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Comparison of the German Rule PAS1078 with MCNPX™ Calculations

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Comparison of PAS1078 with MCNPX™ Content of Presentation

- Introduction
- Input Data for the Calculation
- Unshielded Equivalent Dose Rate due to Secondary Neutrons
- Bulk Shielding
- Penetrations and Labyrinths in Shielding Walls
- Conclusion

Introduction

Introduction

- **PAS1078 = Public Available Specification, distributed by DIN**
- **Applicability: medical accelerator facilities licensed under §11 of German Radiation Protection Ordinance, E_{prot} up to 300 MeV**
- **Published: Jan. 2008**
- **Model: DIN 6871-1/-2 for PET cyclotrons**
- **Main Topics:**
  - **Necessary input data**
    - Legal limits
    - Requirements for rooms of such facilities
    - Necessary information to be provided by manufacturer and future owner
    - Operational data
    - Presence factors for persons
  - **Calculation**

Introduction: Calculation Topics

- **Neutron source strength and unshielded neutron dose rate**
- **General calculation scheme for bulk shielding**
- **Transmission of neutrons through penetrations in walls**
- **Transmission of neutrons through labyrinths**

- **Radiation protection against radioactive substances generated due to neutron activation (very roughly, not treated in this presentation)**

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Input Data for the Calculation

Input Data

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Unshielded Equivalent Dose Rate due to Secondary Neutrons

Unshielded Dose Rate of Second. Neutrons Formulae

- **Total neutron flux in 1 m distance from target point**
  - $\theta_0 = 1°$
  - θ within [0°;180°]
  - $E_0 = 1000$ MeV

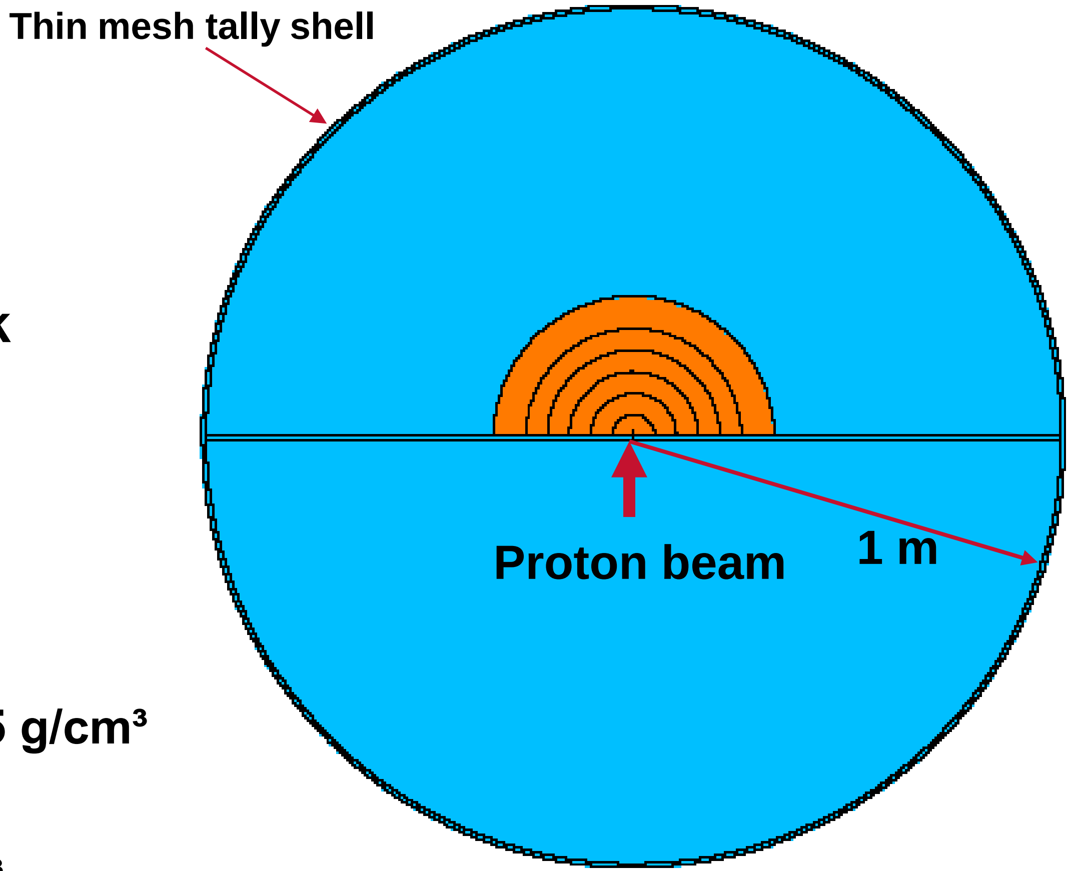
$$\varphi(\theta) = 5000 * \frac{1 - e^{-3.6*\left(\frac{E}{E_0}\right)^{1.6}}}{\left(\frac{\theta}{\theta_0} + \frac{40}{\sqrt{\frac{E}{E_0}}}\right)^2}$$

- **Corresponding neutron equivalent dose rate**
  - I_0 in protons/s
  - 4E-14 Sv/(neutron/m²) in 1 cm tissue depth, ICRU57

