Discovery of the Neodymium Isotopes

J. L. Gross, M. Thoennessen*

National Superconducting Cyclotron Laboratory and
Department of Physics and Astronomy, Michigan State University,
East Lansing, MI 48824, USA

Abstract

Thirty-one neodymium 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.

*Corresponding author.
Email address: thoennessen@nscl.msu.edu (M. Thoennessen)

Contents

1. Introduction . . . 2
2. Discovery of $^{125-156}$Nd . . . 3
   2.1. ^{125}Nd . . . 3
   2.2. ^{127}Nd . . . 3
   2.3. ^{128}Nd . . . 5
   2.4. $^{129-133}$Nd . . . 5
   2.5. ^{134,135}Nd . . . 5
   2.6. ^{136}Nd . . . 5
   2.7. ^{137}Nd . . . 6
   2.8. ^{138}Nd . . . 6
   2.9. ^{139}Nd . . . 6
   2.10. ^{140,141}Nd . . . 6
   2.11. ^{142}Nd . . . 7
   2.12. ^{143}Nd . . . 7
   2.13. ^{144}Nd . . . 7
   2.14. ^{145}Nd . . . 7
   2.15. ^{146}Nd . . . 7
   2.16. ^{147}Nd . . . 7
   2.17. ^{148}Nd . . . 8
   2.18. ^{149}Nd . . . 8
   2.19. ^{150}Nd . . . 8
   2.20. ^{151}Nd . . . 8
   2.21. ^{152}Nd . . . 9
   2.22. ^{153}Nd . . . 9
   2.23. ^{154}Nd . . . 9
   2.24. ^{155}Nd . . . 9
   2.25. ^{156}Nd . . . 10
3. Summary . . . 10

References . . . 10

Explanation of Tables . . . 13

Table

1. Discovery of Neodymium Isotopes. See page 13 for Explanation of Tables . . . 14

1. Introduction

The discovery of the neodymium 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 adopted value taken from the NUBASE evaluation [2] which is based on the ENSDF database [3]. In cases where the reported half-life differed significantly from the adapted half-life (up to approximately a factor of two), we searched the subsequent literature for indications that the measurement was erroneous. If that was not the case we credited the authors with the discovery in spite of the inaccurate half-life.

2. Discovery of $^{125-156}$Nd

Thirty-one neodymium isotopes from A = 125-156 have been discovered so far; these include 7 stable, 16 proton-rich and 8 neutron-rich isotopes. ^{126}Nd, [4] ^{157}Nd, and ^{158}Nd [5] have only been reported in conference proceedings, but have not yet been published in the refereed literature. According to the HFB-14 model [6], ^{185}Nd should be the last odd-even particle stable neutron-rich nucleus while the even-even particle stable neutron-rich nuclei should continue through ^{196}Nd. At the proton dripline four more isotopes could be observed (^{120}Nd through ^{124}Nd, and ^{126}Nd still have to be confirmed). It is estimated that six additional nuclei beyond the proton dripline could live long enough to be observed [7]. About 46 isotopes have yet to be discovered corresponding to 60% of all possible neodymium isotopes.

Figure 1 summarizes the year of first discovery for all neodymium 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 neodymium isotopes were produced using fusion evaporation reactions (FE), light-particle reactions (LP), neutron induced fission (NF), spontaneous fission (SF) and spallation reactions (SP). The stable isotopes were identified using mass spectroscopy (MS). Light particles also include neutrons produced by accelerators. In the following, the discovery of each neodymium isotope is discussed in detail.

2.1. ^{125}*Nd*

Xu et al. first identified ^{125}Nd in 1999 and reported the results in "New β-delayed proton precursors in the rare-earth region near the proton drip line" [8]. A 169 MeV ^{36}Ar beam was accelerated with the sector-focused cyclotron at the National Laboratory of Heavy-Ion Accelerator in Lanzhou, China, and bombarded an enriched ^{92}Mo target. Proton-γ coincidences were measured in combination with a He-jet tape transport system. "The decay curve of the 142-keV γ line coincident with 2.5−5.5 MeV protons is shown in the inset [of the figure], from which the half-life of the new nuclide ^{125}Nd was extracted to be 0.60±0.15 s." This is the only reported half-life measurement, though a more recent paper by the same group reported the half-life as 0.65(15) s [9].

