

Discovery of the Indium Isotopes

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Thirty-eight indium 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 indium 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 γ -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 adapted value taken from the NUBASE evaluation [2] which is based on the ENSDF database [3].

2. DISCOVERY OF $^{98-135}\text{IN}$

Thirty-eight indium isotopes from $A = 98 - 135$ have been discovered so far; these include 2 stable, 16 proton-rich and 20 neutron-rich isotopes. According to the HFB-14 model [4], ^{165}In should be the last particle stable neutron-rich nucleus (^{160}In is calculated to be unbound). Along the proton dripline one more isotope is predicted to be stable and it is estimated that five additional nuclei beyond the proton dripline could live long enough to be observed [5]. Thus, there remain 35 isotopes to be discovered. About 50% of all possible indium isotopes have been produced and identified so far.

Figure A summarizes the year of first discovery for all indium 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 indium isotopes were produced using fusion evaporation (FE), projectile fragmentation or projectile fission (PF), light-particle reactions (LP), neutron capture (NC), neutron-induced fission (NF),

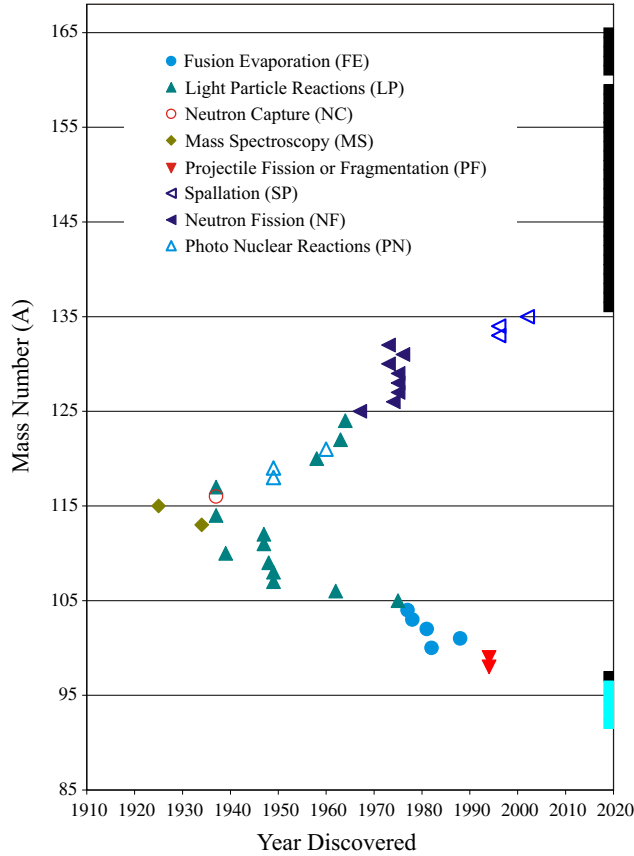


FIG. A. Indium isotopes as a function of time they were discovered. The different production methods are indicated. The solid black squares on the right hand side of the plot are isotopes predicted to be bound by the HFB-14 model. On the proton-rich side the light blue squares correspond to unbound isotopes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

photo-nuclear reaction (PN) and spallation reactions (SP). 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 indium isotope is discussed in detail.

$^{98,99}\text{In}$

The discovery of ^{98}In and ^{99}In was presented in “Production and Identification of ^{100}Sn ” by Schneider *et al.* in 1994 [7]. ^{98}In and ^{99}In were produced from a beryllium target bombarded by a $1095 \text{ A}\cdot\text{MeV}$ ^{124}Xe beam from the heavy-ion synchrotron SIS at GSI, Darmstadt. The products were separated with the fragment separator FRS and identified in flight by recording magnetic rigidity, multiple time-of-flights, and energy. “The individual isotopes are clearly resolved... The majority of the events are as-

signed to ^{101}Sn , the new isotope ^{99}In , and ^{100}In . The four events at $M/Q \sim 2.0$ and $\Delta E \sim 960$ a.u. in Fig. 2 are preliminarily attributed to ^{98}In .” 142 events of ^{99}In were recorded.

