Neutron Shielding Tools

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www.europeanspallationsource.se

Tools

- Handbook calculations

  e.g: A.H. Sullivan: “A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators.” Nuclear Technology Publishing Ashford, Kent, TN23 1JW, England

- Monte Carlo Particle transport codes
  - MCNP(X)
  - FLUKA
  - PHITS
  - MARS
  - Not GEANT

- Variance reductions

- Activation: Hand calculations

- Activation Codes
  - CINDER
  - FISPACT
  - Activation Script
  - Gamma Script

Handbook: Attenuation through solid shielding

$$H = \frac{H_0 e^{-\frac{d}{\lambda}}}{R^2}$$

Accelerator source term:

$$H_0(90^0) = 1.7 * 10^{-14} E_0^{0.8} \quad \mathrm{Sv}^*\mathrm{m}^2 / p$$

Handbook: target shielding (Moyer Model)

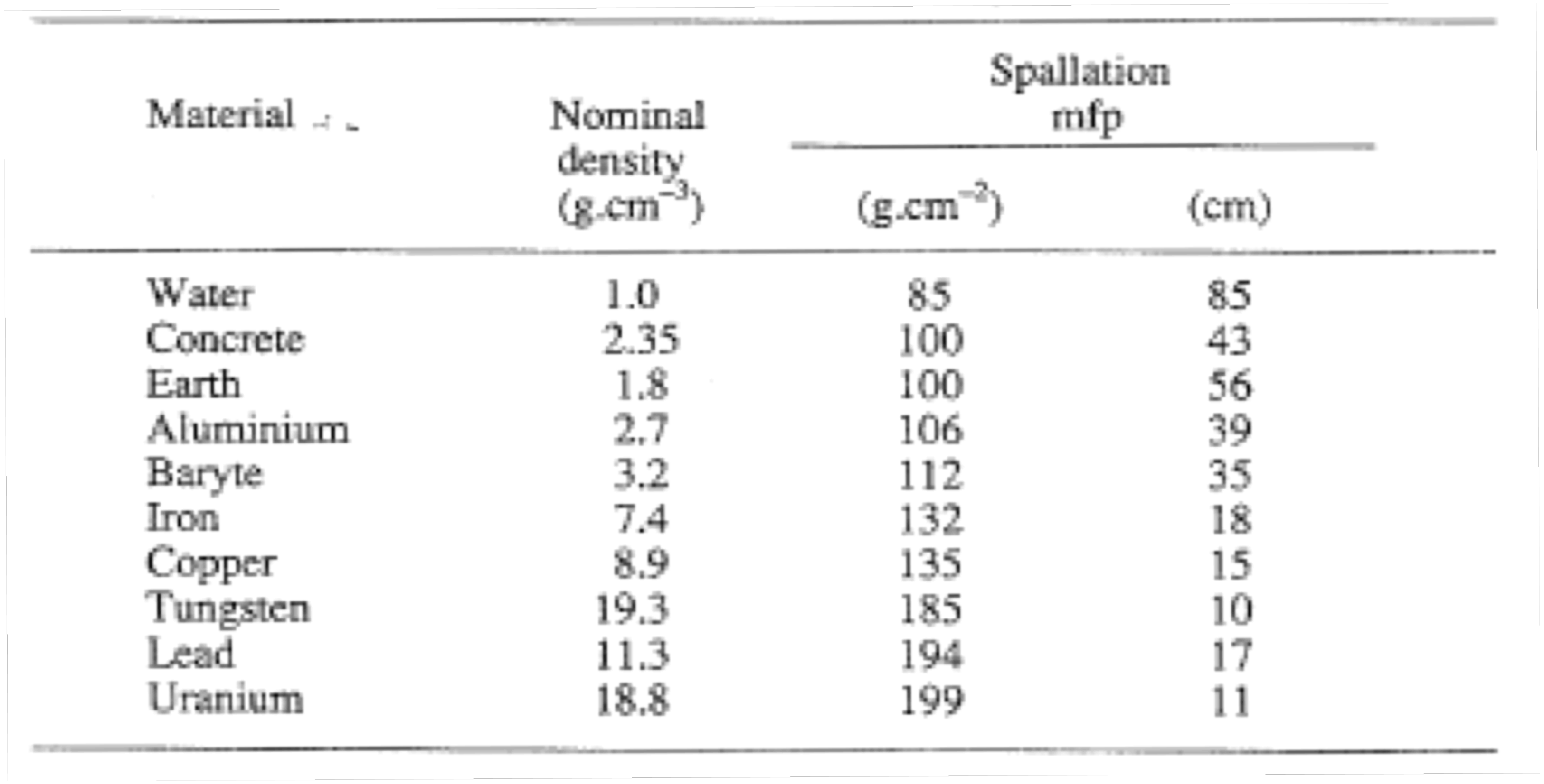
Moyer Model:

$$H=I*H_0(E_p)/r^2*e^{-\beta\theta}*e^{-d/\lambda}$$

- $H_0(E_p)=4*10^{-7}\ E_p^{0.8}\ \mathrm{Sv\ h^{-1}\ m^2\ nA^{-1}}$ = source term*
- r = distance from the spill point to the detector
- β = 2.3/radian*
- d = shielding thickness
- λ = dose attenuation length in the shielding material
- θ = angle between the proton beam and the direction from the spill to the detector
- I = proton current

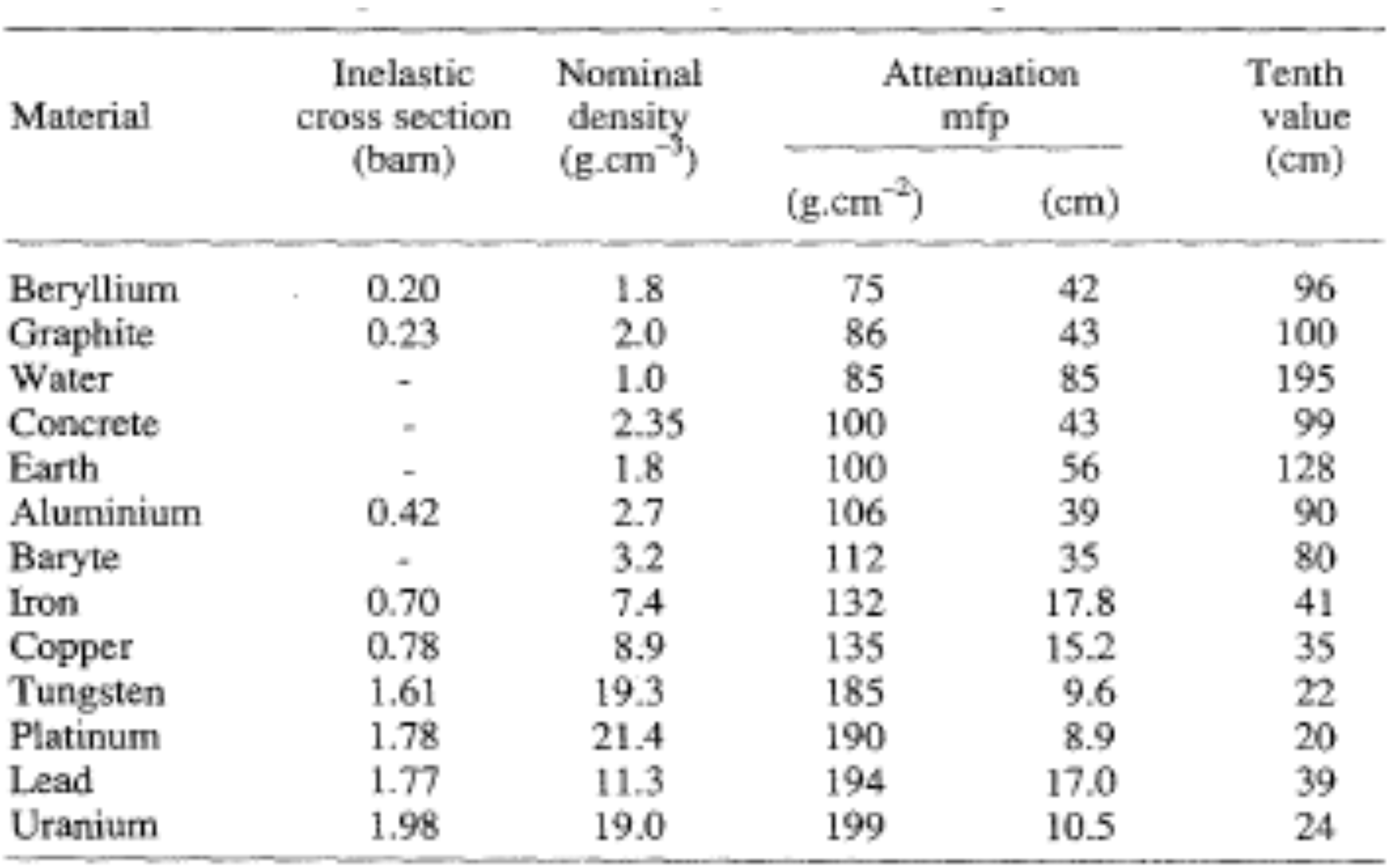
*Thomas and Thomas, Health Physics **46**, 954 (1984)

