Cancer Therapy using Proton Beams

Ewart Blackmore, TRIUMF

Topics

- Cancer treatment – quick summary
- Radiotherapy – electron, X-ray, proton
- How protons behave in matter?
- Why protons are good for cancer treatment?
- TRIUMF treatment of eye cancer
- Proton therapy around the world
- Commercial from Hitachi

Cancer Treatment

18,000 new cases each year in BC

1. Surgery – to remove the tumour
2. Chemotherapy – to kill the tumour with drugs
3. Radiotherapy – to kill the tumour with radiation

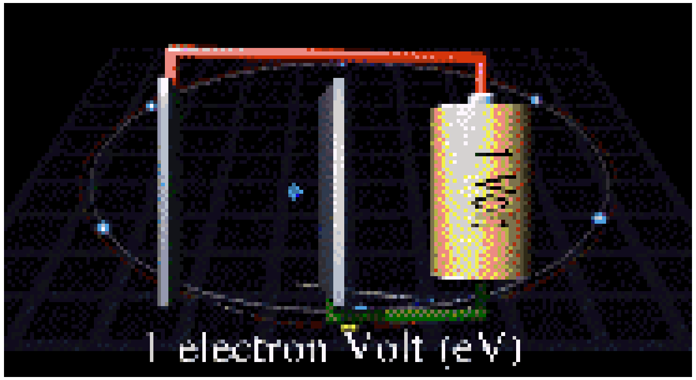
External beam therapy – X-rays, gamma rays, protons

Internal therapy – brachiotherapy (radioactive isotopes)

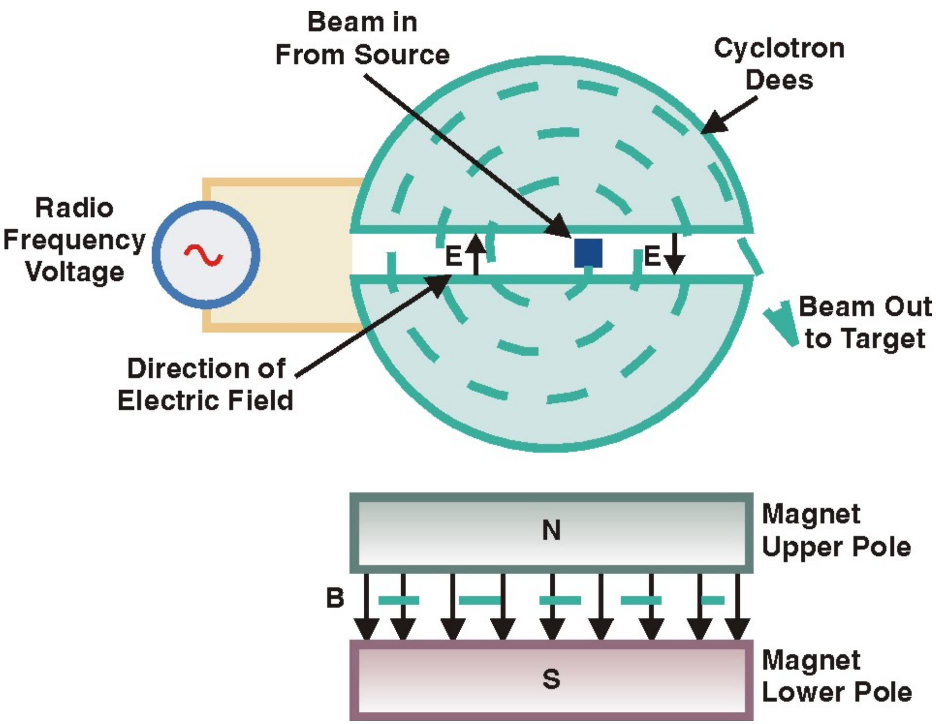
Success: Tumour control vs. complications
Destroy/remove tumour without damaging healthy or normal tissue nearby

Energy Scale – electron Volts

kilo (keV) = thousand, mega (MeV) = million



Battery ~ 1-10 eV



Televison ~ 20 keV

Cyclotron ~ 100 MeV

What is a Photon (X-ray), Electron & Proton?

Photon

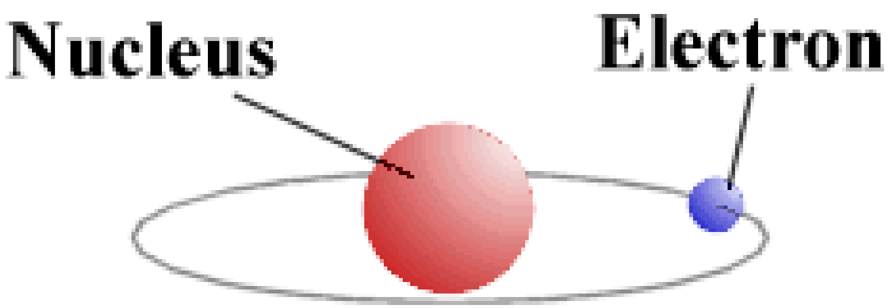
- quantum or packet of EM energy
- visible light (low E)
- X-ray ~ keV to MeV (atomic transition)
- gamma ray ~ MeV (nuclear decay)

Electron

- negatively charged light particle
- found in all atoms
- easily produced beams
- used to make X-rays

Proton

- much heavier than the electron x 1840
- nucleus of the hydrogen atom
- positively charged
- protons and neutrons make up all nuclei



Conventional Radiotherapy

BC Cancer Agency
600 West 10th Avenue
Vancouver, BC Canada
V5Z 4E6

Electron linac producing X-ray beam – 7500 units worldwide

Excellent for most cases of cancer

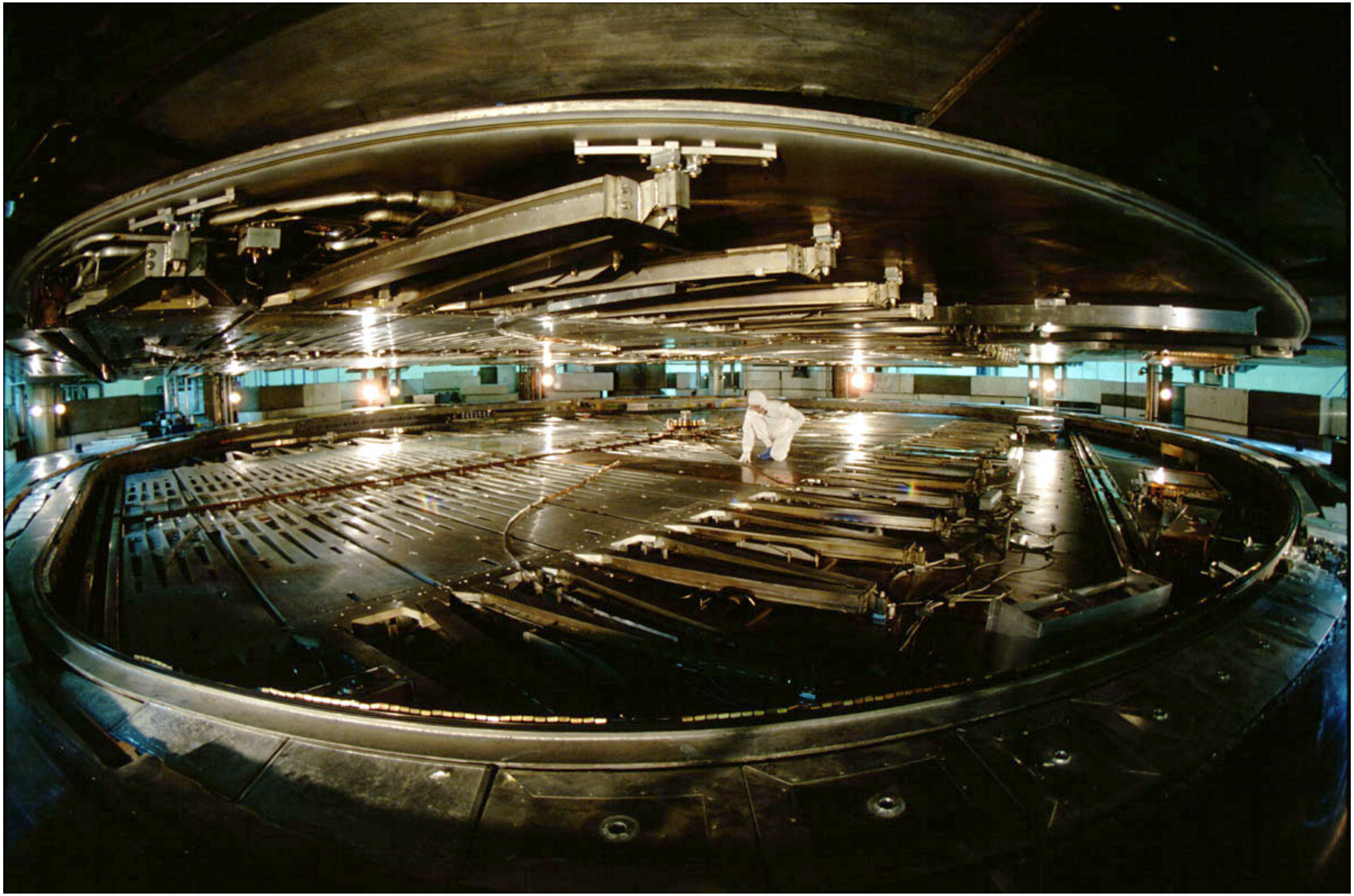
Cobalt Therapy Unit Co-60 produces a gamma ray beam

