Joint ICTP-IAEA Workshop on Monte Carlo Radiation Transport and Associated Data Needs for Medical Applications
28 October – 8 November 2024
ICTP, Trieste, Italy

Lecture 31

Fundamental quantities in dosimetry

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Fundamental quantities in dosimetry

- Absorbed Dose D

  mean energy imparted by ionizing radiation to matter

- Total Kerma K

  mean initial **K**inetic **E**nergy of charged particles **R**eleased in **MA**tter

- Collission Kerma K_{col}

  absorbed **K**inetic **E**nergy of charged particles **R**eleased in **MA**tter

Basic quantities in dosimetry

Establishing air-kerma and dose-to-water primary standards requires quantities such as:

- mass energy absorption coefficients μ_{en}/ρ
- average radiative loss fraction, $\overline{g}$
- particle fluence, $\phi\left(E\right)$
- restricted collision mass stopping powers, L_{Δ}/ρ

The EGSnrc g application

- calculates $\overline{g}$, the average kinetic energy fraction lost to radiative events for primary photon interactions (radiative loss fraction)

- radiative yield Y in the case of charged particle beams as they slow down.

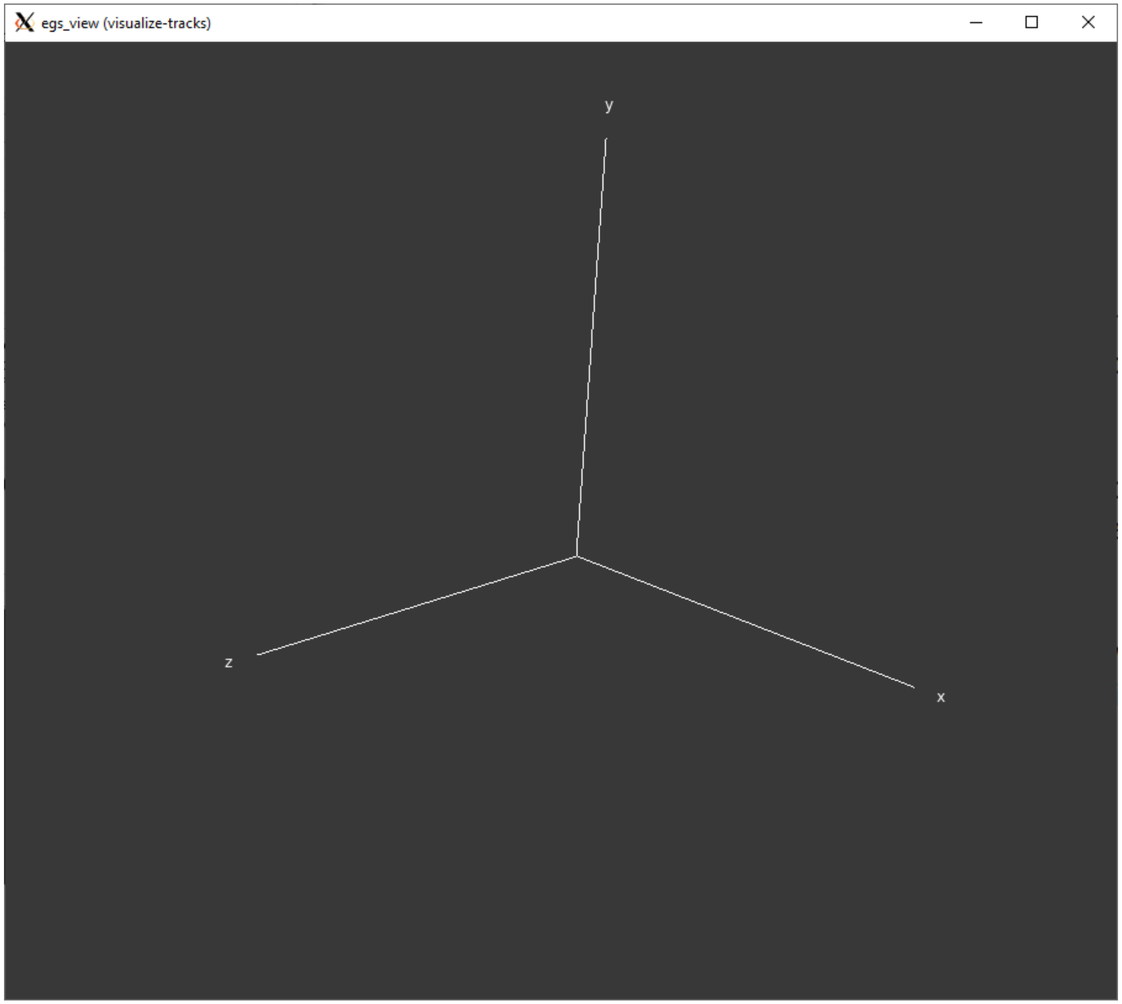
- photon beam quantities such as
  - total kerma, K,
  - collision kerma, $\mathrm{K}_{\mathrm{col}}$
  - energy-fluence-averaged mass energy-transfer coefficient, $\overline{\mu}_{\mathrm{tr}}/\rho$
  - energy-fluence-averaged mass energy-absorption coefficient, $\overline{\mu}_{\mathrm{en}}/\rho$

- Efficient calculation of μ_{en}/ρ databases

- No parallel calculations available (yet)!