Handbook: Neutron dose attenuation lengths



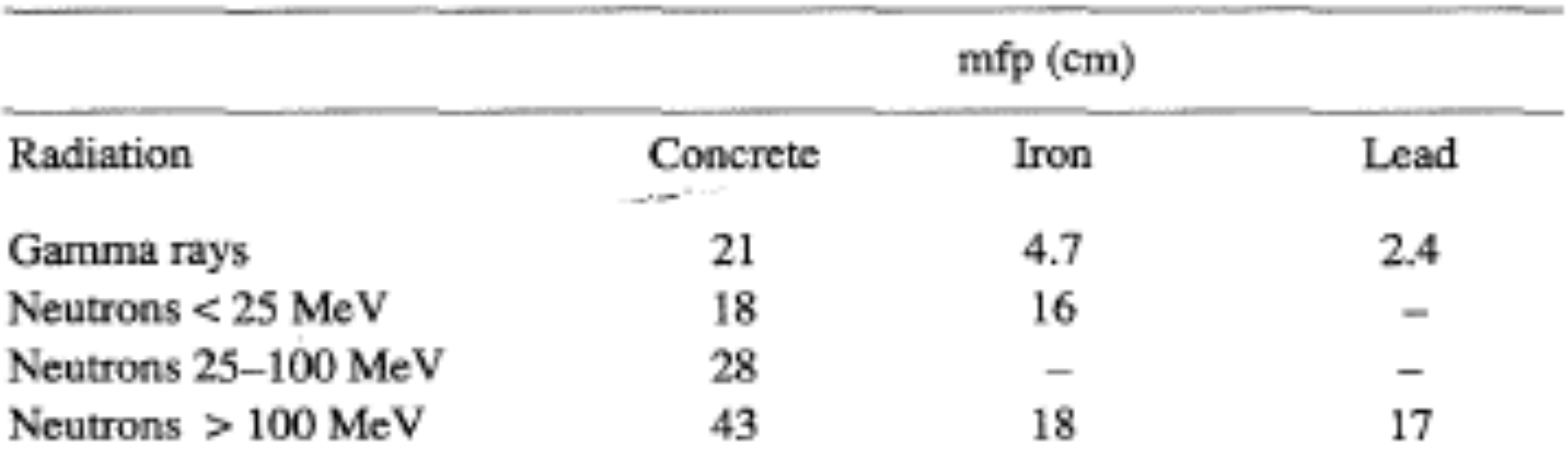
Material	Nominal density ($g.cm^{-3}$)	Spallation mfp ($g.cm^{-2}$)	Spallation mfp (cm)
Water	1.0	85	85
Concrete	2.35	100	43
Earth	1.8	100	56
Aluminium	2.7	106	39
Baryte	3.2	112	35
Iron	7.4	132	18
Copper	8.9	135	15
Tungsten	19.3	185	10
Lead	11.3	194	17
Uranium	18.8	199	11

Handbook: Neutron dose attenuation lengths and tenth layers



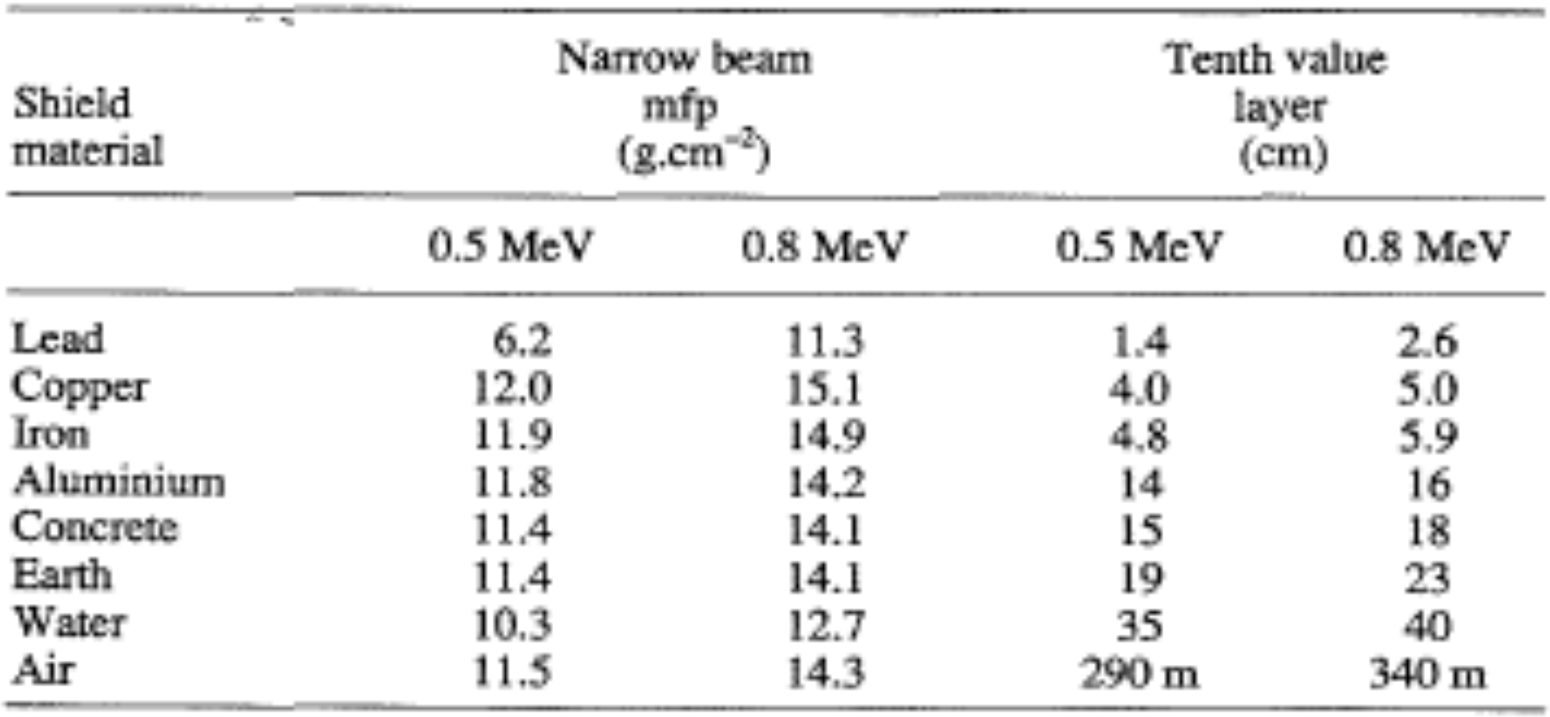
Material	Inelastic cross section (barn)	Nominal density ($g.cm^{-3}$)	Attenuation mfp		Tenth value (cm)
			($g.cm^{-2}$)	(cm)	
Beryllium	0.20	1.8	75	42	96
Graphite	0.23	2.0	86	43	100
Water	-	1.0	85	85	195
Concrete	-	2.35	100	43	99
Earth	-	1.8	100	56	128
Aluminium	0.42	2.7	106	39	90
Baryte	-	3.2	112	35	80
Iron	0.70	7.4	132	17.8	41
Copper	0.78	8.9	135	15.2	35
Tungsten	1.61	19.3	185	9.6	22
Platinum	1.78	21.4	190	8.9	20
Lead	1.77	11.3	194	17.0	39
Uranium	1.98	19.0	199	10.5	24

