# CONSIDERATIONS ON THE RELIABILITY OF THE PROSCAN FACILITY

*J.M. Schippers, J. Duppich, G. Goitein, M. Jermann, A. Lomax, A. Mezger, E. Pedroni, H. Reist*

*An important specification (and motivation) for the PROSCAN facility is a very high availability of the beam for patient treatment. An overview is given of the reasons for this specification and the considerations and measures to achieve this ambitious goal.*

## INTRODUCTION

A major disadvantage of the existing proton therapy facility at PSI is the parasitic use of the beam from the large 590 MeV proton cyclotron in a multi-user environment, with shut down periods of three to four months per year. This was one of the reasons why PSI launched the so called PROSCAN project. The new facility consists of a dedicated cyclotron COMET, an energy degrader, beam lines, therapy equipment (the currently existing gantry, a new gantry and a new eye treatment facility) and a beam line for experiments. It has been designed to be capable of providing reliable stable beams of varying energy during the whole year. An important design goal is a high availability of the beam.

## MEDICAL AND BIOLOGICAL MOTIVATIONS

Fractionated radiotherapy is based on the daily application of small amounts of dose – a fraction - to the tumour during typically 5 to 7 weeks. This fractionation is necessary to secure that the healthy tissue, which is also irradiated, gets time to repair and recover between the single fractions, which results in an overall better tolerance. A regime of 5 fractions per week is a well-established and documented method, used very widely in radiotherapy. Interruption of the fractionation causes a step backward in the therapy process. The longer the interruption, the more time the tumor cells will have to repair, so the less effective the preceding radiation dose will be. Since this effect is particularly important at the beginning of a treatment course, new treatment courses usually start on Mondays, in order to prevent a treatment interruption right at the beginning. Consequently, it is important for the response of the tumour, and for the comparison of proton therapy with conventional radiotherapy, that the total dose should be delivered whenever possible in consecutive working days and consecutive weeks without a break.

Shutdowns delay and disturb the patient schedule and endanger the outcome of already started treatments. An interruption of two or maybe three days could be acceptable, when planned well in advance. If a longer shut down e.g. of three or more days is expected, a new patient will not be accepted to start his treatment. A planned shutdown of e.g. one week effectively results in a decrease of a number of treated patients, which is equivalent to the number that could be accepted in a period of two months. In addition to the reason mentioned above, this is also caused by limitations in logistics, treatment-planning practice and QA, which do not allow a group of new patients to start treatment on the first day after a shutdown.

In addition to the above mentioned biological considerations, also the “(dis)comfort” of a patient must be taken into account. The psychological effects of major discomfort experienced during each fraction, which has to be applied every day for a number of weeks, should not be underestimated.

Interruptions may also have considerable consequences for the treatment accuracy (especially an uncertainty in the location where the dose is delivered). Therefore, any downtime with a patient on the treatment table should be reduced to seconds, and at most a few minutes. Downtime of more than about 10-15 minutes can often mean that the patient has to be removed from the gantry, and perhaps the whole positioning procedure repeated. When such an interruption happens in the middle of a field, the accuracy of the delivery of this fraction could be compromised due to inevitable misalignments of the patient between the two partial treatment sessions.

## LOCAL SITUATION

Since the PROSCAN facility is the first of its kind it is difficult to make an accurate estimate on the achievable reliability as long as operational experience is still lacking. However, based on experience with the existing accelerator complex at PSI, we tried to optimize the design. In the operational phase we intend to analyze the performance to obtain insight in how reliable such a facility would work in a hospital-based environment. When analyzing technical subsystems that play a role in the reliability of the system, it is therefore important to distinguish PSI-specific devices, conditions or environment from those that would be used in a hospital environment. The PROSCAN facility will be embedded in the PSI infrastructure and, although much effort will be done to obtain a system which is as independent as possible from the rest of the facilities, the costs would be too high to setup a completely separated facility within PSI.

A big difference with hospital-based linear accelerators used for photon treatment (the availability of which is often used as the goal for proton-therapy facilities), is that in many hospitals there is usually more than one accelerator available. This allows a certain degree of backup in case of technical problems. On the other hand, at PSI there is a large crew of experts and experienced technicians permanently on duty, to allow a quick reaction on technical problems.

| ***Availability parameter*** | | ***Spec. (per year)*** |
|---|---|---|
| Scheduled **up**time | ***SUT*** | 3700 hours |
| Scheduled **down**time | ***SDT*** | <13 days + weekend + pub. hol. |
| Max **block-length** of any downtime | ***MxDT*** | 3 days |

**Table 1:** Specifications on scheduled operation time.

| ***Reliability parameter*** | ***Specification*** ***MTBF*** | ***<max UDT>*** |
|---|---|---|
| *TTR < 1 min* | > 2 h | total 1 h/wk |
| *TTR 1 – 10 min* | > 2 d | |
| *TTR 10 – 60 min* | > 4 wk | |
| *TTR 1 – 4 h* | > 9 wk | |
| *TTR > 4 h* | > 3 months | total 24 h /yr |

