

Monte Carlo simulations

Lesson FYSKJM4710

Eirik Malinen

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MC simulations 1

- Simulations of stochastic processes
- Interactions are stochastic: the path of a single ionizing particle may not be predicted
- Interactions are quantified by probabilities (cross sections)
- Random numbers and cross sections may be used to simulate single events
- Better than analytical methods, but requires CPU-time

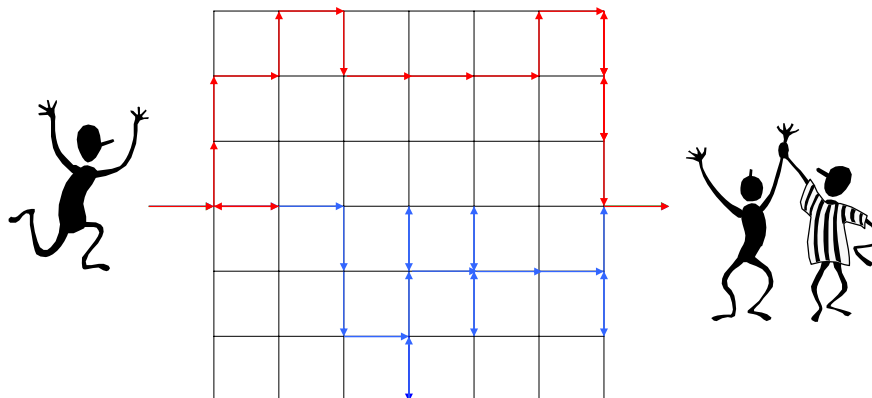
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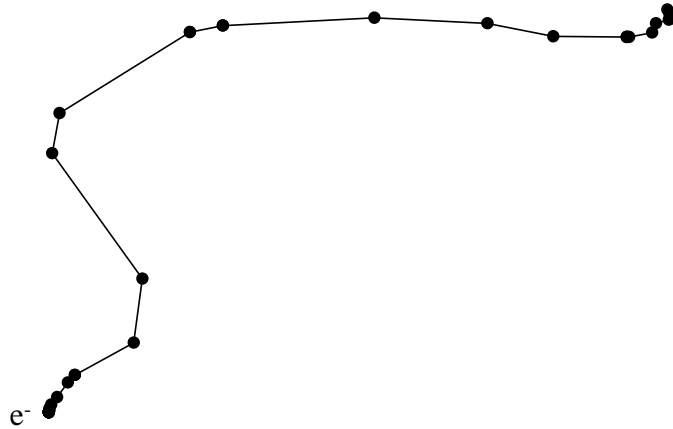
MC simulations 2

- Photons give rise to electrons and vice versa; coupled energy transport
- Analytic methods are suboptimal for:
 - Modeling of scatter
 - Generating electron- and photon spectra
 - Modeling interface effects
 - Calculating energy dependence of dosimeter response

Random walk



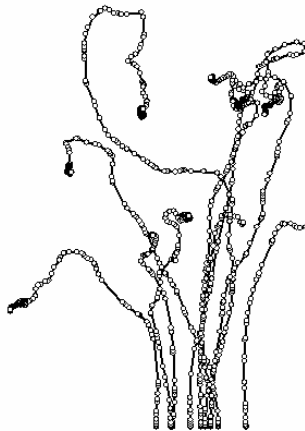
Electron 'walk'



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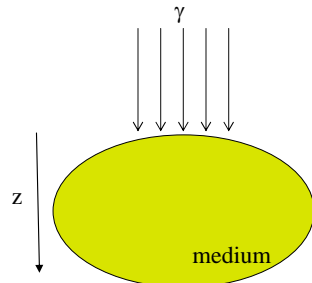
Electron 'tree'



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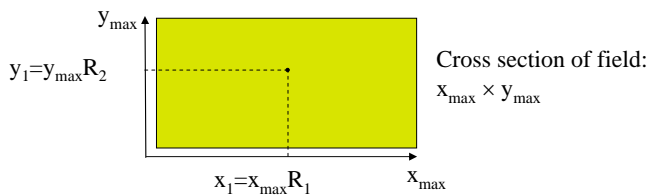
Photon MC



Description of photons and their energy depositions:

1. Position
 2. Pathlength
 3. Interaction
 4. Secondary photon?
- } Depends on photon energy

1: Draw two random numbers; $0 < R < 1$



Photon pathlength

- Photon attenuation:

$$N = N_0 e^{-\mu z}$$

- Describes the number of photons at depth z – is a type of *frequency distribution*:

$$f(z) = C e^{-\mu z} \quad , \quad \int_0^{\infty} f(z) dz = 1 \Rightarrow C = \mu$$

$$\Rightarrow \langle z \rangle = \int_0^{\infty} z f(z) dz = \frac{1}{\mu}$$

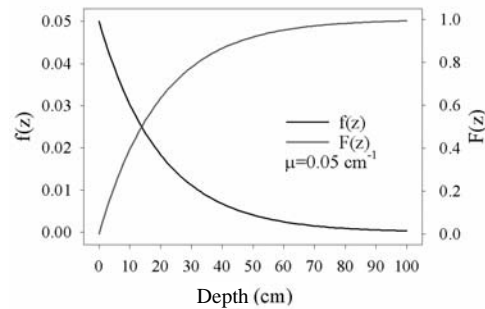
- Expected pathlength: $1/\mu$

Photon interaction point 1

- At what depth does an event (interaction) take place?
- Need a cumulative distribution with respect to depth:

$$F(z) = \int_0^z f(z') dz' = \int_0^z \mu e^{-\mu z'} dz' = 1 - e^{-\mu z}$$

$F(z)$: probability that a photon has interacted between 0 and z



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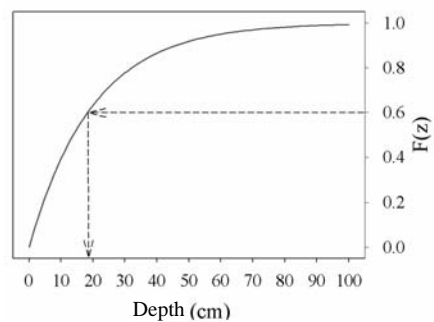
Photon interaction point 2

- Draw a random number R_1 – what is the corresponding pathlength for this photon?

$$F(z_1) = R_1 = 1 - e^{-\mu z_1} \Rightarrow e^{-\mu z_1} = 1 - R_1$$

$$z_1 = -\frac{\ln(1 - R_1)}{\mu}$$

Example: $R_1 = 0.6 \rightarrow z_1 = 18.3$ cm

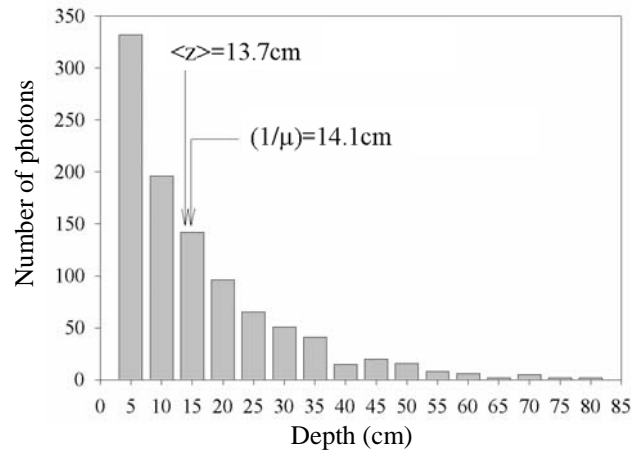


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Pathlength sampling

- Sampled pathlength of 1000 photons (1 MeV):



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Interaction sampling

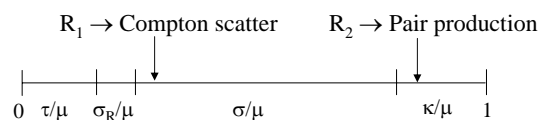
- What interaction occur at given depth?
- Total probability:

$$\mu = \tau + \sigma_R + \sigma + \kappa$$

- Probability for e.g. Compton scatter:

$$P_{\text{Compton}} = \frac{\sigma}{\mu}$$

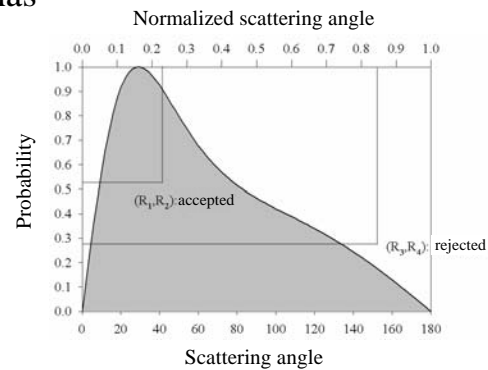
- Draw random number:



