Ruđer Bošković Institute
Zagreb, Croatia

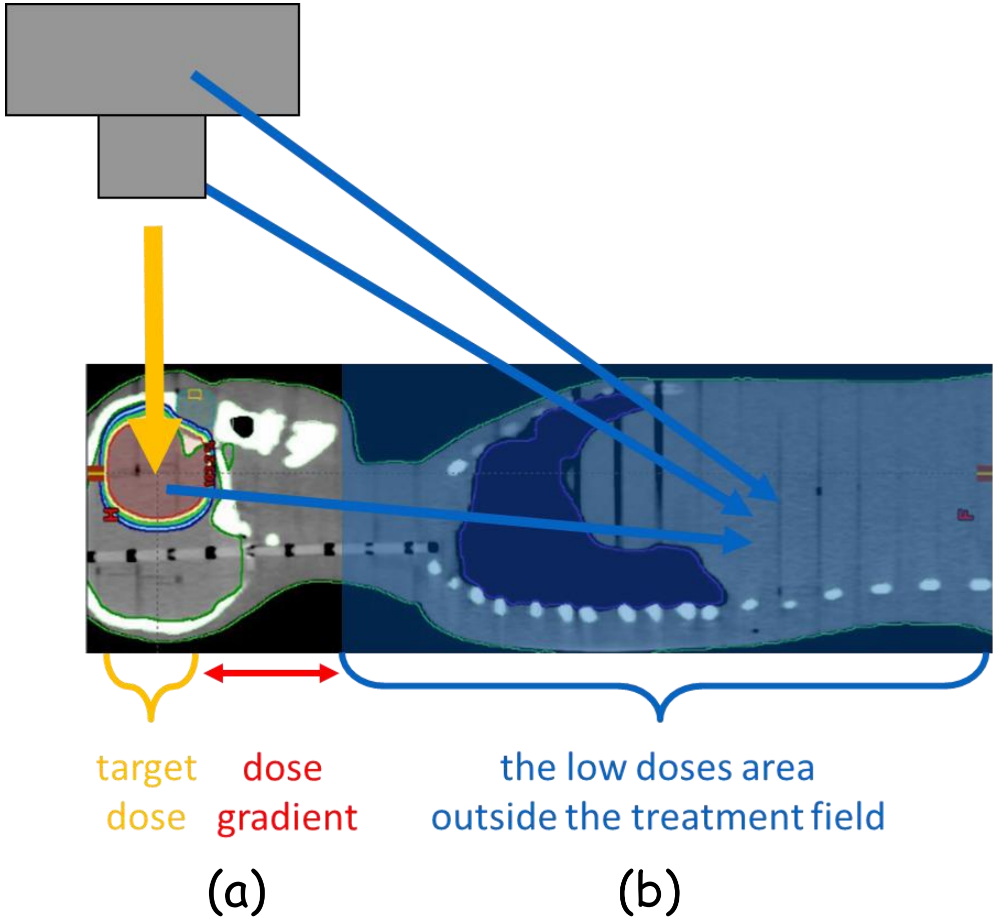
European Radiation Dosimetry Group

Dosimetry for secondary radiation in radiotherapy

Marija Majer

EURADOS WG9 webinar 25/05/2023

Secondary radiation and out-of-field doses



- The tissue outside of the target („non-target tissue") is unavoitably irradiated
- Secondary radiation → Radiation produced by interaction between the primary beam and the matter; all radiation except the primary beam
- „Non-target dose"

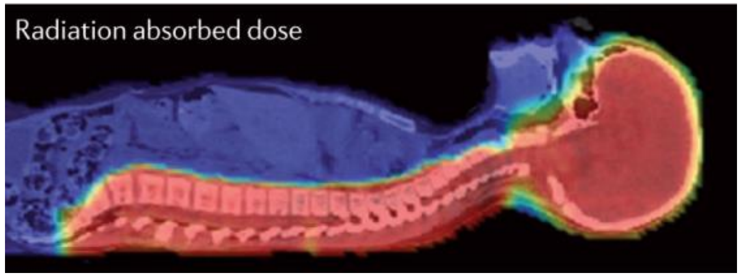
  (a) „in-field non-target dose"

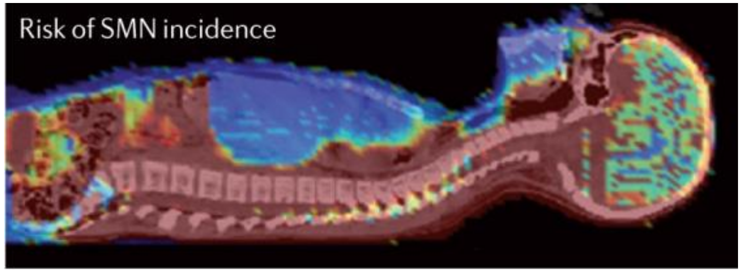
  (b) „out-of-field non-target dose" or „out-of-field dose"

  → deposited by secondary radiation

Out-of-field dosimetry

- Out-of-field doses may lead to an increased probability of unwanted effects of radiotherapy including the generation od secondary cancers





Newhauser W., Durante, M.,
Assessing the risk of second malignancies after modern Radiotherapy.
Nat Rev Cancer. 2011 June ; 11(6): 438–448.

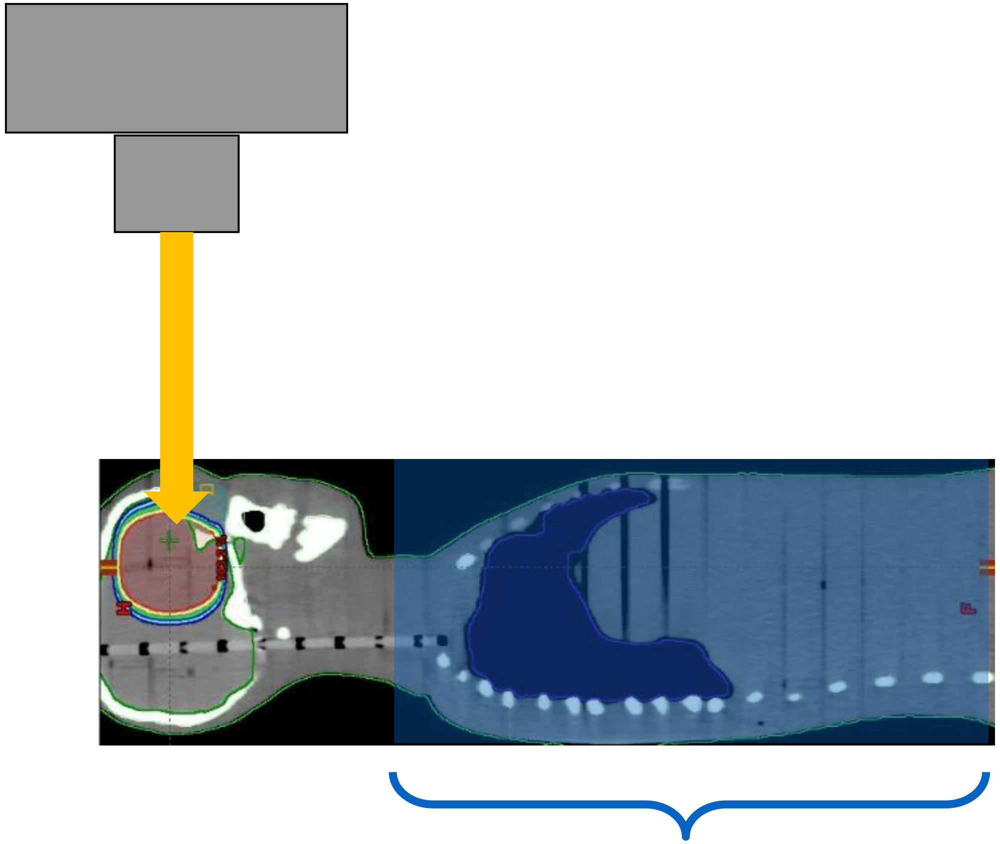
- In planning phase dosimetric focus is on the target and critical organs nearby
- Out-of-field doses are not considered (Treatment Planning System (TPS) does not allow to accuratelly assess)

- Epidemiological studies need a complete dose specification

- Data in literature spread-out and it is difficult to apply for the particular cases

- Priority in the case od irradiation of children, during pregnancy or for reirradiations

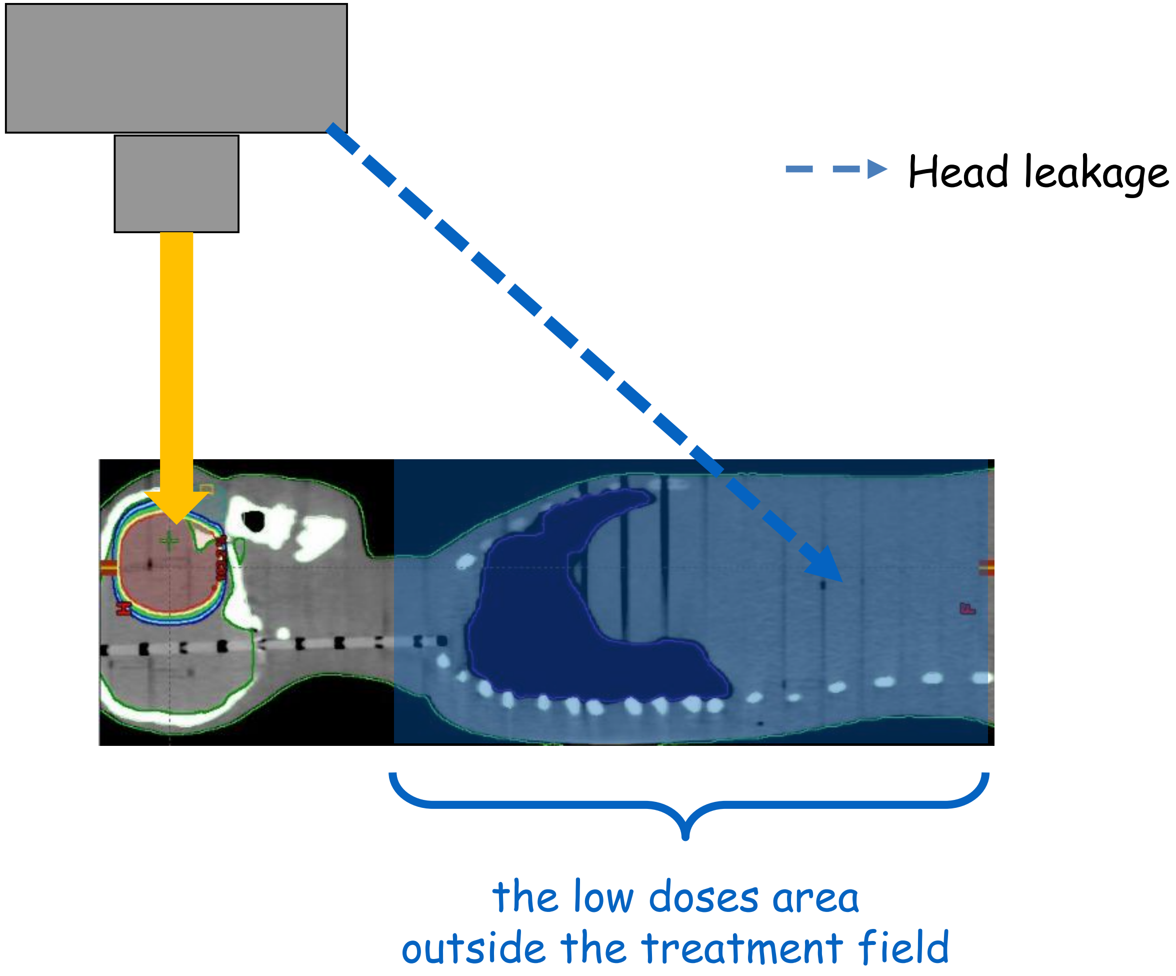
Sources of secondary radiation for photon beams



the low doses area
outside the treatment field

- MV X-rays radiotherapy
  - Treatment nozzle and inside the patient body
  - **Scattered X-ray, photoneutrons**, secondary γ radiation

Sources of secondary radiation for photon beams



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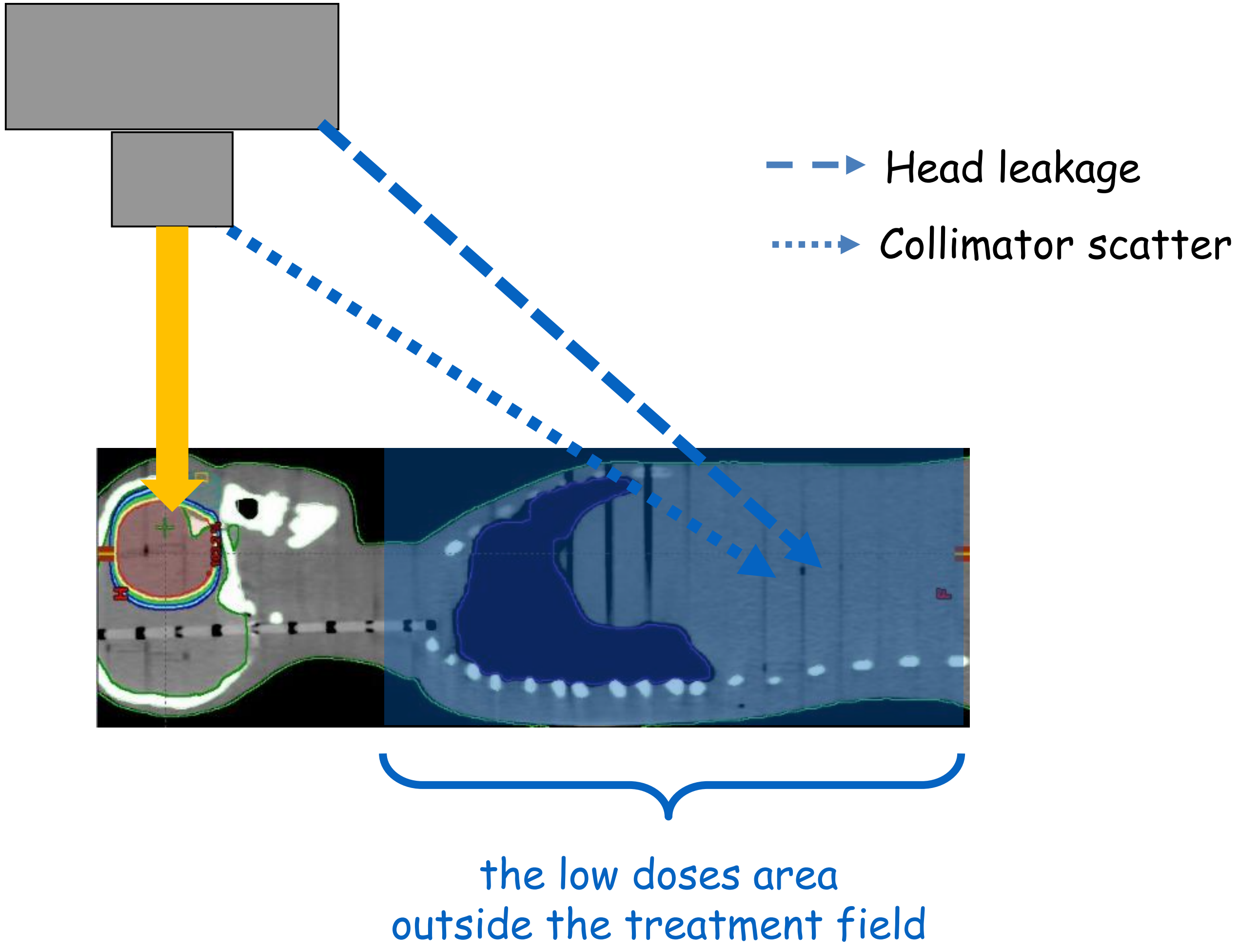

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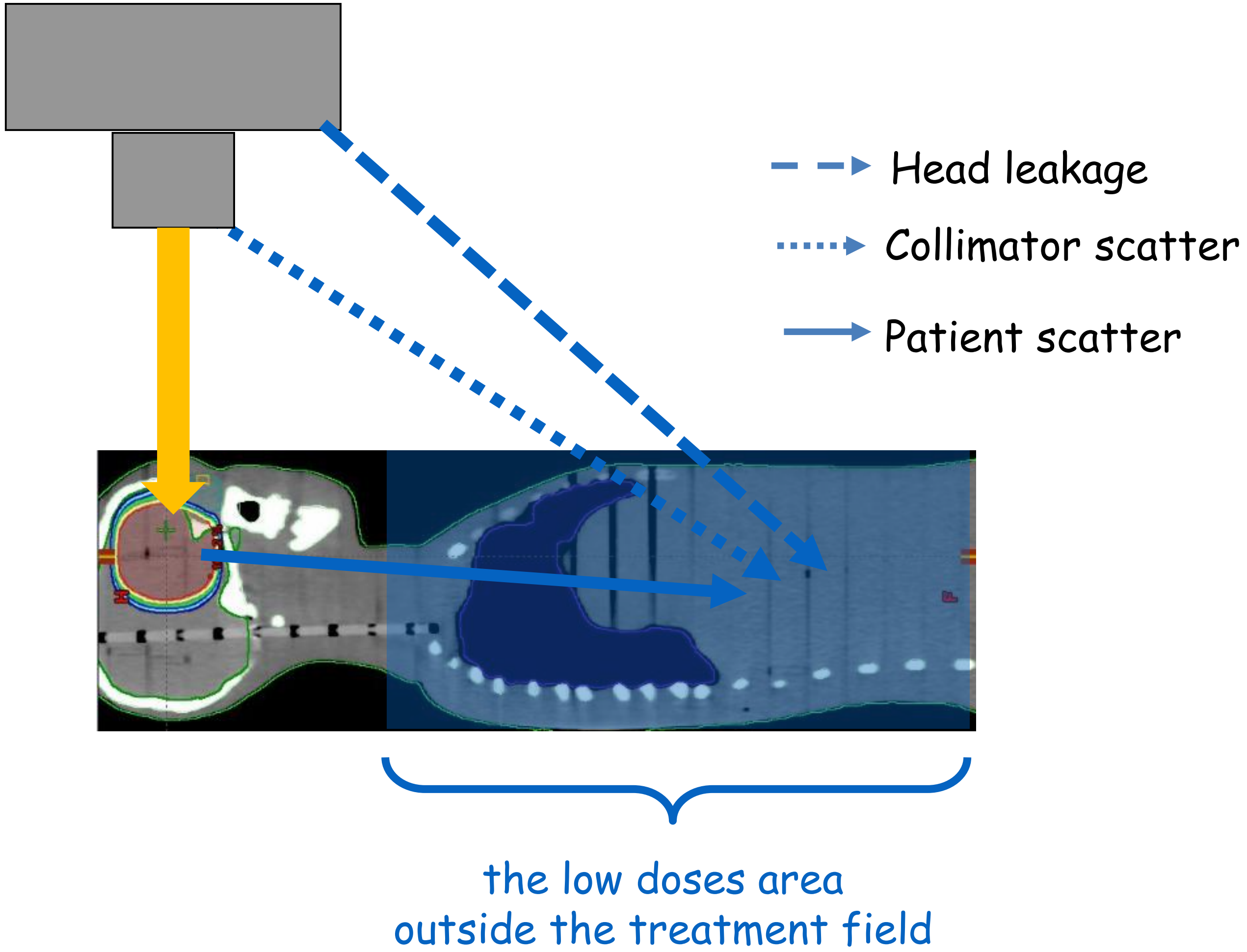