2.2. ^{127}*Nd*

Nitschke et al. discovered ^{127}Nd in the 1983 paper "New Beta-Delayed Proton Emitter in the Lanthanide Region" [10]. A ^{40}Ca beam from the Berkeley SuperHILAC bombarded a gas-cooled ^{92}Mo target. ^{127}Nd was produced in the fusion-evaporation reaction ^{92}Mo(^{40}Ca,αn) and identified with the on-line isotope separator OASIS. "From the growth and decay data, a half-life of 1.9 ± 0.4 s was deduced, which is in good agreement with the calculated value of 1.8 s for ^{127}Nd." This half-life is included in the currently accepted average value of 1.8(4) s.

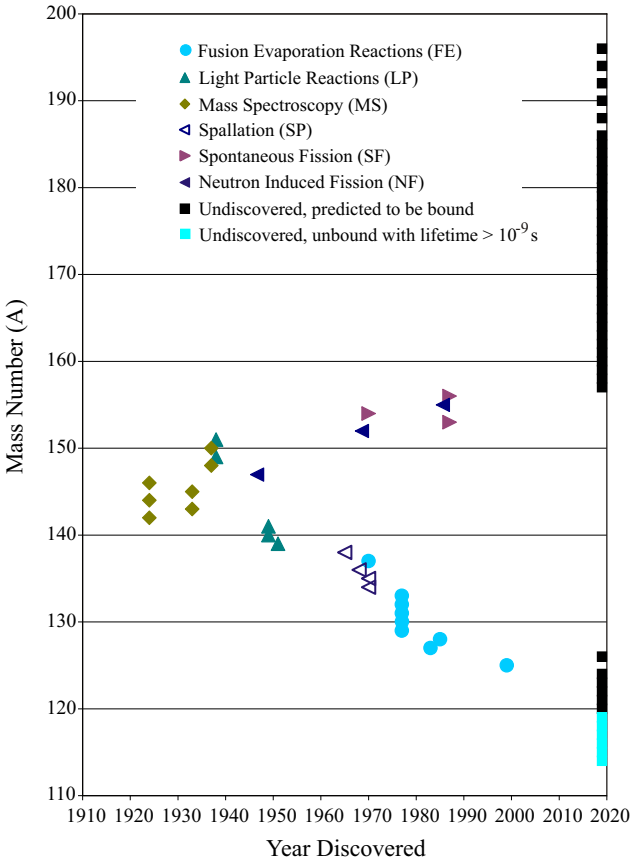

Fig. 1: Neodymium isotopes as a function of time when they were discovered. The different production methods are indicated. The solid black squares on the right hand side of the plot are isotopes predicted to be bound by the HFB-14 model. On the proton-rich side the light blue squares correspond to unbound isotopes predicted to have lifetimes larger than $\sim 10^{-9}$ s.

2.3. ^{128}*Nd*

In 1985 ^{128}Nd was identified by Lister et al. in "Deformation of Very Light Rare-Earth Nuclei" [11]. A ^{40}Ca beam from the Daresbury Laboratory Van de Graaff accelerator was incident on a ^{92}Mo target and ^{128}Nd was produced in the fusion-evaporation reaction ^{92}Mo(^{40}Ca,2p2n). Gamma rays, neutrons and charged particles were detected and new ground-state bands observed. "This letter reports results on the ground-state bands in the even-even nuclei $^{128}_{58}$Ce$_{68}$, $^{132}_{60}$Nd$_{68,70,72}$, $^{134,136}_{62}$Sm$_{72,74}$, and $^{138,140}_{64}$Gd$_{74,76}$." An earlier identification and half-life measurement of 4(2) s [10] was later refuted [12].

2.4. $^{129-133}$*Nd*

The first identification of ^{130}Nd, ^{131}Nd, ^{132}Nd, and ^{133}Nd, was reported in 1977 by Bogdanov et al. in "New Neutron-Deficient Isotopes of Barium and Rare-Earth Elements" [13]. The Dubna U-300 Heavy Ion Cyclotron accelerated a ^{32}S beam which bombarded enriched targets of ^{102}Pd and ^{106}Cd. The isotopes were identified with the BEMS-2 isotope separator. "In the present paper, isotopes were mainly identified by measuring the γ-ray and X-ray spectra of the daughter nuclei formed as a result of measuring the β^+ decay. In addition, the decay curves of the total β-activity of given isobars have been measured." The reported half-live of 5.9(6) s for ^{129}Nd is close to the accepted value of 4.9(2) s. The half-life of 28(3) s for ^{130}Nd is within a factor of two of the currently accepted value of 13(3) s. The half-lives of 24(3) s (^{131}Nd) and 105(10) s (^{132}Nd) are included in the currently accepted average values of 25.4(9) s and 94(8) s. The half-life of 70(10) s for ^{133}Nd corresponds to the presently adopted half-life.

