The Use of ISIS as a Proton Therapy Facility

D.J.Adams, C.M.Warsop, M.R.Harold, I.S.K.Gardner, ISIS Facility, RAL, Oxford, UK.

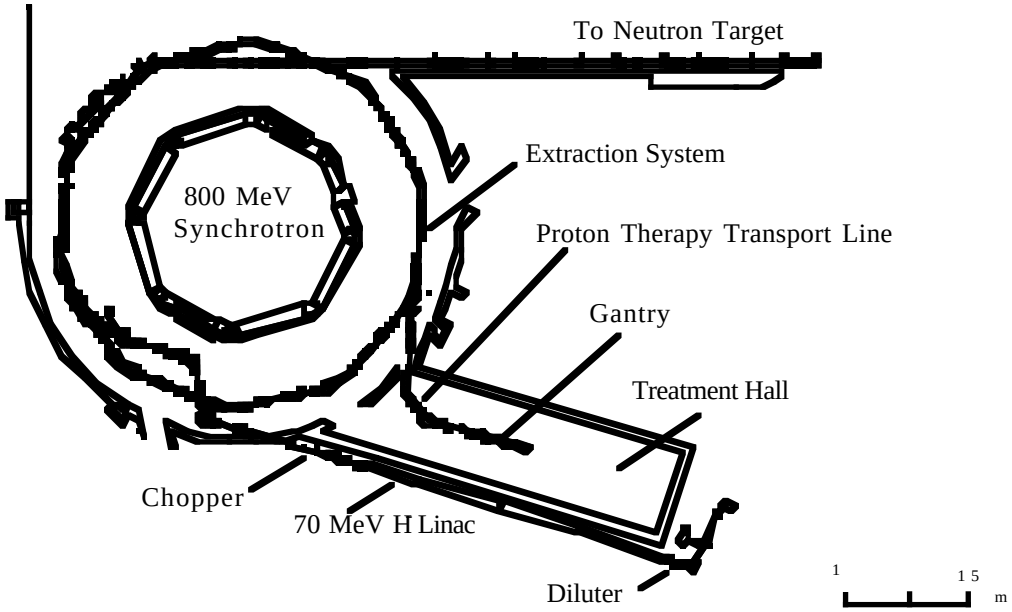

Fig 1: Layout of the ISIS facility with the proposed modifications for the proton therapy facility.

1 Introduction.

ISIS is the Spallation Neutron Source at the Rutherford Appleton Laboratory in the UK, designed and built for condensed matter research. Following recent studies reviewing possible medical applications of the ISIS Accelerators [1], the UK Medical Community has shown considerable interest in development of a Proton Therapy Facility. A collaboration, 'PROTOX', which includes the Oxford Radcliffe Hospital and RAL, is now engaged in preliminary studies, investigating how such a therapy facility might be realised.

Clearly, such a project will have to represent a significant cost saving compared with a new, purpose built facility. It is hoped a UK facility, comparable with those at PSI in Switzerland [3,4] and Groningen in Holland will be possible. The medical remit of the project would include clinical trials and substantial research: it would form the pilot project for developing proton therapy in the UK. In this paper, an outline is given of how a workable proton therapy centre might be incorporated in the ISIS Facility.

2 Medical Requirements.

Specific aims of the project are to provide conformal therapy using the spot scanning technique, and multiple treatment directions with an isocentric gantry.
Spot scanning builds up a conformal dose by dividing the tumour volume into many elements, and dosing each element sequentially. This requires a well controlled, stable beam, with widths and positions defined to 1 mm and typical energy spreads of 0.1%.

Proton therapy also requires beam energies in the range 70-225 MeV, accurate to 0.1%, to treat tumours at all depths. Beam intensities of approximately $2x10^{10}$ protons per second are needed (5 Gray/min), to keep treatment times to a few minutes. Intensities should be controllable over a wide dynamic range to an accuracy of 1%.