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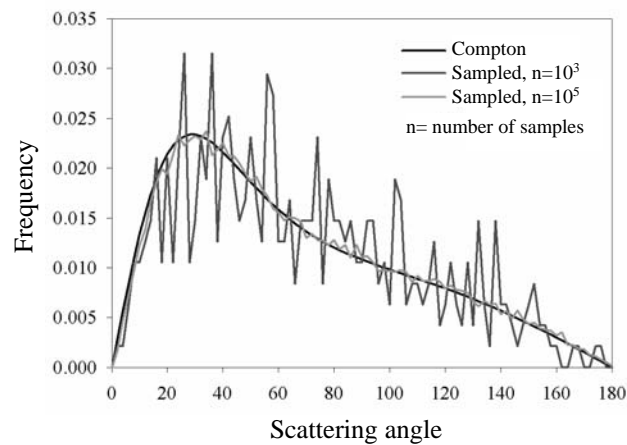
Sampling of scattered photons

- Is the photon scattered? In what direction?
- Angular distribution follows Compton cross section:
- Compton distribution has no analytic cumulative
- Must draw *two* random numbers



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Sampling Compton scatter



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Electron MC 1

- Simulations of electrons and positrons are more complicated
- A 0.5 MeV electron interacts ~10000 times when slowing down to 1 keV in aluminium!
- Number of calculations $\rightarrow \infty$
- *Macroscopic* Monte Carlo: Evaluate the electron after a given steplength – several interactions included in one step (simulations of every interaction: *microscopic* Monte Carlo)

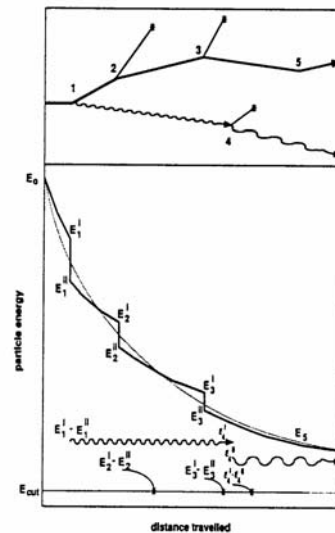
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Electron MC 2

- Relative energy loss per step, η :

$$\eta = \frac{T_{k+1} - T_k}{T_k} = \frac{\Delta T}{T_k}$$
- T_k : electron energy in interaction point k
- η is set by user
 – may be sampled: $\eta' = \eta R$
- Step length: $\Delta s = \eta \frac{T_k}{\left(\frac{dT}{dx}\right)_{k,k+1}}$

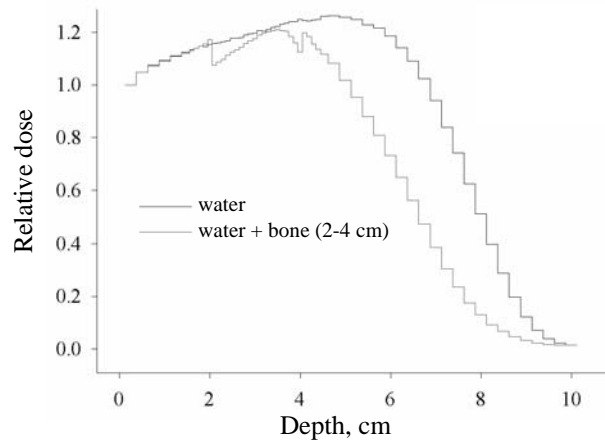


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Electron MC, example

- 18 MeV electrons in water/bone



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EGSnrc

- EGSnrc is a widely used MC code for e.g. simulations of photon- and electron beams
- Complicated programming, but simplified, user-friendly interface available: egs_inprz