Invented by Dr. Harold Johns – Canadian 1915-1998

Connection to AECL (MDS-Nordion)

3000 in use worldwide (most made in Canada)

TRIUMF Cyclotron



Protons in Matter – Some Basic Concepts

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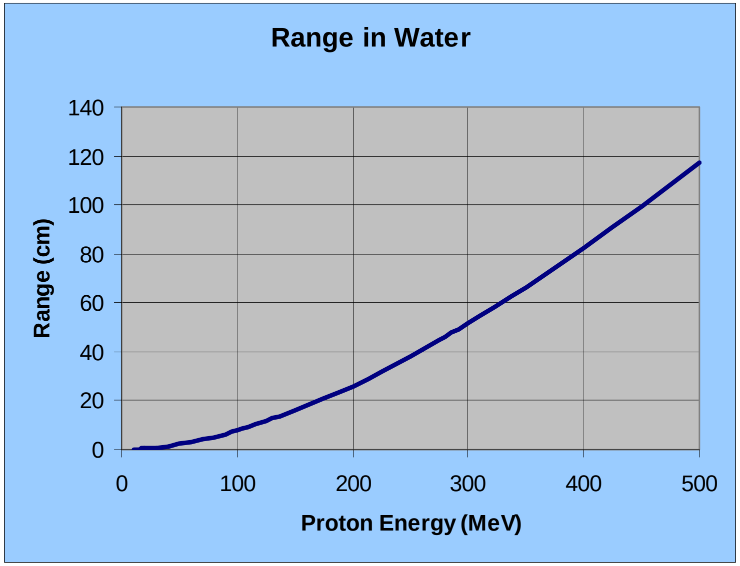
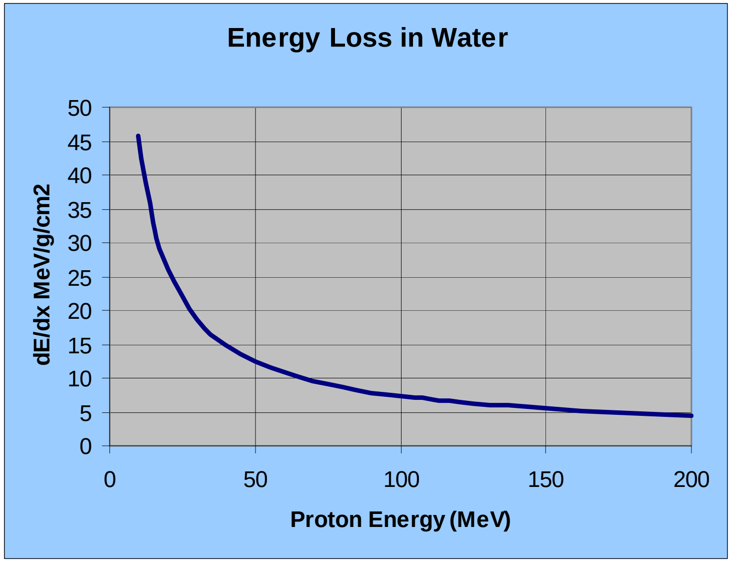
- protons have a well defined range in matter
  eg. 200 MeV proton, range 25 cm
- protons lose energy by ionizing electrons – more loss as they slow down (Bragg curve)
- protons stopping in living tissue produce damage to DNA causing cells to die.

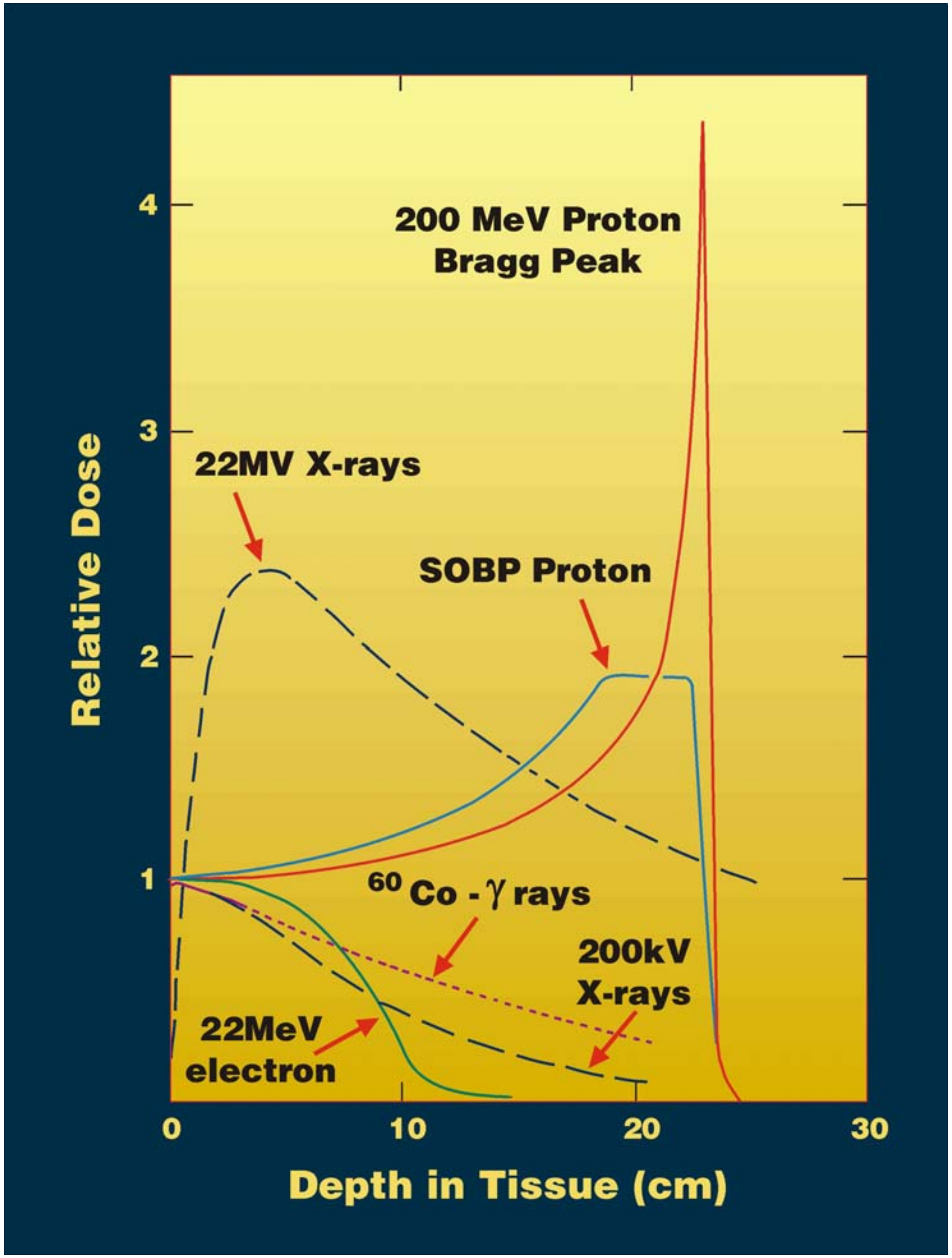




A monenergetic proton beam stopping in matter produces a rapid increase in dose near the end of its range.

