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Radiation Engineering Laboratory

Calculation of Local Skin Dose Coefficients with ICRP Mesh-type Reference Computational Phantoms

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HANYANG UNIVERSITY

Skin Dose Limits

ICRP Publication 103

Table 6. Recommended dose limits in planned exposure situations[a].

Type of limit	Occupational	Public
Effective dose	20 mSv per year, averaged over defined periods of 5 years[e]	1 mSv in a year[f]
Annual equivalent dose in:		
Lens of the eye[b]	150 mSv	15 mSv
Skin[c,d]	500 mSv	50 mSv
Hands and feet	500 mSv	–

[a] Limits on effective dose are for the sum of the relevant effective doses from external exposure in the specified time period and the committed effective dose from intakes of radionuclides in the same period. For adults, the committed effective dose is computed for a 50-year period after intake, whereas for children it is computed for the period up to age 70 years.

[b] This limit is currently being reviewed by an ICRP Task Group.

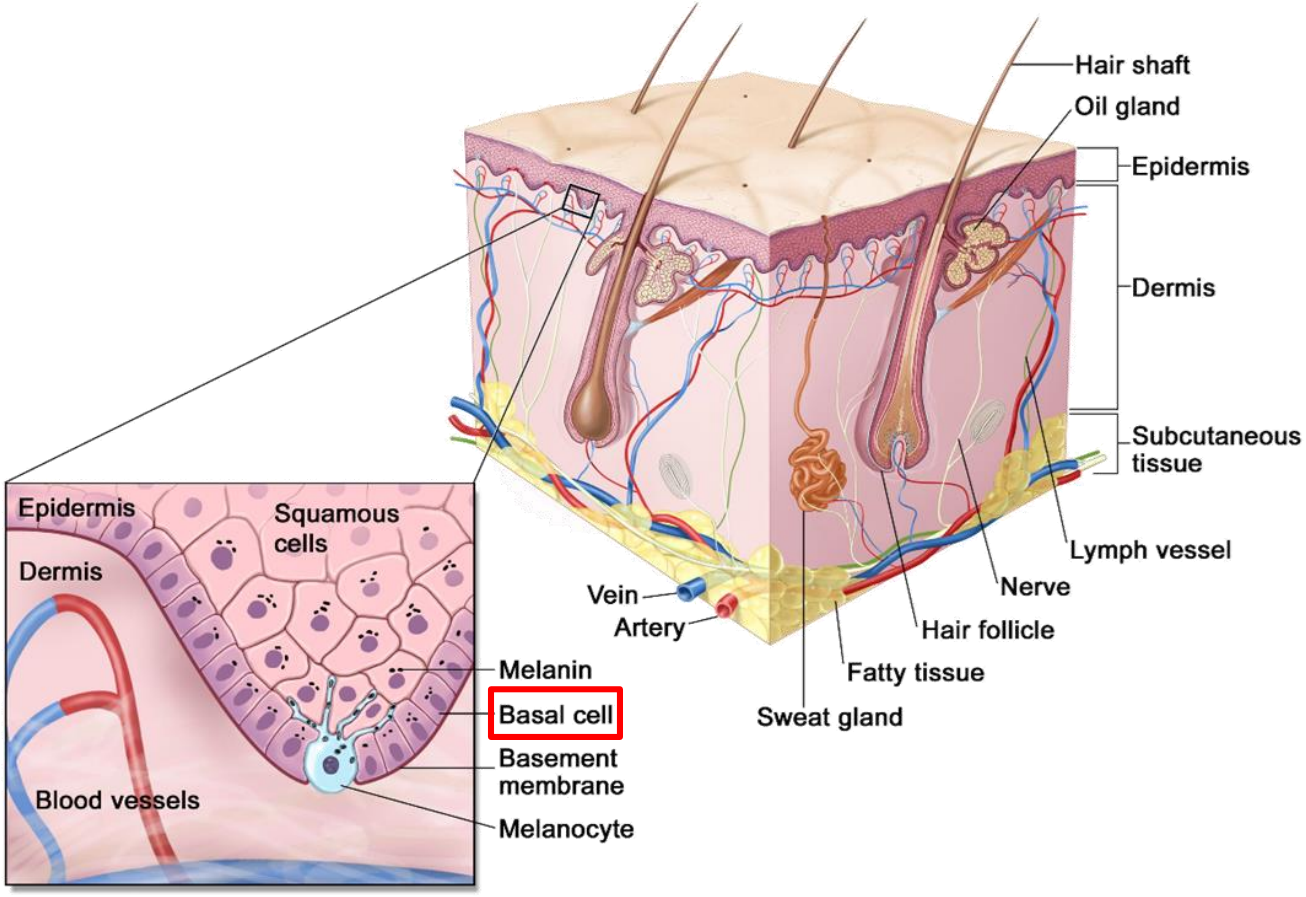
[c] The limitation on effective dose provides sufficient protection for the skin against stochastic effects.

[d] Averaged over 1 cm^2 area of skin regardless of the area exposed.

ICRP, The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, Ann. ICRP 37 (2-4), 2007.

- The annual limit on skin dose (500 mSv for occupational exposure and 50 mSv for public exposure) is controlled by the **local skin dose average over any 1 cm^2 of the skin at the basal cell layer**.

Basal Cell Layer

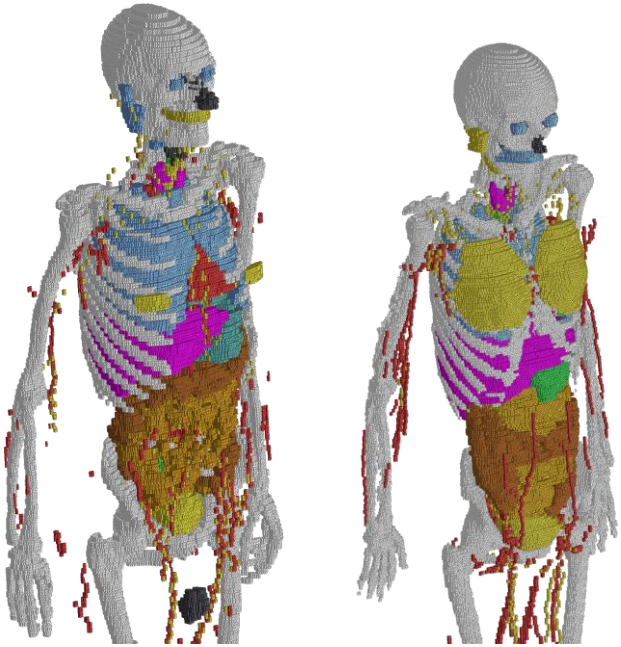


- The ICRP recommends that the depth of the basal cell layer as **50-100 µm** at the nominal depth of 70 µm.

Limitation of ICRP-110 Reference Phantoms

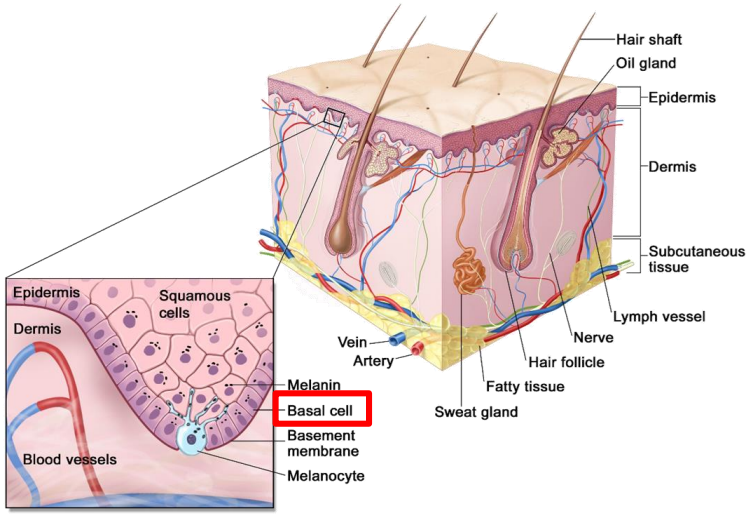
- **Voxel size (male): 2.137 x 2.137 x 8 *mm³***
- **Voxel size (female): 1.775 x 1.775 x 4.8 *mm³***

- **Depth of basal cell: 50-100 *μm***



ICRP adult reference voxel phantoms (ICRP Publication 110)

cannot define



- **<u>The 50-μm thick skin basal layer cannot be defined</u>** in the ICRP-110 reference phantoms due to the limited voxel resolutions.

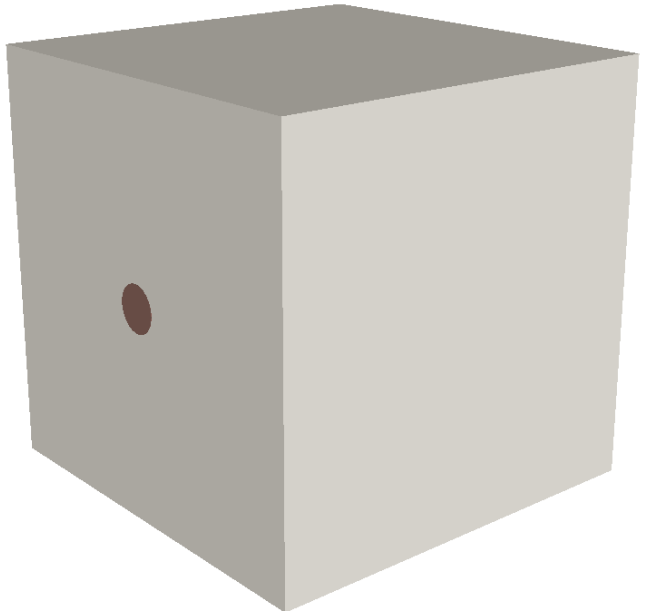
ICRP-116 Local Skin Dose Coefficients

- Instead of using the ICRP-110 reference phantoms, ICRP used **a simple cube model** to calculate local skin dose coefficients for electrons and alpha particles, provided in ICRP Publication 116.

