Medical accelerators

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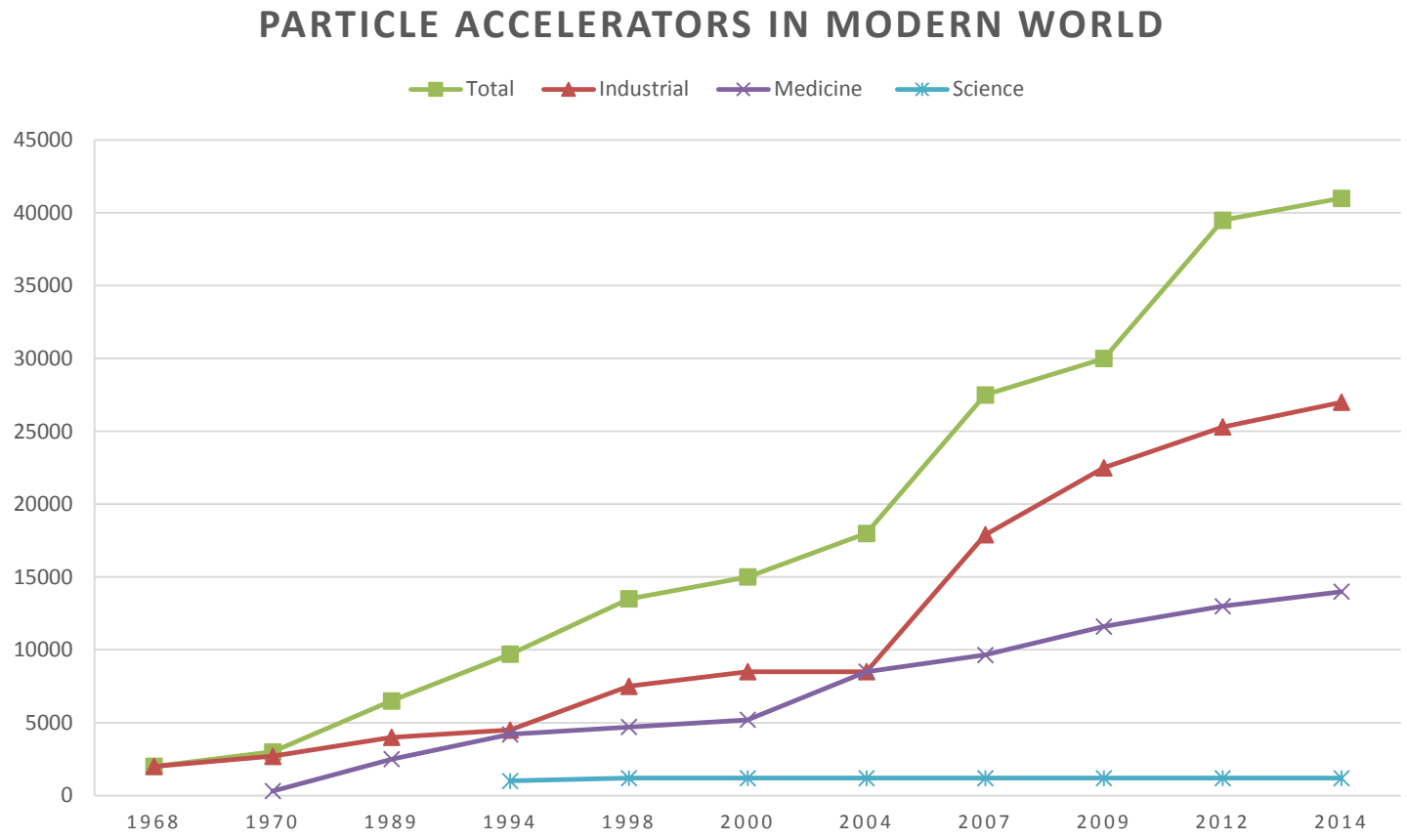
Particle accelerators operational in the world

Three main applications: 1) Scientific research, 2) Medical applications 3) Industrial uses

Accelerators	1968 [1]	1970 [2]	1989 [3]	1994 [4, 5]	1998 [6–8]	2000 [9, 10]	2004 [11, 12]	2007 [13, 14]	2009 [15, 16]	2012 [17, 18]	2014 forecast
Industrial accelerators,	~2000	~2700	>4000	>4500	~7500	~8500	>8500	~17 900	22 500	25 300	27 000
including											
Electron accelerators rated to energies in excess of 300 keV			~650	1500	1500	1500	>1500	2700	2750	~5000	~5000
Electron accelerators rated to energies below 300 keV			>350	>1000				4500	7000	7500	~8000
Ion implanters and accelerators for ion analysis			~3000	>2000	~6000	~7000	>7000	~9700	~10 000	~11 300	~12 000
Neutron generators								~1000	~2000	~2000	~2000
Accelerators in science				~1000	~1200	~1200	~1200	~1200	~1200	~1200	~1200
Accelerators in medcine,		306	>2500	~4200	~4700	~5200	~8500	~9650	~11 600	~13 000	~14 000
including											
Electron accelerators			~2500	~4000	~4500	~5000	~7500	~9000	>11 000	~12 000	~13 000
Proton and ion accelerators (radiotherapy) [19]			11	17	20	20	25	29	32	39	~59
Production of radioisotopes for medicine				~200	~200	~200	~260	>550	>600	~1000	~1100
Total	~2000	~3000	>6500	>9700	>13 500	>15 000	>18 000	~27 500	~30 000	~39 500	41 000

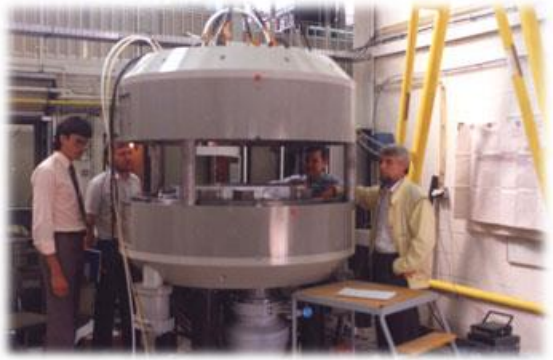
A. P. Chernyaev and S. M. Varzar, Particle Accelerators in Modern World, Physics of Atomic Nuclei, 2014, Vol. 77, No. 10, pp. 1203–1215.

Three main applications: 1) Scientific research, 2) Medical applications 3) Industrial uses



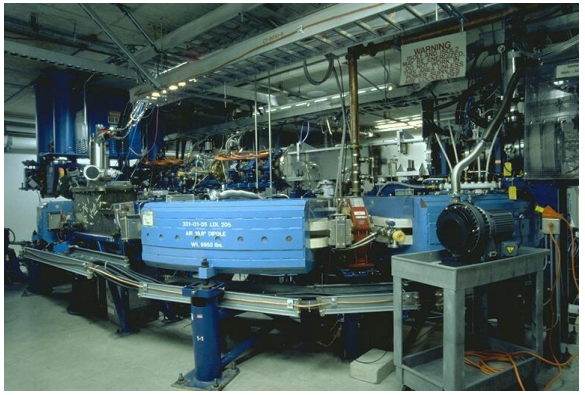
A. P. Chernyaev and S. M. Varzar, Particle Accelerators in Modern World, Physics of Atomic Nuclei, 2014, Vol. 77, No. 10, pp. 1203–1215.

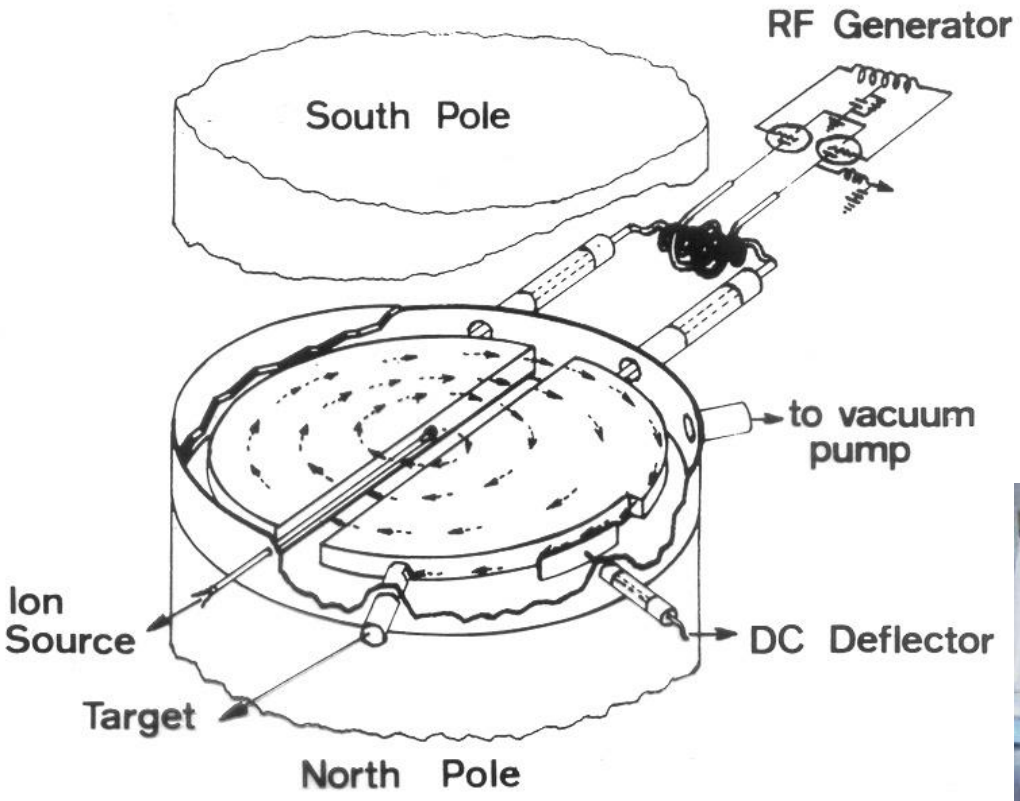
- Production of radionuclides with (low-energy) cyclotrons
  - Imaging (PET and SPECT)
  - Therapy



