Economics of Light Ion Teletherapy

Michael F. Moyers

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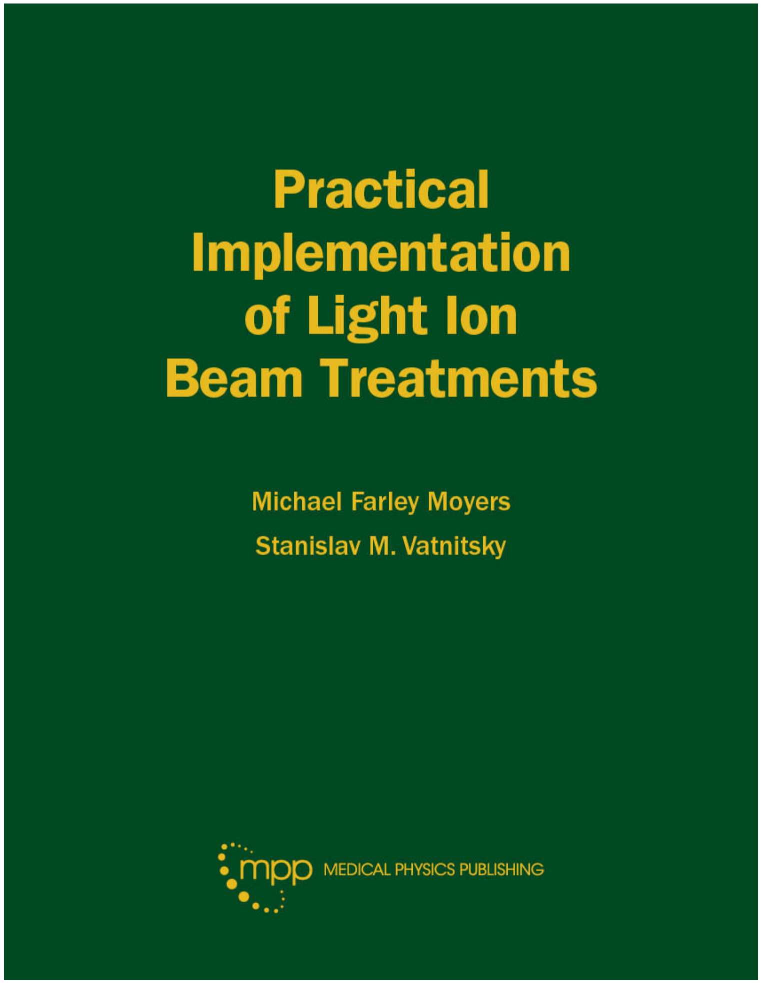
Professional Symposium
13:00 - 13:55, August 2, 2012

Presentation

- Purpose
  - » assist those considering entry into the field to make informed decisions
- Audience
  - » novices to light ion teletherapy
- Outline
  - » introduction to light ion teletherapy and challenges to widespread implementation
  - » example costs and reimbursements for current generation of light ion equipment
  - » example methods of decreasing cost and associated tradeoffs in performance these methods may incur

Acknowledgements and References

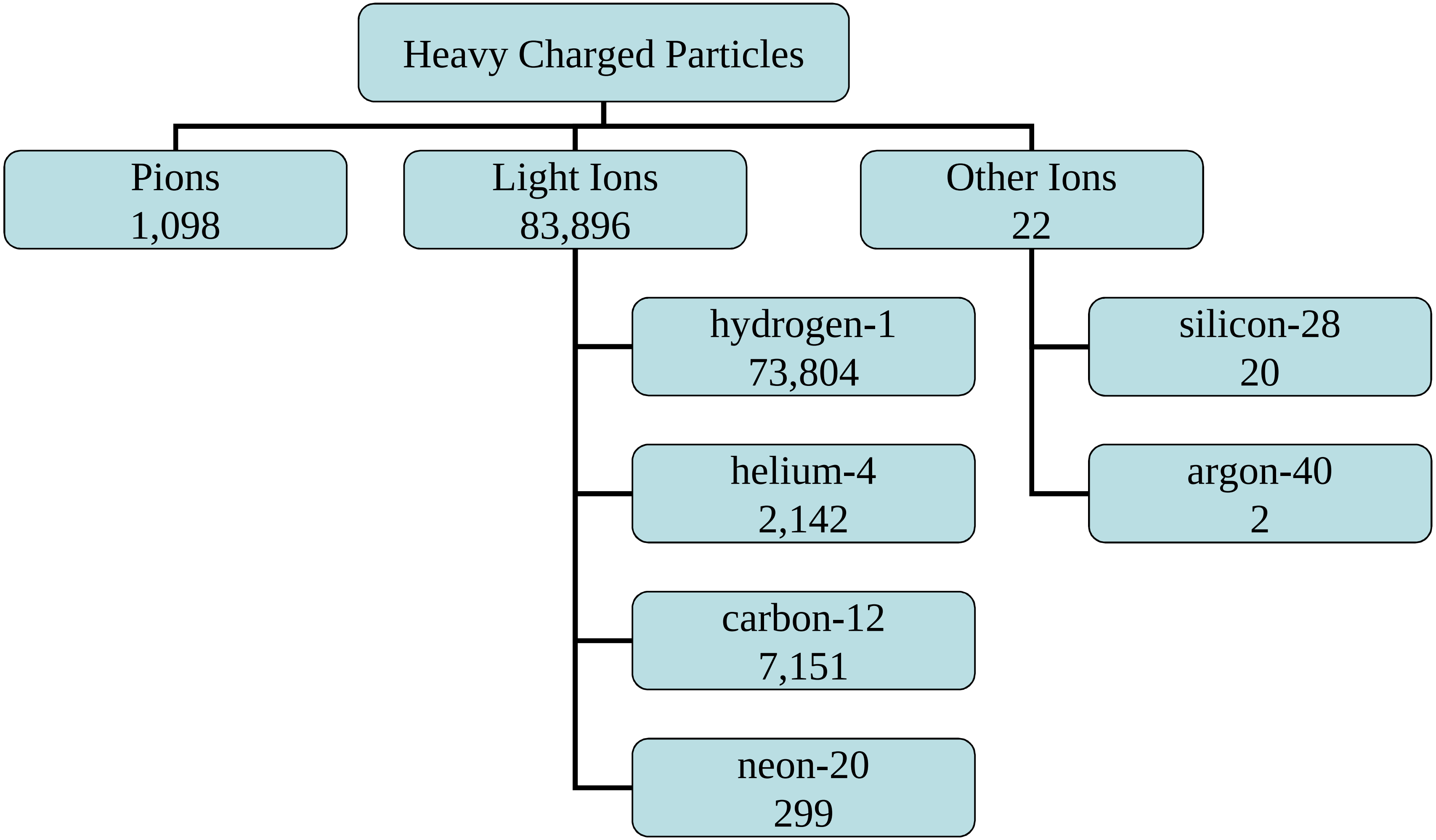


The Modern Technology of Radiation Oncology, v. 3
editor Van Dyk, J.

Chapter 10:
Radiation therapy with light ions
Vatnitsky, S. M. Moyers, M. F.

Medical Physics Publishing
expected publication
spring 2013.

