Optimization of iodine-125 production for prostate brachytherapy considering iodine-126 contamination and irradiation time

Ilca M. M. A. Medeiros, PhD; Ana C. S. S. Koka, MSc; João A. Moura, PhD; José A. G. Medeiros, PhD; Lucas V. Angelocci, PhD; Lara E. H. Teodoro, MSc; David A. U. Leal, MSc; Priscila S. Rodrigues, MSc; Maria E. C. M. Rostelato, PhD and Carlos A. Zeituni, PhD, Nuclear and Energy Research Institute (IPEN), São Paulo, Brazil

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ABSTRACT

The production of iodine-125 (^{125}I) for permanent prostate brachytherapy seeds requires both clinically suitable activity and high radionuclidic purity, as these parameters directly influence dosimetric performance, treatment quality, and patient safety.

During reactor irradiation, however, successive neutron capture reactions promote the formation of iodine-126 (^{126}I), the main radionuclidic impurity associated with the production process.

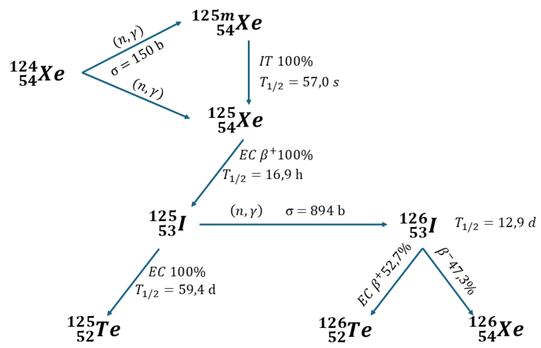
This study investigated the influence of irradiation time on ^{125}I production and ^{126}I formation to establish an operational irradiation window capable of maximizing the therapeutic yield of ^{125}I while maintaining radionuclidic purity within clinically acceptable limits..

INTRODUCTION

Iodine-125 (^{125}I) is the radionuclide of choice for permanent prostate brachytherapy because of its 59.4-day half-life and low-energy photon emissions (27–35 keV), which provide excellent dose conformity within the target volume and rapid dose fall-off in surrounding healthy tissues.

Reactor-based production of ^{125}I relies on neutron activation; however, successive neutron capture reactions also generate iodine-126 (^{126}I), reducing radionuclidic purity and potentially limiting the clinical applicability of the final product.

Consequently, irradiation time represents a key production parameter, simultaneously affecting therapeutic yield and radionuclidic purity. Defining an operational irradiation window is therefore essential for optimizing routine production, strengthening quality assurance, and supporting the implementation of reliable domestic production of ^{125}I for prostate brachytherapy.



METHODS AND MATERIALS

Natural xenon samples were irradiated in the IEA-R1 research reactor under neutron fluxes ranging from (3–8) × 10^{13} n·cm^{-2}·s^{-1} for irradiation times of 8, 16, 32, and 48 h.

Following optimized decay periods, the produced iodine was chemically extracted into a fixed NaI solution volume and analyzed by HPGe gamma-ray spectrometry.

The activity of ^{125}I was determined using the sum-peak method, whereas ^{126}I activity was quantified through an efficiency calibration curve refined with a ^{166}mHo standard source. Radionuclidic purity was assessed using the ^{126}I/^{125}I activity ratio.

RESULTS

Irradiation times shorter than 32 h produced insufficient ^{125}I activity for permanent prostate brachytherapy seeds. Irradiations of 32 h or longer yielded activities within the recommended clinical range (0.2–0.8 mCi per seed), considering the NaI solution volume used.

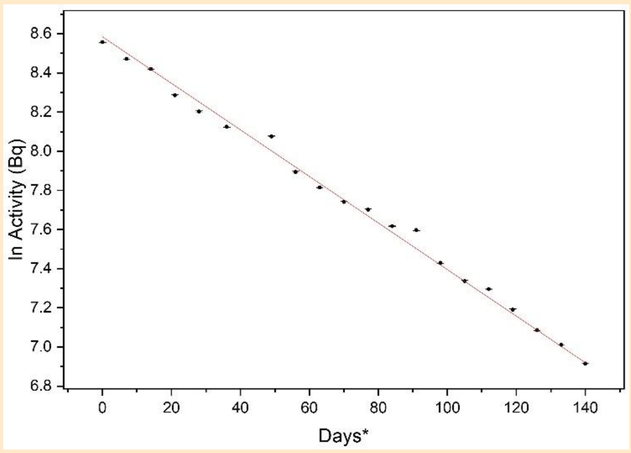


Chart 1. Exponential decay of ^{125}I activity after 48 h of neutron irradiation. The linear behavior in logarithmic scale validates the activity determination and confirms the expected radioactive decay.

