close to the adopted values of 10.8(4) ms and 20.3(14) ms for  $^{175}\text{Hg}$  and  $^{176}\text{Hg}$ , respectively.

### $^{177}\text{Hg}$

$^{177}\text{Hg}$  was first observed in 1975 in *Mise en évidence d’un nouvel isotope de mercure de masse 177* by Cabot *et al.* [11]. A neodymium target was bombarded by a beam of calcium ions from the ALICE accelerator at Orsay, and the isotope was created by the reaction  $^{142}\text{Nd}(^{40}\text{Ca},5\text{n})^{177}\text{Hg}$ . “L’identification de  $^{177}\text{Hg}$  nous parat donc bien tablie” (The identification of  $^{177}\text{Hg}$  seems to us well established). No half-life measurement was made.

### <sup>178</sup>Hg

In 1971 Hansen *et al.* discovered <sup>178</sup>Hg in *The Alpha Decay of <sup>179</sup>Hg and <sup>178</sup>Hg* [12]. A lead target was bombarded with 600 MeV protons by the synchrocyclotron at CERN. <sup>178</sup>Hg was separated and identified with the the isotope-separator-on-line facility ISOLDE by measuring  $\alpha$  energies and half-lives. “The assignment of the 6425 keV line to <sup>178</sup>Hg cannot be doubted since all conceivable contaminants have lower alpha energies.” The measured half-life of 0.47(14) s agrees with the currently adopted value of 0.266(25) s.

### <sup>179,180</sup>Hg

<sup>179</sup>Hg and <sup>180</sup>Hg were discovered by Hansen *et al.* in 1970 and reported in *Studies of the  $\alpha$ -active isotopes of mercury, gold and platinum* [13]. A lead target was bombarded with 600 MeV protons by the synchrocyclotron at CERN and <sup>179</sup>Hg and <sup>180</sup>Hg were separated and identified with the the isotope-separator-on-line facility ISOLDE. “The  $\alpha$ -decay energy for <sup>180</sup>Hg is 6.118 MeV;  $T_{1/2}$  was found to be  $2.9 \pm 0.3$  sec... The line at 6.270 MeV, containing altogether 19 counts, is from <sup>179</sup>Hg. The assignment is certain, because the energy is higher than any other observed in connection with the study of the mercury isotope.” The measured half-life of 2.9(3) s for <sup>180</sup>Hg agrees with the currently adopted value of 2.58(1) s. The half-life of <sup>179</sup>Hg was not determined.

### <sup>181</sup>Hg

Hansen *et al.* reported the first observation of <sup>181</sup>Hg in the paper *Decay Characteristics of Short-Lived Radio-Nuclides Studied by On-Line Isotope Separator Techniques* in 1969 [14]. 600 MeV protons from the CERN synchrocyclotron bombarded a lead target and <sup>181</sup>Hg was separated using the ISOLDE facility. The paper summarized the ISOLDE program and did not contain details about the individual nuclei other than in tabular form. The detailed analysis was published in reference [13]. The measured half-life of 3.6(3) s was misprinted as 3.6(3) m in [14] and corrected in an errata. This value agrees with the adopted value of 3.6(1) s.

### <sup>182</sup>Hg

<sup>182</sup>Hg was discovered by Demin in 1968 *et al.* in *New Mercury Isotopes* [15]. <sup>182</sup>Hg was produced by the fusion-evaporation reactions <sup>147</sup>Sm + <sup>40</sup>Ar and <sup>170</sup>Yb + <sup>20</sup>Ne at the homogeneous magnetic-field cyclotron of the Laboratory for Nuclear Reactions in Dubna, Russia. The alpha radiation was then analyzed by a semiconductor spectrometer. “The <sup>182</sup>Hg assignment is confirmed also by the fact that the decay curve of <sup>178</sup>Pt in the appropriate part of the excitation function shows a slight activation in accordance with the half-life of <sup>182</sup>Hg.” The measured half life of 9.6(2) s is close to the adopted value of 10.83(6) s.

### <sup>183,184</sup>Hg

Hansen *et al.* reported the first observations of <sup>183</sup>Hg and <sup>184</sup>Hg in the paper *Decay Characteristics of Short-Lived Radio-Nuclides Studied by On-Line Isotope Separator Techniques* in 1969 [14]. 600 MeV protons from the CERN synchrocyclotron bombarded a lead target and <sup>183</sup>Hg and <sup>184</sup>Hg were

separated using the ISOLDE facility. The paper summarized the ISOLDE program and did not contain details about the individual nuclei other than in tabular form. The detailed analysis was published in reference [13]. The measured half-lives of 8.8(5) s for  $^{183}\text{Hg}$  and 32.0(10) s for  $^{184}\text{Hg}$  agree with the adopted values of 9.4(7) s for  $^{183}\text{Hg}$  and 30.9(3) s for  $^{184}\text{Hg}$ . The previously reported half-life for  $^{183}\text{Hg}$  of approximately 26 s [15] was misidentified and may have been from the decay of  $^{184}\text{Hg}$ .