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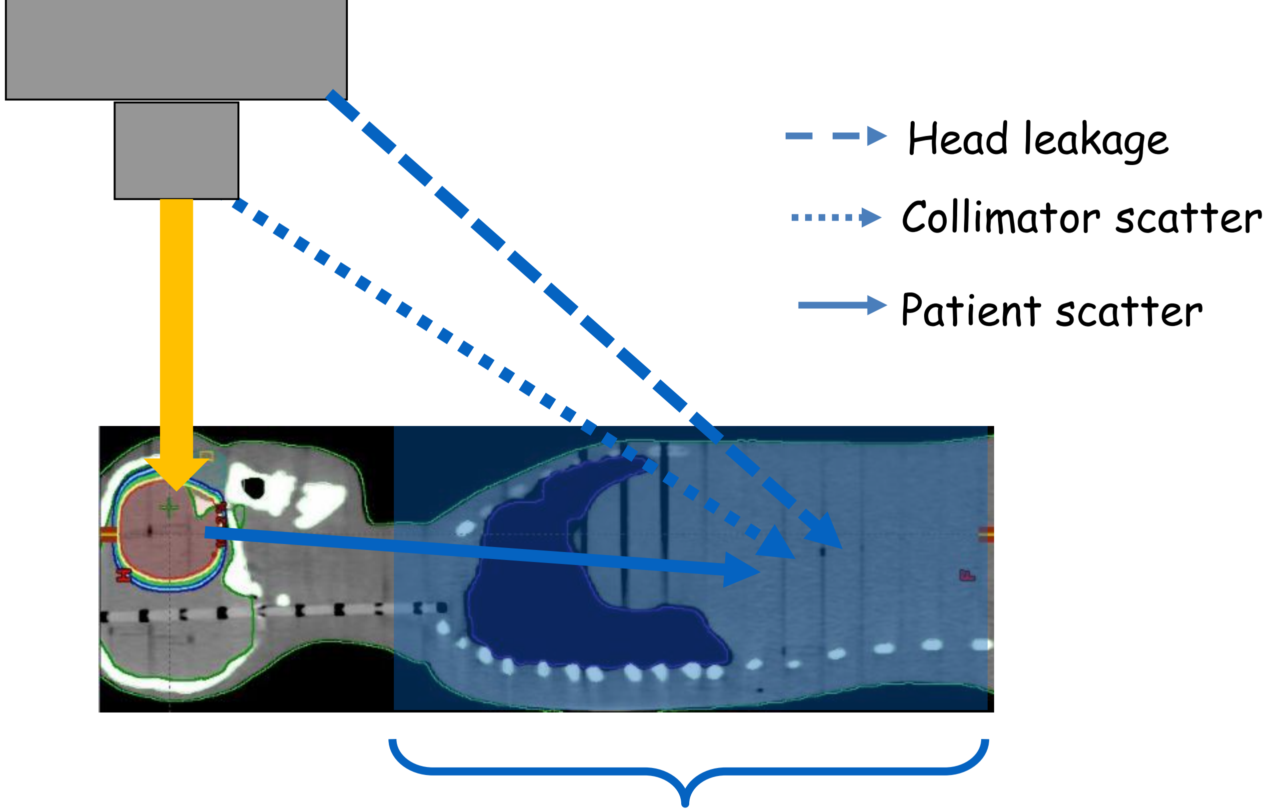
Sources of secondary radiation for photon beams

E_{photon}>10MeV ⇒ production of neutrons in photonuclear reactions (high Z material)



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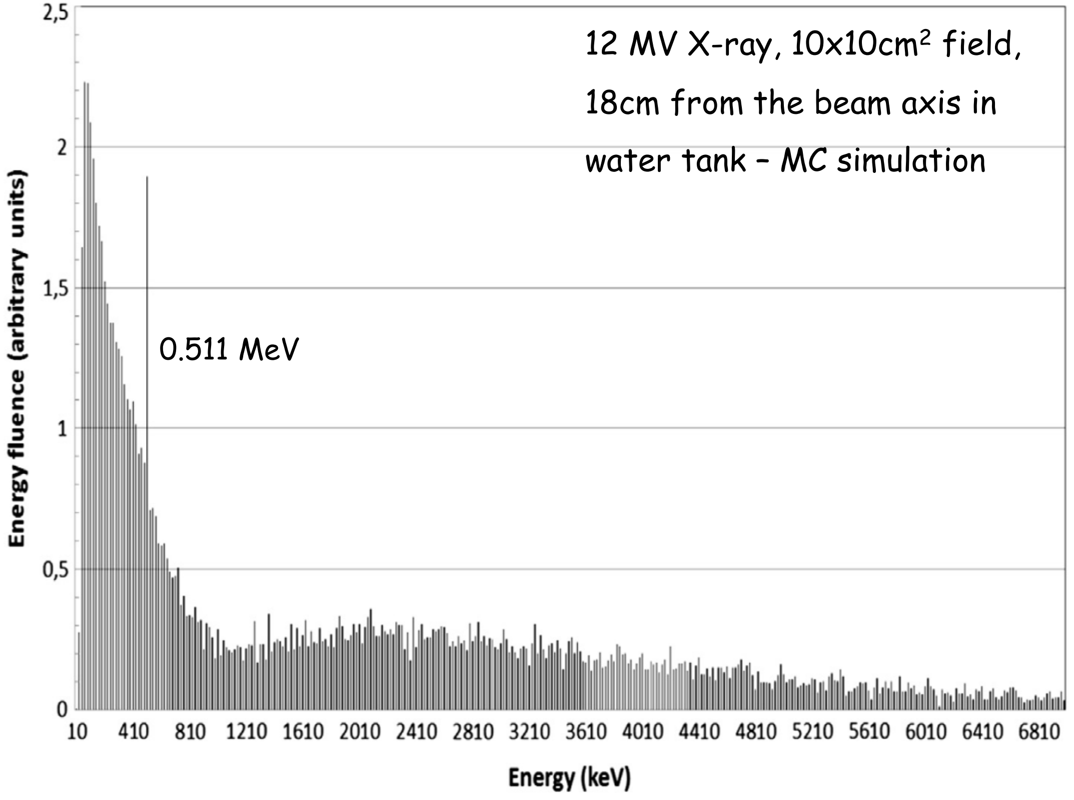

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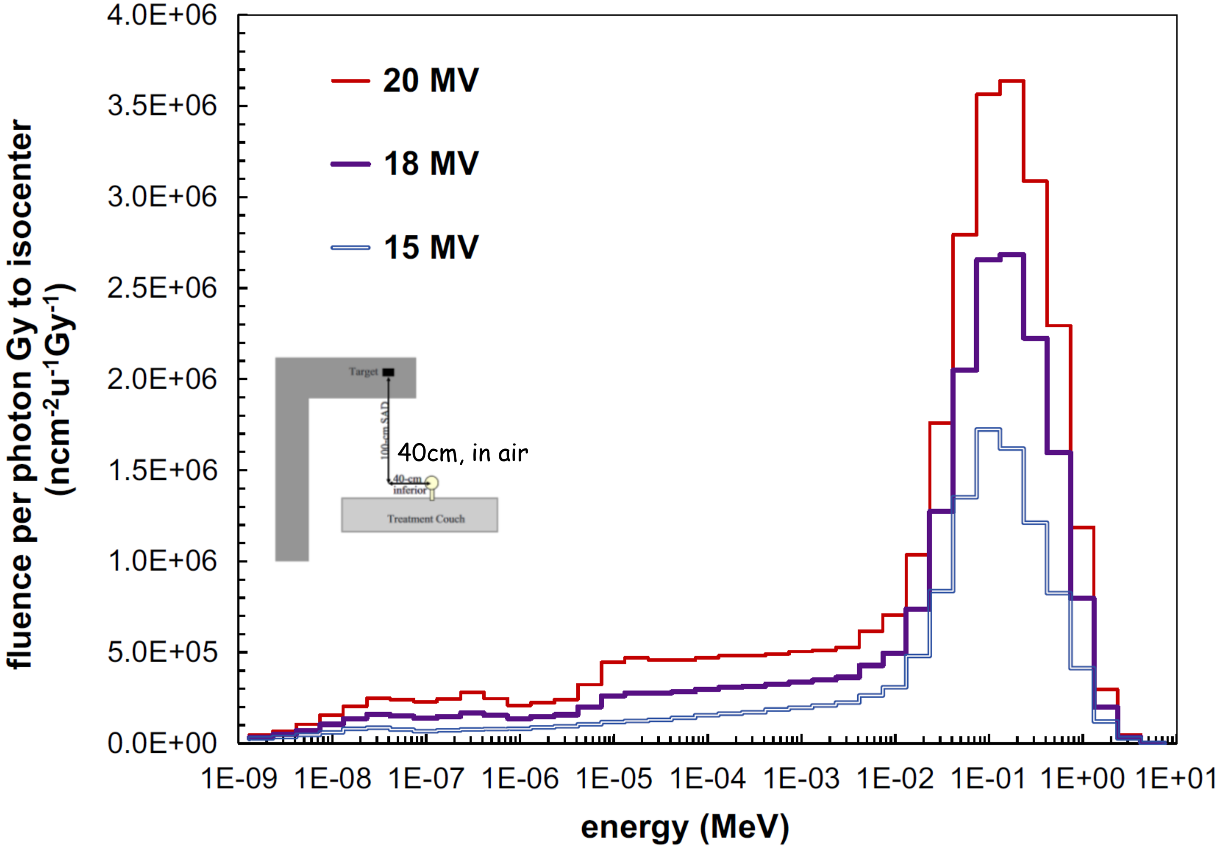

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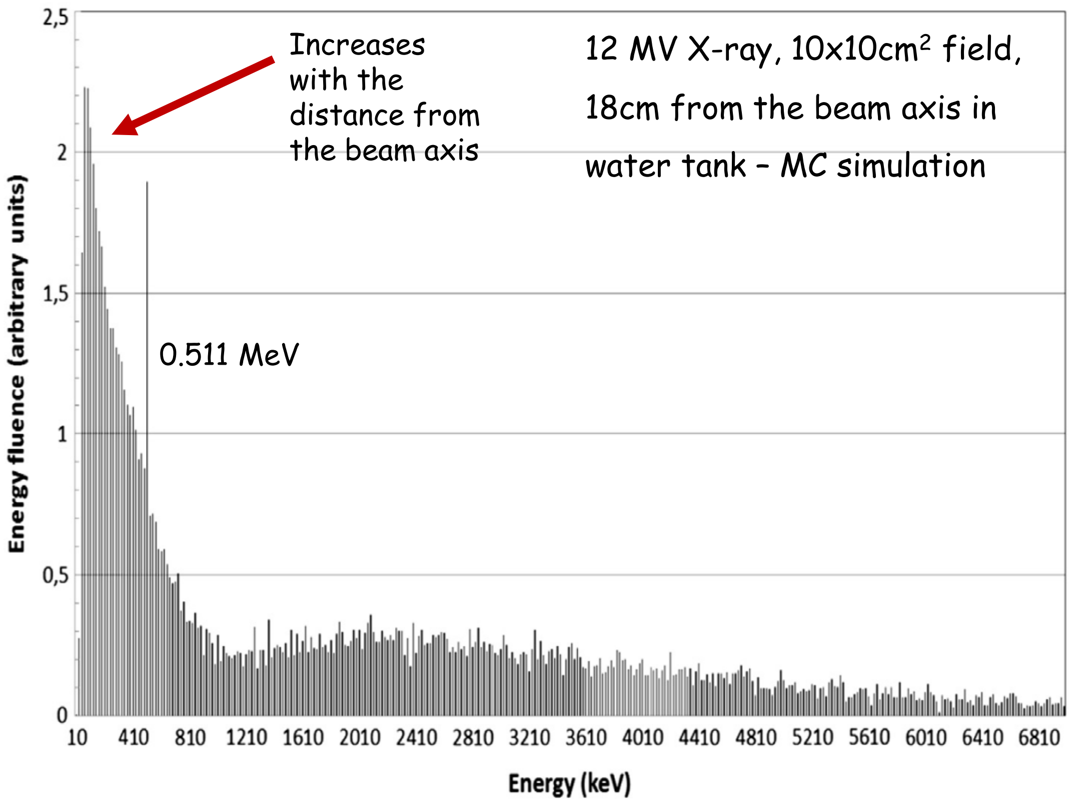

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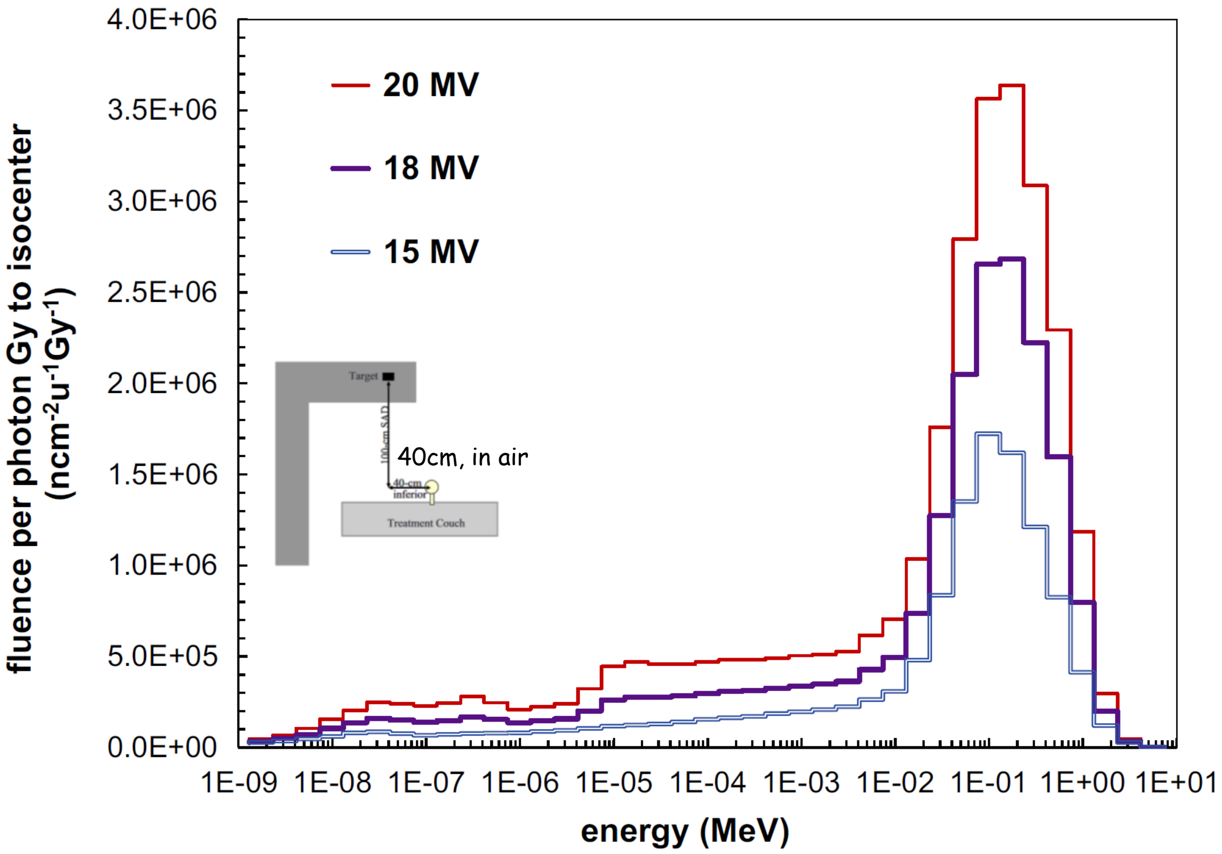

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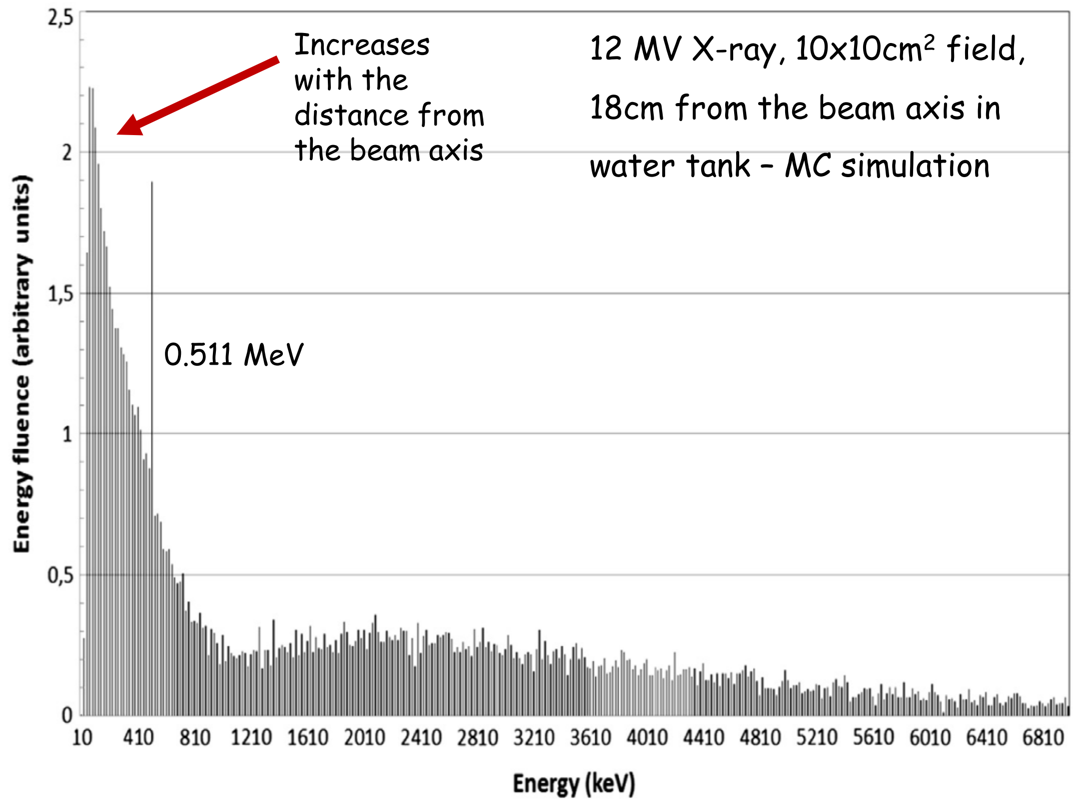

