Int. j. adv. multidisc. res. stud. 2026; 6(5):957-960

Received: 09-08-2026
Accepted: 19-09-2026

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Decay Characteristics of Neutron Excess Strontium Nuclei

JJ Bevelacqua
Bevelacqua Resources, 7531 Flint Crossing Circle SE, Owens Cross Roads, AL 35763, United States of America

Corresponding Author: **JJ Bevelacqua**

Abstract
The properties of neutron excess strontium nuclei are predicted utilizing a single particle model. The single particle model calculations include alpha, beta, positron, electron capture, and spontaneous fission decay modes. Neutron emission decay modes that have short half-lives are not readily determined by the model. However, estimates of the neutron decay mode were evaluated using the methodology of Chowdhury *et al*. Using that model, spontaneous neutron emission is predicted to occur in the range of A = 121 – 123. The Japanese Nuclear Data Compilation terminate their calculations at A = 111. Given these results, strontium single particle model calculations are extended to encompass these values, and were extended to A = 120 with closure of the $1h_{11/2}$ neutron shell.
Single particle model calculations predict that A = 95 – 120 strontium nuclei form bound systems that have limiting beta decay half-lives in the range of 0.275 ms – 23.9 s. Model half-life results for the A = 108 – 111 neutron excess strontium nuclei are within a factor of about 2.6 of the predictions of the Japanese Nuclear Data Compilation calculations.

Keywords: Nucleosynthesis, Neutron Excess Strontium Nuclei, Beta Decay, Nuclear Structure, Spontaneous Neutron Emission

1. Introduction

Interest in neutron excess nuclei [1-39] has stimulated both experimental and theoretical interest. Several physical processes generate neutron excess nuclei, but the r-process usually provides the most significant contribution. Production of neutron excess nuclei in mergers of astrophysical objects (e.g., black holes and neutron stars) is an active area of research in nuclear physics and astrophysics [1, 2].

This paper continues the investigation of neutron excess nuclei by focusing on Z = 38 strontium systems. Neutron excess systems having Z = 9 - 37 were discussed in previous work [8-25, 29-39]. Studies of these systems provide additional insight into nuclear systematics involving the various nucleosynthesis mechanisms and decay modes, and their associated variation with atomic and mass numbers.

2. Calculational Methodology

Methods for investigating neutron excess nuclei are provided in Refs. 8-39. This paper follows the single particle methodology of Lukasiak and Sobiczewski [27] and Petrovich *et al*. [28]. Single particle energies of neutron excess nuclear systems are obtained by incorporating the numerical methods of Refs. 40 and 41.

The radial Schrödinger equation is utilized to determine the binding energy of a nucleon interacting with a nuclear core [8-25, 29-39]:

$$[(\hbar^2/2\mu)\,(d^2/dr^2 - L(L+1)/r^2) - E_{NLSJ} - V_{LSJ}(r)]\, U_{NLSJ}(r) = 0 \qquad (1)$$

In Eq. 1, E_{NLSJ} is the nucleon binding energy, r is the radial coordinate, $V_{LSJ}(r)$ is the nuclear interaction, and $U_{NLSJ}(r)$ is the radial wave function. L, S, and J represent the orbital, spin, and total angular momentum quantum numbers, respectively. The model definition is completed by defining the radial quantum number (N) and reduced mass (μ).

3. Nuclear Interaction

The Rost interaction [42] is selected for the nuclear potential. This interaction has a central strength:

$$V_0 = 51.6\ [1 \pm 0.73\ (N - Z)/A]\ \text{MeV} \quad (2)$$

In Eq. 2, the positive (negative) sign is assigned to protons (neutrons). The spin-orbit interaction strength (V_{so}) is defined in terms of the central interaction strength and the multiplier γ [42]:

$$V_{so} = \gamma\ V_0 / 180 \quad (3)$$

Inclusion of the pairing correction interaction of Blomqvist and Wahlborn [43] completes the definition of the model interaction.

