**Summary**

Recent developments in radiopharmaceutical chemistry allow the incorporation of short-lived, positron-emitting radionuclides into a variety of compounds which when used with a positron emission tomograph provide a means of monitoring physiological disorders by a standard technique. To effectively meet the increased "in-house" clinical demands while maintaining a production schedule, a tandem target was designed and has been installed for the simultaneous "on-line" preparation of oxygen-15 labelled compounds such as CO$_2$, H$_2$O$_{15}$, and nitrogen-13 labelled compounds such as $^{13}$NH$_3$, $^{13}$N$_2$O, and $^{13}$N$_2$. The processing time required for the synthesis of the nitrogen-13 products as compared to that of the essentially instantaneous formation of oxygen-15 labelled compounds has provided the necessary time delay for clinical utilization. The characteristics of this external tandem target system, as well as the automation for the dual processing will be presented.

**Introduction**

A cyclotron as an integral part of a medical center is an extremely versatile tool in the armamentarium for basic biomedical research and clinical applications. The CS-30 cyclotron (Cyclotron Corp.) at Mount Sinai Medical Center is extensively utilized for radionuclide production and is a unique component of the nuclear medicine department for the preparation of various single photon and positron-emitting radiopharmaceuticals. To effectively meet the schedule demands, the efficient and economical use of the accelerator and its staff must be realized. In order to accomplish this objective, efforts were made to develop highly efficient targets including a multitarget system. This paper presents work in progress for improvement in design and operation of the tandem target system for the simultaneous production of oxygen-15 and nitrogen-13 labelled compounds.

**Tandem Target**

An oxygen gas target for $^{16}$O($p$,pn)$^{15}$O reaction as the front target and a water target for $^{16}$O($p$,a)$^{12}$N reaction as the rear target are ideal for a tandem target. The threshold energy of the latter reaction is much lower than that of the former (Table 1). Also, the energy reduction of the proton beam by the front target produces the minimum effect on the rear target productivity. Moreover, the difference in time needed to prepare the nitrogen-13 compound, such as $^{13}$NH$_3$, coupled with an essentially instantaneous preparation of oxygen-15 labelled product, enables one person to process both products.

**Proton Beam Spreading by Aluminum Window**

Knowledge of beam behavior after passage through target windows is necessary in achieving an efficient gas target. A vertically sectioned cylindrical target window barely affects the beam, 0.01 was used for $\delta$ in target design process because the directions of the incoming protons are not always parallel to the target axis and contribute to the beam spreading.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$^{16}$O($p$,pn)$^{15}$O</th>
<th>$^{16}$O($p$,a)$^{12}$N</th>
</tr>
</thead>
<tbody>
<tr>
<td>E$_{\text{threshold}}$ (MeV)</td>
<td>16.6</td>
<td>5.5</td>
</tr>
<tr>
<td>E$_{\text{peak}}$ (MeV)</td>
<td>50</td>
<td>23</td>
</tr>
<tr>
<td>E$_{\text{half}}$ (MeV)</td>
<td>26</td>
<td>16 ~ 30</td>
</tr>
</tbody>
</table>

Table 1. Nuclear Reaction used in Tandem Target

The "spreading factor" ($\delta$) was obtained by subtracting 0.015 from $\delta$. The differences due to various gas pressures up to 50 psi were minor and determined to be within the errors of the experiment.

A three mil aluminum foil was chosen for the oxygen gas target window. Although this thickness of window barely affects the beam, $\delta$ was estimated to be due to the size of the windows. The collimator and the "real spreading factor" ($\delta$) is lower than one half of the peak value.

![Figure 1. Sectioned Target](image_url)
The normal distribution function, \( \frac{1}{2\pi \sigma^2} \exp \left( -\frac{R^2}{2\sigma^2} \right) \), where \( R \) is a radial distance from the center of the beam, is used to describe the beam profile produced after a 26.5 MeV proton beam passes through a 0.25 inch diameter aluminum window where \( \omega \) is the scattering angle.

The optimum shape of the target is sensitive to \( \omega \) and to determine the most efficient shape, an accurate measurement of the incoming beam profile is necessary. In practice, however, the beam width is affected by many factors such as conditions of the deflector and ion source, etc., and the runs are not always made under the ideal tuning of the beam. Also, the angle of the incident beam differs slightly from run to run. Therefore, although not the ideal dimension, a slightly larger radius of 0.5 inch was chosen for a front radius of the gas target to accommodate various beam conditions.

The targeting effectiveness, \( Q \), defined as an integration of the beam density over the entire target volume, was calculated with varying front radius \( R_1 \) and rear radius \( R_2 \) of the target (Figure 3). The normal distribution function, \( \frac{1}{2\pi \sigma^2} \exp \left( -\frac{R^2}{2\sigma^2} \right) \), where \( R \) is a radial distance from the center of the beam and \( \omega \) equal to 1, was used as the incoming beam profile, therefore, the dimensions are unitless, i.e., being a multiple of the incoming beam width \( \omega \).

The chemical syntheses of the various oxygen-15 labelled products and nitrogen-13 labelled compounds have previously been described. Following the irradiation of this target, both products are released to the chemical processing cell. The oxygen-15 labelled oxygen diluted with a nitrogen purge gas, is combusted "on-line" to water and trapped in 1.0 ml of saline within a time period of 100 seconds post end of bombardment. The nitrogen-13 species contained in the water target is forced by a stream of helium into a reaction vessel containing 1.0 gram of sodium hydroxide pellets and 60 milligrams of Devarda's alloy (J.T. Baker Chemical Co.). Distillation of the labelled ammonia is immediately started and collected in 1.5 ml of saline. Solenoid valves are used on the target and the synthesis lines.
Discussion

A well focused beam is required to improve productivity of a gas target (Figure 3). Since the installation of this tandem target, the beam focusing mechanism has been improved and this target is being further improved. As the incoming beam width decreases, the front radius of the target should decrease accordingly. For a fixed volume target, a higher $R_2/R_1$ ratio is required.

The results of our experimentation, although still in progress, appear to be consistent with the goal of effectively meeting the increasing demands for short-lived radiopharmaceutical agents while optimizing the radionuclide production and synthetic incorporation. The principal detriment of short-lived radionuclides is the time restriction imposed in which chemical manipulations can be performed. This time loss may be compensated by increasing the production rate and recovery of the radionuclide from the target chamber. It is anticipated that with prudent internal design of the target chamber, the foregoing goals will be achieved. A tandem target system extends the efficient use of time available to the staff and accelerator schedule.

Acknowledgement

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References