CONCEPT FOR HANDLING AND SERVICE OF THE PROSCAN DEGRADER UNIT

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The selection of the appropriate beam parameters for proton therapy with a fixed energy cyclotron is at the expense of beam losses and of activation that depend largely on the amount of energy degradation and on the size of the chosen collimator apertures for the application of the depth dose. For instance as much as 99% of the beam is lost by the degradation of the beam energy from 250 MeV to 70 MeV and by selecting the beam parameters such that the beam can be transported to the patient without additional disagreeable beam losses. Therefore, the degrader system will be the major beam-loss point within the PROSCAN beam line facility and knowledge of the activation of components both within and around the region is necessary for planning service work on the facility. The design of the PROSCAN degrader unit was assisted by qualified personnel as far as radiation protection and handling are concerned. A concept for handling and service of the degrader unit has been established with regard to reliability and high availability of the scheduled beam time, to a short reaction time, short beam interruption periods for service and repair work, and with respect to the dose load of personnel.

INTRODUCTION

Proton therapy with a fixed energy cyclotron needs additional elements to select and to adjust the proton beam for the application of the depth dose. Within the scope of the PROSCAN project a degrader system has been realized that meets the requirements as given by the application of the spot scan technique. By using two multi-wedge high-density graphite absorbers, the energy of the proton beam can be rapidly and continuously adjusted in the range of 238 MeV down to 70 MeV. Two collimators each with a stack of five different apertures can be inserted into the beam to define the emittance; the first collimator selects the beam spot size at the degrader exit and the second the divergence of the beam after a drift length of 1.25 m.

A fixed energy cyclotron is well suited for the application of the spot scan technique; that is, superimposing individual beam spots in the tumour volume precisely in a rapid sequence and with an accurate dose deposition. On the other hand, selecting and adjusting the beam parameters of the extracted beam for proton therapy is at the cost of beam losses and activation. For instance as much as 99% of the beam is lost in the degrader unit, in the subsequent collimator and momentum slit by the degradation of the beam energy from 250 MeV to 70 MeV and by selecting the beam parameters such that the beam can be transported to the patient without additional disturbing beam losses.

The degrader unit is an important component of the PROSCAN facility, and it has to fulfil the general requirements imposed on the whole facility. These are reliability and high availability of the scheduled beam time, short service periods, and fast accessibility low dose to personnel during servicing. This requires the concept for handling and service of the degrader unit to be an integral part of the design and that it is based on reliable activation calculation.

THE COMPONENTS OF THE DEGRADER UNIT

Fig. 2 shows the degrader unit installed in the first section of the beam line after the cyclotron. It consists of the following elements that are installed in a vacuum chamber: (i) monitors that measure current, position and spot size of the beam at the entrance of the degrader chamber; (ii) a graphite beam stopper/ Faraday cup. The beam can be interrupted either within 50 µs by triggering a fast kicker magnet that moves the beam beyond the aperture of the tapered bore such that it is stopped in the graphite body, or within 1 s by lowering the stopper/ Faraday cup by 40 mm. This latter configuration is also used to measure the beam current for calibration purposes; (iii) five tungsten/copper alloy scatter foils of varying thickness; a suitable number of these can be inserted into the beam to increase the divergence in order to reduce the energy dependence of the acceptance of the beam line as e.g. set for 100 MeV compared to 150 MeV; (iv) the degrader assembly is to be used to give a continuously variable beam energy between 238 MeV and about 70 MeV in a rapid sequence to satisfy the requirements for the implementation of energy modulation in addition to lateral scanning. A change of the penetration depth of the proton beam into the body, typically 4.5 mm water equivalent, has to be accomplished within 50 ms with an accuracy of ±0.1 mm [1]. As illustrated in Fig. 1, the degrader consists of two multi-wedge high-density graphite absorbers that move across the beam simultaneously and from opposite sides; (v) a copper collimator at the exit of the degrader is used to select the beam spot size. It consists of a stack of five different apertures with tapered bores. It is used in combination with a similar collimator, installed 1.25 m downstream, to select the emittance of the beam; (vi) the graphite collimator in front of the degrader chamber exit stops protons that are scattered out of the acceptance of the following beam line.