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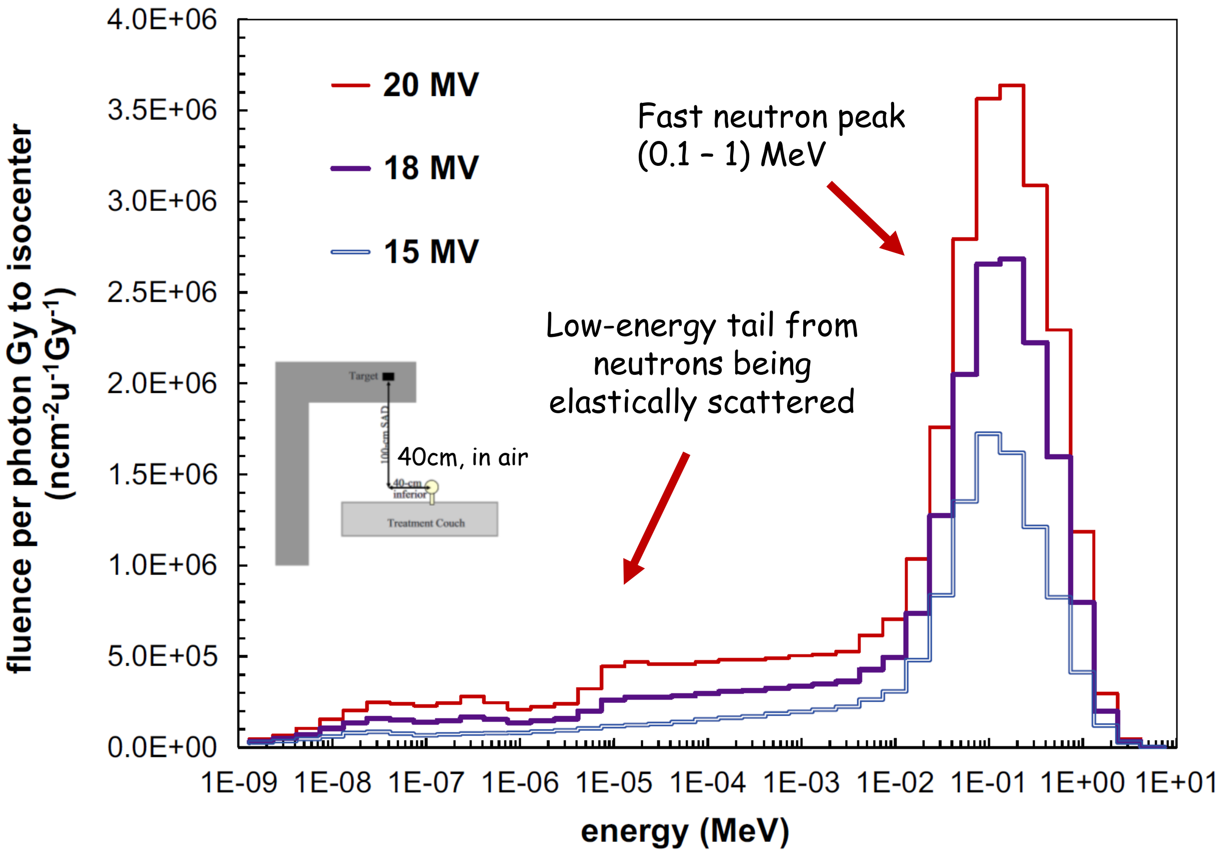

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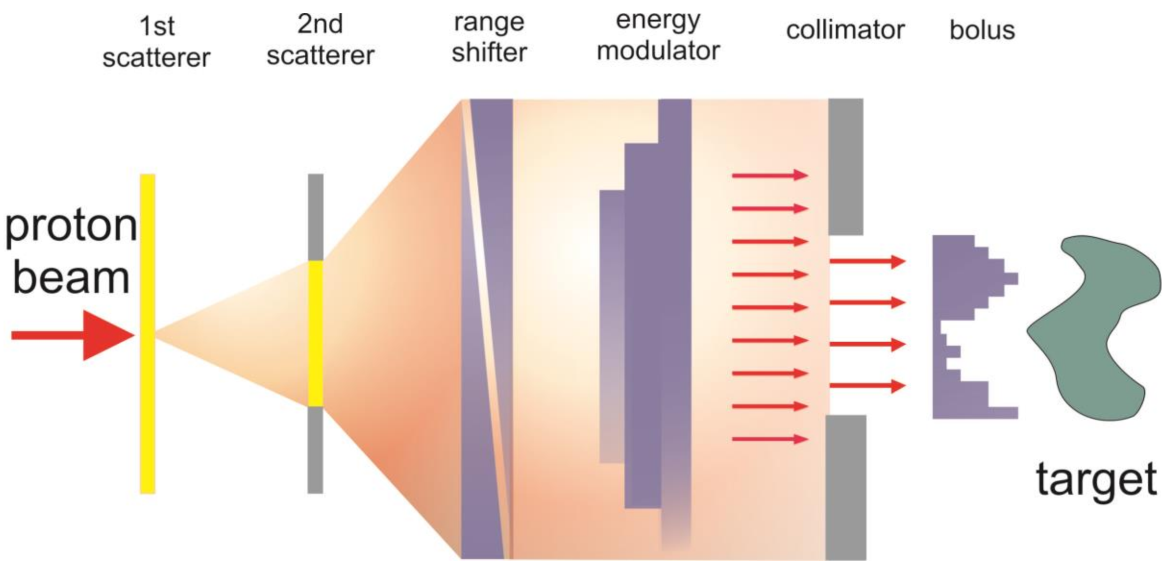
⇒ Dosimeters for neutrons (0.1 – 1) MeV are needed

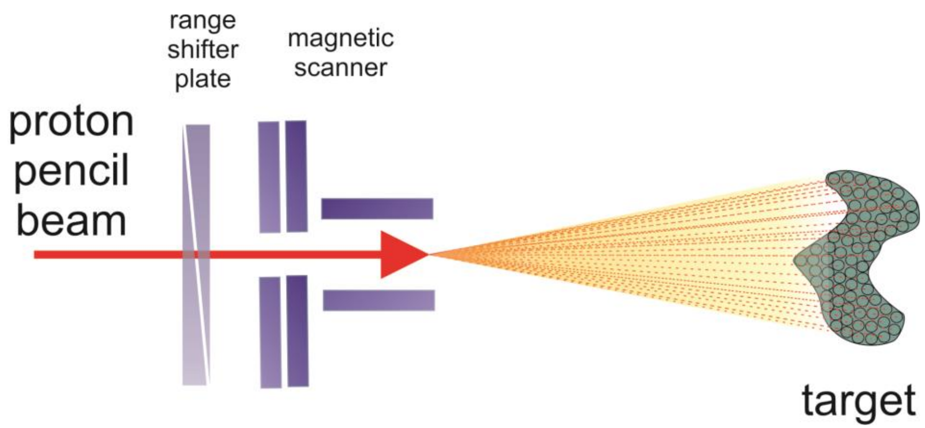
Sources of secondary radiation for proton beams

- Passive scattering
  - Beam forming elements (collimator, range shifter, energy modulator, compensator) and patient body



Sources of secondary radiation for proton PBS beams

- Active scanning → Pencil beam scanning (PBS)
  - Patient body and beam modulators (when used)



Active scaning has greatly reduced amount of interacting material

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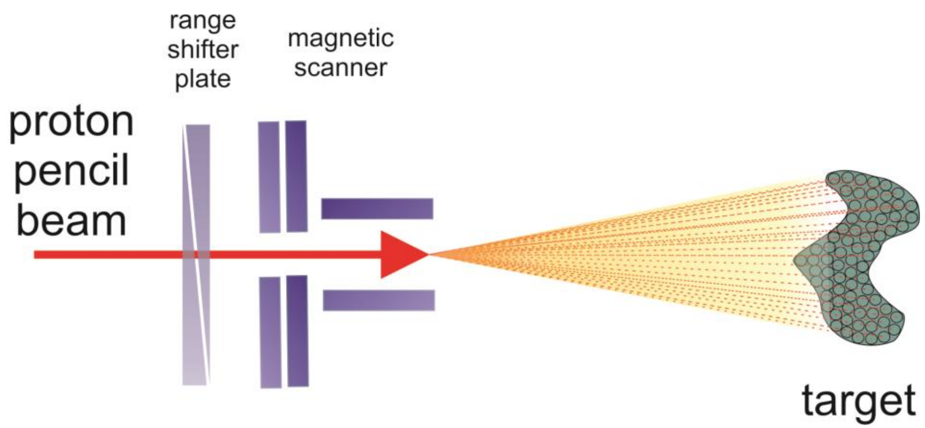

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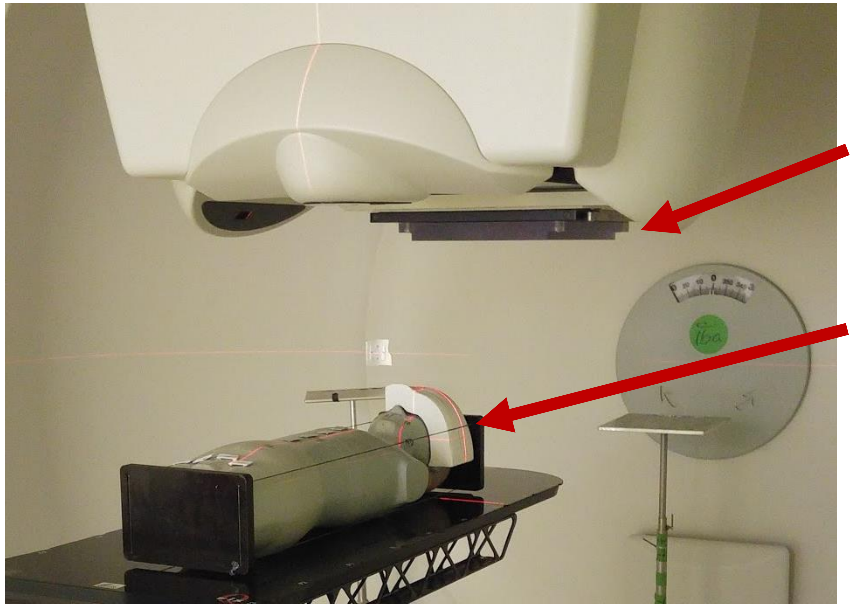

For shallow tumours beam modulators are used to reduce proton energy

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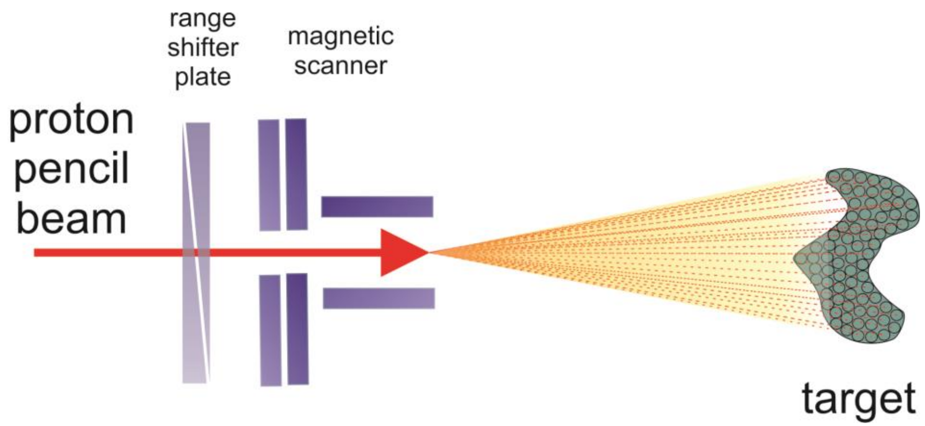

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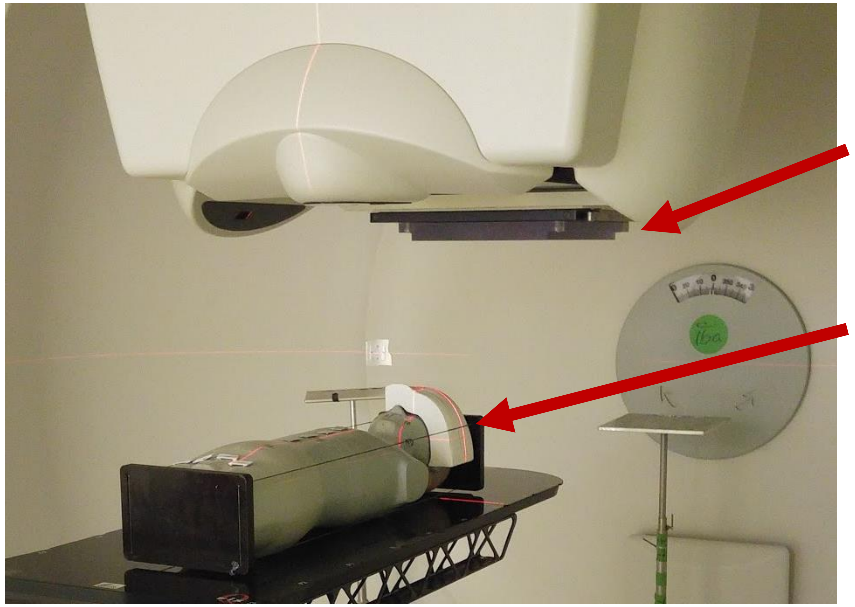

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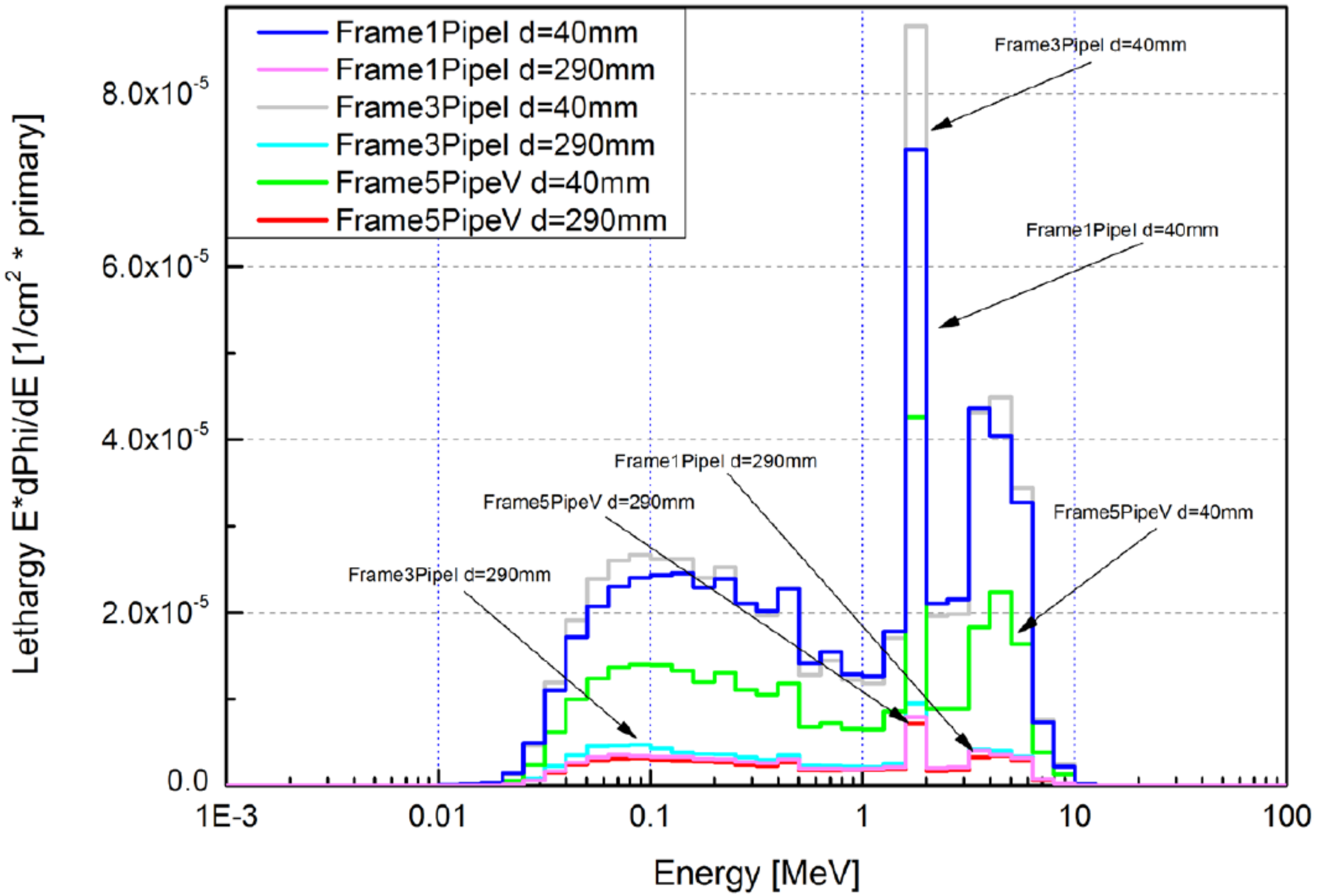

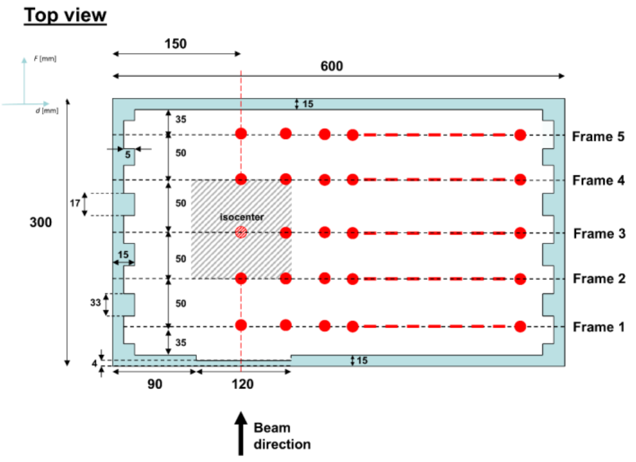

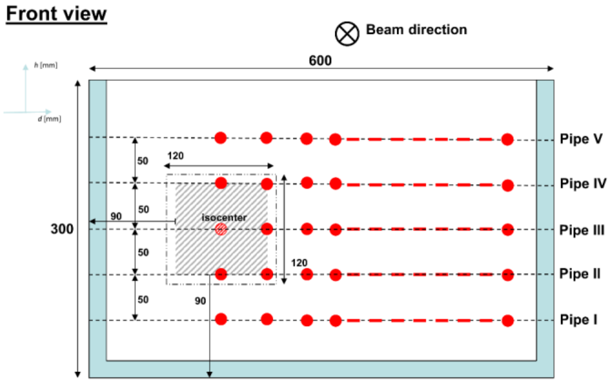

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Phys Med Biol. 63 (2018) 085017