- Electron linacs for conventional radiation therapy
  - Including advanced modalities

- Medium-energy cyclotrons and synchrotrons for hadron therapy with protons (250 MeV) or light ion beams (400 MeV/u ^{12}C-ions)
  - Accelerators and beam delivery



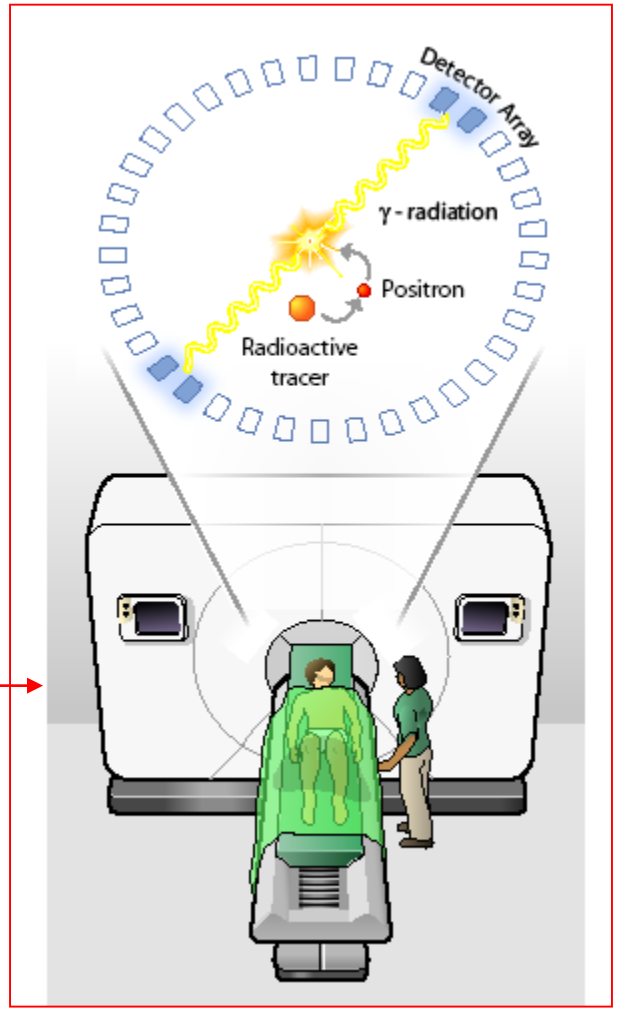


Scanditronix MC40

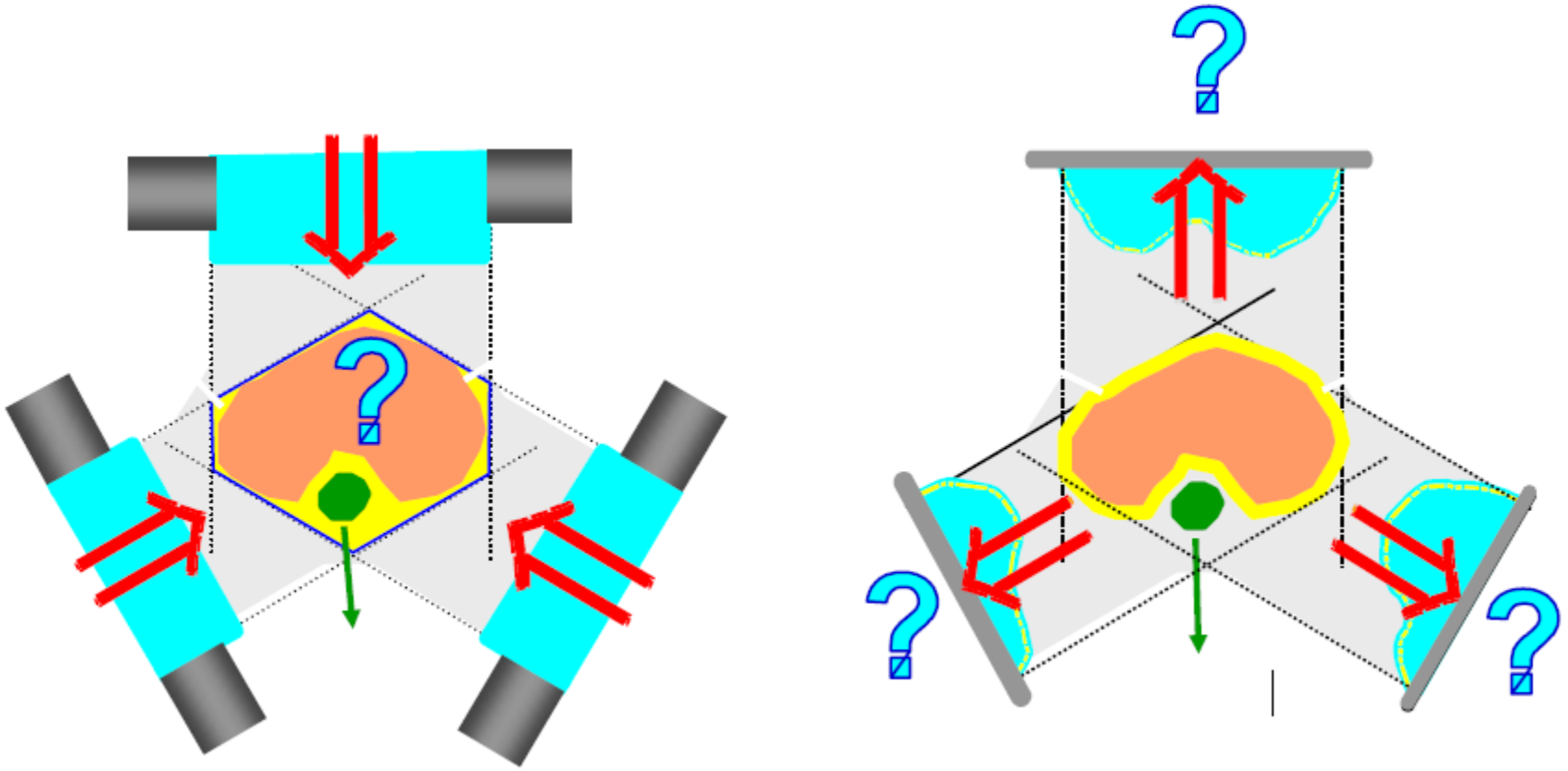
Mini-Cyclotron

Radiochemistry

PET camera

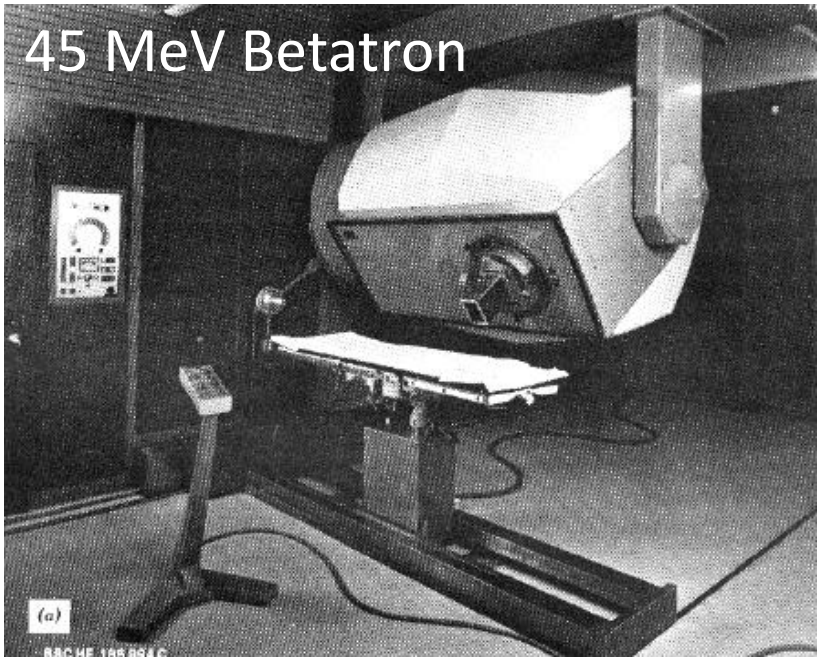


J. Long, "The Science Creative Quarterly",scq.ubc.ca



Treatment planning and dose delivery to tumour volume

Past radiation therapy equipment



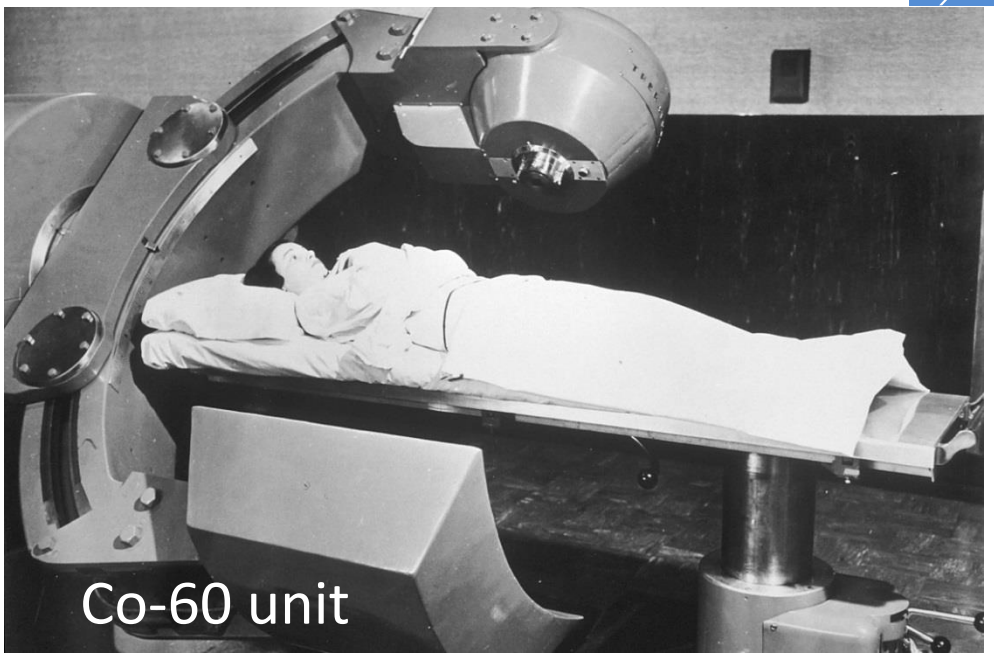
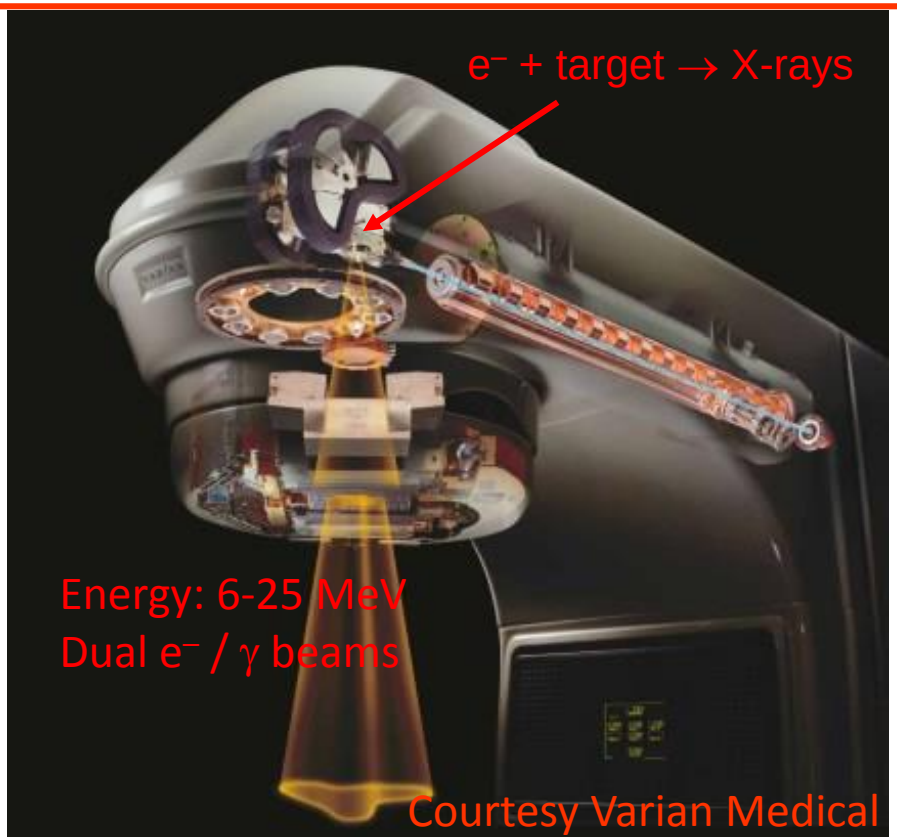


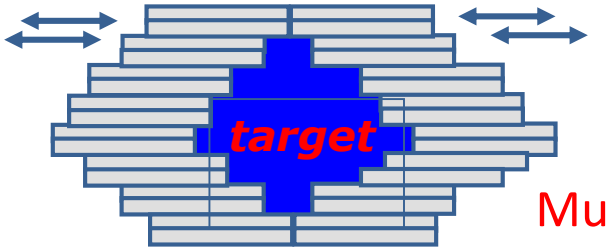
Photo: Wikipedia

Radiation therapy is much more than the radiation source. One also needs:

- diagnostic equipment, CT scanners
- treatment planning software
- patient set-up devices
- computers
- a broad range of professional figures

Medical electron linacs





Multi-leaf collimator

Cyber-knife robotic surgery system

6 MV Linac mounted on a robotic arm

