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PUSHING BEAM CURRENTS TO THE LIMIT

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Abstract

One of the cyclotron systems running at the Nordion Int. radioisotope production facility at TRIUMF is the EBCO TR30. This cyclotron produces up to 250μA on each of two beamlines simultaneously. Two solid (for the production of ^{201}Tl, ^{57}Co, ^{67}Ga and ^{111}In) and a gaseous (for producing ^{123}I) target station are in routine operation on this facility. Since future projections indicate a greater demand for reliable radioisotope production there is a program underway to increase the output of the facility to double the present level. One way that this is being achieved is through a careful thermal analysis of the the solid target system to maximize its performance. In conjunction with this we have developed and tested a 500μA upgrade of our solid target system. Gas targets are being investigated for possible ways of increasing the efficiency of production via rotating/sweeping beams which allow higher beam currents. Finally, the TR30 cyclotron is being upgraded to deliver 50-100% more beam on target. By pushing both the cyclotron and target technology to the limit we will be able to produce significantly higher levels of radioisotopes than many other comparable facilities [1].

TR30 ISOTOPE PRODUCTION FACILITY

Isotope production at TRIUMF proceeds on all four cyclotron systems (520 MeV, CP42, TR30 and TR13) on site. The EBCO TR30 cyclotron, commissioned in July 1990, presently provides the most reliable high intensity beam for isotope production [2]. The TR30 cyclotron is a dual beam, variable energy (15-30 MeV) H^- machine that routinely provides over 200 μA at 29 MeV on each of two (solid) targets simultaneously. In addition to these two solid target systems an I-123 production (from Xe-124 gas) target is also located on the beamline systems of the TR30.

At present the TR30 isotope production facility runs near its maximum capacity of 450-500 μA on target at 30 MeV. Future business plans call for increased beam production and the desire of longer cool down periods for maintenance. To accommodate these requirements it is essential to increase the beam current in the TR30 and also increase the capacity of the targets to accept these higher power levels. A significant development program is underway to achieve our goals over the next 1.5 years. We will now describe some of the work we have undertaken towards those goals.

SOLID TARGET SYSTEMS

The solid target system [3,4] is based on a water-cooled silver face onto which target materials are electroplated and irradiated in vacuum. By placing the target at a 7° angle to the beamline the incident beam is spread out over the silver face to distribute the heat load. The wings of the double-gaussian beam are removed before the beam strikes the target by water-cooled graphite collimators placed immediately in front of the target face. Therefore, a well-defined rectangular beam (2.5 cm x 7.5 cm) strikes the target. Since the target materials are often enriched (and expensive!) it is normal to only plate this strike region of the silver face (to minimize losses during processing etc.).

This type of solid target system has been in use at TRIUMF on the TCC CP42 cyclotron for a decade. Except for minor refinements the system has essentially remained unchanged and has proven to be effective and reliable for radioisotope production from plated metals. Since the CP42 could only produce around 200 μA (i.e. the overall system was "cyclotron limited") there was little incentive to improve or increase the capacity of the targetry. However, the TR30 cyclotron can achieve up to 500 μA (usually split between two beamlines/targets). In addition, plans are under way (see below) to double this capacity. To avoid the situation of being "target limited" in our isotope production it became imperative that we increase the capacity of our targetry at least by a factor of two.

The most straightforward method of increasing the target's ability to accept more beam power is to increase the surface area, increase the cooling water flow rate, and spread the beam out more. Because the targets are transferred from the hot cells to the target stations in a carrier shuttle inside a pneumatic tube there are some size/geometry considerations and limitations. By optimizing the target design [5,6] we were able to produce a new version (see Figure 1) where the strike area is now (4 cm x 10 cm) about twice that presently used. There were very few changes required to our existing system (basically, only minor modifications to the mechanism that manipulates the target to/from the rabbit into the irradiation position were required). Of course the water flow must be proportionally increased. In addition, we will make some further changes in the choice of materials and minor construction modifications in the future [6,7].