Handbook: Gamma and Neutron dose attenuation length



	mfp (cm)		
Radiation	Concrete	Iron	Lead
Gamma rays	21	4.7	2.4
Neutrons < 25 MeV	18	16	–
Neutrons 25–100 MeV	28	–	–
Neutrons > 100 MeV	43	18	17

Handbook: Gamma dose attenuation lengths

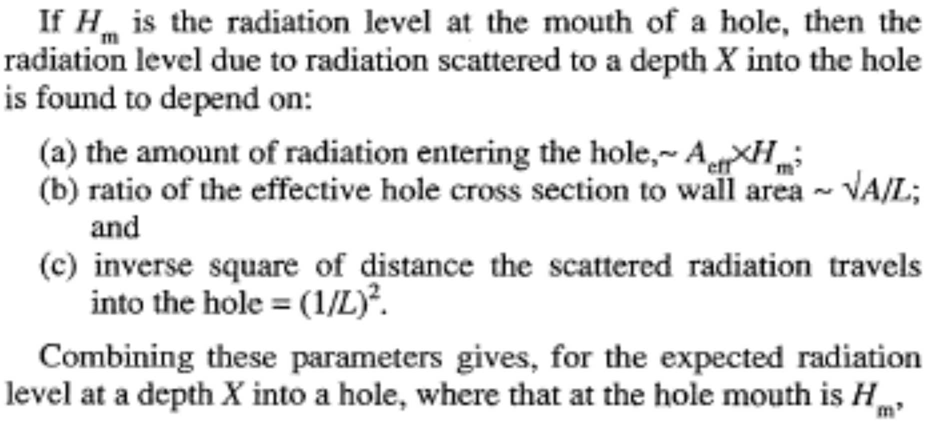


Shield material	Narrow beam mfp (g.cm^{-2})		Tenth value layer (cm)	
	0.5 MeV	0.8 MeV	0.5 MeV	0.8 MeV
Lead	6.2	11.3	1.4	2.6
Copper	12.0	15.1	4.0	5.0
Iron	11.9	14.9	4.8	5.9
Aluminium	11.8	14.2	14	16
Concrete	11.4	14.1	15	18
Earth	11.4	14.1	19	23
Water	10.3	12.7	35	40
Air	11.5	14.3	290 m	340 m

Handbook: Chicane 1(3)

$$A_{eff} = A\tan(\theta) + \lambda\sqrt{A}\sin(\theta)$$

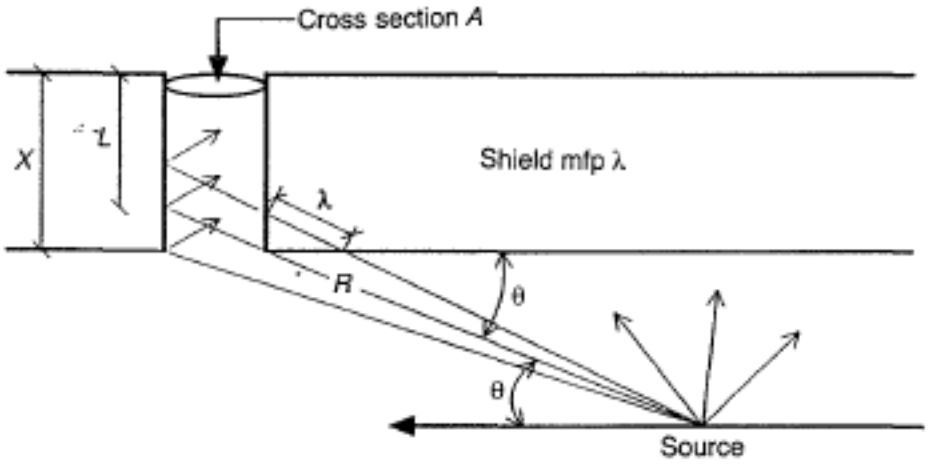
$$L = X - A_{eff}/\sqrt{A}$$



If H_m is the radiation level at the mouth of a hole, then the radiation level due to radiation scattered to a depth X into the hole is found to depend on:

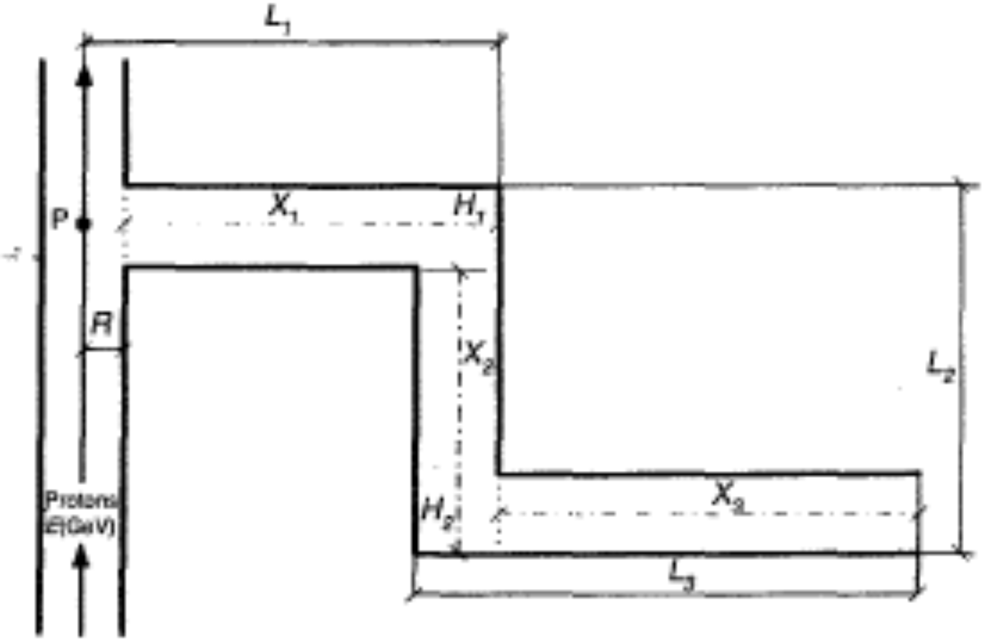
(a) the amount of radiation entering the hole,~ $A_{eff} \times H_m$;
(b) ratio of the effective hole cross section to wall area ~ $\sqrt{A}/L$; and
(c) inverse square of distance the scattered radiation travels into the hole = $(1/L)^2$.

Combining these parameters gives, for the expected radiation level at a depth X into a hole, where that at the hole mouth is H_m,



$$H = H_m \cdot \frac{K.A_{eff}.\sqrt{A_n}}{L^3}$$

Handbook: Chicane 2(3)



$$H_1 = H_0 / L_1^{2}$$

$$L_1 = R + X_1$$

$$L_n = X_n + \sqrt{A_{n-1}}$$

$$H_n = H_{(n-1)} \cdot \frac{K.A_{(n-1)}.\sqrt{A_n}}{L_n^{3}}$$

Handbook: Chicane 3(3)

$$H_n = H_1 \times K^{n-1}\ \frac{A_1}{A_n} \cdot \left(\frac{\sqrt{A_2}}{L_2} \cdot \frac{\sqrt{A_3}}{L_3} \cdots \frac{\sqrt{A_n}}{L_n} \right)^3$$