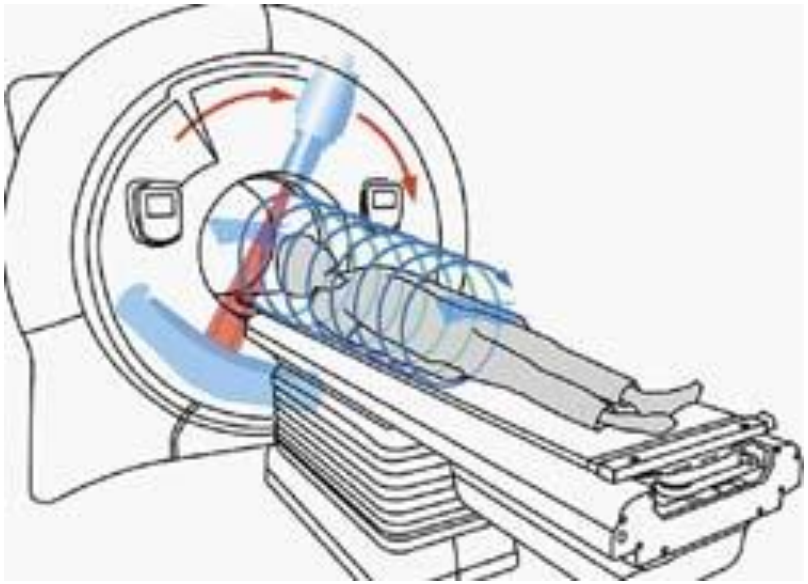
- No flattening filter
- Uses circular cones of diameter 0.5 to 6 cm
- Non-Isocentric
- Average dose delivered per session is 12.5 Gy
- Dose rate @ 80 cm = 400 cGy/min

http://www.accuray.com/Products/Cyberknife/index.aspx

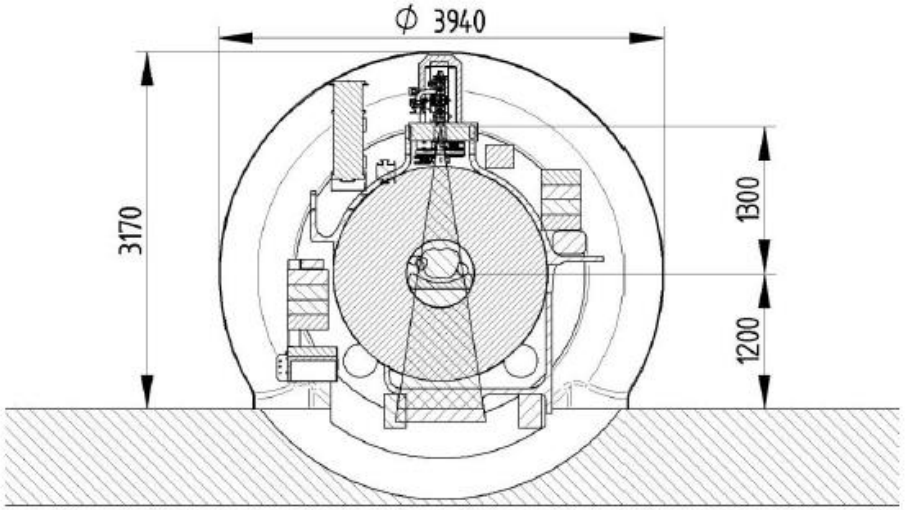
Intra-operative radiation therapy (IORT)

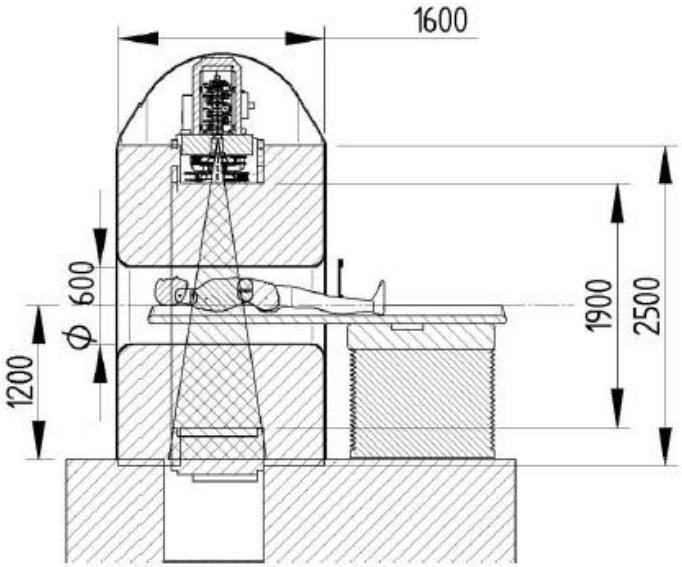
- Small electron linac
- Energy 6 – 12 MeV
- Treatment with electrons only
- Single irradiation
- Three models of linac from three manufacturers

www.tomotherapy.com



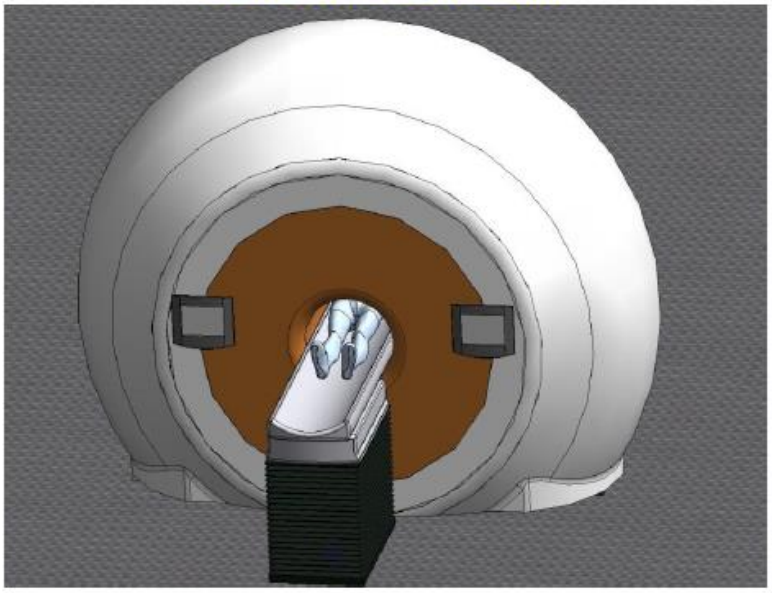
- Integrated CT guidance
  - Integrated CT scanner allowing efficient 3D CT imaging for ensuring the accuracy of treatment
- A binary multi-leaf collimator (MLC) for beam shaping and modulation
- A ring gantry design enabling TomoHelical delivery
  - As the ring gantry rotates in simultaneous motion to the couch, **helical fan-beam IMRT** is continuously delivered from all angles around the patient
  - Very large volumes can be treated in a single set-up



