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The design and performance of a portable handheld $^{11}CO_2$ delivery system

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HIGHLIGHTS

- A portable handheld $[^{11}C]CO_2$ delivery system suitable for 3.7 GBq was constructed.
- 90 mg of molecular sieves trap $>99\%$ of $[^{11}C]CO_2$ at room temperature at 1 L/min.
- $[^{11}C]CO_2$ is released (90 s; 82% efficient) using a 180 W tube furnace built into the pig.

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ABSTRACT

We constructed a hand-held device to efficiently trap $[^{11}C]CO_2$ from the cyclotron target, safely transport up to 3.7 GBq (100 mCi) doses to remote sites and release it without the need for a liquid cryogen. The system consists of a 180 W furnace and a miniature molecular sieve trap (80–100 mg; 80–100 mesh 13 ×) placed inside a lead pig weighing 11.1 kg. The overall $[^{11}C]CO_2$ delivery efficiency of the device is ~82% (> 99% trapping efficiency). Radiation dose rates measured at 30 cm from the surface of the pig are < 43.5 μSv/h (5 mR/h) up to 2.59 GBq (70 mCi).

1. Introduction

Carbon-11 labeled carbon dioxide ($[^{11}C]CO_2$) is conveniently produced by the $^{14}N(p,\alpha)^{11}C$ reaction on nitrogen gas targets using a charged particle accelerator such as a cyclotron (Christman et al., 1975). It is an important molecule used both by radiochemists as a precursor for synthesizing radiolabeled compounds of biological significance (Rotstein et al., 2013), and by plant biologists as a radiotracer for studying the transport and allocation of ^{11}C-photoassimilate from recently fixed carbon in plants (Troughton and Moorby, 1974; Jahnke et al., 1981; Minchin and Thorpe, 2003; Ferrieri et al., 2005; Babst et al., 2005; Kiser et al., 2008; Dirks et al., 2012). Because of the short half-life of carbon-11 ($t^{½}=20.4$ min), the availability of $[^{11}C]CO_2$ to the scientific community is limited by the need for laboratories to be located at or near the accelerator facilities needed to produce carbon-11 (Schlyer, 2003; Qaim 2011). Even when laboratories are nearby radionuclide production facilities, the transport of $[^{11}C]CO_2$ across campus appears not to be common, presumably in part because of the technical constraints that arise when considering the design of a safe and convenient device for moving doses 0.37–37 GBq (10–100 mCi) of radioactivity needed by researchers. A search of the literature finds few descriptions of such devices that could expand the application of $[^{11}C]CO_2$ in the plant sciences beyond the laboratory into the field, and bring $[^{11}C]CO_2$ into the laboratories of organic chemists who may have only limited access to shielded hot cells dedicated to large-scale production.

The most recent description of a transportation device for $[^{11}C]CO_2$ is more than 25 years old. In this work, Mckinney et al. (1989)

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presented details of the design and performance of a movable (wheeled cart) system capable of transporting up to 37 GBq (1 Ci) of activity. This device used liquid nitrogen to trap $[^{11}C]CO_2$ and incorporated a redundant valve system that minimized the chance that activity would leak if the cryogen evaporated during transport. The system was used routinely to ferry activity from an accelerator facility to a plant growth laboratory where administration of tracer was performed. This early work served as an excellent example of the utility and importance of transportation devices for $[^{11}C]CO_2$. The design of a smaller, more portable system for trapping and transporting has also been described (Clark, 1975), although no performance data or results using this device has been reported. In both previously reported systems, transported activity becomes volatile after the liquid cryogen in device evaporates. Although this design feature simplifies the release of radioactivity at the site of use, it does increase the chance that radioactivity could leak during transport.

The goal of this work was to design a simple device that could transport up to 3.7 GBq (100 mCi) of $[^{11}C]CO_2$ in a hand-held device without the need for liquid nitrogen. This device was developed to support plant imaging experiments at Brookhaven's clinical Positron Emission Tomography (PET) facility located ~100 m from the cyclotron facility. The transport path includes a series of steps and stairs, and because of that a handheld system was preferred.