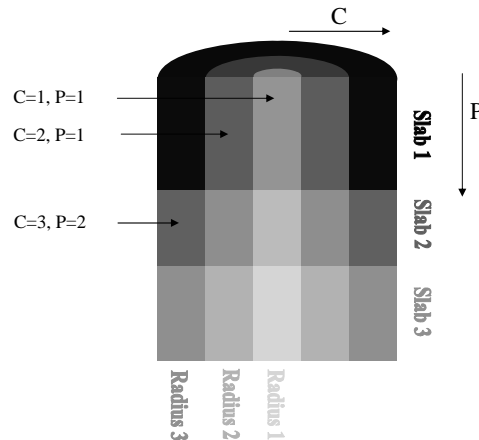
<http://www.irs.inms.nrc.ca/inms/irs/EGSnrc/EGSnrc.html>

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EGSnrc/DOSRZ

- DOSRZ: MC in cylindrical geometry



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DOSRZ

- The user sets:
 - Phantom geometry
 - Radiation type- and energy (or spectrum)
 - Source (parallel beam, point source, ...)
 - Number of "histories", i.e. number of particles
 - Some MC parameters

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DOSRZ

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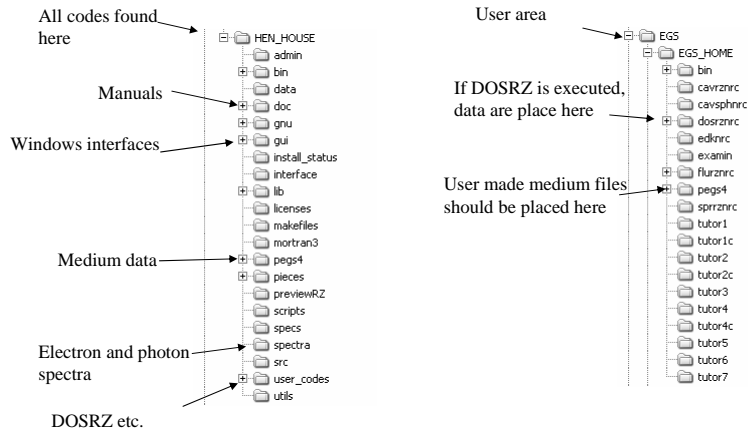


Some important parameters

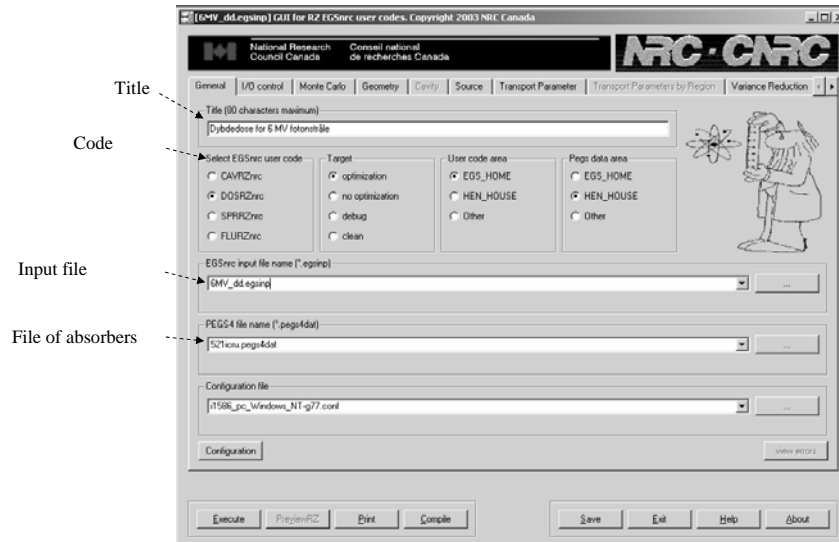
- ECUT: lower limit for electron transport (includes rest mass of 0.511 MeV)
- PCUT: lower limit for photon transport
- AE: lower limit for generation of electrons
- AP: lower limit for generation of photons
- AE and AP is medium specific and must be set in PEGS (see below)