2.5. ^{134,135}*Nd*

^{134}Nd and ^{135}Nd were discovered by Abdurazakov et al. in the 1970 paper "New Isotopes ^{133}Pr, ^{134}Nd, and ^{135}Nd; Decay Schemes of ^{134}Pr and ^{135}Pr" [14]. Spallation reactions were induced by 660 MeV protons irradiating a gadolinium target at the Joint Institute for Nuclear Reactions in Dubna, Russia. The reaction products were then chemically separated and identified by the measured γ-ray spectra. "^{134}Nd was identified and its half-life determined via the strongest γ rays of ^{134}Pr (T = 17$\pm$2 min) with energies 409.2 and 639.0 keV.[The figure] shows the build-up and decline of the intensity of the 409.2 keV γ lray of ^{134}Pr. The half-life of was found from the difference of the curves (k1-k2) to be 8.5$\pm$1 min. A similar determination of this half-life using the 639.0 keV line gave 9$\pm$2 min." The currently accepted half-life of 8.5(15) m is based on these two values. "The half-life of ^{135}Nd was found from the difference of the curves (k1-k2) to be 5.5 $\pm$ 0.5 min..." This half-life has been assigned to an isomeric state but has not yet been confirmed.

2.6. ^{136}*Nd*

The assignment of ^{136}Nd was reported in "A New Neodymium Isotope (A = 136) and its Decay Properties" by Zhelev et al. [15]. A 660 MeV proton beam bombarded a gadolinium target and ^{136}Nd was identified with γ- and β-ray spectra following chemical separation. "We have previously reported the discovery of ^{137}Nd, with a half life of 55.0 $\pm$ 1.5 min. Here we show that the β^+ and γ radiations observed in the 55-min neodymium activity are not due to decay of ^{137}Nd but to decay of a new isotope, ^{136}Nd, and its daughter ^{136}Pr." This half-life agrees with the currently accepted value of 50.65(33) m. The paper mentioned in the quote is reference [16]. A 1-hour activity had previously been measured in neodymium [17–19] but no mass assignment were made.

2.7. ^{137}*Nd*

In 1970 ^{137}Nd was reported in "^{135m}Ce and ^{137m}Nd: Isomeric States in N = 77 Isotones" by Droste et al. [20]. The Dubna U-300 cyclotron accelerated ^{18}O and ^{20,22}Ne beams which bombarded tellurium and tin targets, respectively. ^{137}Nd was produced in the fusion-evaporation reactions ^{119}Sn(^{22}Ne,4n), ^{122}Sn(^{20}Ne,5n), ^{122}Sn(^{22}Ne,7n), and ^{126}Te(^{18}O,7n). Conversion electron and γ-ray spectrometry was used to identify the isotope. "In all cases, γ-rays of 108, 177, 233 and 285 keV which all decay with the same half-life, $T_{1/2}$ = 1.60±0.15 s were observed... That the new activity belongs indeed to the nucleide ^{137}Nd is proved by (i) the energy difference of the K and L electron lines of the isomeric transition EKL = 37.0±0.8 keV as compared to the value 36.8 keV expected for Z = 60(Nd), and (ii) the shape of the excitation functions from which the number of evaporated neutrons can be determined" The reported half-life corresponds to an isomeric state and is currently the accepted value for this state. Previously the 55.0(15) m half-life of ^{136}Nd had incorrectly been assigned to ^{137}Nd [16]. A half-life of 35(5) m corresponding to the ground state was reported already in 1935 [21], but no mass assignment was made.

2.8. ^{138}*Nd*

In 1964 Gromov et al. discovered ^{138}Nd in "Decay of Neutron-Deficient Neodymium Isotopes. A New Isotope Nd^{138}" [22]. Erbium oxide or tantalum targets were irradiated with 660 MeV protons from the Dubna synchrocyclotron. Conversion electron and γ-ray spectra were measured to identify ^{138}Nd. "Observation of the E0 transition conversion lines, whose intensity decays with a ≈5-hour half-life, is experimental proof of the assumed isotope Nd^{138} with this half-life." This half-life of about 5 h agrees with the currently accepted value of 5.04(9) h. An activity of 22(2) m, most likely the half-life of ^{139}Nd, had previously been assigned incorrectly to ^{138}Nd [23].