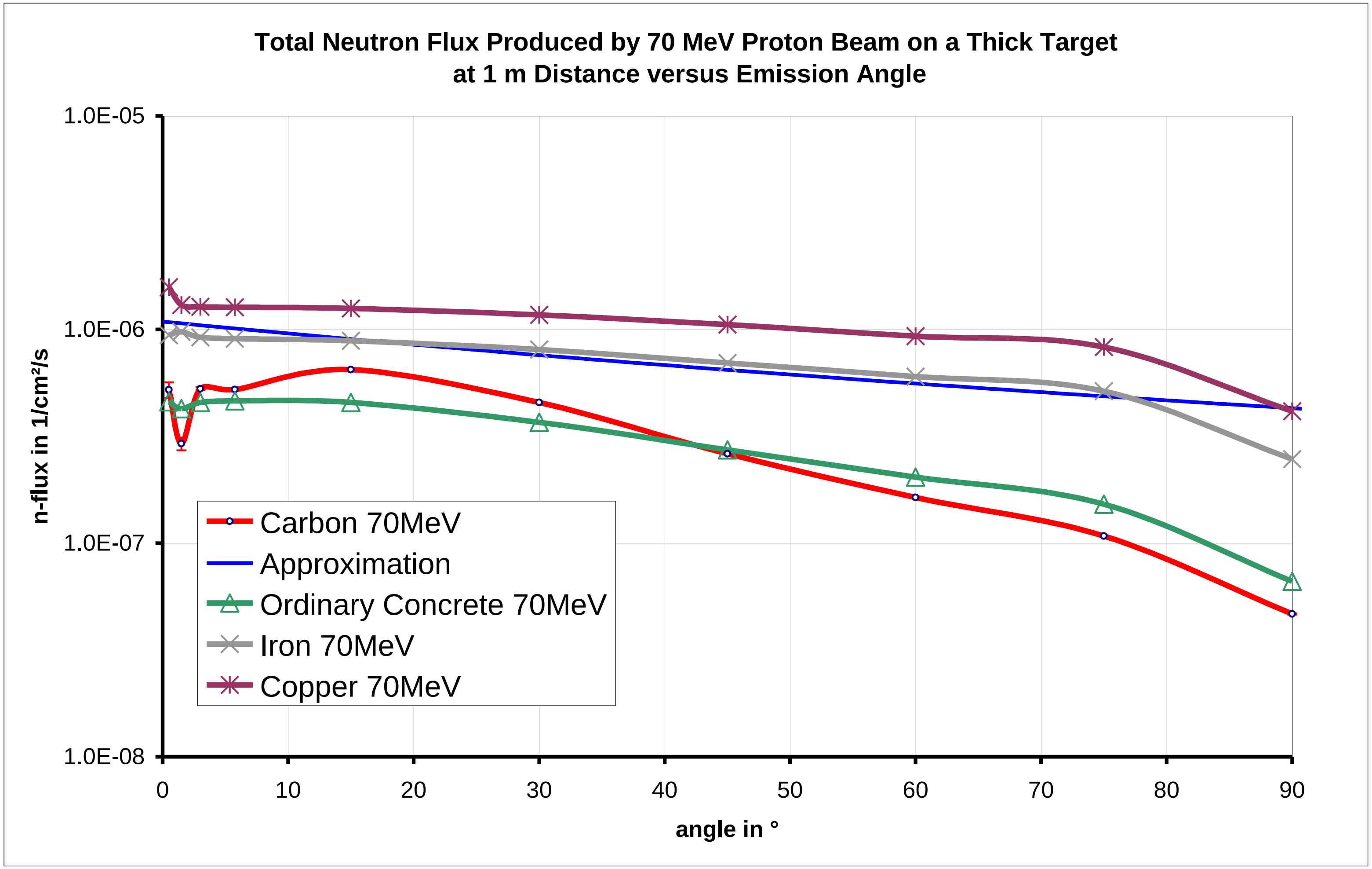
$$(dH/dt)_0 = 7.2*10^{-7} * I_0 * \frac{1 - e^{-3.6*\left(\frac{E}{E_0}\right)^{1.6}}}{\left(\frac{\theta}{\theta_0} + \frac{40}{\sqrt{\frac{E}{E_0}}}\right)^2}$$

Neutrons due to Protons on Thick Targets Model for MCNPX™

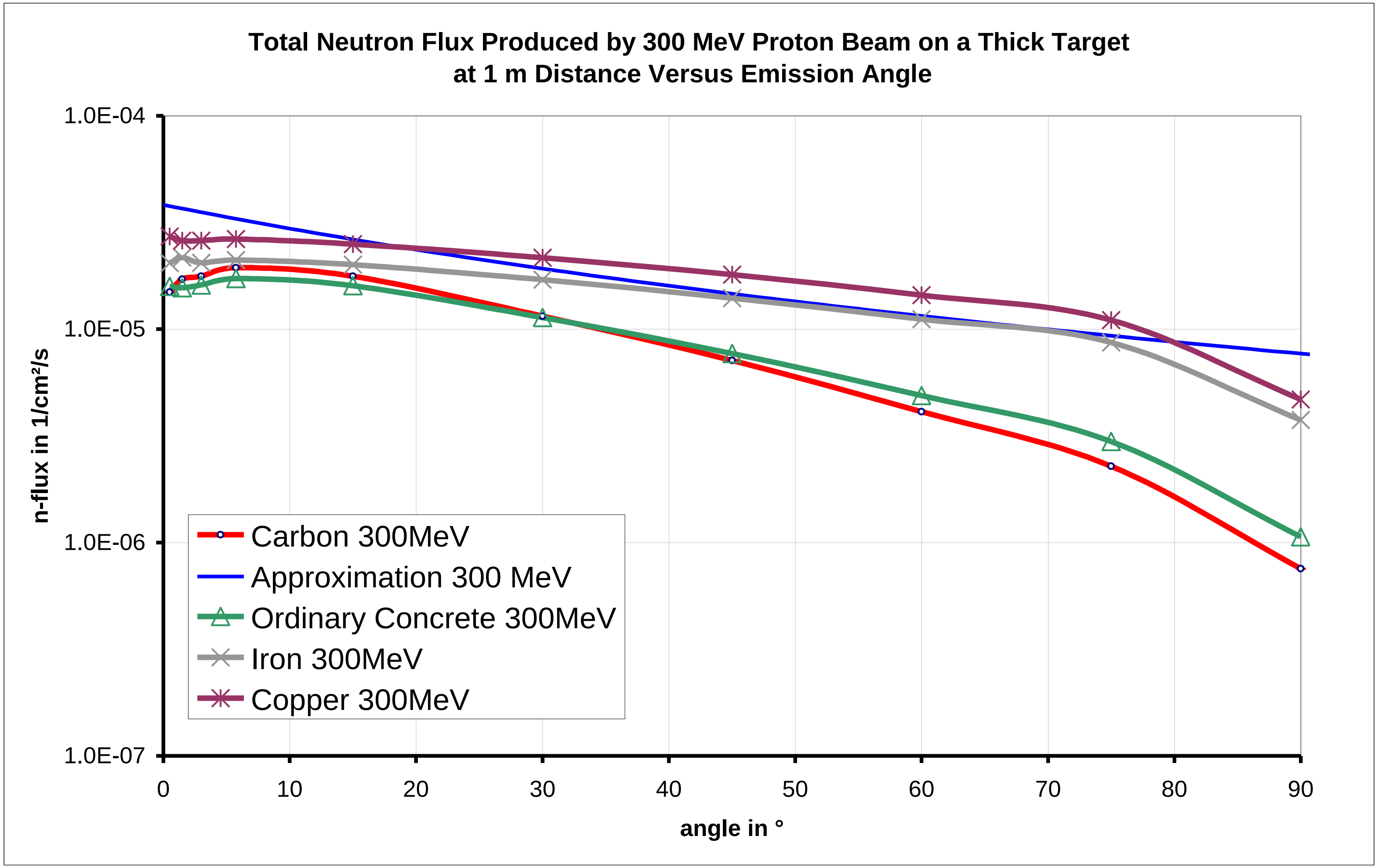
- Pencil beam
- Thick target in air
- Target dimension acc. to Bragg peak
- Neutrons counted within [0°;90°]
- Materials:
  - C … 1.85 g/cm³
  - Concrete … 2.35 g/cm³
  - Fe … 7.86 g/cm³
  - Cu … 8.93 g/cm³