- Details and input examples in *g application reference manual* (PIRS-3100)

g application: general aspects



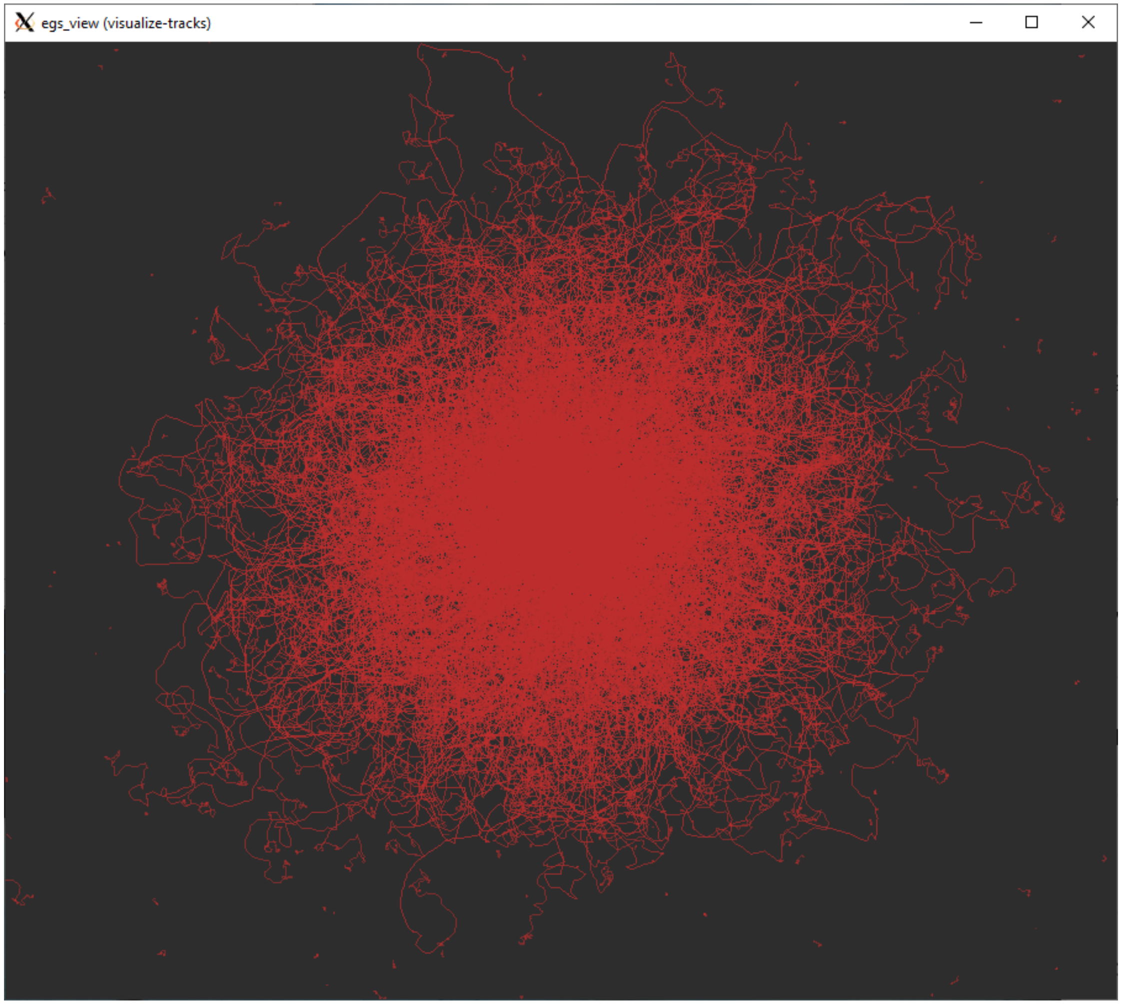
Particle at the center of infinite homogeneous phantom

Particle oriented initially along z-axis (0, 0, 1)

Primary and secondary photons discarded after first interaction

Electrons slow down in the medium until their energy falls below ECUT

g application: photon sources



Score $\overline{E}_{\rm tr}$ $\longrightarrow$ energy transferred to charged particles