ICRP Publication 110 (2009)

ICRP adult reference voxel phantoms

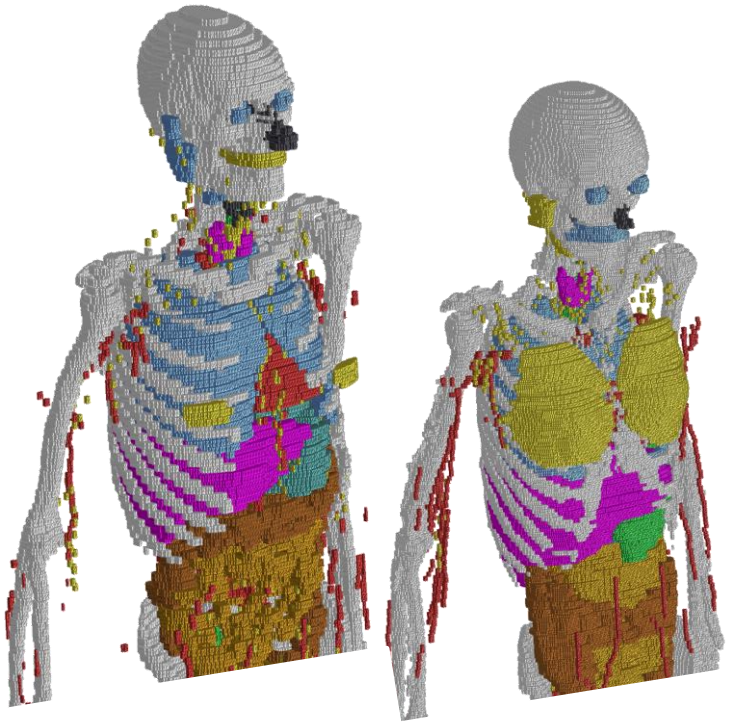
ICRP Publication 116 (2010)



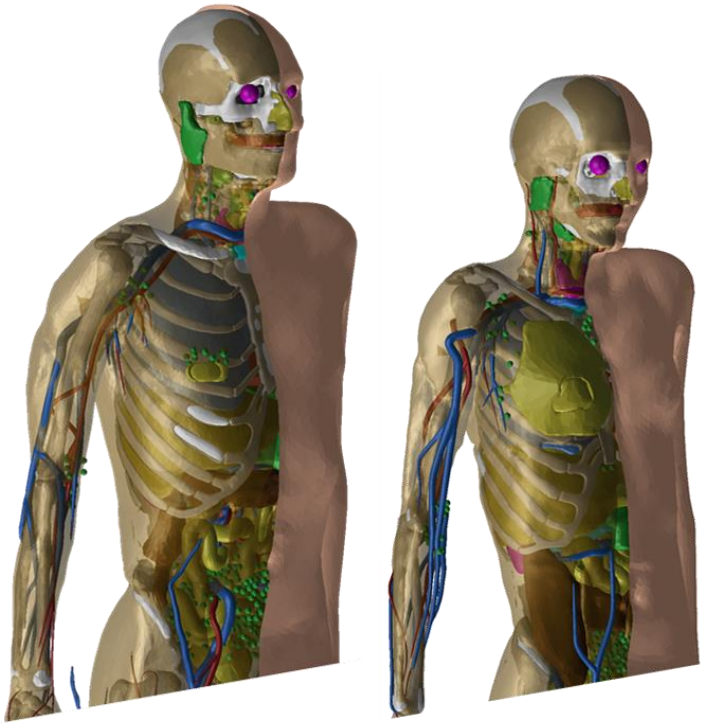
Simple cube model

ICRP Adult Mesh-type Reference Phantoms

- Recently, the ICRP Task Group 103 developed **the adult male and female mesh-type reference computational phantoms (MRCPs)** by converting the ICRP-110 reference phantoms into a high-quality mesh format.

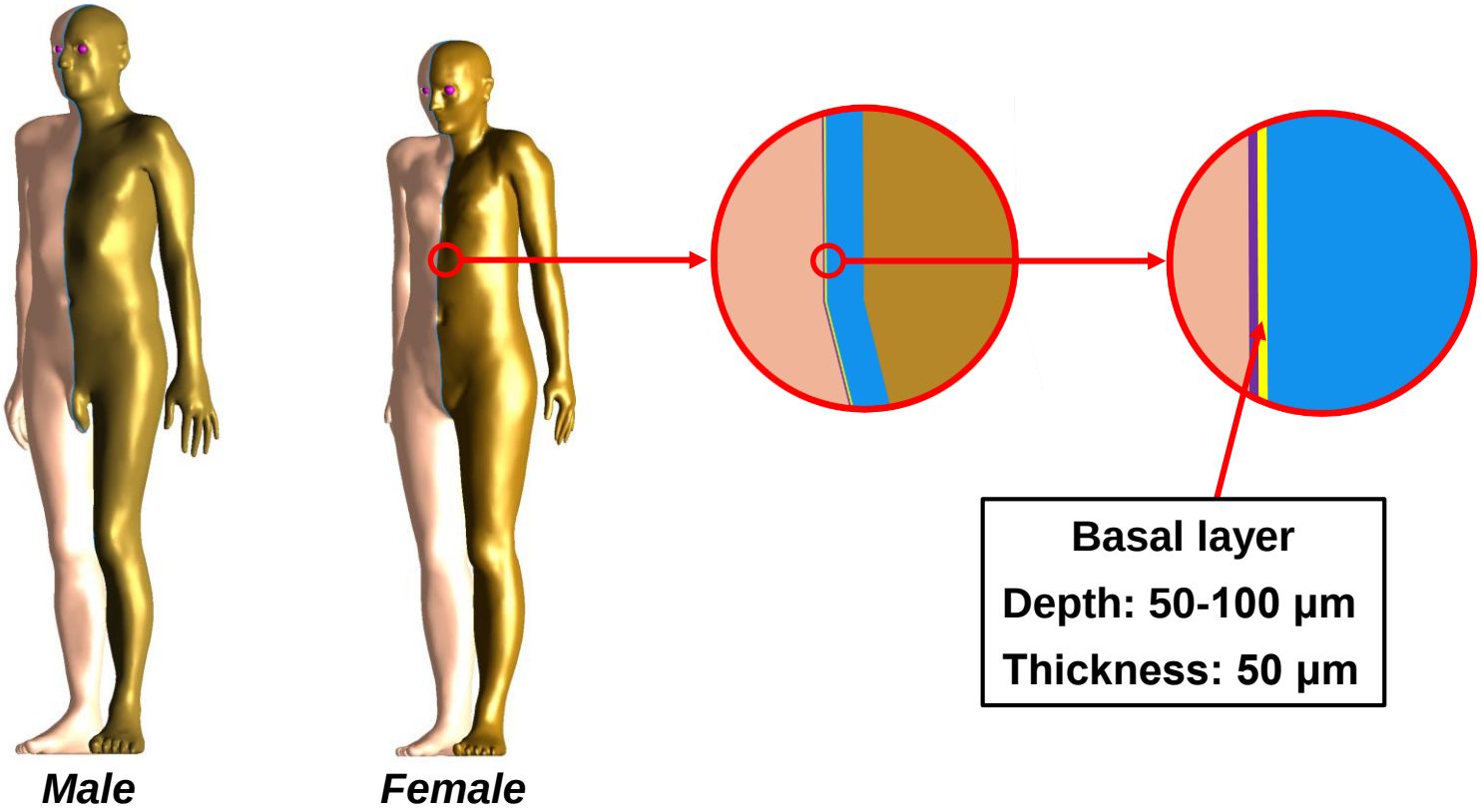


Adult voxel-type reference phantoms (ICRP Publication 110)



Adult mesh-type reference phantoms

Basal Cell Layer Defined in MRCPs



- In contrast with the ICRP-110 phantoms, **the adult MRCPs include the 50-μm thick skin basal cell layer,** which makes it possible to consider the basal layer in skin dose assessment.
- However, a methodology for calculation of local skin dose, i.e., **the maximum dose** of the basal layer averaged over 1 cm^2 area, is yet to be developed.

Objective of Present Study

- The present study developed **a dedicated program for calculation of local skin doses** based on the mean shift algorithm and Geant4 Monte Carlo code.
- The developed program was used to **calculate local skin dose coefficients** for electrons and alpha particles.
- The calculated local skin dose coefficients were **compared with the ICRP-116 values**.