Number of Patients Treated with Heavy Charged Particles Worldwide



2010 totals

Light Ion Teletherapy Milestones

1954	Berkeley	first patient treated with protons
1957	Uppsala	first patient treated with uniform scanning with protons
1958	Berkeley	first patient treated with helium ions
1965	Boston	first AVM treated with protons
1975	Boston	first ocular melanoma treated with protons
1977	Berkeley	first patients treated with carbon and neon ions
1978	Chiba	first patients treated with modulated scanning protons
1989	Tsukuba	first proton patients treated with respiratory beam gating
1990	Loma Linda	first patient treated in hospital with protons
1991	Loma Linda	first use of rotating gantry
1996	Loma Linda	first electronic x ray imaging for daily alignment of protons
1997	Darmstadt	first patients treated with modulated scanning with carbon
1998	Loma Linda	100 proton patients treated in one day
2005	Loma Linda	173 proton patients treated in one day

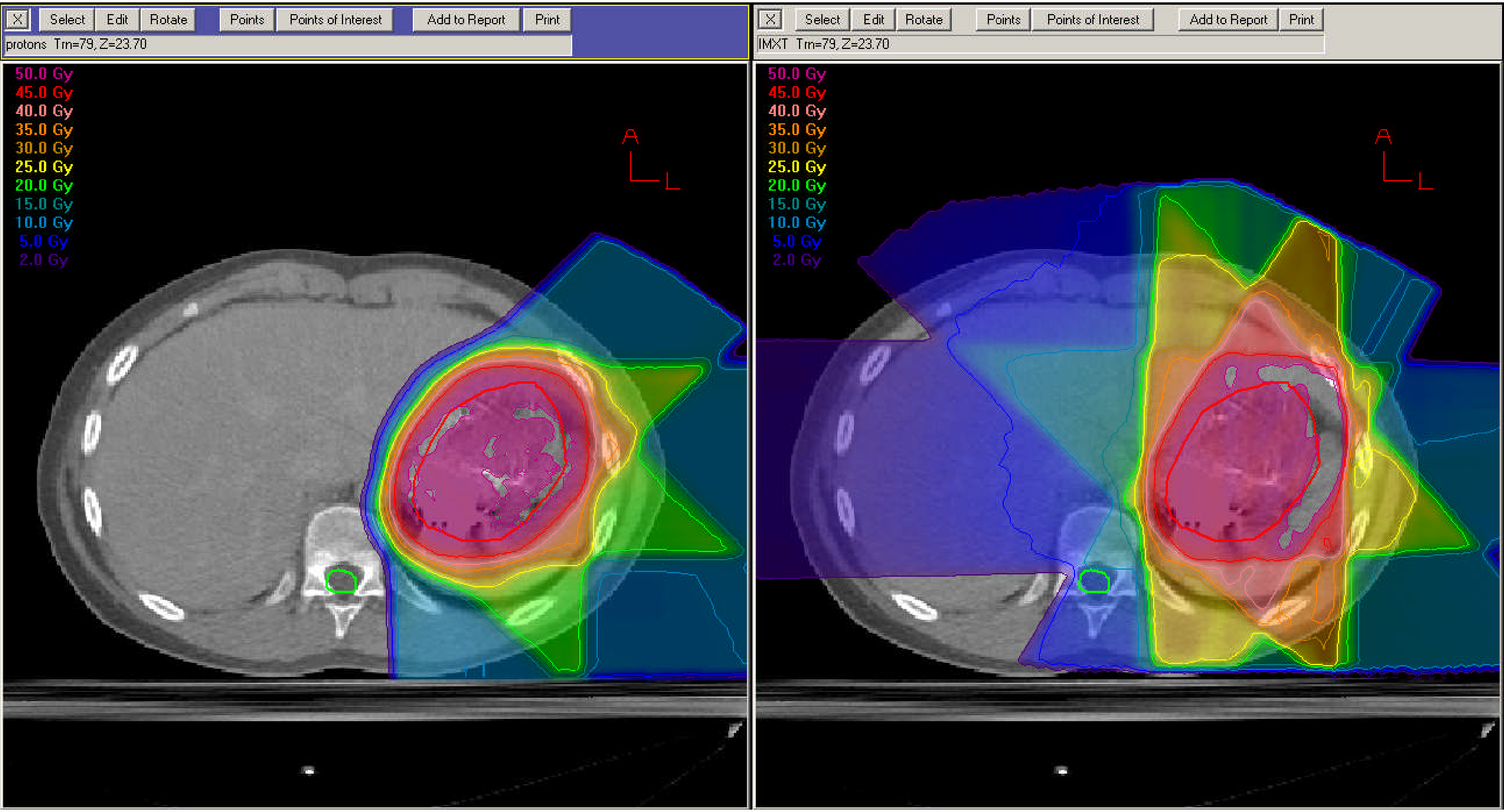
Rationale for Light Ion Teletherapy

1. The dose delivered to non-target tissues relative to the dose delivered to target tissues is lower than for other radiation beams due to the depth dose distribution.

2. The lateral and distal dose gradients are higher than for other radiation beams enabling better splitting of the target and normal tissues.

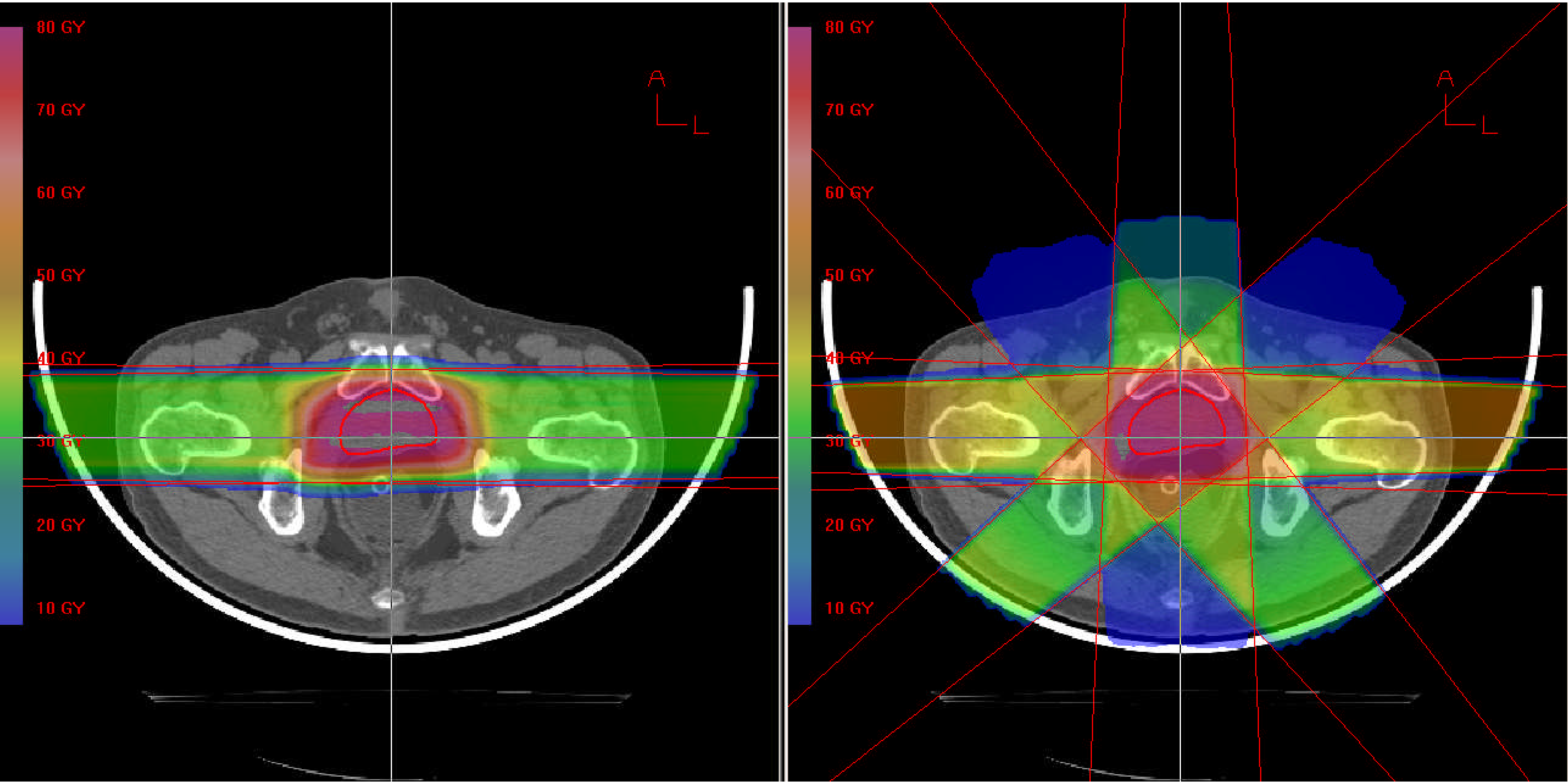
3. For ions heavier than helium, a differential RBE with depth results in a higher biological dose in target tissues compared to surrounding normal tissues.

