Retrospective dosimetry using display glass from mobile phones, simulation approach with ICRP reference man phantom.

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Retrospective dosimetry:

in case of accident from the dose in glass in mobile phone you can estimate the wholebody dose

Simulations: dose per fluence and dose per kerma for ROT geometry

Data from literature, calibration using 137 Cs and 60 Co

Glass from mobile phone (TL material)

ICRP reference man according to ICRP publication 110 (2008)

- From there: matrix , data about voxel dimensions and number of columns (x co-ordinate), rows (y co-ordinate) and slices (z co-ordinate), tissue (53) composition (H, C, N, O, Na, Mg, P, S, Cl, K, Ca, Fe, I), density and tissue assingment (from 1 to 53) to organ ID (from 1 to 140)

Data for write.f file: DX=DY=2.137 mm, DZ=8 mm

NX=254, NY=127, NZ= 222

Voxel anthropomorphic phantom (stand along the Z axis):

X : -27 .. 27 cm, Y : -3 .. 24 cm, Z: 1.5 .. 180 cm

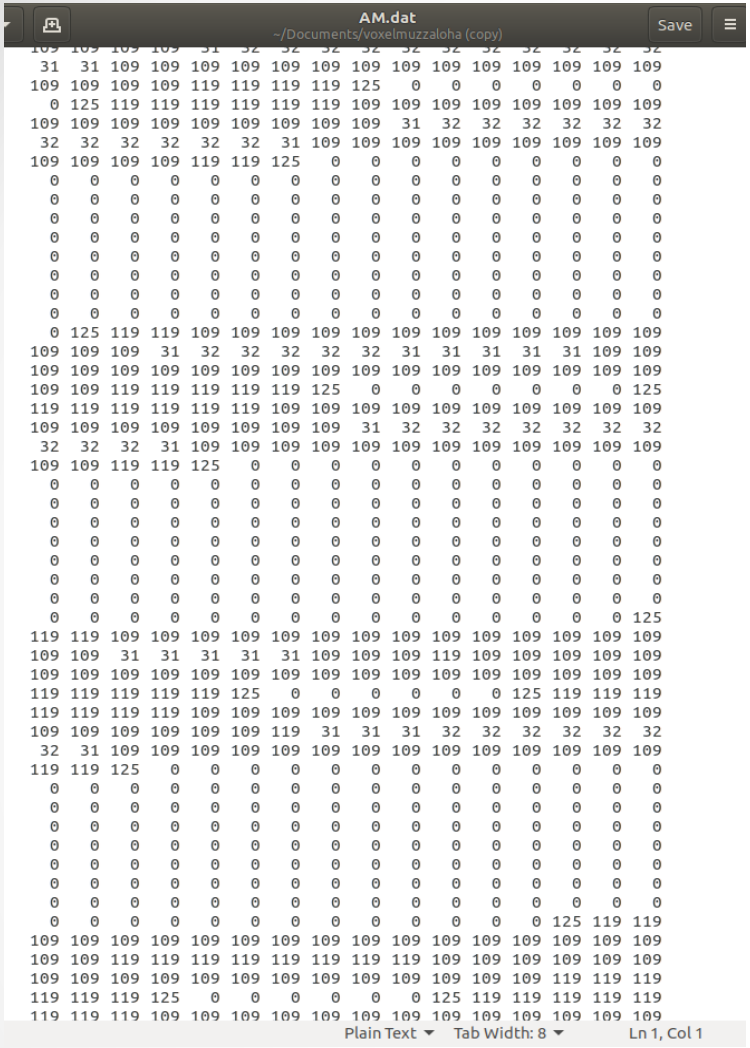


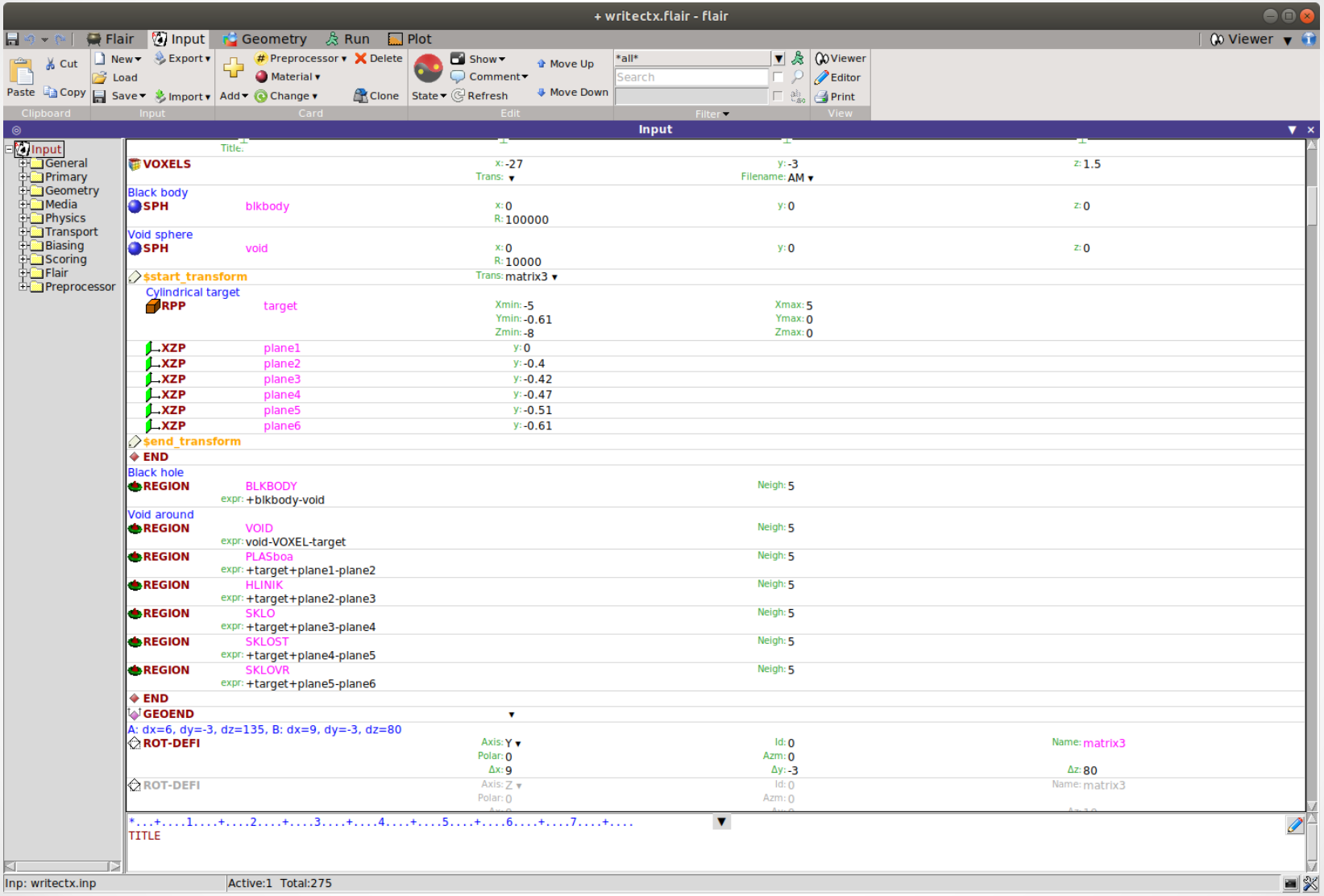
Table 5.1 Main characteristics of the adult male and female reference computational phantoms.