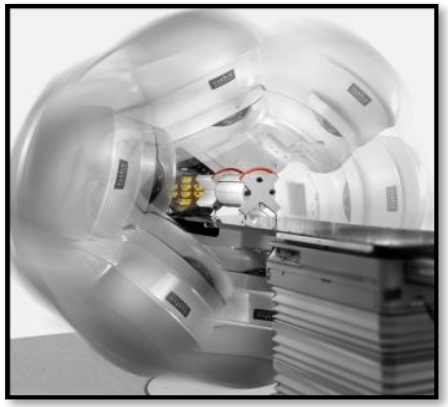


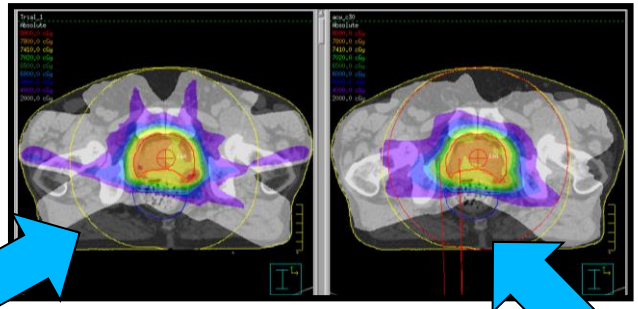
- *Closed bore high field MRI*
- *Gantry ring based 6 MV accelerator with MLC*
  - ➔ *accelerator and MRI system have to operate simultaneously and independently*

Courtesy J. Lagendijk



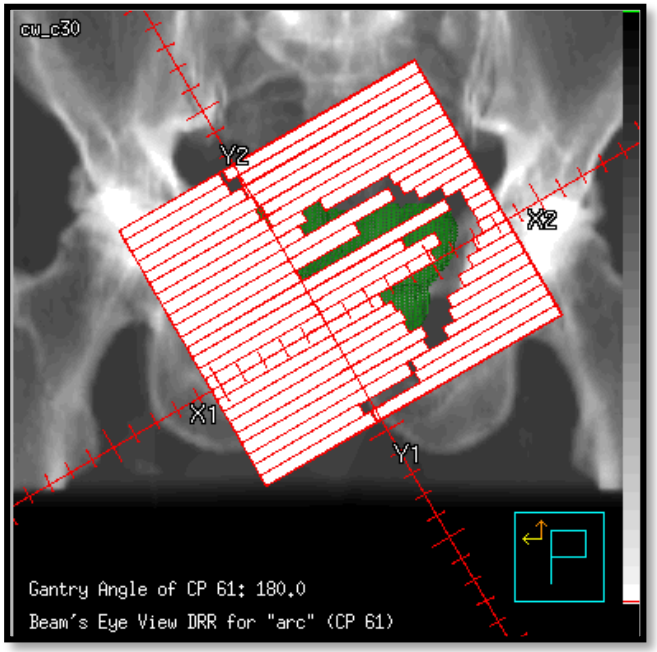
Rotate linac gantry while modulating the beam





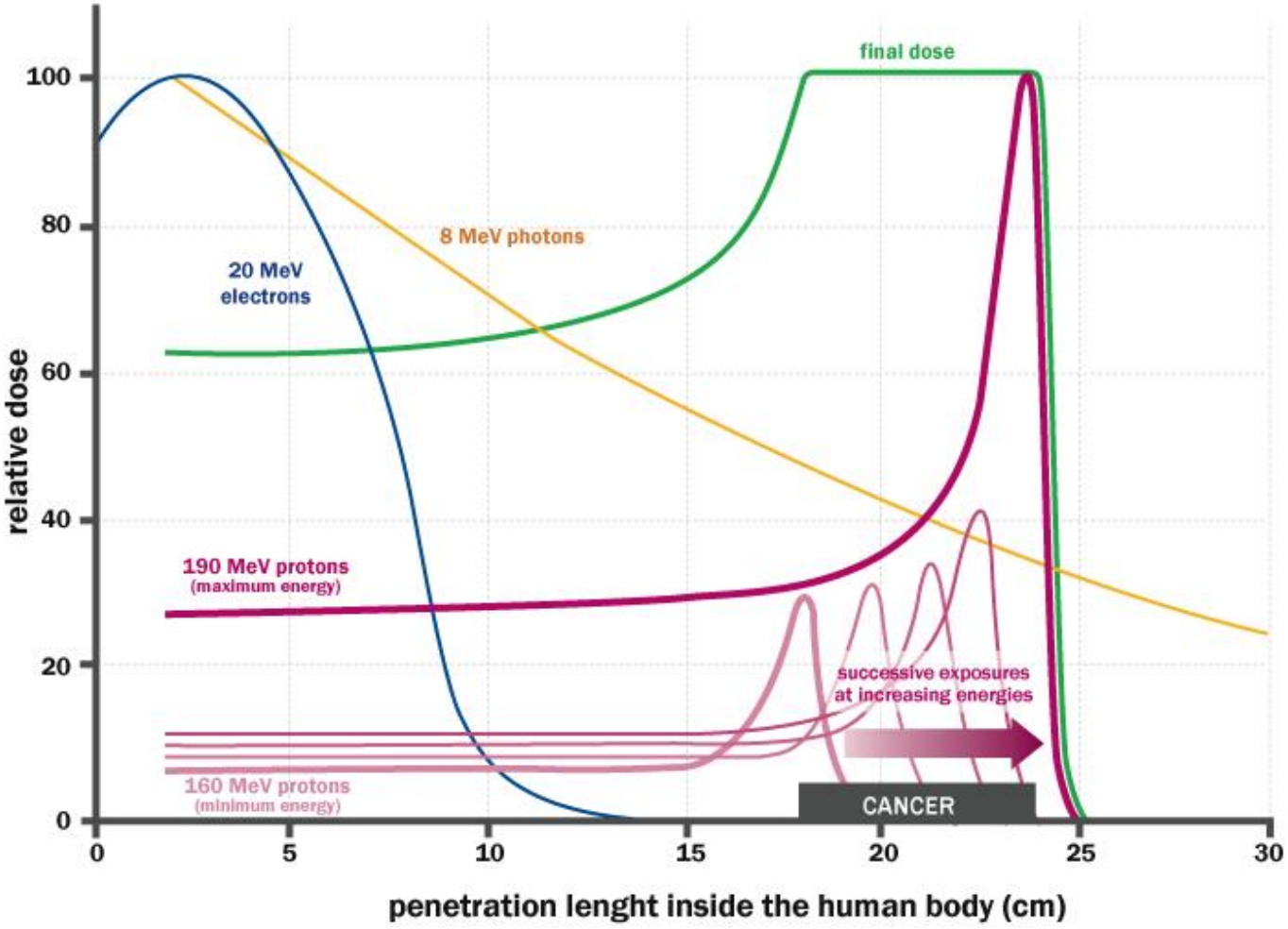
Fixed 6 or so gantry angles

VMAT



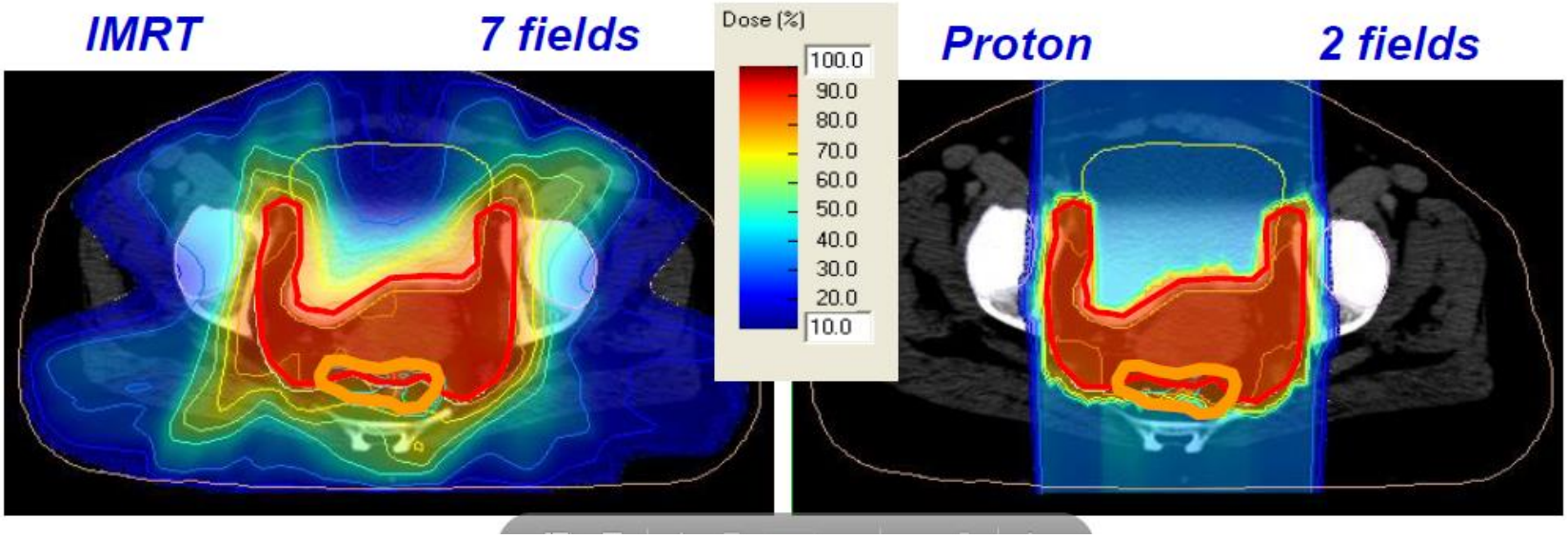
Name-Prof Peter Metcalfe
BSOC lecture 08
University of Wollongong

