# Radiation protection in proton therapy

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## Outline

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- Interactions of protons with matter
- Radiation protection aspects:
  - Shielding
  - Monitoring
  - Personnel dosimetry & protection
  - Activated materials
- Summary

# Introduction

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## Proton therapy in the Netherlands

GPTC Groningen
initiative UMCG
UMCG KeW license
opening late 2017

HollandPTC Delft
initiative LUMC-EMC-TUD
TUD/RID KeW license
opening late 2017

ZON-PTC Maastricht
initiative MAASTRO - MUMC+
'Randwyck' KeW license
opening late 2018

APTC Amsterdam
initiative VUmc-AMC-AvL
decision oct 2018

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# Collaboration Dutch Proton Therapy Centers

- ZON-PTC, GPTC, HollandPTC intend to collaborate:
  - Absolute dosimetry by inter-institunional auditing.
  - In the field of radiation protection.
- Proton therapy is a new application in the Netherlands for the user as well as for the legislator.
- Collaboration is important and necessary to not re-invent the wheel and to shorten the learning curve.

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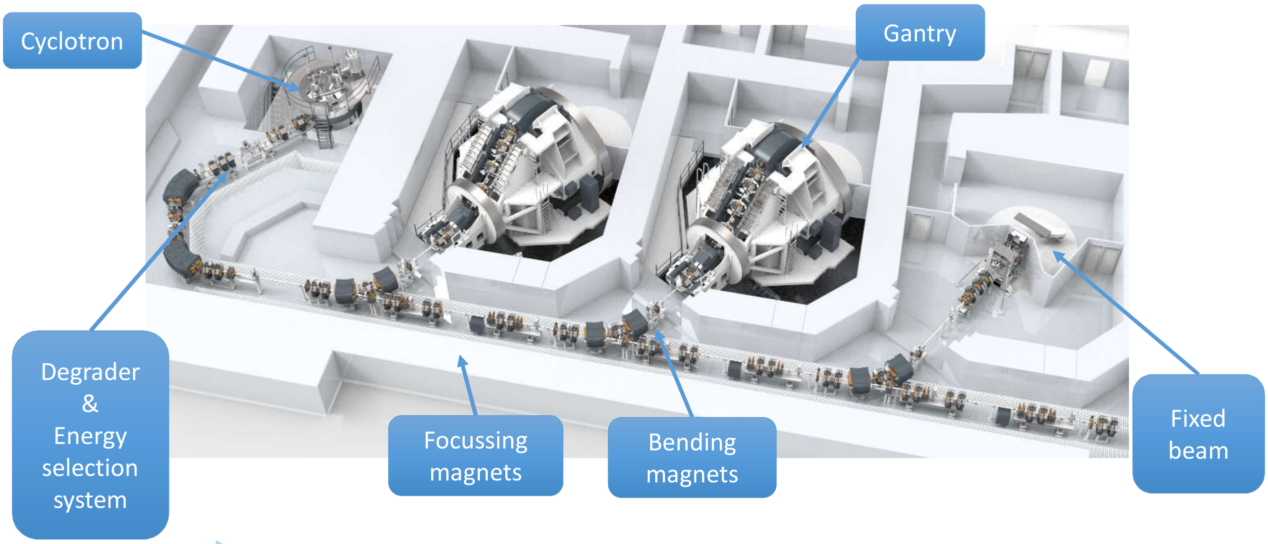
# Proton facility layout – multi gantry

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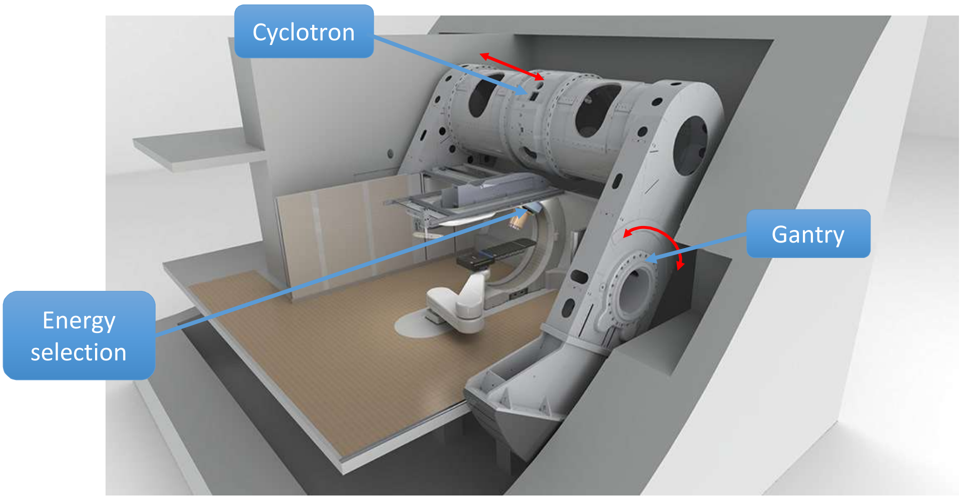
## Proton facility layout – compact