^{100}In

In 1982 the article, “Investigations of Very Neutron-Deficient Isotopes Below ^{100}Sn in ^{40}Ca -Induced Reactions,” by Kurcewicz *et al.* reported the discovery of ^{100}In [8]. A 4.0 MeV/u ^{40}Ca from the heavy-ion accelerator UNILAC at GSI was used to produce ^{100}In in the fusion evaporation reaction $^{63}\text{Cu}(^{40}\text{Ca},3n)$. Beta-delayed protons were measured following online mass separation. These particles were mass separated and analyzed by β - x- and γ - rays. “From systematic considerations... the β -delayed protons observed at 97, 99 and 100 mass numbers were assigned to ^{97}Cd , ^{99}Cd and ^{100}In , respectively.” No half-life was extracted due to the limited statistics.

^{101}In

In “Decay Study of Neutron-Deficient ^{101}In ” ^{101}In was reported for the first time in 1988 by Huyse *et al.* [9]. At the Instituut voor Kern- en Stralingsfysica in Leuven a 240 MeV ^{20}Ne beam bombarded a ^{92}Mo target and ^{101}In was separated and identified with the Leuven Isotope Separator On Line LISOL. “The very neutron-deficient nucleus ^{101}In has been identified for the first time by studying the β -delayed γ rays of on-line mass-separated samples. The deduced half-life is 16(3) s.” This half-life is included in the weighted average of the current value of 15.1(3) s.

^{102}In

In 1981 Beraud *et al.* discovered ^{102}In as reported in “Identification and Decay of ^{102}In , New Neutron Deficient Isotope Close to ^{100}In ,” [10]. An 86 MeV ^{14}N beam from the Grenoble cyclotron produced ^{102}In in the fusion-evaporation reaction $^{92}\text{Mo}(^{14}\text{N},4n)$. Gamma- and X-rays were measured following mass separation. “Although no X-X ray characteristic of Cd element could be seen due to the presence of an enormous amount of K-X lines associated to $^{102}\text{Ag} \rightarrow \text{Pd}$ decay (AG/In production ratio $> 10^3$, the four lines never seen before belong necessarily to the $^{102}\text{In} \rightarrow$ decay.” The measured half-life of 24(4) s agrees with the presently adopted value of 22(1) s.

^{103}In

The discovery of ^{103}In was described by Lhersonneau *et al.* in “Decay of neutron-deficient ^{103}In and ^{103}Cd Isotopes” in 1978 [11]. ^{14}N was accelerated by the Louvain-la-Neuve CYCLONE cyclotron to 72 MeV and bombarded a natural molybdenum filament. ^{103}In was produced with the fusion-evaporation reaction $^{92}\text{Mo}(^{14}\text{N},3n)$ and separated with the online separator LISOL. The isotopes were identified by γ -ray, X-ray, and conversion electron measurements. “The newly discovered activity ^{103}In ($T_{1/2}=1.08\pm 0.11$ min) was found to be populated mainly at $7/2^+$ excited ^{103}Cd state at 188 KeV.” This half-life is currently the only value measured.

^{104}In

In 1977 the article “The decay of ^{104}In ” by Varley *et al.* presented the discovery of ^{104}In [12]. A ~ 100 MeV ^{16}O beam from the Manchester heavy-ion linear accelerator bombarded a ^{92}Mo target to form ^{104}In in the fusion-evaporation reaction $^{92}\text{Mo}(^{16}\text{O},p3n)$. ^{104}In was identified with the He-jet recoil transport system HeJRT. “Measurements of half-lives, excitation functions gamma-x-ray and gamma-gamma coincidences have allowed the identification of gamma rays emitted in the decay of an isomer of ^{104}In .” The half-life of 1.5(2) m is consistent with the current value of 1.80(3) m for this isomer. Previously assigned half-life values of 25(6) m and 4.6(2) m to ^{104}In [13] could not be confirmed.

^{105}In

Rivier and Moret describe the ^{105}In observation of 1975 in “Mise en Evidence de L’isotope ^{105}In et Etude de la Desintegration $^{105}\text{In} \rightarrow ^{105}\text{Cd}$ ” [14]. Enriched ^{106}Cd targets were bombarded with 19-31 MeV protons from the Grenoble variable energy cyclotron. ^{105}In was produced in the (p,2n) reaction and identified by measuring γ - γ coincidences. “A new isotope ^{105}In was produced by means of the reaction $^{106}\text{Cd}(p,2n)$.” The measured half-life for the ground state of 5.1(3) m agrees with the currently adopted value of 5.07(7) m. The article was published two years after submission. The ^{105}In results were included in a separate article submitted two weeks after the paper by Rivier and Moret and published within six months [15]. It should also be mentioned that in 1974 another article reported the discovery of ^{105}In [16].

