CIRCULAR SWEEPING OF A HIGHLY-FOCUSED 66 MEV PROTON BEAM FOR RADIOISOTOPE PRODUCTION

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Proton beams (66 MeV) with currents of up to 100 μA are available at NAC for the production of radioisotopes while the solid targets employed for this purpose are usually small (20 mm diameter) disc-shaped pellets. This results in the dissipation of very high beam power densities (up to 6 kW/cm^2) in the target assembly. In order to prevent the thermal failure of targets during bombardment with these intense beams, a method of reducing the peak power density on the target is required in addition to proper cooling. A magnet system designed to sweep the highly-focused beam in a circle around the radioisotope production target face has been in operation at NAC for several years and it has proved to be very successful. A finite-element thermal analysis of a typical solid target under bombardment conditions emphasises the value of such a system and illustrates how the beam parameters can be optimised to obtain a target temperature distribution with the lowest maximum.

1 Introduction

The National Accelerator Centre is a multidisciplinary facility and its multi-particle accelerator is operated 24 hours per day 7 days per week. In spite of this there still exists stiff competition among the various users' groups for cyclotron beam time. Radioisotopes for medical use are produced with a 66 MeV proton beam, which is shared with the neutron therapy programme. Only 33 hours of beam time pr week - divided into 4 night shifts - are available for the production of radioisotopes. In addition to this, bits of unused beam between neutron therapy sessions and some idle beam are also utilised. Beam time is, however, limited and it requires production targets to be safely operated at the highest possible beam currents in order to maximise our production rates.

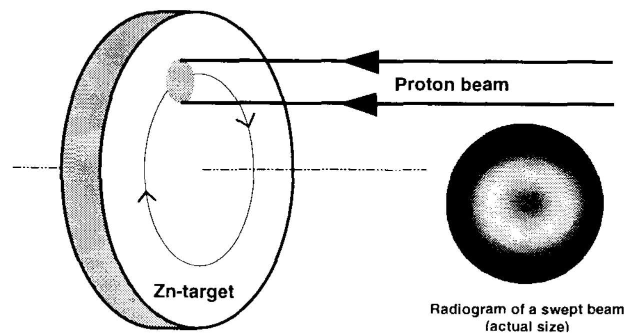

Figure 1: An illustration of how the beam is swept. A radiogram of a foil activated by an 80 μA swept beam is also shown.

Beam current limits associated with individual targets are usually dictated by occasional catastrophic thermal failures of these targets. Two main methods exist to increase these limits without increasing the peak target temperature and, consequently, the risk of catastrophic target failure. These include a lowering of the beam power density by optimisation of the beam distribution on target and the improvement of target cooling. Only the former method is addressed here. Previous studies on the smearing effect of a beam sweeping system have been done for beam window foils [1-3] only. Some of these studies [2, 1] indicate that a significant temperature reduction is obtained only at relatively high sweeping frequencies.

2 Beam sweeping system

A typical NAC solid target is disk-shaped and is cooled by means of a 1 mm thick layer of water, which is forced with a high linear speed of 10-15 m/s over each face. In addition, a magnet system was also designed [4] and installed at NAC. This sweeps the beam in a circular motion around the target face in order to achieve a more even distribution of the beam and to reduce the peak power density on the target (see figure 1). Two dipole sweeper magnets sweep the beam in orthogonal directions. The two current signals are 90° out of phase and the amplitudes can be varied independently to obtain circular or elliptical beam profiles with a maximum sweep radius of 8 mm.

3 Time structure

Individual target regions experience temperature cycling as a result of the sweeping beam. A sweep frequency of 450 Hz is used in order to reduce the effect of such thermal cycling. Each cycle consists of a short heating period when the beam passes a particular region, followed by a longer cooling period. The temperature variation experienced by a representative target element in the beam path was calculated by means of a finite-element analysis (FEA) code [5] and the result is shown in figure 2. After the initial warming-up period of less than one second the temperature reaches a constant average value with a small variation during each cycle. This allows the use of time-averaged beam profiles in steady-state temperature profile calculations.

