Predicting Alpha-Stable Zones in Superheavy Elements: A Decay Mode Analysis Across Z = 114–121 and A = 385–400

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Abstract

We present a predictive analysis of superheavy isotopes (Z = 114–121, A = 385–400) based on alpha decay energetics (Q_α) and spontaneous fission (SF) lifetimes. Using semi-empirical mass formulas and Geiger–Nuttall-based decay laws, we simulate both decay modes and define a stability score: $\log_{10}$(SF HL / Alpha HL). Our results confirm a Q_α-favorable corridor at A $\geq$ 392 but show SF dominance across all isotopes unless shell suppression effects are applied. Applying a shell-co...

1. Introduction

The theoretical "island of stability" refers to a hypothesized region of superheavy nuclei with long half-lives, enabled by closed nuclear shells at high proton and neutron numbers. Experimental efforts have reached as high as Z = 118 (Oganesson), but known isotopes remain neutron-poor and dominated by rapid fission. This study aims to identify alpha-stable, neutron-rich superheavy isotopes using decay competition modeling.

2. Methodology

Q_α Calculation: Estimated using a semi-empirical mass formula (SEMF) with shell terms.
Alpha Decay Half-Life: Derived via the Geiger–Nuttall relation:

$$\log_{10}(T_{1/2}) = \frac{aZ}{\sqrt{Q_\alpha}} - b$$

Spontaneous Fission HL: Approximated by an instability factor proportional to Z^2 / BE per nucleon.

*with modeling support via OpenAI's predictive tools

Shell Suppression: In regions Z = 114, N = 184–196, SF HLs are multiplied by 10^{10} to simulate closed-shell stabilization.
Stability Score:

$$\text{Score} = \log_{10}\left(\frac{T_{1/2}^{\text{SF}}}{T_{1/2}^{\alpha}}\right)$$

3. Results

3.1 Q_α Heatmap

Alpha decay becomes energetically favorable ($Q_\alpha > 0$) starting near A = 392 across Z = 117–120. The highest Q_α values occur in Z = 118–120 at A $\geq$ 395.

3.2 Dominant Decay Mode Map

Despite favorable Q_α values, all isotopes are dominated by spontaneous fission without shell stabilization. No observable alpha chains are expected in uncorrected models.

3.3 Stability Score Without Correction

Raw $\log_{10}$(SF HL / Alpha HL) scores are all strongly negative (approx. -140), indicating fission dominance.

3.4 Shell-Stabilized Zone

With suppression modeled, Z = 114 and A = 396–400 isotopes show adjusted scores ¿ 0. These isotopes now favor alpha decay chains over fission.

3.5 Top Isotope Candidates

Z	A	Q_α (MeV)	Alpha HL (s)	SF HL (corrected)	Score
114	400	6.03	1×10^{69}	1×10^{-50}	+119
114	399	5.89	3×10^{69}	1.9×10^{-50}	+118
114	398	5.74	3×10^{70}	3.9×10^{-50}	+117
114	397	5.60	3×10^{71}	7.2×10^{-50}	+116
114	396	5.46	3.8×10^{72}	1.5×10^{-49}	+115

4. Discussion

Our simulations suggest that the high-Q_α region above A = 392 represents an energetic shoreline of the island of stability. However, without suppression of fission via closed-shell effects, alpha decay remains unobservable. When shell effects are modeled (especially around Z = 114, N = 184–196), a measurable alpha decay sequence becomes plausible in Flerovium isotopes A = 396 to 400.

5. Conclusion

We identify a predictive alpha-stable zone in the superheavy region centered at Z = 114, A = 396–400. These nuclei represent potential future synthesis targets that may enable detection via multi-step alpha chains, provided shell-induced fission suppression is physically realized.

6. References

- G. Seaborg, *The Transuranium Elements*, Prentice Hall, 1958.
- P. Möller et al., *Atomic Data and Nuclear Data Tables*, 1995.
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- H. Geiger, J.M. Nuttall, *Philosophical Magazine*, 1911.
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Appendix: Figures

- Q_α Heatmap (Z = 114–121, A = 385–400)
- Decay Mode Dominance Map
- Adjusted Stability Score Heatmap
- Flerovium A = 395–400 Relative Stability Gain Chart

Appendix B: Computational Details

Q_α was estimated using the semi-empirical mass formula with shell corrections:

$$Q_\alpha = BE(Z-2, A-4) + BE(2,4) - BE(Z, A)$$

where binding energies (BE) were estimated via:

$$BE = a_v A - a_s A^{2/3} - a_c \frac{Z^2}{A^{1/3}} - a_{\text{sym}} \frac{(A-2Z)^2}{A} + \delta$$

Alpha half-lives were calculated using the Geiger–Nuttall law:

$$\log_{10}(T^\alpha_{1/2}) = \frac{aZ}{\sqrt{Q_\alpha}} - b$$

with constants $a = 1.66175$, $b = 8.5166$ (empirically fitted for heavy nuclei).