Mean Shift Algorithm

- **Mean Shift algorithm**

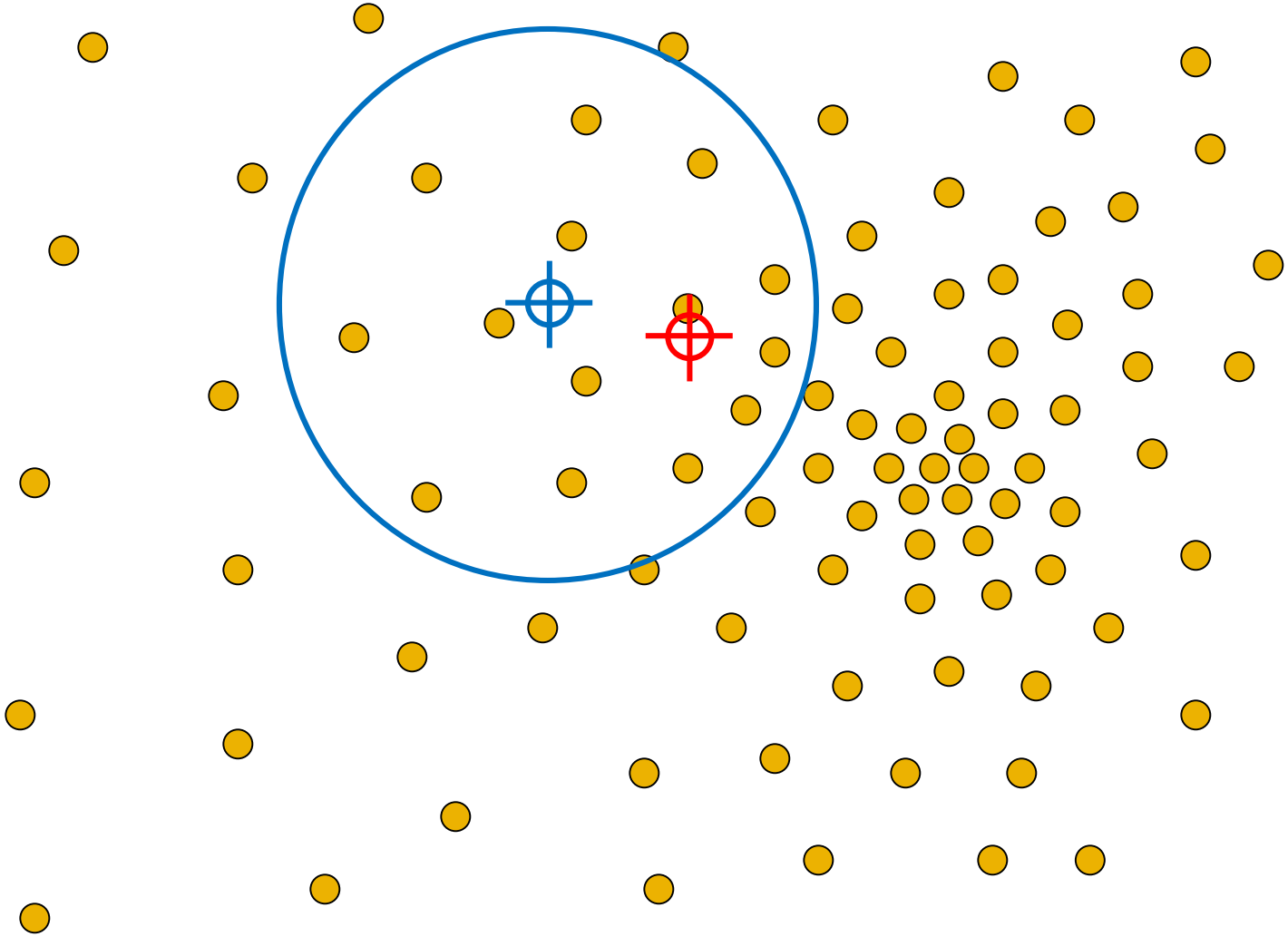
  A method for searching ***modes*** *from the* given discrete data

- **Applications**

  Clustering, image segmentation, image tracking

Comaniciu D and Meer P. Mean shift: a robust approach toward feature space analysis. IEEE Transactions on Pattern Analysis and Machine Intelligence 2002;24;603–619.