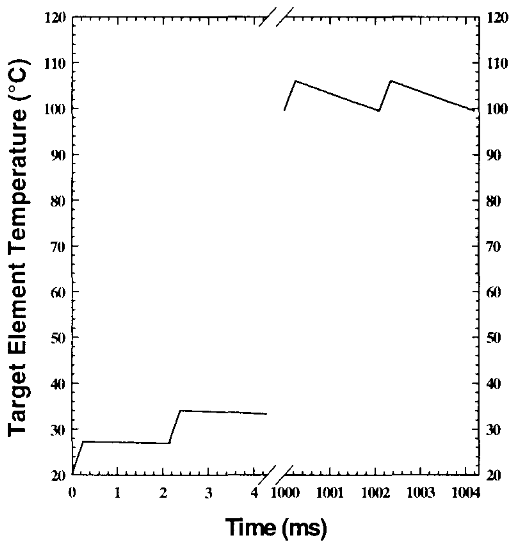

Figure 2: Temperature variation as a function of time experienced by a representative target element in the beam path.

4 Beam profiles

Monte Carlo calculations were used to generate time-averaged beam profiles ranging from that of a stationary beam (sweep radius = 0) to a variety of ring-shaped profiles. Gaussian beams were assumed and profiles were calculated only for beams swept in a circular motion about the target axis (see figure 1). For this purpose the assumption was made that a beam swept in a circle with a radius r is equivalent to a stationary beam displaced from the target axis by a distance r and a target spinning about its axis. This assumption is only valid for cylindrically symmetrical beams. A density plot of such a displaced beam is shown as an example in figure 3.

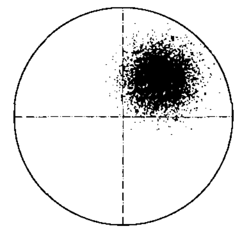

Figure 3: Density plot of a displaced Gaussian beam.

For each beam diameter (FWHM) a corresponding sweep radius was determined so that only 5% of the swept beam falls outside the target. Each beam profile (see figure 4) is associated with a maximum power density value in the target. This peak power density is a function of the sweep radius and it reaches a minimum at a sweep radius of 5.5 mm in the case of our 20 mm diameter target (see figure 5).

5 Temperature distributions

The beam profiles were used to determine heat-load profiles in a Zn-target. Corresponding temperature distributions in a Zn-target were then calculated by means of an FEA-code [2]. The results are presented in figure 6 and show that the shape of the temperature profile on the target surface closely follows that of the beam profile. Figure 7 shows that the lowest peak surface temperature is obtained with a sweep radius of 5.6 mm and a corresponding beam spot diameter of about 5.7 mm. This optimum peak temperature is about a factor of 2 lower than that induced by a stationary beam (sweep radius = 0), allowing an increase in beam current by more or less the same factor.

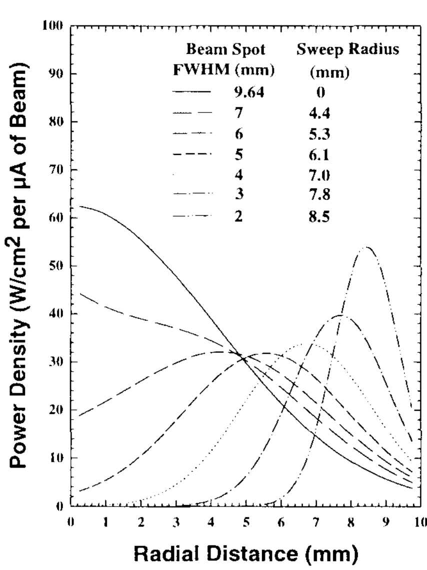

Figure 4: Beam profiles.