Directories



Interface

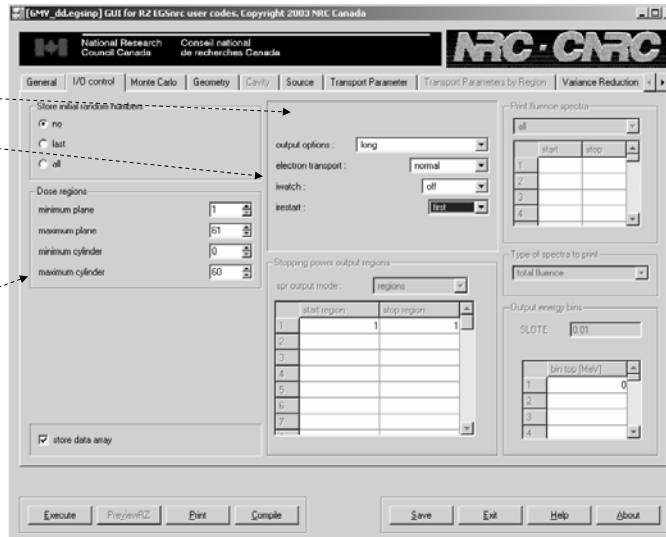


Interface

"long": most relevant

iwatch "on": all interactions are written to file (NB!)

Maximum number of regions



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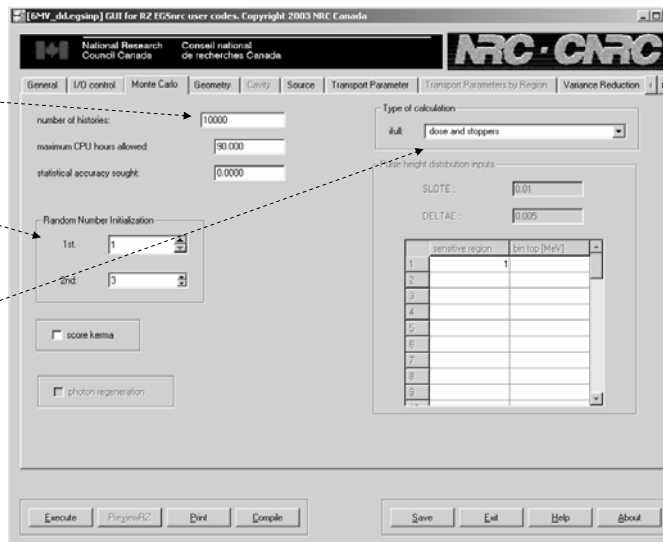


Interface

Number of histories

Initial random numbers

What should be calculated



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Interface

Arrangement of regions

Distance from source to first slab

Number of slabs and thickness

Cylinders and radius

Medium in each region

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Interface

Type of particle

Beam type

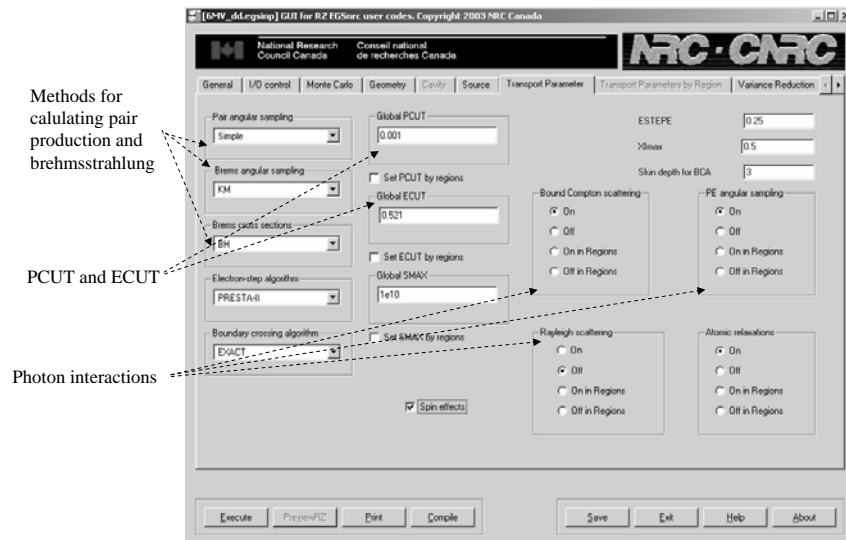
Beam radius (cm)