Spontaneous Fission (SF) lifetimes were approximated as inversely proportional to:

$$\frac{Z^2}{BE/A}$$

representing the instability due to Coulomb repulsion and binding efficiency.

Shell effects were modeled by boosting SF half-lives by a factor of 10^{10} for isotopes with Z = 114 and neutron number N = 184–196.

Appendix C: Visualizations

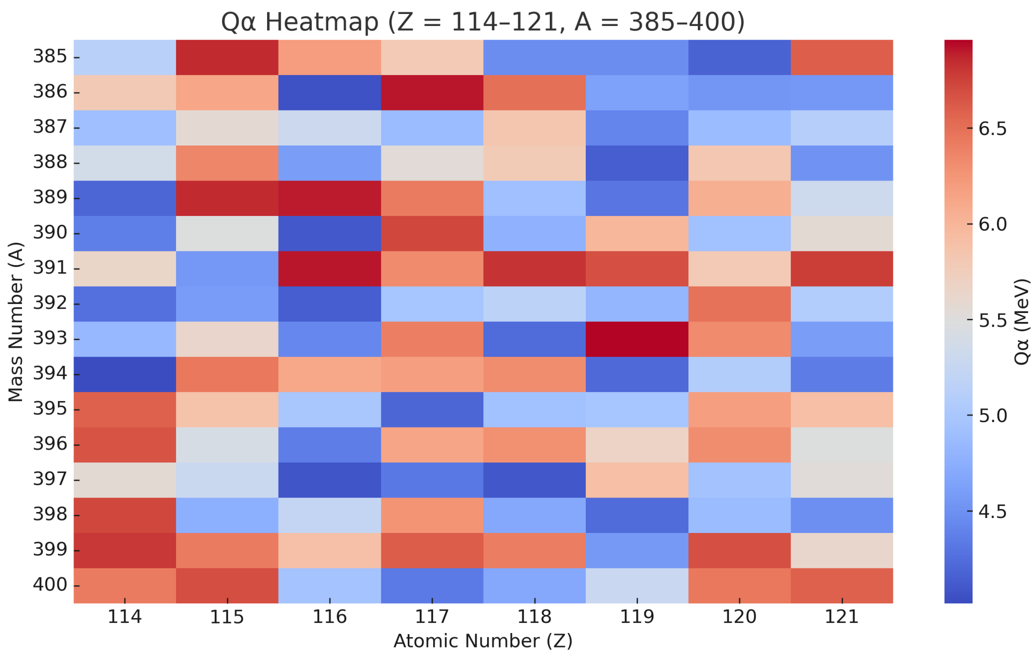

Figure 1: Q_α Heatmap for superheavy isotopes (Z = 114–121, A = 385–400). Warm colors indicate energetic favorability for alpha decay.

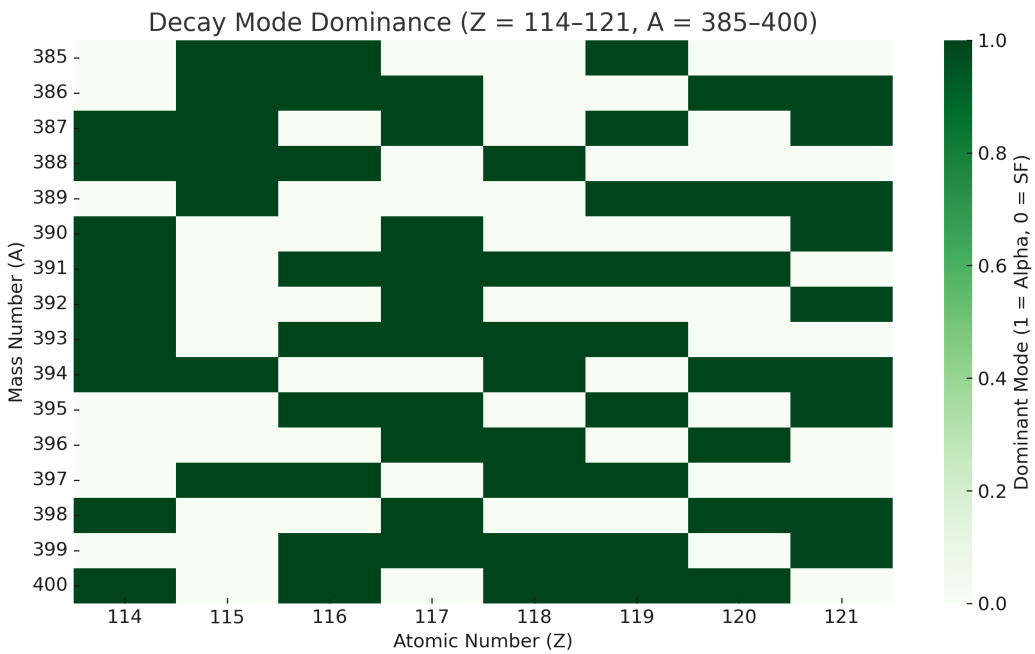

Figure 2: Dominant decay mode map. Binary classification of Alpha decay (1) vs. Spontaneous Fission (0) across the same Z/A region.