Proton vs. IMXT - Chest



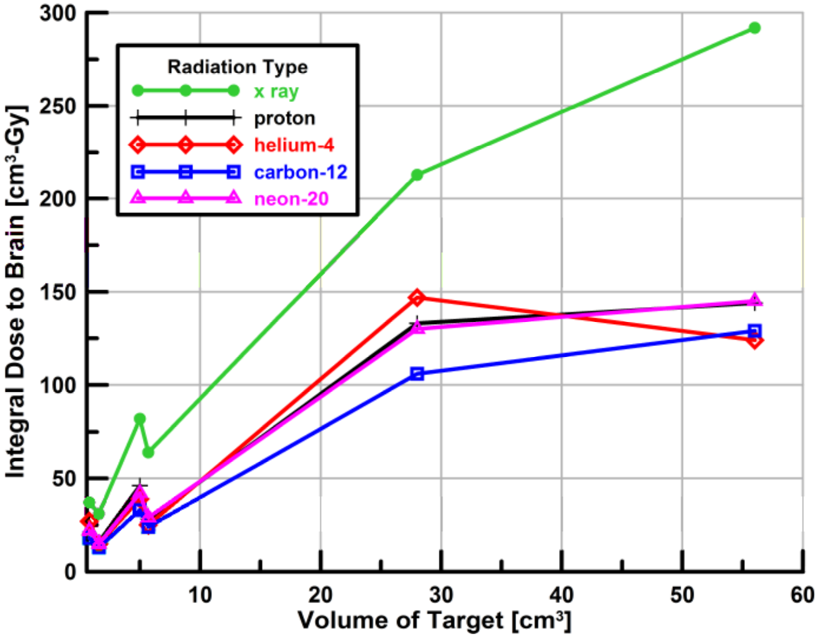
- ratio of integral dose to body outside target = 1.76
- ratio of volume of body outside target receiving > 2 Gy = 2.47

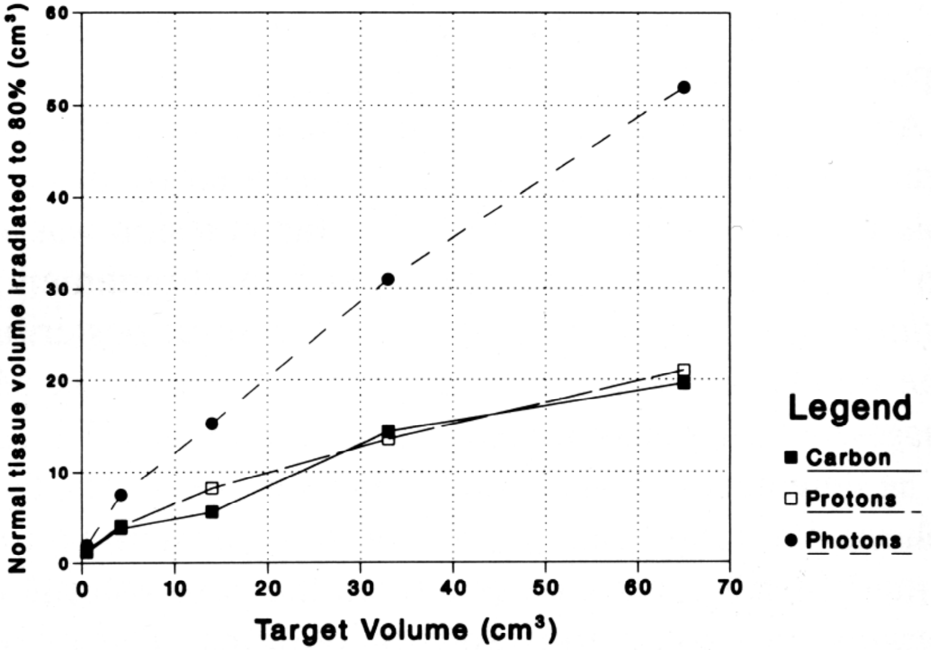
Proton vs. IMXT - Prostate



- ratio of integral dose to body outside target = 1.81
- ratio of volume of body outside target receiving > 2 Gy = 2.59