^{106}In

In “New Isotope Indium-106” the discovery of ^{106}In was reported in 1962 by Catura and Richardson [17]. Enriched ^{106}Cd targets were bombarded by 14 MeV protons from the UCLA cyclotron. ^{106}In , produced in the (p,n) charge-exchange reaction was identified by γ -ray measurements following chemical separation. “Measurements on the yield of gamma rays above 1.8 Mev as a function of proton energy indicated the 5.3-min activity to be the result of a p,n reaction and placed an upper limit on its threshold of 8 Mev. With the above information this activity can definitely be assigned to In^{106} .” The measured half-life of 5.3 m is close to the currently accepted value of 6.2(1) m.

$^{107,108}\text{In}$

In 1949 Mallary and Pool discovered ^{107}In and ^{108}In in “Radioactive In^{107} , In^{108} , In^{109} and Sn^{108} ” [18]. 10 MeV Deuterons and 5 MeV protons from the Mendenhall Laboratory at Ohio State University bombarded enriched ^{106}Cd and ^{108}Cd targets to produce ^{107}In and ^{108}In , respectively. Decay curves measured with a spectrometer counter and a Wulf unifilar electrometer were recorded following chemical separation. “When cadmium enriched in isotope 106 was bombarded with deuterons and with protons, there was produced in the indium fraction a new radioactive isotope which decayed with a 33 ± 2 min half-life by emitting positrons and gamma-rays in excess of the annihilations radiation.... The mass assignment is thus made to isotope 107 instead of 106... Two genetically related isotopes in tin and indium have been assigned to mass number 108. The indium isotope, which is produced by the decay of the tin isotope and by bombarding cadmium 108 with deuterons, decays with a half-life of about 55 min. by emitting positrons of 2-Mev energy and gamma-rays.” These half-lives agree with the

presently accepted values of 32.4(3) m and 58.0(12) m for ^{107}In and ^{108}In , respectively. A 5-h half-life had previously incorrectly been assigned to ^{108}In [19].

^{109}In

^{109}In was first reported in “Excitation Curves of (α ,n); (α ,2n); (α ,3n) Reactions on Silver” by Ghoshal in 1948 [19]. ^{109}In was produced by bombarding silver targets with α -particles accelerated by the Berkeley 60-in cyclotron up to 37 MeV. The isotopes were separated with a mass-spectrograph and excitation functions and decay curves were recorded. “The 5.2 hr. period is produced by $\text{Ag}^{107}(\alpha,2n)\text{In}^{109}$ reaction. The excitation curve is similar to the excitation curve of In^{111} , as is expected, since both are products of (α ,2n) reactions.” The measured half-life is close to the currently adopted value of 4.167(18) h.

^{110}In

In the 1939 article, “Proton Activation of Indium and Cadmium,” Barnes reported the first observation of ^{110}In [20]. Cadmium foils were bombarded by 7.2 MeV protons from the University of Rochester’s cyclotron and decay curves were measured with an ionization chamber. “The positron activity with half-life of 65 ± 5 min. has not been previously reported... In^{106} , In^{108} and In^{110} must be positron emitters, and since Cd^{110} is ten times as abundant as either Cd^{106} or Cd^{108} this activity is tentatively assigned to In^{110} .” This half-life agrees with the value of the 69.1(5) m isomeric state.