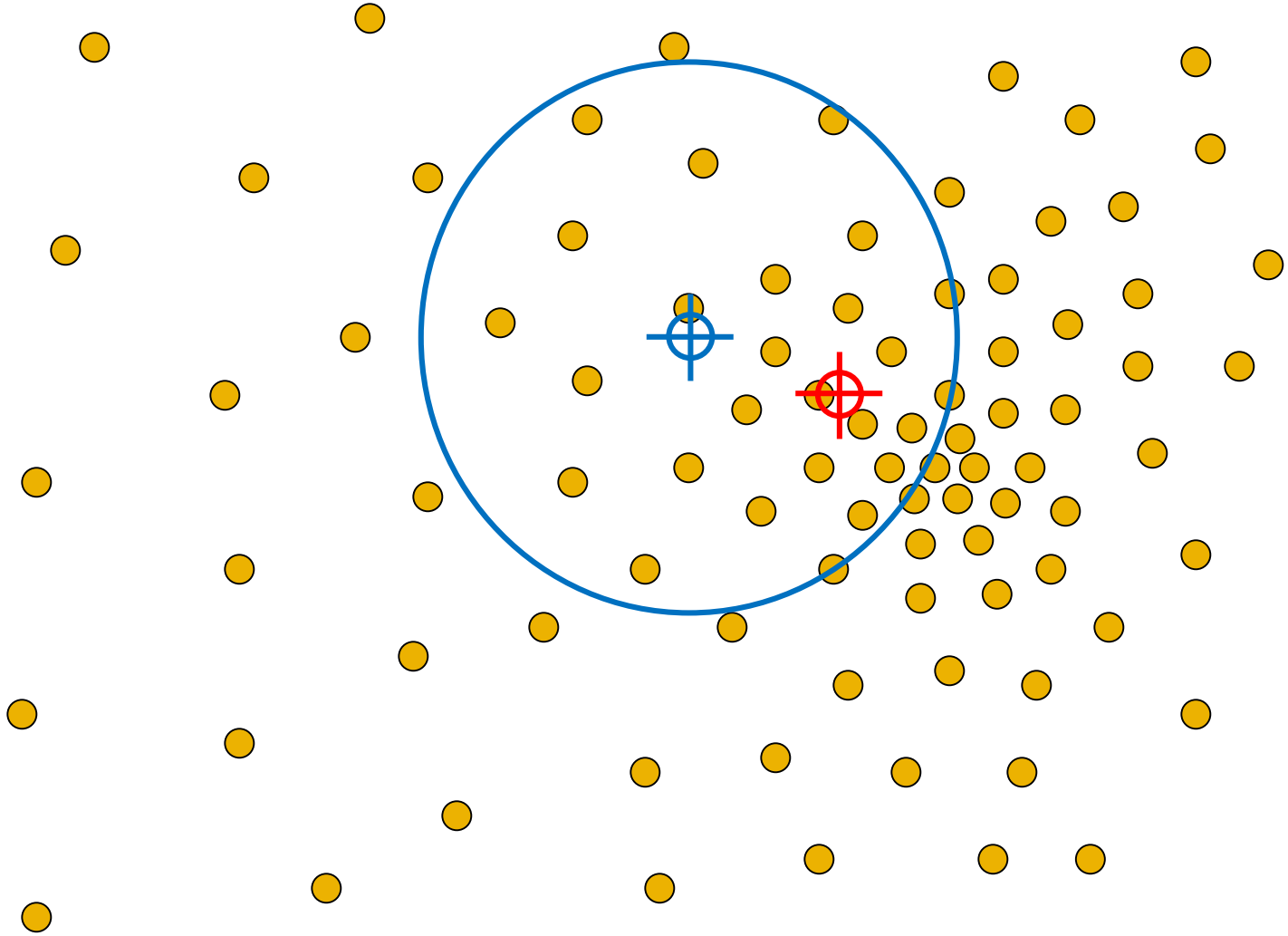
Basic Idea of Mean Shift Algorithm



Region of interest

Center of mass

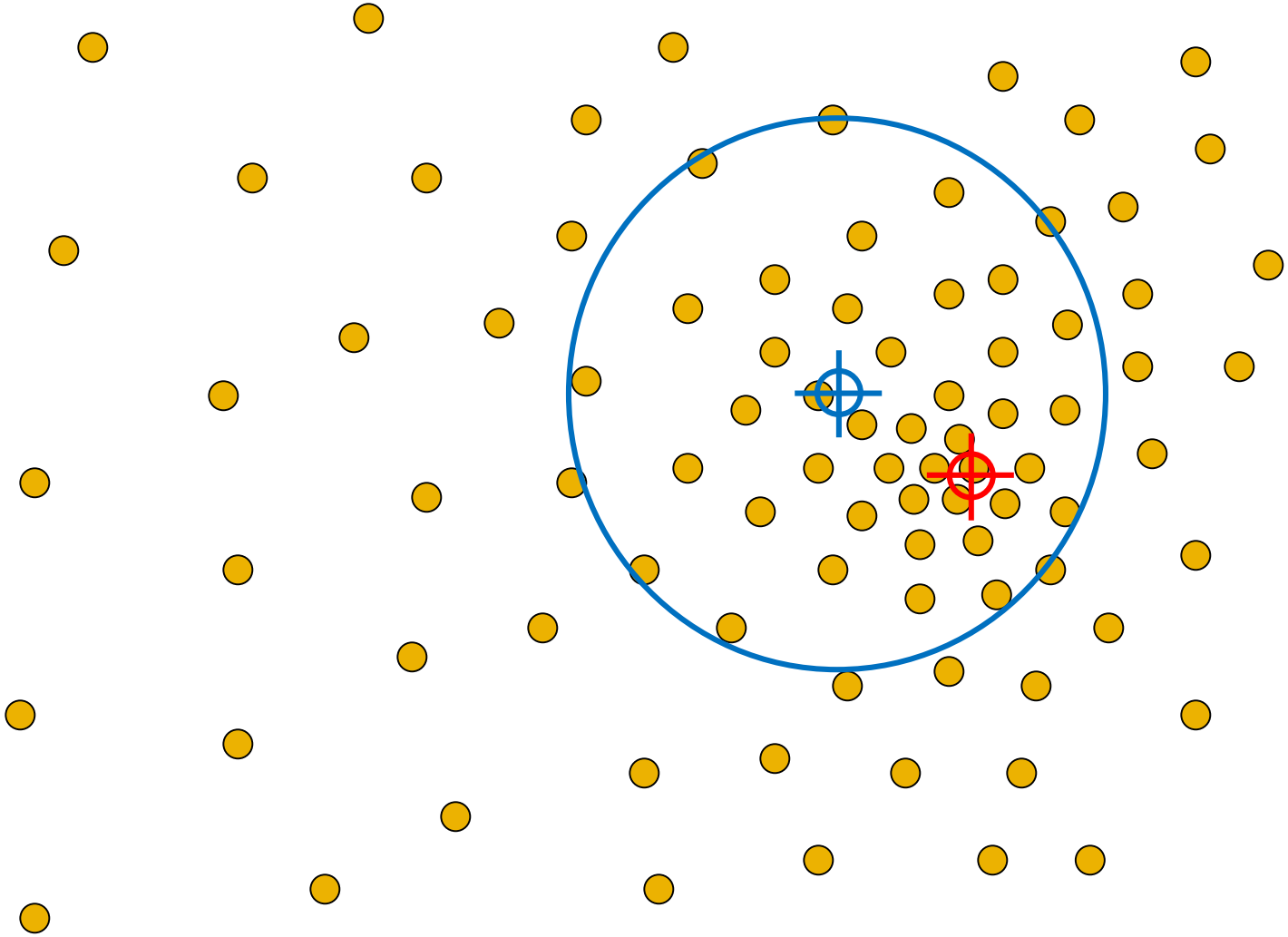
Basic Idea of Mean Shift Algorithm



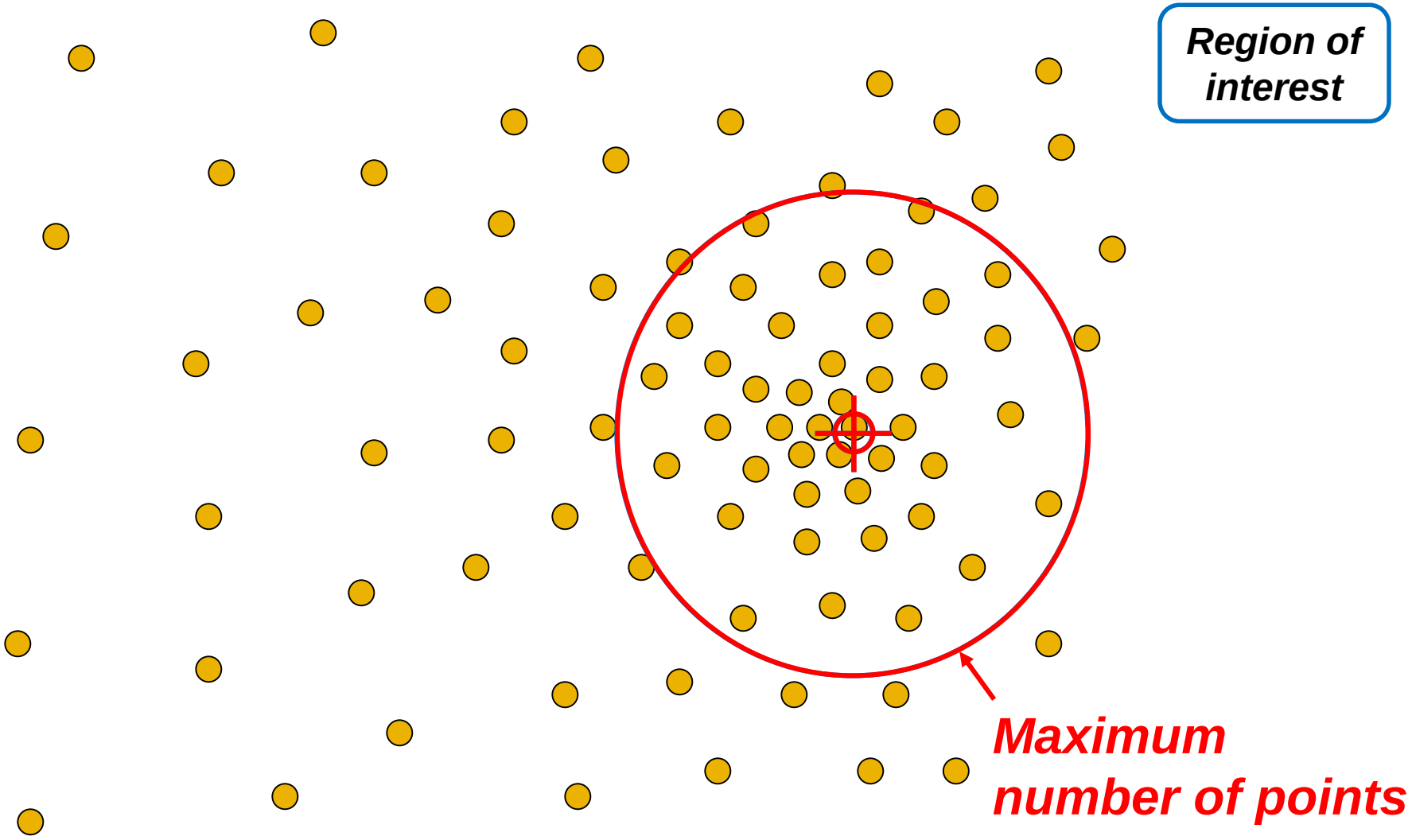
Region of interest

Center of mass

Basic Idea of Mean Shift Algorithm



Basic Idea of Mean Shift Algorithm



Formula for Mean Shift Algorithm

$$w_{center} = \frac{\sum_{i=1}^{n} x_i w(x_i)}{\sum_{i=1}^{n} w(x_i)}$$

w_{center}: center of weight of the positions

x_i: coordinate of i^{th} position

$w(x_i)$: weight of i^{th} position

Weight

↓

Deposited energy

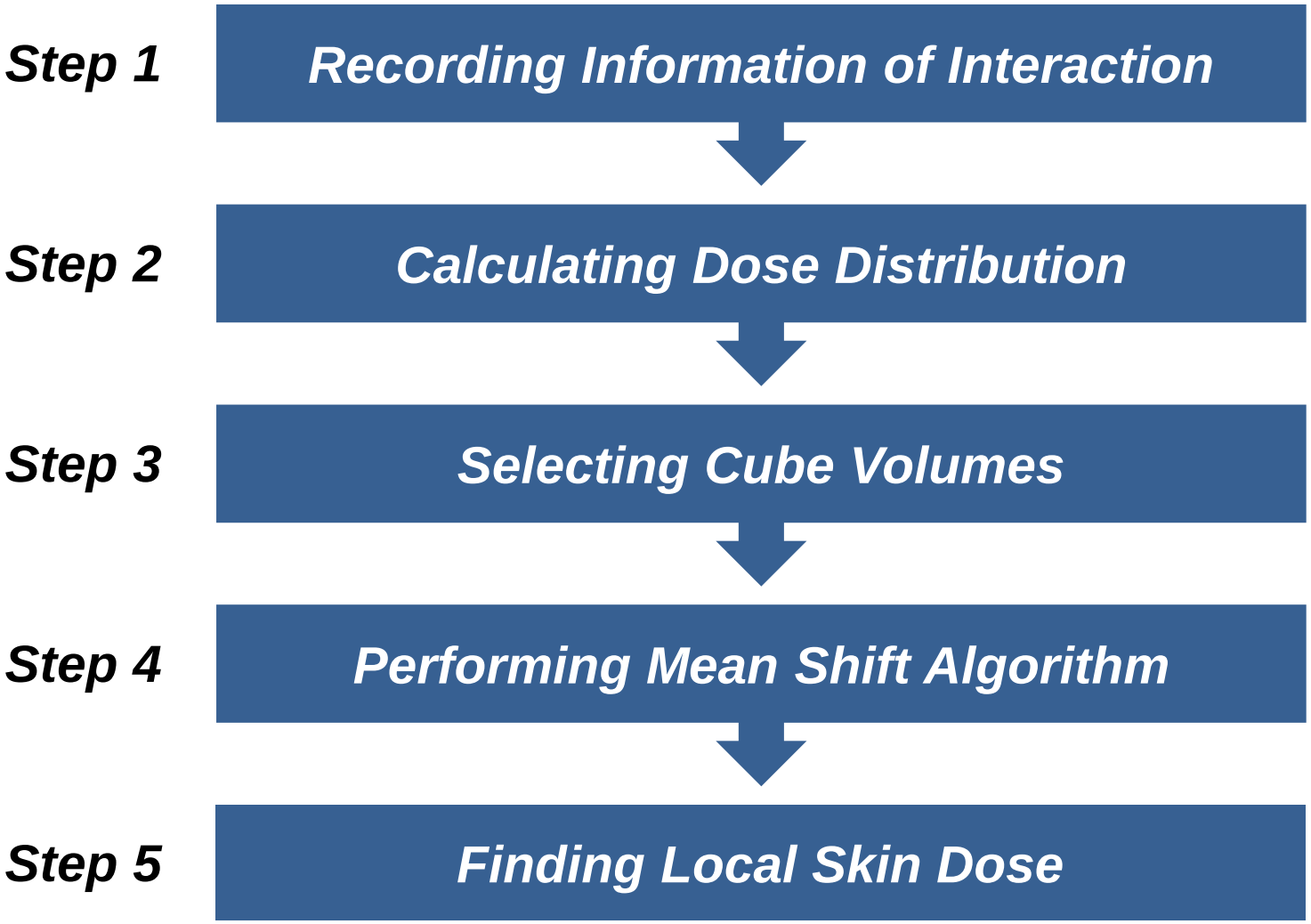
$$E_{center} = \frac{\sum_{i=1}^{n} x_i E(x_i)}{\sum_{i=1}^{n} E(x_i)}$$

