

RECENT DEVELOPMENTS IN THE PRODUCTION OF I^{123} AT THE MILAN AVF CYCLOTRON

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Abstract

In this paper we report on recent results obtained at the Milan AVF Cyclotron in the production and use of I^{123} .

A new method has been developed for the separation of iodine, based on the dry distillation of I^{123} from the irradiated target, carried out at $400^{\circ}C$ in a 20-40cc/min gas carrier flux.

This technique turns out to be suitable for an "on line" separation of the isotope. Equipment being built for this purpose is briefly described.

1. Introduction

Production of I^{123} was started at the Milan AVF Cyclotron some time ago ¹⁾. This paper reports some recent results on the use of this isotope at the Clinical Physiology Laboratory in Pisa and the developments now under way at the Cyclotron Laboratory in order to improve the production method.

We might recall ¹⁾ that we chose to produce I^{123} via a (p,2n) reaction on a 92% enriched Te^{124} target, at a proton energy of 24 MeV. Target thickness is usually around 350 mg/cm^2 , corresponding to a beam energy loss of 4 MeV. Details of the early irradiation set-up are found in ref. 1).

The more or less conventional chemical separation process used so far yielded the following results:

- separation efficiency of I^{123} = 70% - 80% after 6 hours,
- labelling efficiency of iodine compounds such as "hyppuran" or antipyrine is about 75% and 55% respectively, for a 30 minutes process,
- efficiency of Te recovery between 70% and 80%.

Because of the time needed for the separation and labelling process, and the distance between producers and users, it takes about two half lives (24-26 hours) from irradiation for the isotope to be delivered to the patient. Therefore, taking into account all losses, only 1 mCi of labelled compounds reaches the patient out of 12 mCi of produced I^{123} .

2. Results from the use of I^{123}

Labelled antipyrine has been used for scintigraphic studies of patient chests. An example is shown in Fig. 1. This picture was taken with about 5 mCi, and shows quite clearly details of pulmonary region, heart and liver ²⁾.

Labelled antipyrine will also be used for the detection of the aqueous content of the pulmonary region in a patient. This technique is now being set-up. It is based upon the simultaneous detection of the 159 keV γ line of I^{123} and the K-lines of Te^{123} characteristic x-rays. The latter is formed in the decay of I^{123} by EC.

In fact the spectrum of these γ and x-ray lines is remarkably pure in the preparations made so far. An example obtained with a NaI(Tl) scintillator counting system, is shown in Fig. 2.

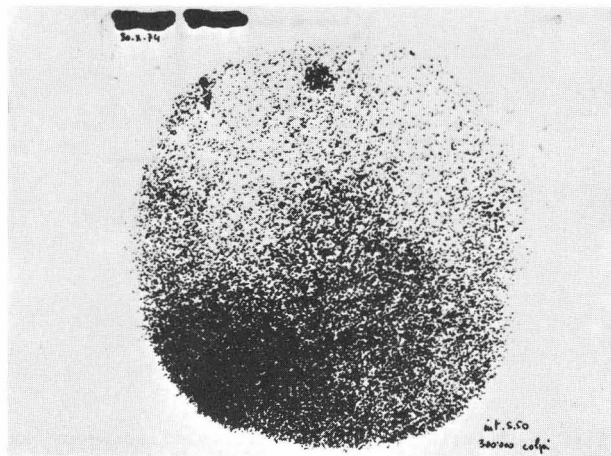


Fig. 1 Scintigraphy of a patient chest obtained with 5 mCi I^{123} antipyrine.

The simultaneous detection of γ and x-ray lines allows the separation of the contribution to the total counting rate of iodine contained in the pulmonary region and of iodine contained in the chest walls. Details of the technique are given in a self-explanatory way in Fig. 3.

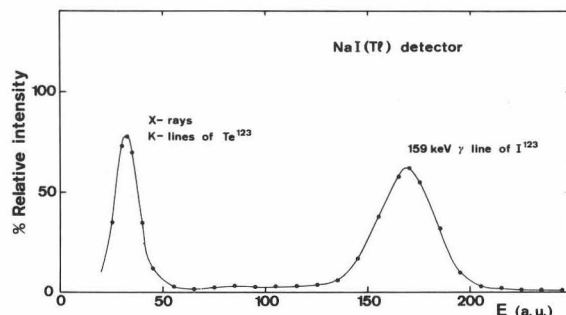


Fig. 2 Spectrum of an I^{123} source obtained with a NaI(Tl) collimated scintillator.

Tests were made so far with NaI^{123} on a phantom built out of saw dust, with perspex walls, which should simulate pulmonary tissue and chest respectively. The results obtained look promising and it is expected that routine measurements on patients with labelled antipyrine will begin in about two months.