This dose can be spread out over a desired depth by modulating the energy of the proton beam – SOBP Spread Out Bragg Peak

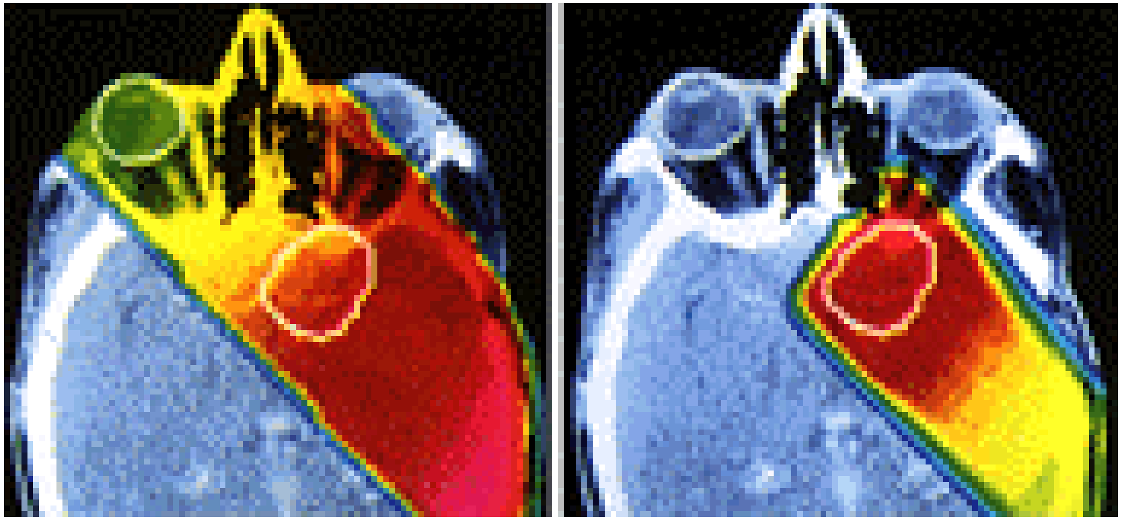
Success of radiation therapy comes from delivering maximum dose to the tumour and minimizing dose to nearby sensitive structures.



Comparison of Treatment Planning using Protons vs. X-rays

Highest dose
- red

Lowest dose
- yellow



X-rays **Protons**

BCCA/UBC/TRIUMF Collaboration on Proton Therapy

BC Cancer Agency
600 West 10th Avenue
Vancouver, BC Canada
V5Z 4E6

BC Cancer Agency

Dr. Tom Pickles, Oncologist
Dr. Roy Ma, Oncologist
Dr. William Kwa. Medical Physicist
Dr. Richard Lee, Medical Physicist

UBC Department of Ophthalmology & Eye Care Centre

Dr. Katherine Paton, Ophthalmologist
Dr. Jack Rootman, Ophthalmologist

TRIUMF

Dr. Ewart Blackmore, Physicist

Patients referred from Western Canada
Population base of ~ 10 million
Both Proton & ^{198}Au Plaque Therapy

Cyclotron and Beam Line

E_{max} = 500 MeV

I ~ 120-150 μA

Variable Energy Extraction by H^- stripping

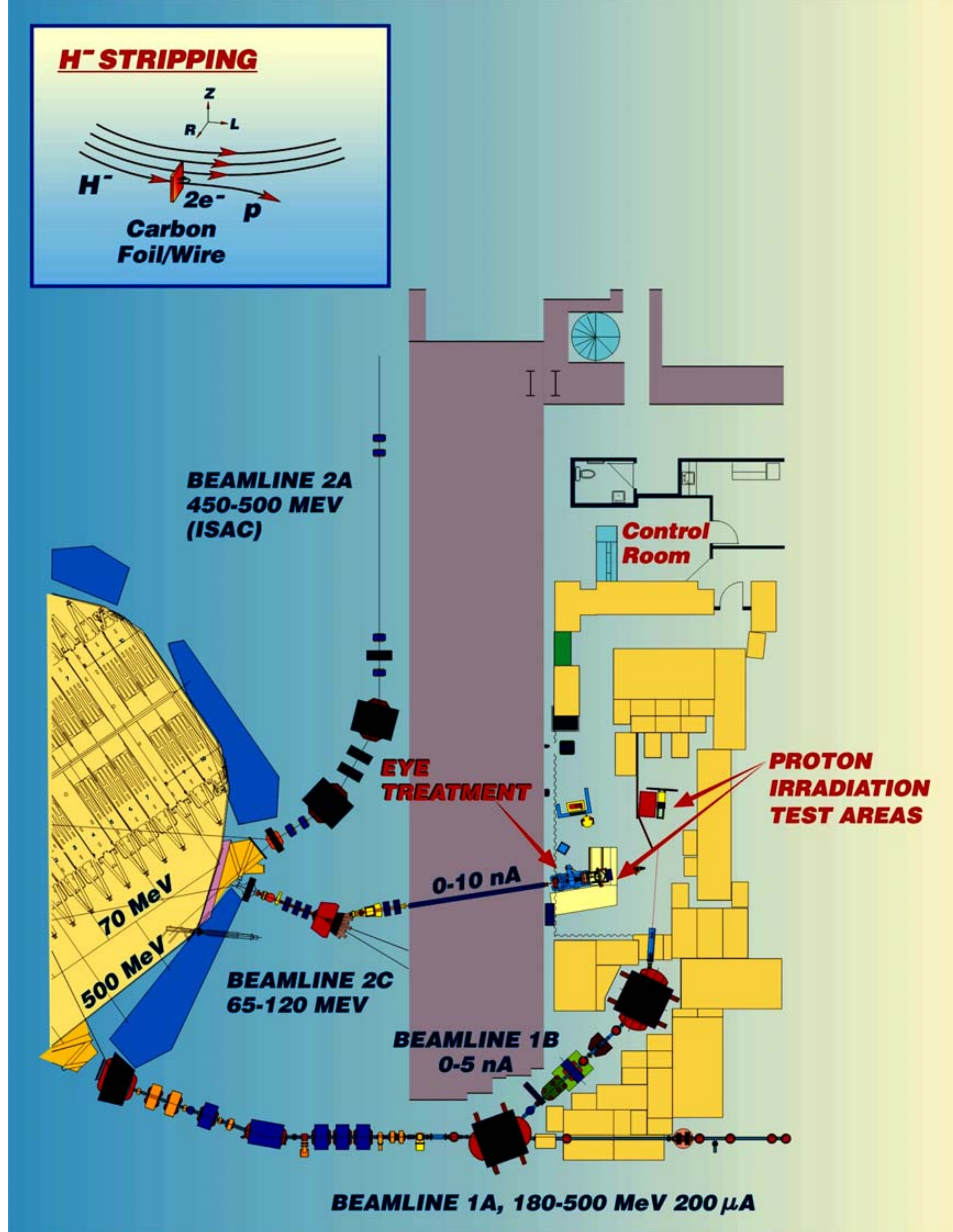
Use of Pepperpot ÷40 intensity

"Patient Mode"

<u>Treatment parameters</u>

BL2C 74 MeV
6 nA

Delivers 12.5 Gy in 100 sec.