Recent tests with our original targetry on the TR30 showed it could perform at routine currents of up to 250 μA at 30 MeV. Calculations using a thermal modeling finite element analysis computer program [8,9] for the new target design implied that double this current should be possible. In order to test this we set up a temporary "ultra-high" current target station on a spare TR30 beamline. Using some scintillating material pasted onto the surface of the target we were able to produce a defocused beam that was aligned on the outlined strike area. A special target which contained an imbedded K-type TC along with five plated Ni-Ag TCs on the silver face [10] was then tested with beam currents (29 MeV) up to 450 μA. With a water flow of ~40 L/m through the target we monitored the temperature of the silver face during bombardment. Although not all TCs survived the ordeal we were able to extract sufficient information to conclude our confidence in the system at its design goal of 500 μA on target. Figure 2 shows the surface temperature measurements and indicates temperatures at maximum capacity (500 μA) which are below 140° – our present operating conditions on standard targets.

Subsequent to a few further tests we will proceed with the assembly of a complete 500 μA target station and incorporate it into the TR30 system during the next year. This will allow us to run either single beam at currents up to 500 μA or a total of 750 μA when running dual beam. For the latter case, the TR30 upgrade (see below) will be necessary. Subsequent to the TR30 upgrade being proven successful we will consider a second ultra-high current target station in order to maximize the overall TR30 system's capacity and flexibility at 1 mA (30 MeV) on-target.

GAS TARGET SYSTEMS

The gas target system being used on the TR30 is based on Xe-124 for the production of I-123. This target contains the Xe gas within a cylindrical volume and has a double He-cooled havar entrance window. The present current limitation (30 MeV) of this target is 150 μA and it is routinely run at 125 μA for Nordion Int. in their commercial I-123 production program.

We undertook an examination of the performance of this (and similar PET) gas target under typical bombardment conditions by first making an analysis of the beam loss resulting from multiple scattering in the target. By varying such parameters as gas density and beam focus we were able to make some general conclusions with regard to the efficiency of the system under typical irradiation conditions. Typically, we found that the geometry of the target under normal operating conditions resulted in a make-rate loss of about 44% due to lost beam (as calculated from a standard production yield curve). By changing from a parallel beam to one that was slightly focussed we were able to reduce this to 37%. However, by far the largest effect was seen when the target length was halved and the pressure of the Xe gas was doubled. In this case our theoretical model predicted a loss of only 18%.

Of course, our model could not simulate one of the biggest effects we are aware of notably "hole punching" or depletion of gas in the path of the beam due to heating. To perform this analysis would require a complex finite element analysis modeling program. However, it should be possible to make empirical measurements of the effect if it can be removed or significantly diminished. This might be achieved either by an internal stirring system (fan) or, alternatively, by rapidly moving or oscillating the beam over the target window to avoid gas depletion at a particular location. The latter method is particularly advantageous since it also diminishes the effects of beam hot-spots and also reduces the maximum foil temperature. However, for this to be effective the appropriate beam parameters must be used e.g. the frequency of oscillation must be several hundred Hz in order to minimize potential thermal cycling effects on the long-term mechanical strength of the foil [11].

In a number of calculations we varied the beam distribution on the face of the gas target in terms of the sweep radius and width of the beam and assumed that the sweep frequency was rapid enough such that the temperature distributions on the window could be well represented by time-averaged values. We found that for a given beam current on target an optimum beam size and sweep radius exists (for a particular target geometry) that results in a minimum peak foil temperature. Figure 3 highlights these conditions for our particular targetry. If peak foil temperature is the limit we have on our targetry then this method of distributing the heat load would also enable us to make a corresponding increase in the beam current.

CYCLOTRON UPGRADE

The TR30 routinely produces over 400 μA on target and can achieve a maximum of 500 μA [2]. With suitable upgrades and changes we intend to double this capacity by the end of 1994. The major changes are :

- Upgrading the RF system from 40 KW to 70 kW.
- Upgrading the ion source and injection line. The present ion source delivers 5 mA DC. Some recent development work is indicating that this can be increased to 7 mA with few modifications. Development work is also underway on a small (1 MeV) "central region model" cyclotron to improve the injection line by reconfiguring elements and adding a buncher to improve on injection efficiency.
- Other services (power, cooling water etc.) must be upgraded. In addition solid target chemistry must accommodate the larger targets (discussed above) that will be prepared and processed. Beamline optics require minor changes (one interesting option [12] that has been suggested is incorporating octopoles to flatten the beam i.e. reduce the peak power density at the center of the target face).