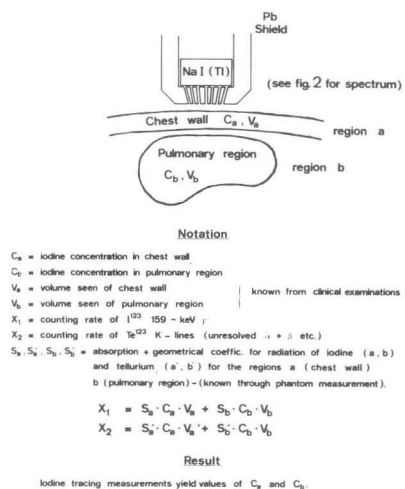


Fig. 3 Principle of the detection of aqueous content in pulmonary regions.

3. Needs for a new separation technique for ^{123}I .

Even though the production and chemical separation technique used so far did prove successful, some shortcomings did show up on the technical side, which ultimately result in a higher production cost with respect to the anticipated one. Here we briefly review the reasons which suggested an entirely different approach to the problem.

a) ^{123}I production. The poor thermal conductivity of Te sets an upper value to the proton beam intensity of about $3-4 \mu\text{A}/\text{cm}^2$, if normal water cooled targets, as described in ref. 1), are used. As a consequence, in order to produce 1 Ci quantities of ^{123}I in irradiation times of a few hours, large area targets ($4-6 \text{ cm}^2$) are necessary, employing up to 2 g of Te. This technique requires therefore a high reliability in the tellurium recovery.

Otherwise the limit on the beam density can be overcome with sealed vacuum proof targets. In this case possible fusion of the target during irradiation does not give rise to losses of either tellurium or iodine. However, in order to separate the iodine, it would be necessary to dissolve the target and its container. This technique requires a fair amount of development work.

b) ^{123}I separation and tellurium recovery. As mentioned above, our chemical separation yield is at most around 80% in 6 hours. This is then a rather slow process, 25% of ^{123}I is lost just because of the time lapse. Besides, the recovery yield of tellurium, at least in the test made so far, is around 80% with a consequent large cost per irradiation due to the relatively large amount of lost tellurium.

These results and the difficulty stemming out of the fact that our laboratory is not equipped nor has the manpower for extended chemical develop-

ment work, suggested an effort in the direction of separating the ^{123}I through physical techniques.

The goal of this research line was to develop a method which would reduce tellurium losses to less than 2%, thus reducing targets cost to negligible levels. It was also hoped that the development of a purely physical technique would allow the set-up of an "on line" ^{123}I production system.

The method consists in the separation of ^{123}I via the diffusion process enhanced in the target by heating it at a proper temperature. To the best of our knowledge this method has never been tried before in the case of iodine diffusing out of tellurium matrix. However such a technique as been developed and used by others Authors for the separation of radioisotopes with short life-times^{4,5}.

4. Diffusion process

In the diffusion process the concentration C of the diffusing element in a pure matrix varies with time t according to the Fick's equation:

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} \quad (1)$$

where x is the distance along the diffusion direction and D is the diffusion coefficient, which is assumed independent of C, but depends upon:

- i) the physical and chemical properties of the matrix substance and the diffusing element,
- ii) the temperature T of the matrix.

If we assume that after irradiation the ^{123}I is uniformly distributed within the target volume, the initial concentration C is given by

$$C(x, 0) = C(0) \quad 0 < x < a \quad (2)$$

where a is the target thickness.

Under the hypothesis that the diffusing iodine is constantly carried away by a gas flux, one has that:

$$C(x, t) = 0 \quad x \leq 0, x \geq a \quad (3)$$

Given the boundary conditions (2) and (3) the solution of (1) can be expressed as:

$$\bar{C}(t) = \frac{8}{\pi^2} C(0) \sum_{n=0}^{\infty} (2n+1)^{-2} \exp\left[-(2n+1)^2 \frac{t}{\tau}\right] \quad (4)$$

where τ is the time constant of the diffusion process and is given by $\tau(T) = a^2/\pi^2 D(T)$

The diffusion efficiency η_D , defined as $\eta_D = [C(0) - \bar{C}(t)]/C(0)$ is given by:

$$\eta_D = 1 - \frac{8}{\pi^2} \sum_{n=0}^{\infty} (2n+1)^{-2} \exp\left[-(2n+1)^2 \frac{t}{\tau}\right] \quad (5)$$

The temperature dependence of the time constant τ can be expressed through a relation like³⁾:

$$\tau(T) = \frac{a^2}{\pi^2 D_0} \exp(Q/RT) = \tau_0 \exp(Q/RT) \quad (6)$$

where D_0 depends upon the target material and the diffusing element, and Q is the diffusion activation energy.