**Table 2:** Specification on unscheduled down time.

## SUBJECTIVE EXPERIENCE

The conversion from availability related numbers, such as *MTBF* (mean time between failures) and *TTR* (time to repair or time during which the beam is “not ready”) to daily annoyance is difficult. From interviews with the staff at other facilities it became clear that a reliability figure of 95 % satisfies the machine crew, but for the therapists it still can be experienced as insufficient. One also has to distinguish between the burden experienced by the patient and the annoyance of the therapists.

From a machine point of view, one might expect a preference to have the largest times between failures with a long time to repair. An additional argument is that repetitive short interruptions may be more disturbing (many times one has to make an excuse to the patient) than single long interruptions (one time “sorry”). Given the motivations mentioned earlier, waiting times longer than 10 minutes are regarded as more serious than short interruptions of less than a minute. It is therefore useful to define different categories of *TTR*, each with its own specification on frequency of occurrence.

## AVAILABILITY SPECIFICATIONS

For the PROSCAN facility it has been specified that it must be available during the whole year for 5 days of 15 hours per week. Every 4 weeks one day shut down for maintenance is planned. This yields a scheduled uptime (*SUT*) of approximately 3700 hours of operation per year (see table 1). The uptime is to be used for patient treatment as well as for QA, dosimetry, tests and beam development. It should be noted that uptime is defined as the period that beam is either “on” or “ready” (immediately available upon request). The scheduled downtime (*SDT*) is used for maintenance, repairs and modifications. The maximum length of any downtime (scheduled or not) has been specified separately to be 3 days.

For the cyclotron it has been specified that the beam should be back within 4 hours after a failure. This sets the upper limit of the *TTR* specification. From the desired availability number and the *TTR*, one can calculate the maximum allowed failure frequency and the specification for *MTBF* for the different *TTR* groups. From these numbers (Table 2) it follows that the total unscheduled downtime is specified as < 74 hours per year. This needs an availability during the scheduled operation time of 98 %.

## MEASURES TO INCREASE AVAILABILITY

For individual components the design has been based on well-proven concepts and optimized for reliability, easy access, repair or replacement. Extra costs to improve the reliability were incorporated into the budget. For critical components the reliability and service aspects have been considered in detail, and periodical service and preventive maintenance were already discussed in the design phase. The measures are summarized in table 3 and listed explicitly below.

### Optimization of components and infrastructure

In general we have chosen for relaxed operating conditions of components to ensure long life times. This means e.g. moderate operating temperatures, ample cooling, not too high voltages or currents.

The optimization of the accessibility and minimization of the replacement time had consequences for e.g. trajectories of cables and piping, but also for the number of quick-fit connections and valves. Dedicated mounting tools, supports and a carriage (Fig. 1) have been designed e.g. for the extraction elements and for the components in the degrader box. Replacements of components have been exercised with the maintenance staff and, when necessary, design improvements have been made. The demonstration that several critical parts can be replaced within a specified time is part of the acceptance tests of the cyclotron. This has improved the effort taken by the manufacturer on the service friendliness.

Similar to the other proton accelerators and beam lines at PSI, all electronics has been mounted outside the vault. Although this has required considerable extra cabling, it will allow for easier diagnosis and fast replacement.