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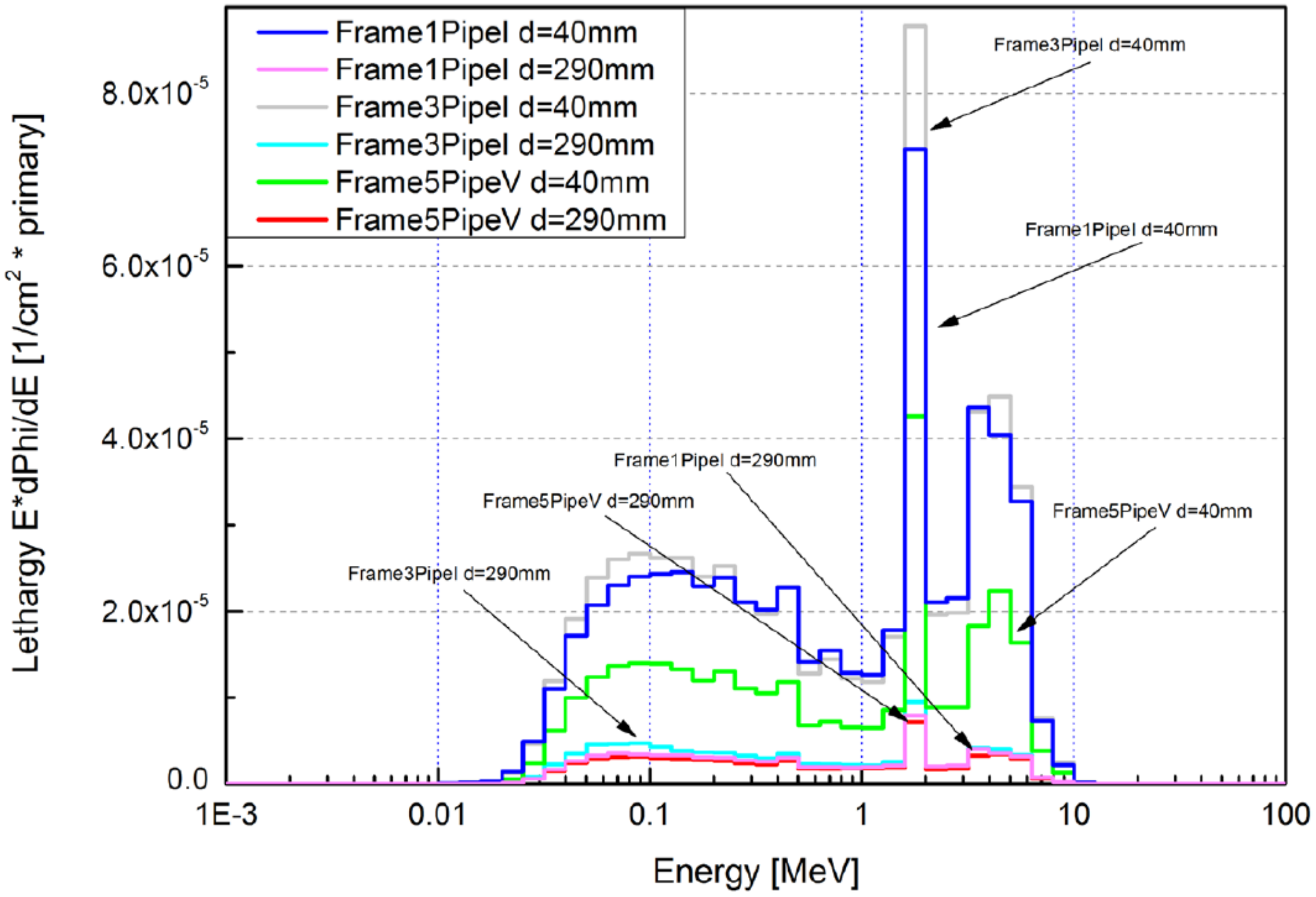
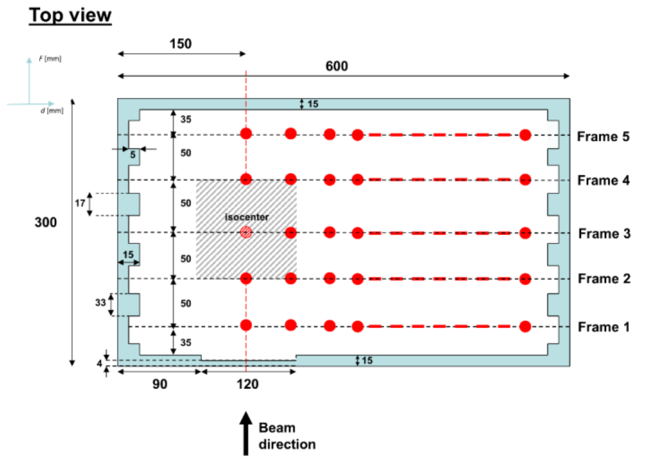
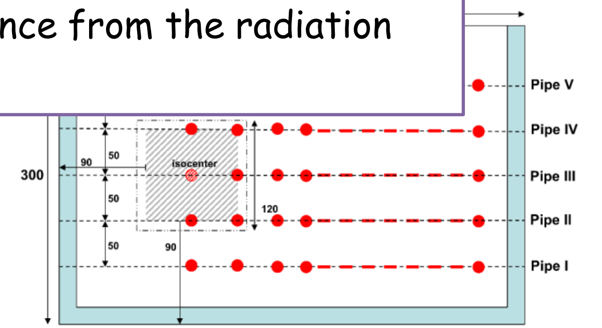




⇒ Total photon fluence decreases with distance from the radiation field



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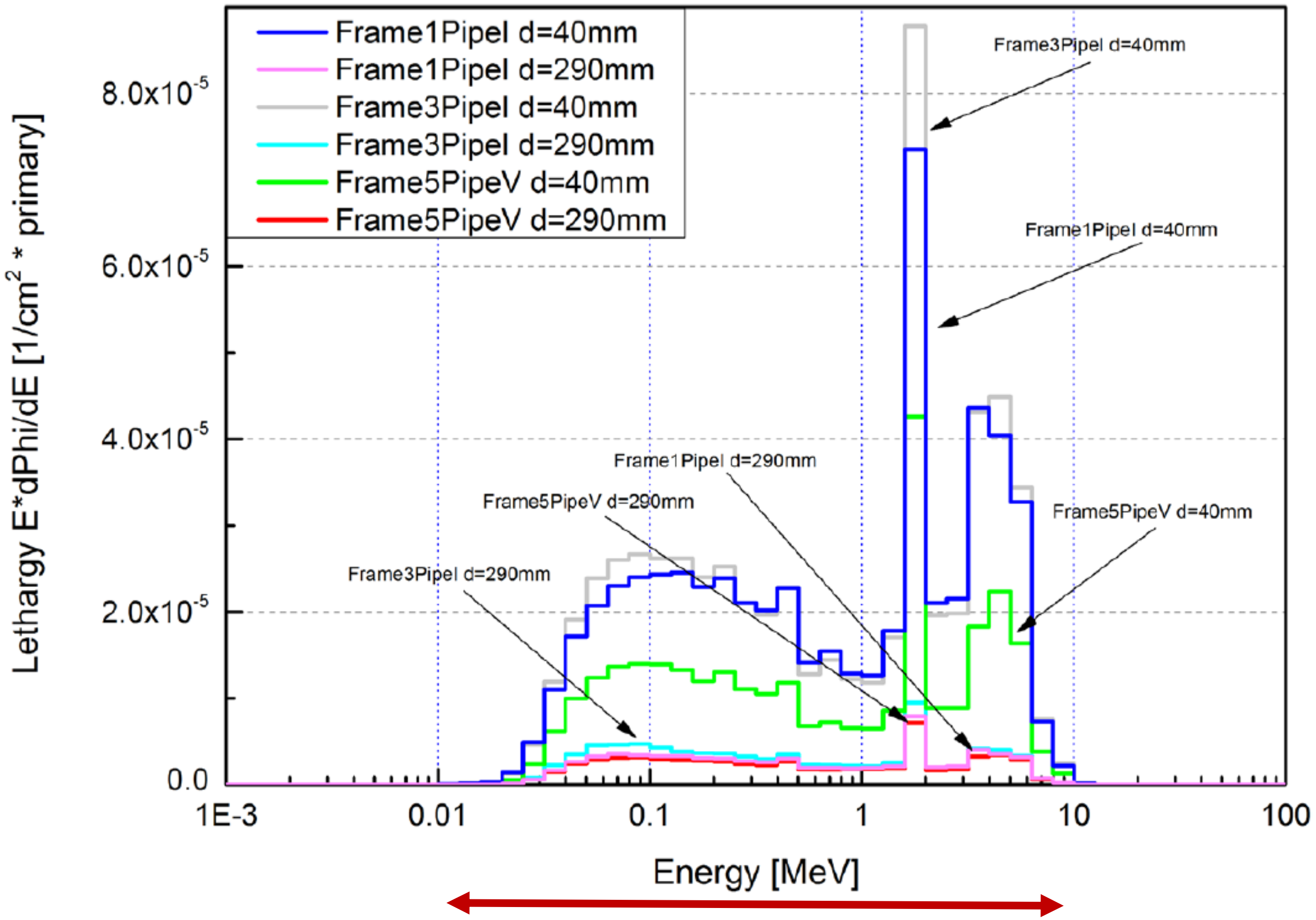

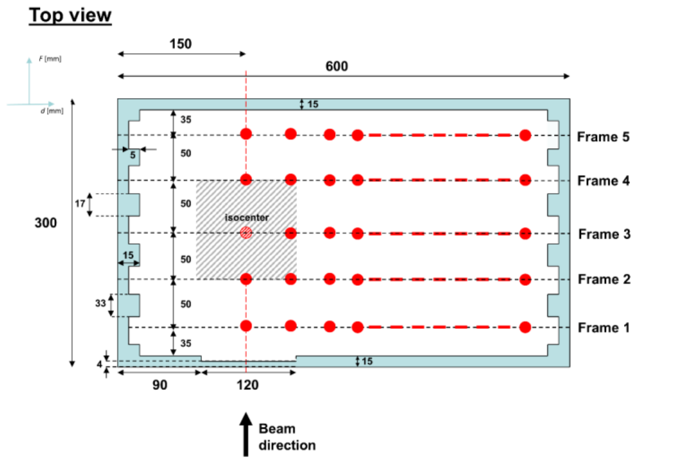

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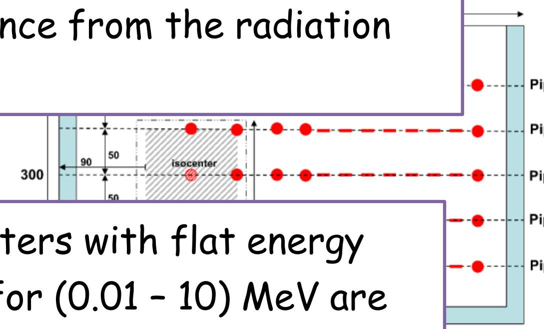

⇒ Dosimeters with flat energy response for (0.01 – 10) MeV are reccomended

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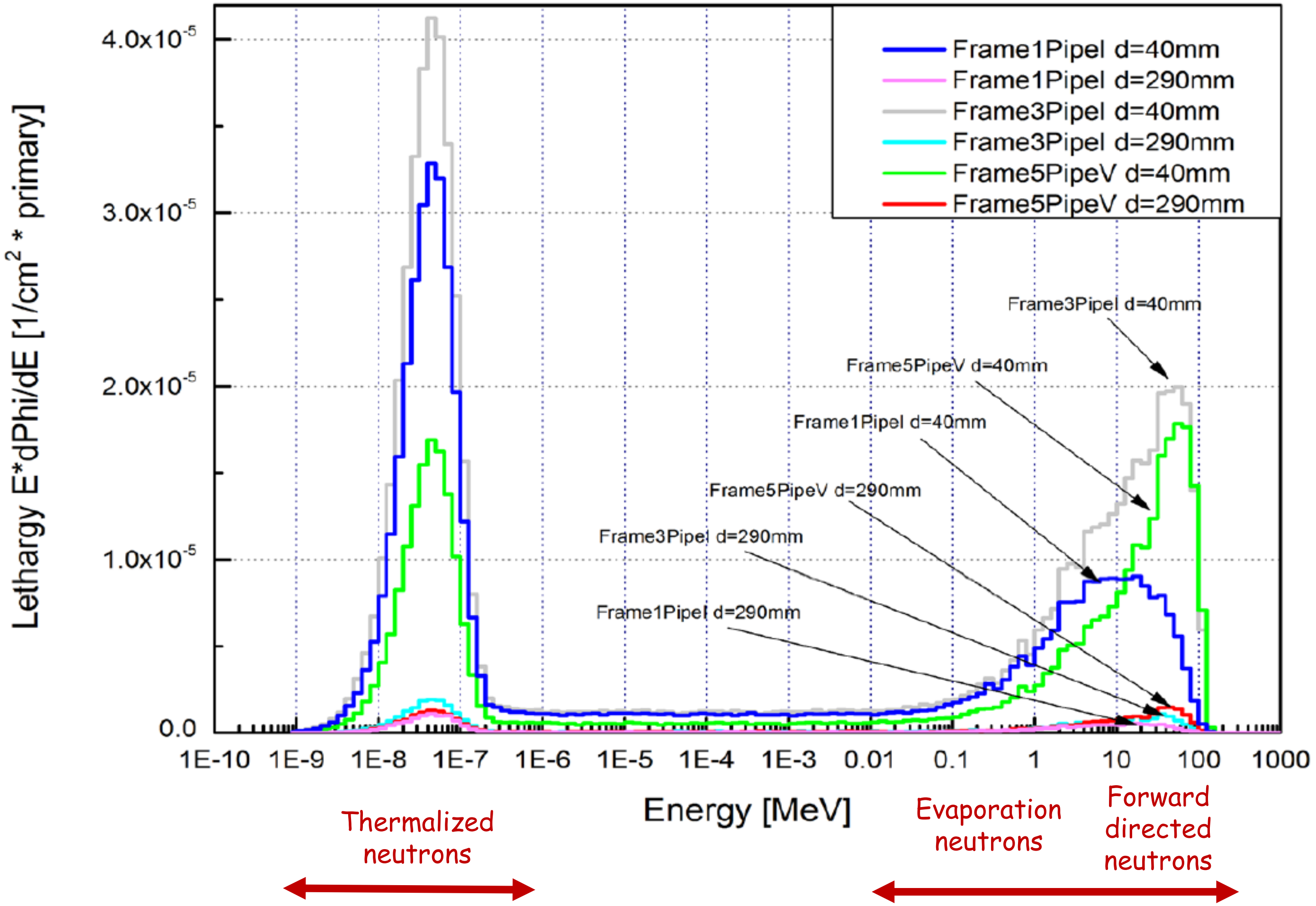

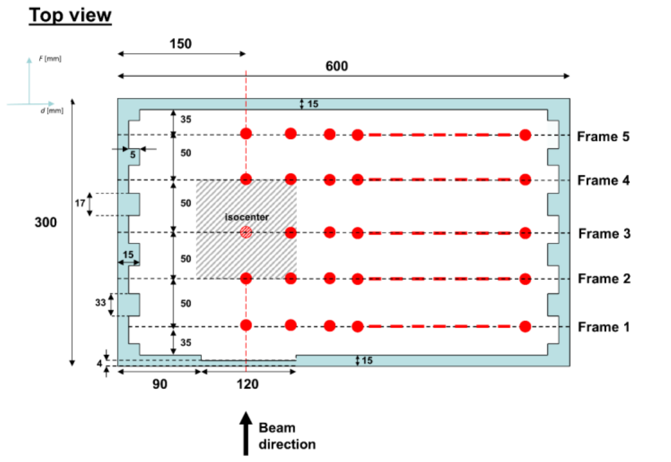

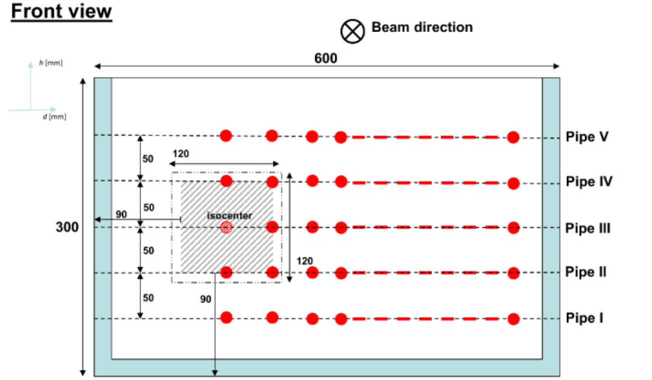

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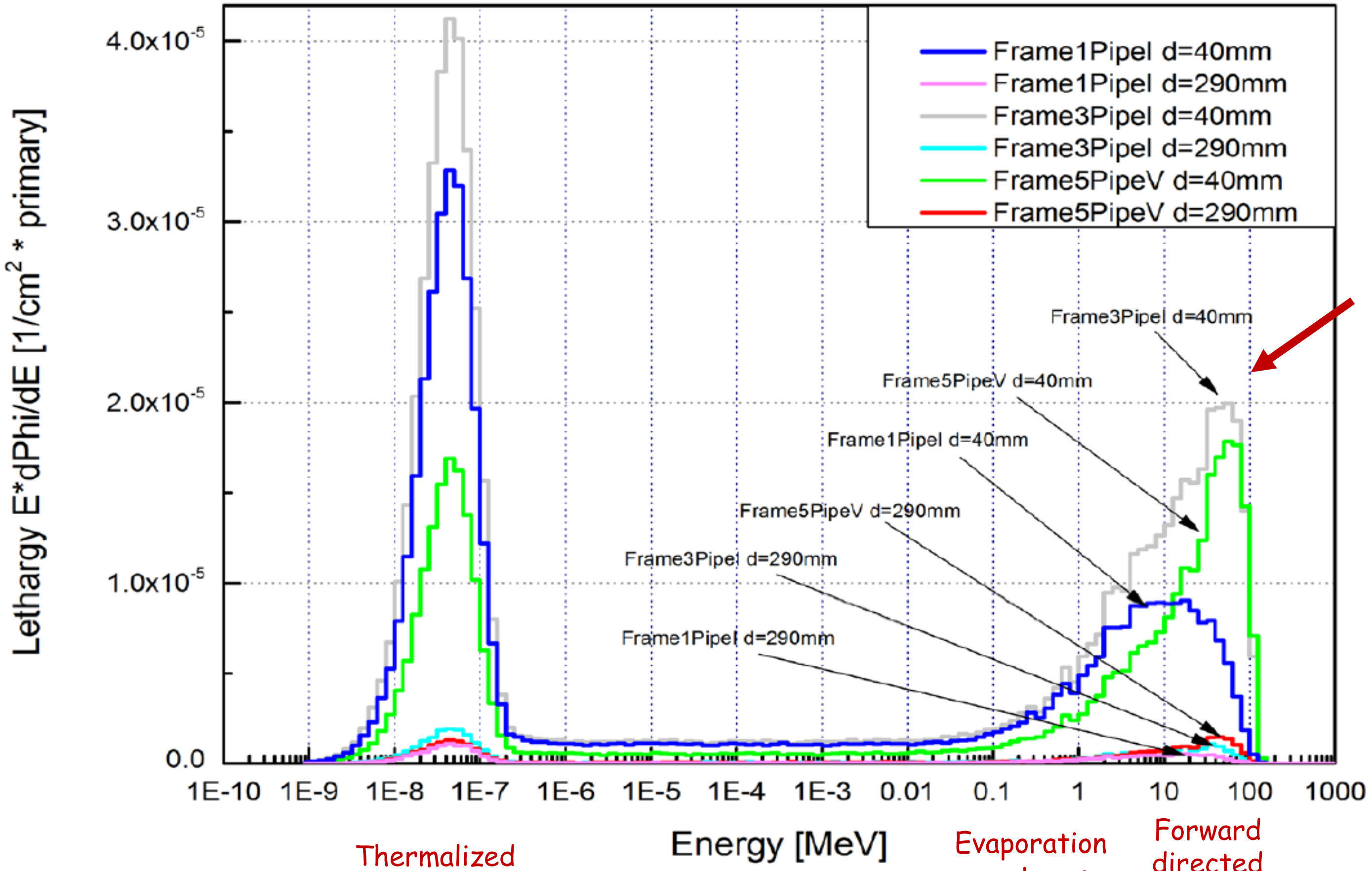
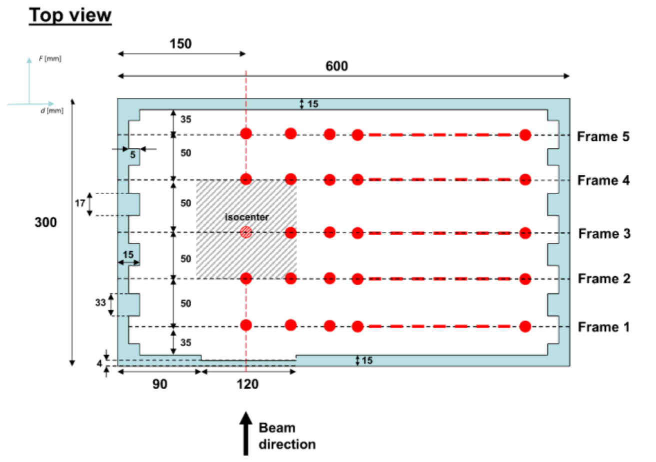