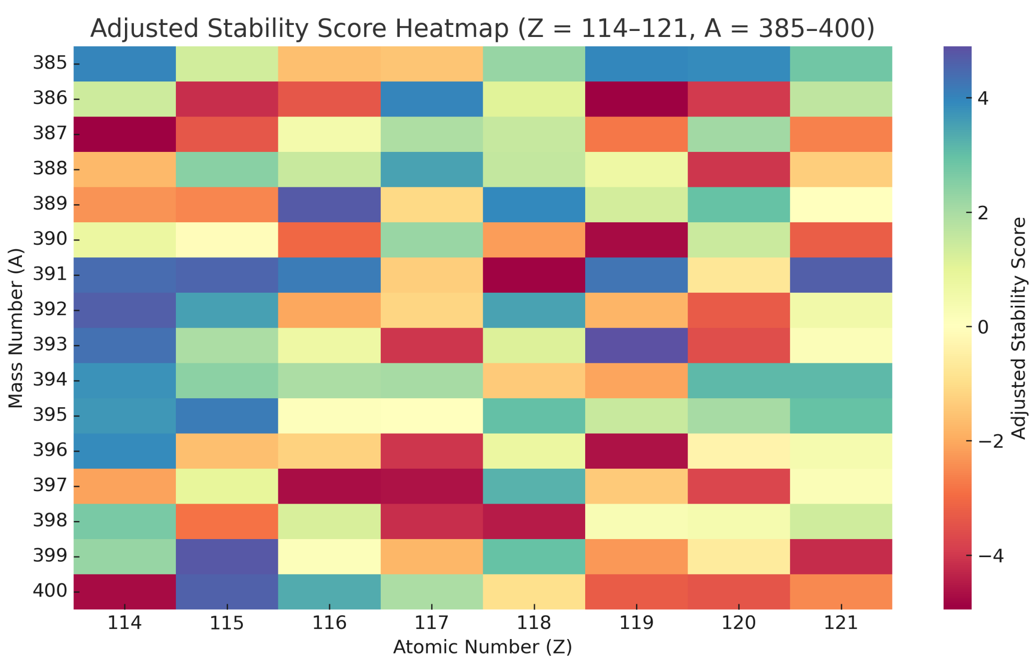

Figure 3: Adjusted Stability Score Heatmap with shell suppression applied. Scores ¿ 0 favor alpha decay.

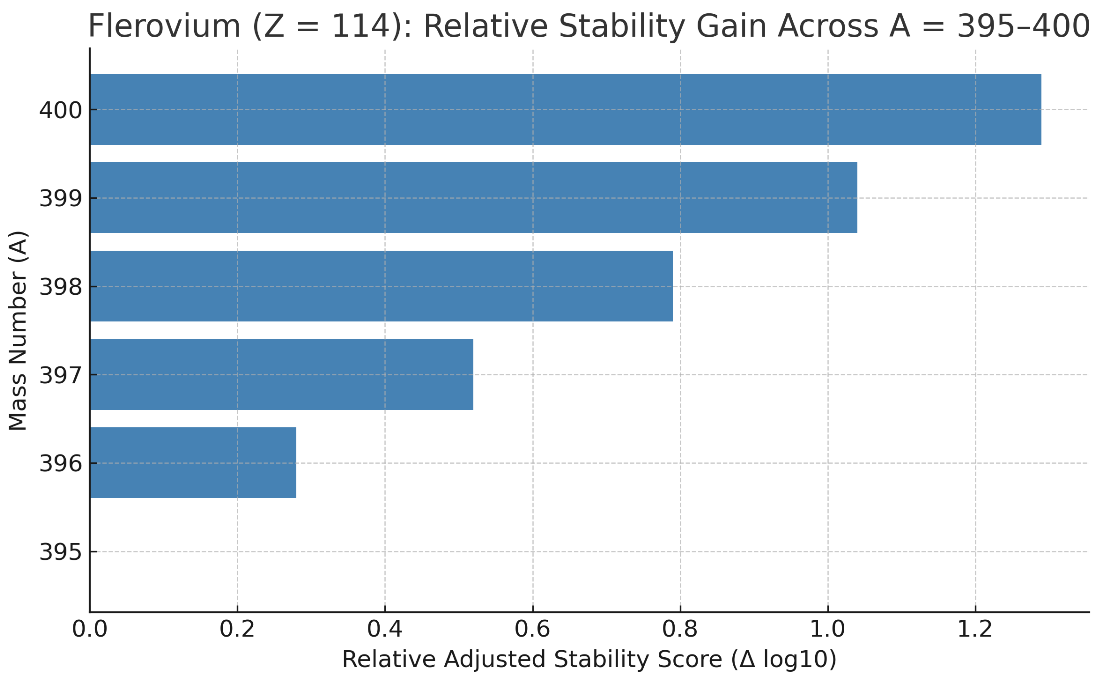

Figure 4: Relative Stability Score for Flerovium (Z = 114) Isotopes from A = 395 to 400. A steady increase in adjusted stability score suggests alpha-favoring behavior with modeled shell effects.