Light Ions vs. Photons - Brain Radiosurgery





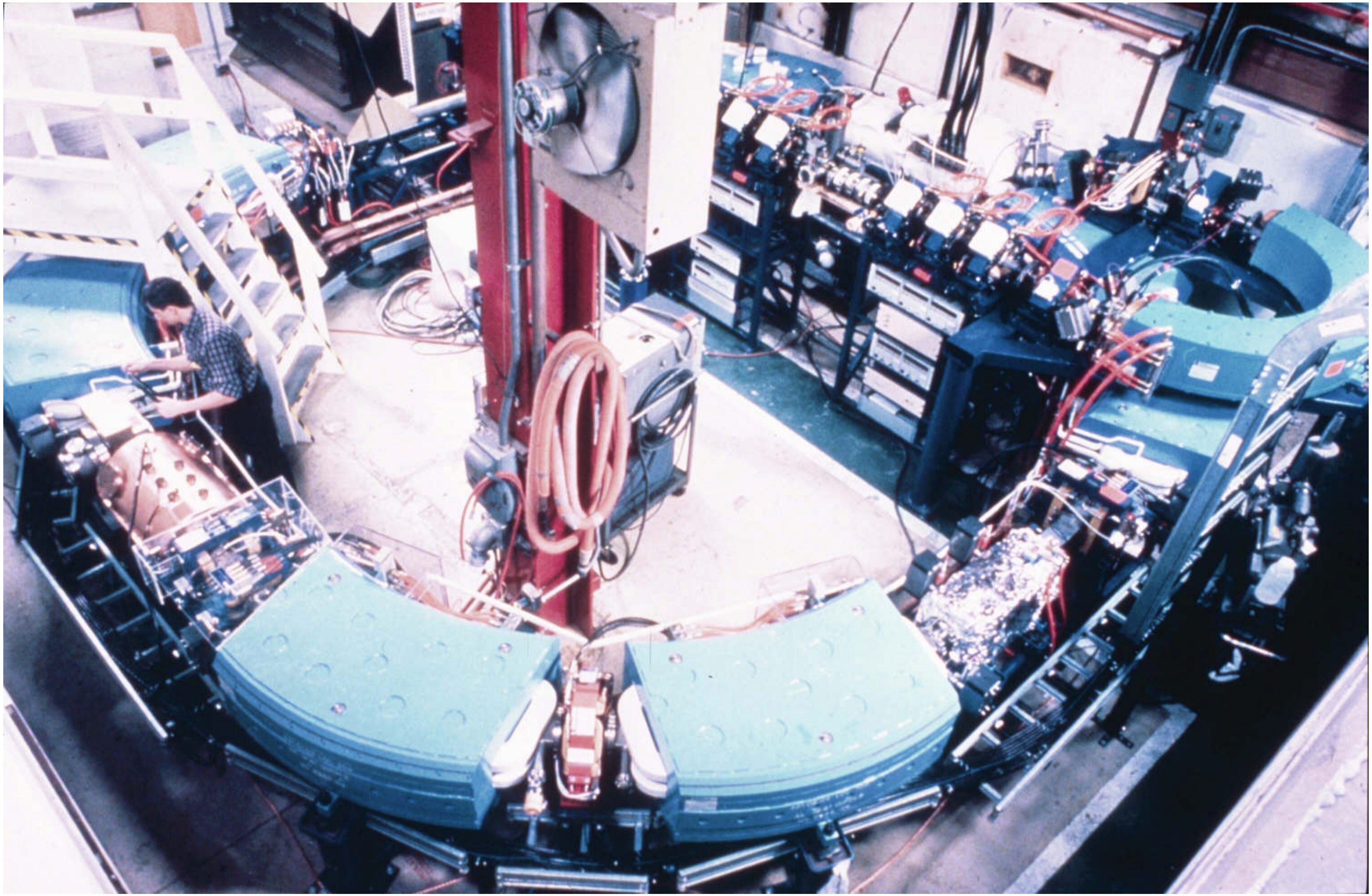
Phillips et al., 1990

Challenges to Widespread Implementation of Light Ion Teletherapy

- Question:
  - » If light ions are so much better than other forms of radiation, then why are they not being used?
    - – <1% of patients receiving radiotherapy in the USA receive protons
    - – no patients in the USA receive light ions heavier than protons
- Possible Answers:
  - » initial cost of equipment
  - » initial cost of facility (large equipment ➔ large shielding)
  - » cost of maintenance contracts
  - » availability and reliability of equipment
  - » inefficient operations
  - » lack of trained personnel

Example Costs and Reimbursement for the Current Generation of Equipment

Many Components to Accelerators

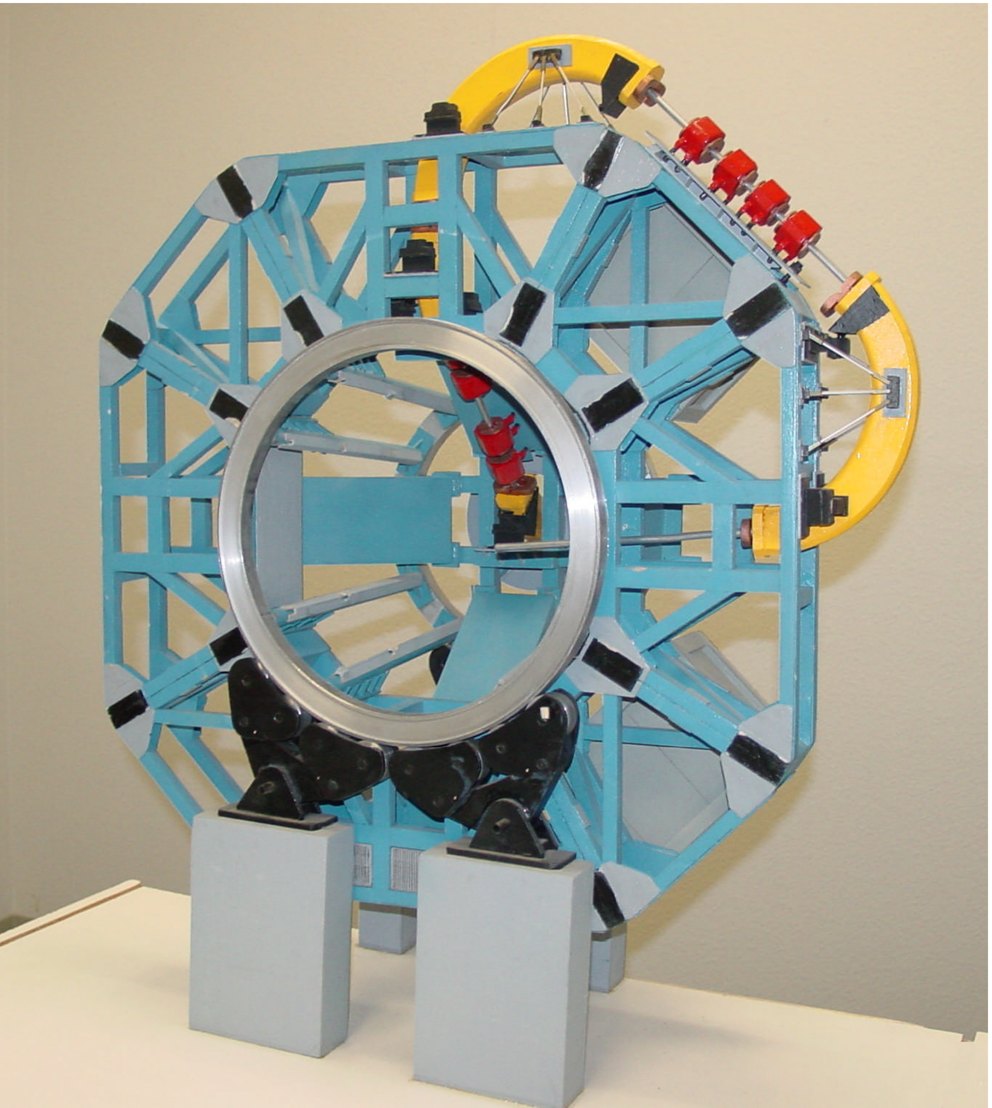


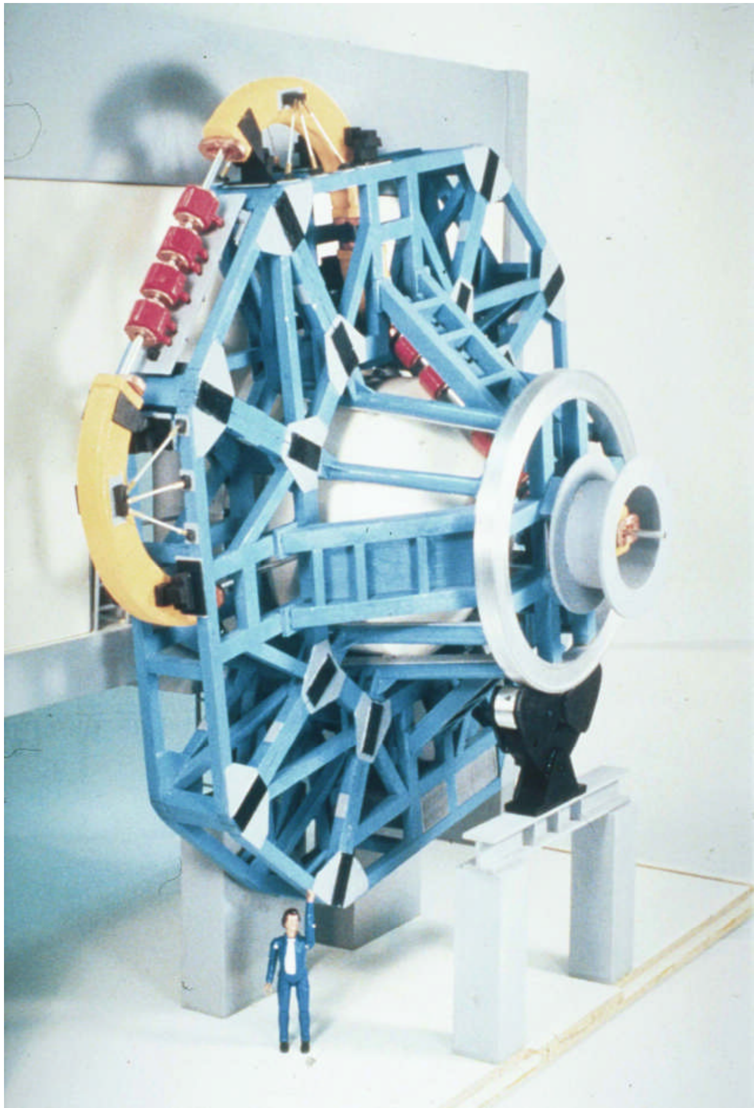
Crude Estimates of Component Costs to Customer of Proton Synchrotron