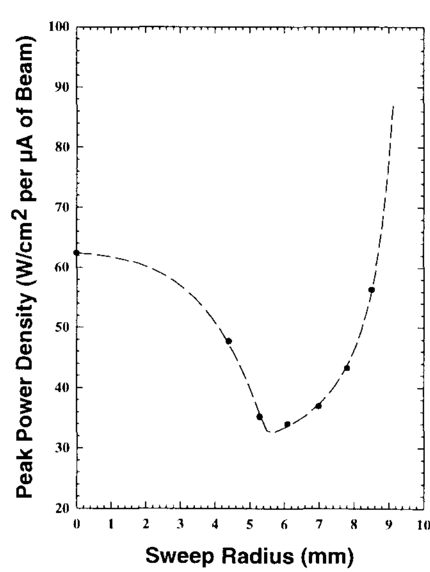

Figure 5: Peak power density as a function of sweep radius.

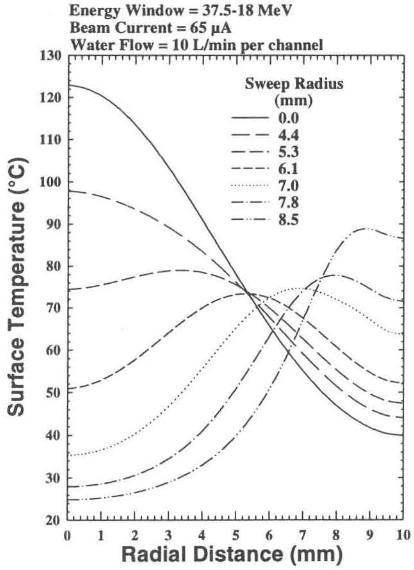

Figure 6: Temperature distributions in a Zn-target.

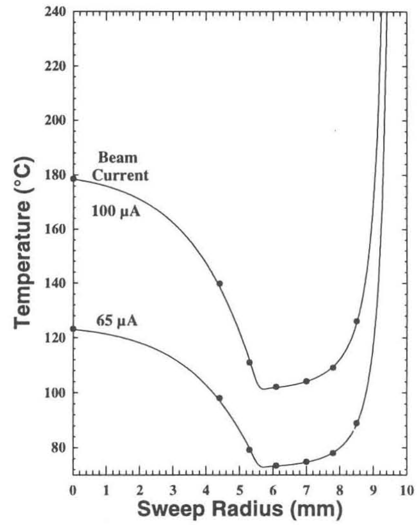

Figure 7: Peak surface temperature in a Zn-target as a function of sweep radius.

6 The NAC experience

The 66 MeV proton beams used for routine radioisotope production have to be generated and tuned several times during a particular week. The aim of the optimisation procedure for these intense beams (up to 80 µA) is to achieve the smallest spot size and, consequently, the largest sweep amplitude in each direction. A maximum of 4 µA in total is allowed on the 4 sectors of the ring-shaped graphite collimator directly upstream of the target. The maximum sweep amplitude one can achieve, therefore, depends on how good the beam quality is. Figure 8 shows a distribution of the maximum sweep amplitudes achieved in the X and Y directions over a period of about one year.

7 Conclusions

- Beam currents for radioisotope production can be significantly increased by sweeping the beam in a circular motion around the target face.

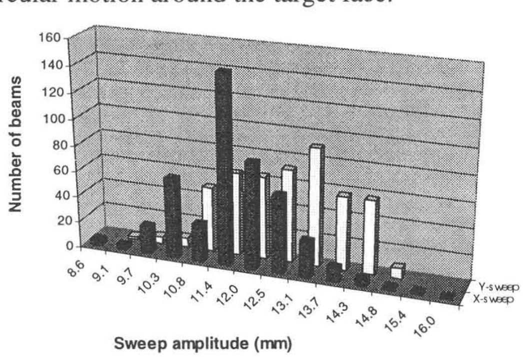

Figure 8: Distribution of sweep amplitudes in the X and Y directions achieved over the period of one year.

- Temperature distribution calculations based on time-averaged beam profiles show that the optimum sweep radius for a typical NAC target (20 mm diameter) is 5.6 mm.
- The 66 MeV beams available at NAC are of sufficient quality for radioisotope production under sweep conditions very close to this optimum.
- Based on these results we have increased the beam current on some of our solid targets from 65 µA to 80 µA, which is the maximum presently available on a regular basis and we hope to run with 100 µA or more on target in the near future.

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