Longer irradiation times increased ^{125}I production but also enhanced secondary neutron capture reactions, resulting in greater ^{126}I formation.

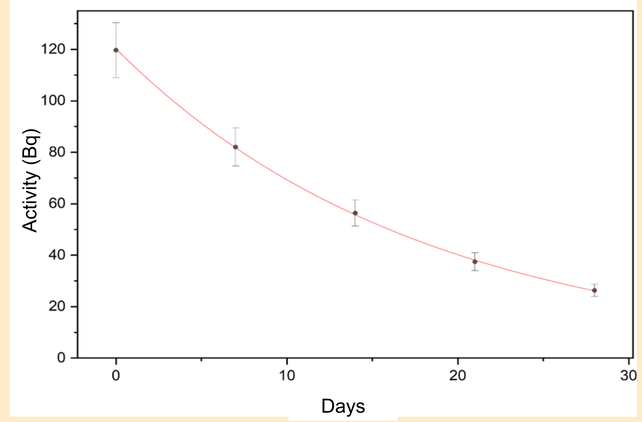


Chart 2. Decay of ^{126}I activity after 48 h of irradiation, demonstrating the progressive reduction of radionuclidic impurity with decay time.

Although the ^{126}I/^{125}I activity ratio increased with irradiation time, all investigated conditions remained below clinically accepted contamination limits.

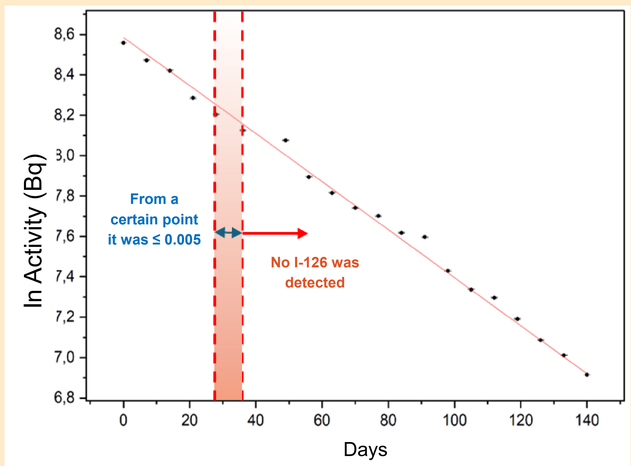


Chart 3. Time evolution of the ^{126}I/^{125}I activity ratio, indicating the interval at which the contamination index becomes ≤0.005 and the subsequent absence of detectable ^{126}I.

DISCUSSION

The results demonstrate that irradiation time governs the trade-off between maximizing therapeutic ^{125}I yield and minimizing radionuclidic impurity.

While prolonged irradiations enhance ^{125}I production (Figure 1), they also increase successive neutron capture reactions responsible for ^{126}I formation (Figure 2).

More importantly, the combined analysis of ^{125}I activity and the temporal evolution of the ^{126}I/^{125}I activity ratio (Figure 3) enabled the definition of an operational irradiation window that simultaneously satisfies clinical activity requirements and radionuclidic purity criteria.

From a production perspective, this operational window provides an objective basis for selecting irradiation conditions and defining appropriate decay times before clinical use, thereby improving process reproducibility, quality assurance, and manufacturing reliability.

CONCLUSIONS

Irradiation time is the primary parameter governing both therapeutic ^{125}I yield and radionuclidic purity during reactor-based production.

Under the investigated conditions, a minimum irradiation time of 32 h is required to achieve clinically suitable ^{125}I activity while maintaining ^{126}I contamination below accepted limits.

More importantly, this study establishes an operational irradiation window that integrates irradiation time, therapeutic activity, radionuclidic purity, and decay time into a single production criterion.

This approach provides practical guidance for process optimization, routine quality assurance, and the future implementation of reliable domestic production of ^{125}I brachytherapy sources.

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CONTACT

Ilca M. M. A. Medeiros, PhD
Nuclear and Energy Research Institute - IPEN
2242 Professor Lineu Prestes Avenue – CEP: 05508-000 - Cidade Universitária, São Paulo, Brazil
Ilca.marli@alumni.usp.br
+55 (11) 97393-4982