[costs in millions of U. S. dollars]

Large Complex Gantries

[model of Loma Linda gantry]

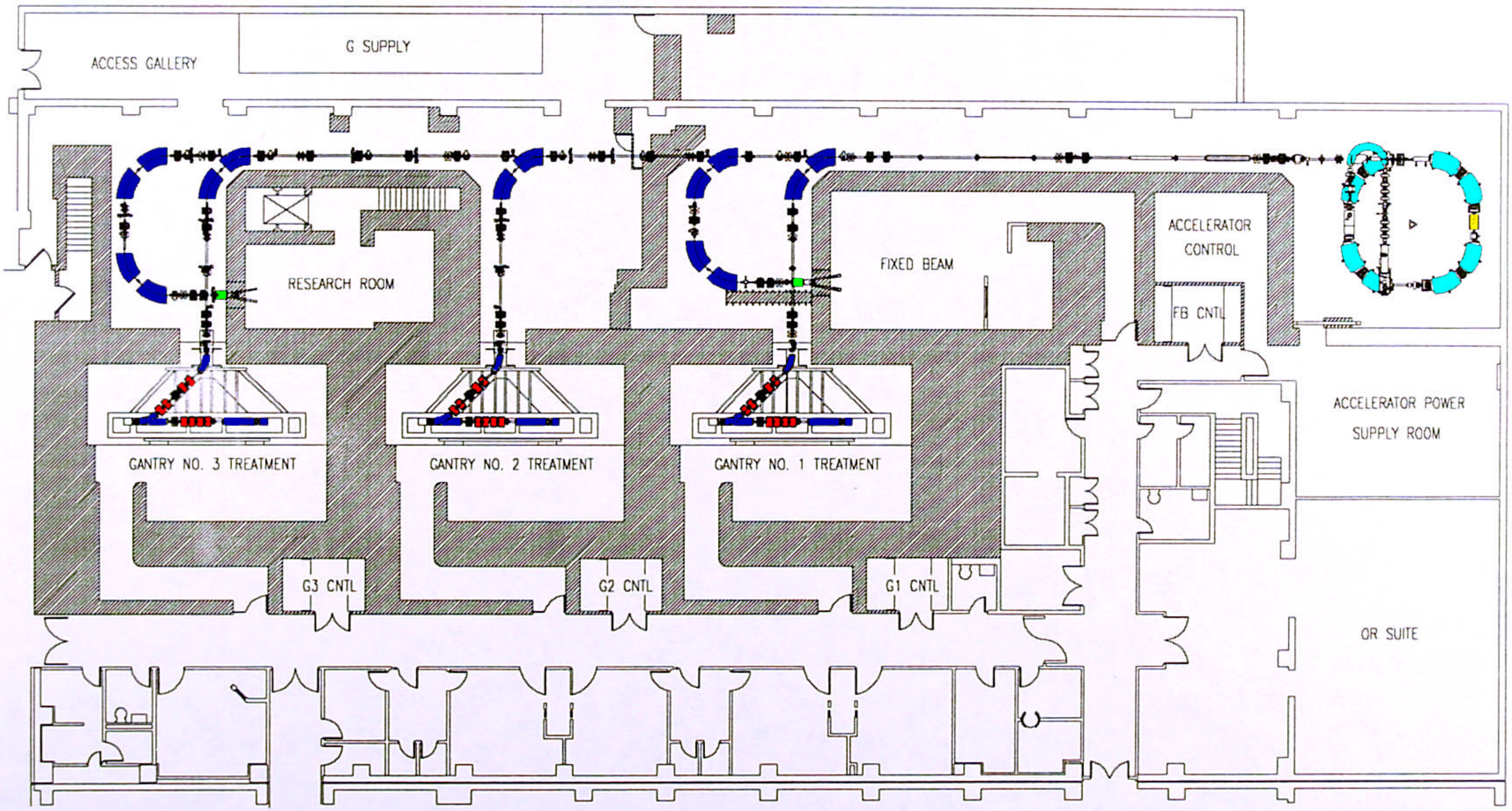




Crude Estimates of Component Costs to Customer of Proton Gantry

[costs in millions of U. S. dollars]

Cost Sharing of Accelerator Between 4 Treatment Rooms



Crude Estimates of Component Costs to Customer of Radiation Distribution System

[costs in millions of U. S. dollars]

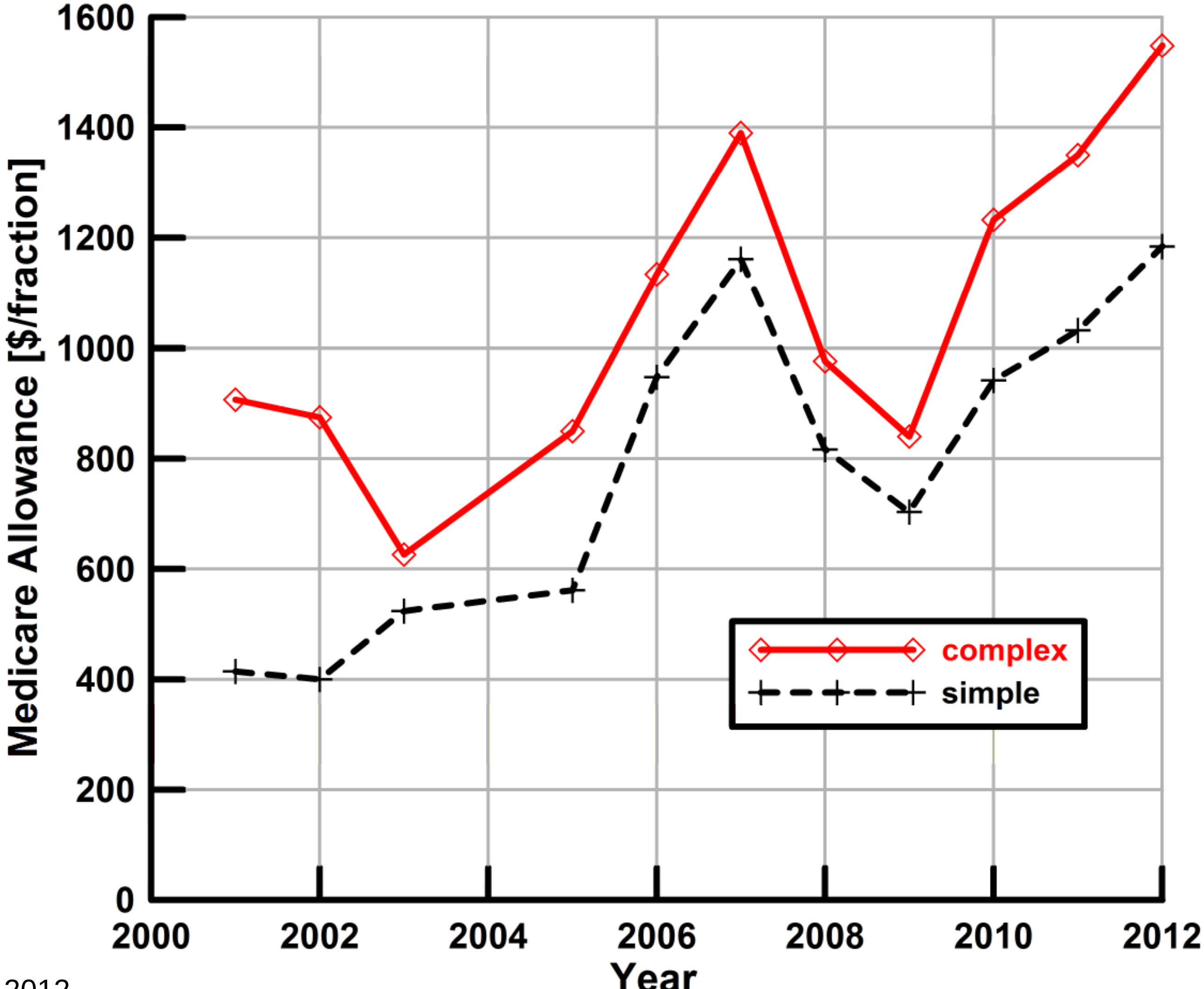
Proton Initial Costs and Financing

[costs in millions of U. S. dollars]

Initial Costs

Loan?

