Optimization of ^{94m}Tc Production by Cyclotron Proton Irradiation of Phosphomolybdic Acid using an Automated Liquid Target System

Chloe Green[1, 2*], Ross Harper[1], Leeon Fernandez[1], Dhyey Mehta[1], Jordan Cale[1], Michael Farquharson[2], Richard Southworth[3], Philip Blower[3], Stephen Archibald[3], Karin Stephenson[1,2], Karin Nielsen[1,2,3]

[1]Nuclear Operations and Facilities, McMaster University, Hamilton, ON, Canada. [2]Department of Physics and Astronomy, McMaster University, Hamilton, ON, Canada.

*[3]Department of Imaging Chemistry and Biology, King's College London, London, UK. *Contact: greenc15@mcmaster.ca*

INTRODUCTION

Due to its positron branching ratio (72%), medium positron end-point energy (2.47 MeV), and half-life (52 minutes) [1], Technetium-94m (^{94m}Tc) is viewed as a potential candidate for PET imaging. ^{94m}Tc is of interest as a PET alternative for Technetium-99m SPECT imaging, with PET having the benefits of superior sensitivity and resolution [2].

In 2024, our group published results of the production of ^{94m}Tc via proton-irradiation of phosphomolybdic acid (PMA) solutions [3]. Since then, a computer-controlled automated liquid target system (LTA) has been developed to evaluate production capacity. The data collected using this system is presented here.

METHODS

Liquid targetry: The LTA system, based on the original manual target loading setup, was developed for use with a GE PETtrace cyclotron. It supports both atmospheric and closed pressure irradiations. In this study, the open configuration was used. The system features a pressure transducer and 500 psi Valco valves to control the target inlet/outlet, syringe loading, and delivery lines (Figure 1,2).

Figure 1: Valve system

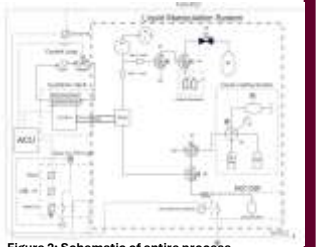

Figure 2: Schematic of entire process

PLC-based automation system: The system, operated via a computer interface (Figure 3) has two modes: operation and maintenance mode. The system runs preset sequences for irradiation and delivery while logging real-time pressure data. Integrated with cyclotron and hot cell interlocks, it ensures safe operation and can automatically shut down in case of faults.

Figure 3: Computer interface

Figure 4: Syringe Drive

Figure 5: Cyclotron target

Sample processing: A 2.7 mL solution of 0.16 M natural abundance PMA was loaded into a modified Nb target (200 µm Nb foil, 25 µm HAVAR foil) using a syringe drive (Figure 4,5), reducing proton energy to 12.9 MeV. Irradiations were performed for up to 60 minutes at 10 µA and 30 minutes at 15 µA. After irradiation, the solution was transferred to the hot cell. The system was then rinsed with 3 × 2.7 mL of water and dried before next use. Activity was measured via HPGe gamma spectroscopy, and trace metals were analyzed by ICP-OES.

RESULTS

Pressure: The pressure data showed that the system delivered the PMA to the hot cell product vial in < 5 minutes by 90 PSI helium purge (Figure 6).

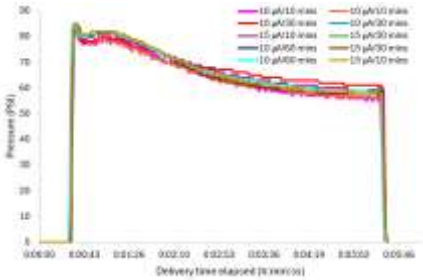

Figure 6: Recorded pressure during PMA delivery to hot cell

Yield: The initial evaluations on the automated system resulted in a ^{94m}Tc saturation yield of 19 ± 1 MBq/µA (n = 10), like the previously reported 20 ± 1 MBq/µA (n = 16) for the manual system (Figure 8).

Degradation: The majority of the ^{94m}Tc activity (89.0 ± 1.9%) was found in the product vial, while 10.7 ± 1.8% was in the rinse 1 and 0.3 ± 0.1% in rinse 2-3. No Nb degradation or PMA precipitation was observed in the target post irradiation (Figure 7).

Figure 7: Nb cavity post irradiation

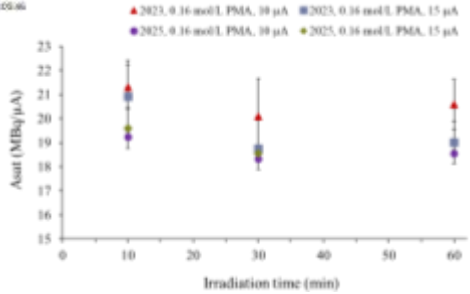

Figure 8: ^{94m}Tc saturation yield as a function of irradiation time

Run comparison: Each vial was weighed and corrected for PMA density to collect volume data after each run. All irradiated volume data (product vial + 3 rinses) were within 2 standard deviations from the mean (Figure 9). A Wilcoxon signed rank test comparing two runs of identical irradiation parameters showed that all pairs produced a W value greater than the critical threshold for 95% confidence level.

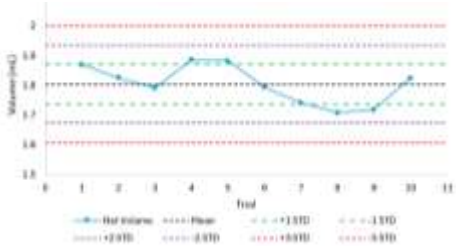

Figure 9: Control chart of product vial volume results

Trace metals: ICP-OES analysis of the irradiated PMA solutions from the LTA operated runs showed less trace metal than previously reported from the manual system for 4/5 metals.

Table 1: ICP-OES results of trace metal from 2023 and 2025

Trace Metal	Max ppm 2023	Max ppm 2025
Al	< 2.5	< 1.4
Cu	35	< 1
Fe	< 2.5	< 0.2
Nb	< 1.2	< 2
Zn	< 2.5	< 2.4

CONCLUSION

The LTA system has shown to be as a consistent and reliable method of automating the PMA delivery process, with activity saturations between the LTA and manual system being comparable.

Volume data shows consistent volumetric output with the automatic system, with no statistically significant difference between data sets of same irradiation parameters.

Next steps: Investigate the target maximum irradiation parameters and investigate tracer ^{94m}Tc labelling for preclinical evaluation.

ACKNOWLEDGEMENTS

The work was supported by the UK EPSRC (EP/S032789/1) & MRC (MR/X502923/1) grants and the Government of Canada, Strategic Innovation Fund.

REFERENCES

[1] Qaim, S.M., 2000. Production of high purity 94mTc for positron emission tomography studies. Nucl. Med. Biol. 27, 323–328.
[2] Bigott, H.M et al., 2006. Advances in the production, processing and microPET image quality of technetium-94m. Nucl. Med. Biol. 33, 923–933.
[3] Harper, R., et al. M., 2024. Optimised production of technetium-94m for PET imaging by proton-irradiation of phosphomolybdic acid in cyclotron liquid target. Applied Radiation and Isotopes, 210, Article 111381.