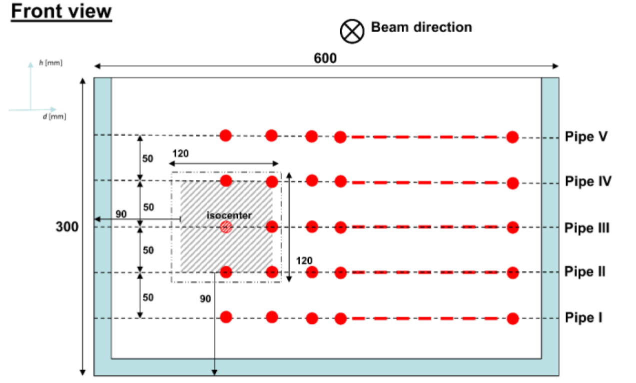
High energy peak at 10-100 MeV

Thermalized neutrons

Evaporation neutrons

Forward directed neutrons





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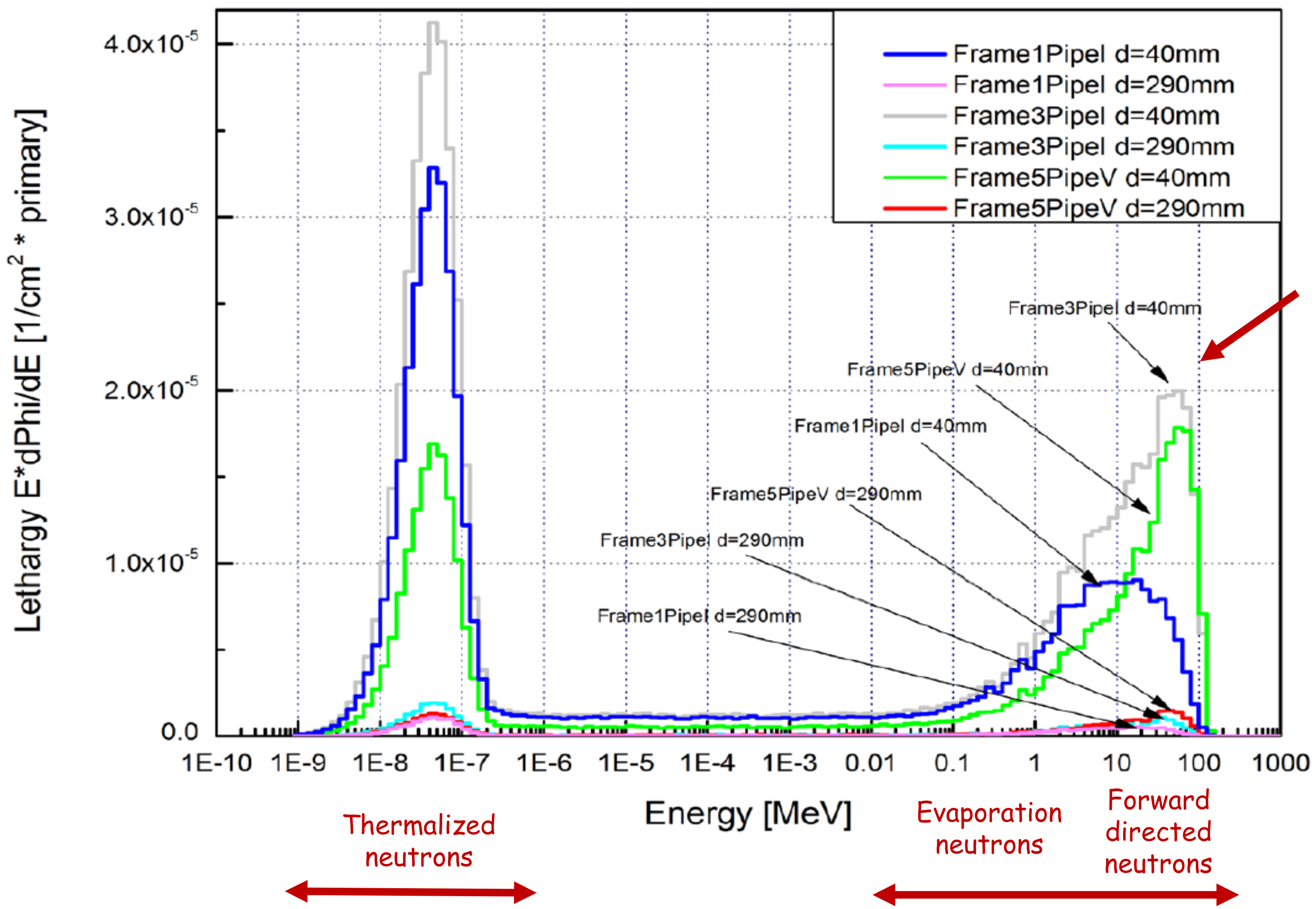

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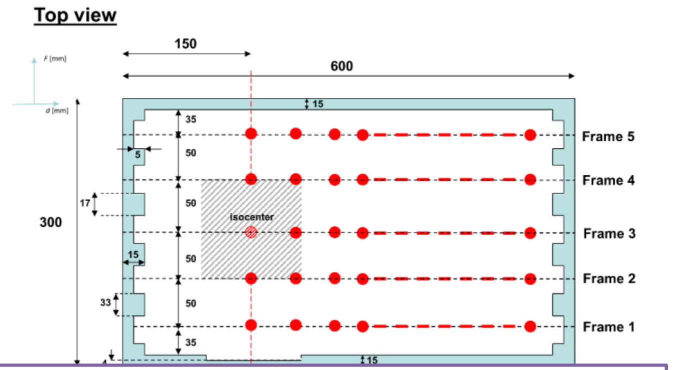
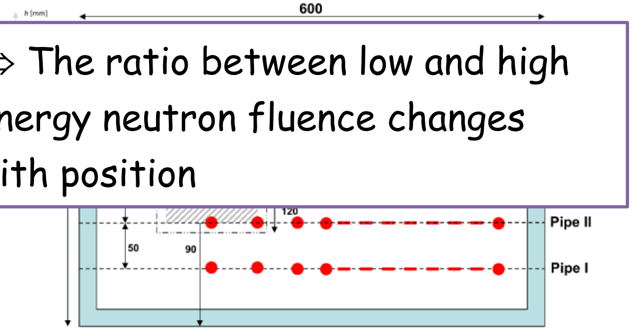


⇒ Total neutron fluence is the highest in the proximity of the proton irradiation

⇒ The ratio between low and high energy neutron fluence changes with position



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Out-of-field doses – mixed radiation field

- **MV X-rays radiotherapy:**
  - **scattered X-ray**, secondary γ radiation, **photoneutrons**

- **Proton PBS radiotherapy:**
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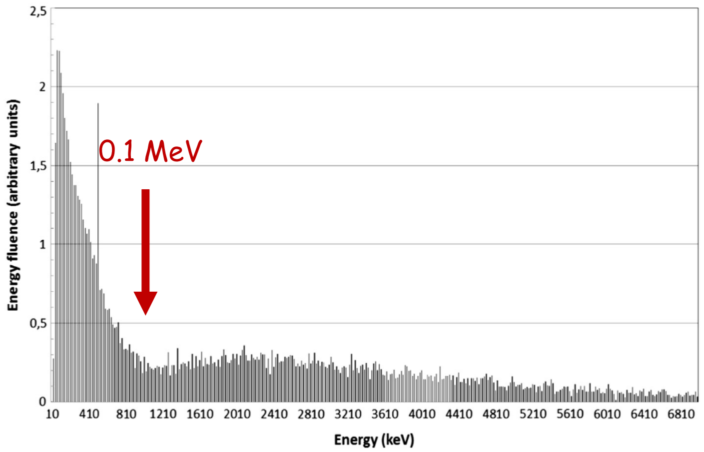
Energy spectrum of secondary **photons**



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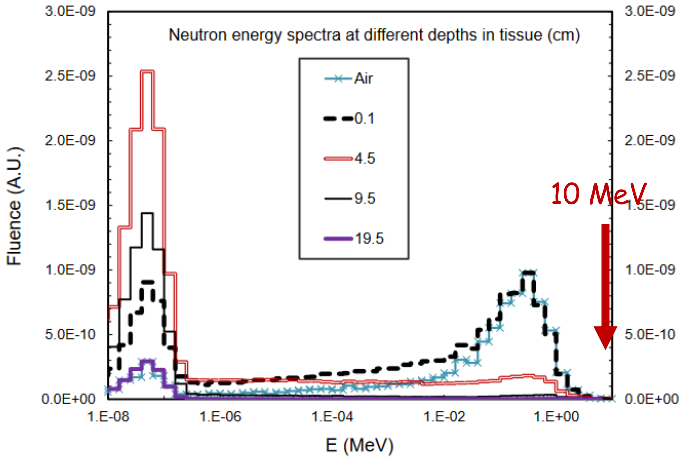

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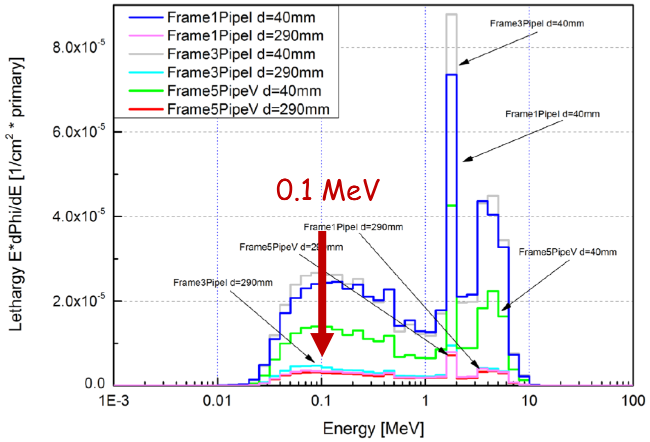

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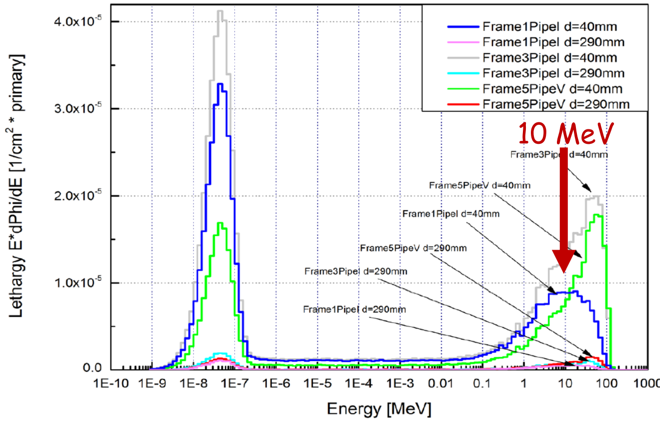

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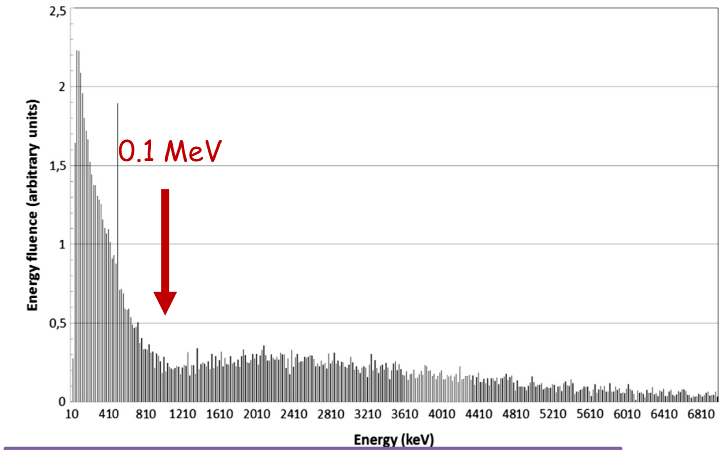

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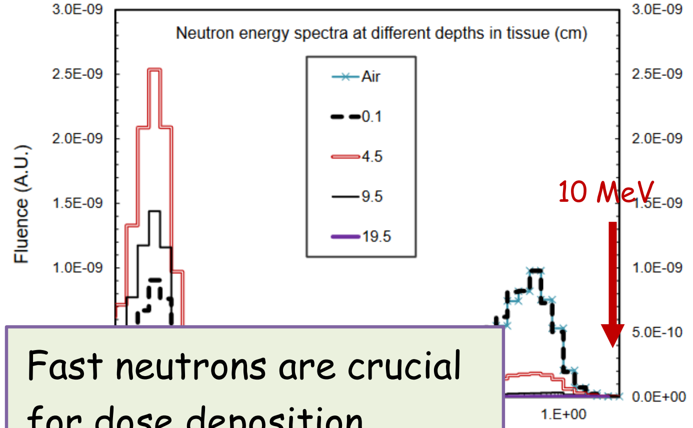
Be aware of low energy photons

Energy spectrum of secondary **neutrons**



...ulation of doses ... m radiation therapy.

Fast neutrons are crucial for dose deposition

MV X-ray → up to 10 MeV

PBS → up to 100 MeV

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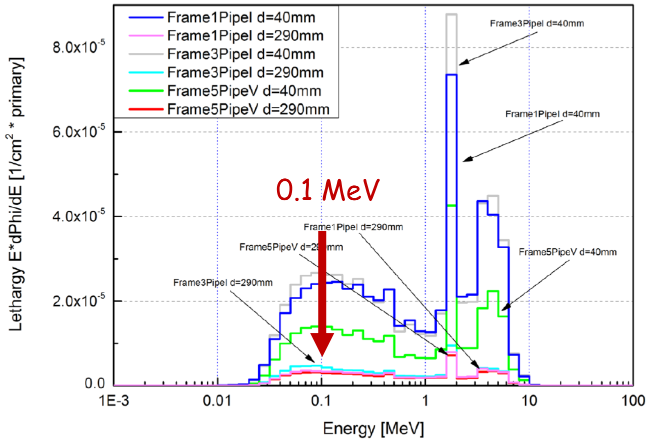

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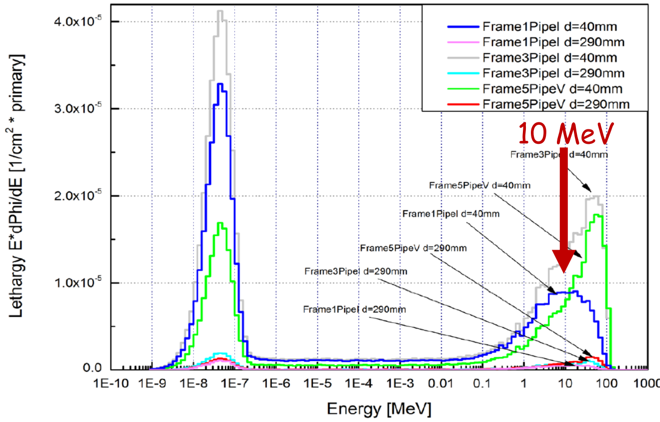

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PHANTOMS and DOSIMETERS

Phantoms

1. WATER TANK

- Simple and reproducible geometry
- Precize positioning of the dosimeters in the tank
- Comparison with reference dosimetry
- Easier comparison with calculated doses and MC simulations

But,

- Clinical treatments cannot be reproduced

Phantoms

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2. BOMAB-like phantom

- Approaching to the real clinical conditions

The Bottle Mannikin Absorber phantom (BOMAB)

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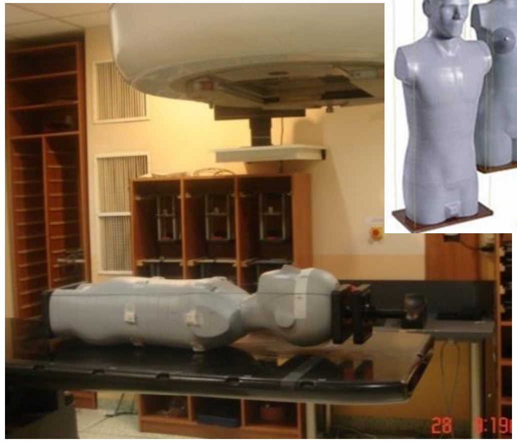


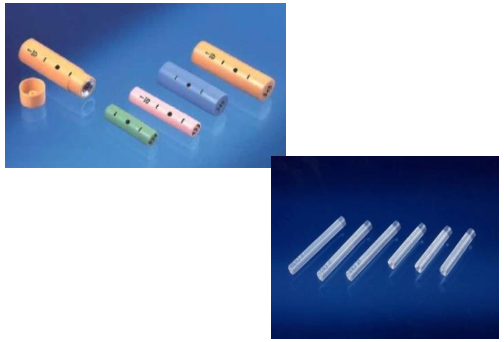
3. Anthropomorphic phantoms

- Real clinical treatments

Dosimeters

- Important characteristics:
  - Linear dose response (mGy to Gy)
  - Low energy dependence (for photons) and low angular dependence
  - Tissue equivalent
  - Small size and mechanically strong
  - Long term stability, reproducibility, batch homogeneity
  - Low sensitivity to other present particles

Passive Solid-State Luminescent Dosimeters



Radiophotoluminescent (RPL) dosimeters

Thermoluminescent (TL) and optically-stimulated luminescent (OSL) dosimeters

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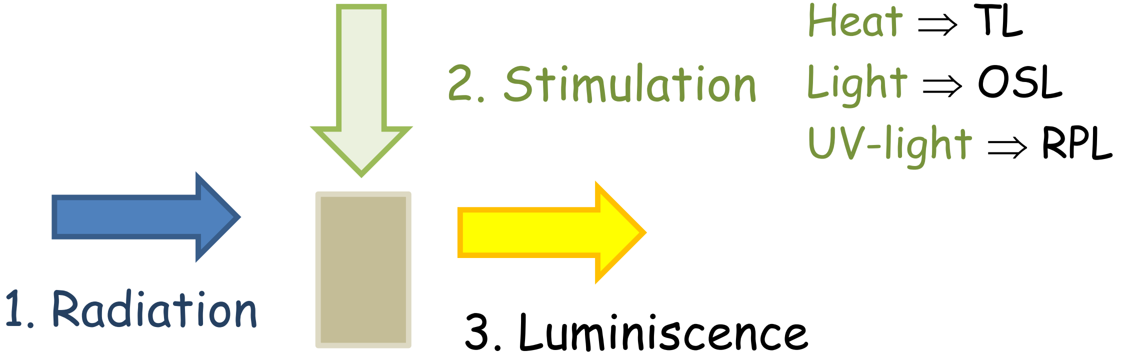


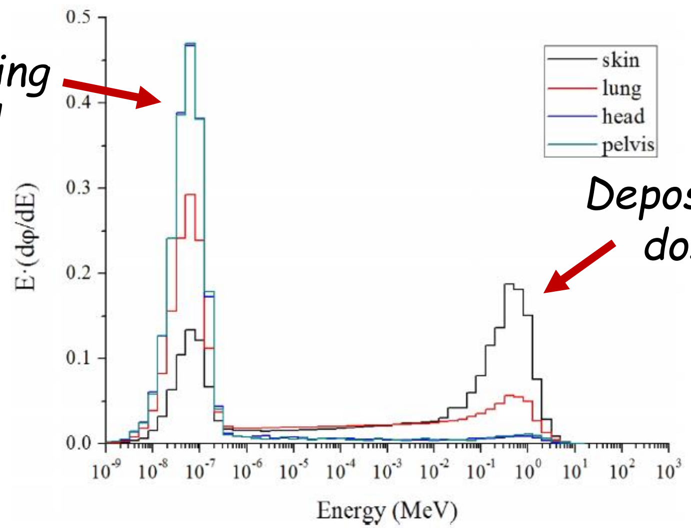
Dosimeters

Neutron dosimetry is challenging!

- Detected neutrons often have different energy than neutrons which contribute to the dose
- Important to know response function - relation to the neutron spectrum being measured!