Layout of Eye Treatment Equipment

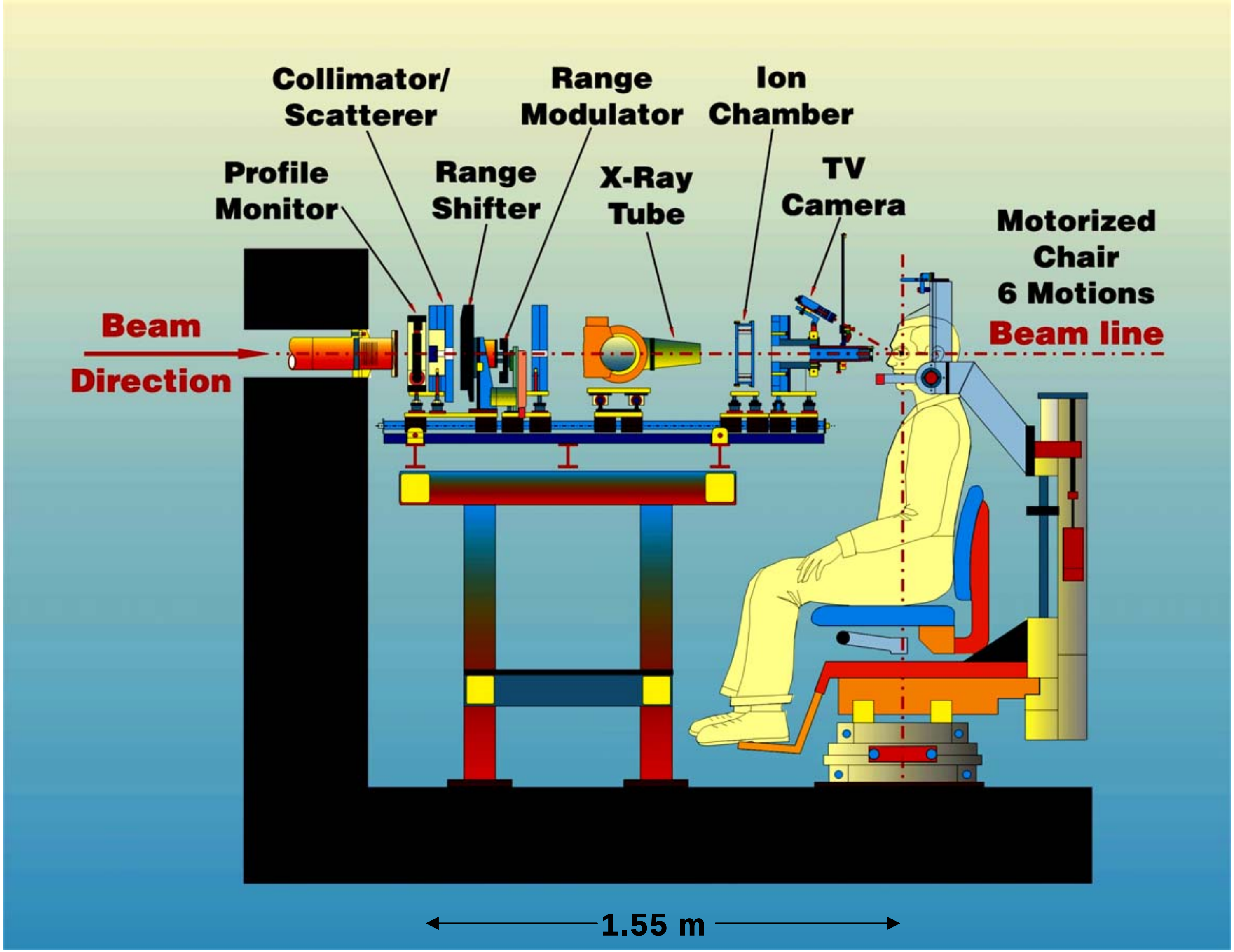
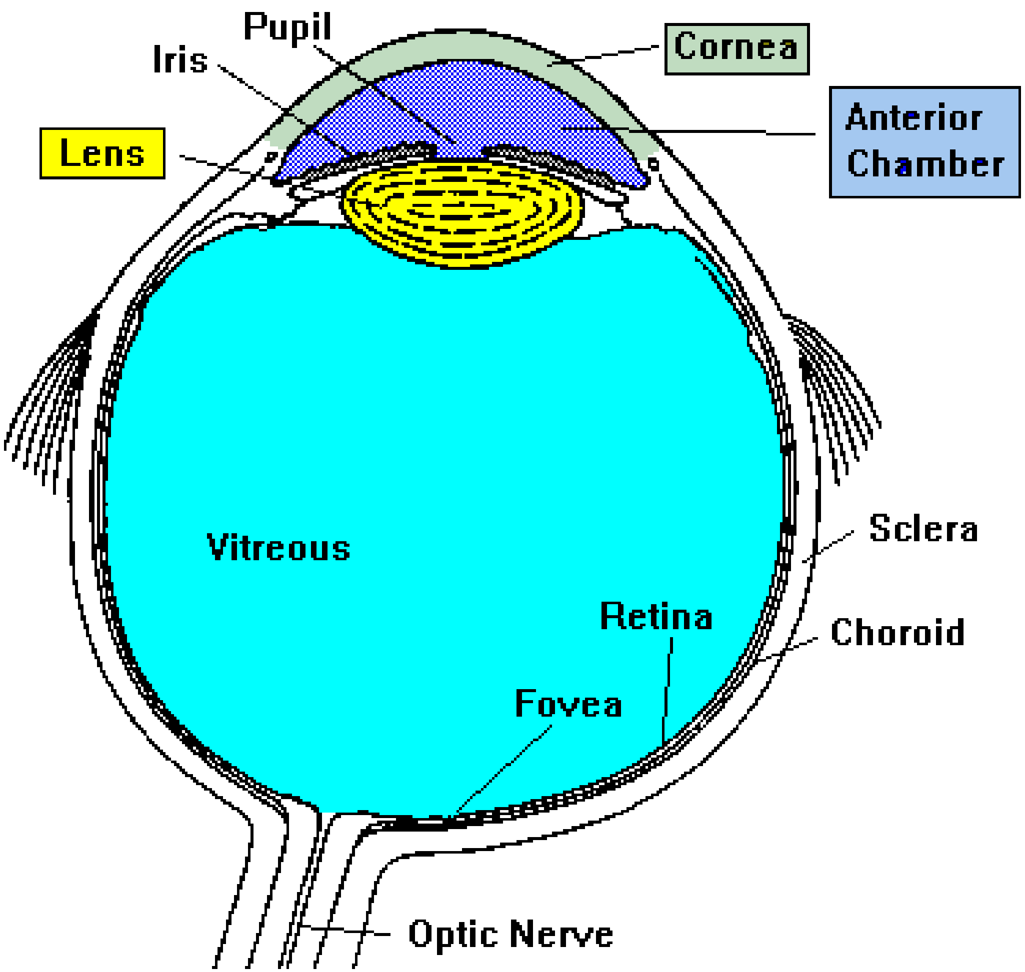


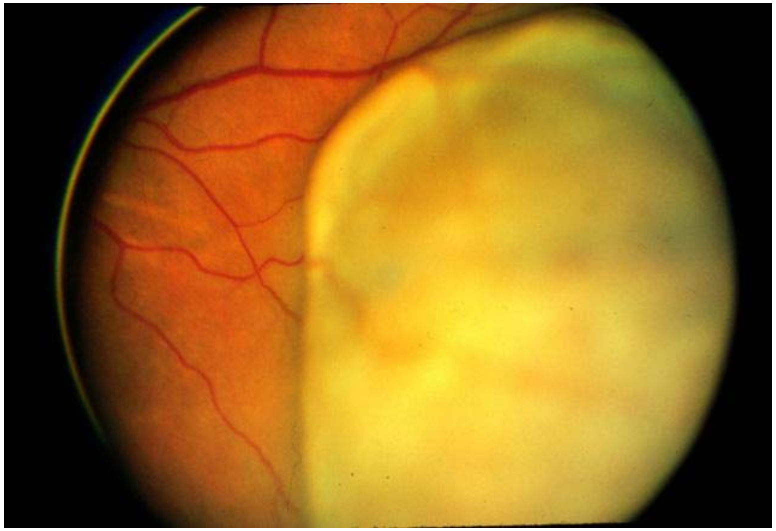
Diagram of the Eye



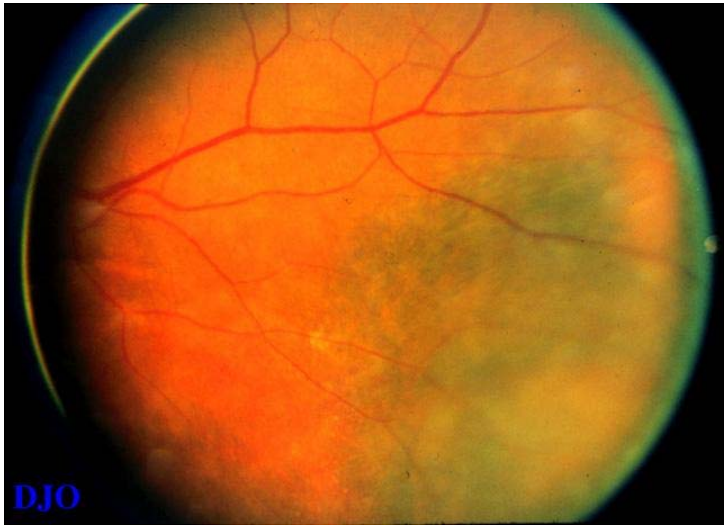
Ocular Melanoma – Uveal or Choroidal Melanoma