Particle energy

Provide spectrum (found under HENHOUSE spectra)

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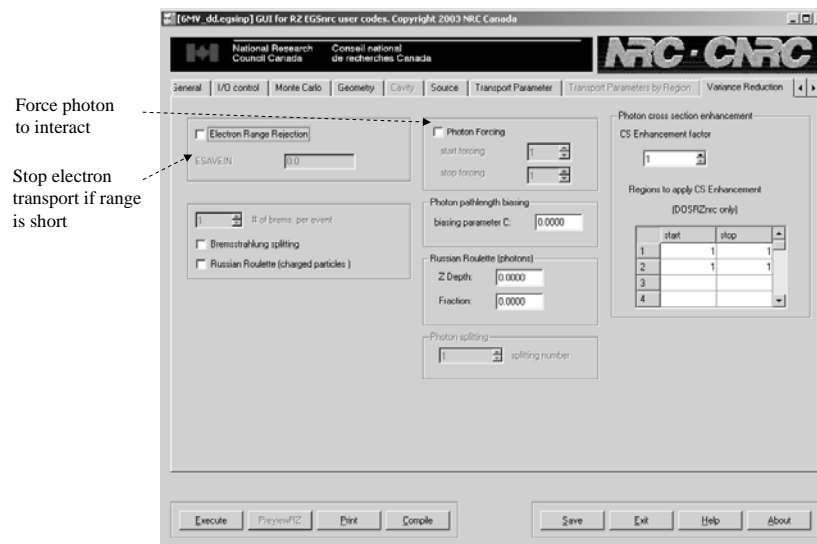
Interface



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Interface



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Output - *.egslst

```

test.egslst - WordPad
File Edit View Settings Format Help
Wed Feb 21 14:42:19 2007

test
*****
ZONAL MATERIAL GRID: NON-ROTATED
*****
/X/Y/Z/MED: X = " " IS DEFAULT; OPTION NOT USED
             - "C" IF DOSE SCORING REGION
             - "V" IF CAVITY REGION
             - "S" IF SPA SCORING REGION
             - "T" IF TRACKING REGION
             - "A" IF TOTALLY ABSORBING REGION
             M = MEDIUM NAME, 11 CHARACTER ABBREVIATION

MASS = MASS OF EACH REGION IN GRAMS
-----
0.0000      1.0000      2.0000      2.5000
-----
IIRL 2 IE 1 IX 1 IIRL 52 IE 1 IX 2 IIRL102 IE 1 IX 3 I
I /D/ /R205211CRU I /D/ /R205211CRU I /D/ /R205211CRU I
I MASS 7.854E-01 I MASS 2.356E+00 I MASS 1.767E+00 I
-----
0.2500-----
IIRL 3 IE 2 IX 1 IIRL 53 IE 2 IX 2 IIRL103 IE 2 IX 3 I
I /D/ /R205211CRU I /D/ /R205211CRU I /D/ /R205211CRU I
I MASS 7.854E-01 I MASS 2.356E+00 I MASS 1.767E+00 I
-----
0.5000-----
IIRL 4 IE 3 IX 1 IIRL 54 IE 3 IX 2 IIRL104 IE 3 IX 3 I
I /D/ /R205211CRU I /D/ /R205211CRU I /D/ /R205211CRU I
I MASS 7.854E-01 I MASS 2.356E+00 I MASS 1.767E+00 I
-----
0.7500-----
IIRL 5 IE 4 IX 1 IIRL 55 IE 4 IX 2 IIRL105 IE 4 IX 3 I
I /D/ /R205211CRU I /D/ /R205211CRU I /D/ /R205211CRU I
I MASS 7.854E-01 I MASS 2.356E+00 I MASS 1.767E+00 I
-----
1.0000-----
IIRL 6 IE 5 IX 1 IIRL 56 IE 5 IX 2 IIRL106 IE 5 IX 3 I
I /D/ /R205211CRU I /D/ /R205211CRU I /D/ /R205211CRU I
I MASS 7.854E-01 I MASS 2.356E+00 I MASS 1.767E+00 I
-----
1.2500-----
IIRL 7 IE 6 IX 1 IIRL 57 IE 6 IX 2 IIRL107 IE 6 IX 3 I
I /D/ /R205211CRU I /D/ /R205211CRU I /D/ /R205211CRU I
I MASS 7.854E-01 I MASS 2.356E+00 I MASS 1.767E+00 I
-----
1.5000-----
IIRL 8 IE 7 IX 1 IIRL 58 IE 7 IX 2 IIRL108 IE 7 IX 3 I
I /D/ /R205211CRU I /D/ /R205211CRU I /D/ /R205211CRU I
I MASS 7.854E-01 I MASS 2.356E+00 I MASS 1.767E+00 I
-----