3 Proton Therapy Facility.

3.1 Review of the ISIS Facility

The facility consists of a 70 MeV H^- injector, an 800 MeV fast cycling proton synchrotron, beam transport lines and a spallation neutron target (see Figure 1). During the multi-turn charge-exchange injection process, $2.8x10^{13}$ protons per pulse are accumulated over 200 μs from the 20 mA injector beam. After injection, protons are accelerated to 800 MeV in 10 ms, then extracted in a single turn and transported to the heavy metal target. The machine repetition rate is 50 Hz, and pulse lengths in the synchrotron are of the order of 1 μs.

3.2 Proposed Scheme of Operation

The proposed scheme utilises the present linac and synchrotron, with modifications, and makes use of an

existing building. The principal new systems required are: an intensity reduction system, specialised diagnostics, a new fast extraction system, a beam transport line and a gantry.

The 10^{10} protons per second required for proton therapy correspond to intensities of $2x10^8$ protons per *pulse* at the ISIS repetition rate of 50 Hz - thus intensities must be reduced by a factor of 10^5. A two stage intensity reduction system is envisaged, using a beam diluter and fast chopper prior to injection. Once the correct intensity has been injected into the synchrotron, the beam is accelerated and the desired beam energy selected by extracting at the appropriate time. The new fast extraction system would deflect the beam vertically into a purpose built beam line, which transports and matches the beam to the therapy gantry. The spot scanning system, incorporated in the gantry, would then direct the beam appropriately. Up to 10^4, 1 μs beam pulses (spots) at 50 Hz would be available per treatment session.

It is an essential prerequisite that proton therapy running would not interfere significantly with neutron production. To this end it is proposed that the accelerators be dedicated to therapy for 5 minutes per hour, the remaining time being required for neutron production. An option to run at 0.8 Hz during normal neutron production, for set-up and diagnostics, is also a possibility.

In the following sections the key features of the project are outlined, indicating areas where further work is required.

4 Beam Control and Stability

The high intensity accelerators of ISIS were not designed with the stringent requirements of proton therapy in mind, therefore research will be required to ensure appropriate levels of control and stability are achieved. In particular, the time structure of ISIS is very different from existing facilities, and introduces some significant problems in dose control and verification. Initial plans for beam control systems are given below.

4.1 Intensity Control.
To reduce the normal ISIS beam intensity from 10^{13} to 10^8 protons per pulse, two measures are proposed. First, a reduction in the injector current by a factor of 1000 using a beam diluter, and second, a reduction of the injection pulse length by a factor of 100 using a fast beam chopper, as in Figure 2. Varying the injected pulse length allows fine control of intensity; beam would be injected until the required intensity is measured in the synchrotron. This measured intensity would then be extracted, and delivered to the patient. The precise operating details are presently under study.

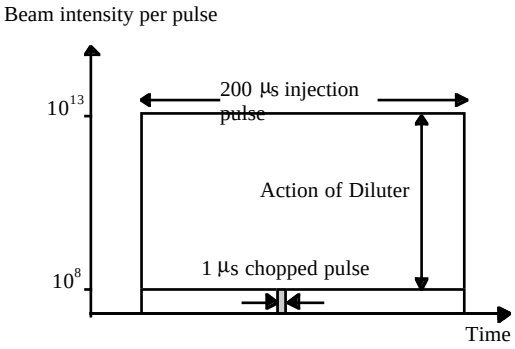

Fig 2: Proposed Scheme for beam reduction

4.2 Transverse Beam Size and Position.
In order to moderate beam line and gantry costs, apertures are to be kept to a minimum. Injector beam emittances are ~25 π mm mr in both planes, and it is expected that the emittance of the extracted therapy beam would be similar. Therapy beam line acceptances of ~40 π mm mr are thus proposed, which are also compatible with use of the PSI Gantry design (see below).

In contrast to injection under high intensity operation, where phase space painting fills much of the (~400 π mm mr) synchrotron acceptances, therapy operation will require minimal increase of emittances during injection. Consequently precise control of injected profiles and positions will be required, and possibly some collimation.

Accuracy and stability of beam position (±1 mm) at the patient demands a well controlled, stable beam at the extraction point in the synchrotron: this will require development work.

