Data-Driven Estimation of ^{225}Ac Yield versus Irradiation Time and Current at Multiple Proton Energies

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ABSTRACT

Actinium-225 (^{225}Ac), a promising alpha-emitting radionuclide for targeted alpha therapy (TAT), offers a suitable half-life (9.9 days) and favorable decay chain, yet its limited availability hinders widespread clinical use. Proton irradiation of thorium-232 (^{232}Th(p,x)^{225}Ac) is a practical and efficient production method. This study utilized the TALYS-2.0 nuclear reaction model to simulate the excitation functions of the ^{232}Th(p,x)^{225}Ac reaction, with parameters optimized for better alignment with experimental cross section data. Additionally, two data driven models (Artificial Neural Network (ANN) and Support Vector Regression (SVR)) were developed to predict reaction cross sections using experimental datasets. The physical yield of ^{225}Ac was calculated via the integral yield formula at proton energies of 70, 90, and 150 MeV, evaluating yield as a function of irradiation time (at 250 µA beam current) and beam current (at 24 h irradiation). Results demonstrate that ANN and SVR models outperform TALYS, providing higher and more accurate yield predictions. These data driven approaches enhance the optimization of production parameters, paving the way for efficient ^{225}Ac generation to support clinical applications.

INTRODUCTION

Actinium-225 (^{225}Ac) is one of the most promising α-emitters for TAT due to its suitable half-life (9.9 days) and favorable decay chain. However, its limited global availability remains a major bottleneck for clinical translation [1]. Among various production routes, proton irradiation of thorium-232 via the ^{232}Th(p,x)^{225}Ac reaction has proven to be the most feasible and efficient approach [2]. Accurate estimation of production yield under different irradiation conditions is therefore essential for optimizing large-scale generation. In this study, both nuclear reaction modeling (TALYS-2.0) and data-driven methods (ANN and SVR) were employed to predict the excitation function and calculate the physical yield of ^{225}Ac at multiple proton energies [3,4].

MATERIALS & METHODS

The production yield of ^{225}Ac was calculated using the integral thick-target yield equation:

$$Y = \frac{N_A I}{A_t}\left(1 - e^{-\lambda t}\right)\int_{E_f}^{E_i} \frac{\sigma(E)}{S_p(E)} dE$$

In this equation, the stopping power $S_p(E)$ was obtained from SRIM Code, and the reaction cross-section $\sigma(E)$ was taken from both machine learning predictions (ANN and SVR) and TALYS model outputs. The integral was evaluated as a function of irradiation time at a fixed beam current of 250 µA, and as a function of beam current at a fixed irradiation time of 24 h.

RESULTS

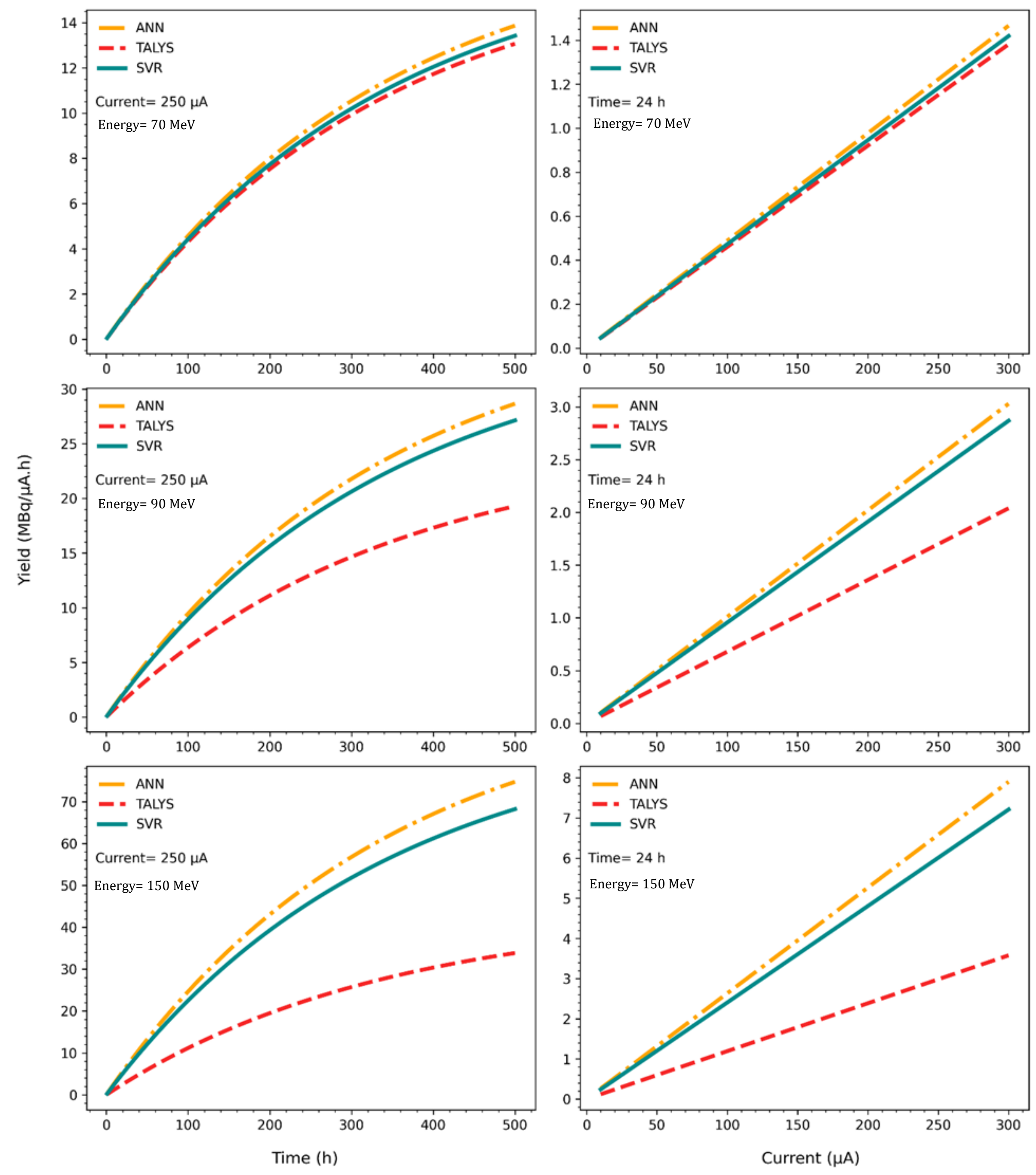

Fig. 1 Production yield of ^{225}Ac versus time (left) and beam current (right) for proton energies of 70, 90, and 150 MeV. TALYS (red dashed), SVR (dark cyan solid), and ANN (orange dash-dot) predictions are compared. Time-dependent plots assume 250 µA beam current; current-dependent plots assume 24 h irradiation.

CONCLUSION

This study demonstrates the effectiveness of data-driven approaches in predicting the excitation function and production yield of ^{225}Ac through the ^{232}Th(p,x)^{225}Ac reaction. The yield calculations were performed using ANN and SVR models combined with the TALYS nuclear reaction code. The machine learning predictions provided more accurate yield estimations across all proton energies (70, 90, and 150 MeV) compared to TALYS results. These outcomes are consistent with our previous study, where the data-driven models achieved superior agreement with experimental cross-section and yield data [4]. Overall, the present work confirms that machine learning–based modeling is a powerful tool for optimizing irradiation parameters and improving the efficiency of ^{225}Ac production for medical applications.

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