The beam tests already performed at 450 μA on a single beamline prove the ability of the system (extraction foils, beamline and target components) to accept and transmit high power beams into the target areas.

CONCLUSIONS

Our tests on the high current targetry together with our ongoing research into the improvements required on the TR30 show that much higher levels of radioisotope production are realistically achievable on this system. By 1995 we will have reached another interesting barrier where the existing cyclotron and targetry will seemingly have both reached their maximum capacities. In that case we will indeed have pushed beam currents to the limit – or can we go even further?

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FIGURE CAPTIONS

1. a) and b) The new '500 μA' target and target station.
2. Surface and embedded TC measurements for the '500 μA' target.
3. Power density calculations for various beam sweeping parameters.

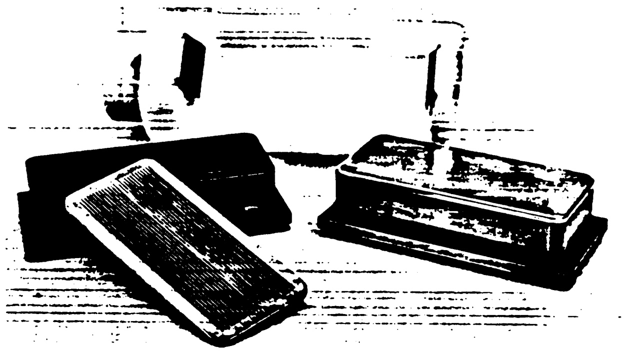

Fig. 1a)

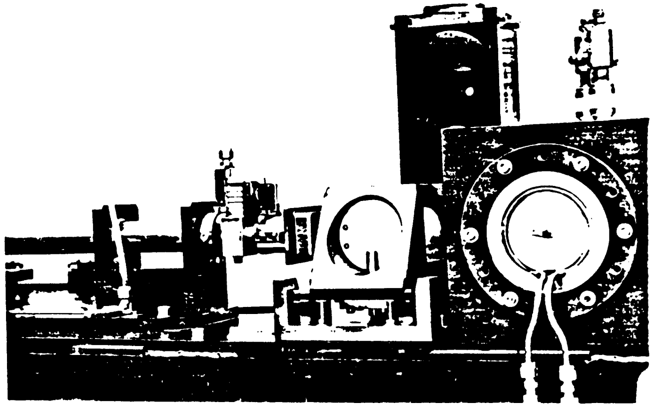

Fig. 1b)

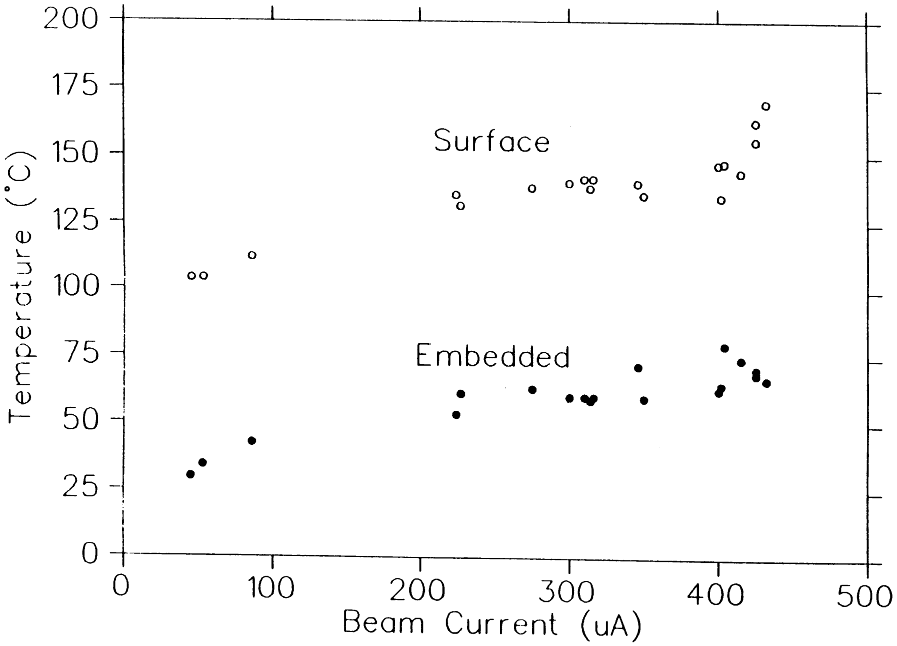
Temperature (°C)
Beam Current (uA)
Surface
Embedded
0
25
50
75
100
125
150
175
200
0
100
200
300
400
500