Reimbursement Rate for Single Fraction



Moyers and Vatnitsky, 2012

Hypothetical Payor Mix

Moyers and Vatnitsky, 2012

Reimbursement Rate for Simple Proton

[based upon 2009 USA Medicare payments x 1.39 to represent typical payor mix]

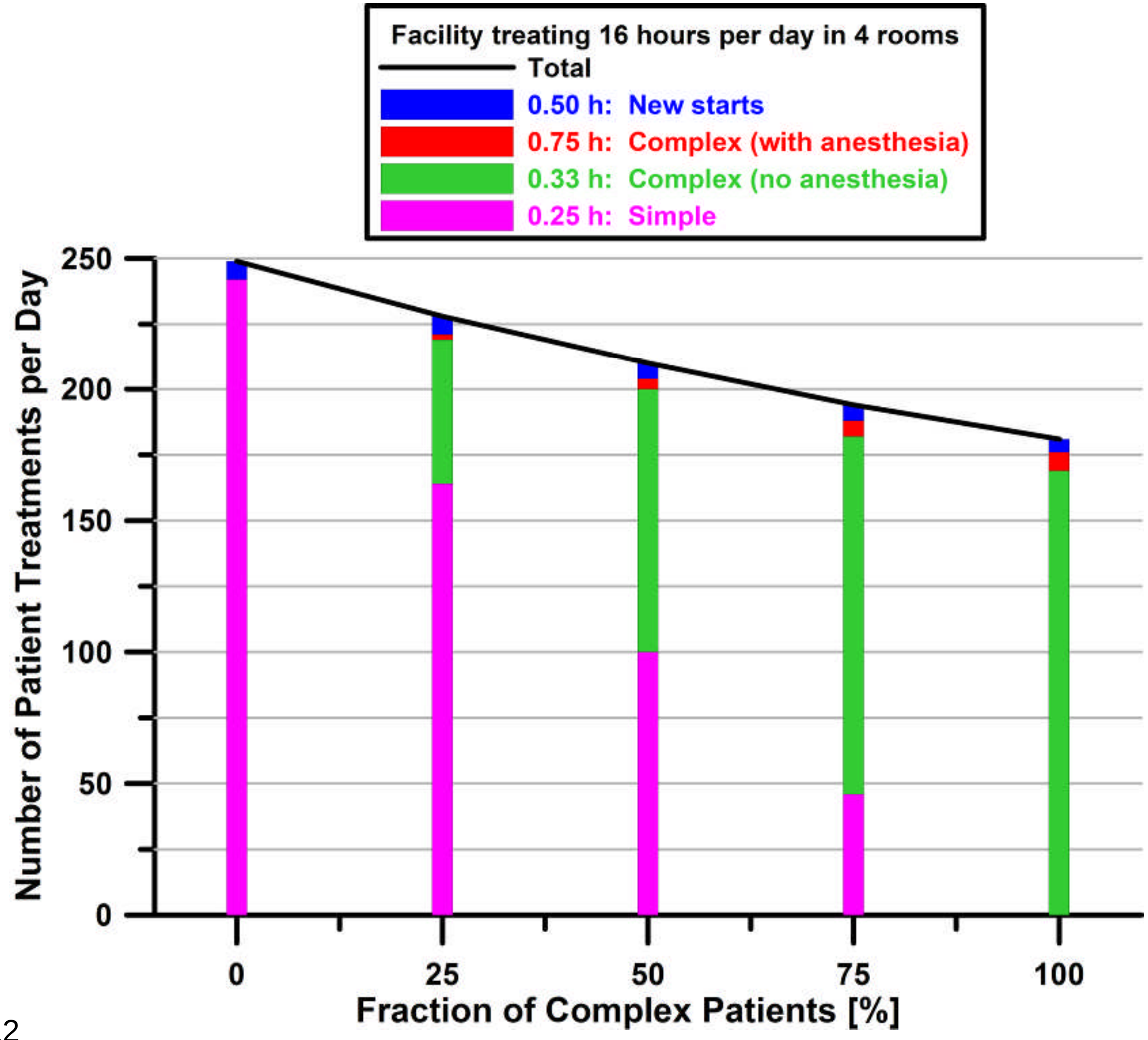
Moyers and Vatnitsky, 2012

Reimbursement Rate for Complex Proton

[based upon 2009 USA Medicare payments x 1.39 to represent typical payor mix]

Moyers and Vatnitsky, 2012

Patient Throughput for 4 Room Facility



Moyers and Vatnitsky, 2012

Annual Reimbursement

[based upon 2009 USA Medicare payments x 1.39 to represent typical payor mix]

Moyers and Vatnitsky, 2012

Proton - Total Cost Versus Lifetime Reimbursement

[assumes 25 year lifetime]

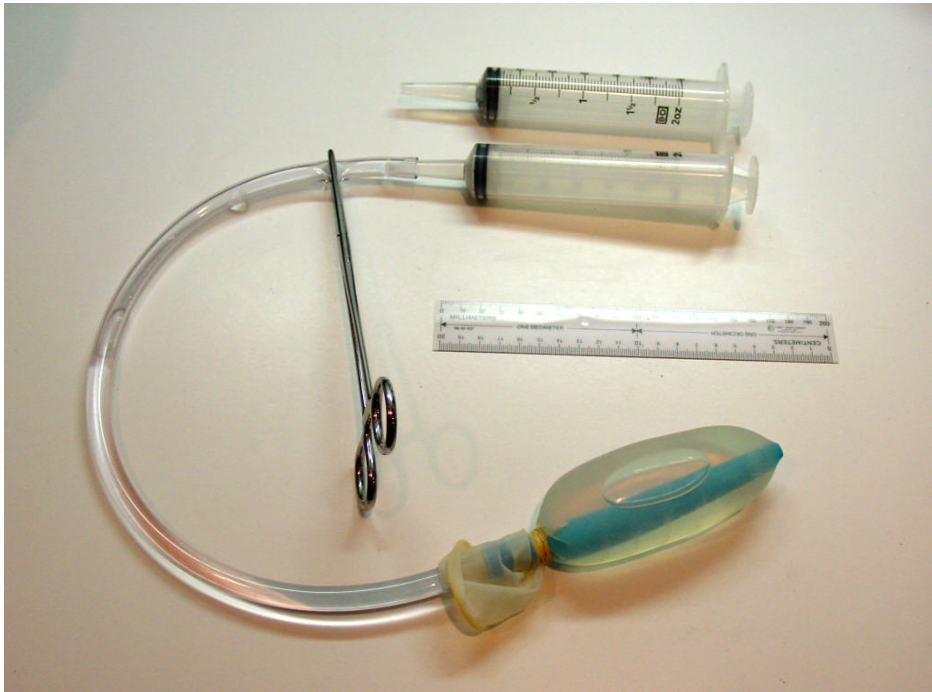
Proton/Helium/Carbon - Total Cost Versus Lifetime Reimbursement

[assumes 25 year lifetime]