2.9. ^{139}*Nd*

Stover reported the observation of ^{139}Nd in the 1950 paper, "New Neutron-Deficient Radioactive Isotopes of the Light Rare-Earth Region" [23]. Praseodymium oxide was bombarded with 40 and 50 MeV protons from the Berkeley 184-in. cyclotron. Activities were measured with end-on type Geiger-Müller counters following chemical separation. "Protons of energies 40 and 50 Mev gave a 22-min. activity, a 5.50-hr one, and the 3.3-day Nd^{140}... The 5.50-hr Nd was shown to be the grandparent of the 140-day Ce^{139} and thus is Nd^{139}." The reported half-life of 5.5(2) h is the currently accepted value for a long-lived isomeric state. The 22(2) m activity is close to the half-life of the ground state (29.7(5) m), however, Stover tentatively assigned this half-life to ^{138}Nd.

2.10. ^{140,141}*Nd*

The discovery of ^{140}Nd and ^{141}Nd was reported by Wilkinson and Hicks in 1949: "Radioactive Isotopes of the Rare Earth Elements II. Neodymium Isotopes" [24]. Deuterons of 9 and 19 MeV and protons of 10 MeV from the Berkeley 60-in. cyclotron bombarded praseodymium targets. Positrons, X- and γ-rays were measured following chemical separation. "The observed radiations of the 3.3-day activity are consistent with the isotope, Nd^{140}, decaying by orbital electron capture, in equilibrium with its positron emitting Pr^{140} daughter." The reported half-life of 3.3(1) d for ^{140}Nd is consistent with the currently accepted value of 3.37(2) d. "145-Minute Nd^{141}:... Further, spectroscopic analysis showed that the 19.3-hour activity followed the praseodymium, while in the first active sample where the 145-minute decay

was observed, praseodymium was below the limits of detection. The chemical identity of the 145-minute activity as neodymium is, therefore, fairly certain." The reported half-life of 145(3) m is included in the currently accepted average value of 2.49(3) h. Previous measurements of a 2.3 h [25] and a 2.5 h half-life [26] were only published as conference abstracts.

2.11. ^{142}*Nd*

In 1924 Aston identified ^{142}Nd in "The Mass Spectra of Zirconium and Some Other Elements" [27]. The Cavendish laboratory mass spectrograph was used to separate accelerated anode rays and identify their mass. "Further experiments with neodymium (at. wt. 144.27) establish its principle isotopes as 142, 144, 146, with a possible (145)."

2.12. ^{143}*Nd*

The 1933 publication "Constitution of Neodymium, Samarium, Europium, Gadolinium and Terbium" by Aston reported the first observation of ^{143}Nd [28]. Accelerated anode rays from the Cavendish laboratory mass spectrograph were analyzed and their masses identified. "Three isotopes, 142, 14, 146, of neodymium (60) had already been identified by the first mass spectrograph. These are now found to be definitely in descending order of abundance and 143 and 145 also shown to be present."

2.13. ^{144}*Nd*

In 1924 Aston identified ^{144}Nd in "The Mass Spectra of Zirconium and Some Other Elements" [27]. The Cavendish laboratory mass spectrograph was used to separate accelerated anode rays and identify their mass. "Further experiments with neodymium (at. wt. 144.27) establish its principle isotopes as 142, 144, 146, with a possible (145)."

2.14. ^{145}*Nd*

The 1933 publication "Constitution of Neodymium, Samarium, Europium, Gadolinium and Terbium" by Aston reported the first observation of ^{145}Nd [28]. Accelerated anode rays from the Cavendish laboratory mass spectrograph were analyzed and their masses identified. "Three isotopes, 142, 14, 146, of neodymium (60) had already been identified by the first mass spectrograph. These are now found to be definitely in descending order of abundance and 143 and 145 also shown to be present." A possible presence of ^{145}Nd had been mentioned by Aston earlier [27, 29].

2.15. ^{146}*Nd*

In 1924 Aston identified ^{146}Nd in "The Mass Spectra of Zirconium and Some Other Elements" [27]. The Cavendish laboratory mass spectrograph was used to separate accelerated anode rays and identify their mass. "Further experiments with neodymium (at. wt. 144.27) establish its principle isotopes as 142, 144, 146, with a possible (145)."

2.16. ^{147}*Nd*

In "The Chemical Identification of Radioisotopes of Neodymium and of Element 61", Marinsky et al. reported the discovery of ^{147}Nd in 1947 [30]. Fission fragments from uranium fission were analyzed as part of the Manhattan Project. ^{147}Nd was separated and identified with a synthetic organic cation exchanger of the sulfonated phenol-formaldehyde type. "Radiochemical studies and fractionations have established the decay characteristics, genetic relation, and mass

assignments of 11 d Nd^{147}, 3.7 y 61^{147}, 1.7 h $Nd^{(149)}$, and 47 h 61^{149}." The 11 d half-life is consistent with the currently accepted value of 10.98(1) d. A 84 h half-life [31] could not be confirmed. Other half-life measurements were only reported in conference abstracts [25, 26]

2.17. ^{148}Nd

^{148}Nd was first identified by Dempster in 1937 as reported in "Isotopic Constitution of Neodymium" [32]. ^{148}Nd was identified in the mass spectrum produced by a spark between neodymium electrodes. "I have recently analyzed the ions from a spark between fairly pure neodymium electrodes, and find that the masses at 148 and 150 belong to this element." Dempster had previously observed lines at 148 and 150 [33] but was unable to assign the element. Aston subsequently had suggested that these line belong to neodymium [34].