#### $^{185-187}\text{Hg}$

$^{185}\text{Hg}$ ,  $^{186}\text{Hg}$  and  $^{187}\text{Hg}$  were first observed by Albouy *et al.* in 1960: *Nouveaux isotopes de période courte obtenus par spallation de l'or* [16]. Gold targets were bombarded with 155 MeV protons from the Orsay synchro-cyclotron and the isotopes were produced in spallation reactions. Half-life and  $\gamma$ -ray measurements were performed following double magnetic separation. “Les isotopes de mass 187, 186 et 185, de période courte, ont pu être observés grâce au montage d’un scintillateur à l’intérieur du séparateur, derrière le collecteur du 2<sup>e</sup> étage.” (The short-lived isotopes of mass 187, 186, and 185 could be observed thanks to a scintillator mounted inside the separator after the collector of the second stage.) The measured half-lives of 50 s ( $^{185}\text{Hg}$ ), 1.5 m ( $^{186}\text{Hg}$ ) and 3 m ( $^{187}\text{Hg}$ ) are consistent with the adopted values of 49.1(10) s, 1.38(6) min, and 2.4(3) min, respectively.

#### $^{188}\text{Hg}$

N. Poffe *et al.* reported the first observation of  $^{188}\text{Hg}$  in *Réactions (p,xn) induites dans l'or par des protons de 155 MeV* in 1960 [17]. Gold targets were bombarded with 155 MeV protons from the synchrocyclotron of the Paris Faculty of Sciences and  $^{188}\text{Hg}$  was identified by half-life and  $\gamma$ -ray measurements following magnetic separation: “Half-lives and main  $\gamma$ -ray energies have been measured for  $^{190}\text{Hg}$ ,  $^{189}\text{Hg}$ ,  $^{188}\text{Hg}$  and their daughter products.” The quoted half-life of 3.7 m is close to the currently accepted value of 3.25(3) min.

#### $^{189}\text{Hg}$

Smith and Hollander first observed  $^{189}\text{Hg}$  in 1955 and the results were reported in *Radiochemical Study of Neutron-Deficient Chains in the Noble Metal Region* [18]. A gold target was bombarded with a beam of 120 MeV protons accelerated with the Berkeley 184-cyclotron producing  $^{189}\text{Hg}$  in (p,9n) reactions. Identification was achieved by timed chemical separation of the  $^{189}\text{Au}$  daughter nuclei. “The experiments cited here which establish the 42-minute gold as  $\text{Au}^{189}$  therefore also set the half-life of  $\text{Hg}^{189}$  as approximately 20 minutes.” This 20(10) m half-life is consistent with the present value of 7.6(1) m for the ground state or the 8.6(1) m isomeric state.

#### $^{190}\text{Hg}$

G. Albouy *et al.* observed  $^{190}\text{Hg}$  for the first time in 1959: *Isotopes de nombre de masse 190 du mercure et de l'or* [19]. Mercury isotopes were produced in (p,xn) spallation reactions at the Orsay synchrocyclotron and mass 190 was selected with an isotope separator. K-X-rays were detected with a NaI(Tl) detector. “Nous avons observé dans la décroissance du rayonnement K principalement deux périodes en filiation  $21\pm 2$  mn suivie de  $45\pm 3$  mn. Nous attribuons ces périodes respectivement à  $^{190}\text{Hg}$  et à son descendant  $^{190}\text{Au}$ .” (We observed the decay by K-radiation to consist mainly of two correlated

periods,  $21 \pm 2$  m followed by  $45 \pm 3$  m. We attributed these periods with  $^{190}\text{Hg}$  and its daughter  $^{190}\text{Au}$ , respectively.) The half-life for  $^{190}\text{Hg}$  agrees with the accepted value of 20.0(5) m.

### $^{191}\text{Hg}$

$^{191}\text{Hg}$  was first identified by Gillon *et al.* from Princeton University in *Nuclear Spectroscopy of Neutron-Deficient Hg Isotopes* in 1954 [20]. The experiment was performed at the Harvard Cyclotron Laboratory using the reaction  $^{197}\text{Au}(p,7n)$  at 65 MeV. Conversion electron spectra were measured with a 119-gauss magnet and K-X-ray lines were attributed to  $^{191}\text{Au}$  following the decay of  $^{191}\text{Hg}$ . “A set of lines decaying with half life 57(5) min was observed” This half-life agrees with the 49(10) m half-life of the ground-state as well as with the 50.8(15)m half-life of the isomeric state.

### $^{192,193}\text{Hg}$

The discovery of  $^{192}\text{Hg}$  and  $^{193}\text{Hg}$  was published in 1952 by Fink *et al.* in *Neutron-deficient Mercury Isotopes* [21]. The Rochester cyclotron was used to bombard gold with 55, 65, and 96 MeV protons.  $^{192}\text{Hg}$  was identified by the activity from the  $^{192}\text{Au}$  daughter. “With protons of 60 to 96 mev. on 0.003 inch gold foil in the Rochester cyclotron, a new mercury activity of half-life  $5.7 \pm 0.5$  hours is observed.” For  $^{193}\text{Hg}$ , “the requisite quantitative relationship between 10-hour mercury and 15.3 hour  $\text{Au}^{193}$  daughter has been demonstrated.” The half-life of  $^{192}\text{Hg}$  is consistent with the adopted value of 4.85(20) hours, while the 10.0(5) hour measured half-life of  $^{193}\text{Hg}$  most probably corresponds to the 11.8(2) hour isomeric state.

