How to Design Medical Accelerator Systems for Reliability: IBA PT System

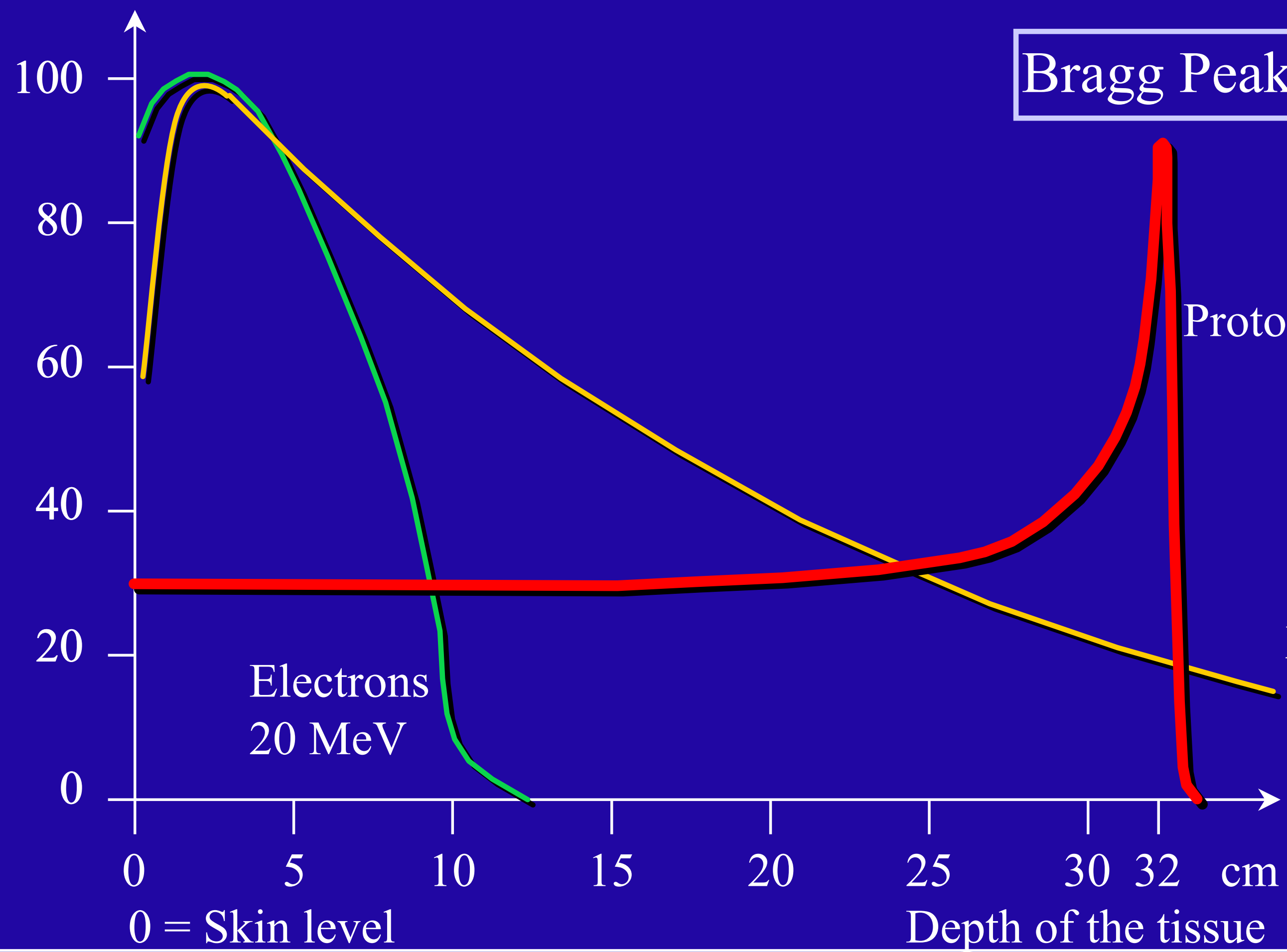
Yves Jongen
Founder & Chief Research Officer
Ion Beam Applications s.a.
Belgium

Outline

- A short introduction of a proton therapy facility
- Why such a high pressure on availability
- Forecasting the availability
- Data on MTBF and MTTR
- Two definitions of availability in radiotherapy systems
- Designing for availability

Why Protons?