4.3 Energy Control.
The beam energy delivered to the medical transport line is controlled by extracting at an appropriate time during the acceleration cycle of the synchrotron. Precise selection of energy (±0.1%) would be achieved by counting beam revolutions; some checks on stability and a method for calibrating absolute energy will be necessary.

4.4 Diagnostics.
In order to achieve the control described above, new diagnostics operating in an intensity regime of 10^8 protons per pulse would be required. Suitable intensity toroids, position monitors and profile monitors for the injector, synchrotron, beam lines and gantry, will need to be developed. Recent studies using chopped beams purely for machine studies [5], at intensities of 10^{10} protons per pulse, have given some relevant experience.

5 Beam Transport Line and Gantry

An existing gantry design in use at PSI [3,4] is in many respects ideal for PROTOX. It incorporates spot scanning,

is compact, and has compatible acceptance. The design is based on a 360° isocentric gantry, with an eccentrically mounted patient platform, that allows a small overall radius of 2 m. A spot scanning system is incorporated into the gantry design, which allows active scanning of the beam in the bend plane. Scanning in the remaining transverse plane is achieved by moving the patient on a transporter.

The gantry optics have been designed to deliver a transverse beam shape which is effectively independent of gantry orientation. This is achieved by designing the optics to be symmetric, reproducing the input beam parameters at the gantry isocenter. Thus a circular input beam remains effectively unchanged irrespective of gantry orientation. The gantry is achromatic in the plane of bend to promote beam stability and to simplify transverse coupling effects.

The beam transport line carries the therapy beam from the synchrotron and matches the beam to the gantry. The boundary conditions imposed by the gantry require the transport line to deliver a circular, achromatic beam. The spot scanning system requires a flexible spot diameter and beam profile which minimises dose to skin and intervening healthy tissue. Therefore the transport line should also produce a controllable beam diameter at a waste. The beam optics of this system are under study. An option to incorporate momentum and beam size collimation is also under consideration.

6 Energy Variation

ISIS has the ability to vary the treatment energy on a pulse to pulse basis by timed extraction from the synchrotron.

Controlling the extraction system, transport line, gantry and spot scanning system at 50 Hz (matching the magnet fields to the extraction energy) would allow a clean, well defined treatment pulse to be used. This system represents the most accurate solution in terms of treatment energy and intensity control but would be expensive to build.

Alternatively, the beam could be degraded to the treatment energy from a single or limited number of extraction energies. The disadvantages of degrading are the associated uncertainties in energy, intensity and position, which are undesirable for spot scanning. A ‘range shifter’ system in use at PSI, comprising 36 plates, can vary the treatment energy by 2-5 MeV per plate, depending on the incident beam energy. A similar arrangement could be used on ISIS, and would simplify matters considerably as the extraction system, beam line and gantry would only need a few fixed momentum settings. The merits of both possibilities are under consideration.

7 Safety

A full safety audit will be needed before design proposals are made. However, the proposed scheme has many implicit safety features. Dedicating the machine to proton therapy for 5 minutes ensures no high intensity pulses are in the machine during proton therapy sessions. The proposed method of intensity control allows for multiple checks on pulse intensity before extraction to the therapy beam line: aborting unsatisfactory pulses is easily achieved by inhibiting extraction.

8 Conclusions

Preliminary studies suggest that a workable, technically feasible and medically useful proton therapy facility on ISIS may be possible. There are a number of key areas in which details need to be established before any proposals are made, and it is hoped funding will be found to allow the necessary study. PROTOX could be an excellent opportunity for development of proton therapy in the UK.

References

[1] Possible medical applications of the ISIS accelerators. D J Adams, C M Warsop and M R Harold, ISIS/SYN/1/95.

[2] Spallation Neutron Source: Description of Accelerator and Target, B Boardman, RAL Report RL-82-006, 1982.

[3] The 200 MeV proton therapy project at the Paul Scherrer Institute: Conceptual Design and Practical Realisation. E Pedroni et al, Medical Physics, vol. 22, No 1, Jan 95

[4] Beam optics design of compact gantry for proton therapy. E Pedroni.

[5] Low Intensity and Injection Studies on the ISIS Synchrotron. C M Warsop, Proceedings of EPAC 94.