### $^{194}\text{Hg}$

$^{194}\text{Hg}$  was first observed in 1973 by Orth *et al.* in *Half-life Measurements on  $^{172}\text{Hf}$  and  $^{194}\text{Hg}$*  [22]. The isotope was produced by bombarding a lead target with 600 MeV protons in the circulating beam of the synchrocyclotron at the Space Radiation Effects Laboratory at Newport News, Virginia. Four months after the bombardment,  $^{194}\text{Hg}$  was radiochemically separated and isolated for a half-life analysis: “A comparison of the disintegration rate and expected spallation yield of  $^{194}\text{Hg}$  with those of  $^{195}\text{Au}$  from Pb indicates limits of  $90 \text{ y} < t_{1/2} < 540 \text{ y}$  for  $^{194}\text{Hg}$ .” This agrees with the adopted half-life of 444(77) y. A previous incorrect half-life measurement of  $\approx 1 \text{ y}$  may have been do to volatilization losses from the sample [23].

### $^{195}\text{Hg}$

The discovery of  $^{195}\text{Hg}$  was published by Fink *et al.* in 1952 in *Neutron-deficient Mercury Isotopes* [21]. The Berkeley 184-inch cyclotron was used to bombard gold with 30 to 60 MeV protons. Half-life measurements were performed following chemical separation: “A 31-hour activity from 30 mev. proton bombardment of gold is assigned to  $\text{Hg}^{195}$ .” This half-life is most probably a measurement of the 41.6(3) h isomeric state.

### <sup>196</sup>Hg

Aston first identified <sup>196</sup>Hg in *Photometry of Mass-Spectra* in 1930 [24]. The isotope was discovered by taking a mass-spectrograph of naturally occurring mercury. “The rough value for the very faint isotope 196 was obtained as in the case of xenon by contour plotting from a very long exposure.”

### <sup>197</sup>Hg

<sup>197</sup>Hg was first identified in 1941 by Sherr *et al.* in *Transmutation of Mercury by Fast Neutrons* [25]. A mercury target was bombarded with fast neutrons from the Li + d reaction. The deuterons were produced by the Harvard cyclotron. Referring to a private communication by G.E. Valley the paper states: “The assignment of the 25-hour period to Hg<sup>197</sup> is consistent with the present investigations.” This half-life agrees with the adopted value of 23.8(1) h. Previously a ~ 45-m half-life first observed by Heyn [26] was incorrectly assigned to <sup>197</sup>Hg [27].

### <sup>198–201</sup>Hg

The stable isotopes <sup>198–201</sup>Hg were discovered by Aston in 1925 published in *The Isotopes of Mercury* [28]. A new mass spectrograph with twice the dispersion of the previous one made the identification of the mercury isotopes possible. “Preliminary photographs of the mass-spectra of mercury show its lines clearly resolved and so enable a definite statement to be made on the mass numbers of its most important constituents.”

### <sup>202</sup>Hg

In 1920 Aston reported the discovery of the stable isotope <sup>202</sup>Hg in *The Constitution of the Elements* [29]. Aston used a mass spectrograph to identify two isotopes of mercury: “Further examination of the multiply charged mercury clusters indicate the probability of a strong line at 202, a weak component at 204.” Aston published the actual spectra a few months later [30].

### <sup>203</sup>Hg

<sup>203</sup>Hg was first identified by Friedlander *et al.* in 1943 in *Radioactive Isotopes of Mercury* [31]. The isotope was formed by irradiating stable mercury isotopes with neutrons produced by the bombardment of lithium with 14 MeV deuterons from the 60-inch cyclotron at the University of California, Berkeley. “Since both slow and fast neutrons produce the activity, the best assignment is Hg<sup>203</sup> which can be produced by *n-γ* reaction from Hg<sup>202</sup>, and by *n-2n* reaction from Hg<sup>204</sup>.” The half-life of 51.5(15) d is consistent with the adopted value of 46.594(12) d. In 1937 a ~45 m half-life had been incorrectly assigned to <sup>203</sup>Hg [32]. A half-life of ~50 d had been previously observed, but no mass assignment was made [25].

### <sup>204</sup>Hg

In 1920 Aston reported the discovery of the stable isotope <sup>204</sup>Hg in *The Constitution of the Elements* [29]. Aston used a mass spectrograph to identify two isotopes of mercury: “Further examination of the

multiply charged mercury clusters indicate the probability of a strong line at 202, a weak component at 204.” Aston published the actual spectra a few months later [30].