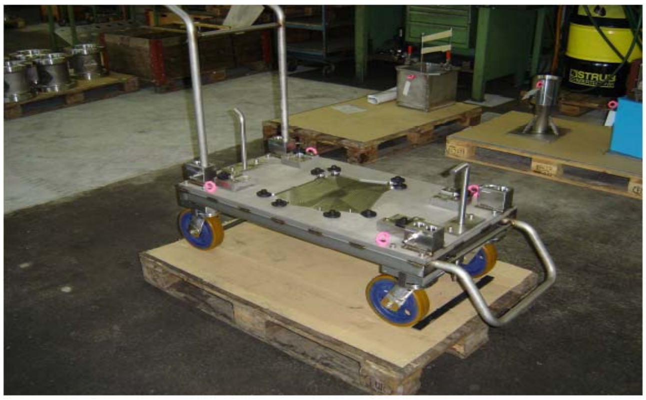

**Fig. 1:** Dedicated carrier for the components of the degrader and the extractor.

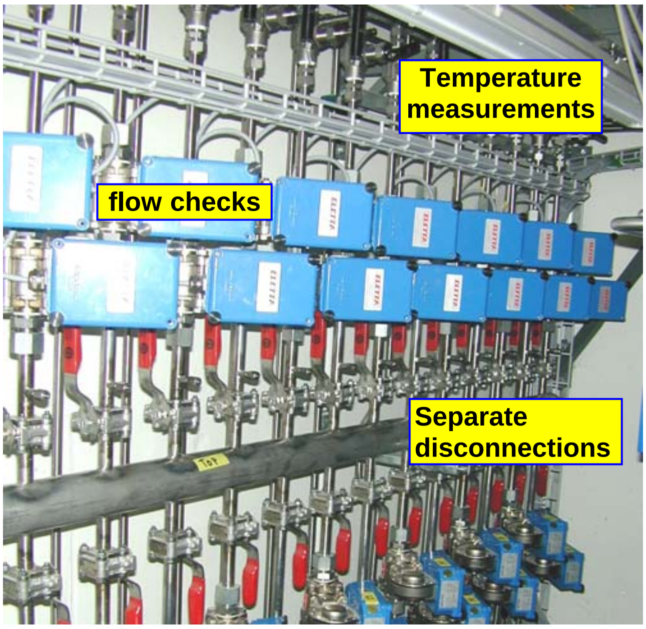


**Fig. 2:** The 100 cooling circuits of the RF cavity are each monitored and controlled.

Systems have been designed in a modular way to separate functions. This allows for separate shut off and replacement. E.g. the ~100 cooling circuits of the Dee and liner in the cyclotron are monitored separately and each of the circuits can be decoupled without too much loss of (radioactive) cooling water (Fig. 2).

Care has also been taken to have uniformity in design, connections and components. This increases flexibility and reduces the number of different spare parts and tools needed.

Much effort has been put in redundant diagnostics and monitoring of beam characteristics and of machine parameters. This allows a fast diagnosis of a problem.

During therapy the beam needs to be suppressed many times. Such requests should not be followed by a time consuming restart. On the other hand, the radioactivity induced by a blocked beam should be minimized. Therefore a graded-action concept is used to stop the beam. Initially the beam is swept on a beam blocker by a fast kicker magnet, and after a specified amount of charge deposited, the RF of the cyclotron will reduce its voltage to stop the beam in the center of the cyclotron. The RF is not switched off completely in order to keep the temperature of the Dees at their operational values. The ion source will only be switched off in emergency cases.

Redundancy has been foreseen in the supply of electric power, cooling water and helium. In all cases the supply is guaranteed via independent channels within the PSI infrastructure.

The consequences of a power breakdown on the availability have also been studied. Effort has been put into a reduction of the time to get back to the operational conditions after a power breakdown. A UPS will ensure that the system status is saved and that the subsystems can restart.

| | |
|---|---|
| Cyclotron | Designed to permit short service periods for replacement of all components of finite lifetime (e.g. ion source, deflector, RF-tube, cryo-coolers). Manufacturer maintains a pool of spare parts. |
| Degrader | Modular design, fast access, short service periods, quick exchange possibility (drive outside the vacuum chamber, low activation, low dose load), redundant diagnostics. |
| Beam diagnostics | Uniform design in cassettes allows quick replacement, spare parts. |
| Power supplies | Easy access, located outside the shielding, modular design, spares parts, diagnostics. |
| Magnets | Limited current density, safe and reliable cooling, diagnostics. |
| Electronic racks | Easy access, located outside the shielding |
| Cooling system | De-mineralized water, temperature > room temperature, limited speed of flow. |
| Vacuum system | Standard pumps, quick replacement, spare parts. |

**Table 3:** Summary of precautionary measures to increase the reliability of the system.

A time consuming problem can be the purchasing of components. Therefore a list of spare parts is discussed with the manufacturers. For many components spare parts will be available on site. For subsystems for which we do not have spare parts (e.g. new coils of the cyclotron or spare coils of the gantry magnet), the design has been made such that the probability of a catastrophic event (one that takes more than a week of repair) is minimized during the lifetime of the facility. Of course excessive costs are balanced against the risks we have accepted.

**Availability optimization of COMET**

An intensive collaboration between ACCEL and PSI, led to a cyclotron design in which also the availability has been optimized. An important specification is the high extraction efficiency (>80 %), to minimize the amount of radioactivity in the machine. This is very important to limit the repair time of components in the cyclotron.

Other design aspects are e.g. extensive diagnostic tools in the RF system. The (micro-)spark detection circuits in the low level part of the RF-amplifier are provided by PSI and operate analogous to those for the 590 MeV cyclotron. Due to the possibility of distinguishing so called micro-sparks from larger discharges, the RF need not to switch off completely at every spark. It is expected that this will also enhance the availability of the beam.