Property	Male	Female
Height (m)	1.76	1.63
Mass (kg)	73.0	60.0
Number of tissue voxels	1,946,375	3,886,020
Slice thickness (voxel height, mm)	8.0	4.84
Voxel in-plane resolution (mm)	2.137	1.775
Voxel volume (mm^3)	36.54	15.25
Number of columns	254	299
Number of rows	127	137
Number of slices	220 (+2)*	346 (+2)*

* Additional slices of skin at the top and bottom as discussed in the text (Para. 33).

additional object: slices of glass, aluminum and plastics
Table 1. Model of mobile phone (-5..5, -0.61 .. 0, -8 .. 0). RPP Rectangular Parallel Piped(one) and XZP Infinite half space delimited by coordinate plane (5 ..)

	Thickness (cm)	Width (cm)	Length (cm)
upper glass	0.1	8	10
middle glass	0.04	8	10
back glass	0.05	8	10
aluminium	0.02	8	10
plastics	0.4	8	10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Flair
Input
Geometry
Run
Plot
Viewer
Paste
Cut
Copy
New
Load
Save
Export
Import
Preprocessor
Material
Add
Change
Delete
Clone
Show
Comment
Refresh
State
Move Up
Move Down
all
Search
Filter
Viewer
Editor
Print
Clipboard
Input
Card
Edit
View
Input
Input
General
Primary
Geometry
Media
Physics
Transport
Biasing
Scoring
Flair
Preprocessor
Title:
VOXELS
x: -27
y: -3
z: 1.5
Trans:
Filename: AM
Black body
SPH blkbody
x: 0
y: 0
z: 0
R: 100000
Void sphere
SPH void
x: 0
y: 0
z: 0
R: 10000
$start_transform
Trans: matrix3
Cylindrical target
RPP target
Xmin: -5
Xmax: 5
Ymin: -0.61
Ymax: 0
Zmin: -8
Zmax: 0
XZP plane1
y: 0
XZP plane2
y: -0.4
XZP plane3
y: -0.42
XZP plane4
y: -0.47
XZP plane5
y: -0.51
XZP plane6
y: -0.61
$end_transform
END
Black hole
REGION BLKBODY
Neigh: 5
expr: +blkbody-void
Void around
REGION VOID
Neigh: 5
expr: void-VOXEL-target
REGION PLASboa
Neigh: 5
expr: +target+plane1-plane2
REGION HLINIK
Neigh: 5
expr: +target+plane2-plane3
REGION SKLO
Neigh: 5
expr: +target+plane3-plane4
REGION SKLOST
Neigh: 5
expr: +target+plane4-plane5
REGION SKLOVR
Neigh: 5
expr: +target+plane5-plane6
END
GEOEND
A: dx=6, dy=-3, dz=135, B: dx=9, dy=-3, dz=80
ROT-DEFI
Axis: Y
Id: 0
Name: matrix3
Polar: 0
Azm: 0
Δx: 9
Δy: -3
Δz: 80
ROT-DEFI
Axis: Z
Id: 0
Name: matrix3
Polar: 0
Azm: 0
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....
TITLE
Inp: writectx.inp
Active:1 Total:275

Middle was shifted for X=6 cm, Y=-3 cm, Z=135 cm to the left chest of the anthropomorphic phantom.

ROT-DEFIni card was used

Beam – rotate in XY plane around the anthropomorphic phantom from 0 to 360 degrees with a step of 15 degrees.