Relative dose deposited in the tissue



Treatment room in PT

IBA

Proton Therapy Center

IBA Proton Therapy System

- A Proton therapy system is much more than an accelerator
- It is a complex, multi-room system, filling a Hospital building.
- The total investment is around 100 M€, of which 45 M€ for the equipment
- More than 120 people (doctors, therapist, physicists, nurses) work daily in a PT facility
- A PT facility can treat 3500 patients/year, generating revenues in excess of 60 M€/year, or 250,000€/day, or 20,000€/hour!
- The availability is required as much for financial as for medical reasons

Equipment in IBA PT system

- 230 MeV Proton Accelerator (Isochronous Cyclotron + Energy Selection System)
- Beam Transport and Switching System
- Isocentric Gantries (typically 3) and one Fixed Beam Line
- Nozzles for Scattering and Wobbling (scanning compatibles)
- Robotic Patient Positioners
- Control System and Safety System

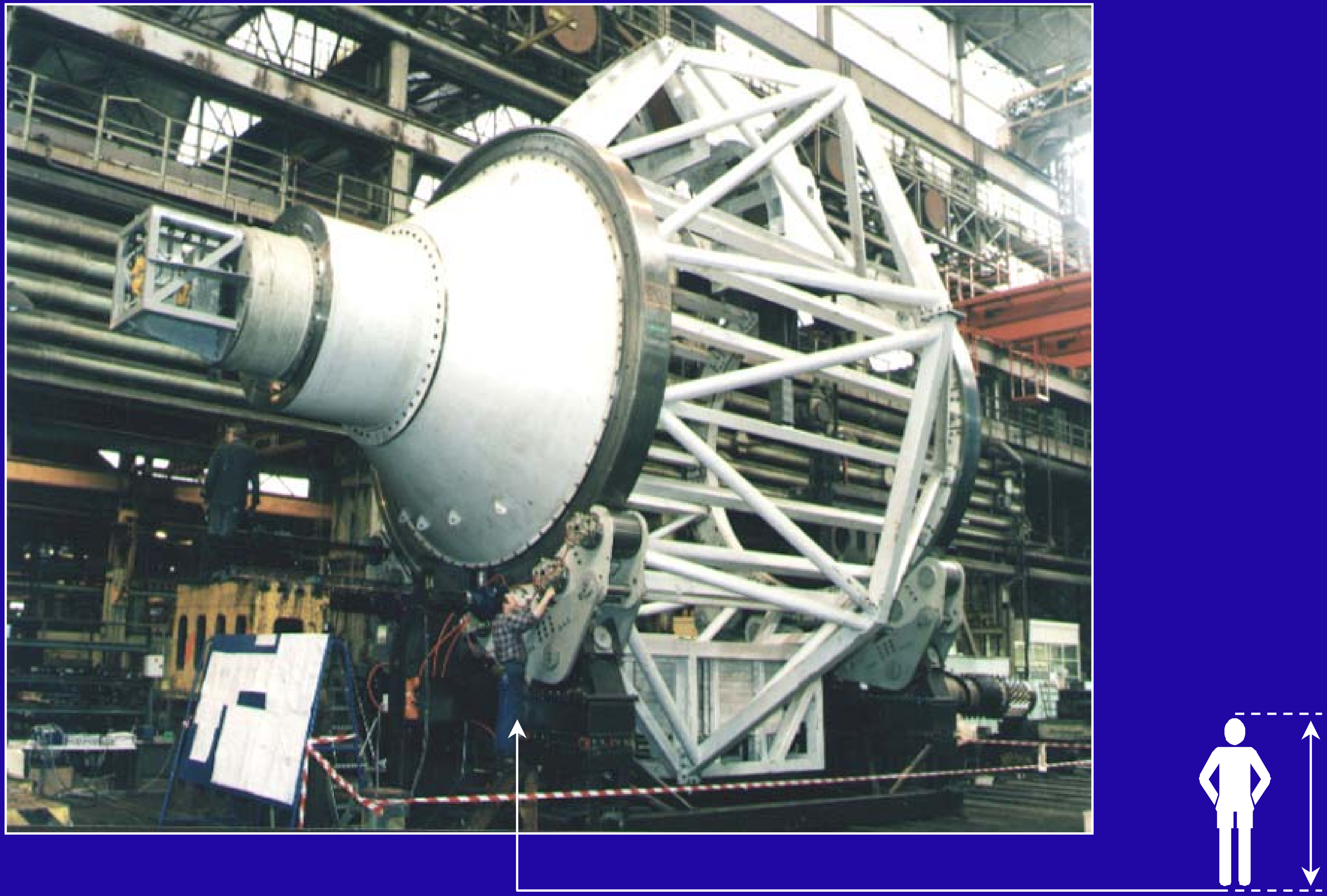
IBA

The 230 MeV Cyclotron at MGH

The Beam Transport System

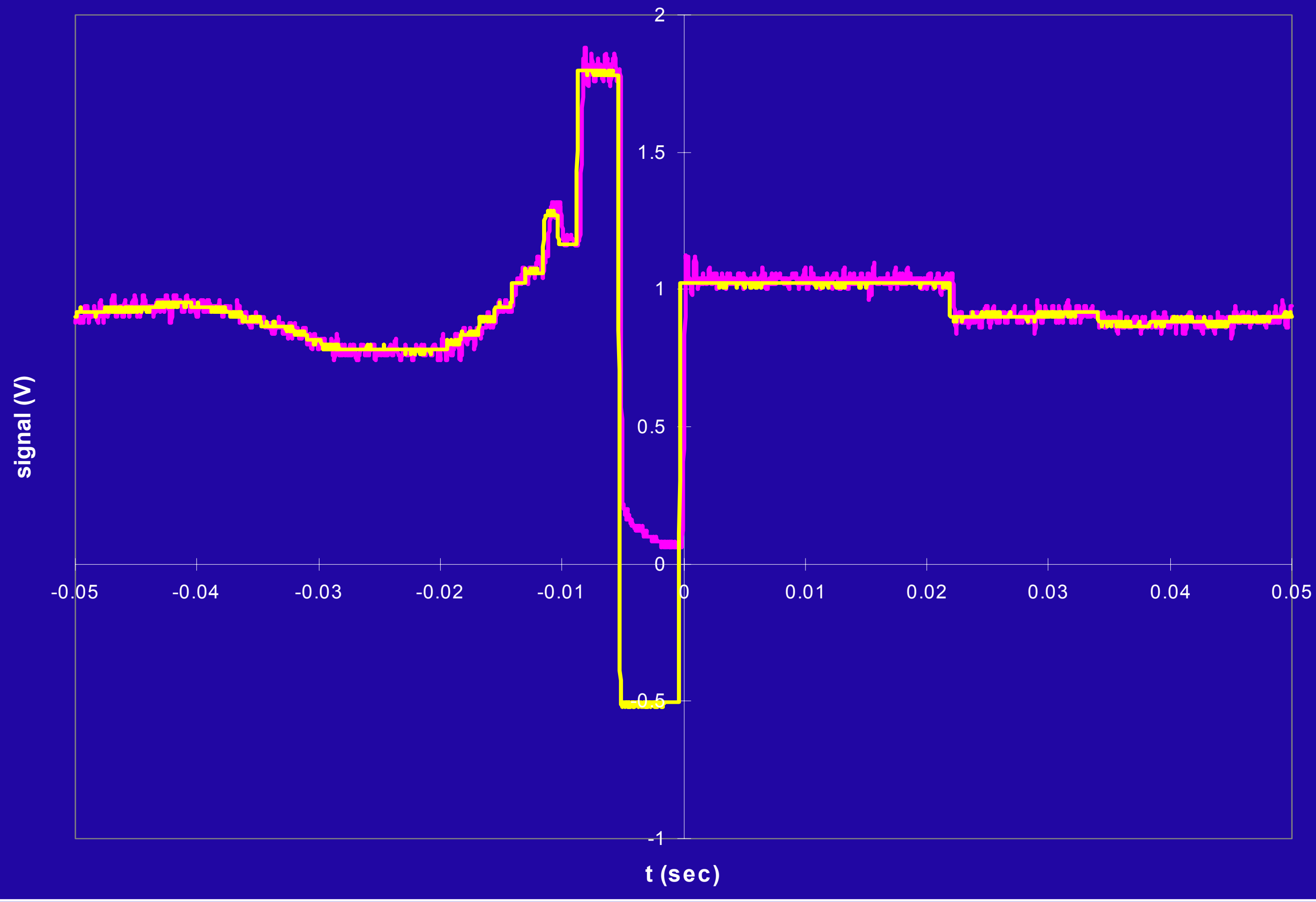
IBA

Isocentric Gantry



Beam current regulation

Oscillogram of the proton beam current (pink) following the required time function (yellow)



Calculating the availability

- Let's concentrate on unscheduled down-time