E_{center}: center of energy of the interaction positions

x_i: coordinate of i^{th} interaction position

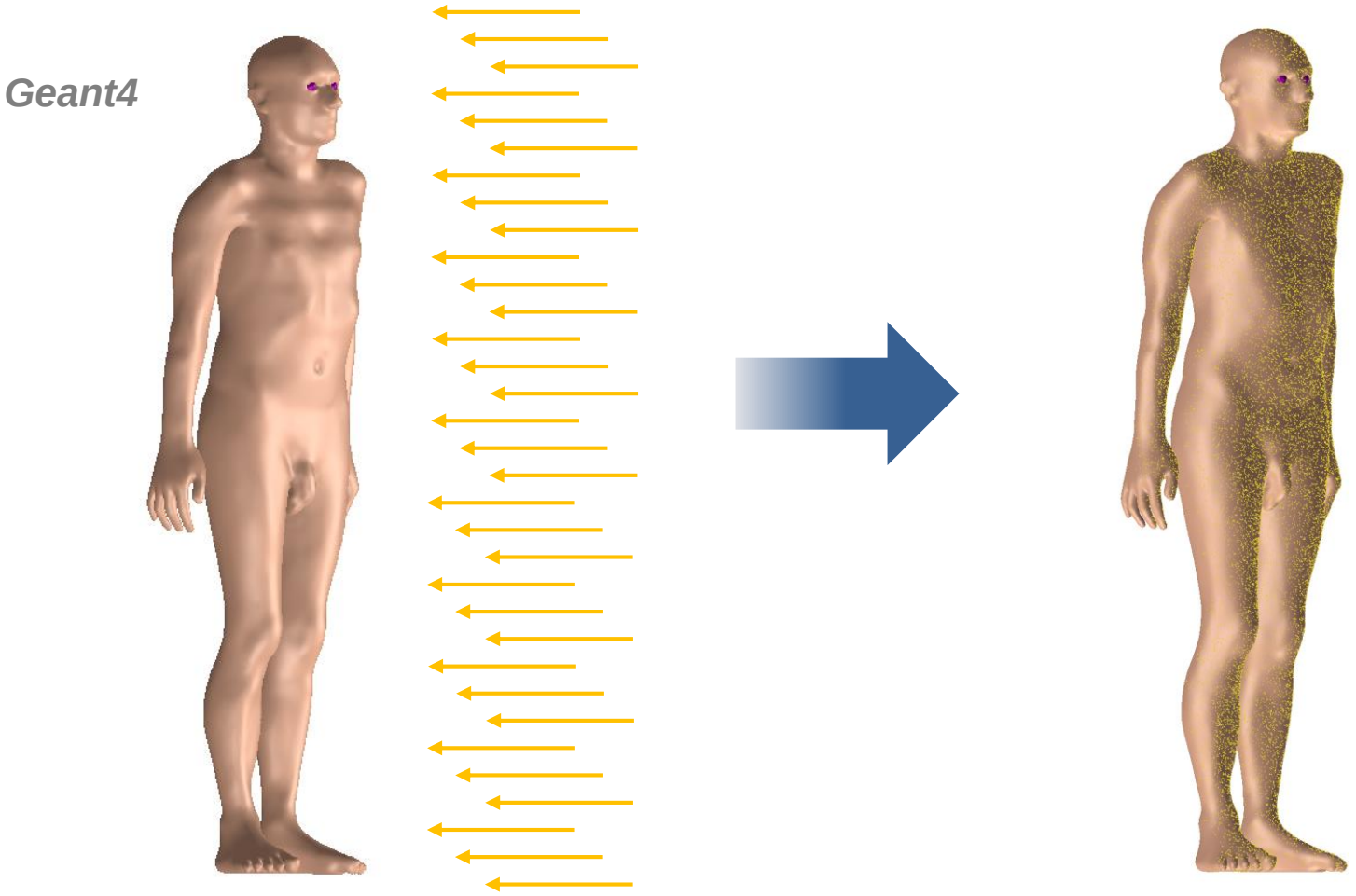
$E(x_i)$: deposited energy of i^{th} interaction position

Overall Procedure for Local Skin Dose Calculation



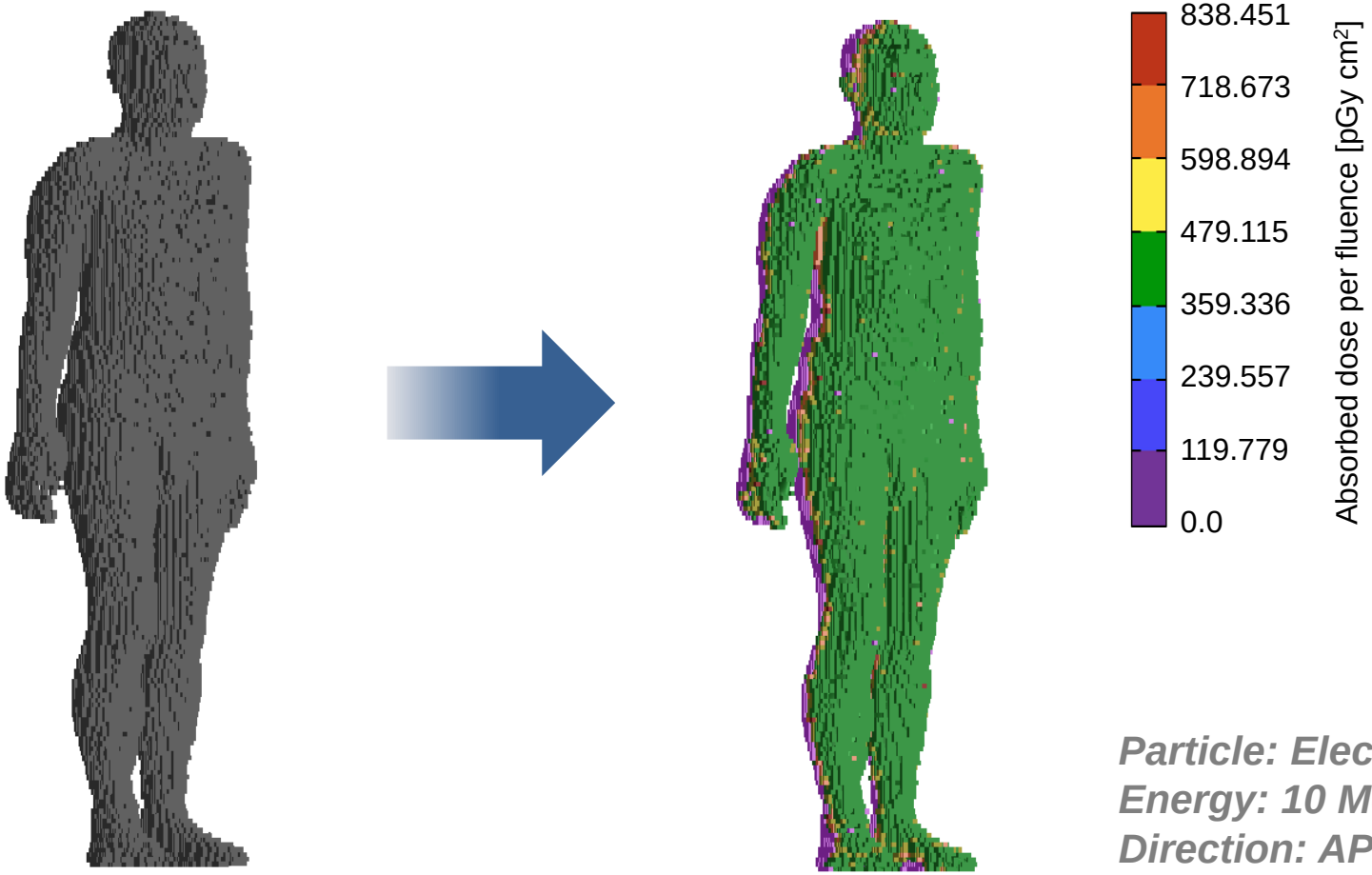
Step 1 – Recording Information of Interactions

- Record **interaction position** and **deposited energy** for each particle step within the skin basal layer.



Step 2 – Calculating Dose Distribution

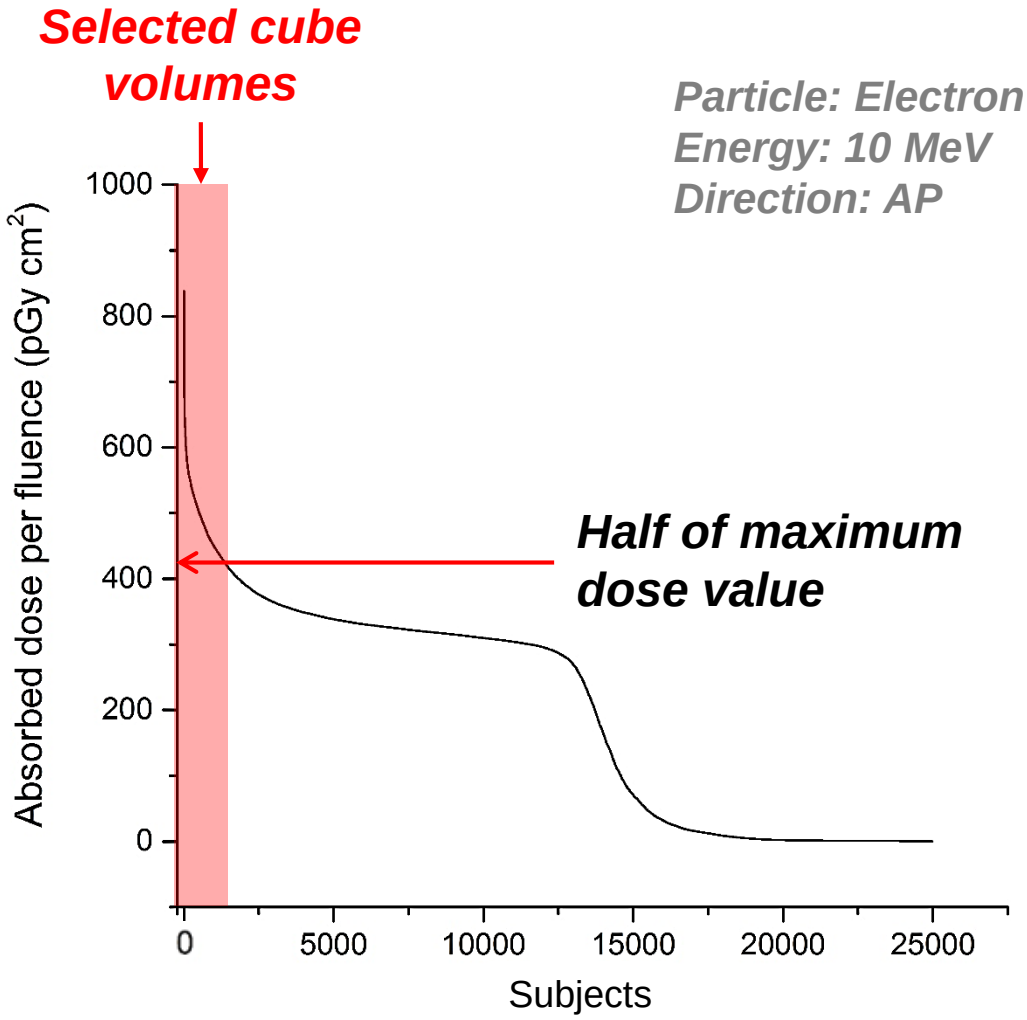
- **<u>Calculate dose distribution</u>** of the skin basal layer with the dose grid resolution of 1 x 1 x 1 cm^3.

