Target Systems for the RDS-111 Cyclotron

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Introduction

In an effort to reduce the cost of operating a PET center, a new line of cost-effective, self-shielded, 11 MeV, proton-only accelerators has been developed at CTI. The RDS-111 is a single coil, closed yoke, deep valley accelerator capable of producing 40 μA of target current simultaneously on each of two beamlines. The target system for the RDS-111 consists of an 8 position target changer, modular target bodies, and target support equipment. The system maintains the same production yields of the RDS-112 accelerator targets, but with smaller target volumes and double the beam intensity of the earlier machine due to a reduction in beam diameter from 10 mm to 7 mm. This results in less enriched target material consumed and higher specific activity achieved, while maintaining high reliability. Flexibility of operation and ease of use are enhanced.

Target Changer System

The target changer is depicted in Figure 1. It consists of a barrel that provides 8 ports for accelerator targets, a hub assembly that distributes water and helium cooling to the targets, a chain drive mechanism that provides the remote positioning required, a ring collimator that provides beam shaping, a modular target design that allows any target to be installed in any port, and an umbilical system that provides for the quick installation and removal of any target. The barrel is the rotating portion, while the hub, collimator and motor assemblies are fixed to the iron. In addition to housing the targets, the barrel (15 cm o.d. x 10 cm l) acts as a first layer of high-Z material for shielding purposes. This is not only useful during bombardment; dose to service personnel is significantly reduced when working around activated foils inside the barrel.

The barrel rotates on the hub assembly, which consists of a large brass flange with a stainless steel shaft on axis. The hub provides connect points for single circuits of target body cooling water and window cooling helium. Water is brought to rotating o-ring seals on the axis of the target changer, and from there cools every target body externally and in series. The helium goes through the collimator assembly to the vacuum window, and across a sliding face seal o-ring to the target in the bombardment position. Since both water and helium flow are interlocked on the return path, installation of a target without proper cooling is prevented. By intimate contact with the barrel, target current monitoring is automatic on installation of a target body. The collimator is a graphite ring providing a 7 mm diameter beam. Included in the collimator housing is the vacuum window assembly. The vacuum window assembly can be retracted through any target port for servicing. Because there is a single collimator/vacuum window assembly, the vacuum is not affected in any way by target service, or rotation of targets.

Modular targets

A typical target is depicted in Figure 2. Similar features to all targets include external cooling traces, a target window flange, and umbilical connections. The barrel provides cooling water to the outside of the target body. The target has a large screw thread cut on the outside to force the cooling water to flow at high velocity over a large surface area. Every target requires a target window flange. This flange holds the target window in place while installing or removing targets, and is attached to the target "bayonet style". The target is held in the barrel, and the product connections are made by means of an umbilical assembly. This umbilical is installed or removed by means of a single captured screw. When the umbilical is tightened down all high pressure seals are guaranteed, including the target window and the product connections.

The target changer is mounted on the cyclotron without the capability for adjustment in the field. Instead, an alignment fixture is used in the factory to establish beam position exiting the machine. The alignment procedure can be done remotely (outside of the shield) and dynamically (with the beam running). Once the proper position is determined, the iron surface where the target changer is to be mounted is drilled at specific points and to specific depths. Then