$^{111,112}\text{In}$

“The Radioactive Indium Isotopes of Mass Numbers 111 and 112” by Tendam and Bradt was published in 1947 identifying ^{111}In and ^{112}In [21]. At Purdue University silver targets were bombarded with 15-20 MeV α -particles. Indium was identified by chemical analysis, and the isotopes were identified via excitation energy measurements and decay curves. “It is seen from its excitation curve that the 2.7-day period is the product of an (α ,2n) reaction with a threshold of 15.5 ± 0.5 MeV and must be assigned to In^{111} ... Since its excitation curve is almost identical with that of the 66-min. In^{110} , produced by the $\text{Ag}^{107}(\alpha,n)\text{In}^{110}$ reaction, the 23-min. period must be assigned to mass number 112 as the product of the $\text{Ag}^{109}(\alpha,n)\text{In}^{112}$ reaction.” These half-lives are consistent with the currently accepted values of 2.8047(4) d and 20.56(6) m, for ^{111}In and ^{112}In , respectively. The half-life for ^{112}In corresponds to an isomeric state. Lawson and Cork had previously assigned a ~ 20 m half-life to ^{111}In in several papers [22,23,24]. Barnes also assigned an 18-20 m half-life to ^{111}In and he attributed a 2.7 d half-life to an ^{112}In isomer in 1939 [20]. Cork and Lawson assigned a 65.0(45) h half-life first to ^{113}In [23] and later to ^{112}In [24].

^{113}In

Wehrli reported the discovery of ^{113}In in the 1934 article “Das Indium-Isotop 113” [25]. ^{113}In was identified by means of anode ray spectrography. “Gemeinsam mit E. Meischer habe ich im Bandenspektrum des InJ 2 schwache Kanten festgestellt, welche als Isotopenkanten gedeutet und dem In_{113}J zugeordnet wurden.” (Together with E. Meischer I have determined two weak edges in the line spectrum

of InJ, which were interpreted as isotope edges and assigned to ^{113}In .) Further details were presented in a subsequent publication [26].

^{114}In

The isotope ^{114}In was first identified in 1937 by Lawson and Cork in “The Radioactive Isotopes of Indium” [22]. Indium was irradiated with 14 to 20 MeV neutrons produced from the bombardment of lithium with 6.3 MeV deuterons at the University of Michigan. ^{114}In was identified via decay curve measurements. “The 50-day period has so far been observe only when the activation has been with fast neutrons. This therefore might be placed as either an isomer of 112 or 114. It has been tentatively placed as 114.” The 50 d half-life agrees with the currently accepted value for the 49.51(1) d isomeric state. The half-life of the ^{114}In ground state is 71.9(1) s. Half-lives of 1 m [27] and 1.1 m [28] had been measured previously but no mass assignments were made. Also, a 13 s half-life had been assigned incorrectly to ^{114}In [29].

^{115}In

Aston described the discovery of ^{115}In in the 1925 article “The Mass Spectra of Chemical Elements, Part VI. Accelerated Anode Rays Continued” [30]. ^{115}In was detected using the accelerated anode ray method with a solution of hydrofluoric acid: “This incorporated into the anode gave a mass spectrum showing one line only at 115.”

^{116}In

The isotope ^{116}In was first identified in 1937 by Lawson and Cork in “The Radioactive Isotopes of Indium” [22]. Indium was irradiated with slow neutrons at the University of Michigan. Decay curves of β -activity were measured and half-lives extracted, “...although the 13-second and 54-minute periods could have been associated with either 114 or 116 the are undoubtedly due to 116.” The 13 s half-life agrees with the currently adopted value for the ground state of 14.10(3) s. The 54 m half-life corresponds to the 54.29(13) m isomeric state. The 13 s and the 54 m had been previously observed but without a definite mass assignment [31]. In an article published a few months earlier Cork and Thornton had associated a 58 m half-life with ^{116}In , however, without an actual measurement [29].

^{117}In

The discovery of ^{117}In was described in 1937 by Cork and Thornton in the article “The Disintegration of Cadmium with Deuterons” [29]. A 6.3 MeV deuteron beam bombarded metallic cadmium at the University of Michigan. Indium was successively abstracted from chemically separated cadmium and decay curves measured. “The long-period cadmium activity gives rise to a radioactive indium of half-life 2.3 hr.” This half-life was assigned to ^{117}In in a table and is consistent with the currently adopted value of the 116.2(3) m isomeric state.