Neutrons due to Protons on Thick Targets Example Materials for 70 MeV Beam



Neutrons due to Protons on Thick Targets
Example Materials for 300 MeV Beam



Bulk Shielding

Bulk Shielding Formulae

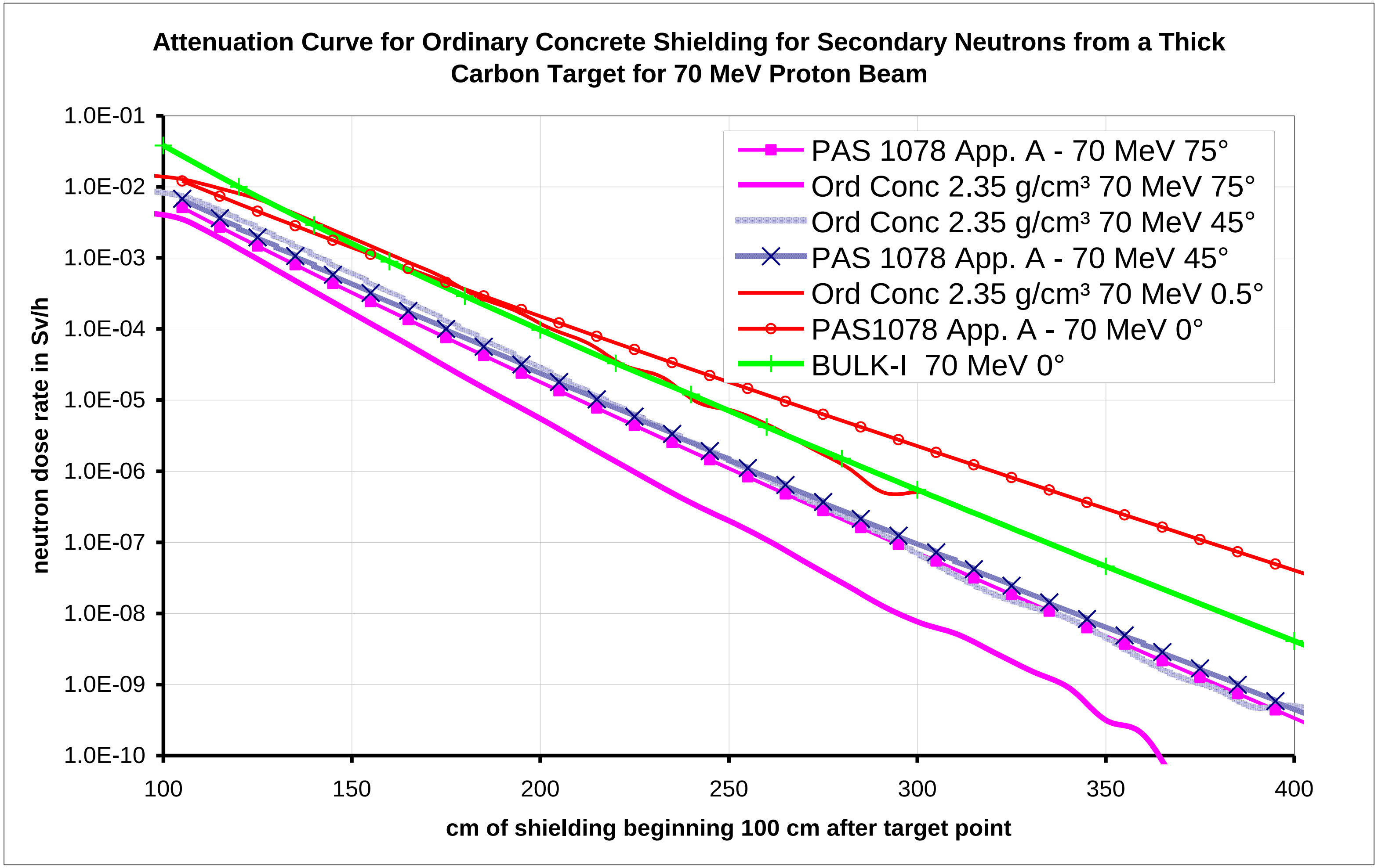
- **Shielded neutron dose rate**
  - x … wall thickness in m
  - a_i … distance in m
  - a_0 = 1 m

$$(dH/dt)_i = (dH/dt)_0 * 10^{-\frac{x}{ZWD}} * \left(\frac{a_0}{a_i}\right)^{1.5}$$