2.18. ^{149}Nd

The first detection of ^{149}Nd was reported in 1938 by Pool and Quill in "Radioactivity Induced in the Rare Earth Elements by Fast Neutrons" [31]. Fast and slow neutrons were produced with 6.3 MeV deuterons from the University of Michigan cyclotron. Decay curves were measured with a Wulf string electrometer. "In order to assign the 2.0-hr. and 84-hr. periods the relative abundance of the stable nuclei and the rate of formation of the radioactive nuclei (branching ratio) must be compared... Consequently, these data suggest, in view of no other guiding information, that the 84-hr. period should be attributed to Nd^{147} and the 2-hr. period to Nd^{149}." This half-life agrees with the currently accepted value of 1.728(1) h.

2.19. ^{150}Nd

^{150}Nd was first identified by Dempster in 1937 as reported in "Isotopic Constitution of Neodymium" [32]. ^{148}Nd was identified in the mass spectrum produced by a spark between neodymium electrodes. "I have recently analyzed the ions from a spark between fairly pure neodymium electrodes, and find that the masses at 148 and 150 belong to this element." Dempster had previously observed lines at 148 and 150 [33] but was unable to assign the element. Aston subsequently had suggested that these line belong to neodymium [34].

2.20. ^{151}Nd

The first detection of ^{151}Nd was reported in 1938 by Pool and Quill in "Radioactivity Induced in the Rare Earth Elements by Fast Neutrons" [31]. Fast and slow neutrons were produced with 6.3 MeV deuterons from the University of Michigan cyclotron. Decay curves were measured with a Wulf string electrometer. "The very much greater neutron equivalent of the cyclotron is easily evident from the fact that in four hours of slow neutron bombardment three periods were easily evident, 21 min., 2.0 hr. and 84 hr... Since the 21-min. period is produced by slow but not by fast neutron bombardment and since Nd^{150} is the heaviest neodymium isotope, it is reasonable to assign this activity to Nd^{151}." Although this half-life is somewhat larger than the presently accepted value (12.44(7) m) it is still within a factor of two.

2.21. ^{152}*Nd*

^{152}Nd was first described in "Rapid Isolation of Individual Rare Earths from Fission and Identification of ^{152}Nd" by Wakat and Griffin in 1969 [35]. The isotope was produced by neutron induced fission of ^{235}U. Decay curves were measured with a $4\pi\beta$ detector after element separation in a resin column. "The decay curves can be resolved into 2 components: a growth and decay component which is consistent with the activity of the daughter in a 11.3→4.1-min genetic pair, and a 52-min activity... These data confirm the presence of 11.3 ± 0.4-min ^{152}Nd, even though characteristic radiations of ^{152}Nd have not been observed directly." This half-life is included in the currently accepted average value of 11.2(2) m. A previous result had been reported in a conference abstract [36] and only a month later an independent identification of ^{152}Nd was submitted [37].

2.22. ^{153}*Nd*

In 1987, Greenwood et al. identified ^{153}Nd in the paper entitled "Identification of New Neutron-Rich Rare-Earth Isotopes Produced in ^{252}Cf Fission" [38]. Spontaneous fission fragments from a ^{252}Cf source were measured with the isotope separation on line (ISOL) system at the Idaho National Engineering Laboratory. ^{153}Nd was identified by mass separation and the measurement of K x-rays. "Identification of the ^{153}Nd isotope was first reported by Pinston et al. In the present work, however, a total of 48 γ-ray transitions could be associated with this decay, compared with the eight transitions reported earlier. The half-life value was obtained from an average of individual values involving the Pm K x rays and the 32.2-, 105.5-, 345.0-, 418.3-, and 976.1-keV γ rays." The reported half-life of 28.9(4) s is included in the currently accepted average value of 31.6(10) s. The quoted Pinston reference was only published in a conference proceedings nine years earlier [39].