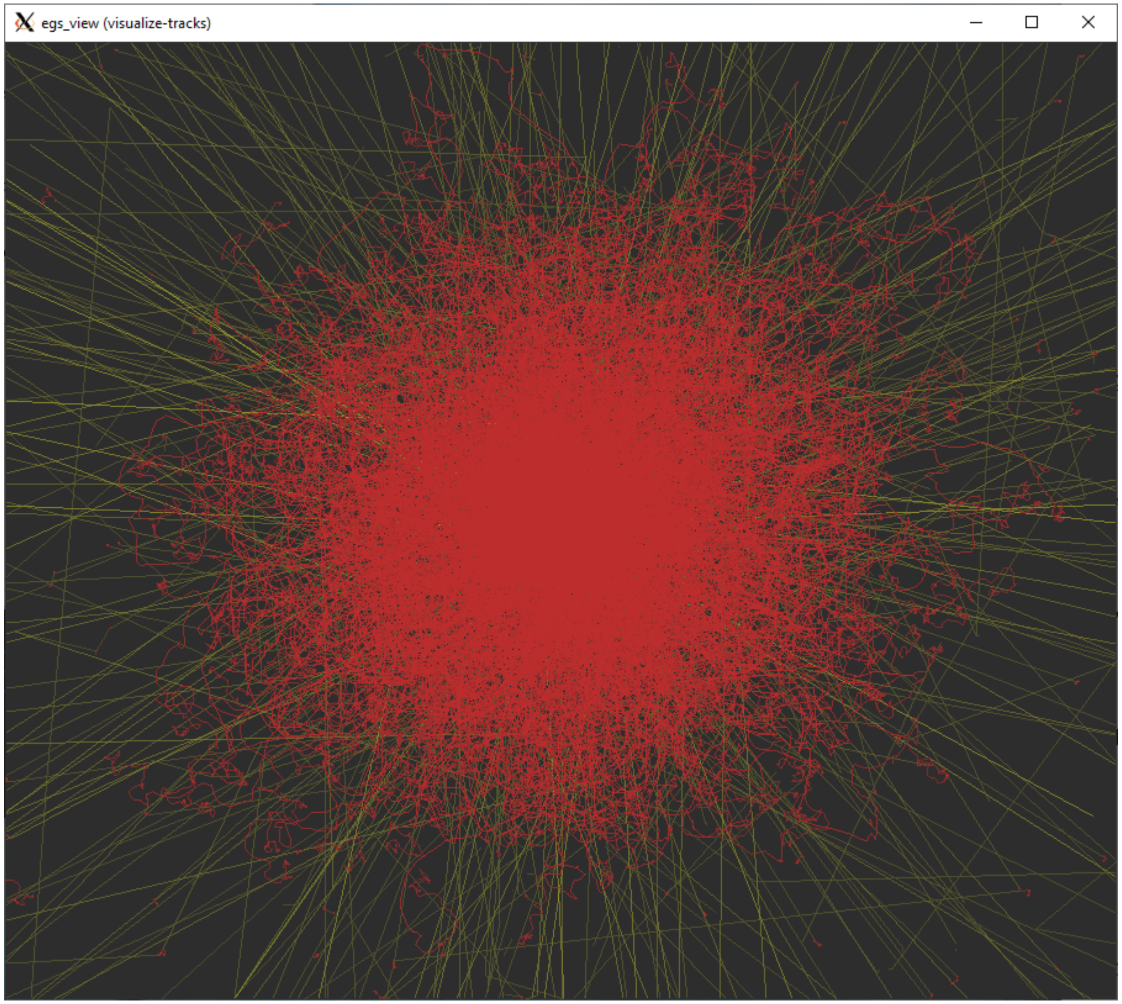
Account for sub-threshold relaxation charged particles (Auger e^-)

Calculate

$$\frac{K}{\phi} = \left\langle \overline{E}_{\rm tr} \cdot \mu/\rho \right\rangle_\phi$$

$$\langle \mu_{\rm tr}/\rho \rangle_\psi = \frac{K}{\phi \cdot \langle E \rangle_\phi}$$

g application: photon sources



Substract radiative events contributions $\overline{E}_{\text{rad}}$

Include sub-threshold relaxation photons (fluorescent γ's)

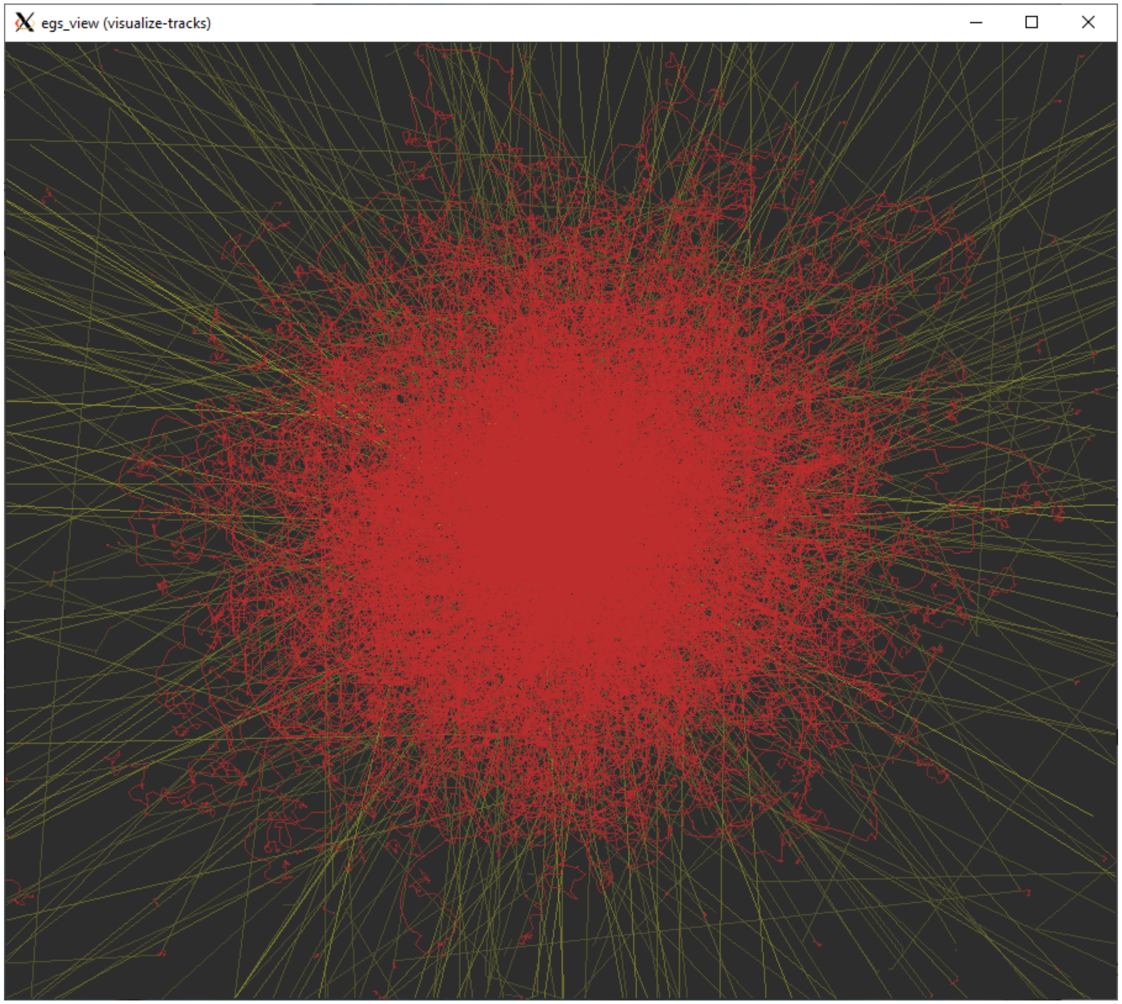
$$\overline{E}_{\text{ab}} = \overline{E}_{\text{tr}} - \overline{E}_{\text{rad}}$$