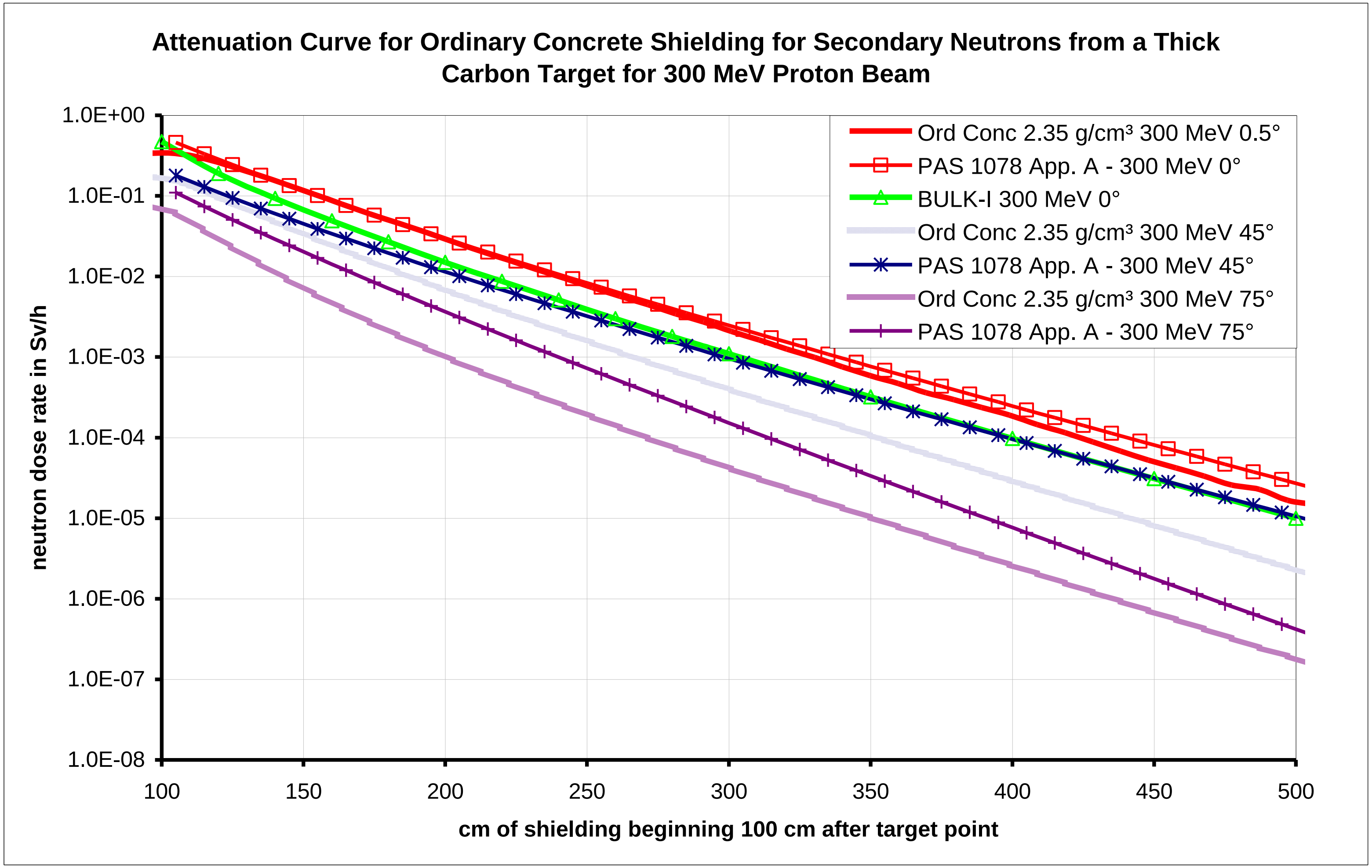
- **Ten-fold length**
  - ZWD_0 (based on 1000 MeV protons)
    - **Ord. concrete 1.62 m**
    - **Barite (3.2 g/cm³) 1.39 m**
    - **Iron (7.4 g/cm³) 0.82 m**
  - **f(θ)**
    - **= 1 … [0°;45°[**
    - **= 0.73 … [45°;90°[**
    - **= 0.49 … [90°; 135°[**
    - **= 0.38 … [135°;180°]**