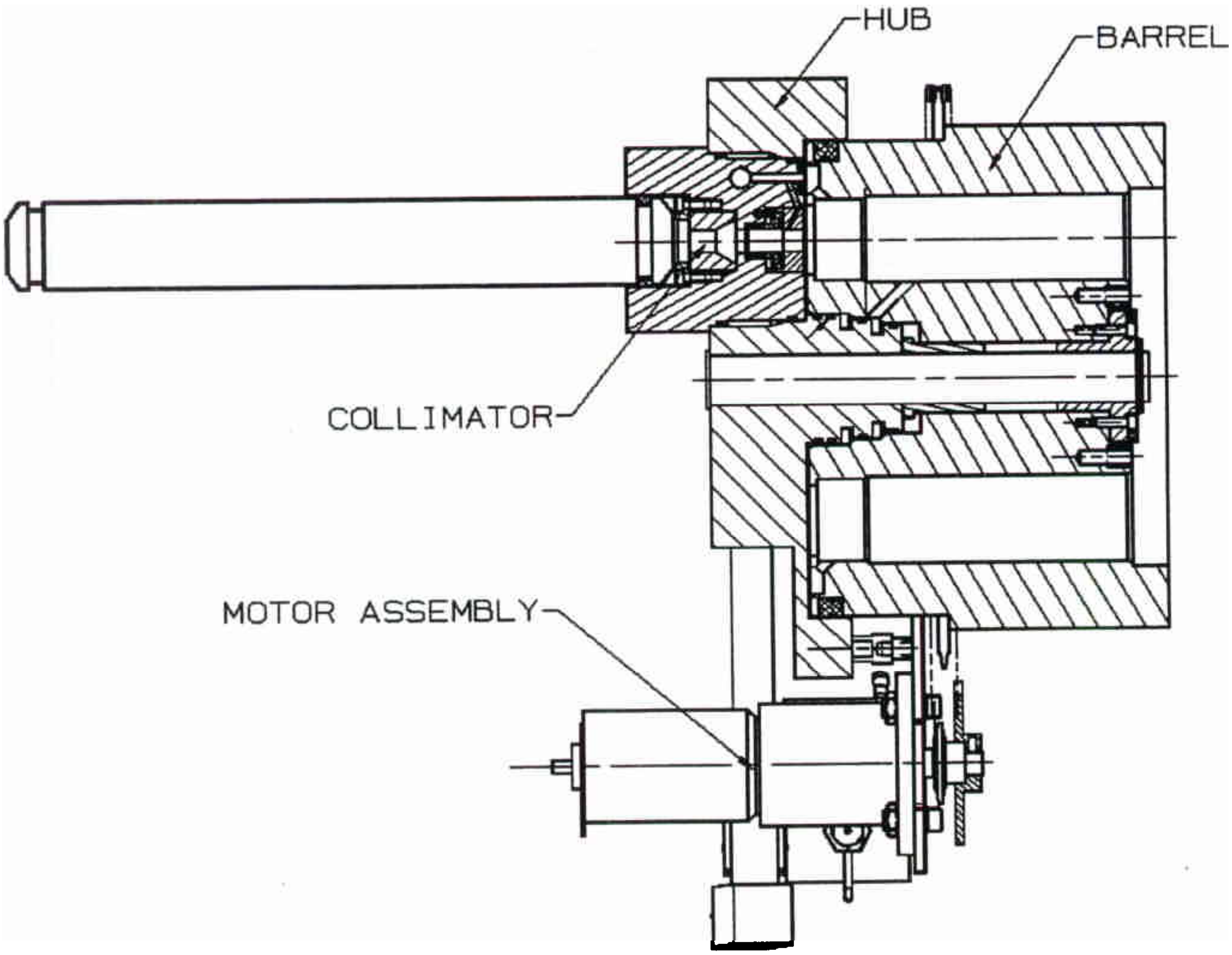

Figure 1. Target changer cross section

the target changer can be mounted on pins of uniform dimension. The adjustment is not lost if the target changer is removed, or even if a different target changer is installed in the same position.

