Multi-Step Laser Ionisation Scheme with J=0-1-0 Optical Selection for High Selectivity Ionisation of Odd-Ca Isotopes

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Ca-41 presents a difficulty for decommissioning nuclear waste due to its long half-life (1.04x10^5 years) and unusual decay pathway (EC to K-41 followed by X-ray release). Here, we report progress on a three-laser-step resonance ionization technique, coupled with polarisation based optical selection rule manipulation, intended to produce odd-isotope optical selectivities greater than previously reported.

Keywords: resonance ionization, polarization optical selection rules, calcium, laser, waste analysis

1. Introduction

Several methods have been developed for the analysis of Ca-41 content in nuclear facility waste that may ascertain if the quantity is larger or lesser than the Japanese clearance level of 100 Bq / g, such as accelerator mass spectroscopy (AMS), liquid scintillation counting, etc. However, these have drawbacks in, for example, extensive sample preparation requirements, isobaric interference and lack of facility availability. Alternative methods for Ca-41 analysis would be desirable. Laser based resonance ionisation represents a promising avenue for this.

2. Experimental

Theoretical calculations of optical selectivities of Ca-41 against the majority abundance isotope Ca-40, on a well-studied three-step resonance ionisation scheme give values on the order 10^{10} [1], but will practically be limited by non-resonant excitation from the second step transition. We propose applying J = 0 → 1 → 0 optical selection rules on a resonance ionization scheme not reported on for this purpose before: $4s^2\ {}^1S_0$→$4s4p\ {}^1P^\circ_1$ [422.8nm] →$4s5s\ {}^1S_0$ [1034.7nm] → Rydberg P states [~630nm] → autoionization [applied E field etc.]. Setting the linear polarisation orientation of the first and second step lasers orthogonal forbids the second step transition only for even isotopes. For odd isotopes, with hyperfine splitting due to their non-zero nuclear spin, the transition is allowed. This application of optical selection rules and RIMS achieved improved selectivity on isotopes of palladium recently [2], but has not yet been applied to calcium. Here we present preliminary 'proof-of-concept' results on Ca-43 as a proxy for Ca-41. We are able to show firstly Ca-40 ion production dependence on the second step polarisation orientation, and Ca-43 production with Ca-40 suppressed by isotope shift and polarisation orientation. Ultimately, we intend to proceed to experimenting on 'live' samples of concrete to measure their Ca-41 content.

3. Conclusion

A laser based, three-step resonance ionisation transition scheme is proposed, enabling application of optical selection rules targeting improved optical selectivity of odd isotopes of calcium, targeting the ultra-trace analysis of Ca-41 for nuclear facility decommissioning. Preliminary progress on the proxy isotope Ca-43 is reported here.

4. Acknowledgements

This project is supported by 中部電力株式会社.

References

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