$$ZWD = ZWD_0 * \left(1 - 0.8 * e^{-4*\frac{E}{E_0}}\right) * f(\theta)$$

Shielding of Neutrons from 70 MeV Beam
Comparison for Ordinary Concrete



Shielding of Neutrons from 300 MeV Beam Comparison for Ordinary Concrete



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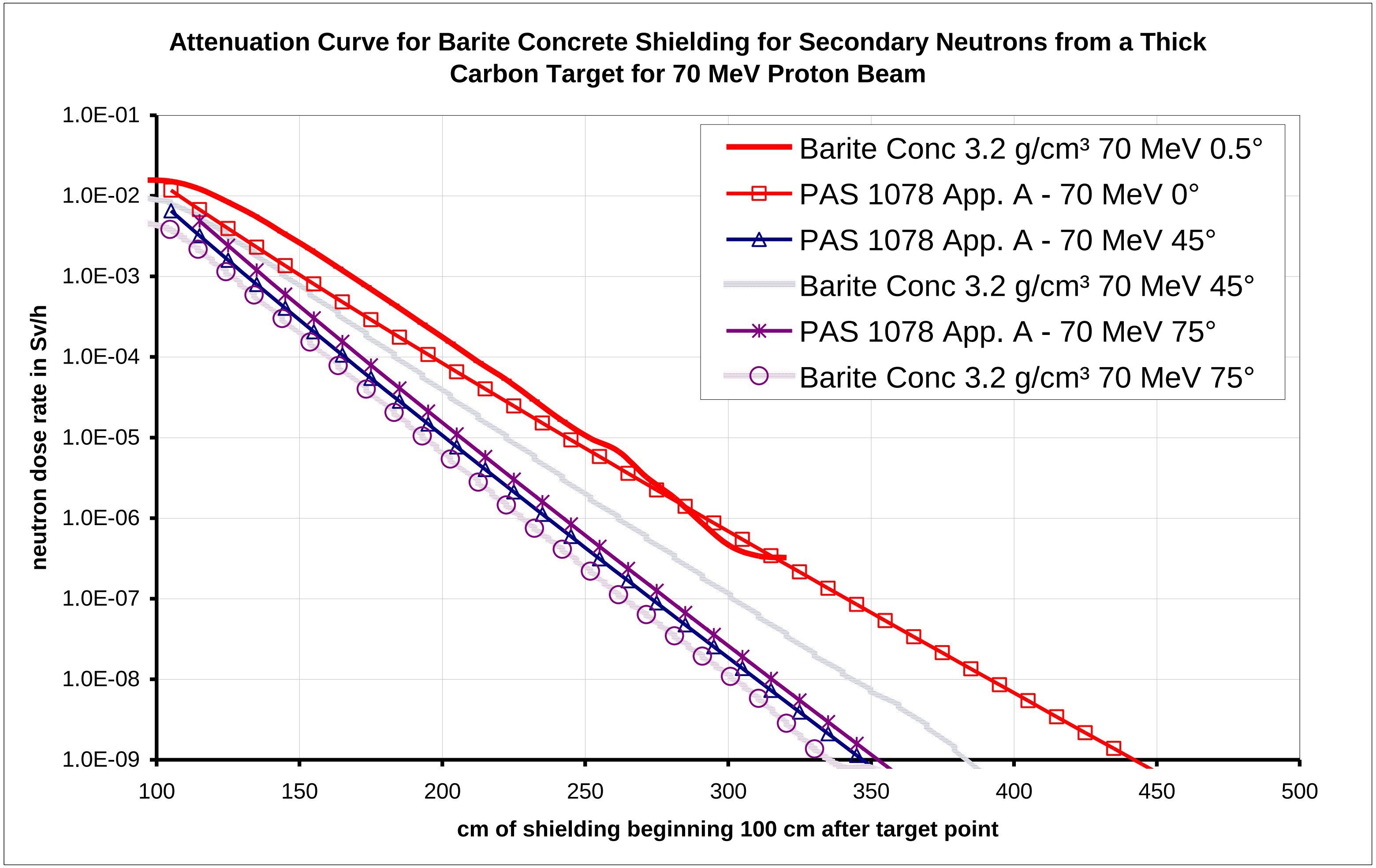
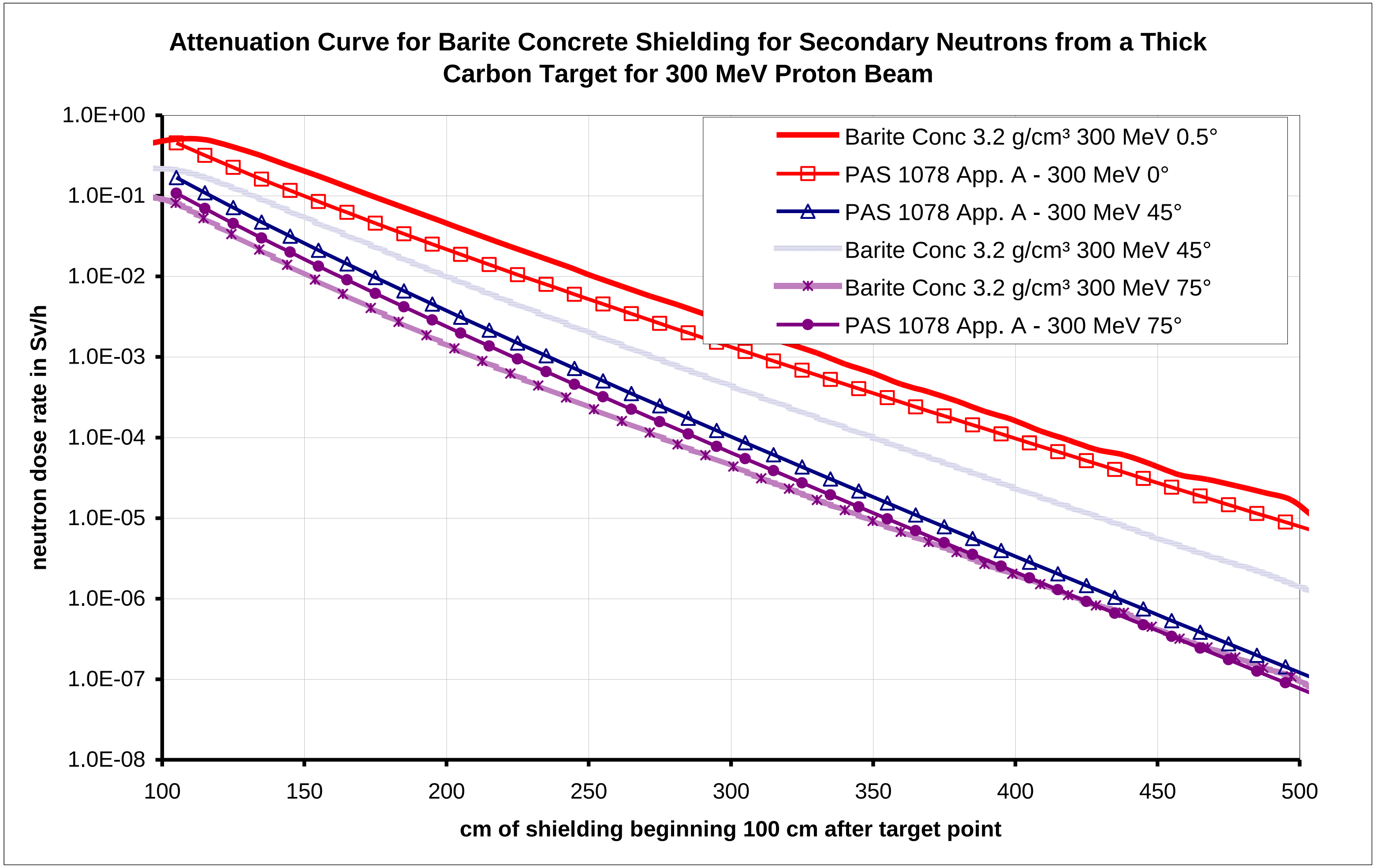
Shielding of Neutrons from 70 MeV Beam
Comparison for Barite Concrete