Frequency: 5-6 cases/year per million population

Treatment protocols: Radioactive plaque therapy
Charged particle radiotherapy
Enucleation

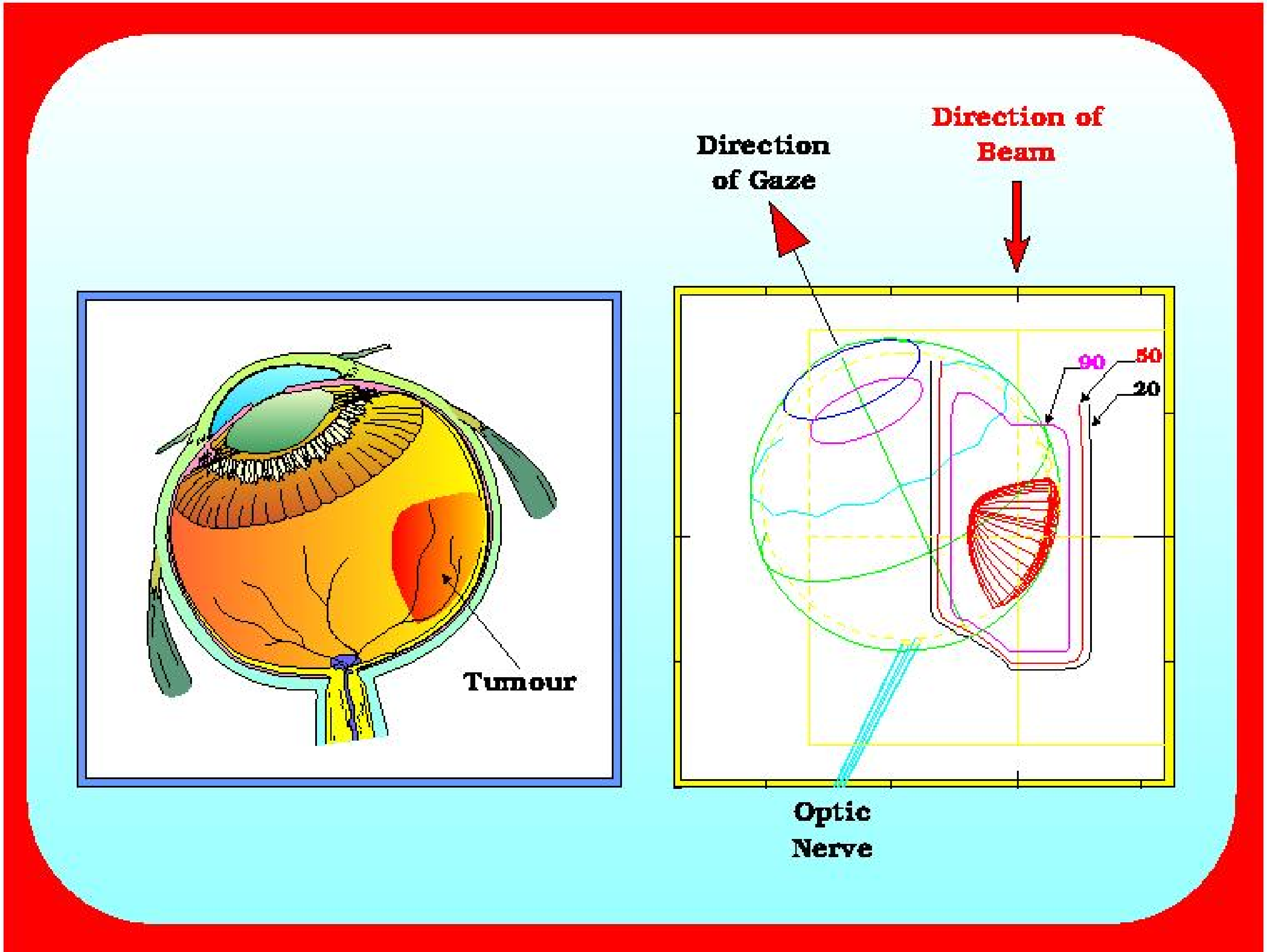


Uveal Melanoma before proton beam treatment

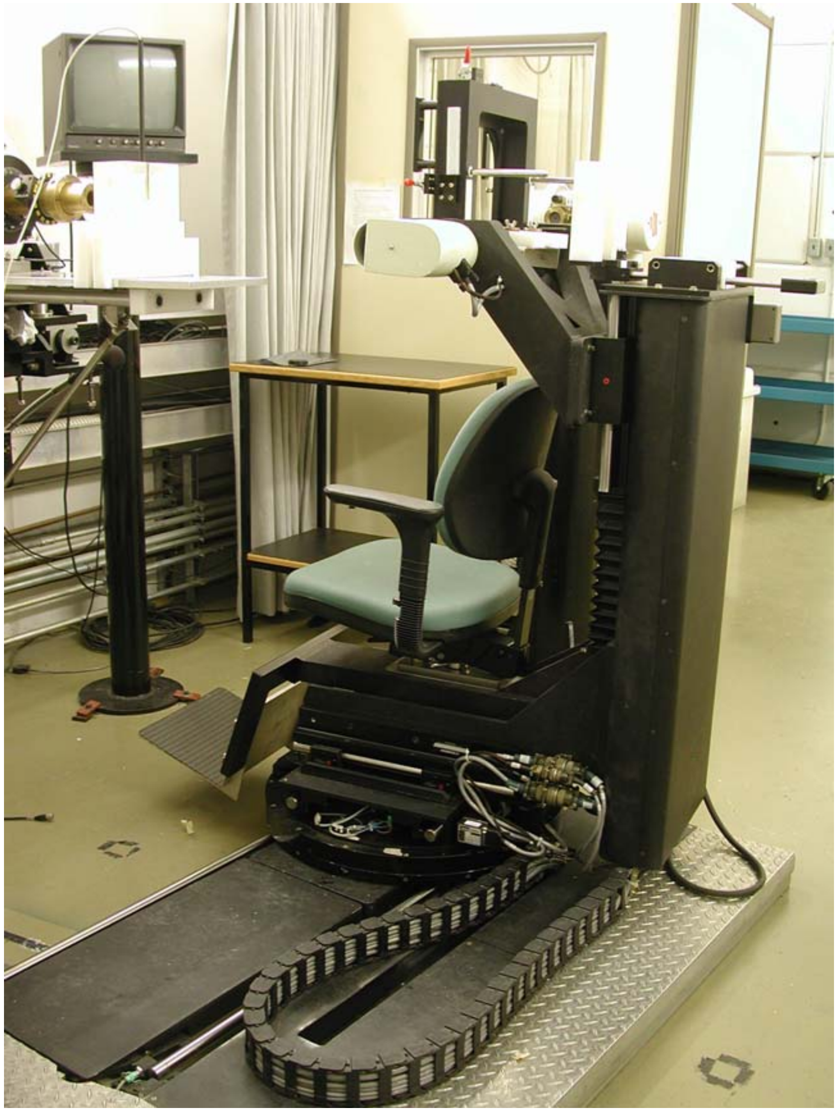


Uveal Melanoma after proton beam treatment

Treatment Planning for Ocular Melanoma



Patient in Treatment Position