Particle therapy (hadron therapy)



Courtesy INFN, Italy

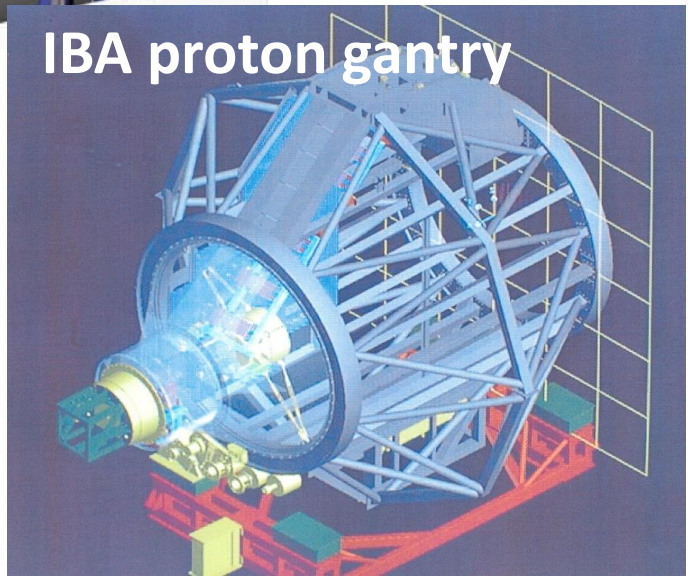
- Ion beam therapy is more conformal than photon beam RT
- Sharper dose fall off
- Range of ions much more influenced by tissue heterogeneities than photon beams with direct impact on TCP and NTCP
- Image guidance is necessary for ion beam therapy



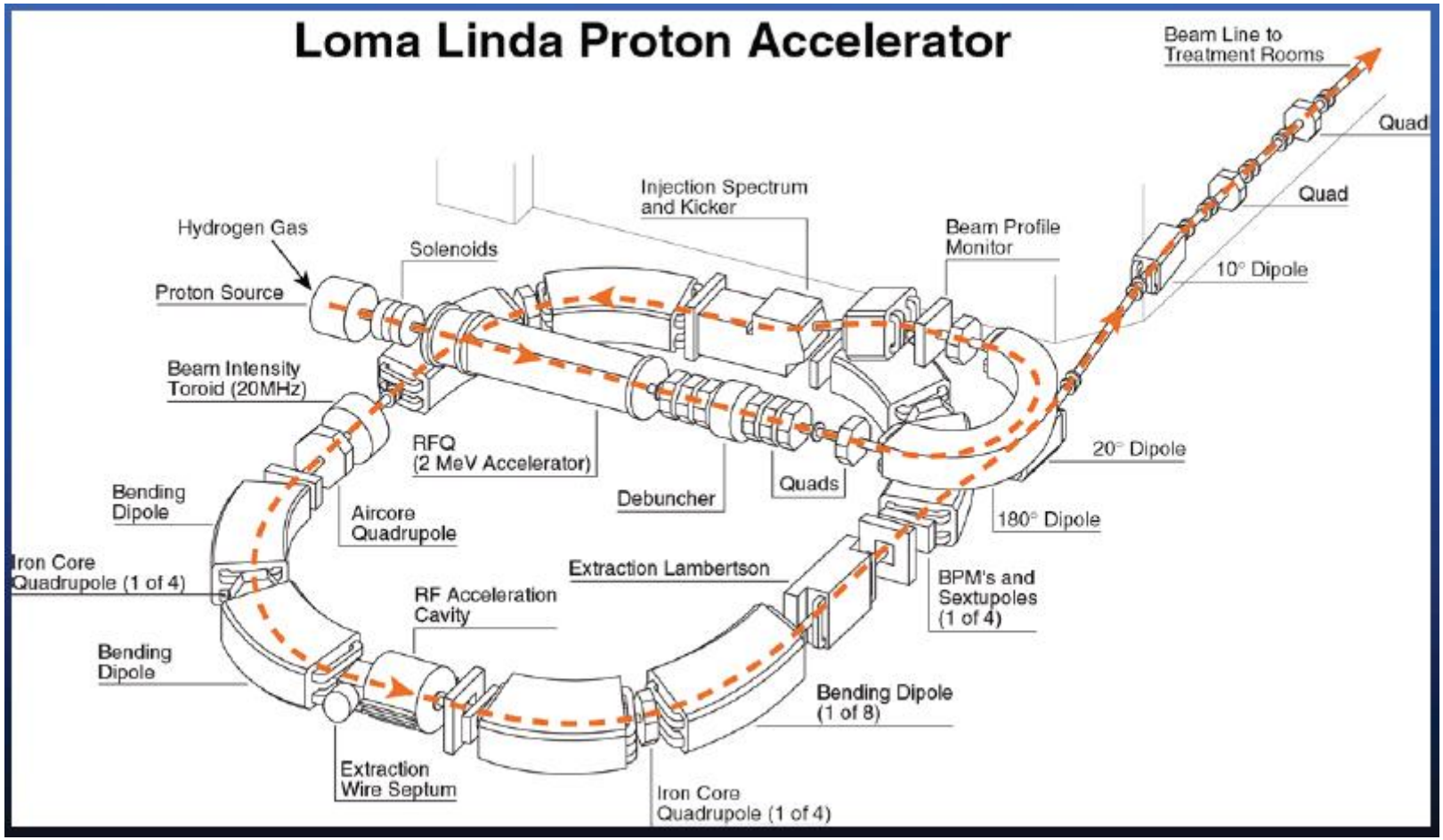
IBA cyclotron

Accel-Varian
(superconducting cyclotron)