Depositing signal

Depositing dose



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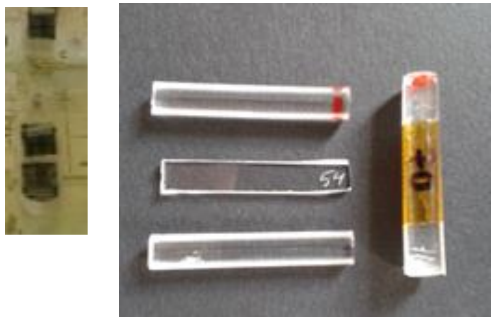
Passive neutron detectors
(for fast neutrons >0.1 MeV)

Nuclear track detectors based on poly-allyl-diglycol carbonate (PADC)



To measure thermal and high energy neutrons, converters can be added

Bubble detectors

Bolzonella et al. Neutron personal dosimetry using polyallyl diglycol carbonate (PADC): Current status, best practices and proposed research. Physics Open (2022) 100114

EURADOS

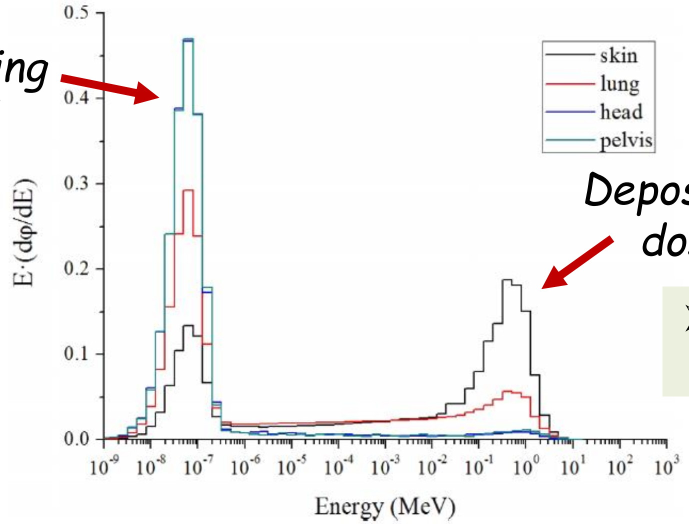
Dosimeters

Neutron dosimetry is challenging!

- Detected neutrons often have different energy than neutrons which contribute to the dose
- Important to know response function - relation to the neutron spectrum being measured!

Depositing signal

Depositing dose



Romero-Exposito et al. Experimental evaluation of neutron dose in radiotherapy patients: Which dose? Med Phys 43 (2016) e391-e429

Passive neutron detectors
(for fast neutrons >0.1 MeV)

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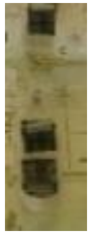

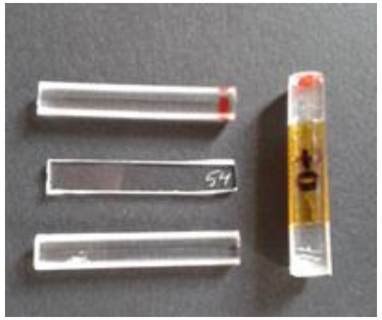

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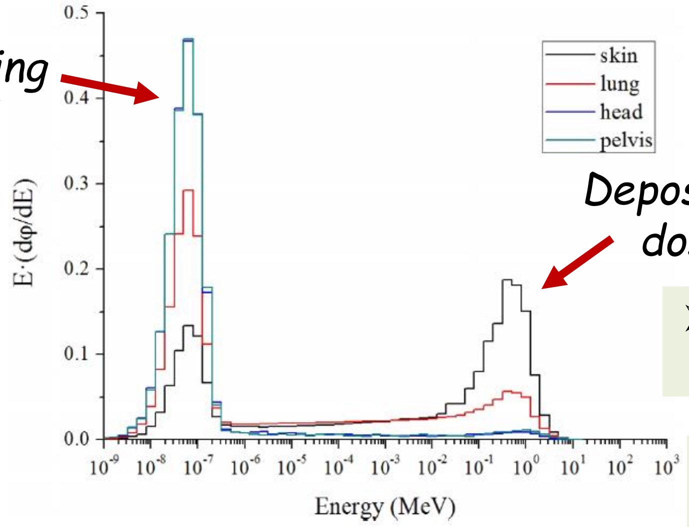

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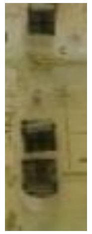

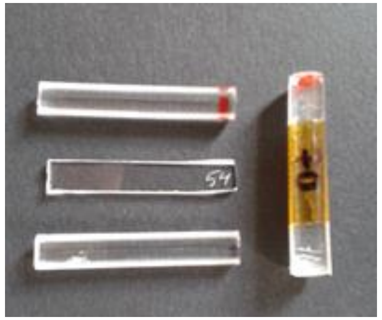

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Bubble detectors

- Neutron fluence to neutron dose equivalent conversion coefficients ⇒ neutron dose equivalent [mSv]

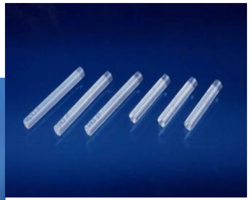
- Be aware that photon dose measured with TL/RPL is reported as apsorbed dose [mGy]

  Just for comparison, photon dose equivalent [mSv] can be calculated by multiplyng with quality factor Q=1.

Dosimetry systems used for comparison

Photon („non-neutron") dose

Dosimetry system	Type	Sensitivity to neutrons
RPL	GD-352M – with energy compensation filter ⇒ for out-of-field doses GD-302M – without energy compensation filter ⇒ for target	Very low
TLD	MTS-7 and TLD-700 ($^{7}LiF:Mg,Ti$) MTS-n and TLD-100 ($^{nat}LiF:Mg,Ti$) MTS-6 ($^{6}LiF:Mg,Ti$)	Low Sensitivity to thermal neutrons is increasing with % of ^{6}Li in detector
OSL	NanoDot ($Al_2O_3:C$)	Very low



Note: All detectors are sensitive to protons (RPL more than TLD)

Dosimetry systems used for comparison

Neutron dose

Dosimetry system	Type	Neutron energy range
Nuclear track detectors	PADC Type I PADC Type II – with converters	(0.1-10 MeV) thermal to high energies
Bubble detectors	BD for personal neutron dosimetry (BD-PND)	(0.1 – 12 MeV)

Note: PADC and BD are not sensitive to photons

Dosimetry systems used for comparison

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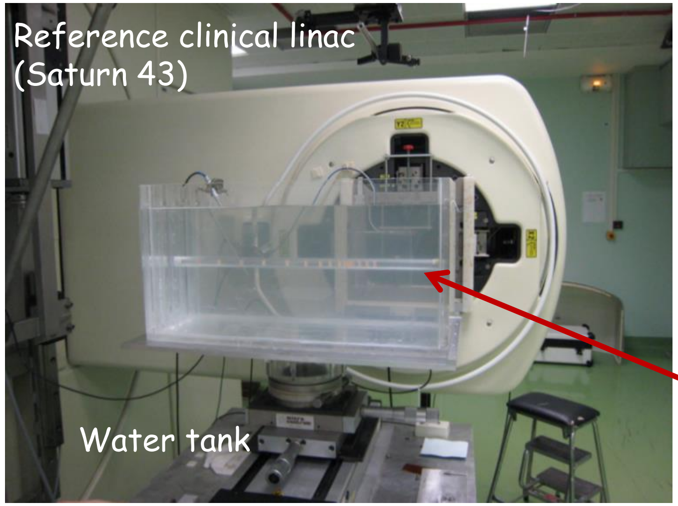
Dosimetry system	Type	
TLD	MTS-7 (^{7}LiF:Mg,Ti) MTS-6 (^{6}LiF:Mg,Ti)	⇒ Difference of signals is indicator of thermal neutron dose

Out-of field doses

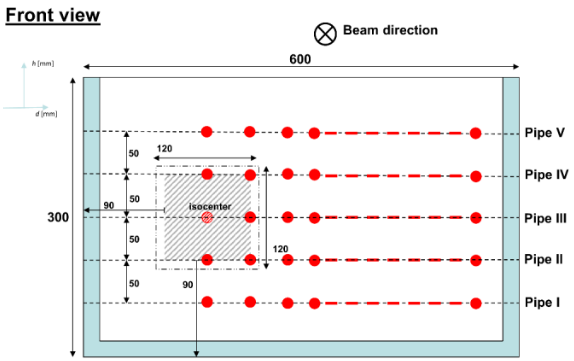
Comparison of dosimetry systems

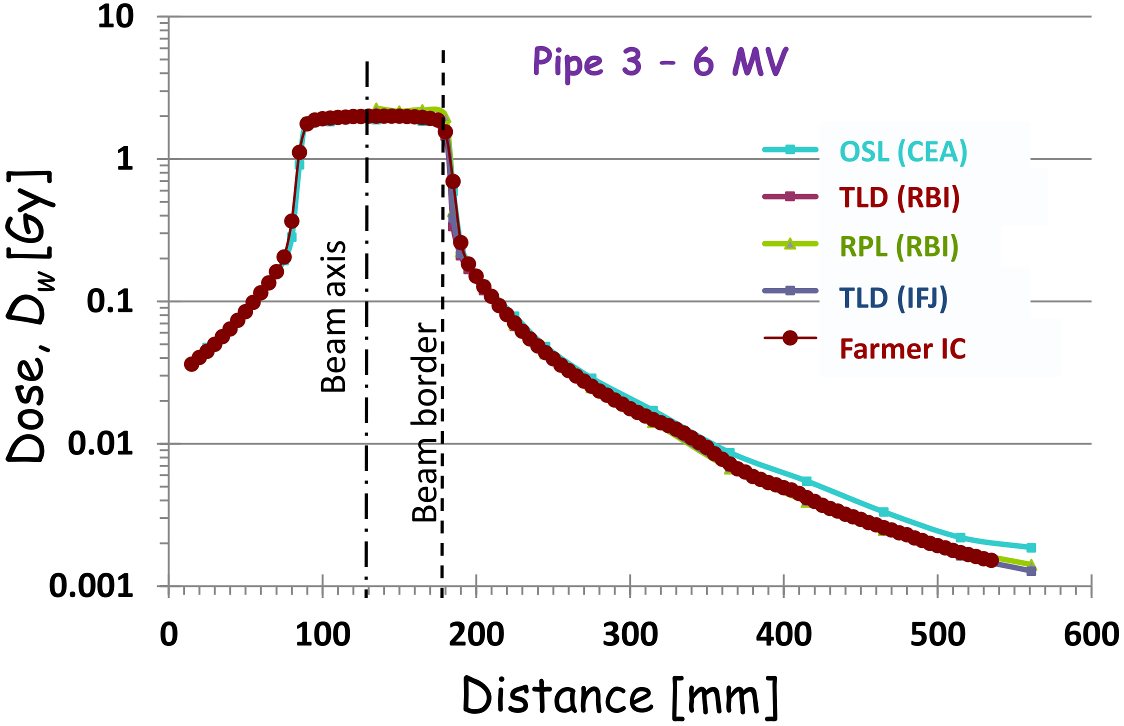
Comparison of dosimetry systems – photon radiotherapy

CEA-LIST/LNHB metrology laboratory, Saclay
(6, 12 and 20 MV X-rays)



Pipes with TL/RPL/OSL dosimeters





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- TL, RPL and OSL* dosimeters can be used for out-of-field photon dosimetry → a good agreement between dosimeters and with reference IC has been achieved

*after energy correction

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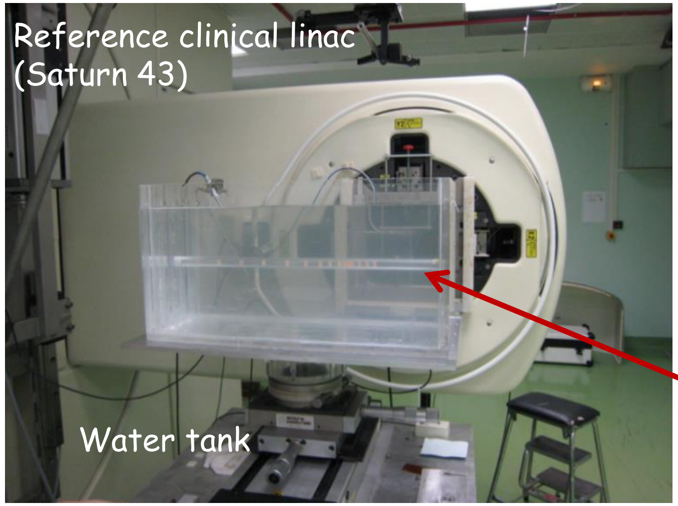

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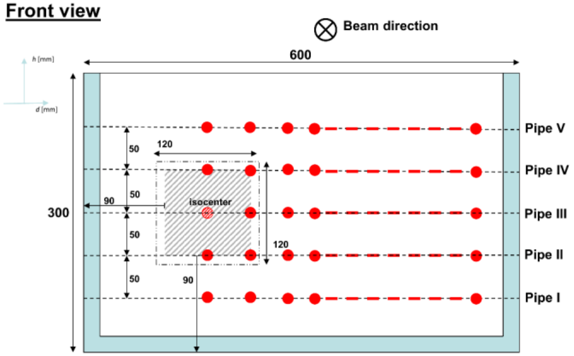

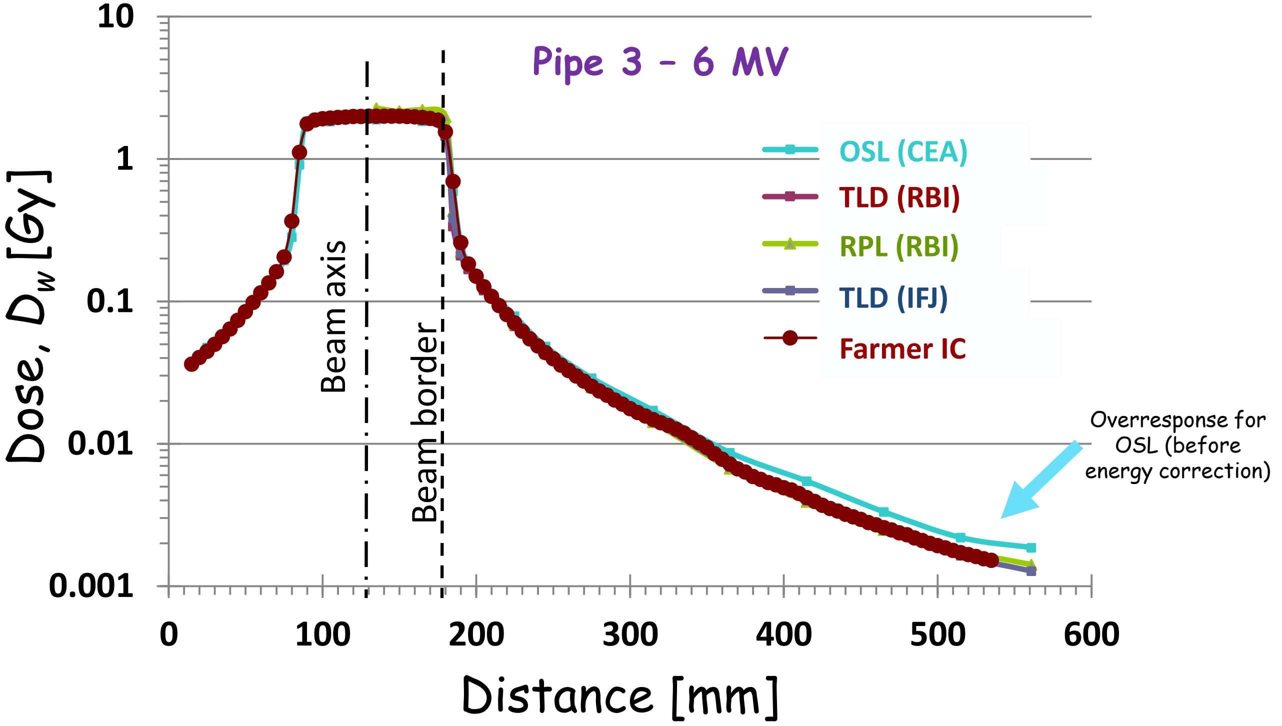

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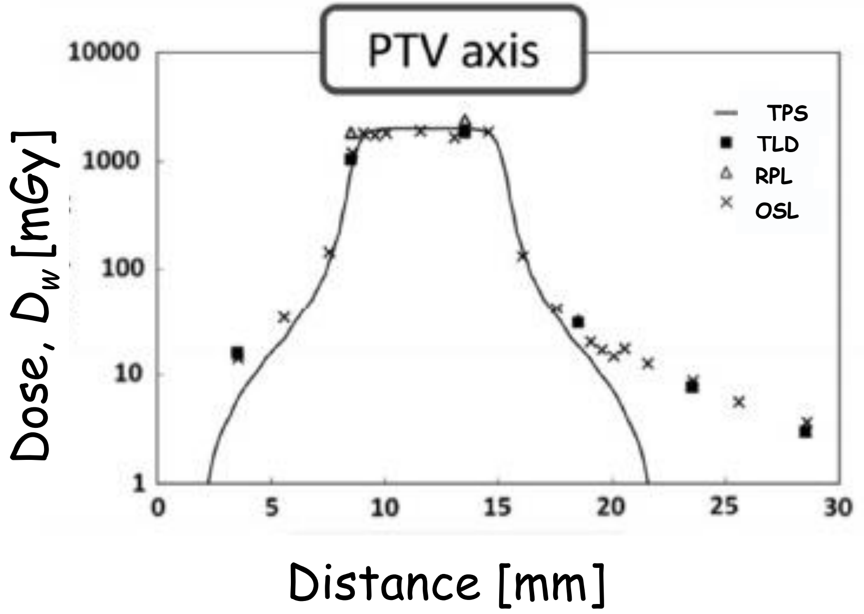

- Clinical simulation of a prostate radiotherapy

Varian Clinac:

- VMAT (6 MV)
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- 5-field 3D-CRT (15 MV)
- 4-field 3D-CRT (6, 18 MV)

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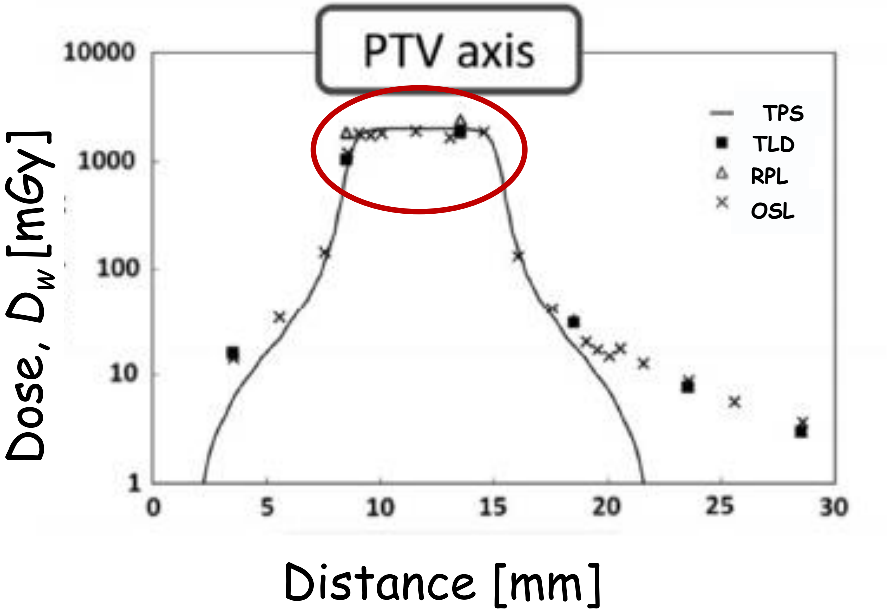