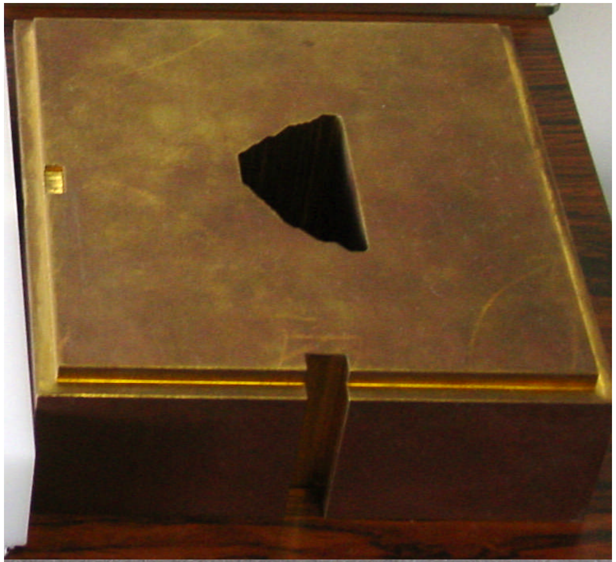
Methods of Reducing Costs and Performance Tradeoffs

- example treatment methods
- example equipment methods

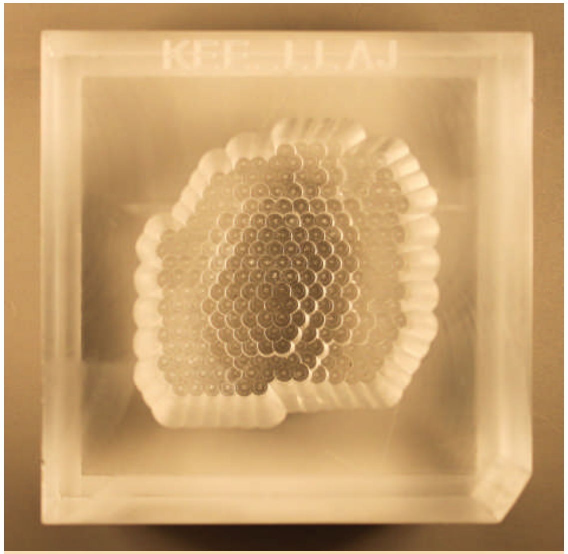
Rectal Balloons -
In-house versus Commercial

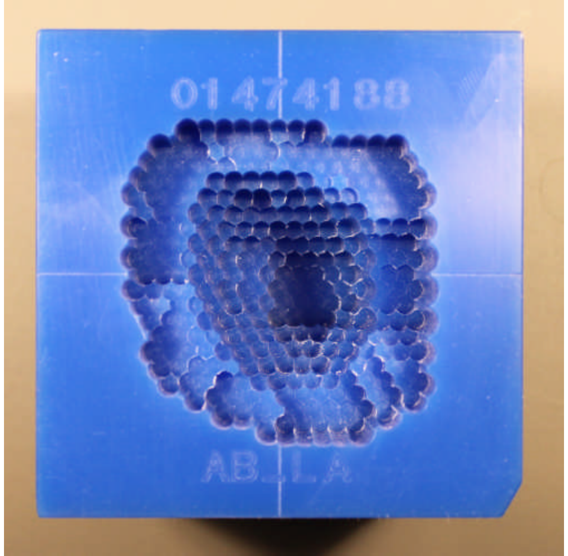


Apertures -
Lipowitz Metal versus Brass



Boluses -
Wax versus PMMA





- Milling time for machinable wax is about half that of PMMA.
- Machinable wax is recyclable on site versus PMMA which is single use.

Modulated Scanning Beams Without Apertures and Boluses

- no devices reduces charges billed to patient ($1,800 / pat)
- no device installation time but slightly longer beam delivery times (differential cost per patient currently indeterminate)
- larger lateral penumbra, less conformal to distal surface of target, and less conformal avoidance to distal critical structures
  - » shaping done upstream in radiation head instead of close to patient
  - » digitization of lateral scanning pattern
  - » digitization of energy stacking pattern
- modulated scanning requires much more beam time for patient specific QA activities potentially reducing number of patients treated per day increasing facility cost per patient.

Hypofractionation Examples

[2009 reimbursement]

- low exit dose and less entrance dose (not surface dose) compared to x rays reduces normal tissue effects allowing hypofractionated treatment course
- prostate
  - » 80 Gy in 40 fractions $38,777
  - » 60 Gy in 20 fractions $21,171
- partial breast
  - » 40 Gy in 10 fractions $12,922
- lung nodule
  - » 70 Gy in 10 fractions $12,922

Mass Production of Equipment

- requirements for "assembly line"
  - » proven continuous customer (healthcare facility) demand
  - » stable design
  - » continuous supply of parts
- requirements for customer demand
  - » healthcare professionals believe light ions are better treatment
  - » patients believe light ions are better treatment
  - » payors believe light ions are an acceptable treatment
  - » payors (patient, insurance company, government agency) reimburse facilities for light ions at rates such that the facilities can break even

Equipment Size

- reduced equipment size ➔ reduced facility costs
  - » land, construction, electricity costs
  - » workflow efficiencies
- folded structures
  - » accelerators, gantries
- reduced range of available gantry angles
- superconducting magnets
- reduced maximum available energy
  - » 300 MeV (50 cm range) allows proton CT and radiography
  - » 250 MeV (37 cm range) allows treatment through long bones and metal implants and use of contralateral approaches to avoid critical structures or previously treated tissues
  - » 220 MeV (30 cm range) allows treatment of ≈ 90% of patients

Comparison of Accelerator Layouts

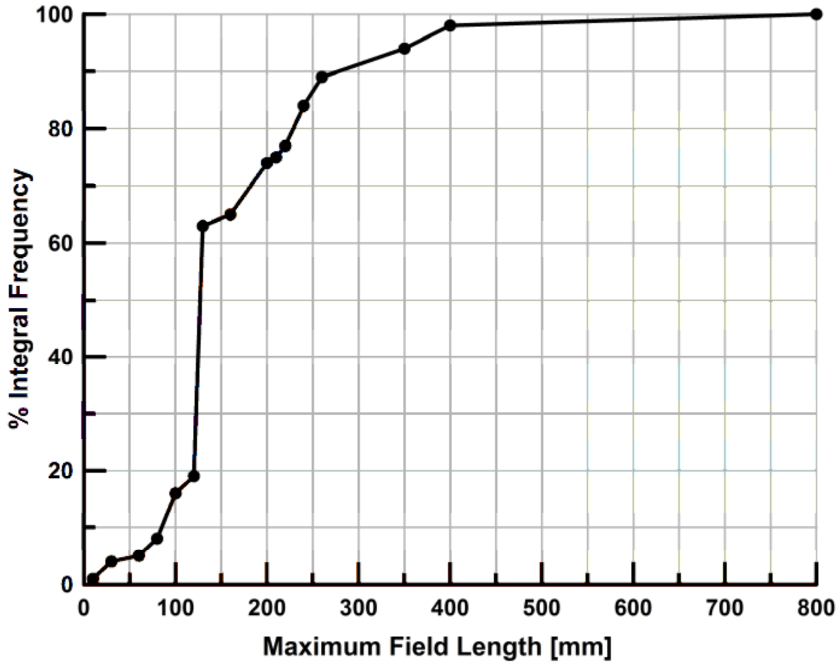
Comparison of Gantry Layouts

Energy / Range Accuracy and Levels

- energy / range interlock
  - » increased costs for instrumentation to monitor and control energy (@ accelerator, switchyard, gantry)
  - » ± 4 mm enables reduction of integral dose relative to x rays
  - » ± 0.5 mm enables patch portals
  - » ± 0.1 to 0.25 mm enables energy stacking
  - » decreased costs for QA effort
- number of user selectable energies
  - » more energies can increase the cost for commissioning and QA time
  - » 18,000 enables conformal energy stacking
  - » 256 enables energy stacking but slightly less conformal
  - » 8 reduces lateral penumbra but eliminates possibility of energy stacking
  - » 1 requires larger margins for blocking of distal critical structures (large distal penumbra at lower energies)