^{118,119}In

In 1949 ¹¹⁸In and ¹¹⁹In were first observed by Duffield and Knight in “In¹¹⁸ and In¹¹⁹ produced by Photo-Disintegration of Tin” [32]. At the University of Illinois, 23 MeV X-rays bombarded enriched ¹¹⁹Sn and ¹²⁰Sn to produce ¹¹⁸In and ¹¹⁹In, respectively. Decay curves were recorded which in the case of ¹¹⁹In was preceded by chemical separation. “An examination of the indium activities produced by the irradiation of tin with 23 MeV betatron x-rays at this laboratory has led to the identification of two additional periods which can be assigned to In¹¹⁸ and In¹¹⁹ on the basis of evidence outlined below.” The measured half-lives for ¹¹⁸In (4.5(5) m) and ¹¹⁹In (17.5(10) m) agree with the currently accepted values for isomeric states in these nuclei of 4.364(7) m and 18.0(3) m, respectively.

¹²⁰In

In “Radioactivity of In¹²⁰ and Sb¹²⁰” McGinnis reported the discovery of ¹²⁰In in 1958 [33]. ¹²⁰In was produced in a (n,p) charge-exchange reaction by bombarding natural tin with 20 MeV neutrons. No chemical separation was performed and γ -rays were measured with a scintillation detector. “The data of Table VII are the basis for assigning the 55 s activity to In^{120m}.” This half-life is consistent with either of two isomeric states with half-lives of 47.3(5) s and 46.2(8) s.

¹²¹In

In 1960 Yuta and Morinaga identified ¹²¹In for the first time in “Study of Heavy Odd-Mass Indium Isotopes from the (γ ,p) Reaction on Tin” [34]. Targets of enriched ¹²²SnO₂ were bombarded by 25 MeV bremsstrahlung from the 25-MeV betatron at Tohoku University. Gamma-ray spectra were measured with a 4” \times 4” NaI crystal and β decay curves were recorded. “Here, a new peak at 0.94 MeV is clearly seen. This peak decayed with a half-life of 30 \pm 3 sec... it is assigned to the g_{9/2} state of In¹²¹.” This half-life is consistent with the currently accepted value of 23.1(6) s. Previously reported half-lives of 12 m and 32 m [35] could not be confirmed.

¹²²In

The discovery of ¹²²In by Kantele and Karras was reported in the 1963 publication “New Isotope In¹²²” [36]. A 14-15 MeV beam of neutrons bombarded a ¹²²Sn enriched target at the University of Arkansas 400 kV Cockcroft-Walton accelerator and produced ¹²²In in the (n,p) charge exchange reaction. γ - and β -radiation and γ - γ coincidences were measured. “In connection with a systematic study of the level structure of even tin isotopes resulting from the decay of neutron-excess indium isotopes, a new 7.5-sec activity was found and was assigned to the hitherto unknown isotope In¹²².” This 7.5(8) s half-life could be either one of two isomeric states of 10.3(6) s or 10.8(4) s.

¹²³In

In 1960 Yuta and Morinaga identified ¹²³In for the first time in “Study of Heavy Odd-Mass Indium Isotopes from the (γ ,p) Reaction on Tin” [34]. Targets of enriched ¹²⁴SnO₂ were bombarded by 25 MeV bremsstrahlung from the 25-MeV betatron at Tohoku University. Gamma-ray spectra were measured and β decay curves were recorded. “A peak at 1.10 MeV appears here and has a half-life of 10 sec. It is

assigned to the $g_{9/2}$ state of ^{123}In as in the cases of Sn^{120} and Sn^{122} .” The measured half-life of 10(2) s is close to the currently accepted value of 6.17(5) s.

^{124}In

In 1964 the article “New Isotope In^{124} ,” by Karras reported the discovery of ^{124}In [37]. The neutron generator at the University of Arkansas provided 14-15 MeV neutrons which bombarded enriched ^{124}Sn and produced ^{124}In in the (n,p) charge exchange reaction. β - and γ -ray spectra were measured. “Irradiation of Sn^{124} samples with 14-15 MeV neutrons was found to produce a new radioactive nuclide which was assigned to In^{124} .” The measured 3.6 s half-life agrees with the currently adopted value of 3.12(9) s for the ground state or with the 3.7(2) s isomeric state.