Hitachi synchrotron

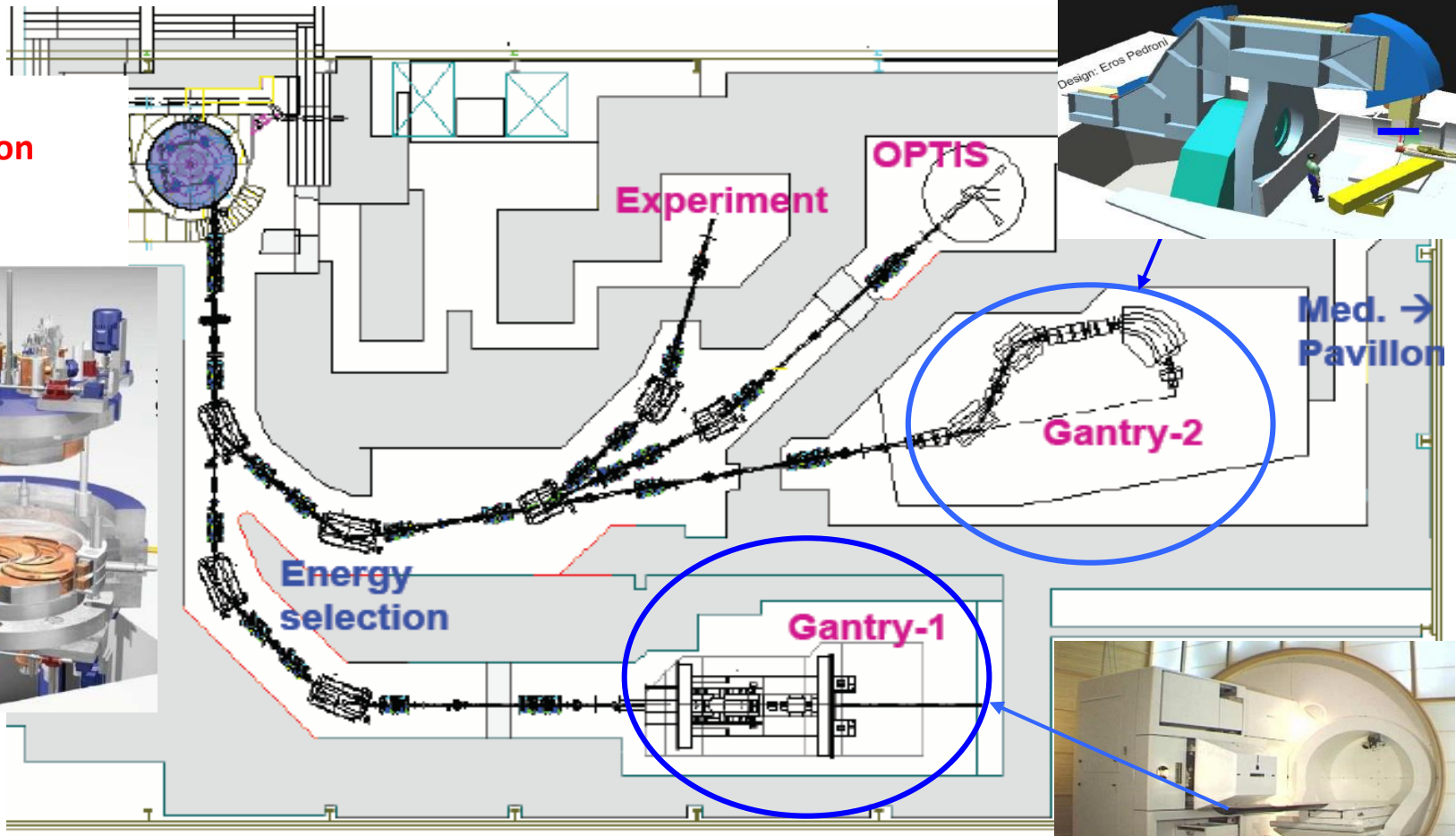

IBA proton gantry

Loma Linda University Medical Center



PROSCAN at Paul Scherrer Institut (PSI), Switzerland

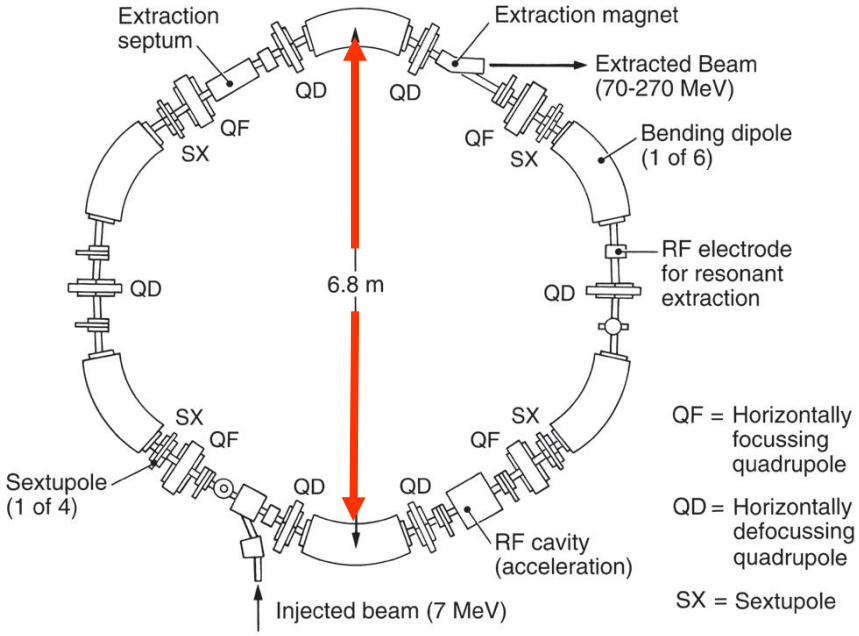
ACCEL
SC cyclotron
250 MeV protons



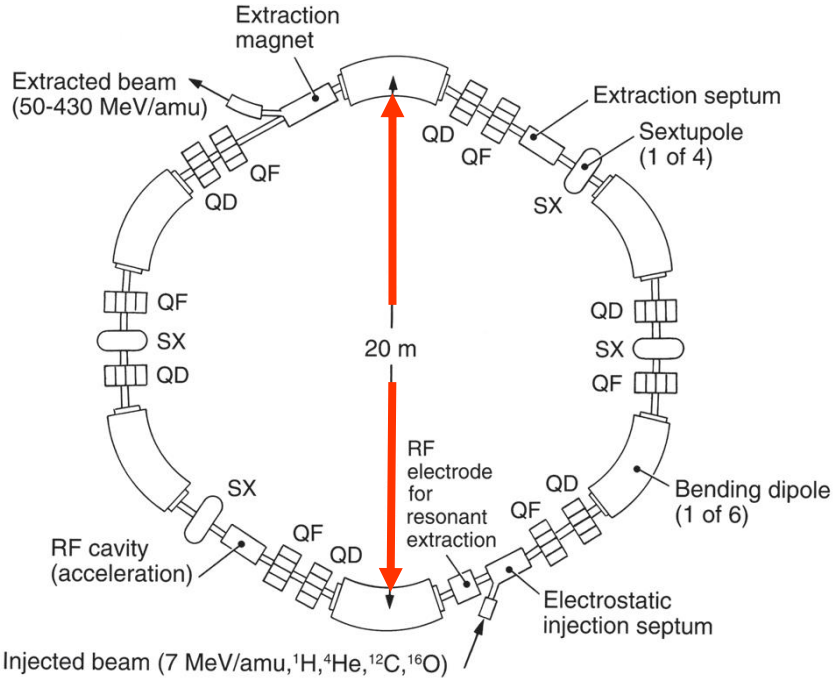
Courtesy PSI and U. Amaldi , *TERA*

J.M. Schippers et al., NIM BB 261 (2007) 773–776

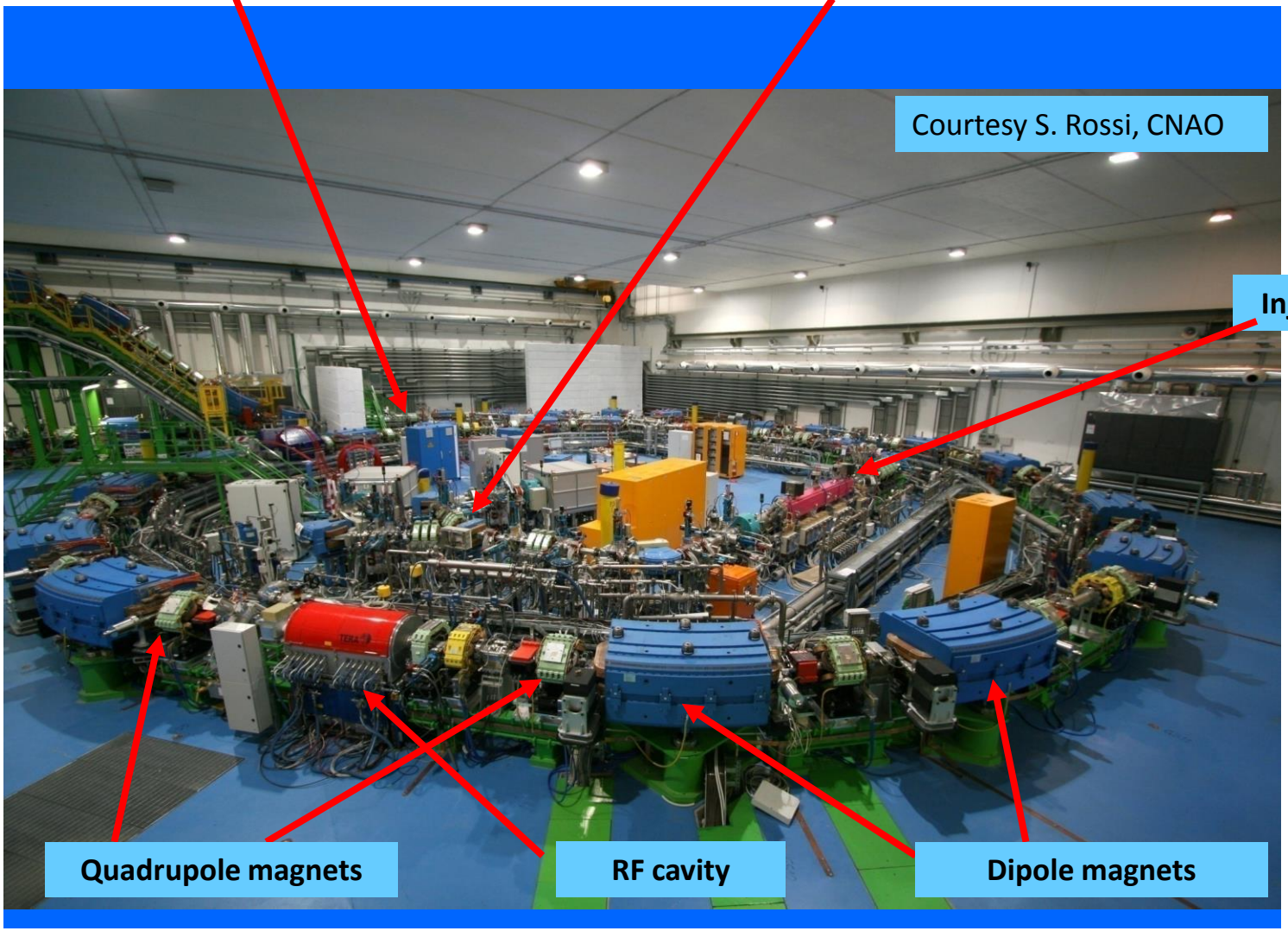
Hitachi proton synchrotron



Siemens ion synchrotron

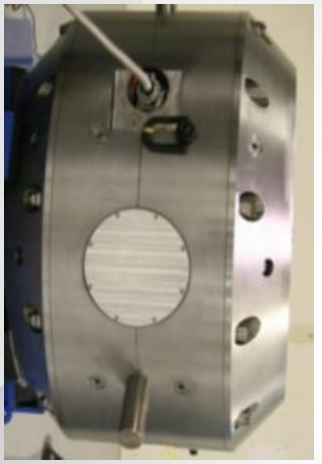


G. Coutrakon, Accelerators for Heavy-charged-particle Radiation Therapy,
Technology in Cancer Research & Treatment, Volume 6, Number 4 Supplement, August 2007

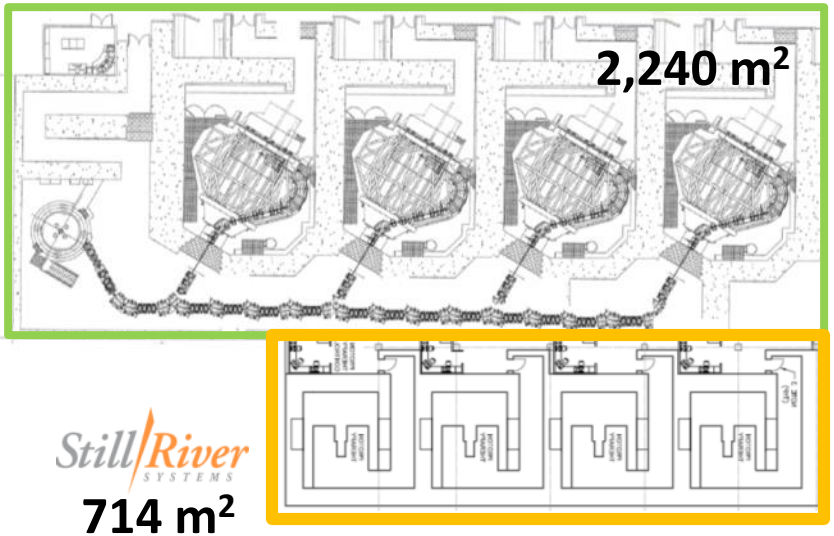

Ion sources
Low Energy Beam Transport components
Courtesy S. Rossi, CNAO
Injector linac
Quadrupole magnets
RF cavity
Dipole magnets