Field Size

- equipment to support larger field sizes (MLCs, applicators, scanning magnets) generally costs more than equipment that supports only small field sizes
- due to reduced drift length, diameter of gantry may be reduced if maximum available field length is reduced



- splitting a large field into multiple small matching fields takes longer to treat and has the potential for poor dose distributions at junctions due to patient movement, divergence, and more possibilities for errors

Temporal-Spatial Dose Delivery

- different instantaneous dose rates have different biological effects on tissues
- instantaneous dose rate dependencies
  - » beam flux, pulse repetition rate, pulse length, spot size, spot overlap, number of aiming points, scanning speed
- a longer treatment time reduces the number of patients treated per day increasing the cost per patient
- reducing the number of aiming points or the overlap between spot paths may reduce the treatment time but may also induce dose non-uniformities within the target.
- the interactions between various beam delivery parameters should be carefully scrutinized before selecting a beam delivery system

Room-to-Room Beam Switching Time

- longer switching time increases probability of patient moving from aligned position while waiting for beam
- longer switching time reduces number of patients treated per day increasing cost per patient
- time to switch beam between rooms for the current generation of equipment varies from a low of 20 s to a high of 240 s
- lower beam switching time may be optional cost
- beam switching time can be impacted by integration of various systems; e.g. treatment information and management system

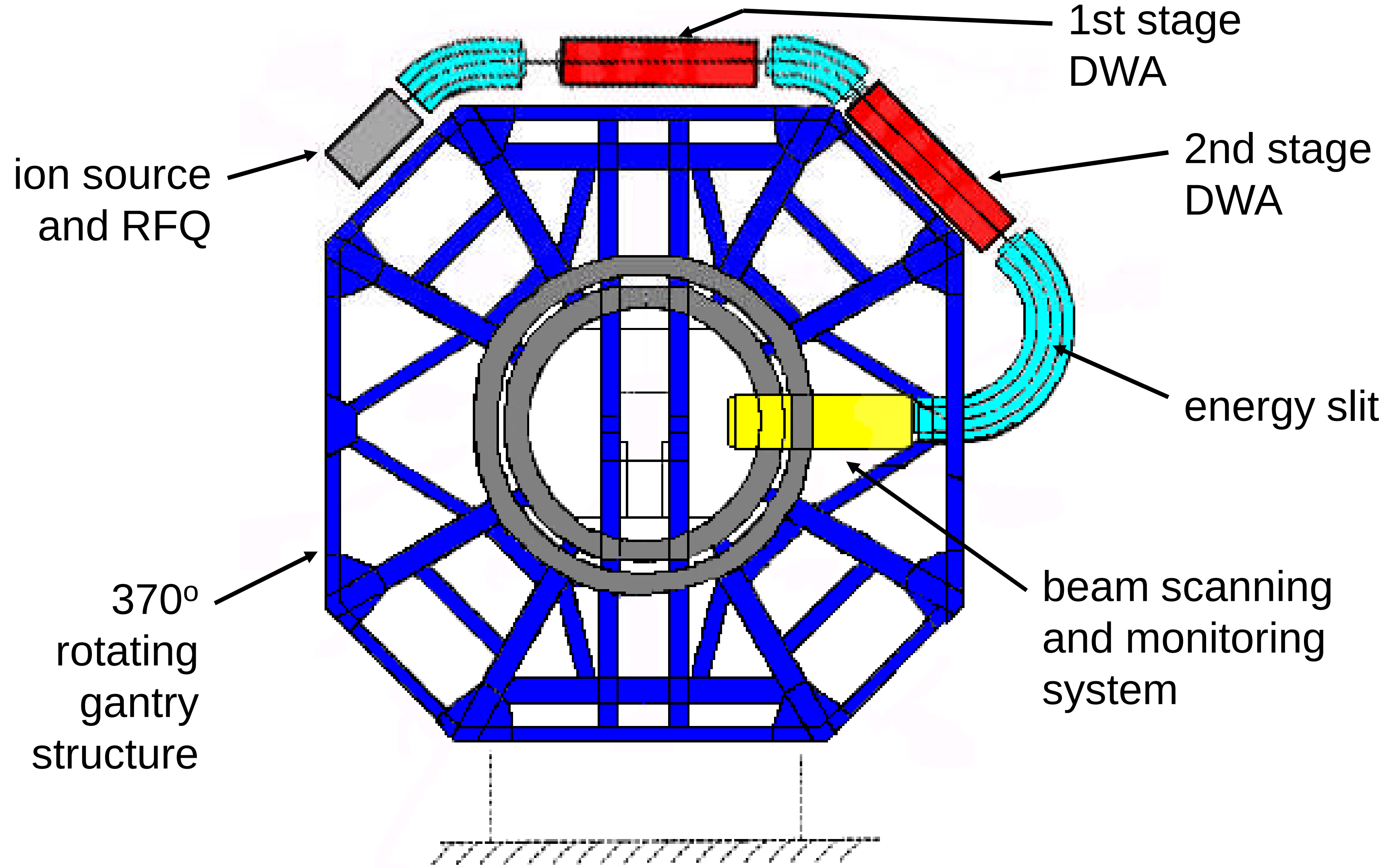
Availability and Reliability

- Loma Linda accelerator has been available 24 h per day, 6.5 days per week, 52 weeks per year for the past 21 years (except for holidays)
  - » treatments 16 h per day
  - » patient and periodic quality assurance 3 - 6 h per night and 12 to 24 h on weekends
  - » research and development 2 h per night and 12 h on weekends
  - » preventative maintenance on one gantry per night for 2 h
  - » preventative maintenance on accelerator and SY on weekends for 12 h
  - » did not repair ring magnets or RFQ over 21 years
- **TIME ALLOTTED FOR MAINTENANCE IN THE SERVICE CONTRACT HAS HUGE IMPACT ON FACILITY REVENUE**
- typical maintenance contract cost may be up to 7% of initial equipment cost each year

Future Single Room Solutions

- smaller patient load easier to justify for smaller facilities
- smaller initial cost, easier to get loan
- treatment cost per patient might be higher or lower than with existing equipment, currently unknown
  - » no cost sharing of accelerator between multiple rooms
  - » more expensive materials used to reduce size
  - » newly introduced technology may require more maintenance
- shorter travel distance for some patients due to more widespread availability reduces cost to patient
- possibly larger energy spread and possible lack of energy interlock capability may impact ability to perform distal blocking, patch portals, or energy stacking

Future LIVMAT and ICT



Recapitulation

- light ion teletherapy has been used for patient treatments since 1954
- leading cost in treating with light ions is salaries, next leading costs are supplies and maintenance
- the cost of the beam delivery equipment has little impact on the cost of treatment but a large impact on the financing of a new facility
- users should implement methods to increase efficiency of treatments and reduce costs
- manufacturers should increase reliability to reduce maintenance costs and increase beam time available for patients and QA procedures
- main impediment to wide-spread implementation is financing for initial cost of equipment and building
- further research is needed to reduce size and cost of equipment
- initial costs can be decreased by reducing specified capabilities but beware of the associated loss of performance

Learning Objectives

I. Become familiar with estimated costs associated with starting and operating a light ion teletherapy facility.

II. Become familiar with the relative costs of various items important for the success of a project.

III. Become familiar with tradeoffs in performance for various cost saving methods.