The difficulties in defining an appropriate nuclear interaction are outlined in Refs. 44 and 45. Ray and Hodgson [44] and Schwierz, Wiedenhöver, and Volya [45] note that modifications, unique to each nuclear system, are required to ensure an accurate representation of the experimental energy levels and decay characteristics. In view of the conclusions of Refs. 44 and 45 and the results of previous excess neutron system calculations [8-25, 29-39], the Rost central interaction strength (V_A) is modified in the following manner:

$$V_A = V_0\ \lambda\ [1 \pm a(A)]\ \text{MeV} \quad (4)$$

Individual nuclear system characteristics are defined by incorporating a potential strength multiplier (λ) and a factor [a(A)] to adjust the potential strength as a function of A. For strontium systems, the multiplier λ is selected to have the value of 1.5. This multiplier value is consistent with previous excess neutron nuclei calculations [8-25, 29-39] that provided model results in agreement with available data [46-48].

4. Model Limitations

Previous calculations [8-25, 29-39, 49] provided a representative description of the various nuclear decay modes (e.g., alpha, beta, positron, electron capture, and spontaneous fission) that could be encountered in neutron excess nuclei. Neutron excess systems can also decay by neutron emission modes that are not well-described by single particle models. Since these neutron emission modes have very short half-lives, single particle models will likely overestimate the lifetimes of neutron excess nuclei.

The onset of spontaneous neutron emission was estimated using the methodology of Chowdhury *et al.* [50]. Using the approach of Ref. 50, the onset of spontaneous neutron emission was estimated to occur in the range of A = 121 - 123 for strontium systems. Although independent of the calculated neutron single particle levels presented herein, the approach of Chowdhury *et al.* yields a candidate value to terminate calculations for excess neutron strontium nuclei. The Japanese Nuclear Data Compilation terminate their calculations at A = 111. These results guide the A value selected to terminate the single particle model calculations for strontium.

5. Results and Discussion

Table 1 summarizes the complete set of $120 \geq A \geq 95$ strontium isotopes considered in this paper. The $120 \geq A \geq 95$ strontium nuclei occupy a variety of neutron shells that are noted in Table 1. The heaviest observed strontium system is ^{107}Sr [48]. In view of the paucity of experimental data, extrapolations of nuclear characteristics beyond A > 107 become more uncertain.

5.1 95 ≥ A ≥ 107 Strontium Isotopes with Experimental Half-Life Data

The limiting decay mode (i.e., the transition that has the shortest decay half-life) for $107 \geq A \geq 95$ strontium isotopes observed experimentally is summarized in Table 1. For example, the ^{96}Sr calculations predict six beta decay transitions (i.e., allowed $2d_{5/2}$(n) to $2d_{5/2}$(p) [1.86 h], allowed $1g_{7/2}$(n) to $1g_{7/2}$ (p) [2.07 h], allowed $1g_{7/2}$(n) to $1g_{9/2}$(p) [1.07 s], allowed $2p_{1/2}$(n) to $2p_{1/2}$(p) [11.9 min], allowed $1g_{9/2}$(n) to $1g_{9/2}$(p) [2.97 min], and first forbidden $2d_{5/2}$(n) to $2p_{1/2}$(p) [7.87 min]). For ^{96}Sr, the allowed $1g_{7/2}$(n) to $1g_{9/2}$(p) [1.07 s] transition is the limiting beta decay mode.

Table 1: Calculated Single Particle and Experimental Decay Properties of Strontium Nuclei with $95 \leq A \leq 120$

