Radioisotopic purity of ^{99m}Tc produced via ^{100}Mo(p,2n)^{99m}Tc as a function of proton irradiation energy

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Introduction

The cyclotron based ^{100}Mo(p,2n)^{99m}Tc reaction has been proposed as an alternative method for solving the recent shortage of ^{99m}Tc, which is the most commonly used radioisotope in nuclear medicine. The medical cyclotrons around the world today operate between 11 and 18 MeV, an ideal range for the production of ^{99m}Tc via the ^{100}Mo(p,2n) reaction and give rise to the possibility to potentially supplement, or replace, conventional ^{99m}Tc production methods that are based on aging and increasingly unreliable nuclear reactors. With this production method, however, even if highly enriched molybdenum is used, various isotopes are produced simultaneously with ^{99m}Tc and they may affect the diagnostic outcome and radiation dosimetry in human studies. All technetium isotopes are chemically identical and cannot be separated during target chemical processing. Experimental measurements were performed to investigate the radio isotopic purity of cyclotron-produced technetium as a function of proton irradiation energy.

Experimental method

95% enriched ^{100}Mo foils were stacked alternating with Al foils as energy degrader, with a Cu foil as beam monitor. The irradiation was carried out at 6M setup at the Pelletron Facility TIFR Mumbai with incident proton energy 20.35 MeV. The foils were irradiated for 40 hours. The gamma-ray spectra of samples in a standardized configuration were acquired using a calibrated High-Purity Germanium (HPGe) detector and analyzed for the presence of characteristic photo peaks of Tc, Mo, and Nb isotopes Blank measurement was taken to account for background radioactivity (subtracted from the sample spectrum). Photopeak integrations were performed using dedicated software interwinner. The net counts (area) under the integrated isotope energy peaks were corrected for relative gamma intensity, detector dead time, detector efficiency, and radioactivity decay and expressed in Bq. The samples were assayed at 10, and 24 h and also at 2 weeks and 2 months after the end of bombardment (EOB) to quantify all isotopes including long-lived isotopes (e.g., ^{95m}Tc and ^{97m}Tc).

Results and discussion

The following isotopes of Tc, Mo and Nb were identified- ^{93g}Tc, ^{94g}Tc, ^{95m}Tc,^{95g}Tc, ^{96g}Tc, ^{97m}Tc, ^{99m}Tc, ^{99}Mo, ^{95g}Nb,^{96g}Nb. Activation products expected to be formed in irradiation of ^{100}Mo with protons of intermediate energies are shown in table 1 [1].Other activation products observed in the study are due to proton-induced nuclear reactions with all stable Mo isotopes, that may be present in the target materials [2]. Percentage ^{99m}Tc radioactivity in the sample was calculated as the radioactivity for the ^{99m}Tc (Bq) divided by total radioactivity in the sample (the sum of the radioactivities of all detected isotopes (Bq). The results are shown in table 2. Other technetium isotopes, may contribute to an increase in patient dose and potentially affect image quality. Mo and Nb isotopes although can be eliminated from the technetium samples, radiation waste disposal mechanisms would need to be implemented.

Table 1: Activation products expected to be formed in irradiation of ^{100}Mo with protons of intermediate energies [1].

Nuclear reaction	Q-value (MeV)	Product Nuclide	$T_{1/2}$
(p,γ)	7.441	^{101}Tc	14.2 min
(p,pn)	-8.290	^{99}Mo	66.0 h
(p,d)	-6.065	^{99}Mo	66.0 h
(p,^{3}He)	-10.298	^{98m}Nb	51.3 min
(p,α)	4.287	^{97g}Nb	72.1 min
	3.543	^{97m}Nb	58.7 sec
(p,αn)	-3.788	^{96g}Nb	23.4 h
(p,α2n)	-10.816	^{95m}Nb	86.6 h
	-10.681	^{95g}Nb	35 d
(p,n)	-0.95	^{100}Tc	15.8 s
(p,2n)	-7.859	^{99m}Tc	6 h
	-7.716	^{99g}Tc	2.1x 10^5 y
(p,3n)	-16.682	^{98g}Tc	4.2x 10^6 y
(p,4n)	-24.056	^{97m}Tc	92.2 d
	-23.960	^{97g}Tc	4 x 10^8 y
(p,5n)	-33.475	^{96m}Tc	52 min
	-33.433	^{96g}Tc	4.3 d

Table 2: The EOB ratios of ^{99m}Tc nuclei to all radioactive isotopes (including ^{99m}Tc) produced with 95 % enriched molybdenum target irradiated for 40 hours.

Energy (MeV)	^{99m}Tc / all radioactive isotopes (%)	^{99m}Tc / all Tc (%) *
14.25	93.73	95.73
16	93.29	97.94
17.5	91.33	97.78
19	89.27	97.63
20.35	85.88	97.19

*includes only ^{93g}Tc, ^{94g}Tc, ^{95m}Tc,^{95g}Tc, ^{96g}Tc, ^{97m}Tc

However, the influence of co-produced long-lived Tc-isotopes on the specific activity of ^{99m}Tc need to be critically considered. As seen from table 1, two long-lived radioisotopes ^{99g}Tc and ^{98}Tc are co-produced in this energy range. Due to the very long half life the number of these nuclei present in a ^{99m}Tc sample would not be very low. Using cross sections of [3] for 100% enriched ^{100}Mo of 2mg/cm^2 and for 1microA proton current, the expected ^{99g}Tc,^{98}Tc activities at EOB produced were determined. From these, isotope dilution factor (IDF) i.e., ratio of number of $^{98+99g+99m}$Tc atoms to ^{99m}Tc atoms at EOB are plotted as a function of irradiation time in Fig 1. The IDF from a conventional ^{99}Mo/^{99m}Tc generator is ~ 3 [1]. The co-production of ^{99g}Tc in cyclotron method may have important implications in both the subsequent radio pharmaceutical chemistry and patient dosimetry. As shown in Fig.1, calculations suggest that the most favorable proton energy for the ^{99m}Tc production would be in the region between 16 and 19 MeV and that shorter irradiation times may also be more favorable [3].

The results highlight (a) The shelf-life of the final product needs to be adjusted on the basis of the radio isotopic purity (b) that parameters of energy and irradiation time need to be selected optimally and there is a necessity to acquire sufficient supporting data about the quality of the cyclotron-produced sodium pertechnetate prior to commencing routine direct manufacturing of ^{99m}Tc.

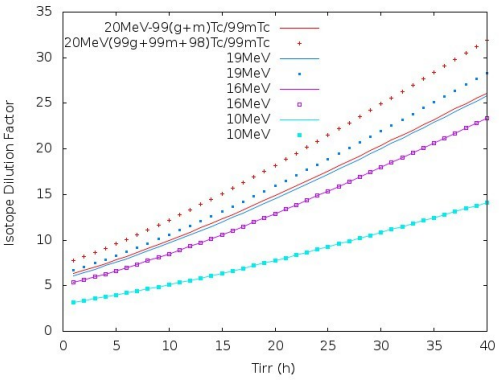

Fig.1 IDF $^{98+99g+99m}$Tc to ^{99m}Tc atoms at EOB as a function of irradiation time Symbols include ^{98}Tc and curves exclude ^{98}Tc contribution.

References

[1] S.M Qaim *et. al.*, App. Rad. Iso. **85** (2014) 101
[2] O.Lebeda *et.al* .Nucl. Med. Bio. **39** (2012) 1286
[3] A.Celler *et. al.* Phys. Med. Bio. **56** (2011) 5469