### $^{205}\text{Hg}$

$^{205}\text{Hg}$  was discovered by Krishnan *et al.* in 1940 and published in *Deuteron Bombardment of the Heavy Elements* [33]. Mercury was bombarded with 9 MeV deuteron beams from the Cavendish cyclotron. Resulting beta radiation “has been assigned to  $\text{Hg}^{205}$  decaying to  $\text{Tl}^{205}$  by the emission of continuous  $\beta$ -rays.” The measured half-life of 5.5(2) m agrees with the adopted value of 5.14(9) m. Previously a half-life measurement of 40 h half-life was incorrectly assigned to  $^{205}\text{Hg}$  [34].

### $^{206}\text{Hg}$

$^{206}\text{Hg}$  was discovered by Nurmia *et al.* in 1961 and published in *Mercury-206: a New Natural Radionuclide* [35]. The isotope was formed by the alpha decay of  $^{210}\text{Pb}$  at the Institute of Physics of the University of Helsinki, Finland. Beta-decay curves were recorded following chemical separation. “The hitherto unknown mercury-206 is formed from lead-210 by alpha decay.” The measured half-life of 7.5(10) min agrees with the adopted value of 8.32(7) min.

### $^{207}\text{Hg}$

Mirzadeh *et al.* discovered  $^{207}\text{Hg}$  in 1982 in *A Rapid Radiochemical Separation Procedure for Mercury from Lead and Bismuth Targets* [36]. The isotope was formed by bombarding lead and bismuth with 30-160 MeV neutrons from the Brookhaven Medium Energy Intense Neutron facility. Gamma-ray spectra were measured following chemical separation. “As part of the systematic studies of fast neutron cross sections for targets over the entire periodic table, we have produced  $^{205-207}\text{Hg}$  by  $^{208}\text{Pb}/n,2\text{pxn}/$  and  $^{209}\text{Bi}/n,3\text{pxn}/$  reactions.” No half life measurement was made. Mirzadeh *et al.* mentions a previously measured half-life without a reference. It is interesting to note that presently the only measured half-life was only published in a 1981 conference proceedings [37].

### $^{208}\text{Hg}$

$^{208}\text{Hg}$  was discovered by Zhang *et al.* in 1994 in *Observation of the new neutron-rich nuclide  $^{208}\text{Hg}$*  [38]. A lead target was bombarded by a 30 MeV/nucleon  $^{12}\text{C}$  beam from the Heavy Ion Research Facility Lanzhou at the Institute of Modern Physics, Lanzhou, China. “The assignment of  $^{208}\text{Hg}$  was based on the identification of its  $\beta^-$  decay daughter  $^{208}\text{Tl}$  observed in the periodically extracted Tl element sample growing in the separated Hg element product solution.” The measured half-life of  $42^{+23}_{-12}$  m agrees with the adopted value of  $41^{+5}_{-4}$  m.

## $^{209}\text{Hg}$

In 1998 Zhang *et al.* reported the discovery of  $^{209}\text{Hg}$  in *Neutron-rich heavy residues and exotic multinucleon transfer* [39]. A lead target was bombarded by a 50 MeV/nucleon  $^{18}\text{O}$  beam from the Heavy Ion Research Facility at the Institute of Modern Physics in Lanzhou, China. The isotopes were separated online with a gas-thermochromatographic device and  $\gamma$ - $\beta$  coincidences were recorded. “ $^{209}\text{Hg}$  was created through an exotic  $-2p3n$  multinucleon transfer process and was identified for the first time.” The half-life value of  $35_{-6}^{+9}$  s is currently the only measurement. It should be noted that Zhang submitted the results simultaneously to a separate journal [40].

## $^{210}\text{Hg}$

$^{210}\text{Hg}$  was produced by Pfützner *et al.* in 1998 in *New isotopes and isomers produced by the fragmentation of  $^{238}\text{U}$  at 1000 MeV/nucleon* [41]. Projectile fragmentation was used to produce the isotope by bombarding a beryllium target with a 1000 MeV/nucleon  $^{238}\text{U}$  beam from the SIS/FRS facility at GSI in Darmstadt, Germany. “Although only five counts represent the experimental evidence for the observation of  $^{210}\text{Hg}$ , the very small number of background events on the identification plots supports the adopted assignment.”

### 3. SUMMARY

The discoveries of the known mercury isotopes have been compiled and the methods of their production discussed. The identification of the odd mercury isotopes between mass 183 and 205 proved to be especially difficult.  $^{183}\text{Hg}$ ,  $^{197}\text{Hg}$ ,  $^{203}\text{Hg}$ , and  $^{205}\text{Hg}$ , were initially incorrectly identified. The half-life of  $^{203}\text{Hg}$  had been observed previously but without a mass assignment. For  $^{189}\text{Hg}$  and  $^{191}\text{Hg}$  it could not be determined if the ground state or an isomeric state was observed, while for  $^{193}\text{Hg}$  and  $^{195}\text{Hg}$  the isomeric state was most likely observed first. The half-life measurement of  $^{194}\text{Hg}$  was initially reported incorrect. It is interesting to note that the half-life of  $^{207}\text{Hg}$  had been reported in a 1981 conference proceedings and even after over 25 years has not been published in a refereed journal. Finally, the discovery of  $^{209}\text{Hg}$  was reported by the authors simultaneously in two different journals.