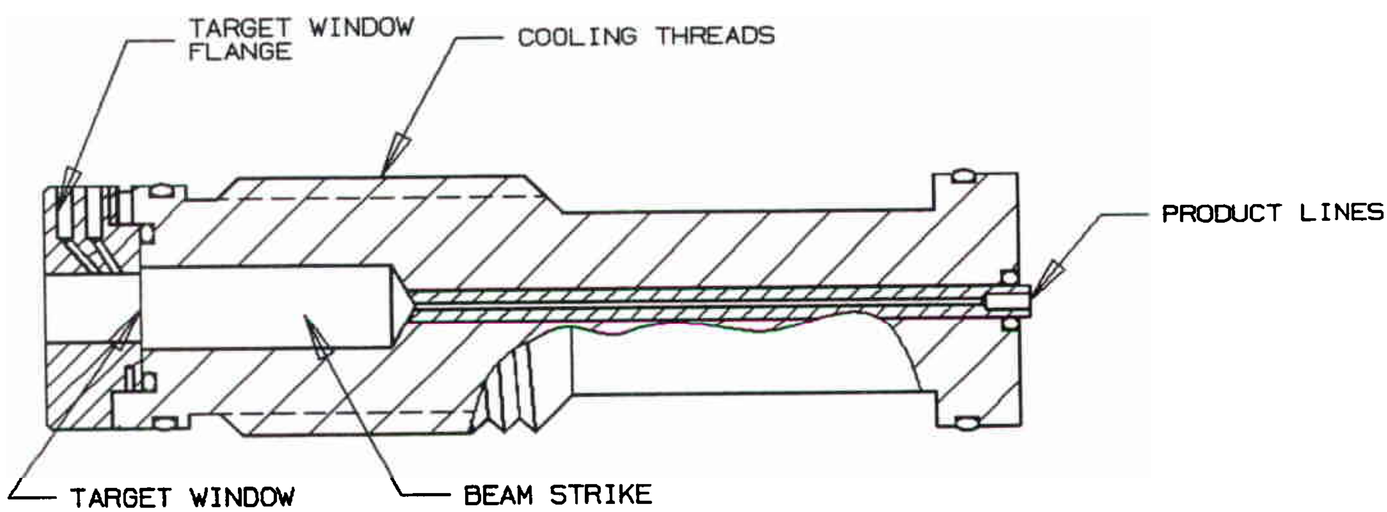

Figure 2. Typical target envelope

[^{11}C]CO_2 Target System

Production of [^{11}C]CO_2 is accomplished via the ^{14}N(p,α)^{11}C reaction. The target body material is 6061-T6 aluminum, and the target window is 25 μm Havar. The beam strike dimensions are 7.0 mm diameter entrance, 14.4 mm diameter back, and 70 mm deep, giving a beam strike volume of about 6.5 cc. The schematic for the target system is shown in Figure 3. The target is loaded to 270 psig with N_2 + 1% O_2. Typical beam-on pressures range from 650 to 800 psig. These high pressures are easily sustainable due to the reduced target window area. Saturation yield ranges from 45 to 60 mCi/μA, which is reasonable for this energy (Wieland 1989, Bida 1980).

The amount of carrier CO_2 present in the target after bombardment was measured by gas chromatography (GC). Combined with the amount of [^{11}C]CO_2 produced in the irradiation, the specific activity (in units of Ci/μmol) was calculated. Depending on the beam current, beam time and the previous use of the target, the specific activity ranged from <1 to 94 Ci/μmol. The specific activity is low immediately following a target rebuild. Two to three bombardments are necessary to reach specific activities >10 Ci/μmol. For five consecutive bombardments within a period of several hours, the specific activity remained stable at 47 to 66 Ci/μmol (average = 55.8, s.d. = 6.7 Ci/μmol). This high specific activity is expected due to reduction in the beam strike volume and surface area from prior targets (Wieland 1989, Ferrieri 1993). The saturation yield and specific activity data are summarized in Table 1.