Calculate

$$\frac{K_{\text{col}}}{\phi} = \left\langle \overline{E}_{\text{ab}} \cdot \mu/\rho \right\rangle_{\phi}$$

$$\langle \mu_{\text{en}}/\rho \rangle_{\psi} = \frac{K_{\text{col}}}{\phi \cdot \langle E \rangle_{\phi}}$$

g application: photon sources

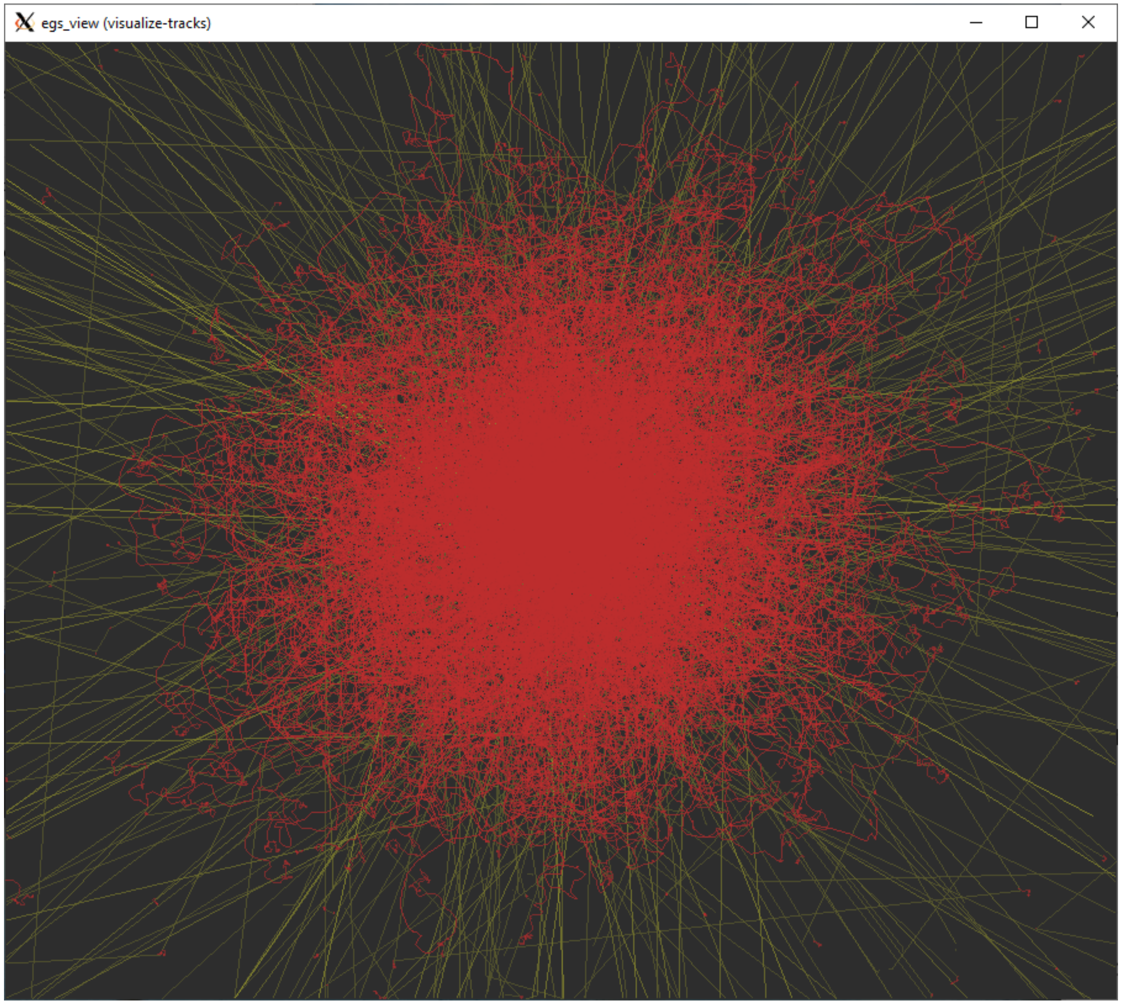


finally obtain $\overline{g}$

$$\overline{g} = \frac{\left\langle \overline{E}_{\mathrm{rad}} \cdot \mu \right\rangle_{\phi}}{\left\langle \overline{E}_{\mathrm{tr}} \cdot \mu \right\rangle_{\phi}}$$

Computing $\overline{E}_{\mathrm{rad}}$ is the inefficient part of these calculations as it requires following electrons down to the threshold energy ECUT.

g application: electron sources



radiative yield Y for e^- beam with energy distribution $\phi(T)$

$$Y = \frac{\langle \overline{E}_{\mathrm{rad}} \rangle_\phi}{\langle T \rangle_\phi}$$

Radiative photons (bremsstrahlung, annihilation photons, fluorescent photons after EII) discarded after scoring their energy

Increasing efficiency for photon sources calculations

If generating tables of $\mu_{\mathrm{en}}/\rho\,(E)$ is the goal, calculation efficiency can be significantly increased by using

$$\mu_{\mathrm{en}}/\rho = \mu_{\mathrm{tr}}/\rho \cdot (1 - \overline{g})\,,$$

taking advantage of the faster convergence of μ_{tr} and 1- $\overline{g}$ (when $\overline{g}$ is small) to a desired statistical precision σ.