$$\frac{H_n}{H_0} = \frac{T(n,A)}{L_1^{\,2}(L_2.L_3 \ldots L_n)^3}$$

$$T(n,A) = (K \times A^{3/2})^{n-1}$$

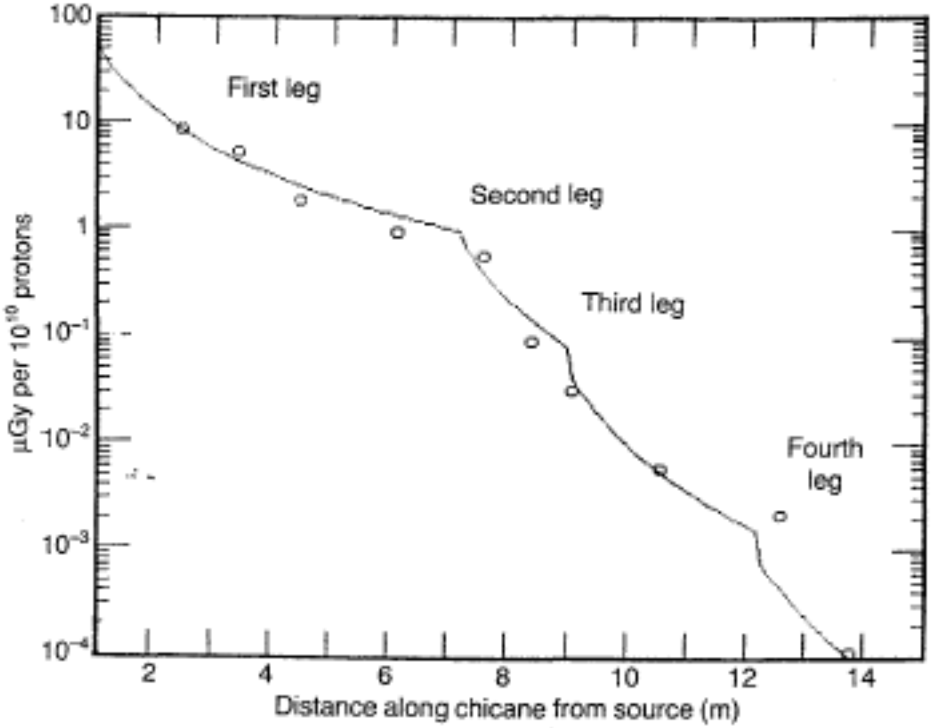
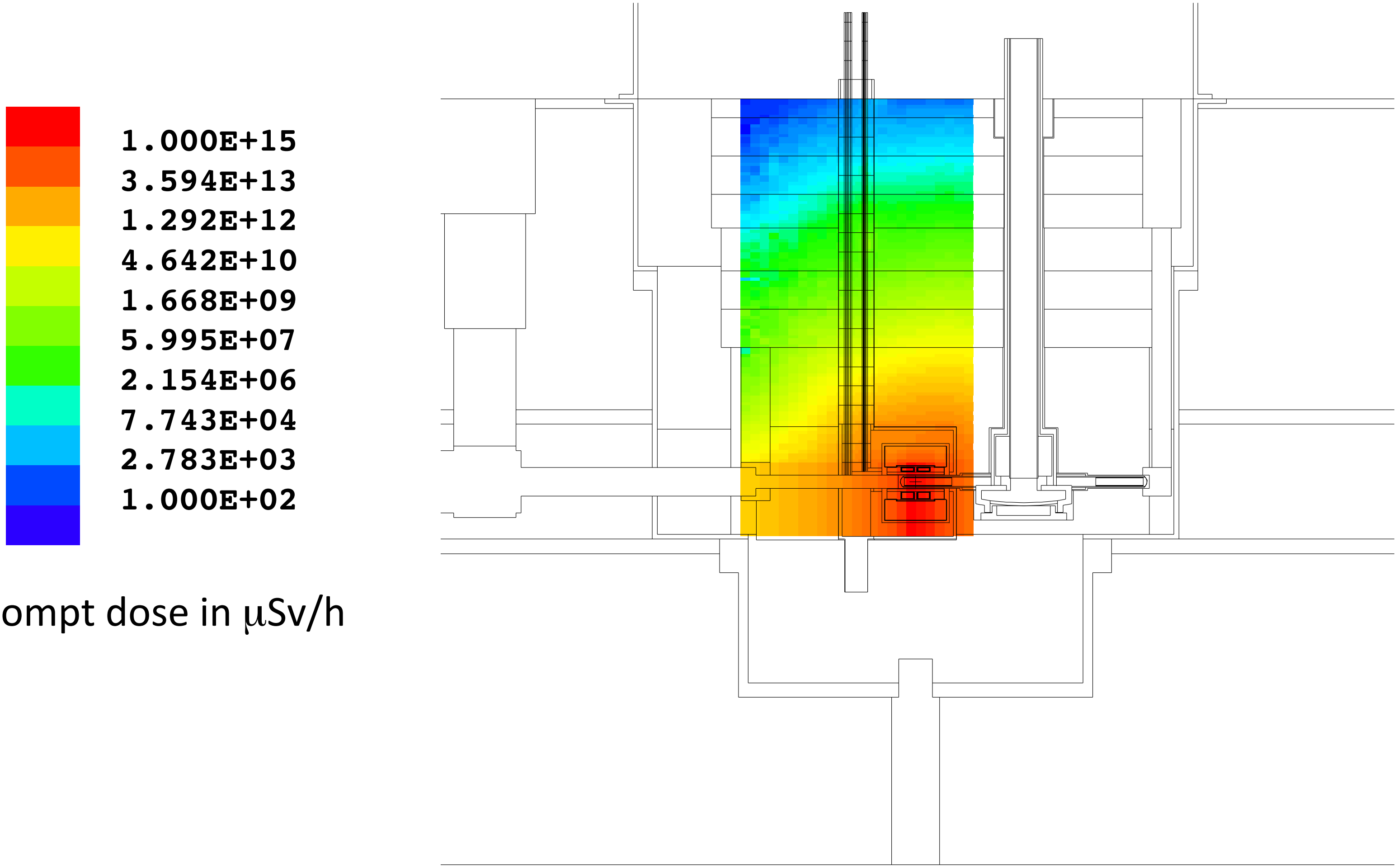


Figure 2.30. The calculated radiation level along the four legs of a chicane compared to measured data(15) using a 400 GeV proton beam on a 1 interaction length target opposite the entrance to the chicane. Dose equivalent given in Figure 2.21 was converted to absorbed dose assuming a constant quality factor of 3.

Variance reductions

- Variance reductions are very power full, while very dangerous methods to cheat time in Monte Carlo simulations.

Variance reductions: Why?