2. Materials and methods

2.1. Lead pig design

A cylindrical lead pig with handle and dimensions of 177 mm height × 86.8 mm outside diameter × 36 mm inside diameter was modified as shown in Fig. 1 to accommodate a screw top lid and a bracket for electrical and plumbing connections. The threaded plastic collar and screw-top lid from a Biodex (Shirley, NY, USA) PET Vial Pig (Part # 001-706) were adapted for use with the cylindrical pig. The inner dimensions of the Biodex pig did not provide sufficient space to be used directly. The threaded plastic shroud was removed from the Biodex pig and fastened to the base of the lead pig using 6 × 6–32 stainless steel machine screws. Previously the steel clad (3.175 mm thick) of the lead pig was drilled and tapped to accommodate the screws. In this manner the Biodex screw-top lid could be used with the larger lead pig. Two small notches were made in the top of the pig leading to a penetration in the plastic collar that provided access for tubing and electrical wiring to connectors mounted on a custom bracket (see Fig. 1). A 1.5875 mm thick annulus of lead vinyl was used as a spacer between the bottom of the lid and the top of the pig to provide additional clearance for tubing and electrical wiring. A small "slice" of the annulus corresponding to the location of the notches in the pig for the electrical cabling and plumbing was removed. During assembly the screw-top lid was tightened just until the lead vinyl spacer was contacted.

An aluminum bracket was machined from 37 mm angle bracket stock and attached to the existing pig handle using two bolts (see Fig. 1). The bracket provided space for mounting a thermocouple bulkhead connector (Omega, Stamford, CT; Part # RMJ-K-R) and an A/C power connector (www.digikey.com, CCM1402-ND) on the side, and 2 × Swagelok (Solon, OH, USA) 3.175 mm quick disconnect unions (stem: SS-QM2-S-200, bulkhead body: SS-QM2-B1-200) including 2 × Swagelok 1.5875 mm to 3.175 mm reducers (SS-100-R-2) mounted on the top. The total weight of the pig and bracket assembly is 11.1 kg.

2.2. Molecular sieve trap and furnace construction

Molecular sieve (90–120 mg; Aldrich 80/100 mesh 13 ×) was packed in a 50 mm length of 3.175 mm O.D. copper tubing that was bent in half to form a "U" shaped trap (see Fig. 2). Quartz wool (~10 mm) was packed on top of the molecular sieve. A 3.175 mm to 1.5875 mm stainless steel reducing union (Swagelok part # SS-200-6-1) was used on each side of the "U" trap to join the end of the trap with 1.5875 mm stainless steel tubing that connected to the bracket-mounted quick disconnect.

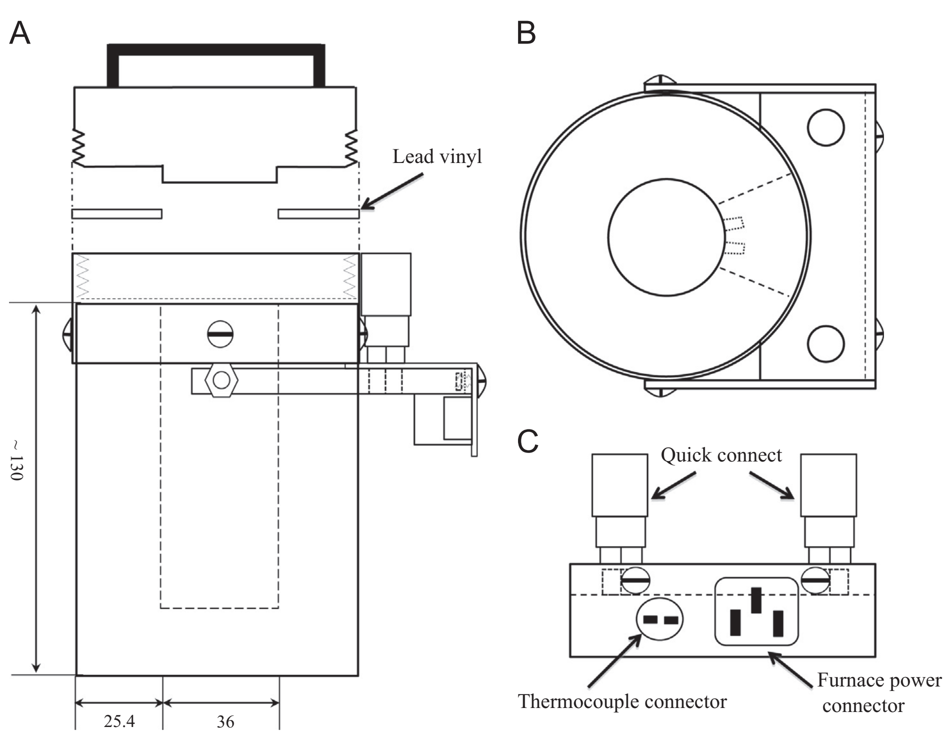

Fig. 1. Drawings of side (A) and top (B) views of lead pig assembly. (C) Front view of bracket assembly only. Dimensions are reported in mm.