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## REFERENCES

1. J.Q. Ginepro, J. Snyder, and M. Thoennessen, *At. Data Nucl. Data Tables*, in print (2009)
2. G. Audi, O. Bersillon, J. Blachot, and A.H. Wapstra, *Nucl. Phys. A* **729**, 3 (2003)
3. ENSDF, Evaluated Nuclear Structure Data File, mainted by the National Nuclear Data Center at Brookhaven National Laboratory, published in *Nuclear Data Sheets* (Academic Press, Elsevier Science).
4. S. Goriely, M. Samyn, and J.M. Pearson, *Phys. Rev. C* **75**, 64312 (2007)
5. M. Thoennessen, *Rep. Prog. Phys.* **67**, 1187 (2004)
6. H.A. Grunder and F.B. Selph, *Annu. Rev. Nucl. Sci.*, **27**, 353 (1977)
7. H. Kettunen, T. Enqvist, T. Grahn, P.T. Greenlees, P. Jones, R. Julin, S. Juutinen, A. Keenan, P. Kuusiniemi, M. Leino, A.-P. Leppänen, P. Nieminen, J. Pakarinen, P. Rahkila, and J. Uusitalo, *Phys. Rev. C* **69**, 054323 (2004)
8. D. Seweryniak, J. Uusitalo, M.P. Carpenter, D. Nisius, C.N. Davids, C.R. Bingham, L.T. Brown, L. Conticchio, D.J. Henderson, R.V.F. Janssens, W.B. Walters, J. Wauters, and P.J. Woods, *Phys. Rev. C* **60**, 031304 (1999)
9. J. Uusitalo, M. Leino, R.G. Allatt, T. Enqvist, K. Eskola, P.T. Greenlees, S. Hurskanen, A. Keenan, H. Kettunen, P. Kuusiniemi, R.D. Page, W.H. Trzaska, *Z. Phys. A* **358**, 375 (1997)
10. J.R.H. Schneider, S. Hoffman, F.P. Heßberger, G. Münzenberg, W. Reisdorf, and P. Armbruster, *Z. Phys. A* **312**, 21 (1983)
11. C. Cabot, C. Deprun, H. Gauvin, Y. Beyec, and M. Lefort, *Compt. Rend. Acad. Sci.* **B281**, 453 (1975)
12. P.G. Hansen, B. Jonson, J. Zylicz, M. Alpsten, A. Appelqvist and G. Nyman, *Nucl. Phys. A* **160**, 445 (1971)
13. P.G. Hansen, H.L. Nielsen, K. Wilsky, M. Alpsten, M. Finger, A. Lindahl, R.A. Naumann, and O.B. Nelson, *Nucl. Phys. A* **148**, 249 (1970)
14. P.G. Hansen, P. Hornshoj, H.L. Nielsen, K. Wilsky, H. Kugler, G. Astner, E. Hagebo, J. Hudis, A. Kjelberg, F. Münnich, P. Patzelt, M. Alpsten, G. Andersson, Aa. Appelqvist, B. Bengtsson, R.A. Naumann, O.B. Nielsen, E. Beck, R. Foucher, P. Husson, J. Jastrzebski, A. Johnson, J. Alstad, T. Jahnsen, A.C. Pappas and T. Tunaal, R. Henck, P. Siffert, and G. Rudstam, *Phys. Lett.* **28B**, 415 (1969), Erratum *Phys. Lett.* **28B**, 663 (1969)
15. A.G. Demin, T. Fenyés, L. Mahunka, V.G. Subbotin, and L. Tron, *Nucl. Phys. A* **106**, 337 (1968)
16. G. Albouy, M.M. Gusakow, and N.Poffe, *J. Phys. Radium* **21**, 751 (1960)
17. N. Poffe, G. Albouy, R. Bernas, M. Gusakow, M. Riou, and J. Teillac, *J. Phys. Radium* **21**, 343 (1960)
18. W.G. Smith and J.M. Hollander, *Phys. Rev.* **98**, 1258 (1955)
19. G. Albouy, R. Bernas, M. Gusakow, N. Poffe, and J. Teillac, *Compt. Rend. Acad. Sci.* **249**, 407 (1959)
20. L.P. Gillon, K. Gopalakrishnan, and A. de-Shalit, *Phys. Rev.* **93**, 124 (1954)
21. R. Fink and E.O. Wiig, *J. Am. Chem. Soc.* **74**, 2457 (1952)