^{125}In

In “Short-Lived Fission Products” the first observation of ^{125}In was reported in 1967 by Fritze and Griffiths [38]. ^{125}In was produced via neutron induced fission of ^{235}U at the McMaster University Reactor. The isotope was identified by its daughter activity following chemical separation. “Proof of the presence of a given nuclide depended on the identification of a known daughter activity resulting from the decay of the unknown short-lived parent, which had been separated completely from daughter activities as soon as possible after the end of the irradiation... Starting 13 min after the end of the irradiation γ -spectra were taken at 7 min intervals and showed the presence of 40 min ^{123}Sn (160 keV) and 10 min ^{125m}Sn (335 keV).”

^{126}In

Grapengiesser *et al.* reported the observation of ^{126}In in “Survey of Short-lived Fission Products Obtained Using the Isotope-Separator-On-Line Facility at Studsvik” in 1974 [39]. ^{126}In was produced by neutron induced fission and identified at the OSIRIS isotope-separator online facility at the Studsvik Neutron Research Laboratory in Nyköping, Sweden. In the long table of experimental half-lives of many different isotopes the half-life of ^{126}In is quoted as 1.53(1) s. This value is included in the currently adopted average 1.53(1) s.

$^{127-129}\text{In}$

In 1975 the first identification of ^{127}In , ^{128}In , and ^{129}In was reported by Aleklett *et al.* “Beta-Decay Properties of Strongly Neutron-Rich Nuclei” [40]. The isotopes were produced by thermal-neutron induced fission of ^{235}U and identified using Studsvik’s OSIRIS separator. In Table 2 listing heavy fission fragments from silver to lanthanum, ^{127}In , ^{128}In , and ^{129}In are identified with half-lives as quoted from the report by Grapengiesser [39]. Grapengiesser did not uniquely assign the elements; for ^{127}In and ^{128}In cadmium or indium are listed as possible element and no element assignment was made for ^{129}In . While the half-lives for ^{128}In (0.80(3) s) and ^{129}In (0.8(3) s) agree, Grapengiesser quotes two values for mass 127 (1.3(2) s and 3.7(1) s) while Aleklett *et al.* quotes only a value of 3.1 s. The half-life of 3.1 s for ^{127}In agrees with the current measurement of 3.67(4) s for an isomeric state, the half-lives of 0.8 s agree with the currently adopted values of 0.84(6) s and 0.61(1) s for ^{128}In and ^{129}In , respectively.

¹³⁰In

“Excited States in the Two-Neutron-Hole Nucleus ${}_{50}^{130}\text{Sn}_{80}$ Observed in the 0.53 sec β^- Decay of ${}^{130}\text{In}$ ” described the first observation of ${}^{130}\text{In}$ by Kerek *et al.* in 1973 [41]. ${}^{130}\text{In}$ was produced by neutron induced fission of ${}^{235}\text{U}$ at Studsvik, Sweden, and identified utilizing the OSIRIS separator. “Among the high-energy β -rays a short-lived component with the half-life 0.53 ± 0.05 sec could be observed. Since the E_{β^-} threshold exceeds all other E_{β^-} in the chain, the half-life is assigned to the ${}^{130}\text{In}\rightarrow{}^{130}\text{Sn}$ decay.” This half-life value is included in the calculation of the currently adopted value of 0.54(1) s.

¹³¹In

${}^{131}\text{In}$ was discovered by Lund and Rundstam in 1976 as reported in “Delayed-neutron activities produced in fission: Mass range 122-146” [42]. ${}^{131}\text{In}$ was produced via neutron fission in a uranium target at the Studsvik R2-0 reactor and separated with the OSIRIS on-line mass-separator facility. 30 ${}^3\text{He}$ neutron counters were used to measure the delayed neutron activities. “The 0.29 sec activity is to be attributed to ${}^{131}\text{In}$ for which the β half-life has been determined to be 0.27 ± 0.02 sec.” This 0.29(1) s activity agrees with the currently accepted value of 0.28(3) s. The cited value of 0.27(2) s referred to a “to be published article” by De Geer *et al.*.