- For a single component
  - A = 1- MTTR / MTBF
- MTBF: mean time between failures
- MTTR: Mean time to repair
  - Time to identify the problem
  - Time to wait for radiation decay
  - Time to bring the spare part in position
  - Time to repair
  - Time to restart, revalidate

Calculating the availability (2)

- For a chain of components/subsystems in serie,
  - A = product (1 - MTTR(i) / MTBF(i))
- The calculation has to take into account the parallel or serie nature of subsystems or components
- Direct algebric calculation, or Monte Carlo methods (little difference!)
- The difficulty of the method is not the data processing, it is the collection of the data! (GIGO principle!)
- The biggest problem is to find the MTBF of the components/ subsystems. Operational experience data of similar accelerators is most useful.
- Military/Governement reliability databases are useful, but errors are easy and frequent (MTBF of RF amplifier = 500,000 hours)

Calculating the availability (3)

- MTTR is more accessible to prospective calculation based on experience and simulations
- In the calculation of the MTTR, the composition and location of the spare parts stock is essential
- Software issues are specially difficult to assess.

Two definitions of availability

- In radiation therapy, not all problems have an equal importance:
  - A problem delaying the delivery of treatments by a couple of hours is annoying, and is a waste of manpower
  - A problem preventing to deliver a treatment fraction on the specified date compromizes the outcome of the treatment and the revenues of the facility
- As a result, two definitions of reliability have emerged
  - R(a) = 1 – (treatment hours lost/ hours scheduled)
  - R(b) = fractions delivered/ fractions scheduled
- A problem causing a delay of 2 hours 5 times, is more acceptable than a problem causing one loss of 10 hours
- This is why supraconductivity was eventually discarded for the IBA PT cyclotron

Designing for reliability

- A = Product (i) (1-MTTR(i)/ MTBF(i))
- Three methods to improve the availability:
  1. Work on simplicity, parallelism
  2. Increase MTBF
  3. Decrease MTTR
- Take any incident as an opportunity to improve reliability

Simplicity

- Simplicity of design is one key aspect for reliability (fixed energy cyclotron versus synchrotron)
- Whenever possible, replace serial chains of components / subsystems by parallel assemblies
- Robustness and fault tolerance must be at the base of the design
- Designing fault-tolerant accelerators is still at the level of concepts