22. C.J. Orth, H.A. O'Brien, Jr., M.E. Schillaci and B.J. Dropesky, *Inorg. Nucl. Chem. Lett.* **9**, 611 (1973)
23. B. Crasemann, V.O. Kostroun, P. Venugopala Rao, and G. Stephas, *Nucl. Phys.* **103A**, 145 (1967)
24. F.W. Aston, *Proc. R. Soc. London* **126**, 511 (1930)
25. R. Sherr, K.T. Bainbridge, and H.H. Anderson, *Phys. Rev.* **60**, 473 (1941)
26. F.A. Heyn, *Nature* **139**, 842 (1937)
27. L.W. Alvarez, *Phys. Rev.* **54**, 486 (1938)
28. F.W. Aston, *Nature* **116**, 208 (1925)
29. F.W. Aston, *Nature* **105**, 8 (1920)
30. F.W. Aston, *Nature* **105**, 617 (1920)
31. G. Friedlander, and C. Wu, *Phys. Rev.* **63**, 227 (1943)
32. E. McMillan, M. Kamen, and S. Ruben, *Phys. Rev.* **52**, 375 (1937)
33. R.S. Krishnan and E.A. Nahum, *Proc. Camb. Phil. Soc.* **36**, 490 (1940)
34. E.B. Andersen, *Nature* **137**, 457 (1936)
35. M. Nurmi, P. Kauranen, M. Karras, A. Siivola, A. Isola, G. Graeffe, A. Lyyjynen, *Nature* **190**, 427 (1961)
36. S. Mirzadeh and Y.Y. Chu, *Radiochem. Radioanal. Lett.* **51**, 279 (1982)
37. B.Jonson, O.B.Nielsen, L.Westgaard, and J.Zylicz, *Proc. Int. Conf. Nuclei Far from Stability*, Helsingor, Denmark, Vol.2, p.640 (1981)
38. Zhang Li, Jin Ghenming, Zhao Jinhua, Yang Weifan, Yang Yongfeng, Zhao Zhizheng, Zheng Jiwen, Sun Xiurong, Wang Jicheng, Li Zongwei, Qin Zhi, Guo Guanghui, Luo Yixiao, Jan Zylicz, and Jing-ye Zhang, *Phys. Rev. C* **49**, R592 (1994)
39. Zhang Li, Zhao Jinhua, Zheng Jiwen, Wang Jicheng, Qin Zhi, Yang Youngfeng, Zhang Chun, Jin Genming, Guo Guanghui, Du Yifei, Guo Tianrui, Wang Tongqing, Guo Bin, Tian Jinfeng, and Lou Yixiao, *Phys. Rev. C* **58**, 156 (1998)
40. L. Zhang, J.H. Zhao, J.W. Zheng, J.C. Wang, Z. Qin, Y.F. Yang, C. Zhang, G.M. Jin, G.H. Guo, Y.F. Du, T.R. Guo, T.Q. Wang, B. Guo, and J.F. Tain, *Eur. Phys. J. A* **2**, 5 (1998)
41. M. Pfützner, P. Armbruster, T. Baumann, J. Benlliure, M. Bernas, W.N. Catford, D. Cortina-Gil, J.M. Daugas, H. Geissel, M. Górska, H. Grawe, R. Grzywacz, M. Hellström, N. Iwasa, Z. Janas, A.R. Junghans, M. Karny, S. Leenhardt, M. Lewitowicz, A.C. Mueller, F. de Oliveira, P.H. Regan, M. Rejmund, K. Rykaczewski, K. Sümmerer, *Phys. Lett.* **444B**, 32 (1998)

## EXPLANATION OF TABLE

**TABLE I. Discovery of Mercury Isotopes**

Isotope	Mercury isotope
Author	First author of refereed publication
Journal	Journal of publication
Ref.	Reference
Method	Production method used in the discovery: FE: fusion evaporation LP: light-particle reactions (including neutrons) MS: mass spectroscopy SP: spallation AD: alpha decay PF: projectile fragmentation NC: neutron-capture reactions
Laboratory	Laboratory where the experiment was performed
Country	Country of laboratory
Year	Year of discovery