¹³²In

The discovery of ${}^{132}\text{In}$ was described in the 1973 article “The First Excited State in the Doubly-Closed-Shell Nucleus ${}^{132}\text{Sn}$ Populated in the 0.12 s β^- -Decay of ${}^{132}\text{In}$ ” by Kerek *et al.* [43]. ${}^{132}\text{In}$ was produced by neutron induced fission of ${}^{235}\text{U}$ at Studsvik, Sweden, and identified utilizing the OSIRIS separator. “A 0.12 ± 0.02 s beta activity assigned to the decay of ${}^{132}\text{In}$ and populating an excited state of 4041 ± 2 KeV in the doubly-closed-shell nucleus ${}_{50}^{132}\text{Sn}_{82}$ has been observed.” This half-life is near the currently accepted value of 0.207(6) s.

^{133,134}In

In 1996 Hoff *et al.* reported the discovery of ${}^{133}\text{In}$ and ${}^{134}\text{In}$ in “Single-Neutron States in ${}^{133}\text{Sn}$ ” [44]. 1 GeV protons induced fission of uranium carbide at the CERN PS-Booster. Mass separation and β - and γ -decay spectroscopy was performed at the ISOLDE facility. Decay characteristics of ${}^{133}\text{In}$ were measured but the half-life was not extracted and assumed to be known: “Some of the present authors attempted to determine the structure of ${}^{133}\text{Sn}$ at the ISOLDE facility at the CERN SC, more than a decade ago... Although two β -decay states $g_{9/2}^{-1}$ and $p_{1/2}^{-1}$, were expected, only one half-life of 180 ± 15 ms was observed.” No specific reference is given but most likely it referred to a 1981 conference proceeding by Blomqvist *et al.* [45]. ${}^{133}\text{Sn}$ was also populated by β -delayed neutron emission from ${}^{134}\text{In}$. “Some distinct transitions in ${}^{133}\text{Sn}$ clearly visible, in particular, those at 854, 1561, and 2005 KeV. An analysis of their time dependence with respect to the beam pulses gave the half-life of ${}^{134}\text{In}$ as 138 ± 8 ms.” The quoted half-life for ${}^{133}\text{In}$ agrees with the currently accepted half-life of 165(3) ms and the measured half-life for ${}^{134}\text{In}$ is included in the currently adopted weighted average of 140(4) ms.

¹³⁵In

The 2002 article, “Selective Laser Ionization of $N \geq 82$ Indium Isotopes: The New r-process Nuclide ¹³⁵In,” by Dillmann *et al.* discussed the first identification of ¹³⁵In [46]. A tantalum converter was bombarded with 1.4 GeV protons at the CERN ISOLDE facility. Neutrons from the converter induced fission in an adjacent UC_x/graphite target. ¹³⁵In was separated and identified using laser ionization. The ISOLDE UC_x at CERN produced 1.4 GeV protons which bombarded graphite with ²³⁸U and carbon with a tantalum converter. Products were identified by means of ionization and mass separation. “With 92(10) ms ¹³⁵In, a new r-process nuclide has been identified...” This half-life is currently the only measured value.

3. SUMMARY

The discoveries of the known indium isotopes have been compiled and the methods of their production discussed. The first measured half-lives of several isotopes (¹⁰⁴In, ¹⁰⁸In, ¹¹¹In, ¹¹²In, ¹¹⁴In, and ¹²¹In) were incorrect. The half-lives of ¹¹⁴In and ¹¹⁶In were first reported without a definite mass assignment. The discovery of ¹⁰⁵In was only published two years after submission of the article during which time ¹⁰⁵In was reported by other authors. The discovery of ¹³³In appeared in a refereed journal 15 years after it had been reported in a conference proceeding.

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EXPLANATION OF TABLE

TABLE I. Discovery of Indium Isotopes

Isotope	Indium 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) NC: neutron capture MS: mass spectroscopy SP: spallation PF: projectile fragmentation or fission NF: neutron induced fission PN: photo nuclear reactions
Laboratory	Laboratory where the experiment was performed
Country	Country of laboratory
Year	Year of discovery