2.23. ^{154}*Nd*

^{154}Nd was discovered by Wilhelmy et al. in 1970 in "Ground-State Bands in Neutron-Rich Even Te, Xe, Ba, Ce, Nd, and Sm Isotopes Produced in the Fission of ^{252}Cf" [40]. The isotope was observed in the spontaneous fission of a ^{252}Cf source. The identification was based on coincidence measurements of both fission fragments and K-x-rays. Gamma-rays for several isotopes were measured and the results were only displayed in a table. The first 4 transitions up to the decay of the 8^+ state were measured for ^{154}Nd. A month earlier another measurement of spontaneous fission fragments extracted isomeric states using the four-parameter method. However, this method does not have a unique mass identification and the atomic number is only deduced from the most probable Z, and is thus not considered sufficient evidence for a discovery.

2.24. ^{155}*Nd*

Okano et al. identified ^{155}Nd in the 1986 paper "The Half-Life of a New Isotope, ^{155}Nd" [41]. An enriched ^{235}U target was irradiated with neutrons from the Kyoto University Reactor and ^{155}Nd was identified with a helium-jet system and the on-line isotope separator KUR-ISOL. "From the analyses of the spectra mentioned, four γ-rays of 67.5±0.3, 180.7±0.2, 418.9±0.3, and 955.1±0.3 keV and two X-rays of 38.4±0.4 (Pm K_α) and 44.2±1.0 keV (Pm K_β) were assigned to the decay of ^{155}Nd." The reported half-life of 9.5(7) s agrees with the currently accepted value of 8.9(2) s. About six months later Greenwood et al. claimed the first observation of ^{155}Nd [38] apparently not aware of the Okano et al. publication.

2.25. ^{156}Nd

In 1987, Greenwood et al. identified ^{156}Nd in the paper entitled "Identification of New Neutron-Rich Rare-Earth Isotopes Produced in ^{252}Cf Fission" [38]. Spontaneous fission fragments from a ^{252}Cf source were measured with the isotope separation on line (ISOL) system at the Idaho National Engineering Laboratory. ^{156}Nd was identified by mass separation and the measurement of K x-rays. "The half-life value for ^{156}Nd was obtained as an average of individual measurements involving the Pm K x rays and the 84.8- and 150.7-keV γ rays which we can definitely associate with this decay at this time." The reported half-life of 5.47(11) s is included in the currently accepted average value of 5.49(7) s.

3. Summary

The discoveries of the known neodymium isotopes have been compiled and the methods of their production discussed. The half-lives of two isotopes (^{128}Nd and ^{147}Nd) were initially measured incorrectly and the half-lives of ^{136}Nd and ^{137}Nd were first measured without a unique mass assignment. Also, the half-life of ^{139}Nd was at first assigned to ^{138}Nd. Finally, the discoveries of ^{141}Nd, ^{147}Nd, and ^{153}Nd were published in refereed journals only several years after the first announcements in conference proceedings.

Acknowledgments

This work was supported by the National Science Foundation under grant No. PHY06-06007 (NSCL).

References

[1] G. Q. Ginepro, J. Snyder, M. Thoennessen, At. Data. Nucl. Data. Tables 95 (2009) 805.

[2] G. Audi, O. Bersillon, J. Blachot, A. H. Wapstra, Nucl. Phys. A 729 (2003) 3.

[3] ENSDF, Evaluated Nuclear Structure Data File, maintained by the National Nuclear Data Center at Brookhaven National Laboratory, published in Nuclear Data Sheets (Academic Press, Elsevier Science) .

[4] G. A. Souliotis, Physica Scripta T88 (2000) 153.

[5] M. Bernas, P. Armbruster, S. Czajkowski, C. Donzaud, H. Geissel, F. Ameil, P. Dessagne, C. Engelmann, A. Heinz, Z. Janas, C. Kozhuharov, C. Miehe, G. Münzenberg, M. Pfützner, C. Böcksteigel, K. H. Schmidt, W. Schwab, C. Stéphan, K. Sümmerer, L. Tassan-Got, B. Voss, Nucl. Phys. A 616 (1997) 352c.

[6] S. Goriely, M. Samyn, J. M. Pearson, Phys. Rev. C 75 (2007) 064312.

[7] M. Thoennessen, Rep. Prog. Phys. 67 (2004) 1187.

[8] S. W. Xu, Z. K. Li, Y. X. Xie, Q. Y. Pan, Y. Yu, J. Adam, C. F. Wang, J. P. Xing, Q. Y. Hu, S. H. Li, H. Y.Chen, T. M. Zhang, G. M. Jin, Y. X. Luo, Y. Penionzhkevich, Y. Gangrsky, Phys. Rev. C 60 (1999) 061302.