Nuclide (neutron shell)	a(A)	Half-Life (Decay Mode)	
		Experiment [a,b,c]/Theory [d]	This Work
^{95}Sr ($1g_{7/2}$)	-0.0731	23.90 s [c]	23.9 s (β^-) [e]
^{96}Sr ($1g_{7/2}$)	-0.0458	1.07 s [c]	1.07 s (β^-) [e]
^{97}Sr ($1g_{7/2}$)	-0.0354	429 s [c]	428 ms (β^-) [e]
^{98}Sr ($2d_{5/2}$)	-0.0495	653 ms [c]	654 ms (β^-) [e]
^{99}Sr ($2d_{5/2}$)	-0.0375	269 ms [c]	270 ms (β^-) [e]
^{100}Sr ($2d_{5/2}$)	-0.0365	201 ms [c]	201 ms(β^-) [e]
^{101}Sr ($2d_{5/2}$)	0.0275	115 ms [c]	115 ms (β^-) [e]
^{102}Sr ($2d_{5/2}$)	-0.0186	71 ms [c]	71.0 ms (β^-) [e]
^{103}Sr ($3s_{1/2}$)	-0.0228	68 ms [c]	68.1 ms (β^-) [e]
^{104}Sr ($3s_{1/2}$)	-0.0156	46.9 ms [c]	46.9 ms (β^-) [e]
^{105}Sr ($2d_{3/2}$)	-0.0252	53 ms [c]	52.9 ms (β^-) [e]
^{106}Sr ($2d_{3/2}$)	-0.0196	39 ms [c]	39.1 ms (β^-) [e]
^{107}Sr ($2d_{3/2}$)	0.0025	20 ms [c]	20.0 ms (β^-) [e]
^{108}Sr ($2d_{3/2}$)	0.0246	13.3 ms [d]	11.3 ms (β^-) [e]
^{109}Sr ($1h_{11/2}$)	0.0467	12.0 ms [d]	6.89 ms (β^-) [e]
^{110}Sr ($1h_{11/2}$)	0.0688	8.78 ms [d]	4.45 ms (β^-) [e]
^{111}Sr ($1h_{11/2}$)	0.0909	7.82 ms [d]	3.00 ms (β^-) [e]
^{112}Sr ($1h_{11/2}$)	0.1130	[f]	2.10 ms (β^-) [e]
^{113}Sr ($1h_{11/2}$)	0.1351	[f]	1.52 ms (β^-) [e]
^{114}Sr ($1h_{11/2}$)	0.1572	[f]	1.13 ms (β^-) [e]
^{115}Sr ($1h_{11/2}$)	0.1793	[f]	0.856 ms (β^-) [e]
^{116}Sr ($1h_{11/2}$)	0.2014	[f]	0.662 ms (β^-) [e]
^{117}Sr ($1h_{11/2}$)	0.2235	[f]	0.521 ms (β^-) [e]
^{118}Sr ($1h_{11/2}$)	0.2456	[f]	0.415 ms (β^-) [e]
^{119}Sr ($1h_{11/2}$)	0.2677	[f]	0.336 ms (β^-) [e]
^{120}Sr ($1h_{11/2}$)	0.2898	[f]	0.275 ms (β^-) [e]

[a] Ref. 46. [b] Ref. 47. [c] Ref. 48.
[d] Japanese data Compilation calculation.
[e] Allowed $1g_{7/2}$(n) to $1g_{9/2}$(p) beta decay transition.
[f] No data provided in Ref. 46 – 48.

The model predicts the correct decay mode for the known $107 \geq A \geq 95$ strontium systems [46 – 48]. As noted in Table 1, the model half-lives are also consistent with data [46 – 48].

The ^{95}Sr – ^{97}Sr systems occupy the $1g_{7/2}$ neutron shell. These systems decay through allowed $1g_{7/2}$(n) to $1g_{9/2}$(p) beta transitions. The half-life values of the ^{95}Sr – ^{97}Sr systems are within 0.25% of the data [48]. Model calculations also predict the correct decay mode for these $1g_{7/2}$ strontium nuclei.

^{98}Sr - ^{102}Sr nuclei occupy the $2d_{5/2}$ neutron shell. These systems decay through allowed $1g_{7/2}$(n) to $1g_{9/2}$(p) beta transitions. Model predictions for the beta decay half-lives of ^{98}Sr - ^{102}Sr are within about 0.4% of the experimental values [48]. In addition beta decay is the predicted decay mode in agreement with Ref. 48.

^{103}Sr and ^{104}Sr nuclei occupy the $3s_{1/2}$ neutron shell. These systems decay through allowed $1g_{7/2}$(n) to $1g_{9/2}$(p) beta transitions. Model predictions for the beta decay half-lives of ^{103}Sr and ^{104}Sr are within 0.2% of the experimental values [48]. In addition beta decay is the predicted decay mode in agreement with Ref. 48.

^{105}Sr - ^{107}Sr nuclei occupy the $2d_{3/2}$ neutron shell. These systems decay through allowed $1g_{7/2}$(n) to $1g_{9/2}$(p) beta transitions. Model predictions for the beta decay half-lives of ^{105}Sr - ^{107}Sr are within about 0.3% of the experimental values [48]. In addition beta decay is the predicted decay mode in agreement with Ref. 48.