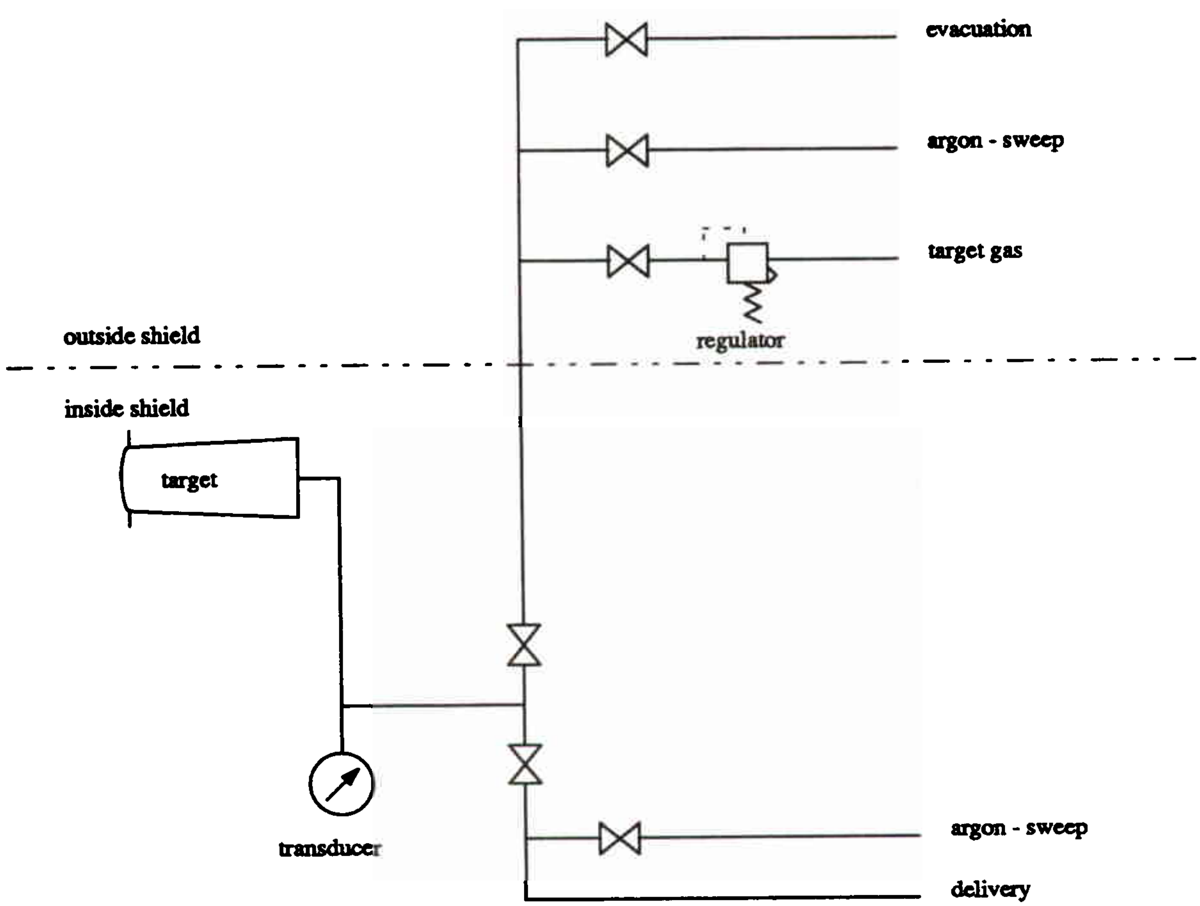

Figure 3. Gas target system schematic

Date	Target Pressure	Beam	Carrier CO_2	Total $^{11}CO_2$ yield	$^{11}CO_2$ SA	Comments
	(psig)	(μAxmin)	μmol	(mCi/μA)	(Ci/μmol)	
3/4/95	278	10x10	5.0	47.8		1st run in several months
3/4/95		10x5	0.0258	57.5	3.6	
3/7/95	242	20x8	0.297	57.4	0.8	1st run after target rebuild
3/7/95	286	30x5	0.0375	60.7	6.3	
3/7/95	260	30x40	0.0738	48.7	12.2	
3/7/95	268	30x40	0.0590	48.0	15.5	
3/7/95	262	30x40	0.0476	45.9	18.2	
3/7/95	264	30x40	0.0443	42.2	18.6	
3/8/95	280	~23/40	0.0142	49.0	50.3	broadened GC peak
3/9/95	280	24/40	0.0225	48.2	28.6	new injection technique, 1st bombardment of day
3/9/95	268	24/40	0.0123	47.6	57.8	
3/10/95	288	27/40	0.439	56.9	2.0	
3/13/95	262	18/40	0.0213	55.8	28.3	Kept target under pressure over weekend
3/13/95	262	20/40	0.00823	42.2	56.8	
3/13/95	262	25/40	0.0110	47.9	65.8	Beforehand, had beamed empty target for 18 min
3/13/95	262	28-29/40	0.0163	50.7	53.9	
3/13/95	262	28/60	0.0173	49.4	55.6	
3/13/95	262	30/20	0.0134	57.7	47.1	
3/14/95	260	29/40	0.190	54.6	5.0	w/ soda lime trap in He and target gas inlet
3/14/95	260	26/35	0.128	45.8	5.6	
3/14/95	262	28/40	0.0402	50.0	17.5	1st run after removing soda lime on inlet
3/14/95	260	26/40	0.00805	51.4	94.4	
3/14/95	258	26/40	0.0433	55.0	17.1	
3/14/95	260	22/40	0.0278	52.1	21.9	

*Sum of two GC peaks

Table 1. Summary of [^{11}C]CO_2 Specific Activity Determinations

[^{15}O]O_2 Target System

Production of [^{15}O]O_2 is accomplished via the ^{15}N(p,n)^{15}O reaction. The target body and window materials, beam strike dimensions, and loading and operating pressures of the ^{15}O target system are similar to the ^{11}C gas target. A typical series of runs is depicted in Table 2. Yields exceed published thick target yield data (Sajjad 1984), but are in keeping with specifications for previous CTI gas targets (Wieland 1989). The target system has been used in conjunction with a prototype system for the automated synthesis of ^{15}O H_2O. The module uses a palladium catalyst furnace and delivers the activity in a 2 to 20 ml volume of water or other fluid. A protocol has been developed to operate the production and synthesis for minimum expenditure of enriched material. The target is loaded to 270 psig, bombarded for 10 minutes, and the pressure is bled down to 230 psig. Depending on beam current, this produces 20-30 mCi of [^{15}O]H_2O. The target is then reloaded to 270 psig for the next bombardment. Because of the 6.5 cc target volume, this results in a consumption of approximately 20 std. cc of enriched gas for each aliquot of [^{15}O]H_2O. Several typical runs of this system are presented in Table 3.