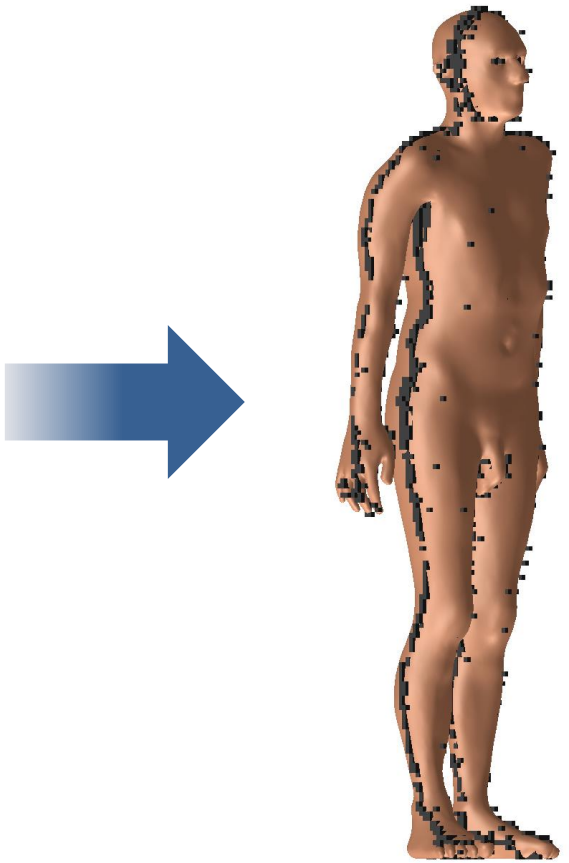


Particle: Electron
Energy: 10 MeV
Direction: AP

Step 3 – Selecting Cube Volumes

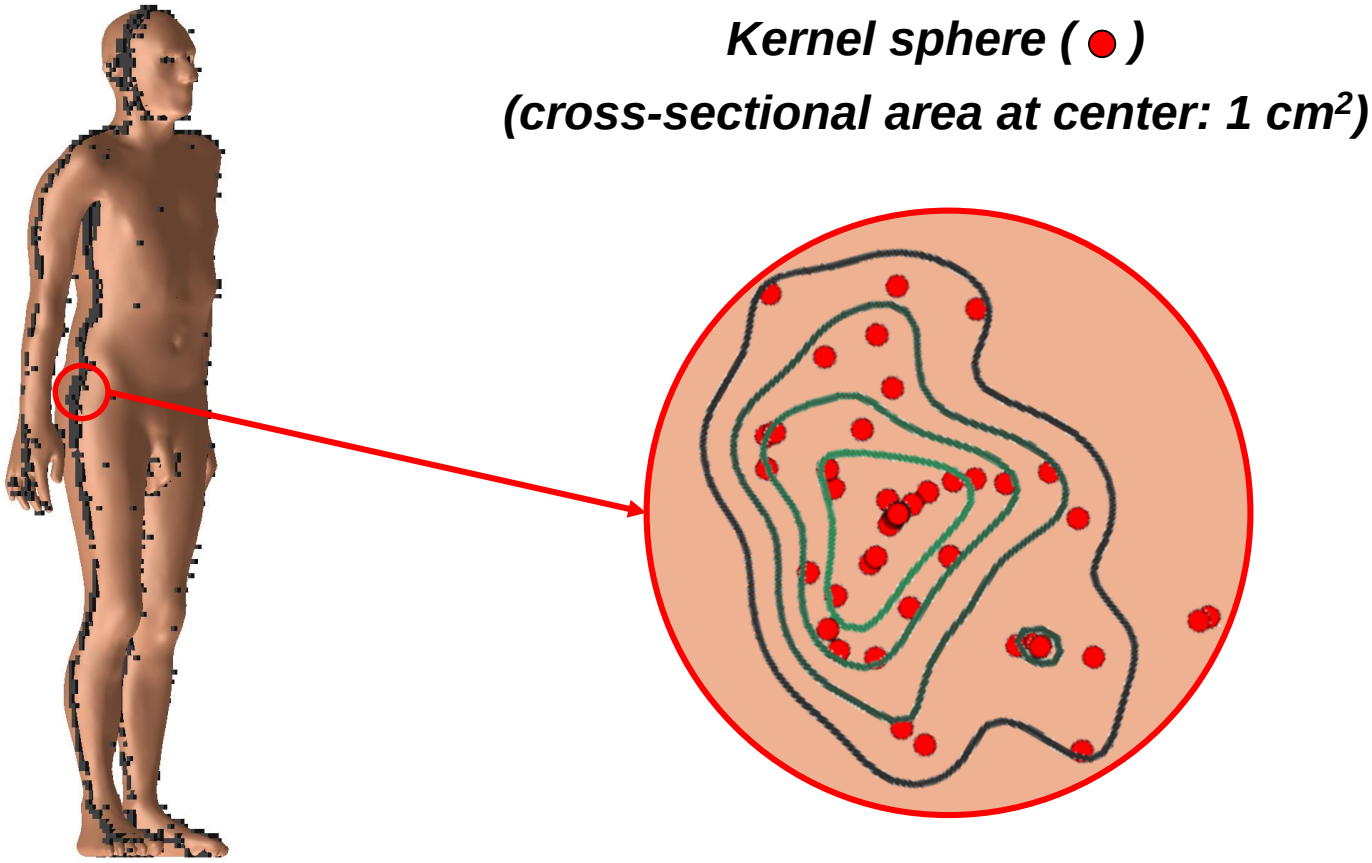
- Select the cube volumes showing dose values **greater than the half of the maximum dose value**.





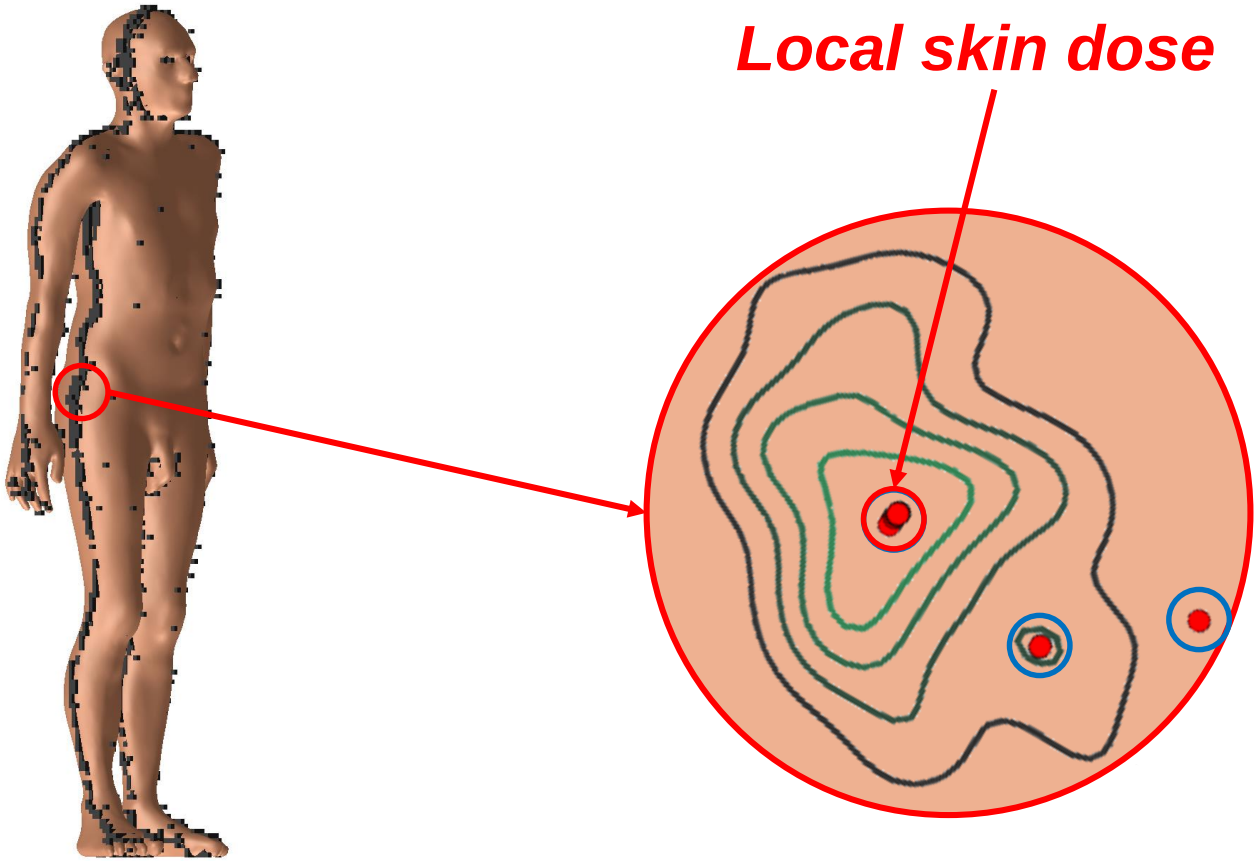
Step 4 – Performing Mean Shift Algorithm

- **The mean shift algorithm is performed** to find local maximum dose around each location.