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# Interactions of protons with matter

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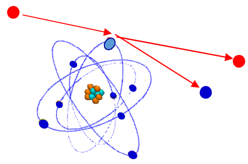
# Dominating proton interactions

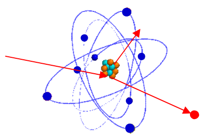
**1) Stopping**

Ionization



**2) Scattering**

Nuclear Coulomb scattering



**3) Nuclear interactions**

Nuclear reaction

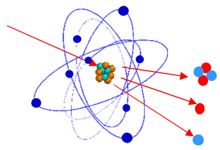
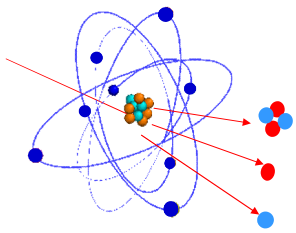


Image by M. Schippers

# Nuclear reactions



- Secondary protons
- Nuclear fragments

Short range not necessary to be considered

- **Neutrons (high energy)**
- **Prompt gamma's**

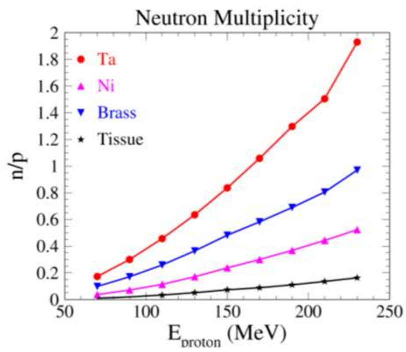
Penetrating prompt radiation determines shielding

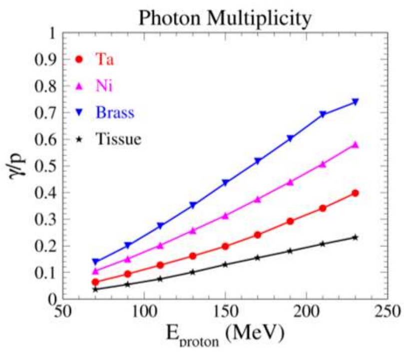
- Radioactivity

Activated parts can cause significant dose to maintenance personnel

Image by M. Schippers

# Nuclear reactions: Neutron & Photon production




- Production rates for neutrons (n/p) and photons (γ/p) strongly vary with **target type** and **beam energy**.
- Neutron production yields strongly increase with A=Z+N of material

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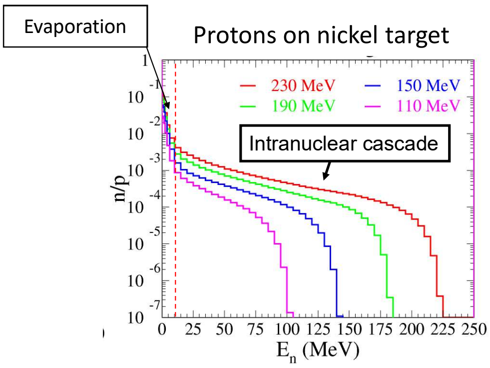
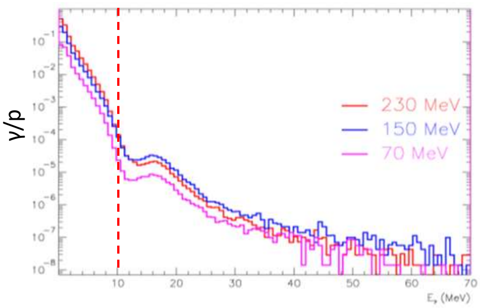
# Secondary Neutrons & Photons

Protons on nickel target




Protons on copper target




- Evaporation: decay of excited fragments with isotropic emission of low-energy neutrons (< 10 MeV)
- Intra-nuclear cascade (INC): emission of high-energy neutrons, mostly in the forward direction.