Users can request this type of calculation using the inputs

```
calculation type  = type  # 0 (default), 1
precision         = accu  # relative precision, defaults to 0.001
precision balance = m     # m = 2 recommended for calculations around 1 MeV
```

anywhere in the input file.

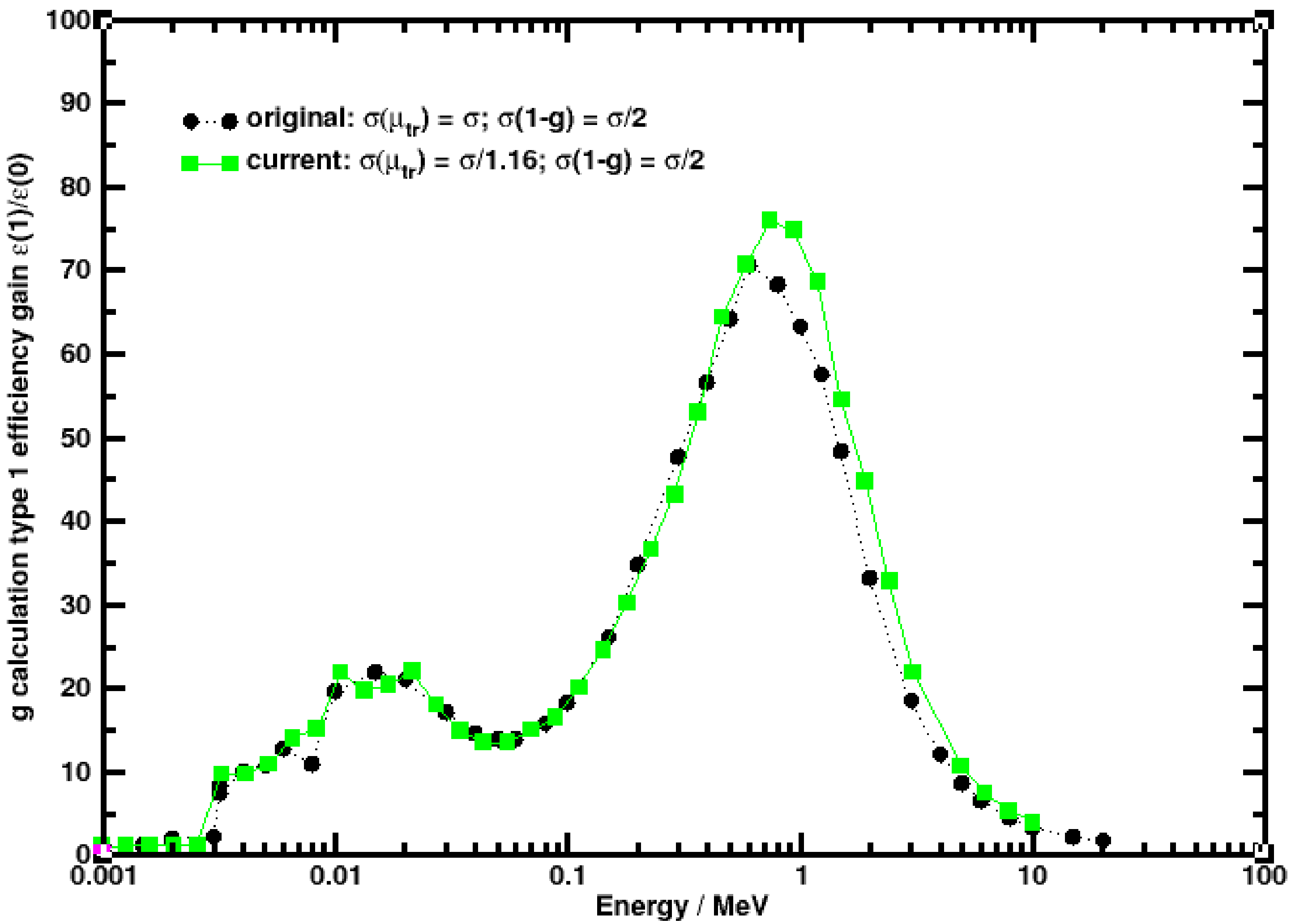
Increasing efficiency for photon sources calculations

- calculation finishes as soon as a user-requested relative uncertainty σ is reached
- the number of histories input entry is ignored
- photon-only μ_{tr} calculation
- Efficiency balancing scheme:

$$\sigma\left(\mu_{\mathrm{tr}}\right) = \sigma/\sqrt{m}$$
$$\sigma\left(1-\overline{g}\right) = \sigma/\sqrt{m/(m-1)}$$