5.2 120 ≥ A ≥ 108 Strontium Isotopes without Experimental Half-Life Data

The a(A) values for 108 ≥ A ≥ 120 strontium isotopes were obtained from a linear fit based on the half-lives of ^{106}Sr and ^{107}Sr. The resulting a(A) values are listed in Table 1.

^{108}Sr completes the $2d_{3/2}$ neutron shell, and this system decays through an allowed $1g_{7/2}$(n) to $1g_{9/2}$(p) beta transition. The half-life of ^{108}Sr is 11.3 ms. This system half-life is within a factor of about 1.2 of the Japanese Data Compilation calculations [48].

^{109}Sr - ^{120}Sr fills the $1h_{11/2}$ neutron shell, and these systems decay through allowed $1g_{7/2}$(n) to $1g_{9/2}$(p) beta transitions. The half-lives of ^{109}Sr - ^{120}Sr are in the range of 0.275 – 6.89 ms. These half-lives are within a factor of about 2.6 of the Japanese Data Compilation calculation [48].

The strontium calculations are terminated at A = 120 to account for the spontaneous neutron emission as the mass increases. Using the methodology of Chowdhury *et al.* [50], spontaneous emission is expected to occur at A = 121 – 123. The Japanese Data Compilation calculations [48] suggest that A = 111 terminates the strontium systems. Model calculations were extended to A = 120 to account for uncertainties in estimates of Refs. 48 and 50, and were terminated with filling of the $1h_{11/2}$ neutron shell.

6. Conclusions

Single particle model calculations incorporate alpha, beta, positron, electron capture, and spontaneous fission decay modes. Neutron emission decay modes have short half-lives that are not readily determined by a single particle model. However, estimates of the neutron decay mode were evaluated using the methodology of Chowdhury *et al*. Using that model, spontaneous neutron emission in strontium nuclei is predicted to occur in the range of A = 121 – 123. The Japanese Nuclear Data Compilation calculations terminate their strontium calculations at A =111. Given these results, single particle model calculations are extended to encompass these values, and were terminated at A = 120 with filling of the $1h_{11/2}$ neutron shell.

Single particle model calculations predict that A = 108 – 120 neutron excess strontium systems form bound nuclei that have limiting beta decay half-lives in the range of 11.3 – 0.275 ms. Model half-life results for the A = 108 – 111 strontium nuclei are within about a factor of about 2.6 of the predictions of the Japanese Nuclear Data Compilation calculations.

The A = 108 – 120 neutron excess strontium systems decay through an allowed $1g_{7/2}$(n) to $1g_{9/2}$(p) beta decay transition. The model likely overestimates the actual half-life values, because it does not explicitly include the short-lived neutron emission decay modes.