1 in 3 neutrons > 10 MeV

1 in 1000 photons > 10 MeV

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# Radiation protection aspects

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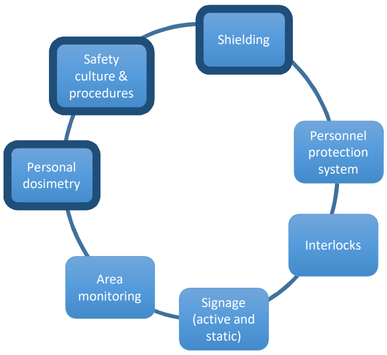
## Radiation protection aspects in proton therapy

- Prompt radiation:
  - Exposure of personnel/public
  - → Controlled by proper shielding
- Activation (due to protons and neutrons):
  - Exposure of (maintenance) personnel
  - → Procedures/personal dose monitoring
  - Emissions to environment can lead to exposure of public
  - → Procedure correct disposal of activated waste, room ventilation

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# Shielding

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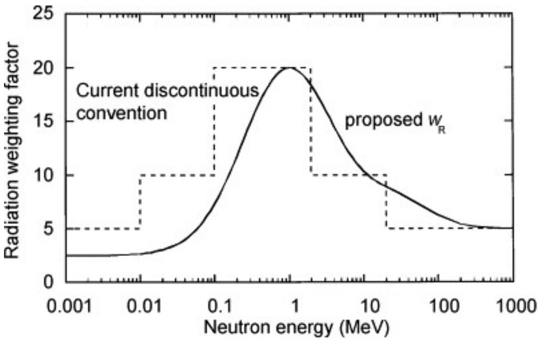
## Neutron dose

Absorbed dose: $D = \left(\frac{\partial e}{\partial m}\right)$

Equivalent dose: $H_T = W_R D_{T,R}$

Effective dose: $E = \sum W_T H_T$




- Neutrons most deleterious at ~1 MeV where the radiation weighting factor ~ 20
- Average weighting factor of **7** for proton therapy produced neutrons

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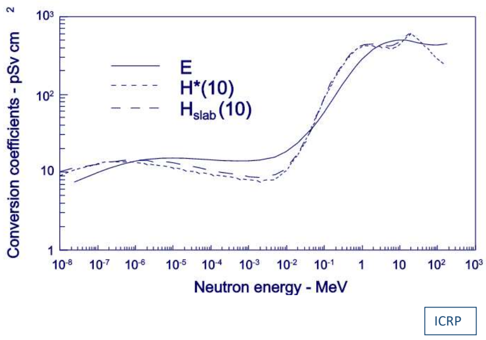
# H*(d) Equivalent ambient dose

- Equivalent ambient dose

  H*(10) = dose ICRU sphere @ 10 cm depth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# Shielding fundamentals

Limit prompt radiation exposure of personnel and public to acceptable levels

Input:

- Equipment type
- Source term
- Workload, patient mix
- Use factor
- Distance to the area of interest
- Occupancy of area of interest
- Limit value in area of interest

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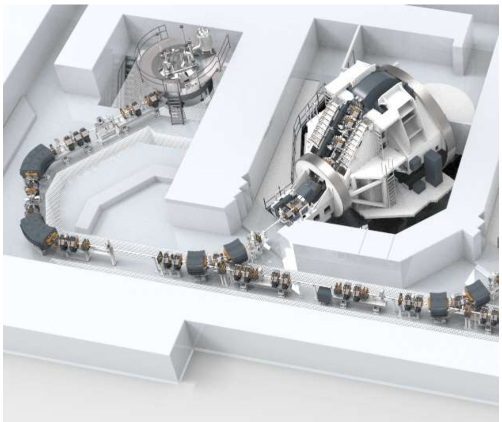
# Radiation source locations & energies

Neutrons and photons can be produced at various locations along the beam path when protons hit matter

- Cyclotron (250 MeV on Cu)
- Degrader (250 MeV on C)
- Collimator (70 - 250 MeV on Ta)
- Energy slits (70 - 250 MeV on Ni)



- Patient (70 – 250 MeV on tissue)
- Nozzle (70 – 250 MeV on brass)