Shielding of Neutrons from 300 MeV Beam
Comparison for Barite Concrete



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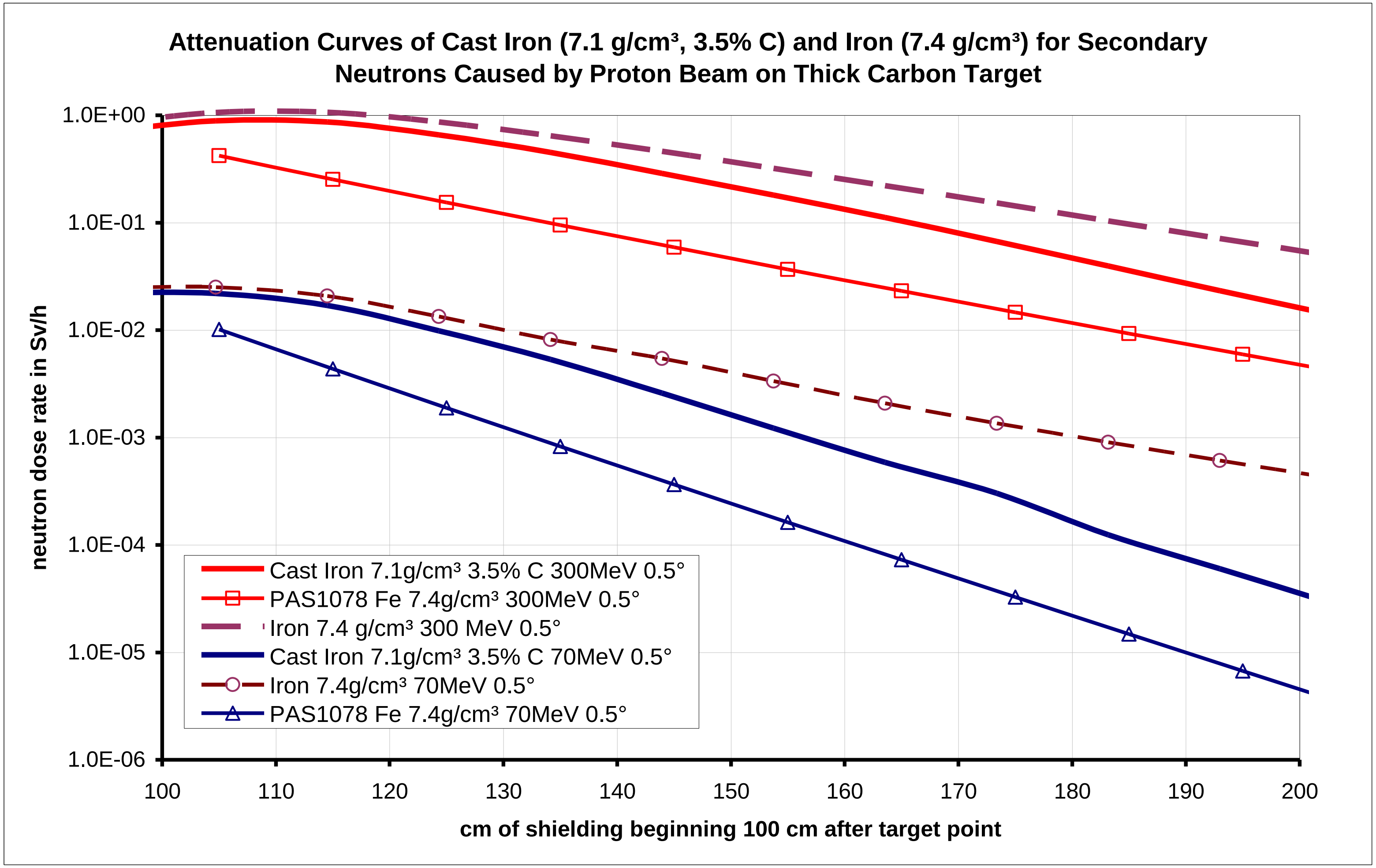
Shielding of Neutrons from Protons Comparison for Iron



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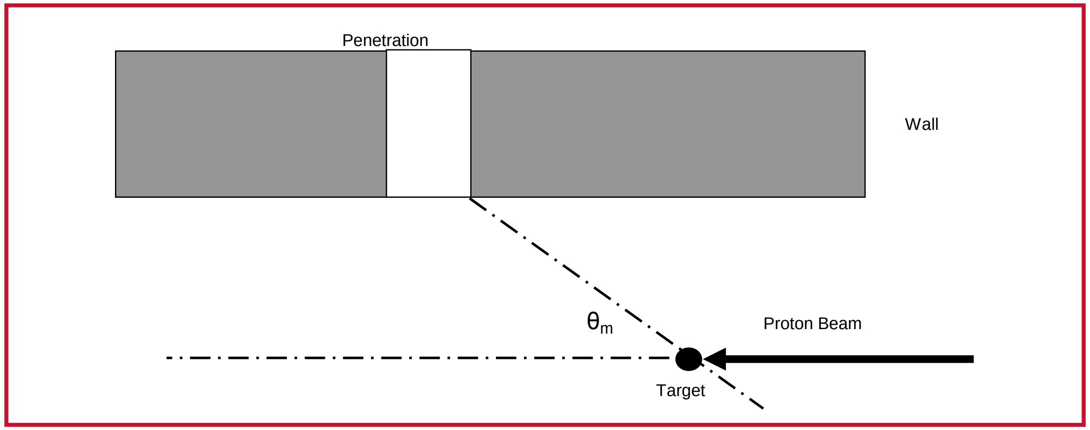
Straight Penetrations and Labyrinths in Shielding Walls