TABLE I. Discovery of Indmium isotopes

See page 14 for Explanation of Tables

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Isotope	Author	Journal	Ref.	Method	Laboratory	Country	Year
⁹⁸ In	R. Schneider	Z. Phys. A	Sch94	PF	Darmstadt	Germany	1994
⁹⁹ In	R. Schneider	Z. Phys. A	Sch94	PF	Darmstadt	Germany	1994
¹⁰⁰ In	W. Kurcewicz	Z. Phys. A	Kur82	FE	Darmstadt	Germany	1982
¹⁰¹ In	M. Huyse	Z. Phys. A	Huy88	FE	Louvain-la-Neuve	Belgium	1988
¹⁰² In	B. Beraud	Z. Phys. A	Ber81	FE	Grenoble	France	1981
¹⁰³ In	G. Lhersonneau	Phys. Rev. C	Lhe78	FE	Louvain-la-Neuve	Belgium	1978
¹⁰⁴ In	B.J. Varley	J. Phys. G	Var77	FE	Manchester	UK	1977
¹⁰⁵ In	J. Rivier	Radiochim. Acta	Riv75	LP	Grenoble	France	1975
¹⁰⁶ In	R.C. Catura	Phys. Rev.	Cat62	LP	UCLA	USA	1962
¹⁰⁷ In	E.C. Mallery	Phys. Rev.	Mal49	LP	Ohio State	USA	1949
¹⁰⁸ In	E.C. Mallery	Phys. Rev.	Mal49	LP	Ohio State	USA	1949
¹⁰⁹ In	S.N. Goshal	Phys. Rev.	Gho48	LP	Berkeley	USA	1948
¹¹⁰ In	S.W. Barnes	Phys. Rev.	Bar39	LP	Rochester	USA	1939
¹¹¹ In	D.J. Tendam	Phys. Rev.	Ten47	LP	Purdue	USA	1947
¹¹² In	D.J. Tendam	Phys. Rev.	Ten47	LP	Purdue	USA	1947
¹¹³ In	M. Wehrli	Naturwiss.	Weh34	MS	Basel	Switzerland	1934
¹¹⁴ In	J.L. Lawson	Phys. Rev.	Law37	LP	Michigan	USA	1937
¹¹⁵ In	F.W. Aston	Phil. Mag.	Ast25	MS	Cambridge	UK	1925
¹¹⁶ In	J.L. Lawson	Phys. Rev.	Law37	NC	Michigan	USA	1937
¹¹⁷ In	J.M. Cork	Phys. Rev.	Cor37	LP	Michigan	USA	1937
¹¹⁸ In	R.B. Duffield	Phys. Rev.	Duf49	PN	Illinois	USA	1949
¹¹⁹ In	R.B. Duffield	Phys. Rev.	Duf49	PN	Illinois	USA	1949
¹²⁰ In	C.L. McGinnis	Phys. Rev.	McG58	LP	NBS	USA	1958
¹²¹ In	H. Yuta	Nucl. Phys.	Yut60	PN	Tohoku	Japan	1960
¹²² In	J. Kantele	Phys. Rev.	Kan63	LP	Arkansas	USA	1963
¹²³ In	H. Yuta	Nucl. Phys.	Yut60	PN	Tohoku	Japan	1960
¹²⁴ In	M. Karras	Phys. Rev.	Kar64	LP	Arkansas	USA	1964
¹²⁵ In	K. Fritzke	Radiochim. Acta	Fri67	NF	McMaster	Canada	1967
¹²⁶ In	B. Grapengiesser	J. Inorg. Nucl. Chem.	Gra74	NF	Studsvik	Sweden	1974
¹²⁷ In	K. Aleklett	Nucl. Phys. A	Ale75	NF	Studsvik	Sweden	1975
¹²⁸ In	K. Aleklett	Nucl. Phys. A	Ale75	NF	Studsvik	Sweden	1975
¹²⁹ In	K. Aleklett	Nucl. Phys. A	Ale75	NF	Studsvik	Sweden	1975
¹³⁰ In	A. Kerek	Nucl. Phys. A	Ker73a	NF	Studsvik	Sweden	1973
¹³¹ In	E. Lund	Phys. Rev. C	Lun76	NF	Studsvik	Sweden	1976
¹³² In	A. Kerek	Phys. Lett. B	Ker73b	NF	Studsvik	Sweden	1973
¹³³ In	P. Hoff	Phys. Rev. Lett.	Hof96	SP	CERN	Switzerland	1996
¹³⁴ In	P. Hoff	Phys. Rev. Lett.	Hof96	SP	CERN	Switzerland	1996
¹³⁵ In	I. Dillmann	Eur. Phys. J. A	Dil02	SP	CERN	Switzerland	2002

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