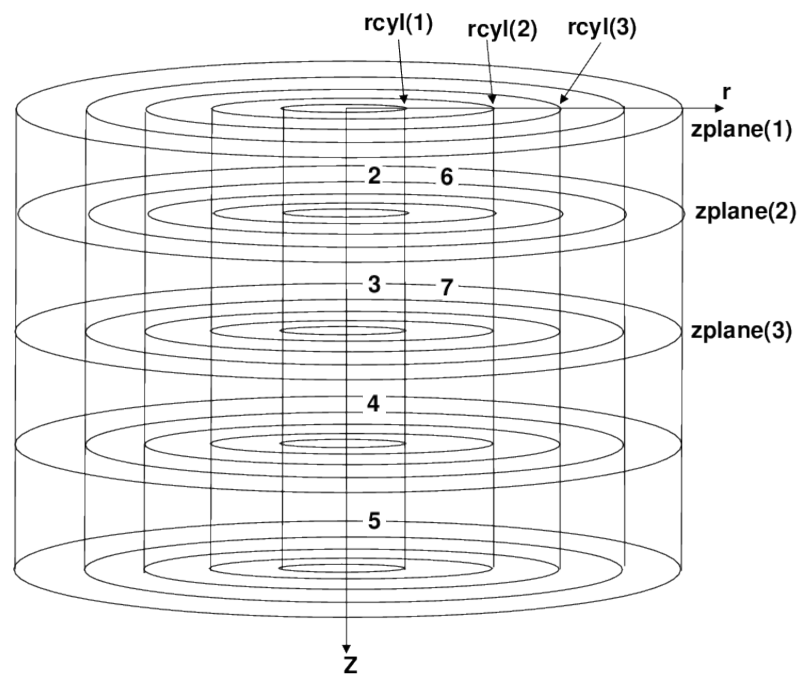
- Default: μ_{tr} calculated to a precision of $\sigma/\sqrt{4/3}$ and $(1-\overline{g})$ of $\sigma/2$

Efficiency gain of calculation type 1 over type 0 in air



The EGSnrc “RZ” applications

- Specific to right-cylindrical symmetric geometries such as
  - ion chambers
  - brachytherapy sources



- Long history at the NRC and extensively used in the Medical Physics community.

The EGSnrc “RZ” applications

- **DOSRZnrc**:
  - dose vs depth, dose vs radius
  - kerma vs depth, kerma vs radius
  - pulse height distribution
- **CAVRZnrc**:
  - dose in cavity
  - $\mathrm{A}_{\mathrm{att}}$, $\mathrm{A}_{\mathrm{scat}}$ and $\mathrm{A}_{\mathrm{wall}}$
- **FLURZnrc**:
  - total and differential fluence in regions
  - fluence vs depth, fluence vs radius
  - separate photons, electrons and positrons
  - primaries and secondaries contributions
- **SPRRZnrc**:
  - SA collision stopping power ratios (SPR) in regions
  - SPR vs depth, SPR vs radius (also dose)

RZ and SPH apps user manual
(PIRS-702)

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RZ and SPH apps user manual
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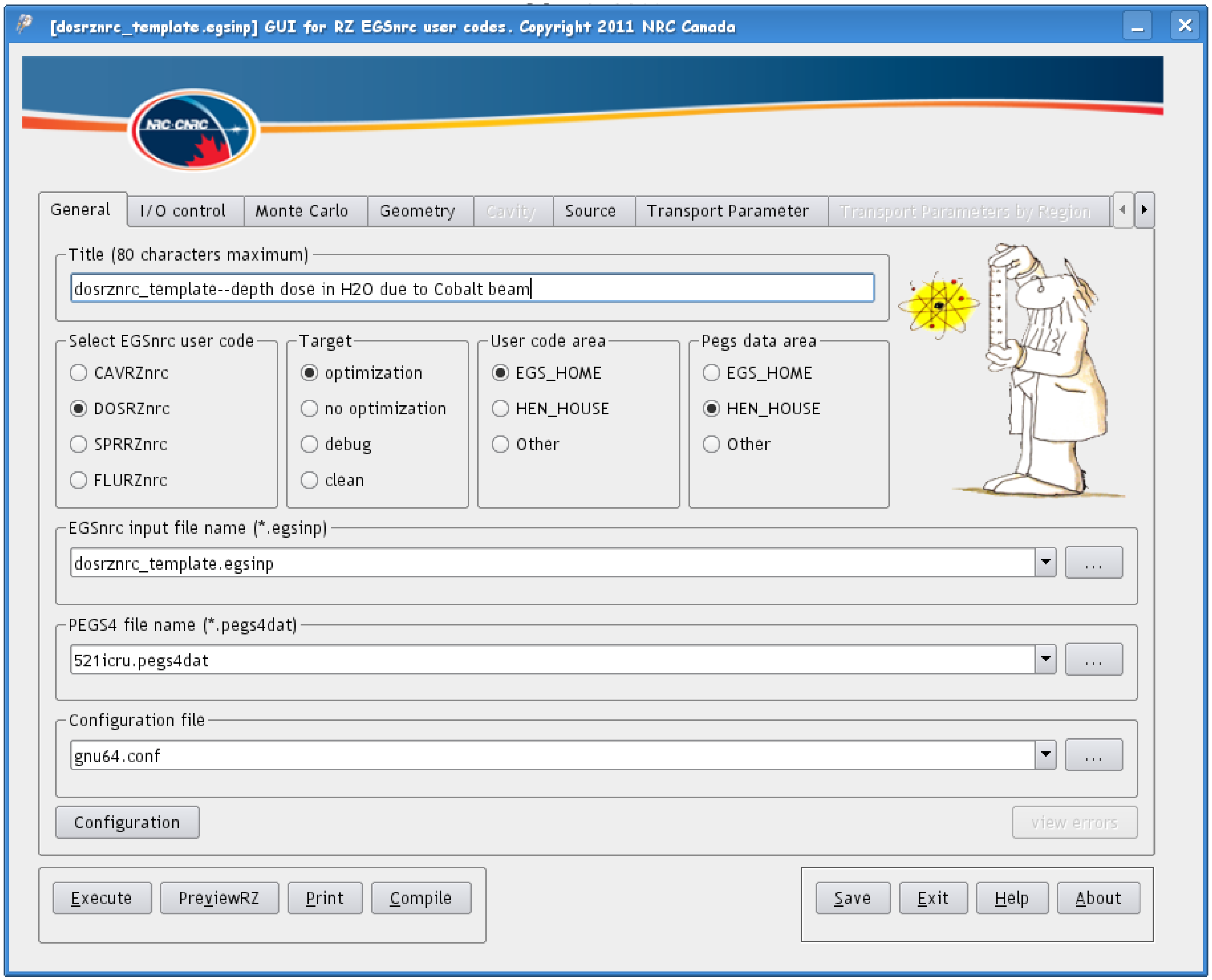
Excellent validation tools!