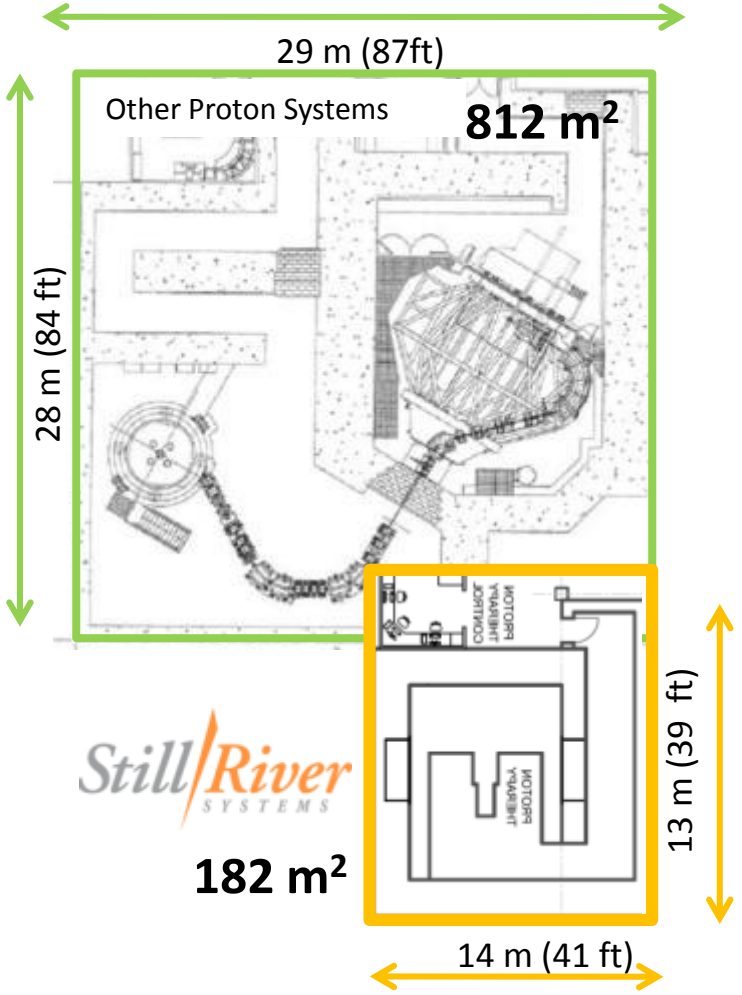
Mevion Medical Systems – single room facility

Synchrocyclotron



Multi-room versus single-room facilities



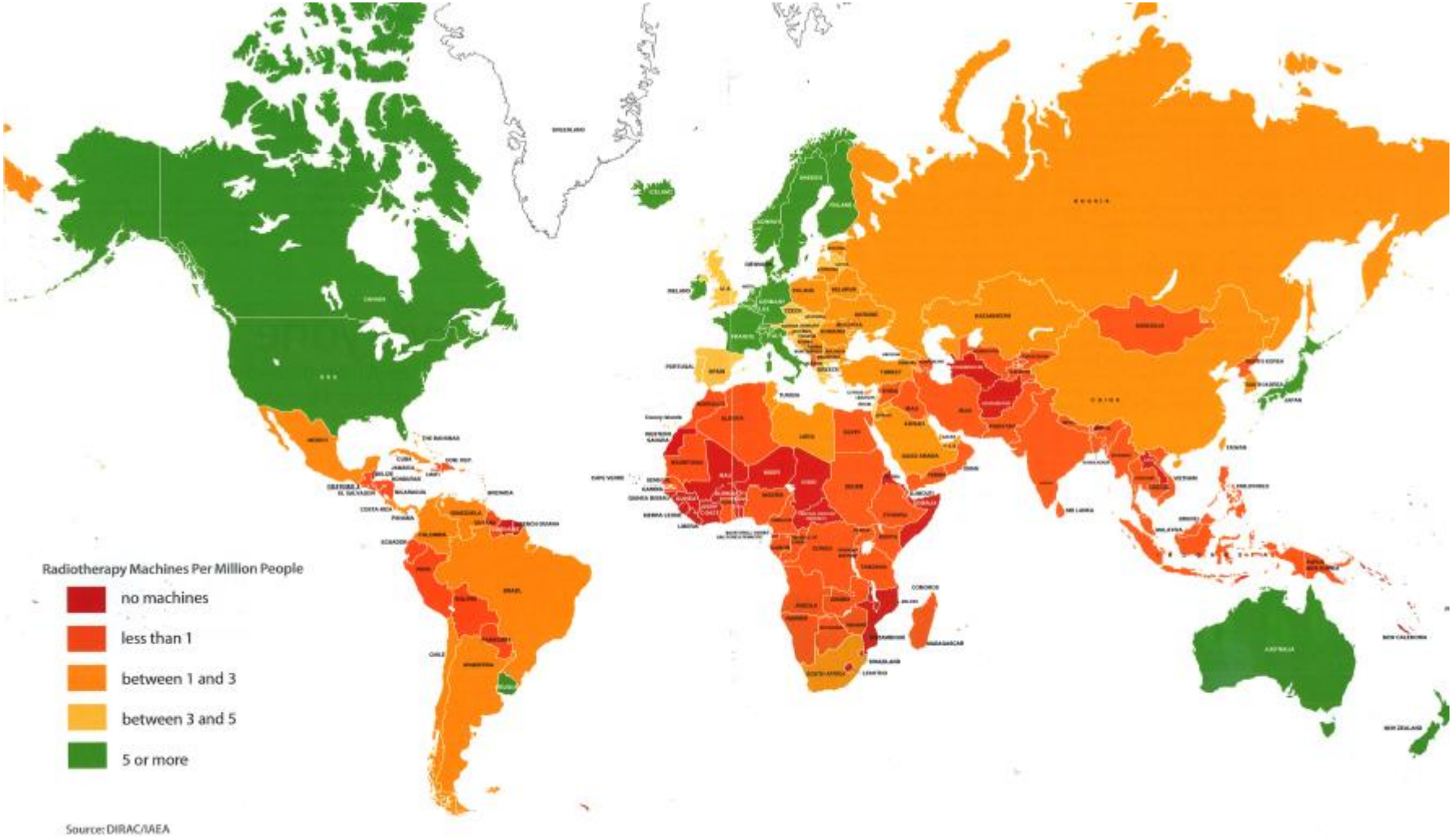


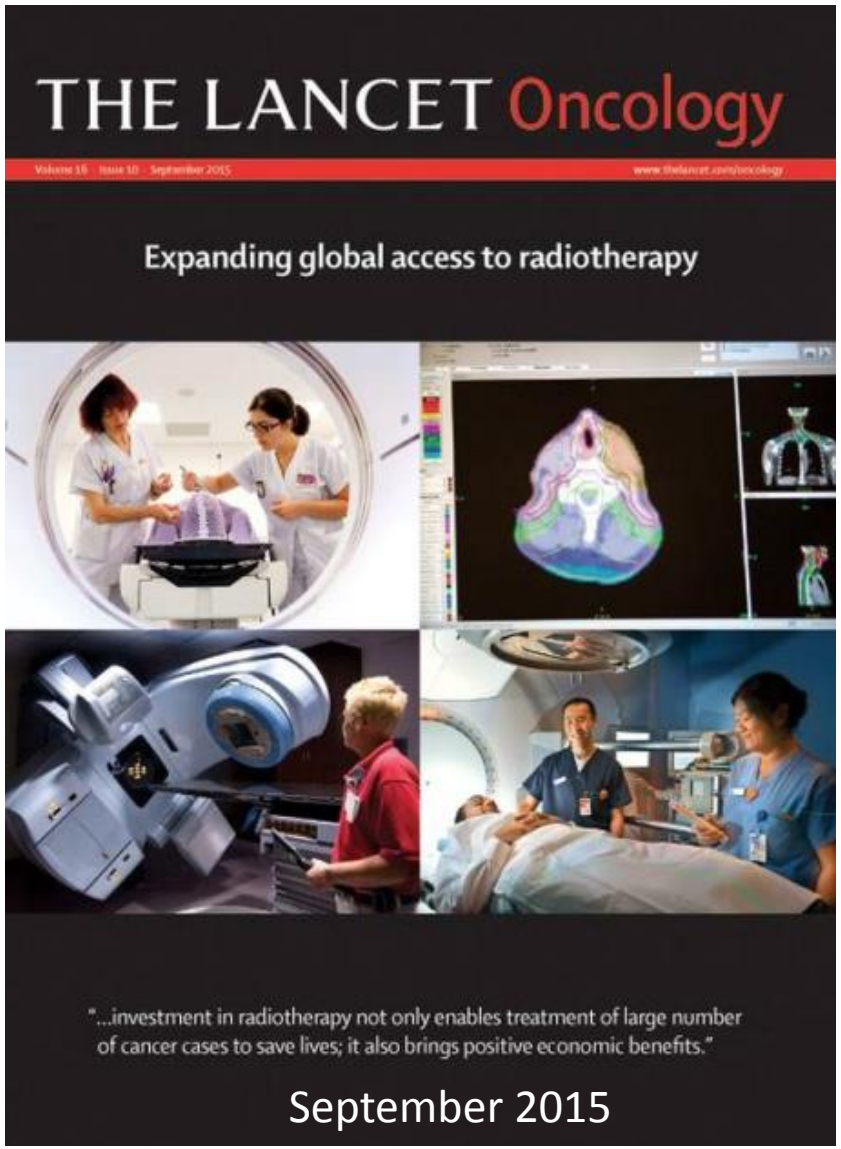
Advantages of single-room facility:

- ✓ **Modularity**
- ✓ **Reliability / back-up**
- ✓ **PT treatment available at more hospitals**
- ✓ **(Hopefully) cost**

Courtesy L. Bouchet, *Still River Systems*

Availability of radiation therapy worldwide





September 2015

International Cancer Expert Corps
Partnering to transform global cancer care

CERN-ICEC workshop, CERN, November 2016

https://indico.cern.ch/event/560969/

CERN
International Cancer Expert Corps
Partnering to transform global cancer care
Science & Technology Facilities Council
10 Years of Impact and Inspiration

CERN-ICEC-STFC workshop, CERN, October 2017

https://indico.cern.ch/event/661597/

Global cancer burden and need for radiotherapy

According to estimates made by the International Agency for Research on Cancer (IARC), there are about 15 million new cancer cases per year worldwide, of which two thirds occur in developing countries.