TABLE I. Discovery of Mercury isotopes

See page 13 for Explanation of Tables

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Isotope	Author	Journal	Ref.	Method	Laboratory	Country	Year
<sup>171</sup> Hg	H. Kettunen	Phys. Rev. C	Ket04	FE	Jyvaskyla	Finland	2004
<sup>172</sup> Hg	D. Seweryniak	Phys. Rev. C	Sew99	FE	Argonne	USA	1999
<sup>173</sup> Hg	D. Seweryniak	Phys. Rev. C	Sew99	FE	Argonne	USA	1999
<sup>174</sup> Hg	J. Uusitalo	Z. Phys. A	Uus97	FE	Jyvaskyla	Finland	1997
<sup>175</sup> Hg	J.R.H. Schneider	Z. Phys. A	Sch83	FE	Darmstadt	Germany	1983
<sup>176</sup> Hg	J.R.H. Schneider	Z. Phys. A	Sch83	FE	Darmstadt	Germany	1983
<sup>177</sup> Hg	C. Cabot	Compt. Rend. Acad. Sci.	Cab75	FE	Orsay	France	1975
<sup>178</sup> Hg	P.G. Hansen	Nucl. Phys. A	Han71	SP	CERN	Switzerland	1971
<sup>179</sup> Hg	P.G. Hansen	Nucl. Phys. A	Han70	SP	CERN	Switzerland	1970
<sup>180</sup> Hg	P.G. Hansen	Nucl. Phys. A	Han70	SP	CERN	Switzerland	1970
<sup>181</sup> Hg	P.G. Hansen	Phys. Lett. B	Han69	SP	CERN	Switzerland	1969
<sup>182</sup> Hg	A.G. Demin	Nucl. Phys. A	Dem68	FE	Dubna	Russia	1968
<sup>183</sup> Hg	P.G. Hansen	Phys. Lett. B	Han69	SP	CERN	Switzerland	1969
<sup>184</sup> Hg	P.G. Hansen	Phys. Lett. B	Han69	SP	CERN	Switzerland	1969
<sup>185</sup> Hg	G. Albouy	J. Phys. Radium	Alb60	SP	Orsay	France	1960
<sup>186</sup> Hg	G. Albouy	J. Phys. Radium	Alb60	SP	Orsay	France	1960
<sup>187</sup> Hg	G. Albouy	J. Phys. Radium	Alb60	SP	Orsay	France	1960
<sup>188</sup> Hg	N. Poffe	J. Phys. Radium	Pof60	SP	Orsay	France	1960
<sup>189</sup> Hg	W.G. Smith	Phys. Rev.	Smi55	LP	Berkeley	USA	1955
<sup>190</sup> Hg	G. Albouy	Compt. Rend. Acad. Sci.	Alb59	SP	Orsay	France	1959
<sup>191</sup> Hg	L.P. Gillon	Phys. Rev.	Gil54	LP	Harvard	USA	1954
<sup>192</sup> Hg	R.W. Fink	J. Am. Chem. Soc.	Fin52	LP	Rochester	USA	1952
<sup>193</sup> Hg	R.W. Fink	J. Am. Chem. Soc.	Fin52	LP	Rochester	USA	1952
<sup>194</sup> Hg	C.J. Orth	Inorg. Nucl. Chem. Lett.	Ort73	SP	Los Alamos	USA	1973
<sup>195</sup> Hg	R.W. Fink	J. Am. Chem. Soc.	Fin52	LP	Rochester	USA	1952
<sup>196</sup> Hg	F.W. Aston	Proc. Roy. Soc.	Ast30	MS	Cambridge	UK	1930
<sup>197</sup> Hg	R. Sherr	Phys. Rev.	She41	LP	Harvard	USA	1941
<sup>198</sup> Hg	F.W. Aston	Nature	Ast25	MS	Cambridge	UK	1925
<sup>199</sup> Hg	F.W. Aston	Nature	Ast25	MS	Cambridge	UK	1925
<sup>200</sup> Hg	F.W. Aston	Nature	Ast25	MS	Cambridge	UK	1925
<sup>201</sup> Hg	F.W. Aston	Nature	Ast25	MS	Cambridge	UK	1925
<sup>202</sup> Hg	F.W. Aston	Nature	Ast20	MS	Cambridge	UK	1920
<sup>203</sup> Hg	G. Friedlander	Phys. Rev.	Fri43	NC	Berkeley	USA	1943
<sup>204</sup> Hg	F.W. Aston	Nature	Ast20	MS	Cambridge	UK	1920
<sup>205</sup> Hg	R.S. Krishnan	Proc. Camb. Phil. Soc.	Kri40	LP	Cambridge	UK	1940
<sup>206</sup> Hg	M. Nurmia	Nature	Nur61	AD	Helsinki	Finland	1961
<sup>207</sup> Hg	S. Mirzadeh	Radiochem. Radioanal. Lett.	Mir82	LP	Brookhaven	USA	1982
<sup>208</sup> Hg	L. Zhang	Phys. Rev. C	Zha94	LP	Lanzhou	China	1994
<sup>209</sup> Hg	L. Zhang	Phys. Rev. C	Zha98	LP	Lanzhou	China	1998
<sup>210</sup> Hg	M. Pfuetzner	Phys. Lett. B	Pfu98	PF	Darmstadt	Germany	1998