Unique!

The egs_inprz graphical user interface



FLURZnrc

SPRRZnrc

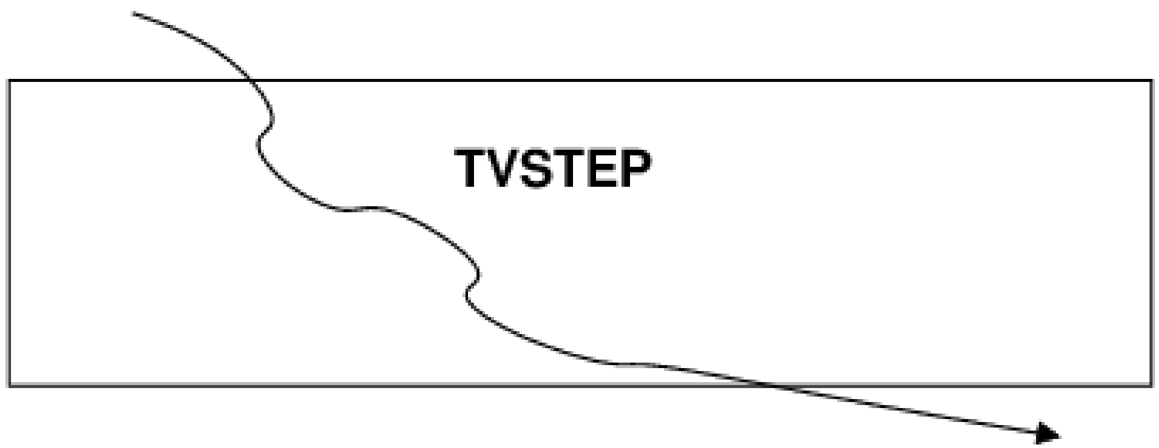
DOSRZnrc

CAVRZnrc

FLURZnrc fluence calculation

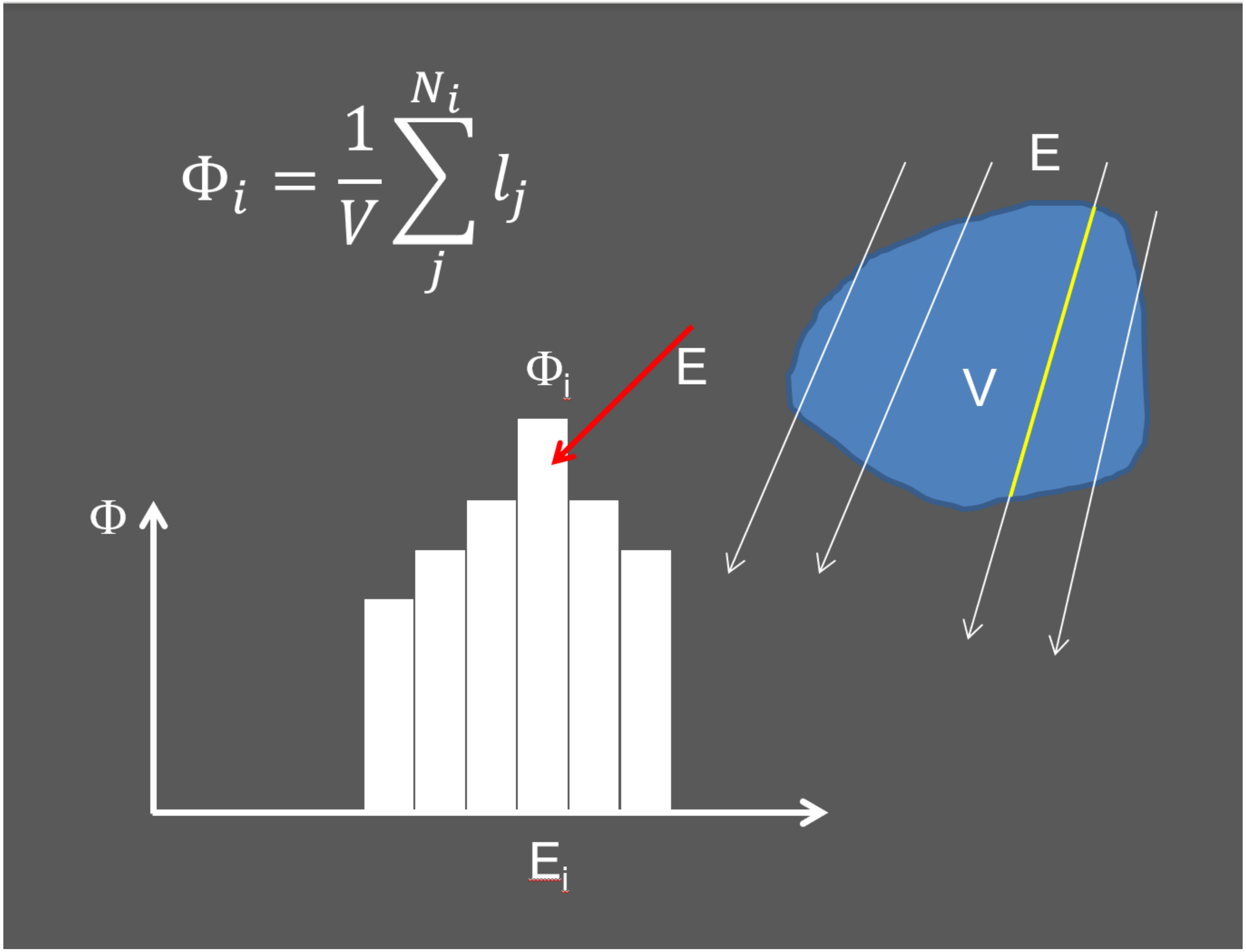
Fluence for different particle types is calculated as the total pathlength divided by the region's volume V, i.e.:

$$\Phi = \frac{\sum l_i}{V}$$

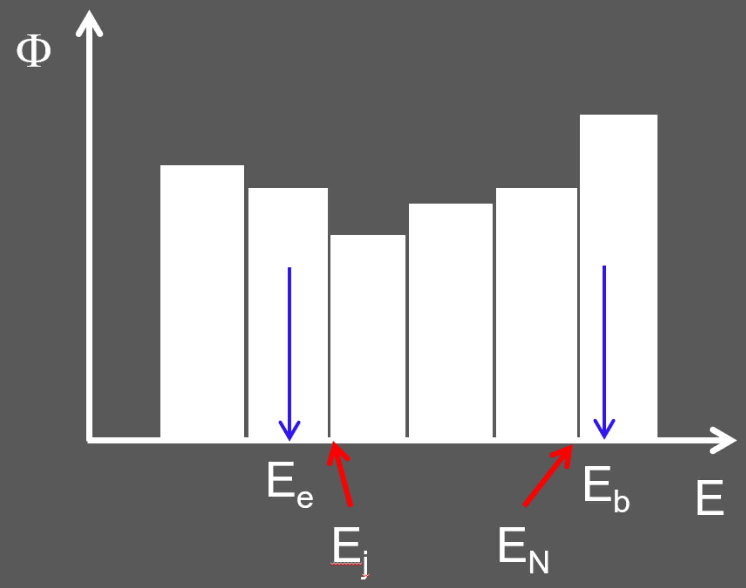


TVSTEP is the total curved path through the voxel.

Differential fluence: photons



Differential fluence: electrons



$$L(E) \approx \bar{L} = \frac{edep}{TVSTEP}$$

$$s(E) = \{\frac{E_b - E_N}{edep} + \frac{E_j - E_e}{edep} + \sum_{i=j}^{N} \frac{\Delta E_i}{edep}\} \cdot TVSTEP$$

FLURZnrc

SPRRZnrc

DOSRZnrc

CAVRZnrc

SPRRZnrc: stopping power ratios calculations

SPRRZnrc calculates Spencer-Attix spectrum averaged restricted collision stopping power ratios in two media. TG-51 protocol is based on SPR calculations by this code.

$$\left(\frac{\overline{L}}{\rho}\right)_g^m = \frac{\displaystyle\int_\Delta^{E_{max}} \frac{d\Phi_T}{dE}\left(\frac{L}{\rho}\right)_m dE + TE_m}{\displaystyle\int_\Delta^{E_{max}} \frac{d\Phi_T}{dE}\left(\frac{L}{\rho}\right)_g dE + TE_g}$$

The energy deposition in a condensed history code can take four distinct forms:

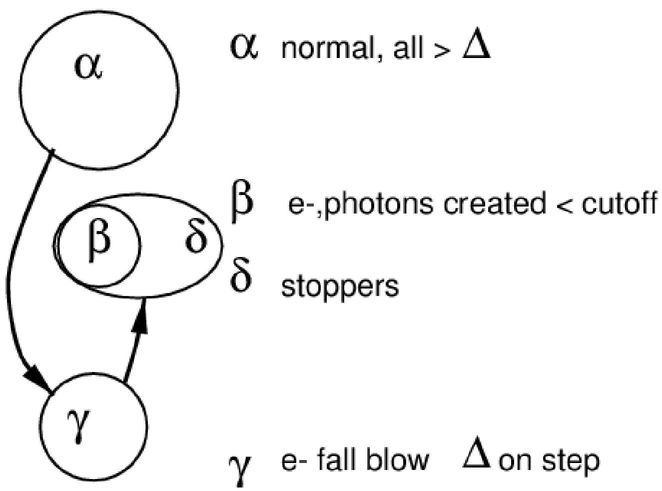
α. energy deposition over a step with initial and final energy above Δ

β. energy deposition by particles created with kinetic energy below Δ

γ. energy deposition over a step that initiates above Δ and that crosses Δ

δ. energy deposition by stoppers, i.e., particles whose energy has fallen below Δ

SPRRZnrc: stopping power ratio calculation (cont'd)



$\alpha.\quad E_{dep}\frac{\left(\frac{L(E_{mid})}{\rho}\right)_g}{\left(\frac{L(E_{mid})}{\rho}\right)_m}$

$\beta.$ not included

$\delta.\quad E_{dep}\frac{\left(\frac{S(\Delta)}{\rho}\right)_g}{\left(\frac{S(\Delta)}{\rho}\right)_m} \equiv$ track-end term.

$\gamma.$ Combination of α and δ

Summation in the numerator of the integral over the energy deposited E_{dep} in medium m, while as in medium g, the energy deposited is evaluated acording to the different cases above. Case β is not included in the calculation.

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