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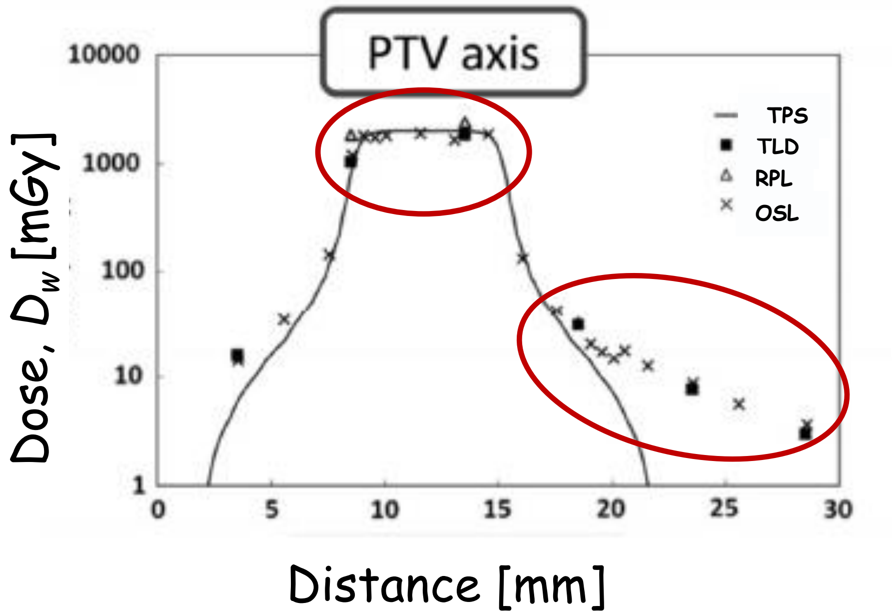

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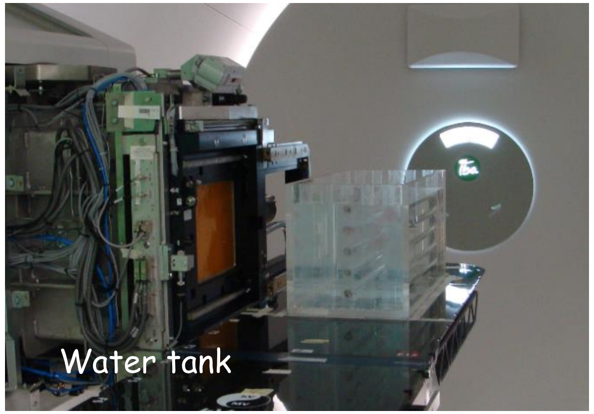
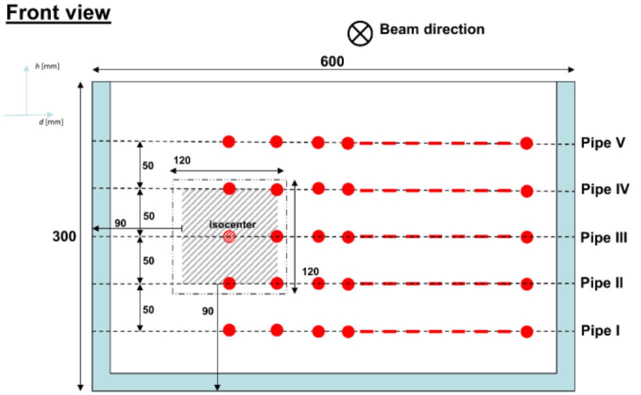
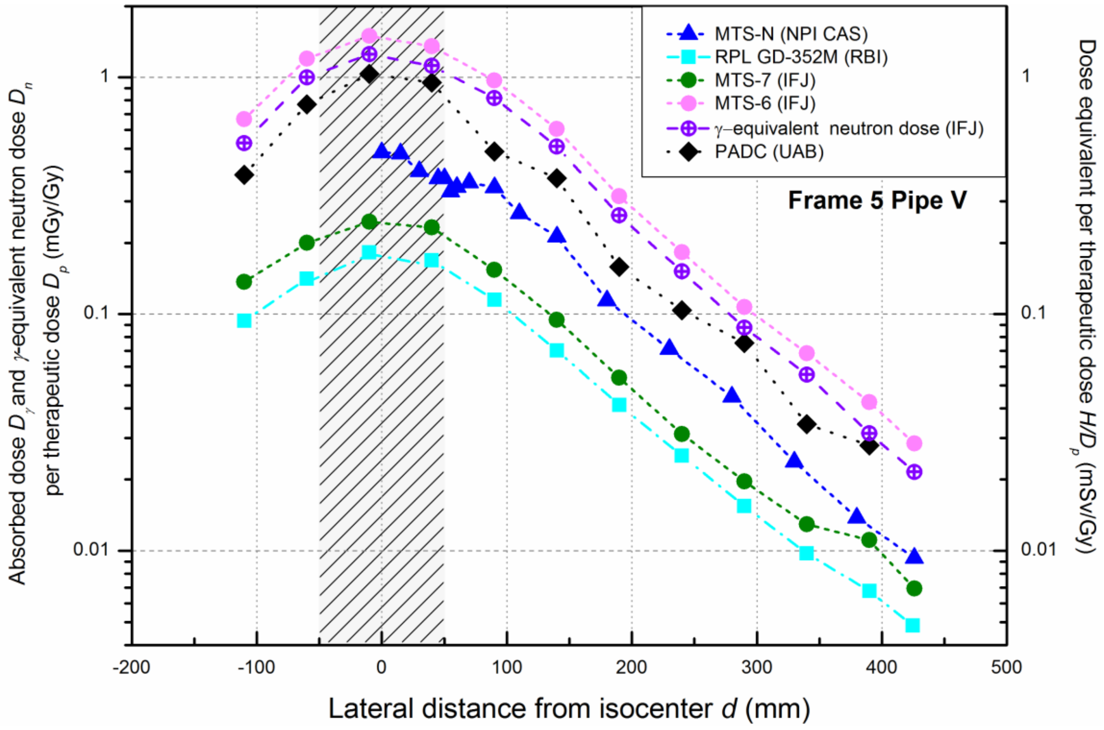
- Good agreement between TL/RPL/OSL dosimeters
- Underestimation of measured out-of-field doses by TPS

Comparison of dosimetry systems – proton PBS radiotherapy

Proton therapy center, Trento
Pencil Beam Scanning (PBS) technique







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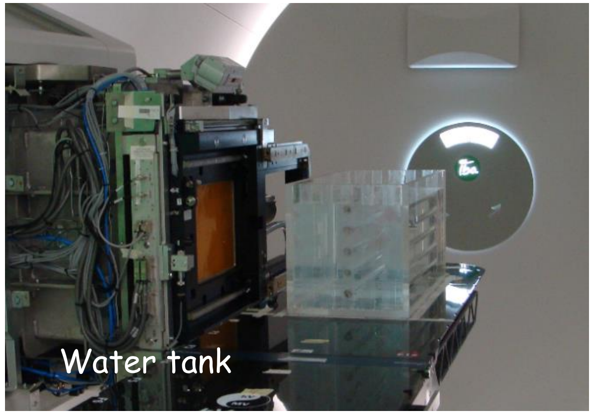

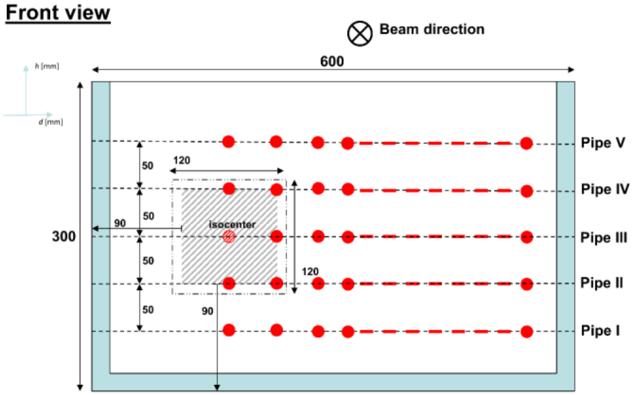

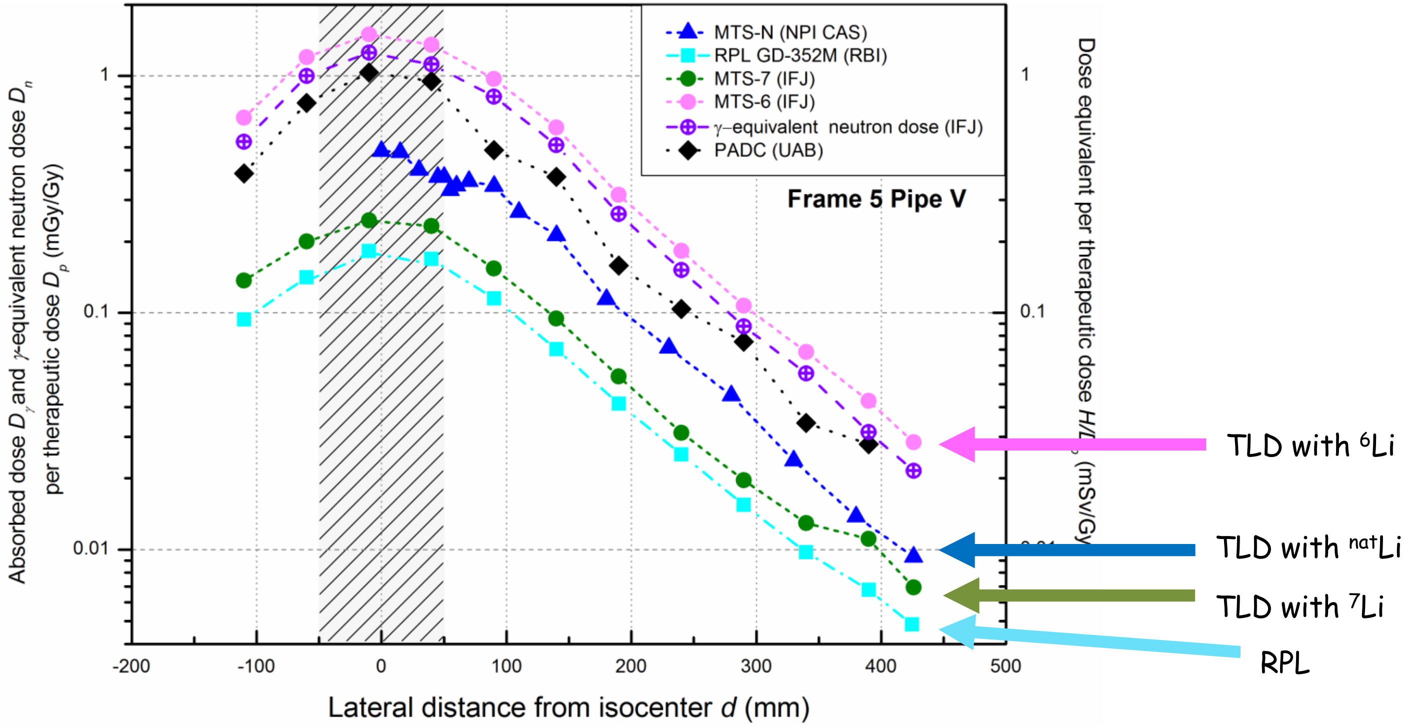

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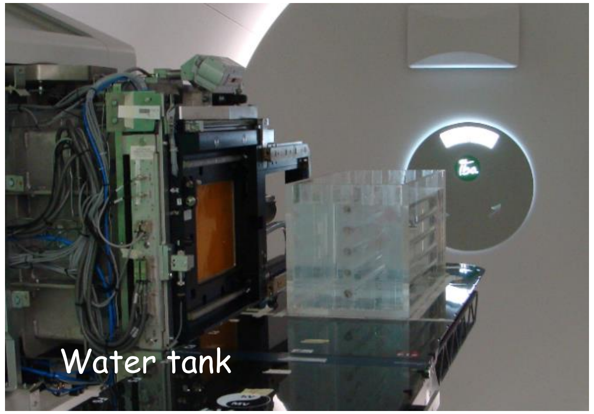

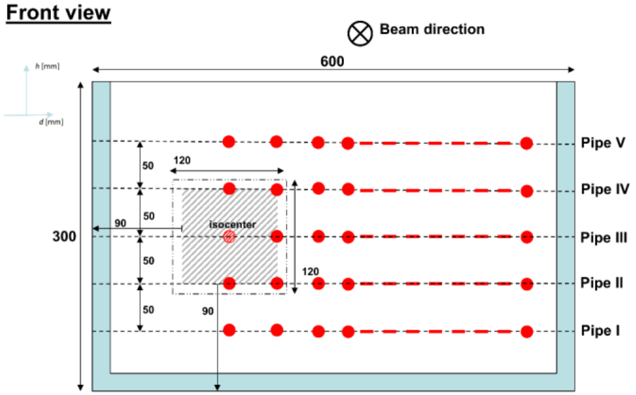

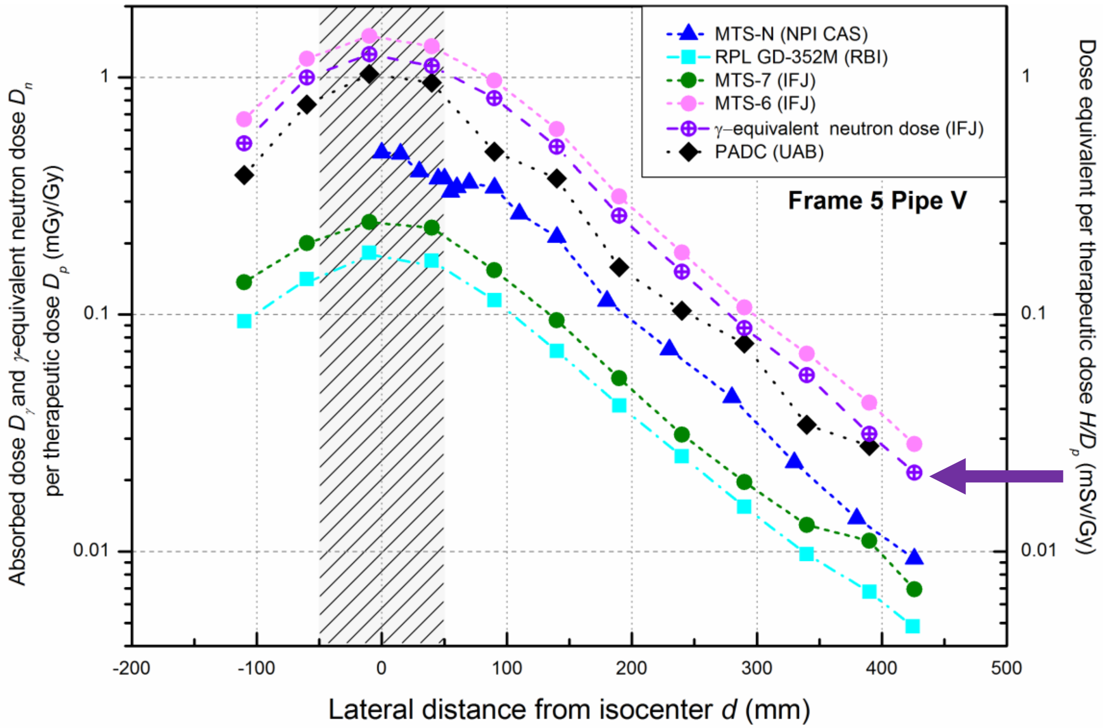

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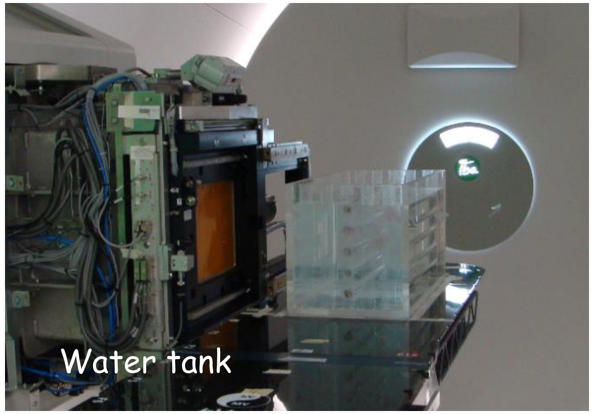

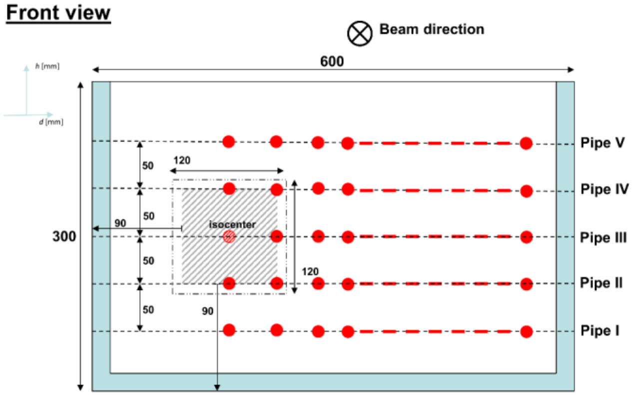

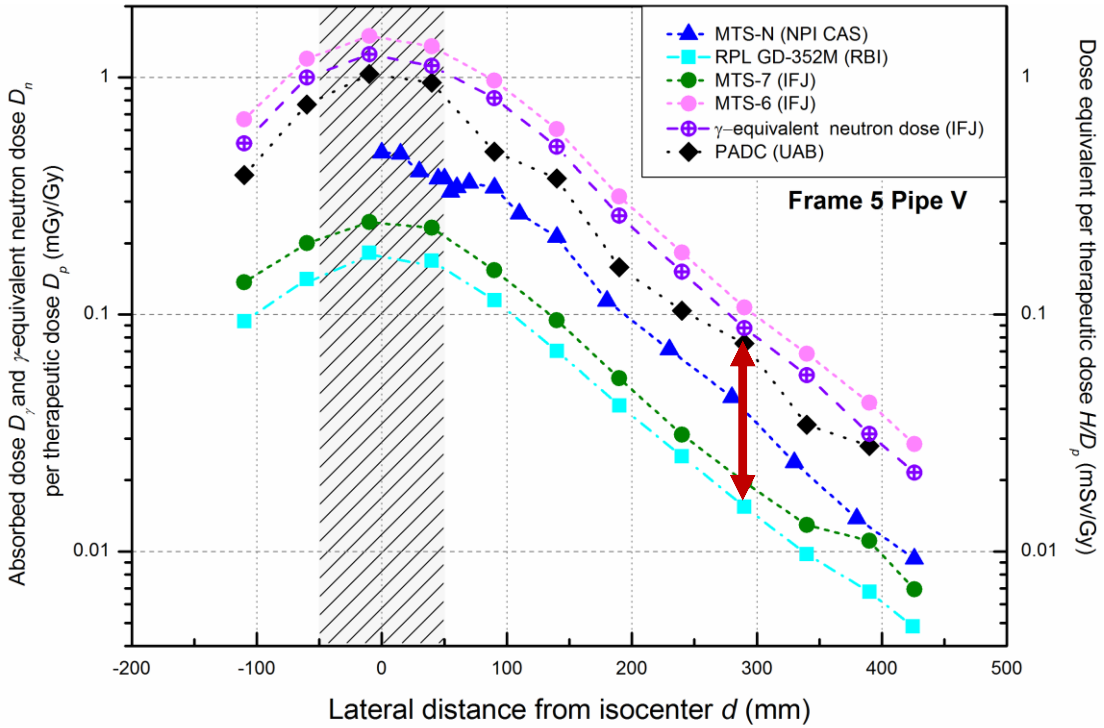

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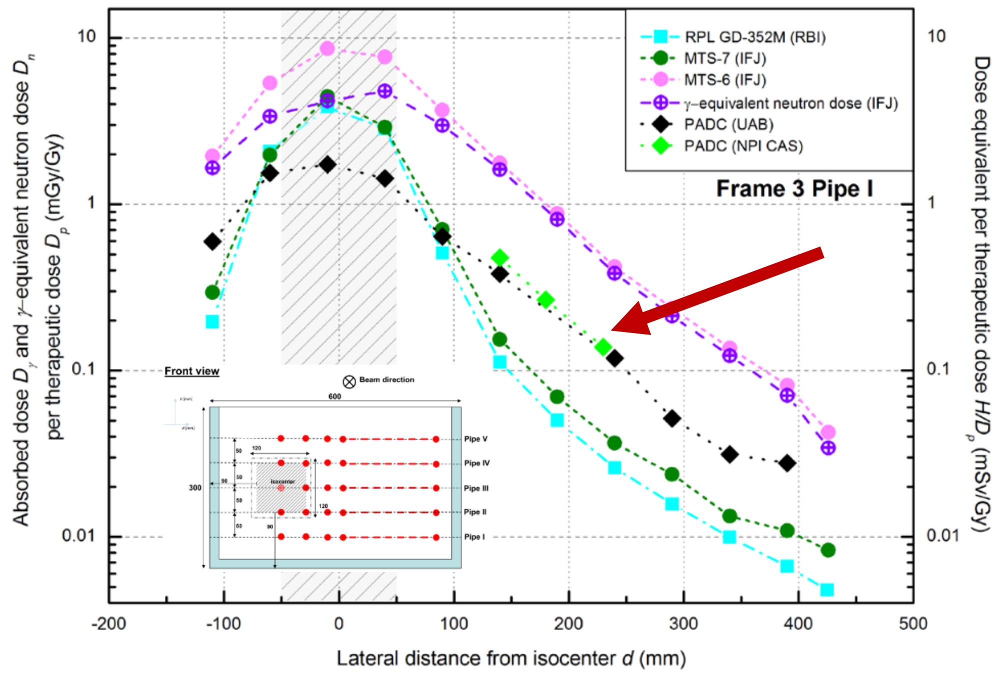