## REFERENCES FOR TABLE

- Alb59 G. Albouy, R. Bernas, M. Gusakow, N. Poffe, and J. Teillac, *Compt. Rend. Acad. Sci.* **249**, 407 (1959)
- Alb60 G. Albouy, M.M. Gusakow, and N.Poffe, *J. Phys. Radium* **21**, 751 (1960)
- Ast20 F.W. Aston, *Nature* **105**, 8 (1920)
- Ast25 F.W. Aston, *Nature* **116**, 208 (1925)
- Ast30 F.W. Aston, *Proc. Roy. Soc. London* **126**, 511 (1930)
- Cab75 C. Cabot, C. Deprun, H. Gauvin, Y. Beyec, and M. Lefort, *Compt. Rend. Acad. Sci.* **B281**, 453 (1975)
- Dem68 A.G. Demin, T. Fenyés, L. Mahunka, V.G. Subbotin, and L. Tron, *Nucl. Phys. A* **106**, 337 (1968)
- Fin52 R. Fink and E.O. Wiig, *J. Am. Chem. Soc.* **74**, 2457 (1952)
- Fri43 G. Friedlander, and C. Wu, *Phys. Rev.* **63**, 227 (1943)
- Gil54 L.P. Gillon, K. Gopalakrishnan, and A. de-Shalit, *Phys. Rev.* **93**, 124 (1954)
- Han69 P.G. Hansen, P. Hornshøj, H.L. Nielsen, K. Wilsky, H. Kugler, G. Astner, E. Hagebo, J. Hudis, A. Kjelberg, F. Münnich, P. Patzelt, M. Alpsten, G. Andersson, Aa. Appelqvist, B. Bengtsson, R.A. Naumann, O.B. Nielsen, E. Beck, R. Foucher, P. Husson, J. Jastrzebski, A. Johnson, J. Alstad, T. Jahnsen, A.C. Pappas and T. Tunaal, R. Henck, P. Siffert, and G. Rudstam, *Phys. Lett.* **28B**, 415 (1969), Erratum *Phys.Lett.* **28B**, 663 (1969)
- Han70 P.G. Hansen, H.L. Nielsen, K. Wilsky, M. Alpsten, M. Finger, A. Lindahl, R.A. Naumann, and O.B. Nelson, *Nucl. Phys. A* **148**, 249 (1970)
- Han71 P.G. Hansen, B. Jonson, J. Zylicz, M. Alpsten, A. Appelqvist and G. Nyman, *Nucl. Phys. A* **160**, 445 (1971)
- Ket04 H. Kettunen, T. Enqvist, T. Grahn, P.T. Greenlees, P. Jones, R. Julin, S. Juutinen, A. Keenan, P. Kuusiniemi, M. Leino, A.-P. Leppänen, P. Nieminen, J. Pakarinen, P. Rahkila, and J. Uusitalo, *Phys. Rev. C* **69**, 054323 (2004)
- Kri40 R.S. Krishnan and E.A. Nahum, *Proc. Camb. Phil. Soc.* **36**, 490 (1940)
- Mir82 S. Mirzadeh and Y.Y. Chu, *Radiochem. Radioanal. Lett.* **51**, 279 (1982)
- Nur61 M. Nurmia, P. Kauranen, M. Karras, A. Siivola, A. Isola, G. Graeffe, A. Lyyjynen, *Nature* **190**, 427 (1961)
- Ort73 C.J. Orth, H.A. O'Brien, Jr., M.E. Schillaci and B.J. Dropesky, *Inorg. Nucl. Chem. Lett.* **9**, 611 (1973)
- Pfu98 M. Pfützner, P. Armbruster, T. Baumann, J. Benlliure, M. Bernas, W.N. Catford, D. Cortina-Gil, J.M. Daugas, H. Geissel, M. Górska, H. Grawe, R. Grzywacz, M. Hellström, N. Iwasa, Z. Janas, A.R. Junghans, M. Karny, S. Leenhardt, M. Lewitowicz, A.C. Mueller, F. de Oliveira, P.H. Regan, M. Rejmund, K. Rykaczewski, K. Sümmerer, *Phys. Lett.* **444B**, 32 (1998)

- Pof60 N. Poffe, G. Albouy, R. Bernas, M. Gusakow, M. Riou, and J. Teillac, *J. Phys. Radium* **21**, 343 (1960)
- Sch83 J.R.H. Schneider, S. Hoffman, F.P. Heßberger, G. Munzenberg, W. Reisdorf, and P. Armbruster, *Z. Phys. A* **312**, 21 (1983)
- Sew99 D. Seweryniak, J. Uusitalo, M.P. Carpenter, D. Nisius, C.N. Davids, C.R. Bingham, L.T. Brown, L. Conticchio, D.J. Henderson, R.V.F. Janssens, W.B. Walters, J. Wauters, and P.J. Woods, *Phys. Rev. C* **60**, 031304 (1999)
- She41 R. Sherr, K.T. Bainbridge, and H.H. Anderson, *Phys. Rev.* **60**, 473 (1941)
- Smi55 W.G. Smith and J.M. Hollander, *Phys. Rev.* **98**, 1258 (1955)
- Uus97 J. Uusitalo, M. Leino, R.G. Allatt, T. Enqvist, K. Eskola, P.T. Greenlees, S. Hurskanen, A. Keenan, H. Kettunen, P. Kuusiniemi, R.D. Page, W.H. Trzaska, *Z. Phys. A* **358**, 375 (1997)
- Zha94 Zhang Li, Jin Ghenming, Zhao Jinhua, Yang Weifan, Yang Yongfeng, Zhao Zhizheng, Zheng Jiwen, Sun Xiurong, Wang Jicheng, Li Zongwei, Qin Zhi, Guo Guanghui, Luo Yixiao, Jan Zylicz, and Jing-ye Zhang, *Phys. Rev.* **C49**, R592 (1994)
- Zha98 Zhang Li, Zhao Jinhua, Zheng Jiwen, Wang Jicheng, Qin Zhi, Yang Youngfeng, Zhang Chun, Jin Genming, Guo Guanghui, Du Yifei, Guo Tianrui, Wang Tongqing, Guo Bin, Tian Jinfeng, and Lou Yixiao, *Phys. Rev.* **C58**, 156 (1998)