Straight Penetrations in Shields: Quotient Shielded vs. Unshielded Dose Rate

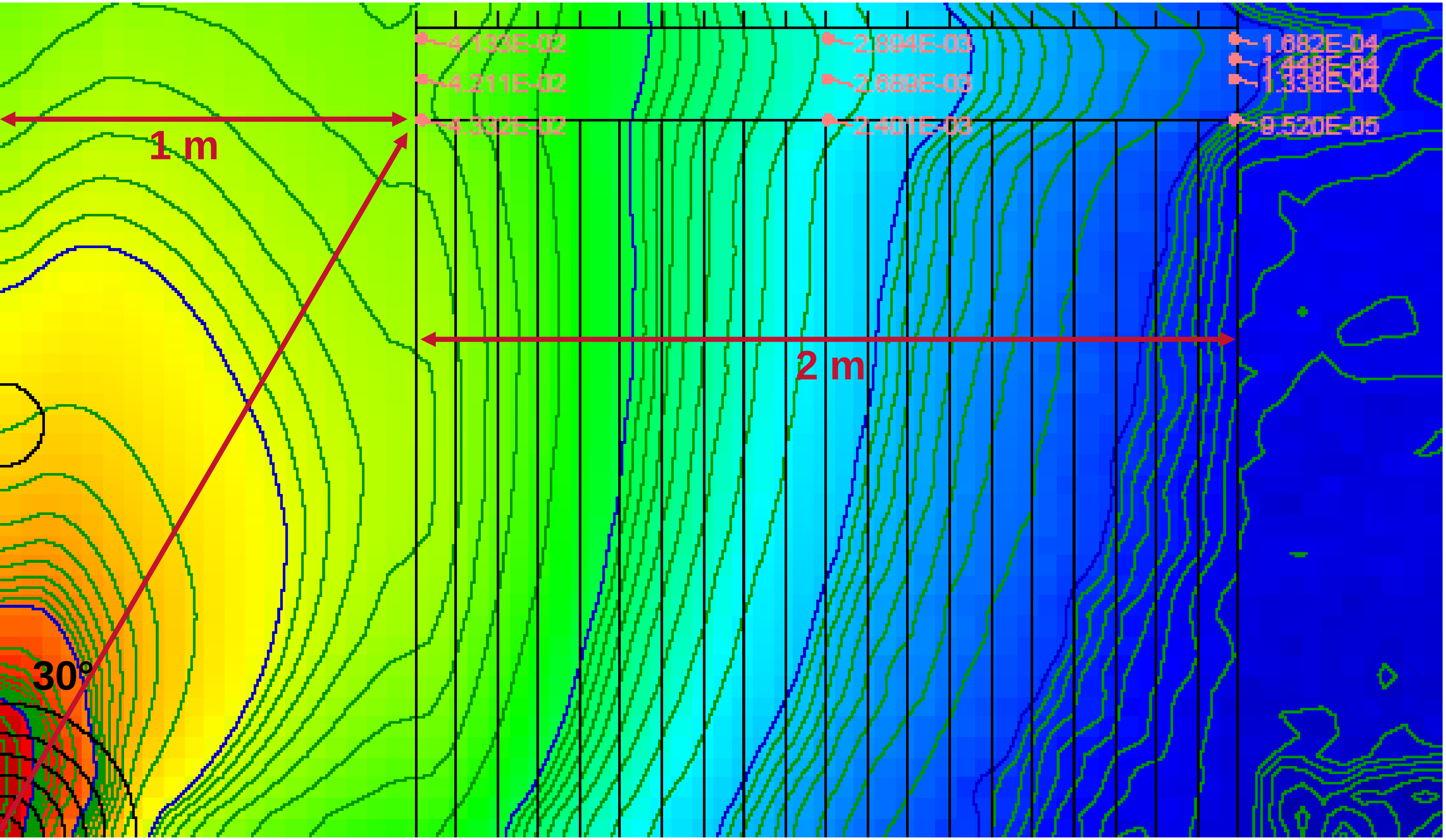
- **For lateral shields:**



- **Factor between dose rate before and behind wall:**
  - θ_m … max. angle
  - $20° \le \theta_m \le 70°$
  - θ_N … 65°
  - D … wall thickness in m
  - A … cross section of penetration in m²

$$TG_W = 10^{\left(\frac{\theta_m}{\theta_N} - \sqrt{\frac{D}{\sqrt{A}}}\right)}$$

Straight Penetrations in Shields
Example of Mesh Tally Result



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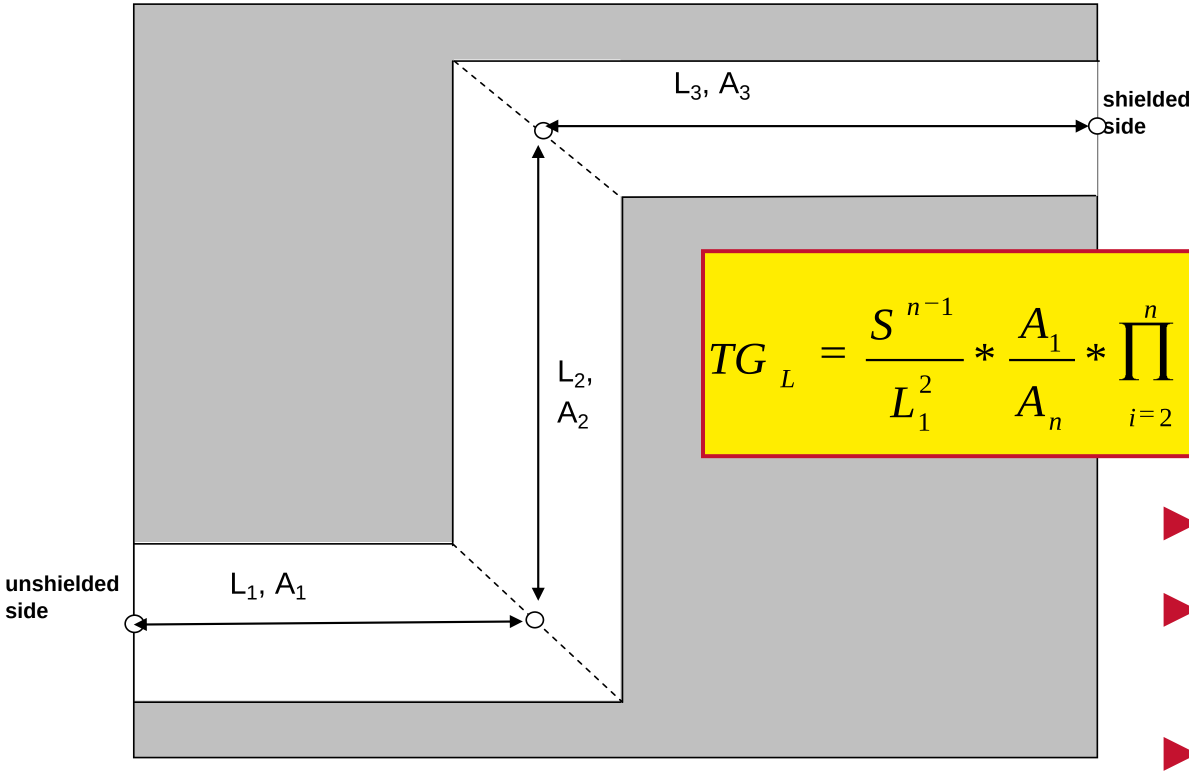
Straight Penetrations in Shields: Example Results for 300 MeV Protons