Date	Beam current	Bombard time	Activity delivered; 2 min. after EOB	EOB Activity	Saturation Yield
	(μA)	(min.)	(Ci)	(Ci)	(mCi/μA)
9/12/94	40	12	1.370	2.679	68.2
9/12/94	40	10	1.358	2.656	68.3
9/12/94	40	15	1.501*	2.935*	73.9*

* Note: ran 50μA briefly during first minute of run

Table 2. [^{15}O] O_2 target performance

Date	Beam Current	Number of aliquots of $[^{15}O]H_2O$	Beam-on-Target Time	Delivered Activity @ EOS
	(µA)		(Hours)	(Avg mCi ± s.d.)
9/20/95	20	36	7.5	26.1 ± 3.5
9/21/95	21	38	9	29.2 ± 2.8
9/22/95	20	42	9	29.3 ± 1.0
9/25/95	20	19	4	25.6 ± 5.7
9/26/95	20	29	6	32.2 ± 2.0
9/27/95	23	42	9	31.4 ± 2.5
9/28/95	23	42	9	28.5 ± 1.0
9/29/95	24	27	5.5	30.3 ± 1.9

Table 3. $[^{15}O]H_2O$ system performance

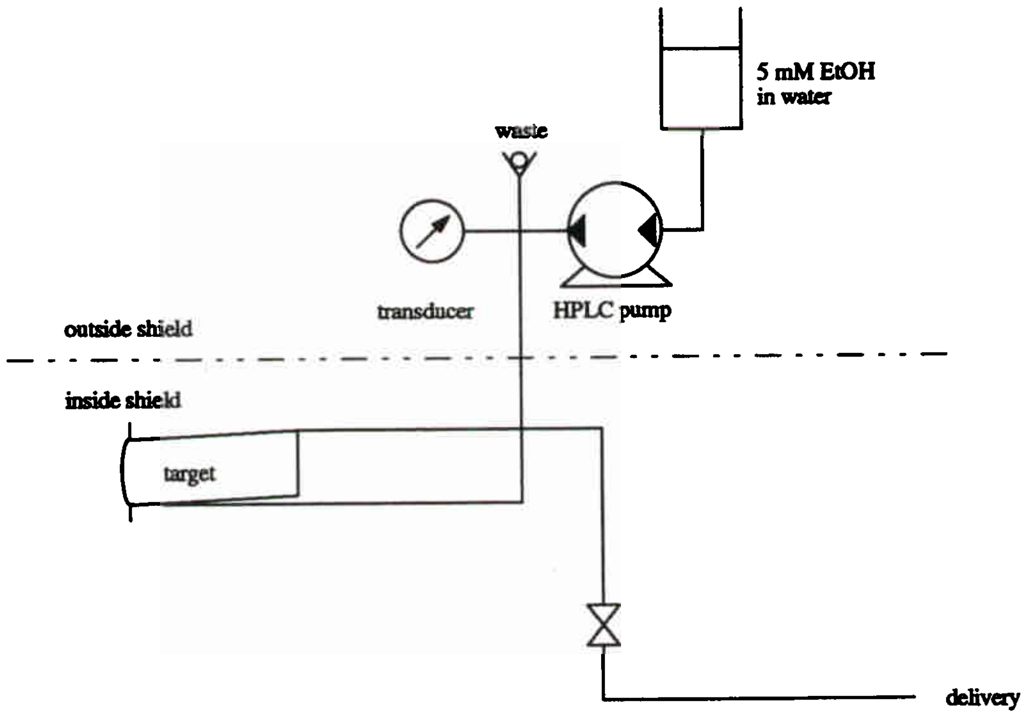

Figure 4. $[^{13}N]$Ammonium ion target system schematic

Date	Beam current	Bombard time	Decay time	Activity	Saturation yield
	(µA)	(min)	(min)	(mCi)	(mCi/µA)
7/28/92	20	20	4	68.2	6.00
7/28/92	20	20	5	60.2	5.68
7/28/92	30	10	5	76.6	7.22
7/29/92	10	10	5	21.8	6.16
7/30/92	10	10	5	25.6	7.24
7/30/92	10	10	5	25.1	7.09
7/30/92	20	10	5	41.3	5.84
7/30/92	30	10	5	55.9	5.27
8/4/92	30	10	5	59.1	5.57