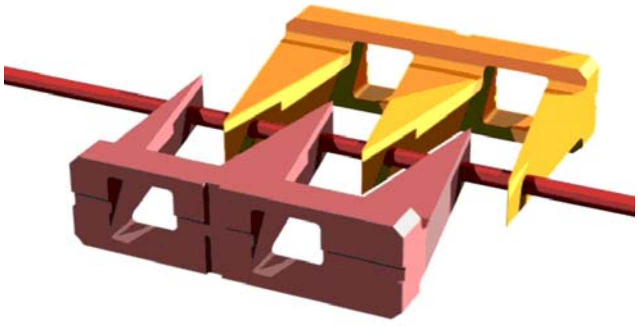


Fig. 1: Illustration of the multi-wedge degrader pair of high-density graphite, partially inserted into the beam. A uniform degradation across the whole beam spot needs a minimal overlap of the wedges of 15 mm. Therefore the highest energy that can be used for therapy is ~238 MeV.

EXPECTED ACTIVATION AND DOSE RATES

Averaged operation parameters and beam losses in the degrader unit

Radiation therapy must avoid interruptions longer than 3 days between sessions. Even though the PROSCAN facility will be in operation throughout the year, there will be scheduled breaks over the weekends and for maintenance. The activation calculations and dose rates are based on the following situation:

- The facility will be in operation for 250 days/y.
- The facility will operate for 15 h/day. The beam will be delivered into the areas for 13.5 h/day.
- The weighted average beam current at the entrance of the degrader is 83 nA.
- The weighted average energy degradation is from 250 to 104 MeV.
- The weighted average of the beam loss integrals in the degrader unit amounts to ~400 µAh/y.

The weights of the cited average running parameters have been determined by the beam loss integrals for the various operation modes. These are the beam losses at the components of the degrader unit if set for the irradiation of deep-seated tumours on the therapy gantries, for the treatment of eye tumours in the OPTIS area and for experiments in the experimental area [3]. When switching to the applications of the next beam spot, the beam will have to be interrupted for checks. During this time it is dumped in the beam stopper. This extra beam loss has been considered as well as the extra beam losses at the collimators when set to give a small beam emittance.

The presented activation and dose loads for the assumed average operating conditions are based on calculation [2] for the situation of 4 years of continuous operation with a beam current of 100 nA extracted from the cyclotron and with an energy degradation from 250 to 130 MeV. The corresponding beam loss integral amounts to ~700 µAh/y.

Expected surface dose rates of the most important components

The following table lists beam loss integrals and surface dose rates after a decay time of 4 h for the most important components of the degrader unit, and in addition for the second collimator stack that limits the divergence of the beam 1.25 m after the degrader unit.

Component in degrader unit	Beam loss integral [µAh/y]	Surface dose rate [τ = 4 h]
Beam stopper	~42 µAh/y	~4 mSv/h
Degrader	~220 µAh/y	~21 mSv/h
1st Collimator stack, copper	~115 µAh/y	~2.1 Sv/h
2nd Collimator stack, copper	~57 µAh/y	~1.0 Sv/h

Table 1: Surface dose rates for the components of the degrader unit after 4 hours decay time.

Due to the short decay time of the activity of the carbon degrader, the copper collimators dominate the dose rate after a decay time of ~0.6 hours. However, following a beam interruption, the surface dose rate of the carbon degrader (~12 Sv/h) is double that of the copper collimator, and its contribution of 0.7 Sv/h to the dose load after 2 hours decay is substantial.

Figures 3 and 4 illustrate the distribution of the dose rates 10 cm beyond the 50 mm thick lead shield wall and 10 cm outside the sidewall of the aluminium degrader-system vacuum chamber.

CONCEPT FOR HANDLING AND SERVICE

The concept for handling and service of the degrader system was developed simultaneously with the mechanical design and in collaboration with experts on radiation protection, design and servicing [4].

The main concern is keeping the dose to personnel as low as possible. This is achieved by a combination of (i) making access to and from all components as easy as possible, (ii) designing all components so that mounting and dismounting can be done rapidly and (iii) providing room for strategically positioned local shielding.

In addition, a dedicated hoist is provided for transfer of components to customised shielded transport containers (see Fig. 5). This allows at least part of the job to be done 'remotely' and hence with reduced dose to personnel. Pre-defined positions equipped with catches are used to facilitate alignment of the hoist with the drive either of the copper collimator-stack or of the beam stopper/Faraday cup.

The various components to be handled with the hoist are equipped with special quick connectors.