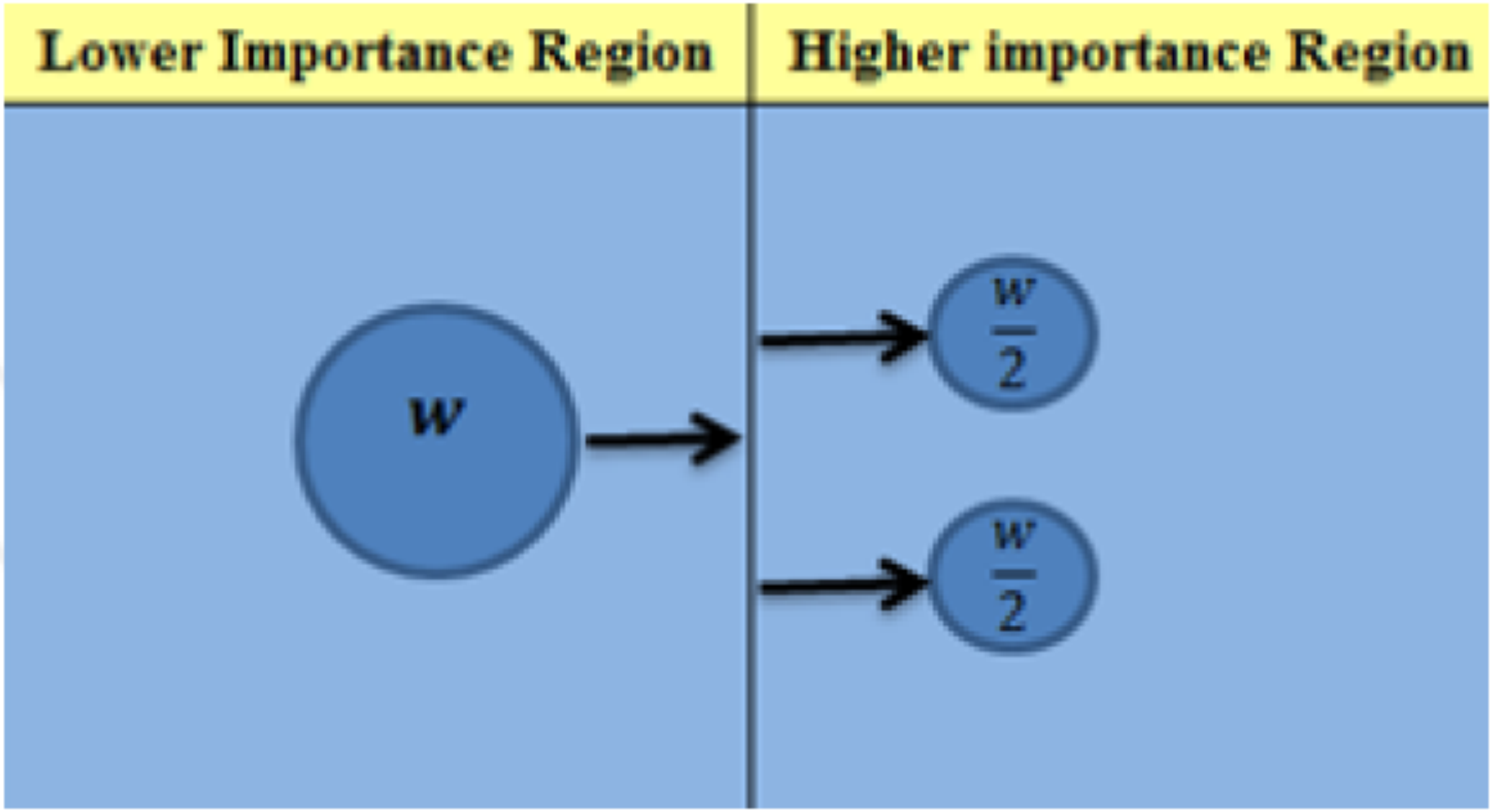


Prompt dose in μSv/h

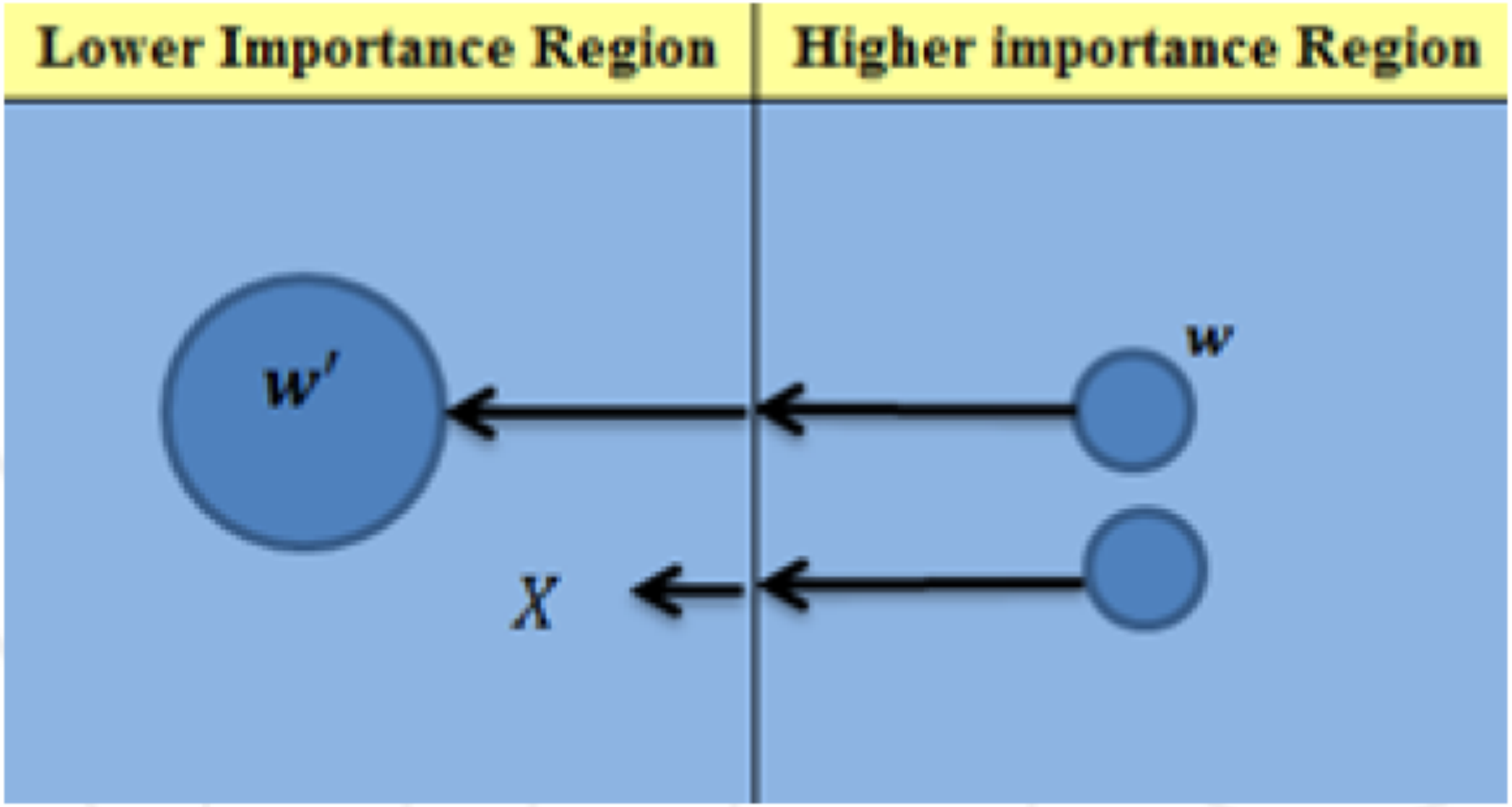
Variance reductions

- Cell importance
- Weight windows
- DXTRAN sphere
- Forced collision
- Energy splitting
- Second particle biasing