7. References

1. Siegel DM, Metzger BD. Three-Dimensional General-Relativistic Magnetohydrodynamic Simulations of Remnant Accretion Disks from Neutron Star Mergers: Outflows and r-Process Nucleosynthesis, Phys. Rev. Lett. 2017; 119:231102.
2. National Academy of Sciences Report No. 11796, Scientific Opportunities with a Rare-Isotope Facility in the United States, Washington DC, National Research Council, 2007.
3. Fukuda N, *et al*. Identification of New Neutron-Rich Isotopes in the Rare-Earth Region Produced by 345 MeV/nucleon ^{238}U, J. Phys. Soc. Jpn. 2018; 87:014202.
4. Shimizu Y, *et al.* Observation of New Neutron-rich Isotopes among Fission Fragments from In-flight Fission of 345 MeV/nucleon ^{238}U: Search for New Isotopes Conducted Concurrently with Decay Measurement Campaigns, J. Phys. Soc. Jpn. 2018; 87:014203.
5. Kurcewicz J, *et al.* Discovery and cross-section measurement of neutron-rich isotopes in the element range from neodymium to platinum with the FRS, Phys. Lett. B. 2012; 717:371.
6. Baumann T, *et al*. Discovery of ^{40}Mg and ^{42}Al suggests neutron drip-line slant towards heavier isotopes, Nature. 2007; 449:1022.
7. Tarasov OB, *et al*. Production cross sections from ^{82}Se fragmentation Se indications of shell effects in neutron-rich isotopes close to the drip-line**,** Phys. Rev. C. 2013; 87:054612.
8. Bevelacqua JJ. Decay Characteristics of Neutron Excess Calcium Nuclei, Physics Essays. 2018; 31(4):462.
9. Bevelacqua JJ. Decay Characteristics of Neutron Excess Iron Nuclei, Physics Essays. 2020; 32(2):175.
10. Bevelacqua JJ. Decay Characteristics of Neutron Excess Fluorine Nuclei, Qeios **24XLL9**. 2020; 1. Doi: https://doi.org/10.32388/24XLL9
11. Bevelacqua JJ. Decay Characteristics of Neutron Excess Zinc Nuclei, Qeios **JZI1LG**. 2020; 1. Doi: https://doi.org/10.32388/JZI1LG
12. Bevelacqua JJ. Decay Characteristics of Neutron Excess Neon Nuclei, Qeios **1WR291**. 2021; 1. Doi: https://doi.org/10.32388/1WR291
13. Bevelacqua JJ. Decay Characteristics of Neutron Excess Sodium Nuclei, Qeios **1Y819A**. 2021; 1. Doi: https://doi.org/10.32388/1Y819A
14. Bevelacqua JJ. Decay Characteristics of Neutron Excess Magnesium Nuclei, Qeios **KIB58L**. 2021; 1. Doi: https://doi.org/10.32388/KIB58L
15. Bevelacqua JJ. Decay Characteristics of Neutron Excess Aluminum Nuclei, Qeios **LCAO3W**. 2022; 1. Doi: https://doi.org/10.32388/LCAO3W
16. Bevelacqua JJ. Decay Characteristics of Neutron Excess Silicon Nuclei, Qeios **Y6HDZF**. 2022; 1. Doi: https://doi.org/10.32388/Y6HDZF
17. Bevelacqua JJ. Decay Characteristics of Neutron Excess Phosphorous Nuclei, Qeios **Z16MGO**. 2023; 1. Doi:

https://doi.org/10.32388/Z16MGO
18. Bevelacqua JJ. Decay Characteristics of Neutron Excess Sulfur Nuclei, Qeios **QO9K3E**. 2023; 1. Doi: https://doi.org/10.32388/QO9K3E
19. Bevelacqua JJ. Decay Characteristics of Neutron Excess Chlorine Nuclei, Qeios **HXV1XN**. 2023; 1. Doi: https://doi.org/10.32388/HXV1XN
20. Bevelacqua JJ. Decay Characteristics of Neutron Excess Argon Nuclei, Qeios **JDLHDL**. 2023; 1. Doi: https://doi.org/10.32388/JDLHDL
21. Bevelacqua JJ. Decay Characteristics of Neutron Excess Potassium Nuclei, Qeios **SRFGK2**. 2024; 1. Doi: https://doi.org/10.32388/SRFGK2
22. Bevelacqua JJ. Decay Characteristics of Neutron Excess Scandium Nuclei, Qeios **25NGQR**. 2024; 1. Doi: https://doi.org/10.32388/25NGQR
23. Bevelacqua JJ. Decay Characteristics of Neutron Excess Titanium Nuclei, Qeios **NFSVCP**. 2024; 1. Doi: https://doi.org/10.32388/NFSVCP
24. Bevelacqua JJ. Decay Characteristics of Neutron Excess Vanadium Nuclei, Qeios **9VY02M**. 2024; 1. Doi: https://doi.org/10.32388/9VY02M
25. Bevelacqua JJ. Decay Characteristics of Neutron Excess Chromium Nuclei, Qeios **K7DJZP**. 2024; 1. Doi: https://doi.org/10.32388/K7DJZP
26. Terasawa M, Sumiyosh K, Kajino T, Mathews GJ, Tanihata I. New Nuclear Reaction Flow during r-Process Nucleosynthesis in Supernovae: Critical Role of Light Neutron-Rich Nuclei, The Astrophysical Journal. 2001; 562:470.
27. Lukasiak A, Sobiczewski A. Estimations of half-lives of far-superheavy nuclei with Z approx. = 154 - 164**,** Acta Phys. Pol. B. 1975; 6:147.
28. Petrovich F, Philpott RJ, Robson D, Bevelacqua JJ, Golin M, Stanley D. Comments on Primordial Superheavy Elements, Phys. Rev. Lett. 1976; 37:558.
29. Bevelacqua JJ. Decay Characteristics of Neutron-Excess Manganese Nuclei, Qeios **FKQ489**. 2025; 1. Doi: doi.org/10.32388/FKQ489
30. Bevelacqua JJ. Decay Characteristics of Neutron Excess Cobalt Nuclei. Sci Set J of Physics. 2025; 4(3):1.
31. Bevelacqua JJ. Decay Characteristics of Neutron Excess Nickel Nuclei. Sci Set J of Physics. 2025; 4(4):1.
32. Bevelacqua JJ. Decay Characteristics of Neutron Excess Copper Nuclei. Int. J. Adv. Multidisc. Res. Stud. 2025; 5(5):242.
33. Bevelacqua JJ. Decay Characteristics of Neutron Excess Gallium Nuclei. Int. J. Adv. Multidisc. Res. Stud. 2025; 5(6):545.
34. Bevelacqua JJ. Decay Characteristics of Neutron Excess Germanium Nuclei. Int. J. Adv. Multidisc. Res. Stud. 2025; 5(6):1317.
35. Bevelacqua JJ. Decay Characteristics of Neutron Excess Arsenic Nuclei. Int. J. Adv. Multidisc. Res. Stud. 2026; 6(1):3102.
36. Bevelacqua JJ. Decay Characteristics of Neutron Excess Selenium Nuclei. Int. J. Adv. Multidisc. Res. Stud. 2026; 6(3):91.
37. Bevelacqua JJ. Decay Characteristics of Neutron Excess Bromine Nuclei. Int. J. Adv. Multidisc. Res. Stud. 2026; 6(3):1515.
38. Bevelacqua JJ. Decay Characteristics of Neutron Excess Krypton Nuclei. Int. J. Adv. Multidisc. Res. Stud. 2026; 6(4):928.
39. Bevelacqua JJ. Decay Characteristics of Neutron Excess Rubidium Nuclei. Int. J. Adv. Multidisc. Res. Stud. 2026; 6(4):1626.
40. Brown GE, Gunn JH, Gould P. Effective mass in nuclei, Nucl. Phys. 1963; 46:598.
41. Fox L, Godwin ET. Some new methods for the numerical integration of ordinary differential equations, Proc. Cambridge Philos. Soc. 1949; 45:373.
42. Rost E. Proton Shell-Model Potentials for Lead and the Stability of Superheavy Nuclei, Phys. Lett. B. 1968; 26:184.
43. Blomqvist J, Wahlborn S. Shell model calculations in the lead region with a diffuse nuclear potential, Ark. Fys. 1959; 16:545.
44. Ray L, Hodgson PE. Neutron densities and the single particle structure of several even-even nuclei from ^{40}Ca to ^{208}Pb**,** Phys. Rev. C. 1979; 20:2403.
45. Schwierz N, Wiedenhöver I, Volya A. Parameterization of the Woods-Saxon Potential for Shell-Model Calculations, arXiv:0709.3525v1 [nucl-th], Sep 21, 2007.
46. Baum EM, Ernesti MC, Knox HD, Miller TR, Watson AM. Nuclides and Isotopes - Chart of the Nuclides, 17th ed, Knolls Atomic Power Laboratory, 2010.
47. National Nuclear Data Center, Brookhaven National Laboratory, NuDat3 (Nuclear Structure and Decay Data), 2026. http://www.nndc.bnl.gov/nudat3/
48. Koura H, *et al*. Chart of the Nuclides 2018, Japanese Nuclear Data Committee and Nuclear Data Center, Japanese Atomic Energy Agency, 2018.
49. Wong CY. Additional evidence of stability of the superheavy element ^{310}126 according to the shell model. Phys. Lett. 1966; 21:688.
50. Chowdhury PR, Samanta C, Basu DN. Modified Bethe-Weinsäcker Mass Formula with Isotonic Shift and New Driplines, Mod. Phys. Lett A. 2005; 20(21):1605.