[9] S. W. Xu, Z. K. Li, Y. X. Xie, Q. Y. Pan, W. X. Huang, X. D. Wang, Y. Yu, Y. B. Xing, Phys. Rev. C 71 (2005) 054318.

[10] J. M. Nitschke, M. D. Cable, W. D. Zeitz, Z. Phys. A 312 (1983) 265.

[11] C. J. Lister, B. J. Varley, R. Moscrop, W. Gellently, P. J. Nolan, D. J. G. Love, P. J. Bishop, A. Kirwan, D. J. Thornley, L. Ying, R. Wadsworth, J. M. O'Donell, H. G. Price, A. H. Nelson, Phys. Rev. Lett. 55 (1985) 810.

[12] P. A. Wilmarth, J. M. Nitschke, P. K. Lemmertz, R. B. Firestone, Z. Phys. A 321 (1985) 179.

[13] D. D. Bogdanov, A. V. Demyanov, V. A. Karnaukhov, L. A. Petrov, A. Plohocki, V. G. Subbotin, J. Voboril, Nucl. Phys. A 275 (1977) 229.

[14] A. A. Abdurazakov, R. Arlt, R. Babadzhanov, G. Baier, V. A. Morozov, G. Musiol, K. Tyrroff, H. Strusny, Izv. Akad. Nauk SSSR, Ser. Fiz 34 (1970) 796.

[15] Z. Zhelev, V. G. Kallinnikov, J. Liptak, L. Peker, Izv. Akad. Nauk SSSR 32 (1968) 1610.

[16] K. Gromov, V. Kalinnikov, V. Kuznetsov, N. Lebedev, G. Musiol, E. Herrmann, Z. Zhelev, B. Dzhelepov, A. Kudryavtseva, Nucl. Phys. 73 (1965) 65.

[17] E. Fermi, E. Amaldi, O. D'Agostino, F. Rasetti, E. Segre, Proc. Roy. Soc. A 146 (1934) 483.

[18] E. Amaldi, O. D'Agostino, F. Rasetti, E. Segre, Proc. Roy. Soc. A 149 (1935) 522.

[19] G. Hevesy, H. Levi, Nature 136 (1935) 103.

[20] C. Droste, W. Neubert, J. Lewitowicz, S. Chojnacki, T. Morek, Z. Wilhelmi, K. F. Alexander, Nucl. Phys. A 152 (1970) 579.

[21] J. C. McLennan, L. G. Grimmett, J. Read, Nature 135 (1935) 147.

[22] K. Y. Gromov, A. S. Danagulyan, L. N. Kikityuk, V. V. Murav'eva, A. A. Sorokin, M. Z. Shtal', V. Shpinel', Zh. Eksperim. i Teor. Fiz. 47 (1964) 1644.

[23] B. J. Stover, Phys. Rev. 81 (1951) 8.

[24] G. Wilkinson, H. G. Hicks, Phys. Rev. 75 (1949) 1687.

[25] H. B. Law, M. L. Pool, J. D. Kurbatov, L. Quill, Phys. Rev. 59 (1941) 936.

[26] J. D. Kurbatov, D. C. MacDonald, M. L. Pool, L. Quill, Phys. Rev. 61 (1951) 106.

[27] F. W. Aston, Nature 114 (1924) 273.

[28] F. W. Aston, Nature 132 (1933) 930.

[29] F. W. Aston, Phil. Mag. 49 (1925) 1191.

[30] J. A. Marinsky, L. Glendenin, C. Coryell, J. Am. Chem. Soc. 69 (1947) 2781.

[31] M. L. Pool, L. L. Quill, Phys. Rev. 53 (1938) 437.

[32] A. J. Dempster, Phys. Rev. 51 (1937) 289.

[33] A. J. Dempster, Proc. Am. Phys. Soc. 75 (1935) 735.

[34] F. W. Aston, Nature 137 (1936) 613.

[35] A. Wakat, C. Griffin, Radiochem. Radioanal. Lett. 2 (1969) 351.

[36] D. C. Hoffman, F. O. Lawrence, W. Daniels, Bull. Am. Phys. Soc. 14 (1969) 1225.

[37] R. Chapman, W. McLatchie, J. Kitching, Phys. Lett. B 31 (1970) 292.

[38] R. C. Greenwood, R. A. Anderl, J. D. Cole, H. Willmes, Phys. Rev. C 35 (1987) 1965.

[39] J. A. Pinston, F. Schussler, E. M. J. P. Zirnheld, V. Raut, G. J. Costa, A. Hanni, R. Seltz, Proc. 6th Intern. Conf. on Atomic Masses and Fund. Const. (1978) 493.