Step 5 – Determining Local Skin Dose

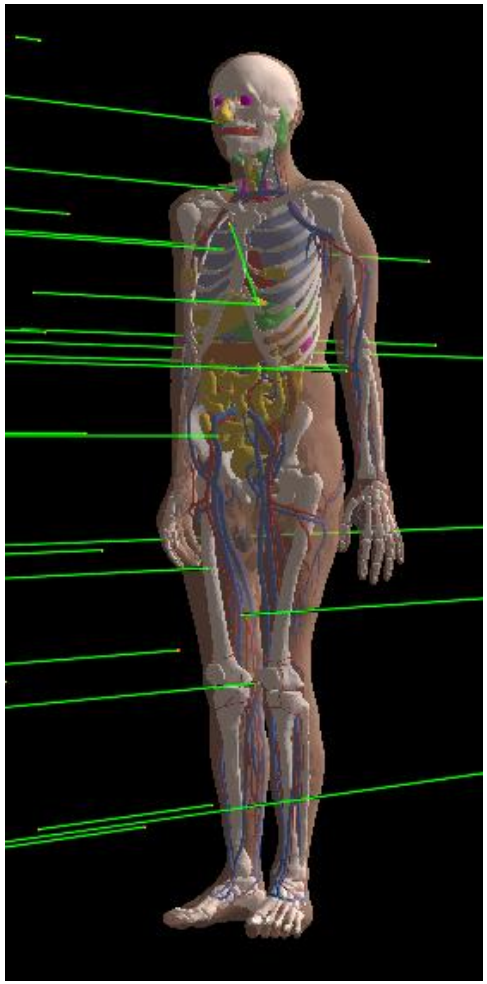
- Consider **the maximum value** of the local maximum doses as **local skin dose**.



Calculation of Local Skin Dose Coefficients

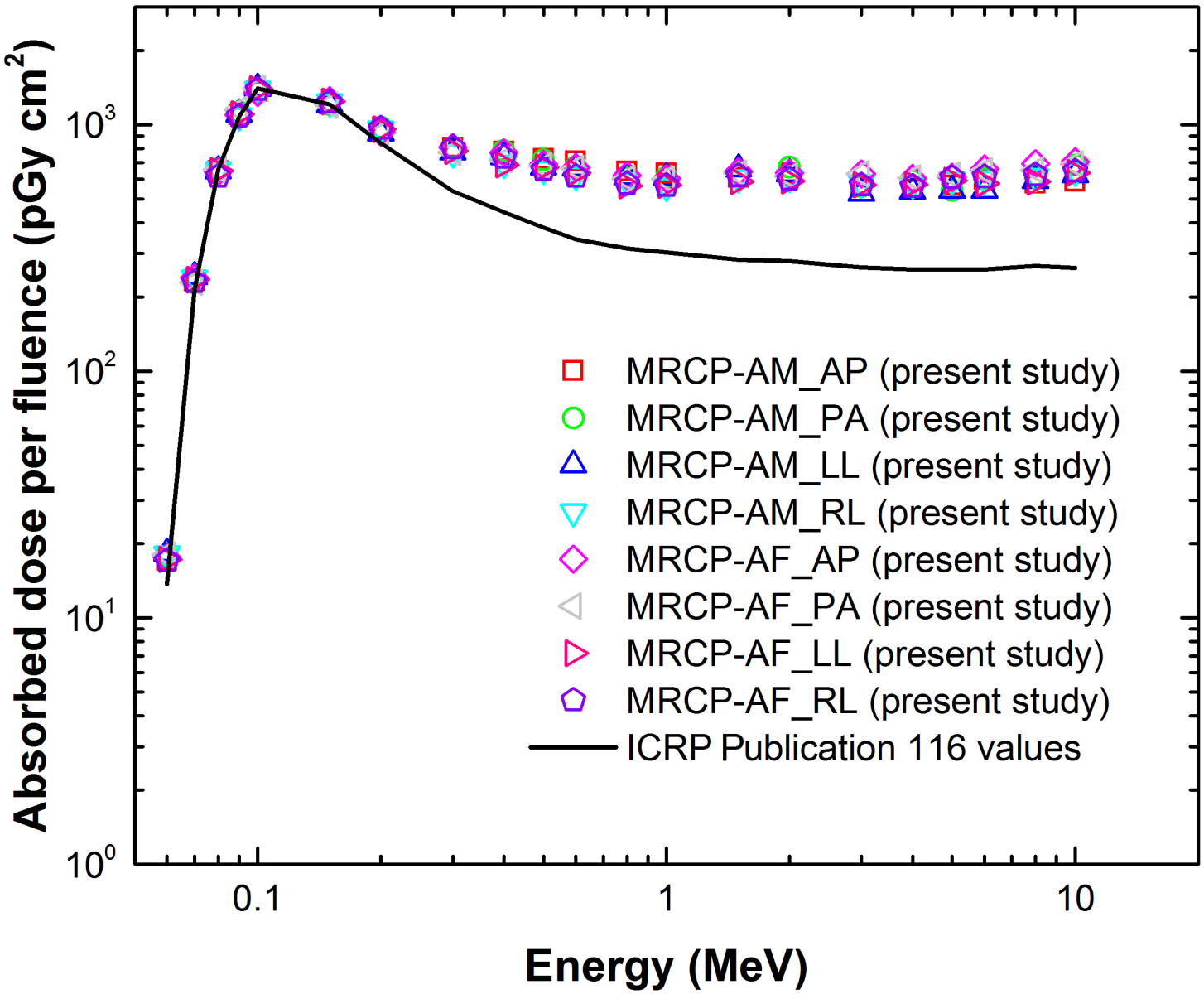
- Geant4 version: 10.02
- Physics library: *G4EmLivermorePhysics*
- Secondary production cut value: 1 μm
- User limit of the maximum step length: 1 μm
- Relative errors: less than 5%
- Sources:
  - Electron
    - Energy: 0.06-10 MeV
    - Direction: AP, PA, LLAT, RLAT
  - Alpha particle
    - Energy: 6.5-10 MeV
    - Direction: AP, PA, LLAT, RLAT

Calculated local skin dose coefficients were compared with the ICRP-116 values.



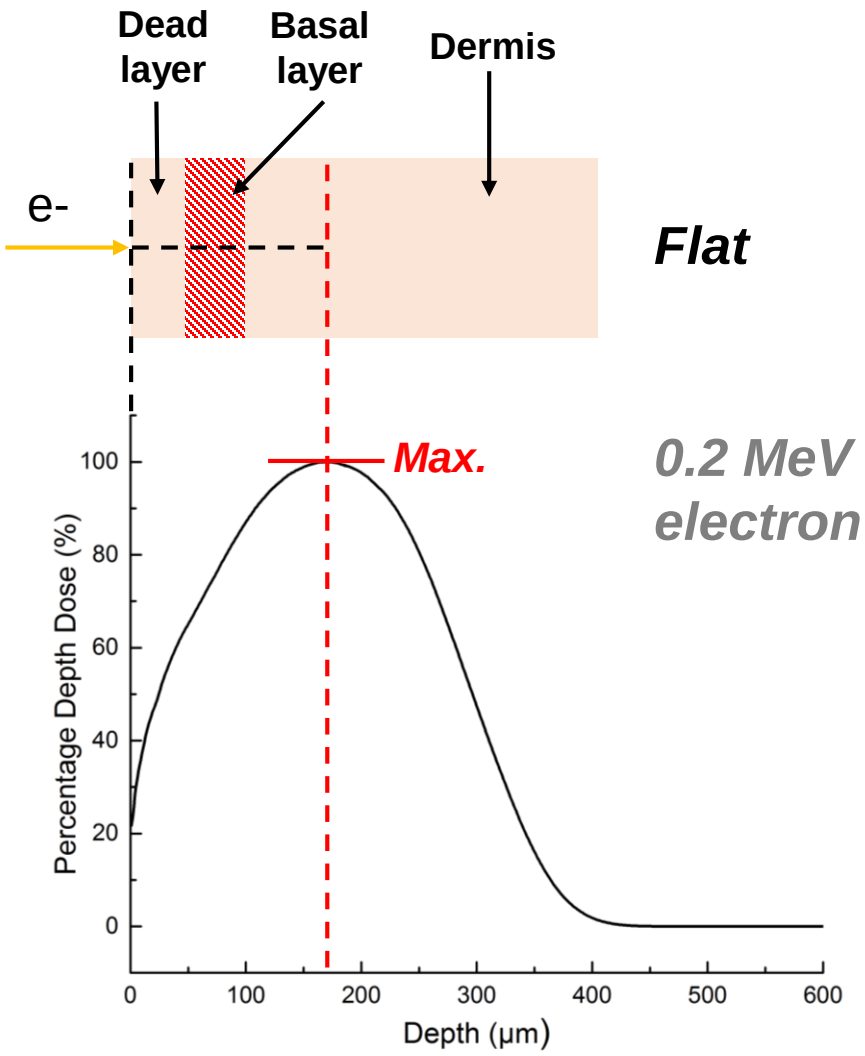
Mesh-type male phantom in Geant4 (version 10.02)