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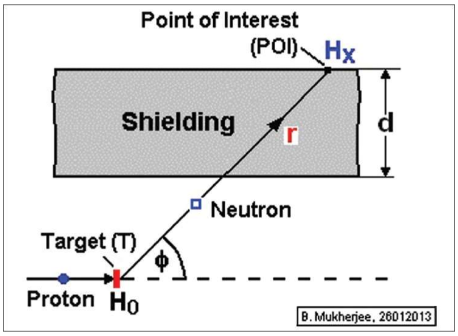
# Shielding calculations

- Analytical models:
  - Simple geometry
  - Simple source term
  - Fast calculation
  - First estimate
- Monte Carlo simulations:
  - Complex geometries
  - Complete source term description
  - Time consuming
  - Verification with measurement needed:
    - (In)accuracies reported upto a factor 2-3

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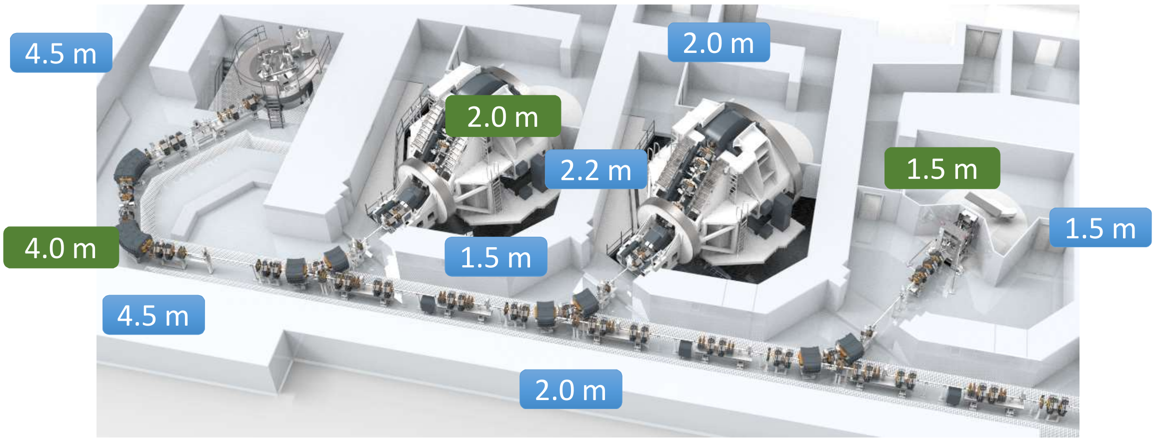
# Shielding example: multi-gantry

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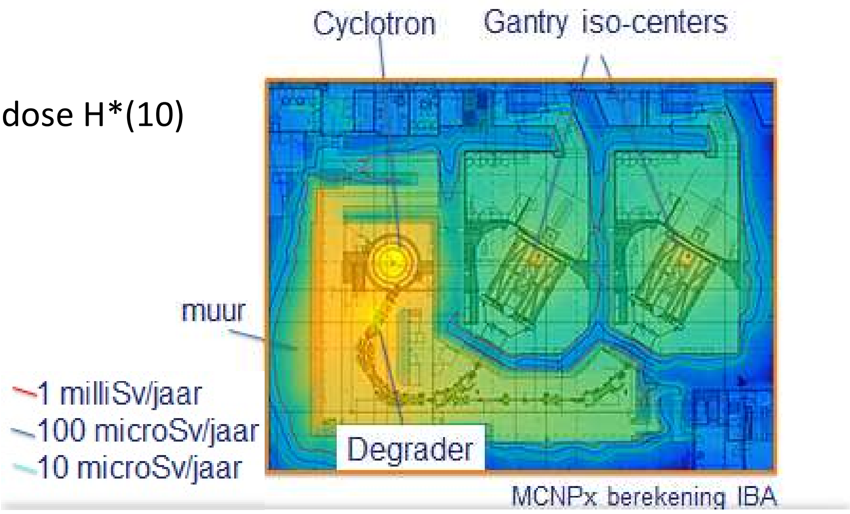
# Shielding example: multi-gantry