Given the lack of experimental data on the dif-

It has been brought recently to our knowledge³⁾ that a group at the Brookhaven Natl. Lab. has succeeded in obtaining, through a different chemical process, 85% efficiency in ^{123}I separation and 99% efficiency in tellurium recovery. The production reaction is the same used by our group.

fusion processes of iodine in tellurium, a series of measurements were carried out with the aim of determining the time constant τ at various temperatures. This knowledge is in fact essential to check the feasibility of this separation method and, in the affirmative case, to design the irradiation set-up.

5. Experimental set-up

Target heating after irradiation has been carried out with the set-up sketched in Fig.4

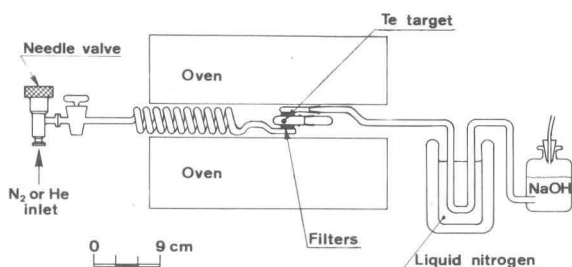


Fig. 4 Sketch of experimental set-up for dry distillation of the iodine from the tellurium target.

The target is placed in a pyrex glass tube of 5 mm diameter, inside a temperature controlled oven. Helium or N_2 gas fluxes of 20 to 40 cc/min are used to carry away the diffused out iodine.

The gas is heated by passage in a glass serpentine inside the oven and subsequently cooled in a liquid nitrogen trap, as shown in Fig. 4 The gas carrier bubbles then in a 0.001 M NaOH solution, where NaI^{123} should be formed.

Several tests were made with this set-up, generally using a 350 mg/cm² thick natural tellurium target irradiated with an integrated charge of 15 mC with 35 MeV protons. Measurements were also made with an enriched Te^{124} target, after the main operating parameters had been determined.

6. Results

6.1. Diffusion rate of iodine.

As shown by equation (6) the diffusion rate of iodine will depend upon the crystalline structure of Te, target thickness and temperature. With the target thickness of 0.5 mm we found that an appreciable diffusion rate of iodine only takes place at oven temperatures above 300 °C. Consequently the temperature range used was between 300 °C and 430 °C, namely just below the tellurium melting point of 452 °C.

In order to have a reliable value of the diffusion rate we measured the activity of the target before and after the heating. From their values, corrected for iodine decay, one gets according to (4) the diffusion efficiency η_D , and therefore the time constant τ

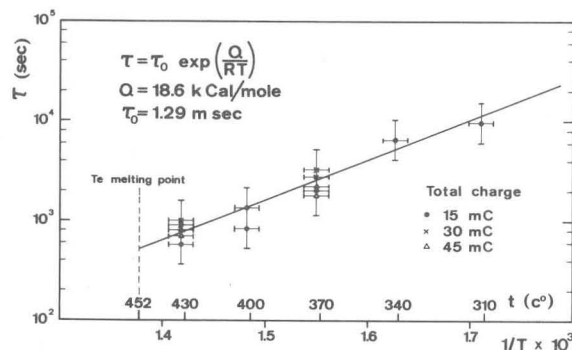


Fig. 5 Time constant of the iodine diffusion process as a function of target temperature.

The results are summarized in Fig. 5. The data look consistent with an exponential law like the one given by (6) if one assumes for $\tau_0 = 1.29$ msec and for $Q = 18.6$ KCal/mole.

In the range of 400 to 430 °C the diffusion efficiency reaches values of 80% to 90% in time periods of 15 to 30 minutes.

These measurements were carried out with the same target irradiated for three consecutive times, up to a total integrated charge of 45 mC. We found that up to these irradiation levels the crystalline structure of Te did not get damaged in such a way as to consistently alterate the diffusion process.

During the tests with enriched Te^{124} a possible radiation damage effect has been observed. In fact for one target, which had been submitted to approximately 100 mC of integrated charge, some drop in the diffusion rate was observed. However, since consistent sets of measurements for enriched tellurium are not yet available, we are unable to set a realistic charge limit for a measurable radiation damage

6.2. Iodine collection.

The diffused iodine did not get collected in

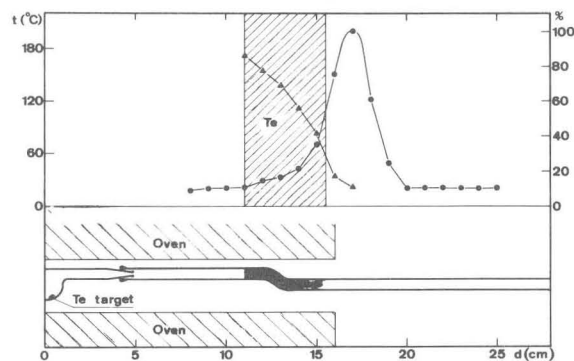


Fig. 6 Percentage iodine distribution along the glass tube and temperature gradient at the exit of oven.

the NaOH solution, but rather deposited (80% - 90%) on the walls of the glass tube immediately at the oven exit. Tellurium vapours, although in negligible quantities, condensed mostly in a higher temperature region of the glass tube, inside the oven.