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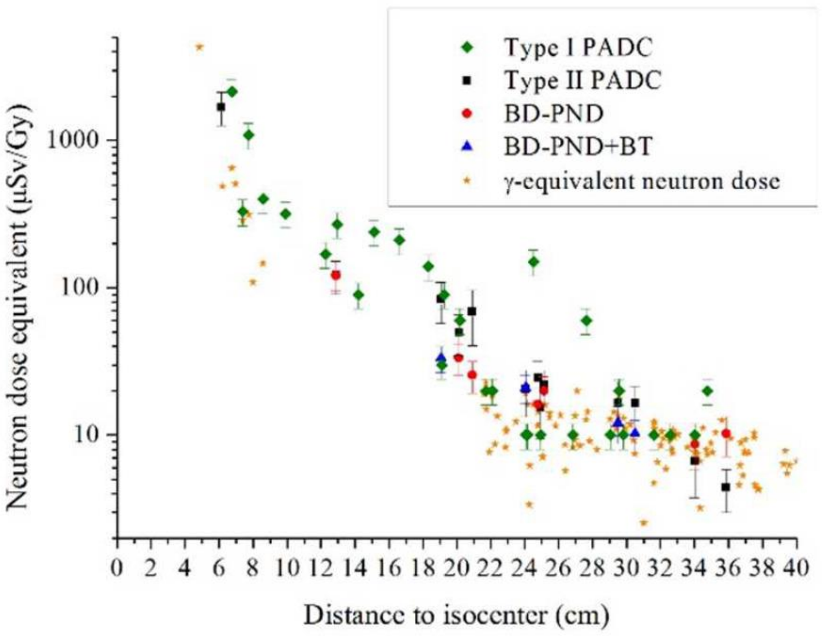
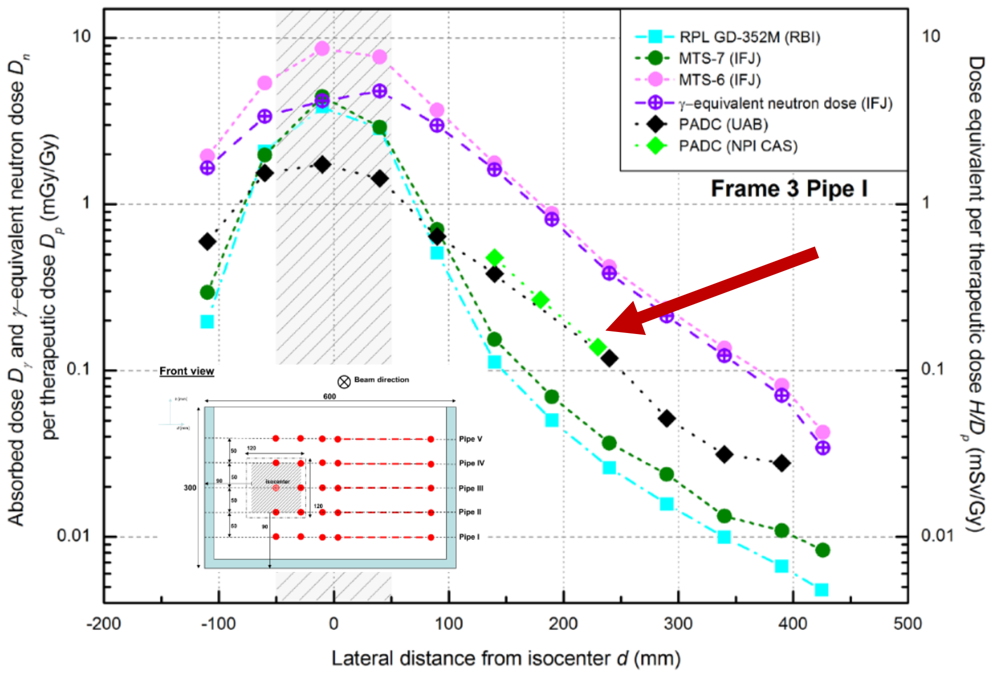


Knežević et al., Comparison of response of passive dosimetry systems in scanning proton radiotherapy – a study using paediatric anthropomorphic phantoms. Rad Prot Dosim (2017)

- Neutron doses determined using PADC and buble detectors are in agreement within measurement uncertainties

Proton therapy center, Trento



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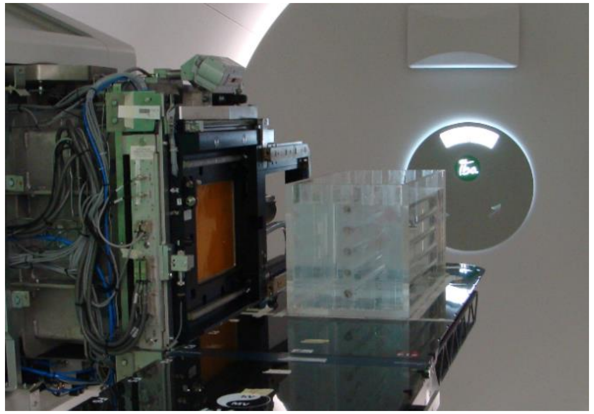

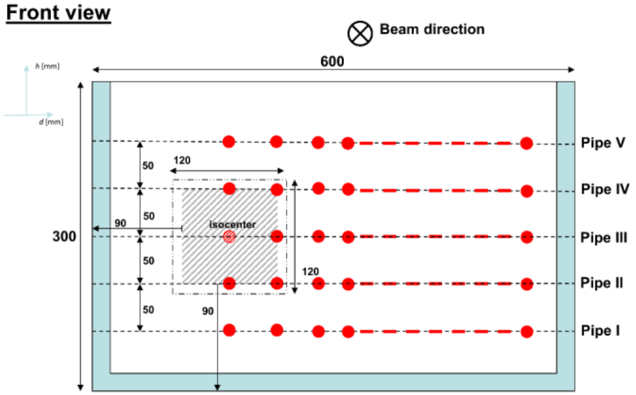

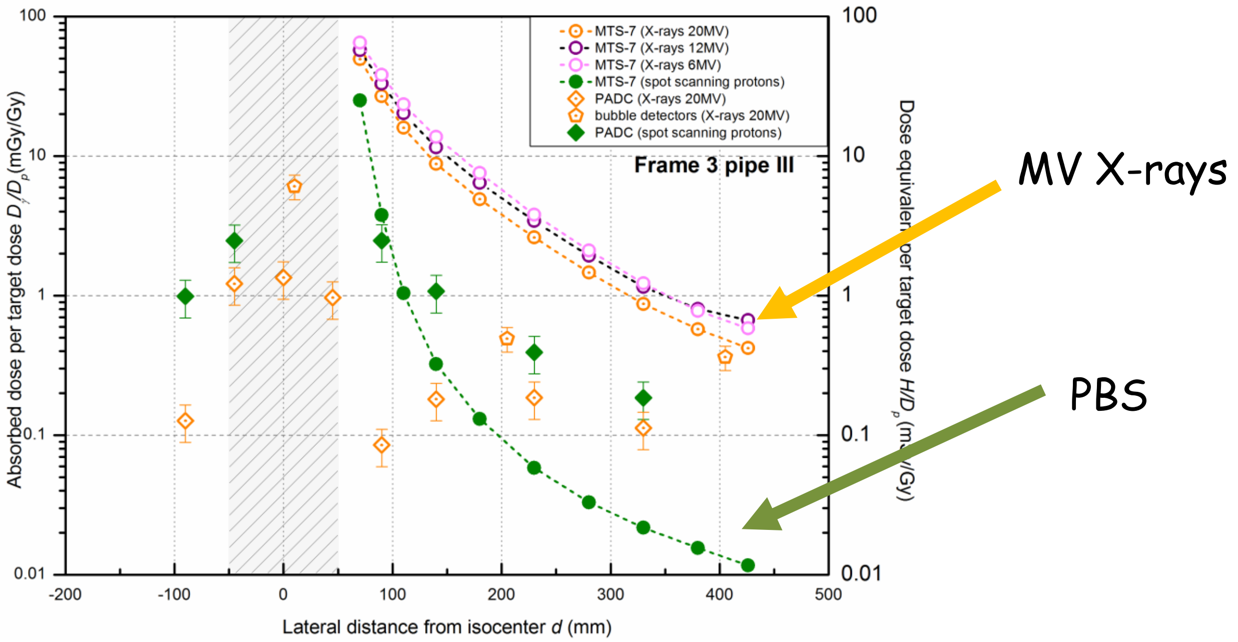

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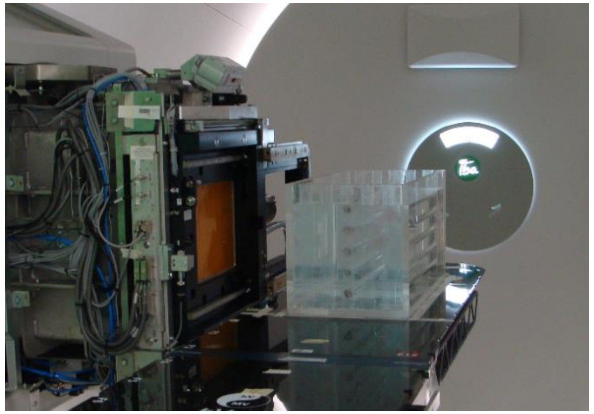

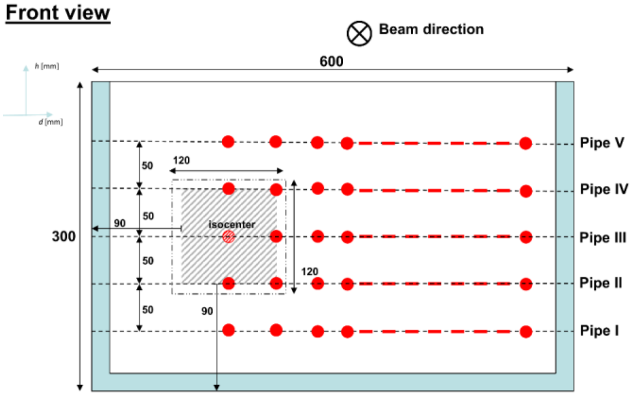

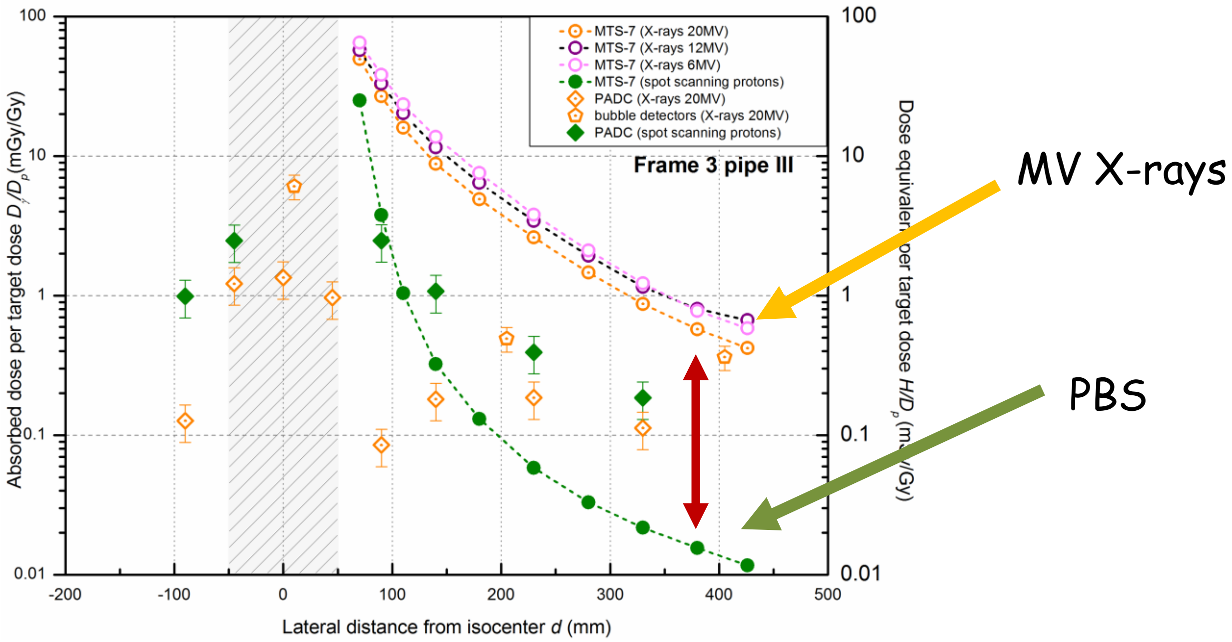

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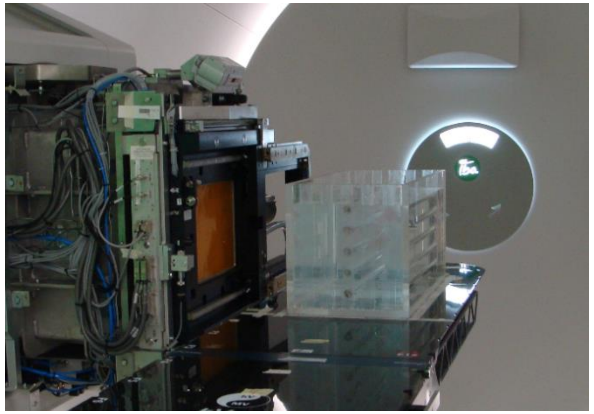

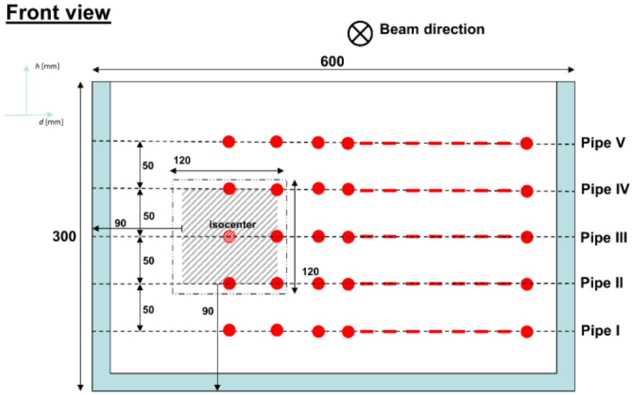

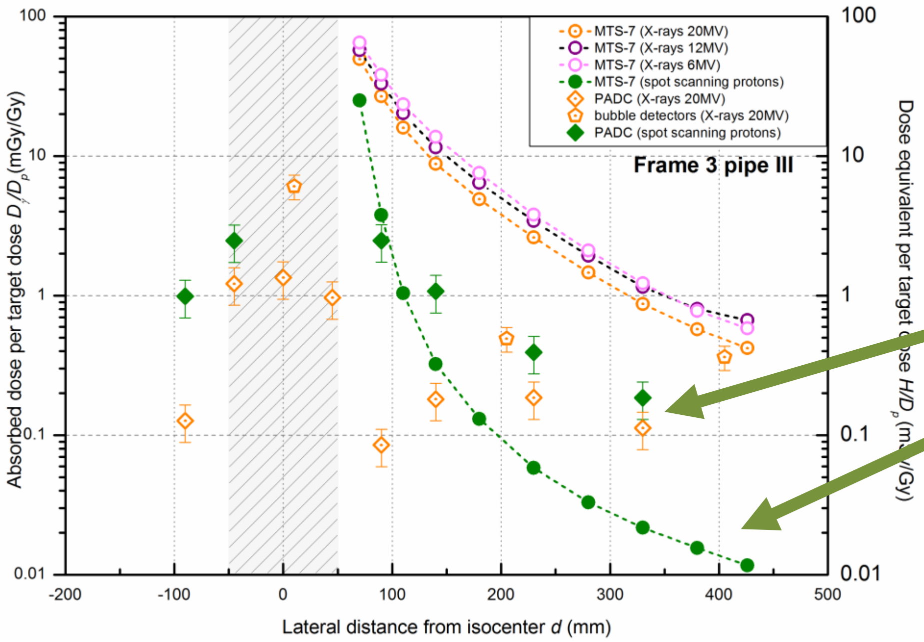

PBS neutron dose

PBS photon dose

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Lessons learned

- Out-of-field doses are of importance in radiotherapy of children, pregnant women and for reirradiations

- TPSs are still not suitable for calculation of out-of-field doses

- Secondary radiation in radiotherapy is mixed (n+γ+charged particles) radiation field.
  Measurements are challenging, particular for neutons.
  Combination of dosimetry systems is needed.

- Selected dosimetry systems can be used for out-of-field dosimetry but always keep in mind characteristics of the radiation field and properties of detectors – particularly energy dependence and sensitivity to all present particles.

⇒ Characterization of the dosimeters allows to continue research activities and move to the next step:

Out-of-field organ doses for <u>real clinical scenario</u>

in modern radiotherapy using different techniques → next ppt given by Željka Knežević

Thank you for your attention!

Iva Ambrozova
Bordy Jean-Marc
Alberto Boso
Miguel Ángel Caballero-Pacheco
Marie Davídková
Marijke De Saint-Hubert
Carles Domingo
Martin Dommert
Vladimir Dufek
Francesco d'Errico
Jad Farah
Roger Harrison
Hrvoje Hršak
Damian Kabat
Magdalena Kłodowska
Željka Knežević
Renata Kopec
Jan Kubancak
Małgorzata Liszka
Marija Majer
Vladimir Mares
Immalucalada Martinez
Saveta Miljanić
Natalia Mojzeszek
Pawel Olko
Marie Romero-Exposito
Ondrej Ploc
Liliana Stolarczyk
Sebastian Trinkl
Agata Tobola

European Radiation Dosimetry Group

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