```

Cylinders

Planes

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Output - *.egslst

```

test.egslst - WordPad
File Edit View Settings Format Help
Wed Feb 21 14:47:22 2007

test
*****
SUMMARY OF DOSE REGION RESULTS
*****
Total # charged particle steps 1.302E+08 +/- 0.043%
# of charged particle steps/initial history 4.340E+01 +/- 0.043%
# of preta-II steps/total # of charged particle steps 0.895 +/- 0.043%

# charged particle steps in done reg. 1.302E+08 +/- 0.043%
# of steps in done reg./initial history 4.340E+01 +/- 0.043%
# of preta-II steps/# of steps in done reg. 0.895 +/- 0.043%

Z# : Geometrical zone number
P# : Planar zone number
C# : Cylindrical zone number
T# : Total dose (Gray/Incident Fluence)
-----
Total dose minus stoppers
-----

```

Z#	P#	C#	T	T-S
1	1	1	3.4567E-12 +/- 1.5688	3.2033E-12 +/- 1.5808
2	1	1	5.1478E-12 +/- 1.3138	4.7737E-12 +/- 1.3228
4	3	1	5.0638E-12 +/- 1.3128	4.6957E-12 +/- 1.3218
5	4	1	4.9970E-12 +/- 1.3148	4.6258E-12 +/- 1.3238
6	5	1	5.1038E-12 +/- 1.3108	4.7298E-12 +/- 1.3198
7	6	1	4.9057E-12 +/- 1.3288	4.5427E-12 +/- 1.3378
8	7	1	4.9133E-12 +/- 1.3288	4.5508E-12 +/- 1.3378
9	8	1	4.8468E-12 +/- 1.3318	4.4938E-12 +/- 1.3418
10	9	1	4.8523E-12 +/- 1.3318	4.4938E-12 +/- 1.3408
11	10	1	4.7977E-12 +/- 1.3388	4.4428E-12 +/- 1.3488
12	11	1	4.7376E-12 +/- 1.3508	4.3823E-12 +/- 1.3608
13	12	1	4.5229E-12 +/- 1.3708	4.1837E-12 +/- 1.3818
14	13	1	4.6263E-12 +/- 1.3578	4.2831E-12 +/- 1.3678
15	14	1	4.5830E-12 +/- 1.3708	4.2434E-12 +/- 1.3808
16	15	1	4.5693E-12 +/- 1.3708	4.2305E-12 +/- 1.3828
17	16	1	4.4733E-12 +/- 1.3858	4.1448E-12 +/- 1.3968
18	17	1	4.3986E-12 +/- 1.3908	4.0725E-12 +/- 1.4038
19	18	1	4.2873E-12 +/- 1.4048	3.9684E-12 +/- 1.4158
20	19	1	4.3588E-12 +/- 1.4098	3.9378E-12 +/- 1.4208
21	20	1	4.2053E-12 +/- 1.4278	3.8899E-12 +/- 1.4398
22	21	1	4.0700E-12 +/- 1.4438	3.7658E-12 +/- 1.4558
23	22	1	4.0901E-12 +/- 1.4438	3.7848E-12 +/- 1.4548
24	23	1	4.0567E-12 +/- 1.4428	3.7548E-12 +/- 1.4548
25	24	1	4.0048E-12 +/- 1.4488	3.7058E-12 +/- 1.4608

Plane number

Cylinder number

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PEGS

- Preprocessor for EGS
- Medium definition is performed in PEGS
- Have to set AE og AP, in addition to UE og UP (upper limit for for electron- and photon energy)



PEGS

Give medium composition

Provide name of substance

Density correction file

Lower limit for generation of secondary photons (AP) or electrons (AE)

File name