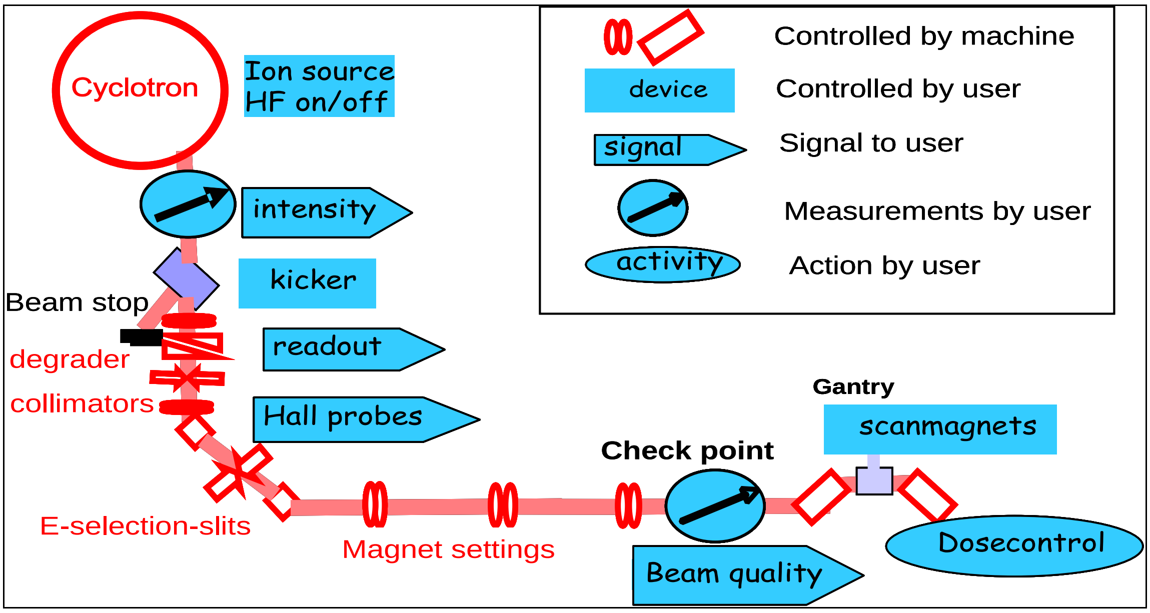


**Fig. 3:** The separation of responsibilities between the “machine” and the “user” is an important design aspect in the PROSCAN facility.

The exchange of service-sensitive components has been made relatively easy, and in the commissioning phase the last iteration steps in the design will be done after exercising with PSI’s service staff.

We expect that, in addition to the advantages of the high magnetic field from the superconducting coil, a stabilization of the room temperature in the vault and a relatively low temperature rise in the cavity cooling-circuits, will lead to a very reproducible magnetic field, which is a primary requirement for the reproducibility of the beam line tune. We expect that this will reduce setup- and recovery time.

## SHARING OF RESPONSIBILITIES

An important design aspect in PROSCAN is a rigorous separation of the cyclotron and beam lines from the treatment equipment. This decouples the tasks and responsibilities of the “machine” as beam delivery system and a “user” who decides whether the beam is accepted or not for a treatment. Apart from a high transparency of the safety aspects, this decoupling will also be of help in the analysis of availability problems.

Before each treatment room, a so called checkpoint has been defined, where the beam should comply with specifications on energy, position, direction, emittance and intensity. For each beam energy, the “machine” will use a predefined setting of the beam line (a “tune”) and, by means of collimators and dedicated beam diagnostics at the checkpoint (plus dedicated read back from energy defining elements), the user has to verify if the beam characteristics satisfy the user’s needs (Fig. 3). This separation is also present in the control system architecture. A “Machine Control System” (MCS) controls the accelerator and beam lines and it only checks the machine performance itself. Each user area has its own “User Control System” (UCS), which decides to take the beam or not. Each UCS communicates with the MCS via an allocation system. When the beam is allocated to a certain user area, its UCS will obtain the so called “mastership” over the facility. The Master-UCS will then ask the MCS to set a tune and independently of the MCS it will start, verify, use and stop the beam.

## SERVICE SCHEDULE OF THE PROSCAN FACILITY

The requirement of five days of operation during the week conflicts with the need of regular service (and improvements) of the system. Although some routine services could be done in the evening or weekend, it is also necessary to have a planned (half) day for service during normal working hours. This allows a quick access to specialists or workshops in case unexpected work has to be done. Of course we have to collect experience during the commissioning phase. The amount of needed service time might be reduced and/or spread over an adapted maintenance schedule.

## CONCLUSIONS

It is difficult to design the *PROSCAN* facility such that the availability specifications will be known separately for all components in advance. No detailed risk analysis (error-trees on all components and events) has been made. However, availability aspects have been explicit design considerations. A failure analysis is in progress. We are collecting data to find out what will happen when a component or subsystem fails and try to make an estimate on the failure probability. By specifying and logging *TTR* and *MTBF* as proposed here, we expect that we can react as effectively as possible by considering machine aspects as well as the interests of the users.