Rotation with command

BEAM and BEAMPOSit

BEAMAXIS

SOURCE

starting point of the beam: x and y coordinate

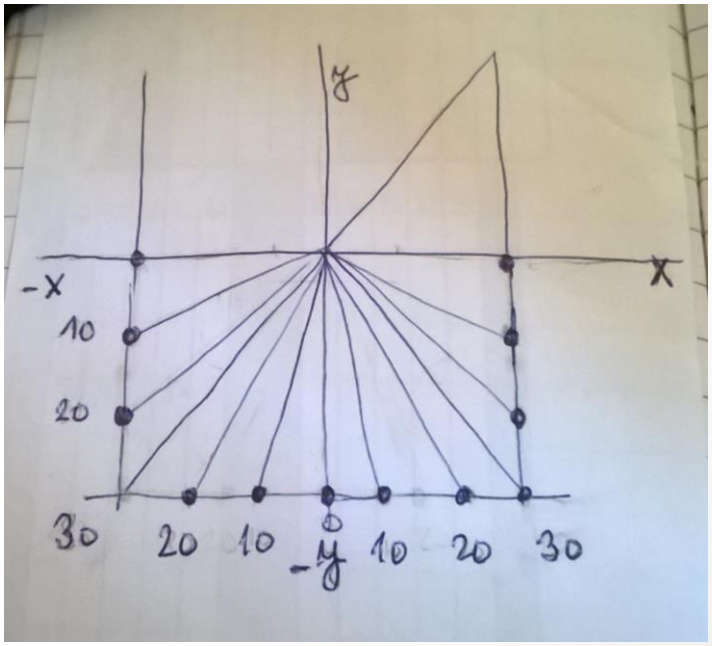
and beam direction:

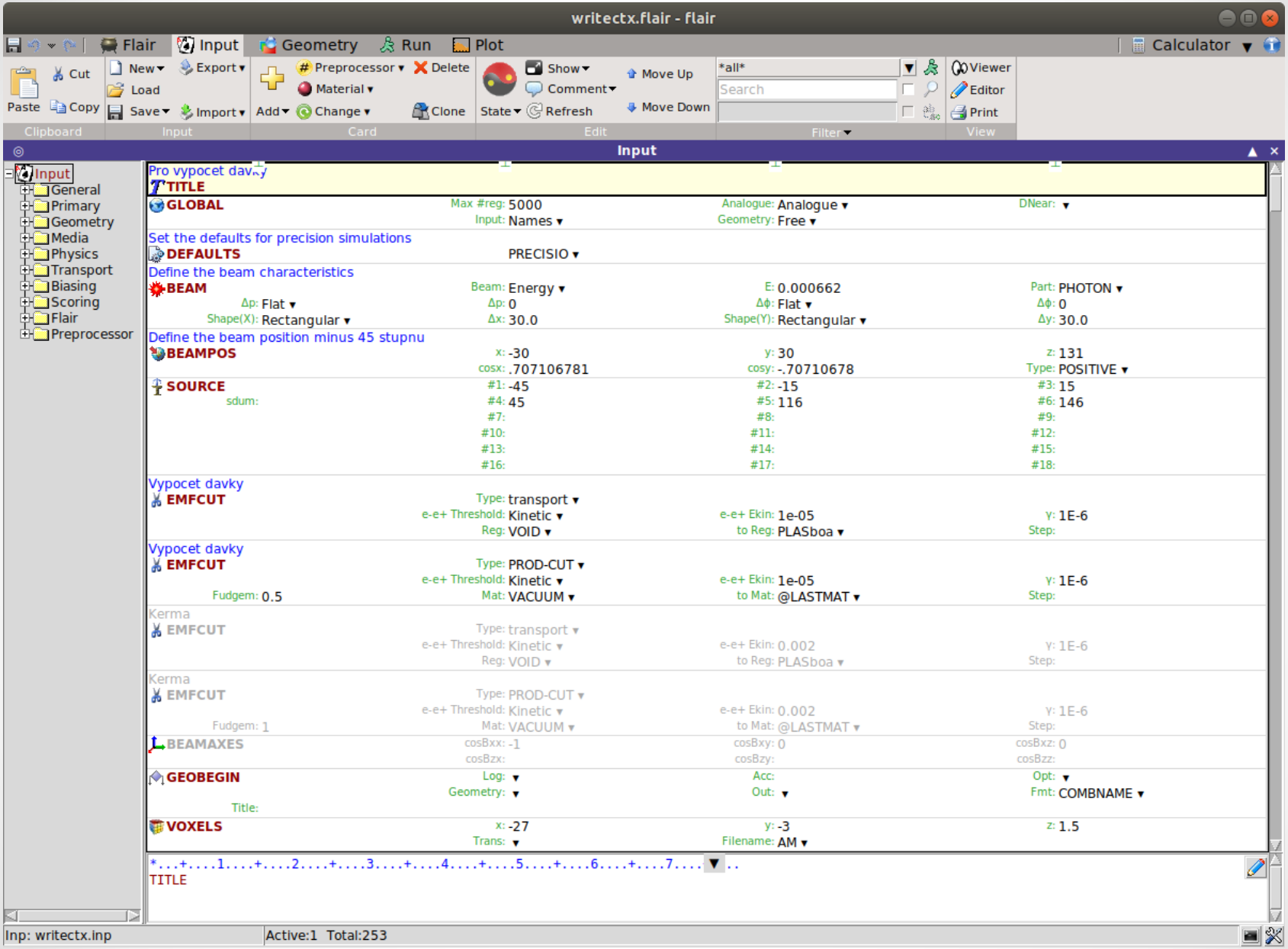
was set with the help of the rectangle where for 15 degrees