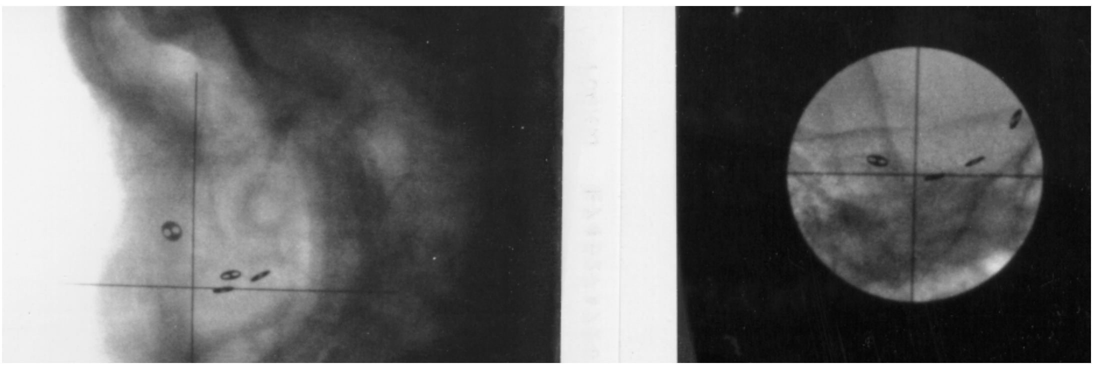


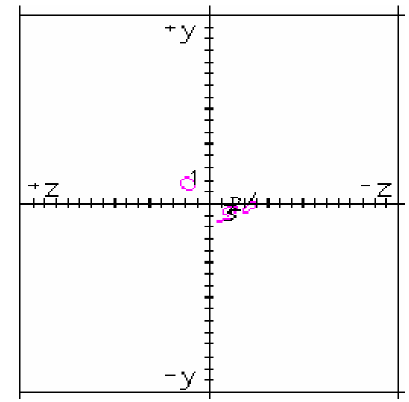
Treatment Chair

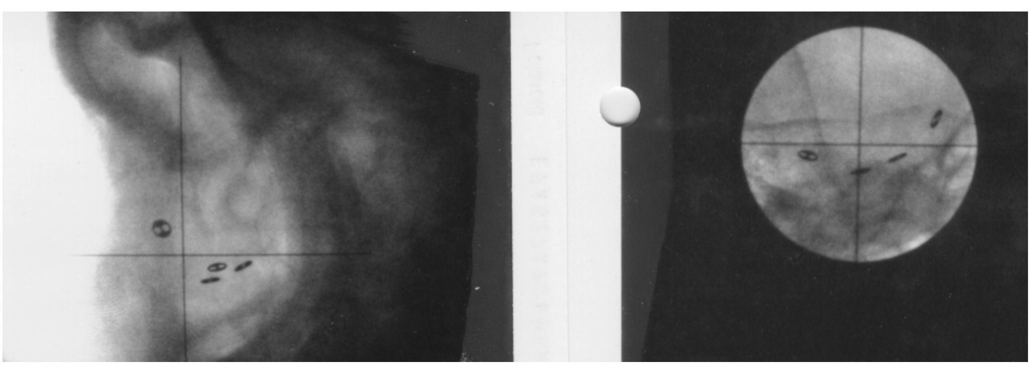
6 motorized motions

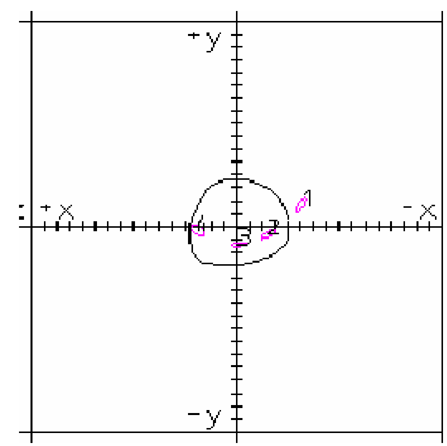
X, Y, Z, K, θ, Φ

Xrays viewed with Polaroid/Lanex Screen

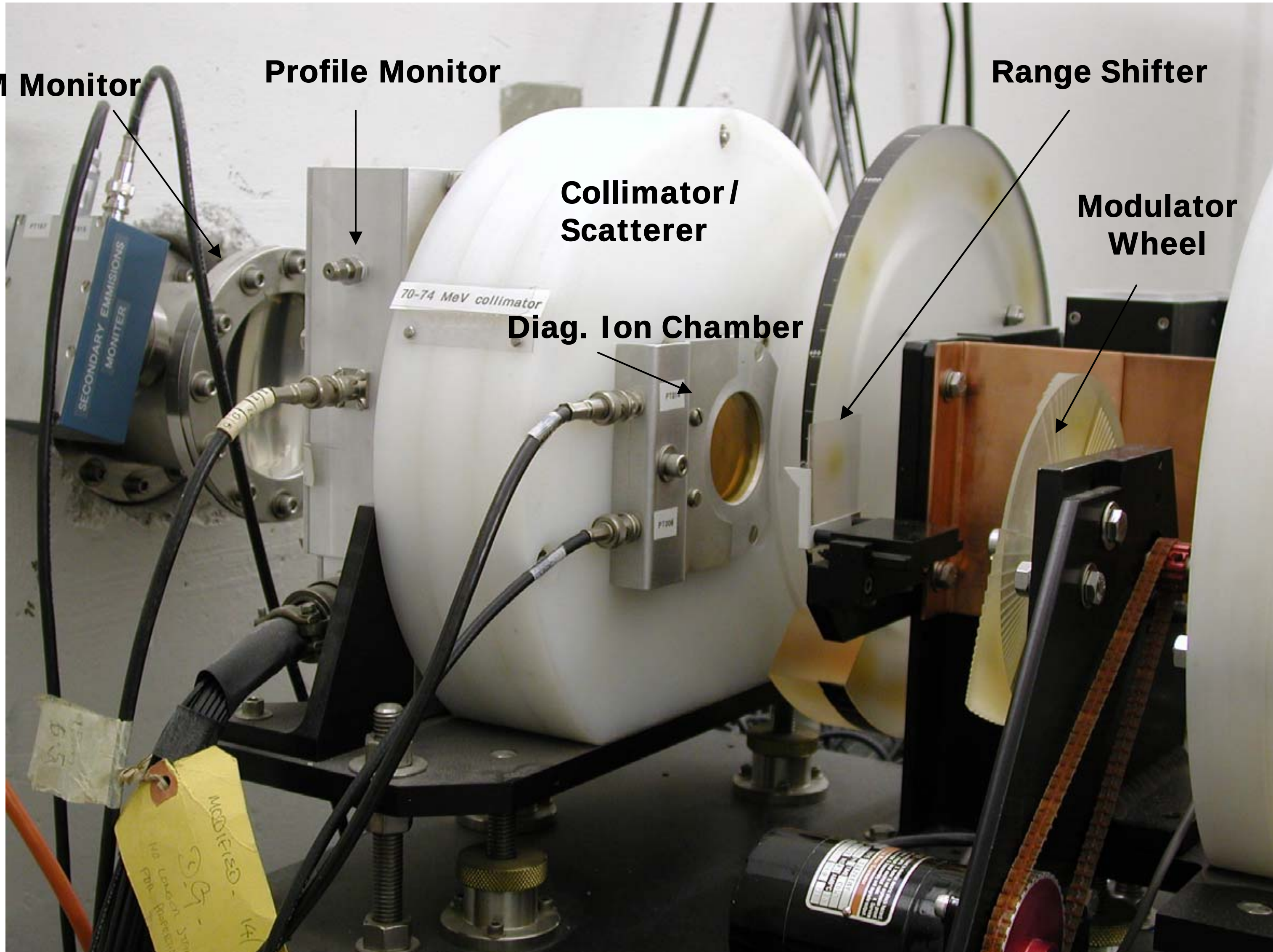




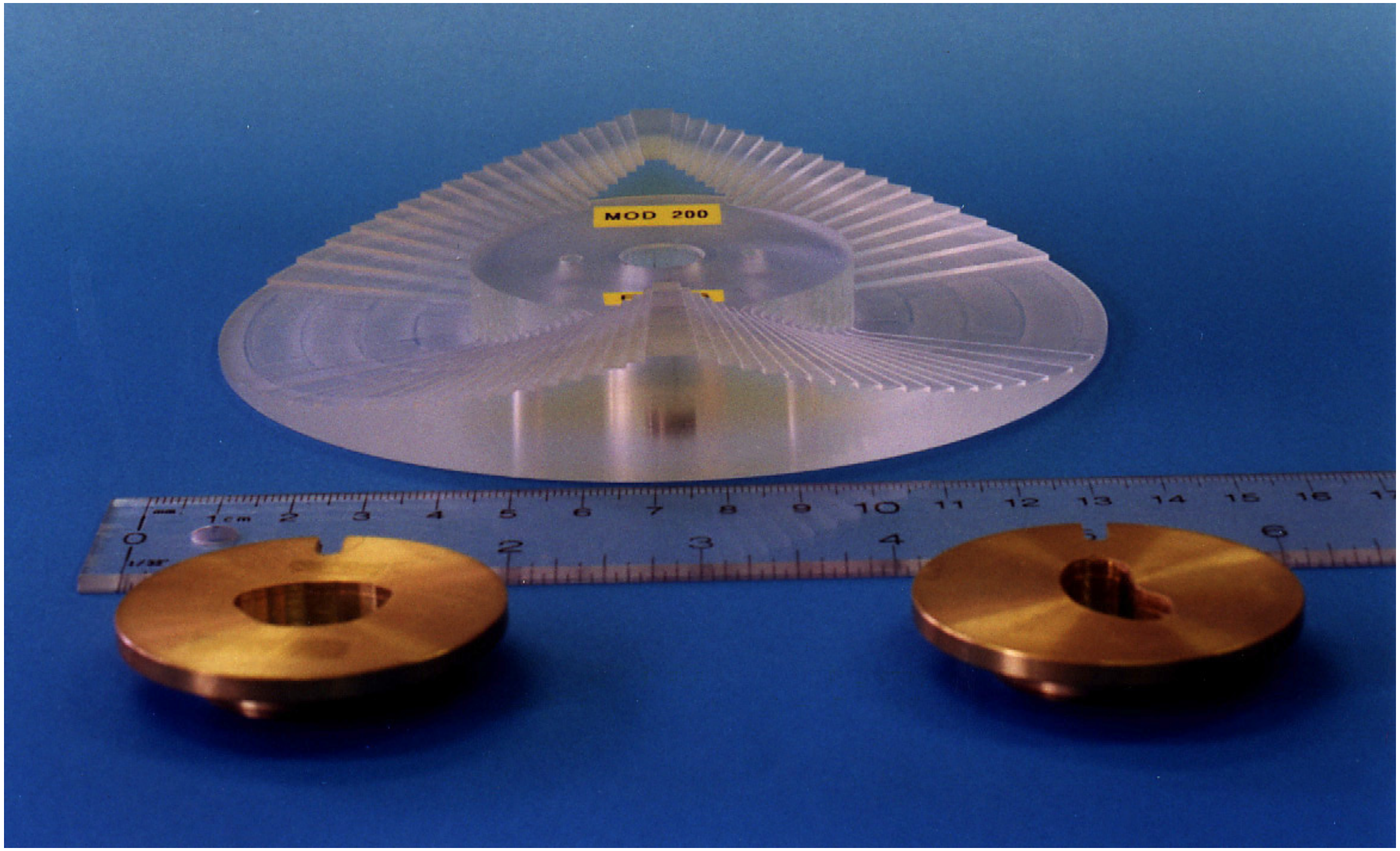




Proton Beam Line Equipment