θ_m in	D/√A	TG_W (PAS1078)	TG_W (MCNPX™)
30	10	2.0E-3	3.6E-3
45	5	2.9E-2	1.2E-2
45	10	3.4E-3	4.4E-3
45	20	1.7E-4	1.2E-3

Labyrinths in Shields: Quotient Shielded vs. Unshielded Dose Rate



$$TG_L = \frac{S^{n-1}}{L_1^2} * \frac{A_1}{A_n} * \prod_{i=2}^{n} \left(\frac{\sqrt{A_i}}{L_i} \right)^3$$

- L_i … lengths in m
- A_i … cross sections in m²
- S = 0.7 (albedo)

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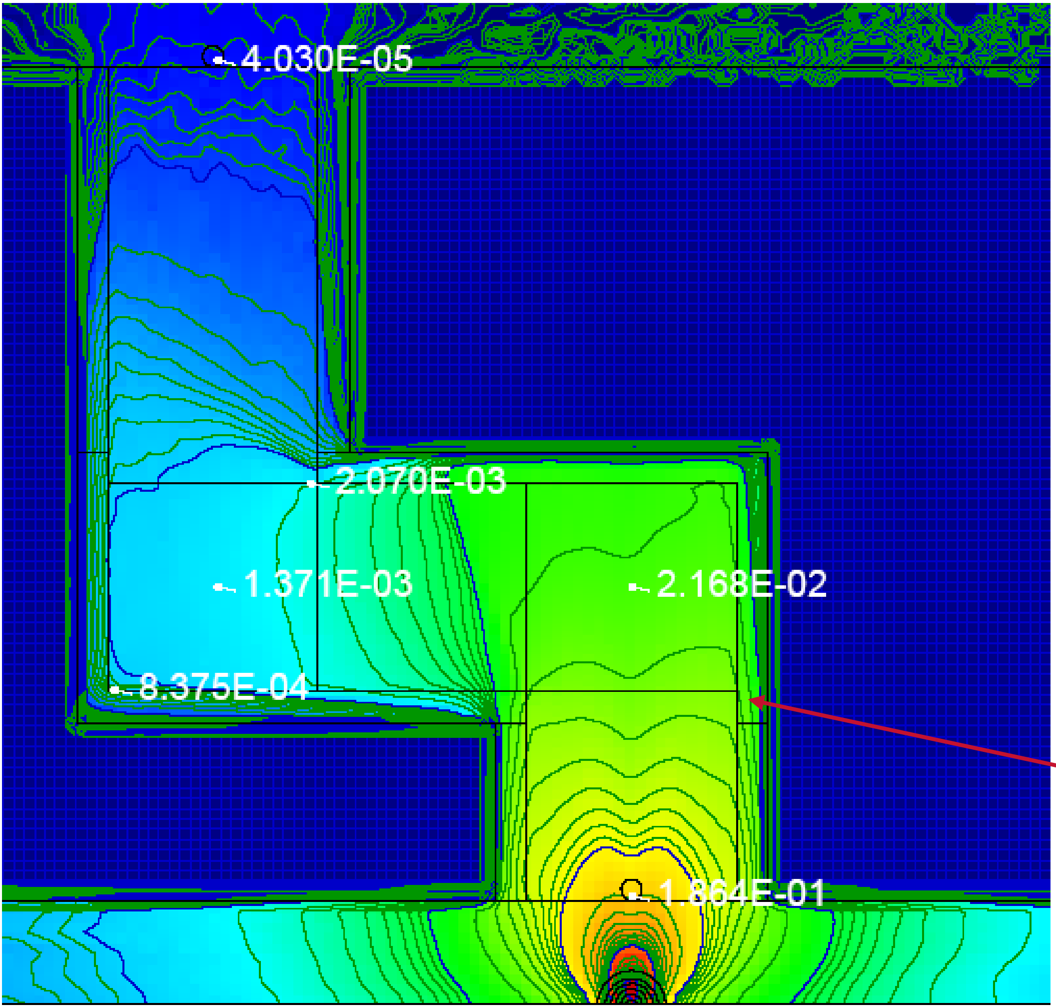
Labyrinth in Shields: Example Mesh Tally Results, E_{prot} = 300 MeV



Labyrinth Data:

A_1 = A2 = A3 = 2 x 2 m²

L1 = 3 m; L2 = L3 = 4 m

Mesh Tally ➔

4.03E-5 : 1.86E-1 = 2.2E-4

PAS1078 ➔ 8.5E-4

30 cm thick concrete layer considered for backscattering

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Conclusion

Comparison of PAS1078 with MCNPX™ Conclusion

- **German PAS1078 provides suitable approximations for shielding of neutron generated in the most common target materials and shielding materials ordinary concrete + barite concrete**
- **Application for iron shields is not recommended**
- **For labyrinths it provides useful first approximation which should be proven before design freeze**
- **Proof by calculations seems vital for straight penetrations.**

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