Fig. 2

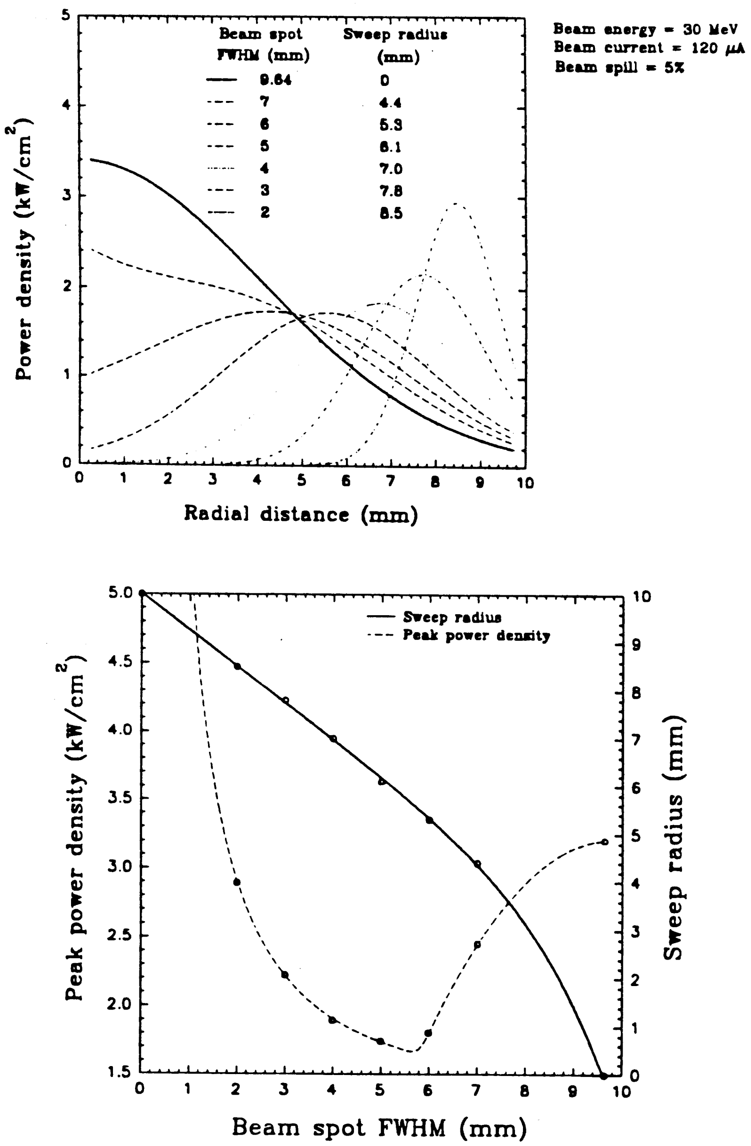
Beam spot FWHM (mm)
Sweep radius (mm)
9.64 0
7 4.4
6 5.3
5 6.1
4 7.0
3 7.8
2 8.5
Beam energy = 30 MeV
Beam current = 120 μA
Beam spill = 5%
Power density (kW/cm²)
Radial distance (mm)
Sweep radius
Peak power density
Peak power density (kW/cm²)
Sweep radius (mm)
Beam spot FWHM (mm)

Fig. 3