Total expected yearly dose H*(10)
@beamheight

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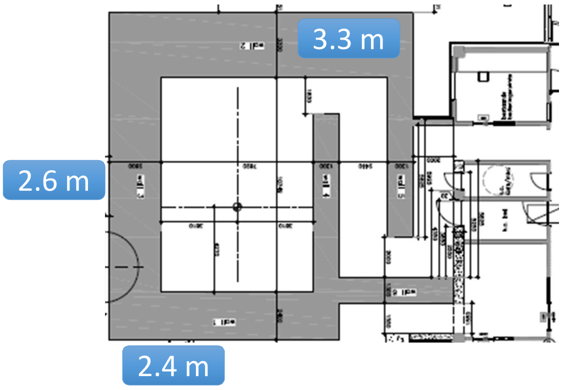
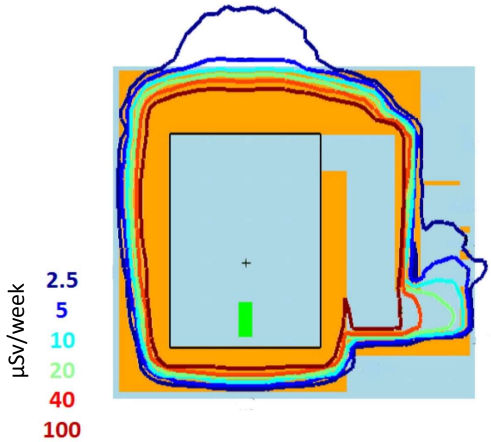
# Shielding example: compact

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# Monitoring

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# Area monitoring and survey

- Survey work area's
  - First beam on
  - After any building works
- Monitoring:
  - Check assumptions shielding calculations (e.g. workload)
  - Measure over longer periods of time



# Area monitoring and survey equipment

Survey equipment:

- Standard survey meters
- Contamination monitors
- Mobile neutron detector

| Attribute | Wendi-2 |
| --- | --- |
| Detector | $^3$He |
| Moderator | Polyethylene & Tungsten |
| Weight | 13.5 kg |
| Gamma-Discrimination | High |
| Detection Range | 10 nSv.h$^{-1}$ – 100 mSv.h$^{-1}$ |
| Energy Range | 0.025 eV – 5 GeV |


Monitoring equipment:

- TLD/neutron badges in controlled and supervised areas, e.g. console.
- Area gamma monitor (e.g. cyclotron area)
- Mobile neutron detector

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# Personnel dosimetry & protection

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## Personal dosimetry

Personal dosimetry to monitor individual external radiation exposures.

Aim is to prove that personnel exposures are below dose limits.

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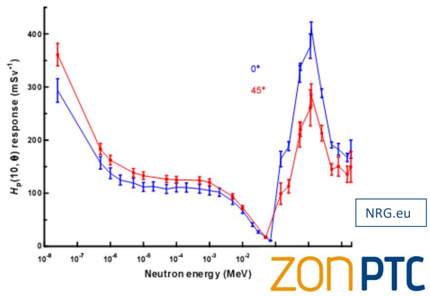
# TLD + PADC badges

- TLD:
  - Photon $H^p(10)$ (~ effective dose)
  - Photon/beta $H^p(0.07)$ (~ skin dose)
  - Neutron detector
- PADC Neutron detector
- Extremity dosemeter

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# Personnel protection system

- Gantry rooms equipped with emergency buttons (stop proton beam and gantry/table motion)
- Search procedures
- Interlocks in place
- Audible/visual indicators:
  - proton beam and x-ray on states
- Static warning signs



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# Activation of materials

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## Activation of materials

- Neutrons can activate materials
  - Snout and apertures (high-Z materials): mostly decommissioning issue
- Protons will activate apertures and measurement equipment
  - Wait before handling 'hot' materials (apertures, phantoms)
  - Keep distance from nozzle and aperture rack
- Patients will be activated
  - Dependent on treatment
  - $^{11}C$, $^{15}O$, $^{13}N$
  - Total activity $\beta^+$ emitters ~10 – 25 MBq

Syed M. Qaim Workshop on Nuclear Data for Science and Technology 2007

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# Summary

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## Summary

- Radiation protection in proton therapy is mainly an activation and neutron shielding issue:
  - High energy secondary neutrons
  - Activation of parts, air, soil and building
- Radiation protection measures similar to radiotherapy, and similar in Dutch proton initiatives:
  - Concrete shielding
  - Area monitoring with mobile neutron detector & TLD/neutron badges
  - Personnel dosimetry & protection system

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# Acknowledgements


| | |
|---|---|
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| ZONPTC | Lars Murrer |


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# Thank you!

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