(lower part of the figure correspond with positive angle)

coordinates for 15 degrees were X=-30 and Y=-10 and

cos(x)= 0.9659… and cos (90-x)=0.258819… etc.




writectx.flair - flair
Flair
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Geometry
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Plot
Calculator
Cut
Paste
Copy
New
Load
Save
Export
Import
Preprocessor
Material
Add
Change
Delete
Clone
Show
Comment
State
Refresh
Move Up
Move Down
all
Search
Viewer
Editor
Print
Clipboard
Input
Card
Edit
Filter
View
Input
Input
General
Primary
Geometry
Media
Physics
Transport
Biasing
Scoring
Flair
Preprocessor
Pro vypocet davky
TITLE
GLOBAL
Max #reg: 5000
Input: Names
Analogue: Analogue
Geometry: Free
DNear:
Set the defaults for precision simulations
DEFAULTS
PRECISIO
Define the beam characteristics
BEAM
Beam: Energy
E: 0.000662
Part: PHOTON
Δp: Flat
Δp: 0
Δϕ: Flat
Δϕ: 0
Shape(X): Rectangular
Δx: 30.0
Shape(Y): Rectangular
Δy: 30.0
Define the beam position minus 45 stupnu
BEAMPOS
x: -30
y: 30
z: 131
cosx: .707106781
cosy: -.70710678
Type: POSITIVE
SOURCE
sdum:
#1: -45
#2: -15
#3: 15
#4: 45
#5: 116
#6: 146
#7:
#8:
#9:
#10:
#11:
#12:
#13:
#14:
#15:
#16:
#17:
#18:
Vypocet davky
EMFCUT
Type: transport
e-e+ Threshold: Kinetic
e-e+ Ekin: 1e-05
γ: 1E-6
Reg: VOID
to Reg: PLASboa
Step:
Vypocet davky
EMFCUT
Type: PROD-CUT
e-e+ Threshold: Kinetic
e-e+ Ekin: 1e-05
γ: 1E-6
Fudgem: 0.5
Mat: VACUUM
to Mat: @LASTMAT
Step:
Kerma
EMFCUT
Type: transport
e-e+ Threshold: Kinetic
e-e+ Ekin: 0.002
γ: 1E-6
Reg: VOID
to Reg: PLASboa
Step:
Kerma
EMFCUT
Type: PROD-CUT
e-e+ Threshold: Kinetic
e-e+ Ekin: 0.002
γ: 1E-6
Fudgem: 1
Mat: VACUUM
to Mat: @LASTMAT
Step:
BEAMAXES
cosBxx: -1
cosBxy: 0
cosBxz: 0
cosBzx:
cosBzy:
cosBzz:
GEOBEGIN
Log:
Acc:
Opt:
Geometry:
Out:
Fmt: COMBNAME
Title:
VOXELS
x: -27
y: -3
z: 1.5
Trans:
Filename: AM
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....
TITLE
Inp: writectx.inp
Active:1 Total:253