The age distributions of cancer are, however, quite different between developed and developing countries; there are significantly more cancer cases in childhood, adolescence and young adults in developing countries, while cancer in the elderly dominates in developed countries

IAEA, Setting up a radiotherapy program, 2008

Need for

- qualified professionals (radiation oncologists, medical radiotherapy physicists, radiotherapy technicians, radiation protection officers, maintenance engineers, etc.)
- development of medical infrastructure for cancer treatment

Technology

- 23 of 54 countries have teletherapy services
- 20 had high- or low-dose brachytherapy resources
- 293 radiotherapy machines serving 1 billion individuals
- 1 machine per 3.6 million people

Abdel-Waheb et al, Lancet Oncology, 2013 / Grover et al, Front in Oncology, Jan 2015 / Balogun et al, Radiation Oncology, Aug 2016

Taken from Surbhi Grover's lecture at the CERN-ICEC-STFC workshop, CERN, October 2017

Human resources

- a gap of 7,500 oncologists, 6,000 physicists and 20,000 technicians in LMICs (in Africa: 1600 medical oncologists, 1000 medical physicists and 4000 technicians)

Taken from Andras Fehervary's lecture at the CERN-ICEC workshop, CERN, November 2016

RT resources needed in 20 years from now

	High Income Countries	LMICS
Megavoltage Machines	9200	12600
Radiation Oncologists	1550	30000
Medical Physicists	17200	22100
Radiation Technologists	51900	78300

LMICS = Low Medium Income Countries

Taken from Mary Gospodarowicz's lecture at the CERN-ICEC workshop, CERN, November 2016

Atun et al., Lancet Oncology 2015

Union for International Cancer Control
www.uicc.org

Linacs

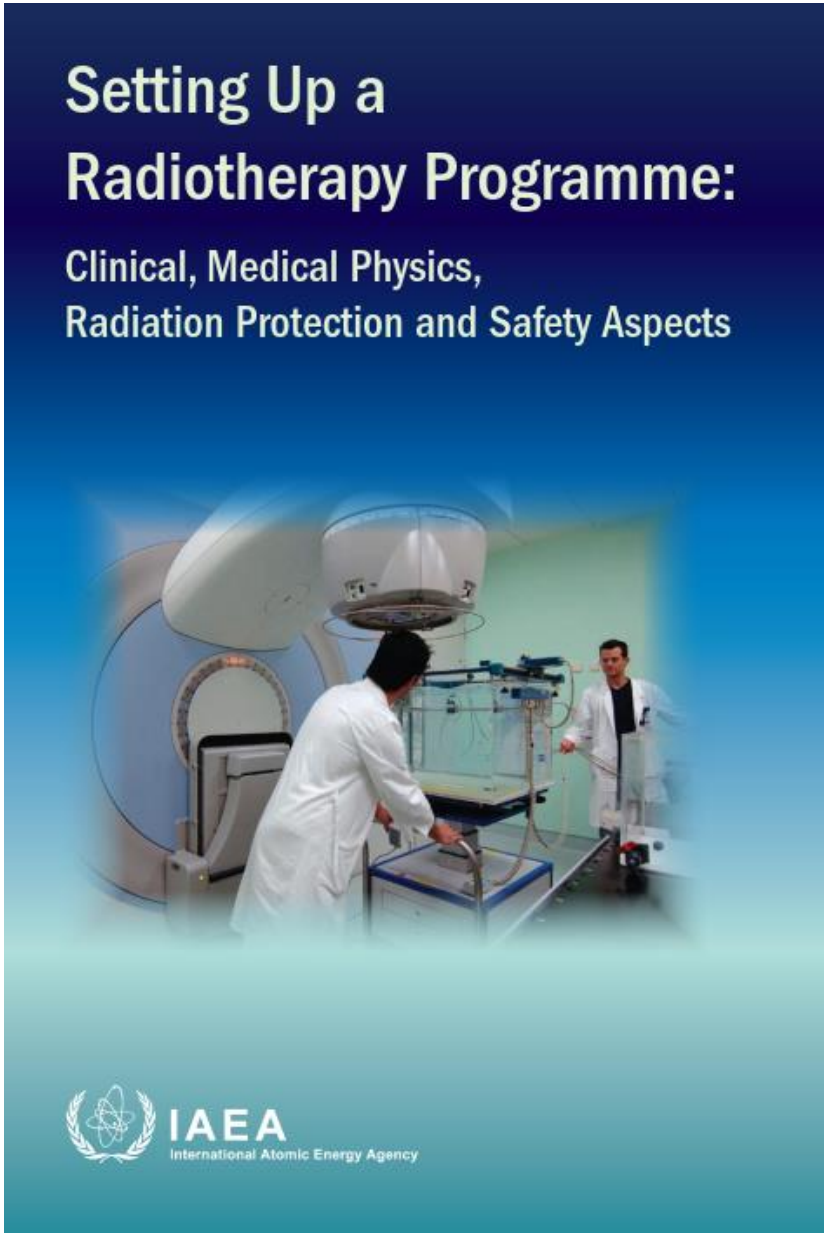
- Ability to operate in a difficult environment
  - Interruptions in electricity / power supply
  - Heat / problem with temperature control
  - Dust and humidity
- Highly modular, so that faulty parts can easily be replaced
- Self-diagnosing, in case of accelerator malfunctioning
- Low power consumption
- …

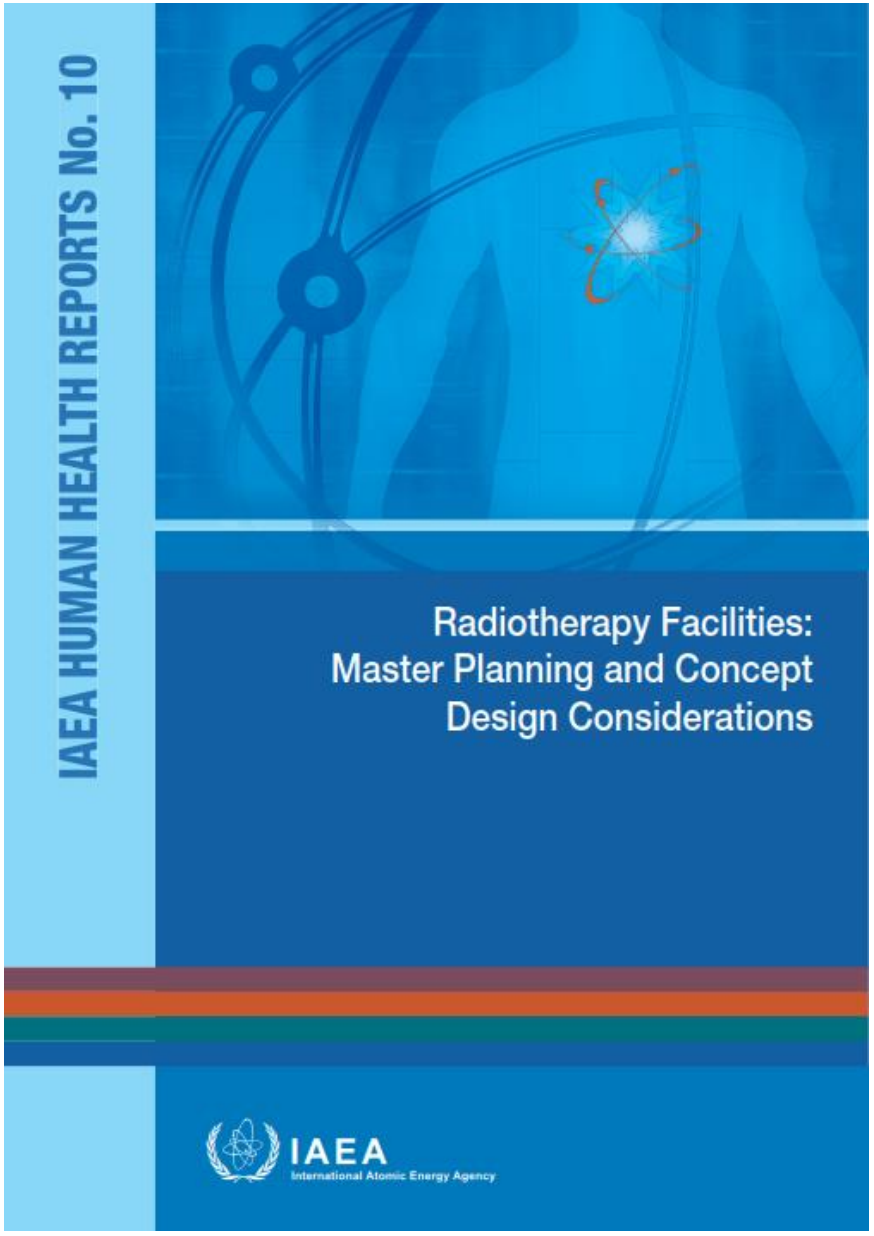
Screening

- Improve screening and early diagnosis to make RT more effective

Need for

- Qualified professionals: radiation oncologists, medical radiotherapy physicists, radiotherapy technicians, radiation protection officers, maintenance engineers, etc.
- Related training programmes
- Development of medical infrastructure


Setting Up a
Radiotherapy Programme:
Clinical, Medical Physics,
Radiation Protection and Safety Aspects
IAEA
International Atomic Energy Agency


IAEA HUMAN HEALTH REPORTS No. 10
Radiotherapy Facilities:
Master Planning and Concept
Design Considerations
IAEA
International Atomic Energy Agency