Table 4. $[^{13}N]$Ammonium ion target system performance

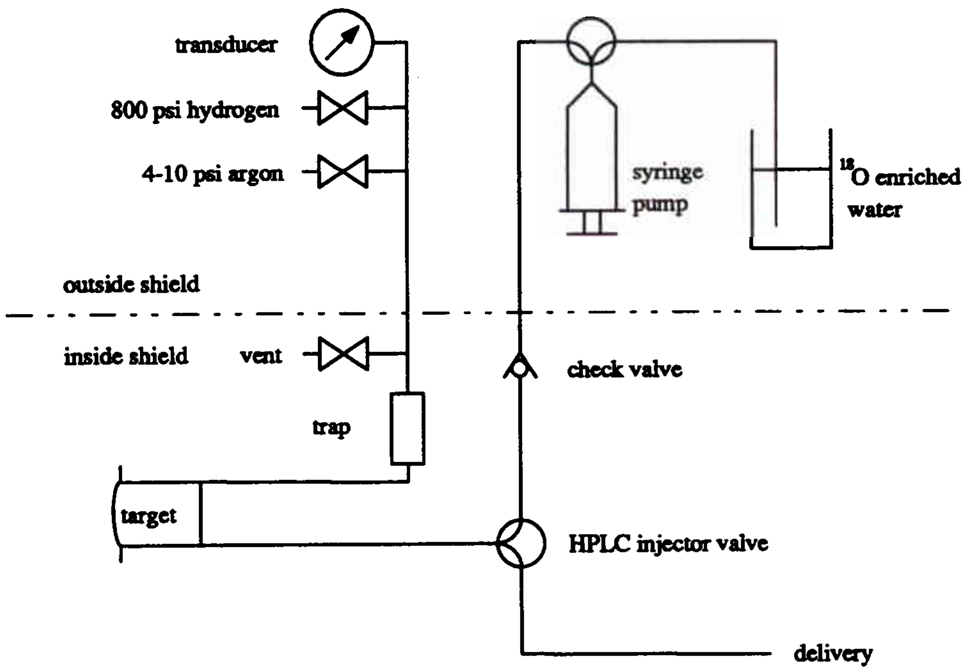

Figure 5. [^{18}F]Fluoride ion target system schematic

[^{13}N]Ammonium Ion Target System

Production of [^{13}N]ammonium ion is accomplished via the $^{16}O(p,\alpha)^{13}N$ reaction, utilizing direct in-target production of ammonia by addition of dilute ethanol in water (Wieland, 1991). The target body is 6061-T6 aluminum, and the target window is 25 µm titanium. The beam strike volume is approximately 1 ml. The target is operated at 400 psig. Target pressurization and target flow through, loading, and unloading are provided by a HPLC pump. A schematic of the target system is presented in Figure 4. Typical yields are presented in Table 4.

[^{18}F]Fluoride Ion Target System

Production of [^{18}F]fluoride ion is accomplished via the $^{18}O(p,n)^{18}F$ reaction. The target is similar to other published high pressure fluoride target designs (Wieland 1991, Roberts 1995). The target body is silver, and the target window is 25 µm havar. The beam strike volume is 8 mm diameter by 8 mm deep, without any reflux area. The target is operated with 800 psig hydrogen or argon overpressure. The target is loaded with a miniature, microprocessor controlled syringe pump (Cavro XP3000), through a high pressure check valve and HPLC injection valve. After irradiation, the injection valve switches to the deliver position. A schematic of the target system is presented in Figure 5. Typical yields for this target system are presented in Table 5.

Date	Beam current (µA)	Bombard time (min)	Decay time (min)	Activity (mCi)	Saturation yield (mCi/µA)
8/9/95	20	60	7	580	96.06
8/11/95	20	26	9	240	83.84
8/11/95	20	17	15	186	100.39
8/15/95	20	60	9	515	86.38
8/16/95	20	30	12	266	83.09
9/14/95	30	60	7	826	91.21
9/15/95	30	60	9	899	100.53
9/15/95	34	24	4	464	99.47
9/22/95	25	60	18	600	85.22
9/28/95	25	60	15	764	106.48

Table 5. [^{18}F]Fluoride ion target system performance

Conclusion

The work presented here is intended to further reduce the initial cost as well as the cost of operation of a PET cyclotron, while simplifying the use and servicing of such a machine. Design refinements and simplifications of this nature are required in all aspects of radiopharmaceutical manufacturing equipment design if use of this modality is to become widespread.

References

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