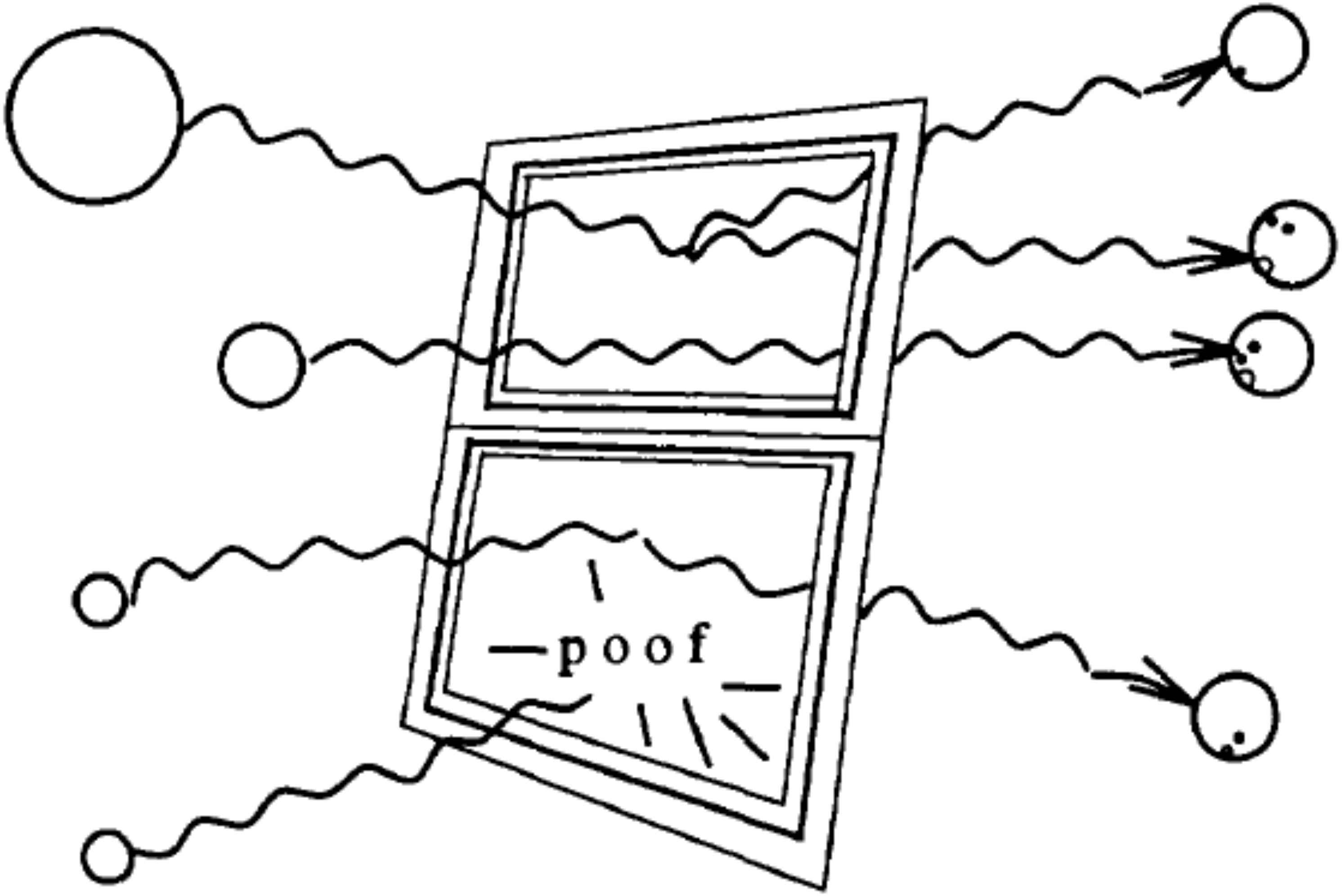
Geometry splitting



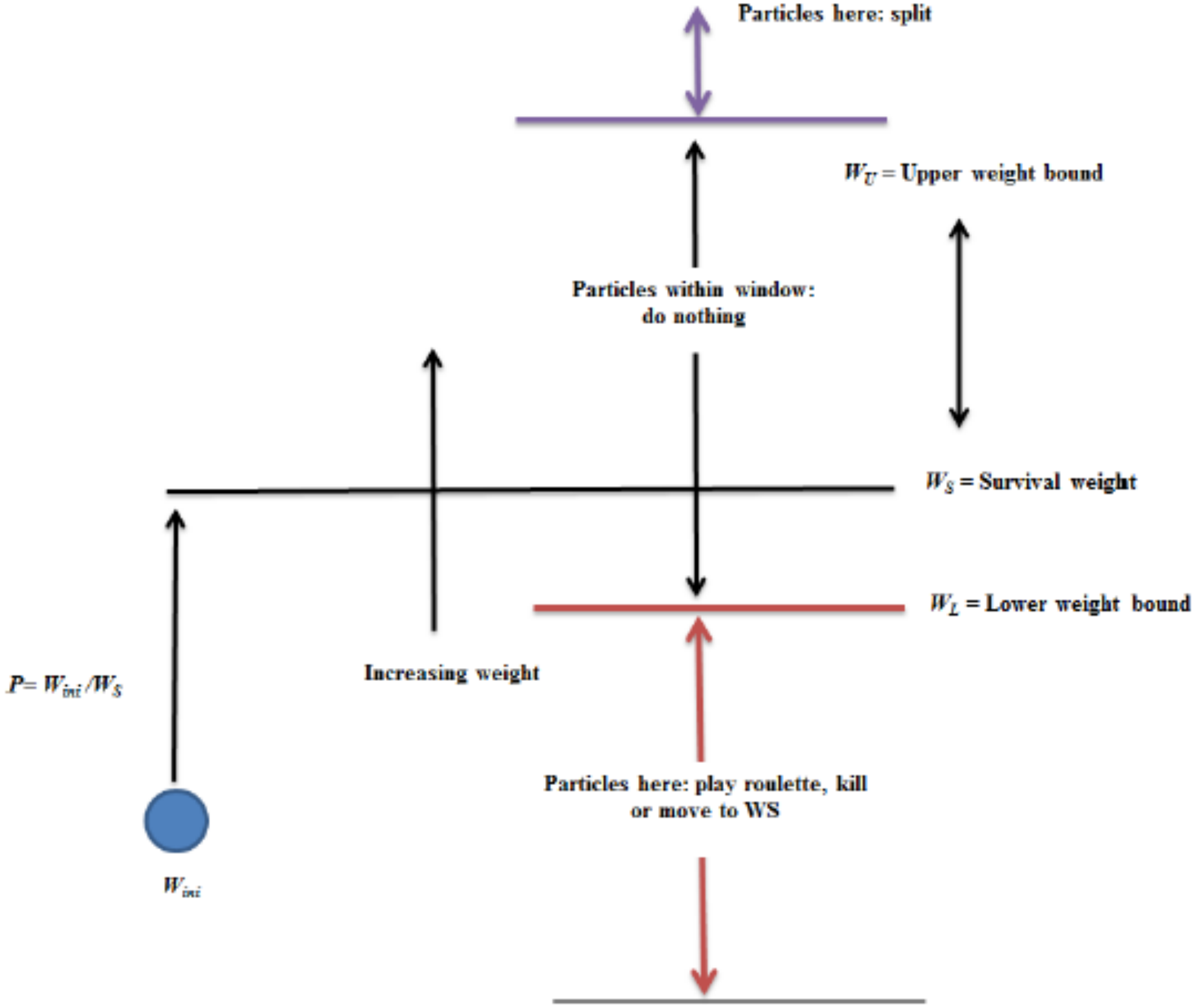
Russian roulette



Weight window principle 1(2)



Weight window principle 2(2)