[40] J. B. Wilhelmy, S. G. Thompson, R. C. Jared, E. Cheifetz, Phys. Rev. Lett. 25 (1970) 1122.

[41] K. Okano, Y. Kawase, K. Aoki, Radiochim. Acta 40 (1986) 57.

Explanation of Tables

Table 1. Discovery of neodymium isotopes

( )

Isotope	Neodymium 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
	NF: neutron induced fission
	SF: spontaneous fission
	SP: spallation reactions
Laboratory	Laboratory where the experiment was performed
Country	Country of laboratory
Year	Year of discovery

Table 1
Discovery of Neodymium Isotopes. See page 13 for Explanation of Tables

Isotope	Author	Journal	Ref.	Method	Laboratory	Country	Year
^{125}Nd	S.-W. Xu	Phys. Rev. C	[8]	FE	Lanzhou	China	1999
^{126}Nd							
^{127}Nd	J.M. Nitschke	Z. Phys. A	[10]	FE	Berkeley	USA	1983
^{128}Nd	C.J. Lister	Phys. Rev. Lett.	[11]	FE	Daresbury	UK	1985
^{129}Nd	D.D. Bogdanov	Nucl. Phys. A	[13]	FE	Dubna	Russia	1977
^{130}Nd	D.D. Bogdanov	Nucl. Phys. A	[13]	FE	Dubna	Russia	1977
^{131}Nd	D.D. Bogdanov	Nucl. Phys. A	[13]	FE	Dubna	Russia	1977
^{132}Nd	D.D. Bogdanov	Nucl. Phys. A	[13]	FE	Dubna	Russia	1977
^{133}Nd	D.D. Bogdanov	Nucl. Phys. A	[13]	FE	Dubna	Russia	1977
^{134}Nd	A.A. Abdurazakov	Izv. Akad. Nauk SSSR, Ser. Fiz	[14]	SP	Dubna	Russia	1970
^{135}Nd	A.A. Abdurazakov	Izv. Akad. Nauk SSSR, Ser. Fiz	[14]	SP	Dubna	Russia	1970
^{136}Nd	Zh. Zhelev	Izv. Akad. Nauk SSSR, Ser. Fiz	[15]	SP	Dubna	Russia	1968
^{137}Nd	Ch. Droste	Nucl. Phys. A	[20]	FE	Dubna	Russia	1970
^{138}Nd	K. Ya. Gromov	Sov. Phys. JETP	[16]	SP	Dubna	Russia	1965
^{139}Nd	B.J. Stover	Phys. Rev.	[23]	LP	Berkeley	USA	1951
^{140}Nd	G. Wilkinson	Phys. Rev.	[24]	LP	Berkeley	USA	1949
^{141}Nd	G. Wilkinson	Phys. Rev.	[24]	LP	Berkeley	USA	1949
^{142}Nd	F.W. Aston	Nature	[27]	MS	Cambridge	UK	1924
^{143}Nd	F.W. Aston	Nature	[28]	MS	Cambridge	UK	1933
^{144}Nd	F.W. Aston	Nature	[27]	MS	Cambridge	UK	1924
^{145}Nd	F.W. Aston	Nature	[28]	MS	Cambridge	UK	1933
^{146}Nd	F.W. Aston	Nature	[27]	MS	Cambridge	UK	1924
^{147}Nd	J.A. Marinsky	J. Am. Chem. Soc.	[30]	NF	Oak Ridge	USA	1947
^{148}Nd	A.J. Dempster	Phys. Rev.	[32]	MS	Chicago	USA	1937
^{149}Nd	M.L. Pool	Phys. Rev.	[31]	LP	Michigan	USA	1938
^{150}Nd	A.J. Dempster	Phys. Rev.	[32]	MS	Chicago	USA	1937
^{151}Nd	M.L. Pool	Phys. Rev.	[31]	LP	Michigan	USA	1938
^{152}Nd	A. Wakat	Radiochem. Radioanal. Lett.	[35]	NF	Michigan	USA	1969
^{153}Nd	R.C. Greenwood	Phys. Rev. C	[38]	SF	Idaho Falls	USA	1987
^{154}Nd	J.B. Wilhelmy	Phys. Rev. Lett.	[40]	SF	Berkeley	USA	1970
^{155}Nd	K. Okano	Radiochim. Acta	[41]	NF	Kyoto	Japan	1986
^{156}Nd	R.C. Greenwood	Phys. Rev. C	[38]	SF	Idaho Falls	USA	1987