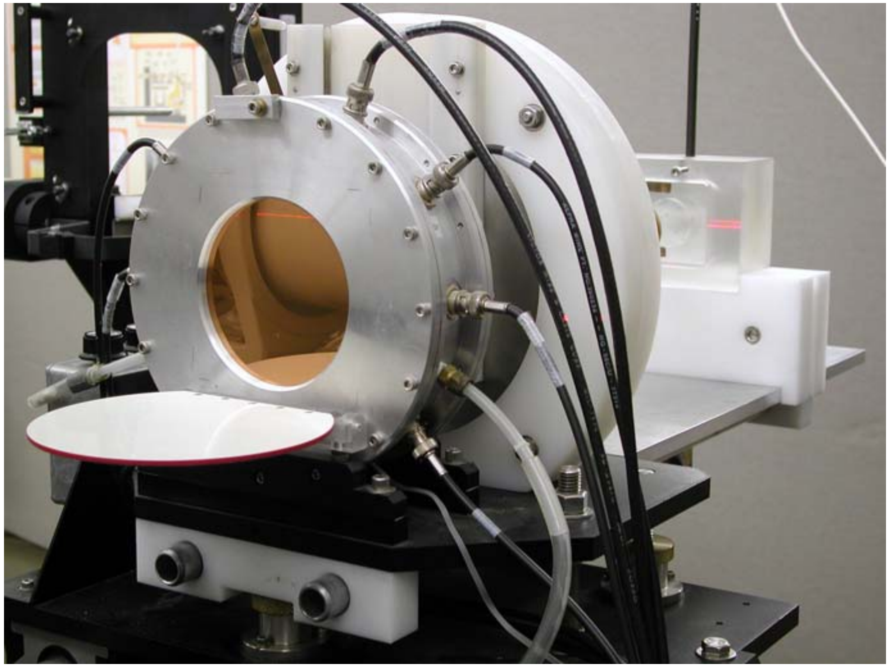
Modulator and Patient Collimator



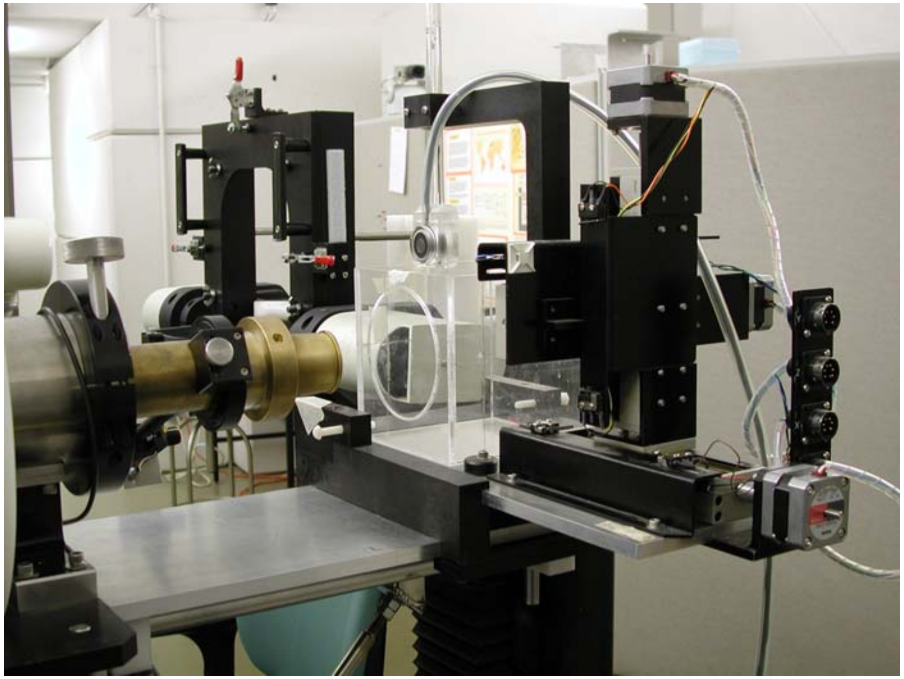
Modulators: 10 mm to 25 mm in 1 mm increments

Brass collimators, Aluminum wedges

Beam Dosimetry

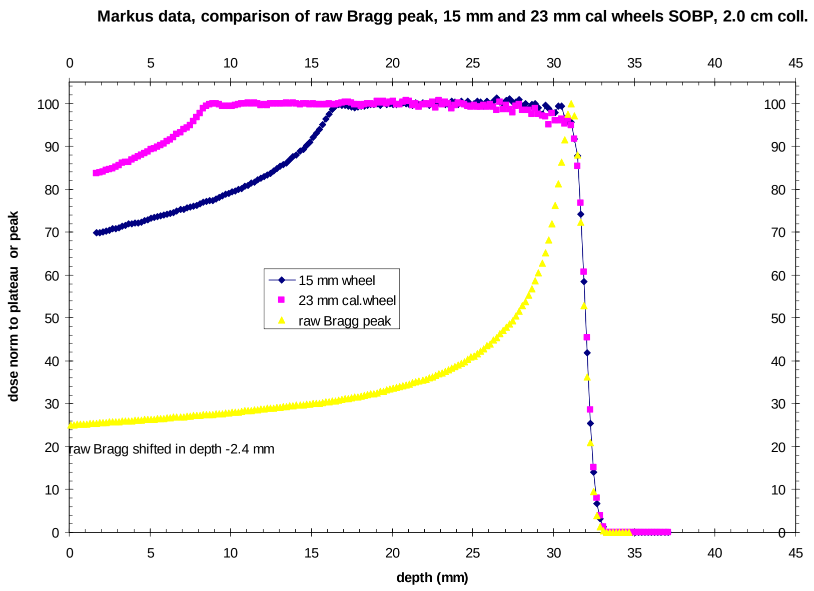


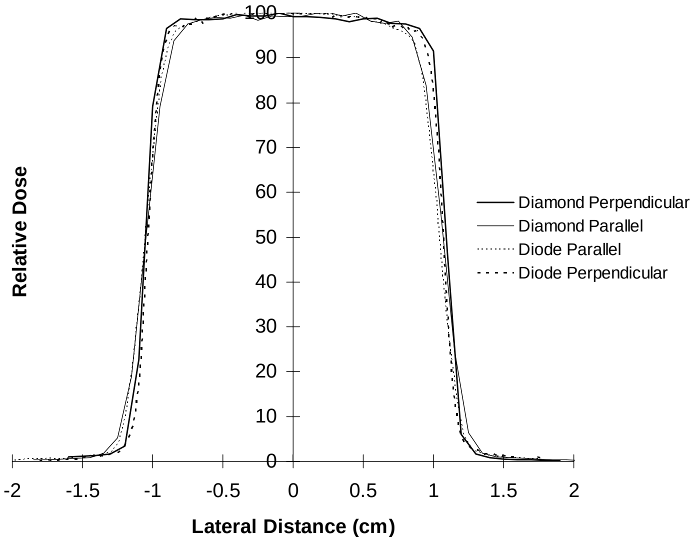
Monitor Chamber with T1 calibration chamber in plastic holder