Particles here: split

W_U = Upper weight bound

Particles within window:
do nothing

W_S = Survival weight

W_L = Lower weight bound

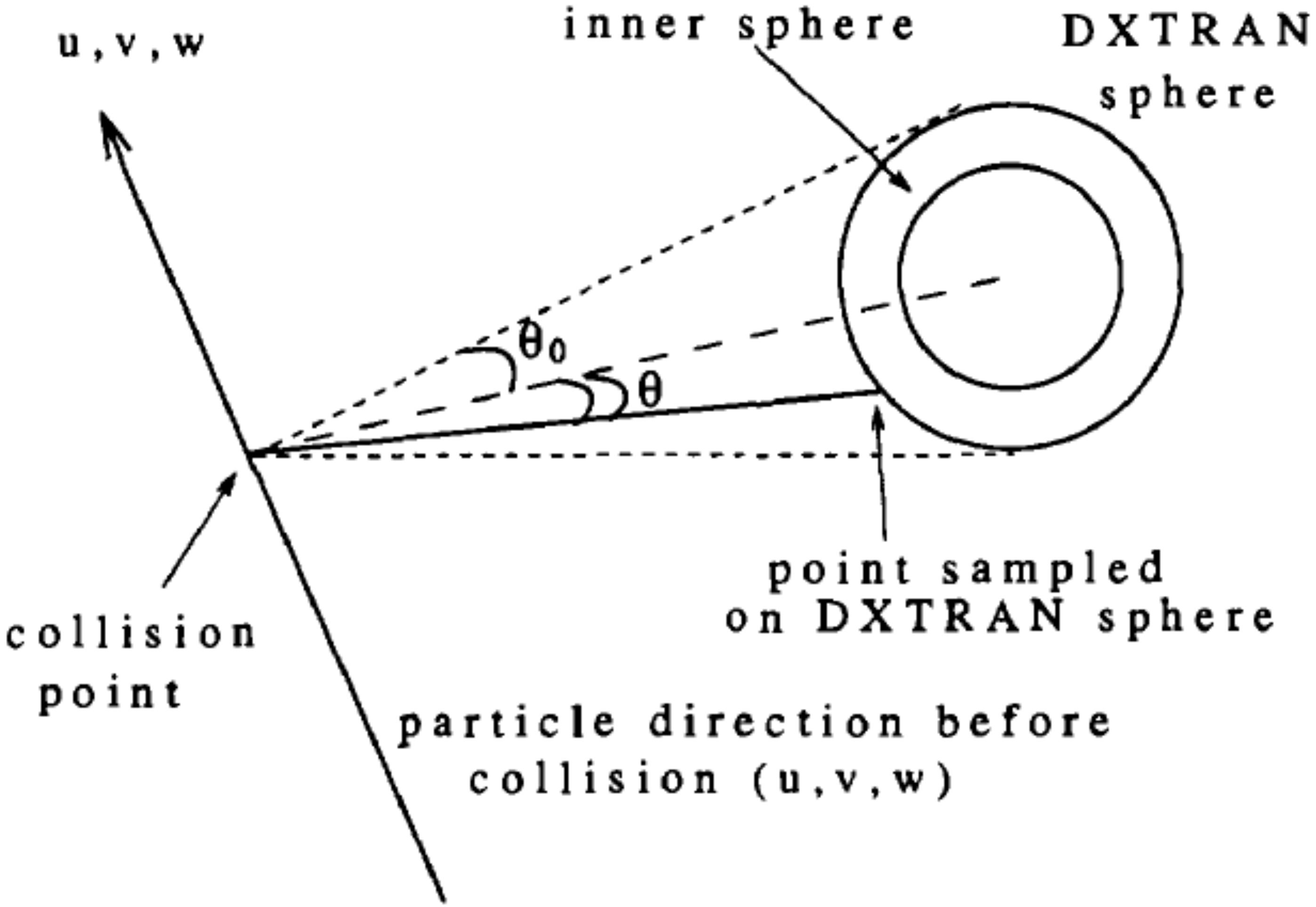
$P= W_{ini} / W_S$

Increasing weight

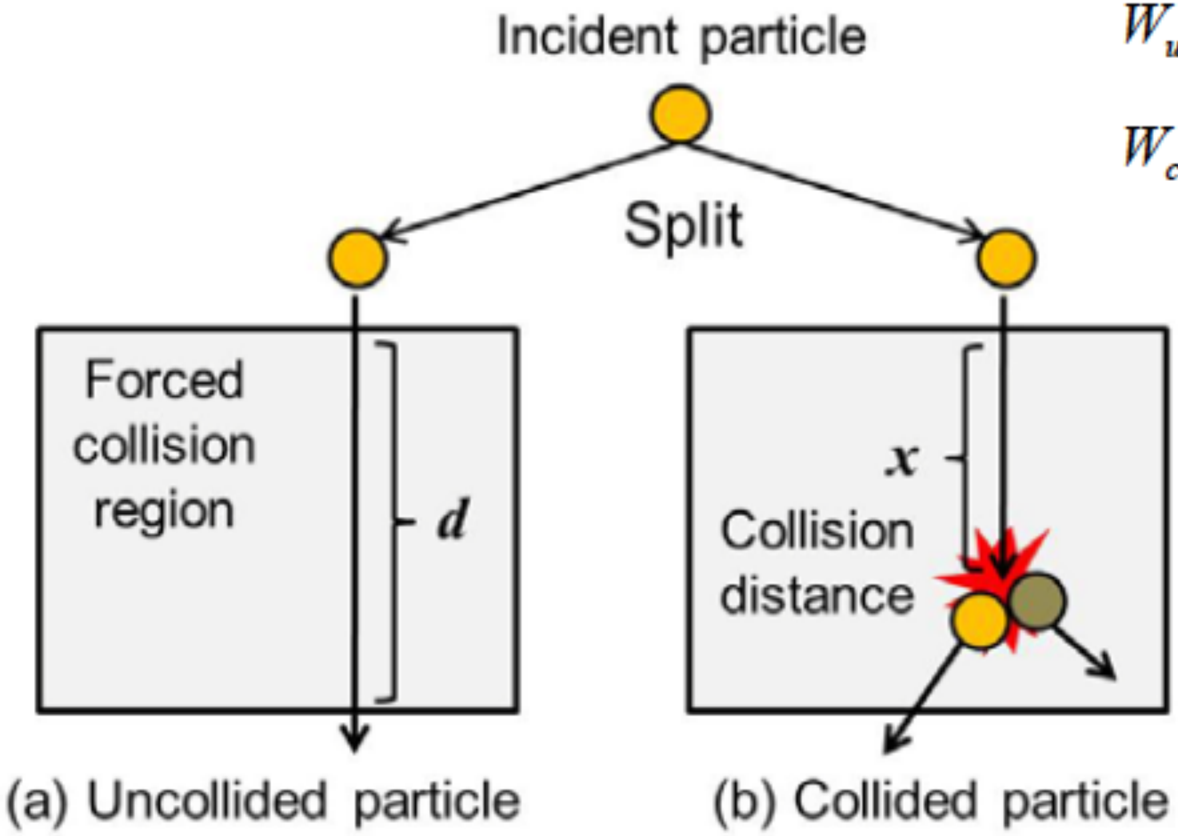
Particles here: play roulette, kill
or move to WS

W_{ini}

Dxtran sphere



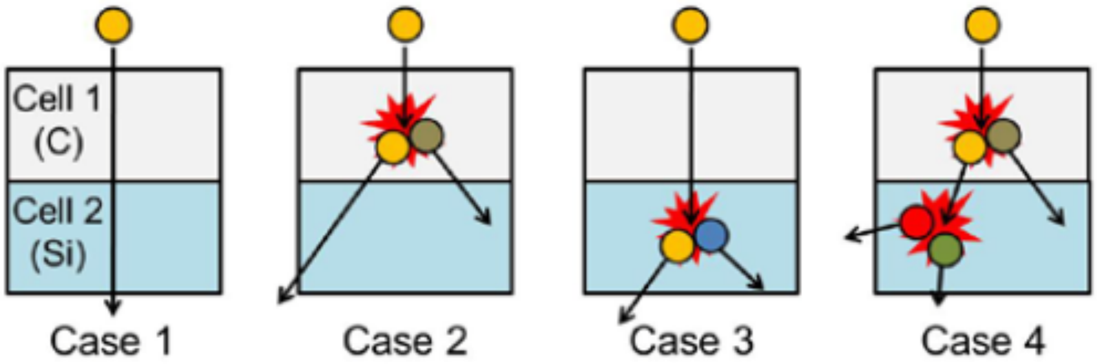
Forced collision 1(2)

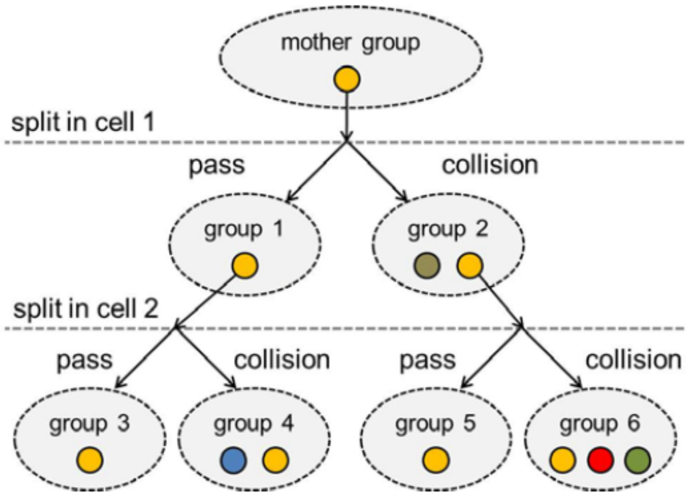


$$W_{uncoll} = W_0 \exp(-\Sigma_t d),$$

$$W_{coll} = W_0 \{1 - \exp(-\Sigma_t d)\}$$

Forced collision 2(2)





$$
\begin{aligned}
E_{mother} &= 0, & W_{mother} &= W_0 \\
E_1 &= 0, & W_1 &= W_{mother}\exp(-\Sigma_1 d_1) \\
E_2 &= e_C, & W_2 &= W_{mother}\left[1-\exp(-\Sigma_1 d_1)\right] \\
E_3 &= 0, & W_3 &= W_1\exp(-\Sigma_2 d_2) \\
E_4 &= e_{Si}, & W_4 &= W_1\left[1-\exp(-\Sigma_2 d_2)\right] \\
E_5 &= 0, & W_5 &= W_2\exp(-\Sigma_2 d_2) \\
E_6 &= e_{Al}+e_p, & W_6 &= W_2\left[1-\exp(-\Sigma_2 d_2)\right],
\end{aligned}
$$

Energy splitting

- Energy splitting is like geometry splitting put in energy space.

Secondary particle biasing

- Secondary particle biasing is like geometry splitting but in secondary particle space.