The percentage iodine distribution along the glass tube, normalized to the maximum, is drawn according to the scale on the right. The temperature variation, again along the tube, is drawn for the scale on the left. The region where tellurium deposition occurs is the dashed one. The total evaporated Te is estimated of the order of 1% at most.

The total iodine fraction which is deposited on the glass tube is practically independent of the oven temperature, while it is strongly influenced by the carrier gas flux. As an example, Fig. 7 shows the integrated fractional deposit of iodine, as a function of time, at a temperature of 410 °C and for N₂ fluxes of 25 and 120 cc/min.

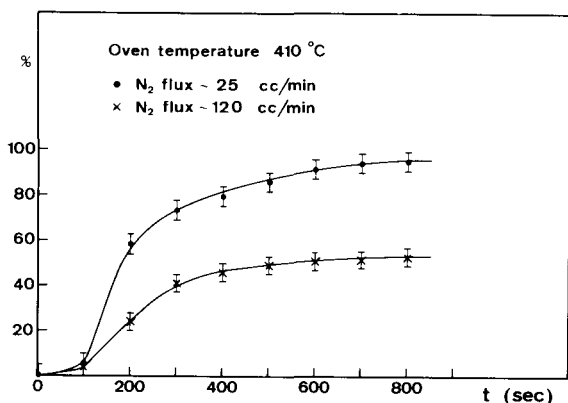


Fig. 7 Percentage of I¹²³ deposited along the tube for two values of the N₂ gas flux.

As one could expect, too large a flux reduces drastically the amount of deposited iodine.

An easy procedure has been developed in order to collect the iodine from the glass pipe. The latter is washed with a 0.001 M solution of NaOH in an ultrasonic washer for 10 minutes and the resulting collection efficiency is larger than 90%.

7. A possible "on-line" separation of iodine

A consequence of the above results is the possibility to build an irradiation set-up with "on-line" separation capability. The apparatus is sketched in Fig. 8, and it follows to a large extent the ideas developed in the off-line dry distillation experiment. Measurements with this set-up will start soon.

We expect to be able to reduce the target handling and isotope separation times, with respect to the off-line procedure. In particular we should get a ratio of iodine delivered to iodine produced improved by a factor of at least 2 and possibly 3.

The overall efficiency of the process, defined in terms of the ratio of iodine produced to NaI¹²³ should be of the order of 70%, with negligible losses of the enriched tellurium.

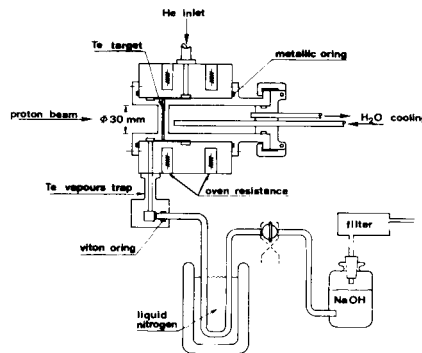


Fig. 8 Sketch of the irradiation set-up for "on-line" I¹²³ separation.

8. Conclusions

We believe that the dry distillation, as developed so far, offers a promising alternative to chemical techniques. This even in the case that the next step, namely the "on-line" method, does not work out as expected. In fact the iodine separation efficiency and tellurium losses are well comparable, while the handling times are perhaps in favour of the dry distillation method.

The one problem which remains to be fully understood and solved is that concerning the radiation damage on the tellurium crystal structure and, therefore, the limiting proton dose after which the diffusion process would not work any more. It is however anticipated that when the limiting dose is reached, chemical dissolution of the target, followed by drying and reconstruction of the target itself, will reestablish the original properties of the tellurium powder.

References

- 1) E. Acerbi, C. Birattari, M. Castiglioni, F. Resmini, G. Villa, Production of I¹²³ for medical purposes at the Milan AVF cyclotron. (to be published on Int. Journal of Applied Rad. and Isot.)
- 2) Private communication (prof. Giuntini - Clinical Physiology Lab. CNR - Pisa 1975)
- 3) Private communication (prof. Wolf - Brookhaven Natl. Lab. 1975)
- 4) M.L. Andersen, O.B. Nielsen and B. Schariff Nucl. Inst. and Meth. 38 (1965) 303
- 5) A. Latuszynski Nucl. Inst. and Meth. 123 (1975) 489