3D scanning table for dosimetry in a water box

Beam Profiles – Depth/Transverse





SAFETY
AUDIO SYSTEM

TRIUMF Proton Patient & Tumor Statistics

Total Patients: 104 **99 choroidal or uveal melanoma, 3 iris, 2 hemangioma (benign)**

Ages: 14 – 80, Median 57

Tumour Control - >95%

Vision improvement/loss : depends on tumour location and size

Complications – 10% neovascular glaucoma (may require enucleation)

Survival rate (> 5 years) 80%

World Wide Charged Particle Patient Totals
January 2004

Who	Where	What	Date First RX	Recent Patient Total	Comments
North America					
Harvard	MA, USA	p	1961	9116	160 MeV synchrocycl.– many pt tech. developed
NPTC, MGH	MA, USA	P	2001	607	hospital based – 230 MeV cycl. + gantries
Loma Linda	CA, USA	p	1990	8626	hospital based – 250 MeV synch +gantries
UCSF – CNL	CA, USA	p	1994	448	68 MeV cyclotron – eyes only
TRIUMF	Canada	π^-	1979	367	phase III trials using pions – stopped in 1994
TRIUMF	**Canada**	**p**	**1995**	**89**	**74 MeV (500 MeV) cyclotron – eyes only**
Europe					
PSI (72 MeV)	Switzerland	p	1984	3712	72 MeV cyclotron – eyes only
PSI (200 MeV)	Switzerland	p	1996	99	200 MeV (580 MeV) cycl. – gantry with scanning
Clatterbridge	England	p	1989	1287	65 MeV cyclotron – eyes only
Nice	France	p	1991	1951	65 MeV cyclotron
GSI, Darmstadt	Germany	ion	1997	172	synchrotron – carbon beams + gantry
Berlin	Germany	p	1998	437	72 MeV cyclotron – eyes only
Japan					
HIMAC, Chiba	Japan	ion	1994	1601	synchrotron - heavy ions
PMRC(1), Tsukuba	Japan	p	1983	700	synchrotron – protons
PMRC(2), Tsukuba	Japan	p	2001	327	270 MeV synch +gantries
NCC, Kashiwa	Japan	p	1998	230	235 MeV cyclotron + gantries

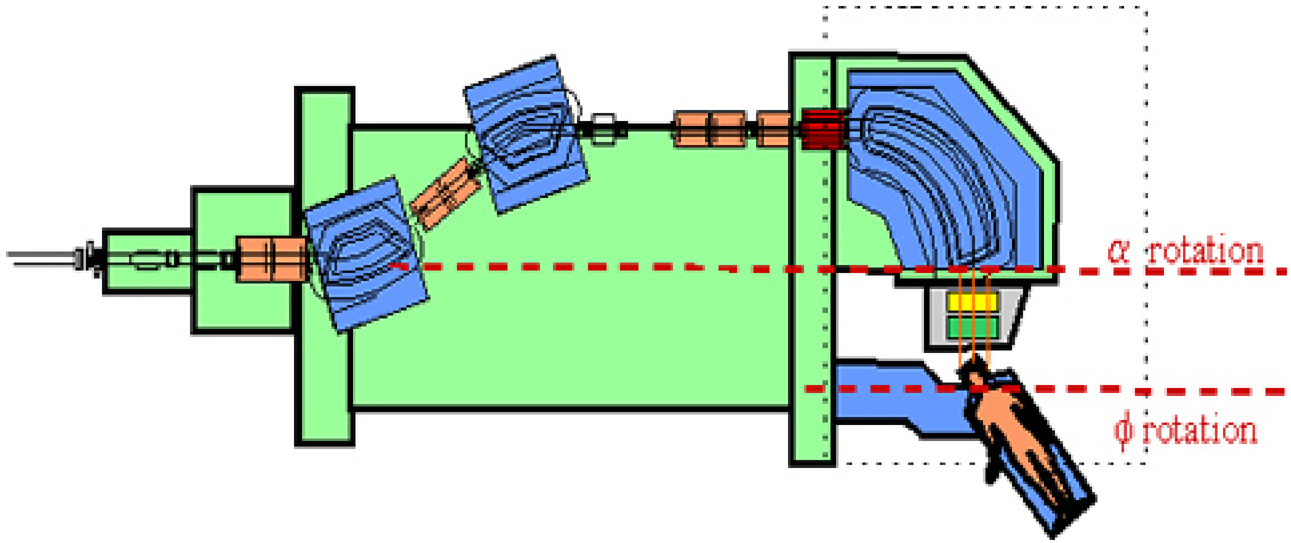
NOT A COMPLETE LIST Total Patients Worldwide 41501 (36111 protons)

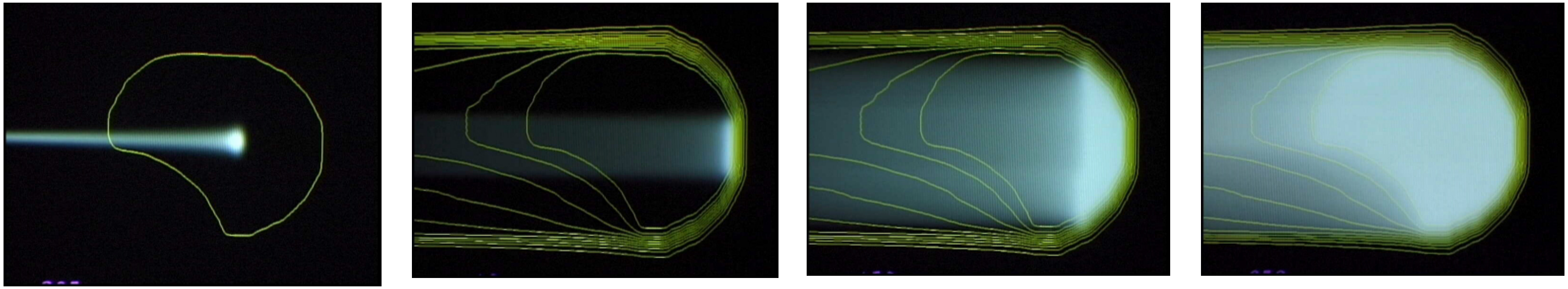
Conditions treated with protons at Loma Linda

Brain and spinal cord	Isolated brain metastases
	Pituitary adenomas
	Arteriovenous malformations (AVMs)
Base of skull	Meningiomas
	Acoustic neuromas
	Chordomas and chondrosarcomas
Eye	Uveal melanomas
Head and neck	Nasopharynx
	Oropharynx (locally advanced)
Chest and abdomen	Medically inoperable non-small-cell lung cancer
	Chordomas and chondrosarcomas
Pelvis	Prostate
	Chordomas and chondrosarcomas
Tumors in children	Brain
	Orbital and ocular tumors
	Sarcomas of the base of skull and spine

Protons best for well-defined tumours located near sensitive / important structures or organs

Beam Delivery – Gantry with Spot Scan





PROSCAN @ PSI

Dose delivered by scanning
beam at different energies

Hitachi - Japan

Hospital Based Proton Therapy Facility

1. Proton accelerator (synchrotron or cyclotron) capable of 250 MeV
2. Beam delivery system with gantries
3. Patient positioning equipment
4. Very sophisticated control system
5. Treatment planning and imaging devices (CT, MRI, ultrasound etc)
6. Building
7. Cost $100 million