IBA

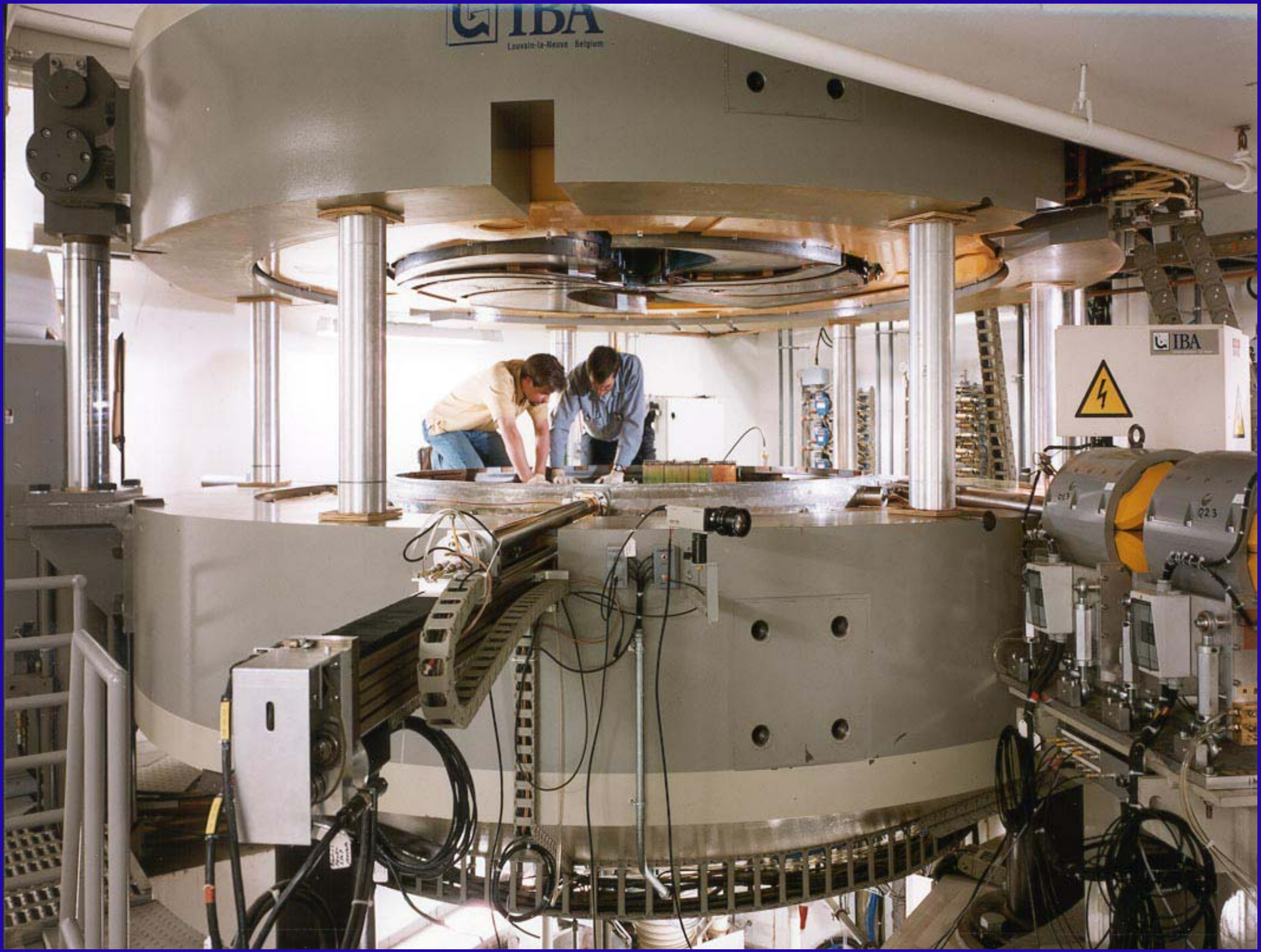
Increasing MTBF

- Using high quality, proven components
- Use conservative designs
- Well known subcontractors (long term partnership spirit)
- Well specified, qualified production technologies and methods
- Components used well below their maximum ratings
- Implementing and enforcing preventive maintenance
- Use every problem as an opportunity for improvement: never just fix a problem: go to the root, analyse and take the steps to improve the design or the production quality

Decreasing MTTR

- Fast diagnosis by built-in computer diagnosis, trained personel, written troubleshooting procedures
- Fast access to repair thanks to low components activation (choice of materials is key) or remote handling
- Composition, location and accessibility of the stock of spare parts
- Design of subsystems for repairability (accessibility)
  - Fast exchange of components (pumps, valves, air locks)
  - Design of power supplies (in plane vs. 3D)
  - Choice of vacuum and vacuum technology for fast pump-down
  - Special tools
  - Design for access

Cyclotron opens at median plane for easy access



IBA

IBA