A special adapter, which is mounted at the graphite collimator just after the collimator-stack, allows alignment of the lever arm of the hoist with the collimator. A specially designed gripping device is used to attach the collimator to the lifting hoist, and for putting the lid into its transport container. The girder of the degrader drive assemblies facilitates de-installation by moving the unscrewed degrader drive back up to a stopping surface, and a handle fixed to the connecting flange enables then to lift it quickly over into the shielded container. A sliding device allows pushing the degrader drive assembly that is installed at the opposite side of the beam line below the beam pipe over to the side where it can be lifted into the transport container. The dose load entailing with the de-installation by hand is lower than by using the hoist.

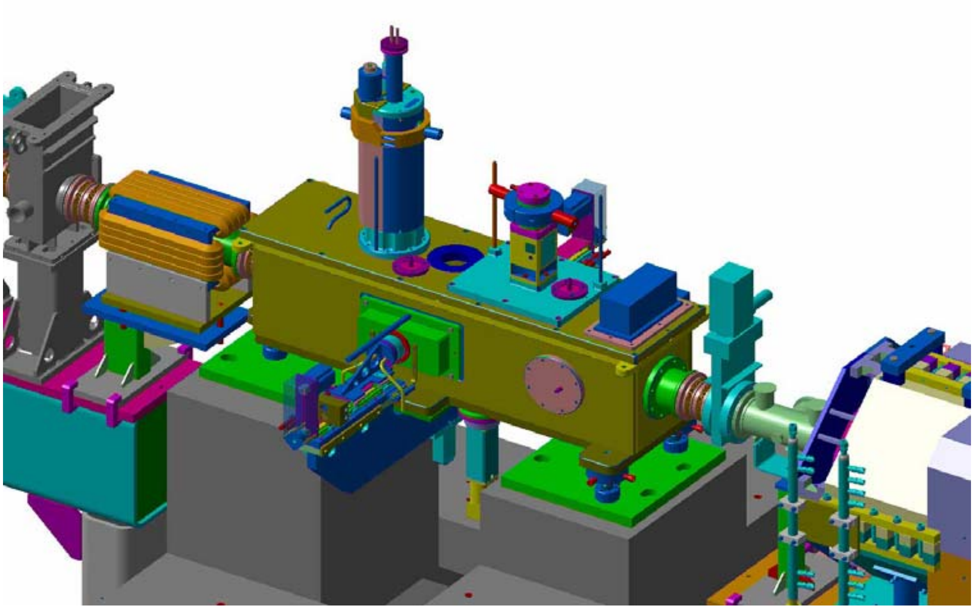
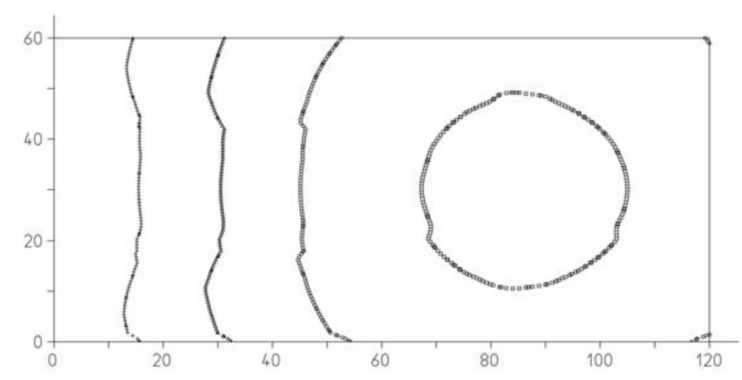


Fig. 2: Fig. 2 illustrates the section of the beam line with the degrader unit. The beam enters the degrader chamber from the right. Following the beam, one recognises at the top of the degrader chamber the diagnostic box, then the drive of the beam stopper/Faraday followed by the drive of the copper collimator-stack. The graphite collimator, which follows the collimator-stack, is inside the degrader chamber. A local hoist assists de-installation of these components, and additionally saves dose load. The quick release catches for attaching to the hoist may be seen on the sides of the drives for the collimator stack and the beam stopper. The girder that is fixed to the bottom of the chamber provides a stable support for the degrader drive assemblies, and together with the handle at the connecting flange facilitates installation and de-installation of the drives. The scatter foils are inserted at the entrance side of the degrader from below and the drive is attached to the bottom of the degrader chamber.