Local Skin Dose Coefficients – Electron

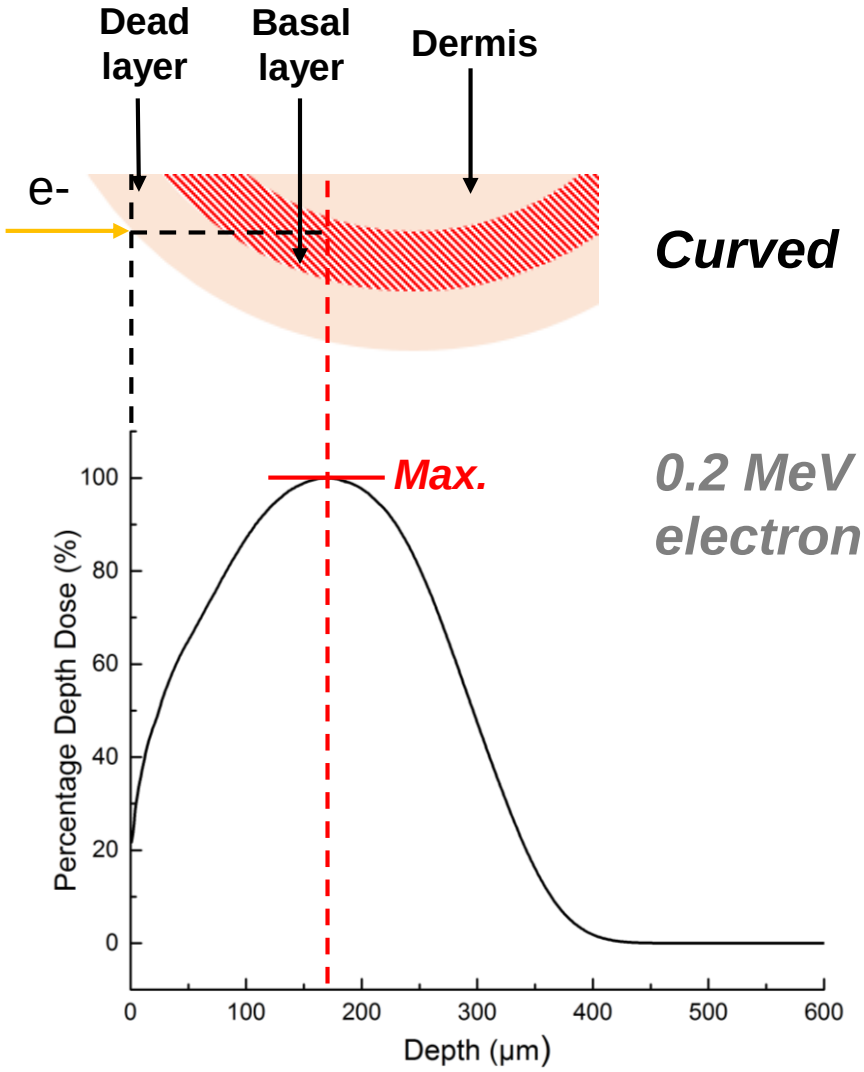


Effect of Phantom Curvature

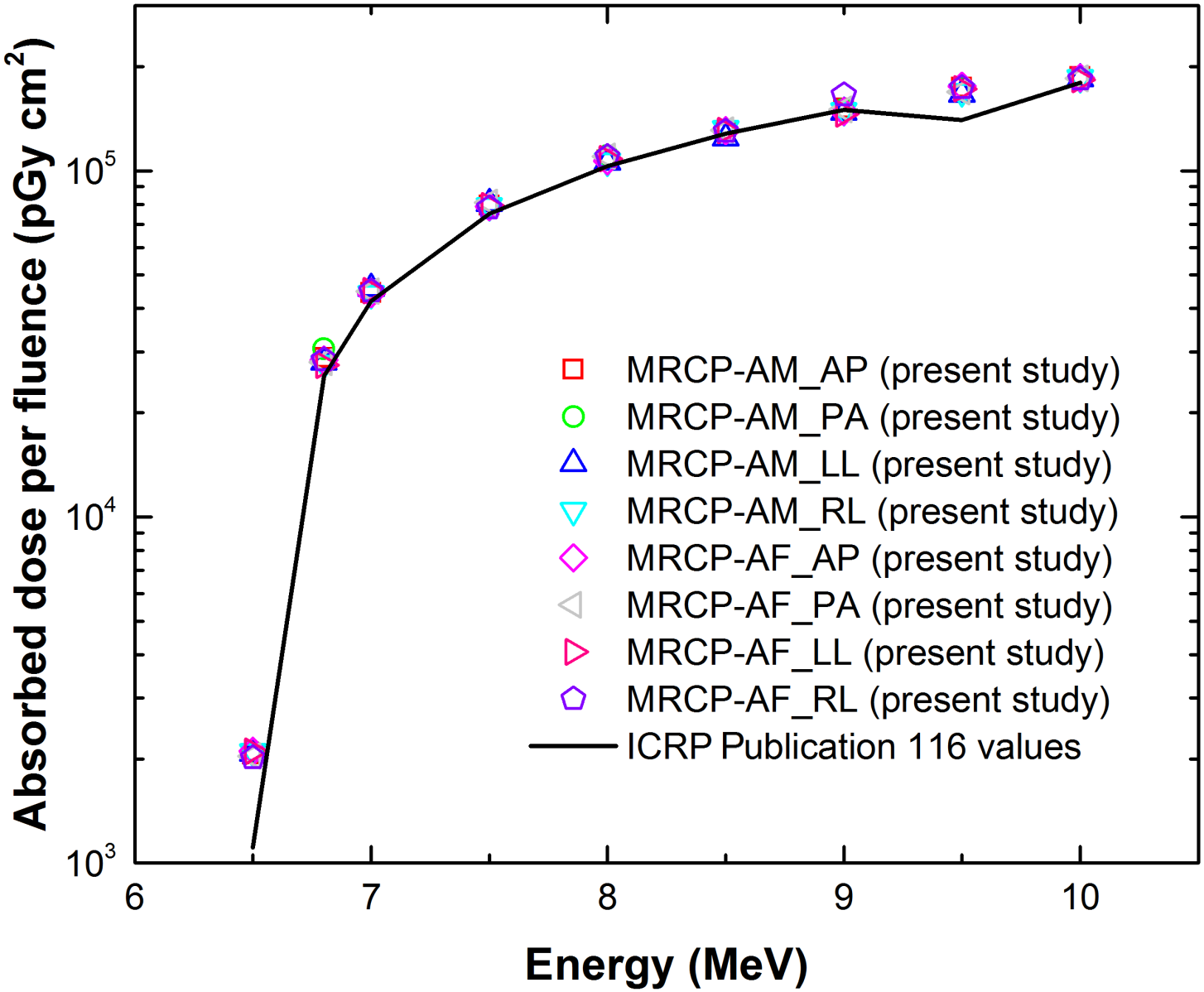
- ***Simple cube model***



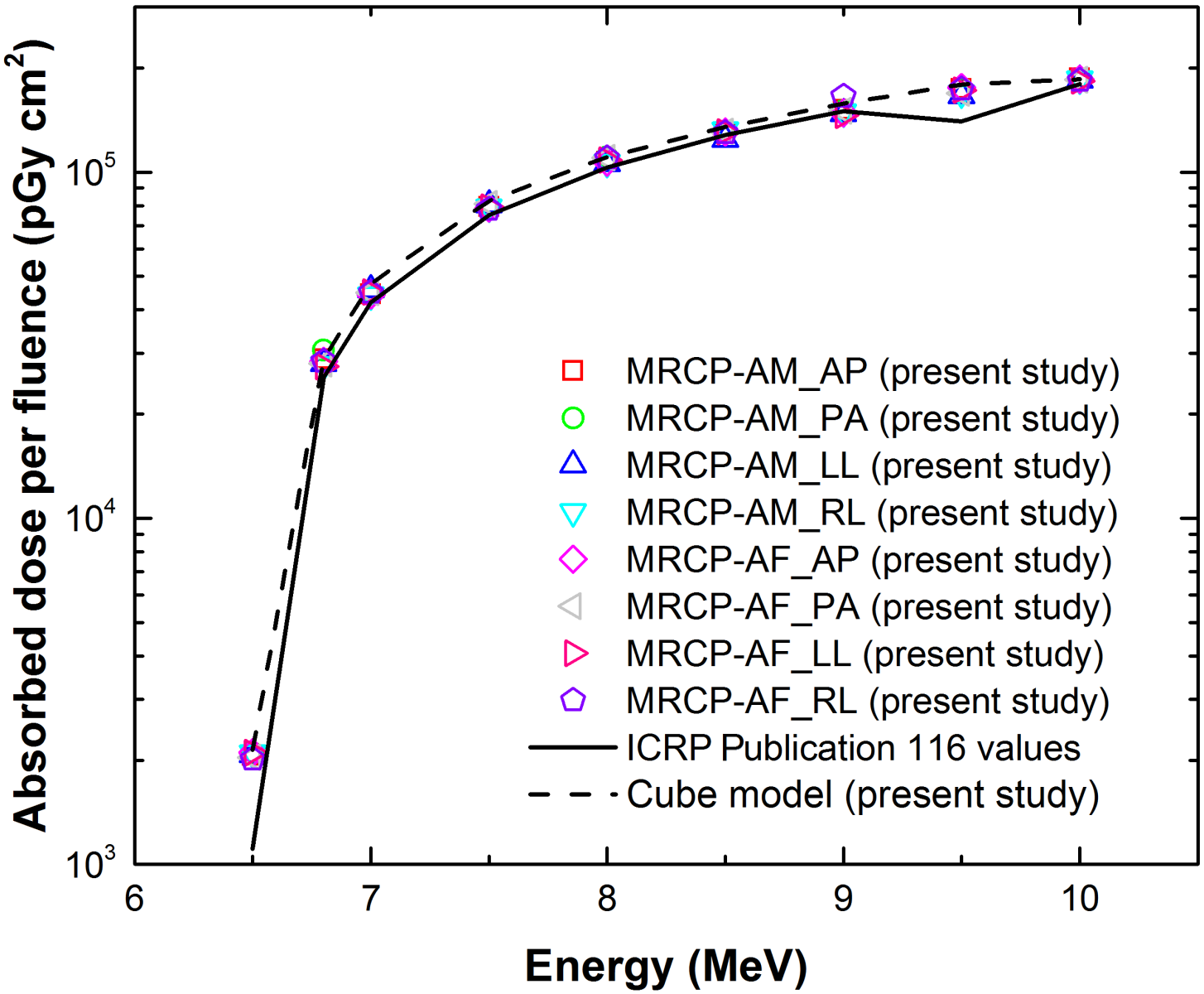
- ***Mesh-type reference phantoms***



Local Skin Dose Coefficients – Alpha Particle



Local Skin Dose Coefficients – Alpha Particle



Conclusion

- The present study developed **a dedicated program for calculation of local skin doses** based on the mean-shift algorithm and Geant4 Monte Carlo code.

- By using the developed program, **local skin dose coefficients** for electrons and alpha particles were calculated **with the adult MRCPs**, and calculated values were **compared with the ICRP-116 values**, produced **with the simple cube model**.

- **For alpha particles**, the calculated local skin dose coefficients are generally in **good agreement** with the ICRP-116 values.

Conclusion

- **For electrons**, there are **significant differences** at the energies higher than 0.15 MeV. The ICRP-116 values are **smaller by as large as ~3 times** at 10 MeV, which is due mainly to the effect of the curvature of the phantoms.

- Considering that the MRCPs are anatomically more realistic than the simple cube model, we believe that the **calculated local skin dose coefficients are more reliable** than the ICRP-116 values.

- The ICRP Task Group 103 are now having a discussion to consider if the results of the present study are included in the preparing report for the phantom distribution.

Thank you