Activation

- Spallation productions
- Neutron flux induced
  - High energy neutron flux induced
  - Thermal and cold neutron absorption

Hand calculations: Production term

$$P = \Phi V \sigma_{abs} \varrho$$

- P … production term
- Φ … volume flux
- V … volume
- σ_{abs} … thermal neutron absorption cross-section
- ρ … density

Hand calculations: activation

EUROPEAN
SPALLATION
SOURCE

$$A(t) = P(1 - e^{-\lambda t}) \qquad \lambda = \frac{\ln 2}{t_{1/2}}$$

- A … activation at time t
- P … production term
- λ … decay rate
- $t_{1/2}$ … half-life time

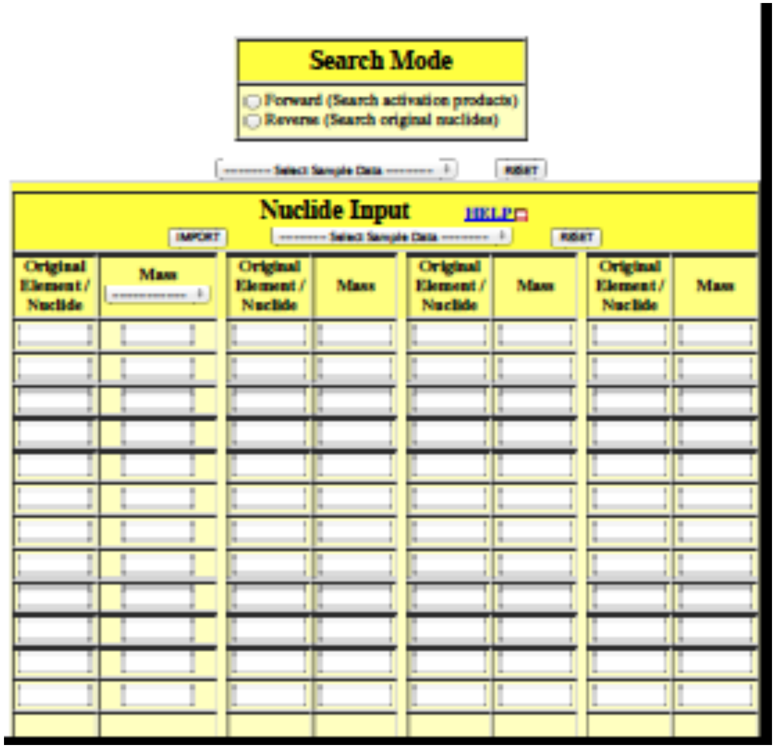
Hand calculations: inventory

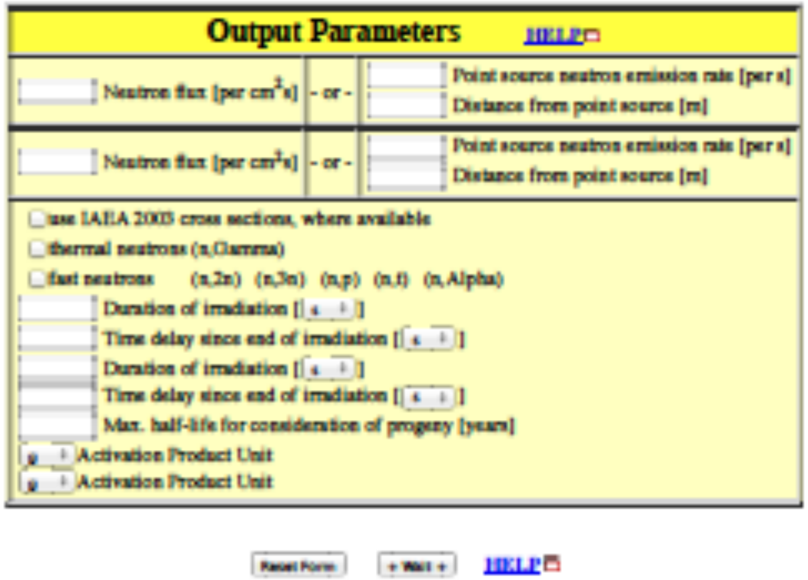
$$I(t) = \frac{P}{\lambda}\left(1 - e^{-\lambda t}\right) \qquad \lambda = \frac{\ln 2}{t_{1/2}}$$

- A … inventory at time t
- P … production term
- λ … decay rate
- $t_{1/2}$ … half-life time

Activation calculator

http://www.wise-uranium.org/rnac.html

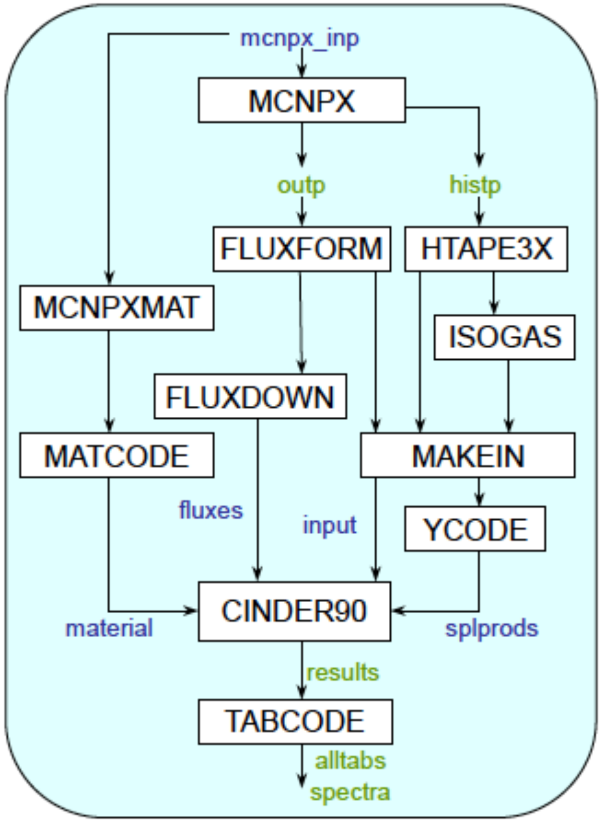




Activation script

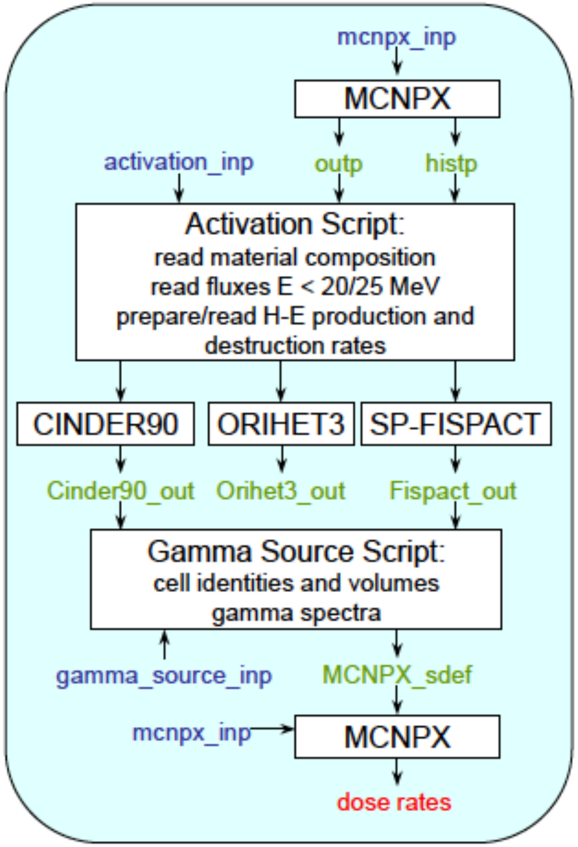
EUROPEAN
SPALLATION
SOURCE

OLD



EXTRACT γ-SPECTRA
MANUALLY

NEW



SCRIPT TO EXTRACT γ-SPECTRA
+ SDEF CARD PREPARATION

Gamma script

EUROPEAN
SPALLATION
SOURCE

MAIN FEATURES

- Perl Script
- All cells treated in previous activation calculations will be considered to contribute to the γ-source that is constructed.
- Capable to extract gamma source information from CINDER90 spectra file and SP-FISPACT TAB2 file.
- Only acoount for single cell entries.
- The time step for which the source should be evaluated can be user defined.
- More than 200 cells ➔ SDEF distribution overflow ➔ source defintion is split.
- Only “regular” cells currently possible; no universes/lattices