cm ~3 μSv/h ~5 μSv/h ~10 μSv/h ~11 μSv/h



cm

Fig. 3: Lines of equal dose-rate 10 cm beyond the 50 mm thick lead shield wall. The dose-rates are based on the specified operation condition and are the sum of the contributions from all various components. For orientation, the proton beam enters from the left at the y =30 cm line, the beam stopper/Faraday cup is between x =35 and 58.5 cm, the degrader between x =60 and 80.5 cm and the copper collimator between x =80.7 and 88.2 cm. The carbon collimator at the end of the degrader unit is between x =88.4 and 114 cm.

cm 0.2 mSv/h 0.6 mSv/h 2.5 mSv/h 4 mSv/h 2 mSv/h

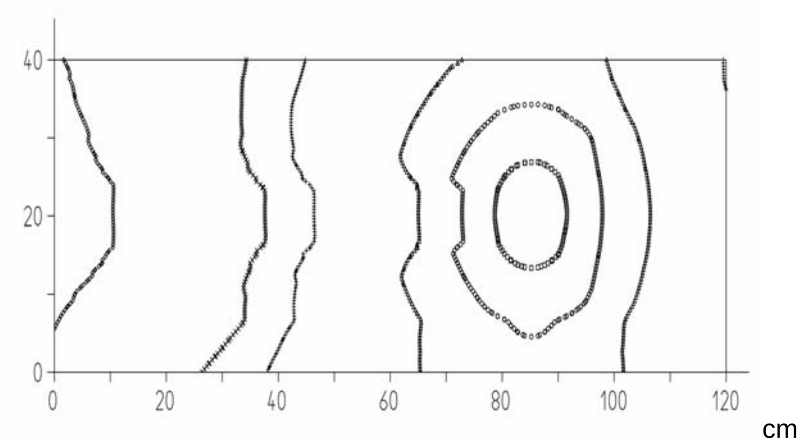


Fig. 4: Lines of equal dose-rate 10 cm outside either sidewall of the vacuum chamber. For orientation, the proton beam enters from the left at the y =20 cm line. Otherwise, the conditions and orientation are the same as in Fig. 3.

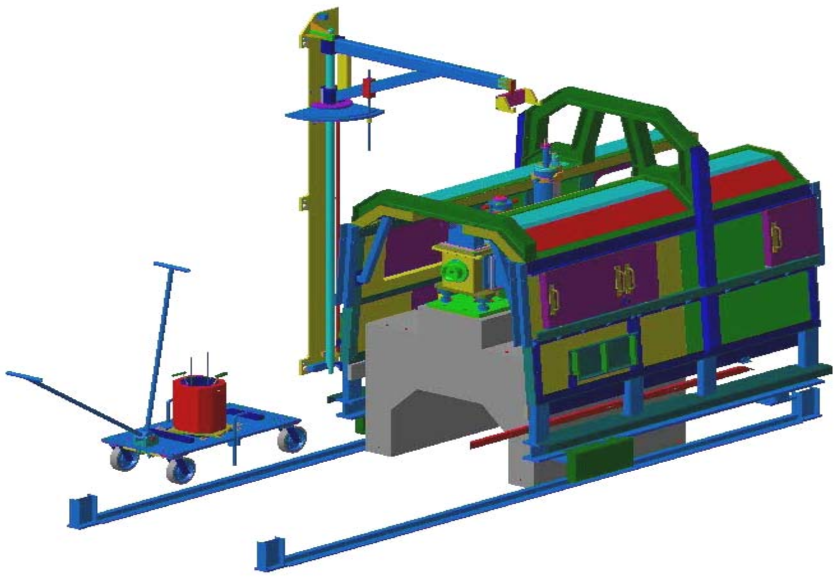


Fig. 5: Degrader unit with the lead shield in service position. Shown behind the assembly is the dedicated hoist for transfer of components of the degrader unit to a near by transport container. The lead shield is equipped with windows that can be adjusted in position and width so that accessibility and radiation protection conditions may be optimised. The lead shield has to be in position at the degrader unit before access is given to the area, and it has to be moved to its parking position away from the degrader unit before the beam ready signal is available. This together with a shield of 99.99 % pure lead reduces the dose-rates from the induced activity from ~2.5 mSv/h to ≤40 μSv/h.

CONCLUSIONS

The activation calculation has provided a base for the design of the handling and servicing systems for the degrader unit. The results of these calculations served to estimate the dose loads one has to deal with for the assumed operational situation. The calculation results have been validated. In addition to the design of the degrader unit, the concept for maintenance and servicing of the PROSCAN degrader unit can provide high availability of the scheduled beam time, a short reaction time, short beam interruption periods for service and repair work together with saving dose load of personnel.

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