Source.f file

```
*  Particle coordinates
      XFLK   (NPFLKA) = XBEAM
      YFLK   (NPFLKA) = YBEAM
      ZFLK   (NPFLKA) = ZBEAM
```

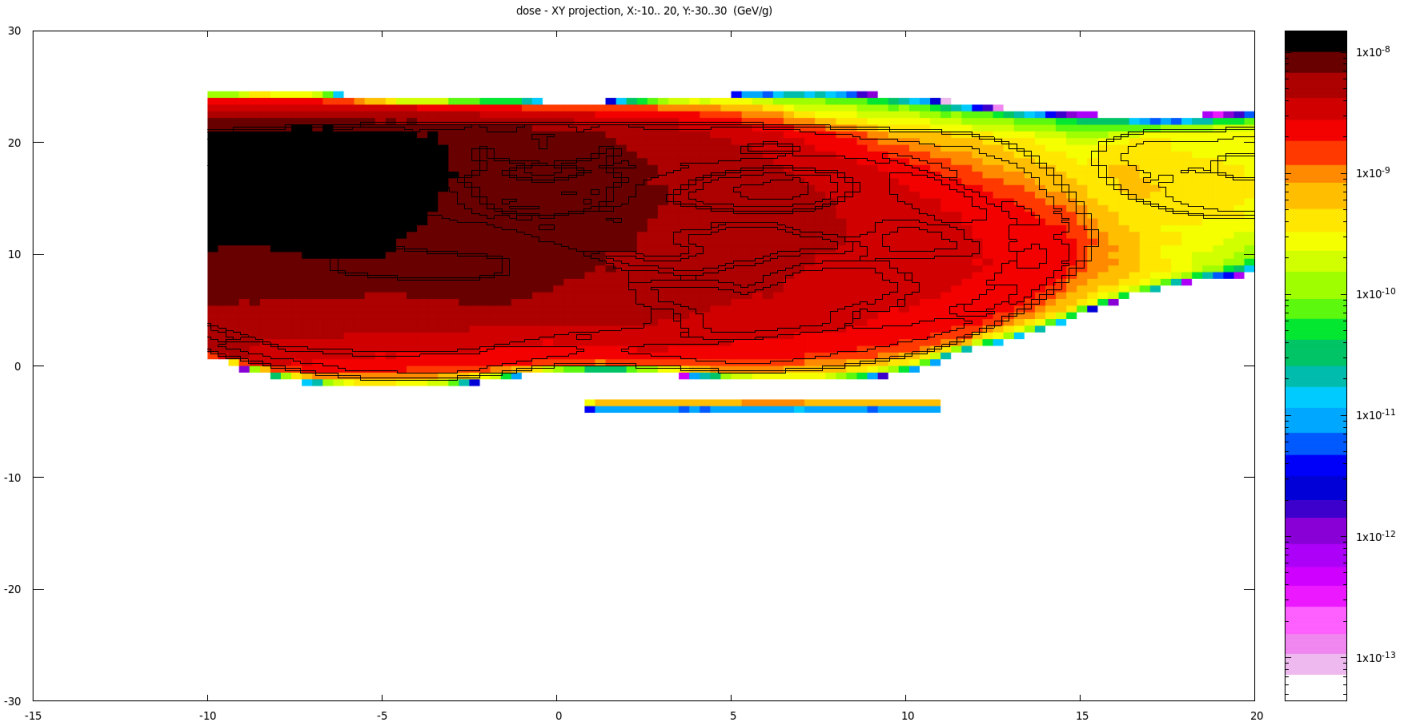
was replaced by:

```
*  Particle coordinates
XFLK   (NPFLKA) = WHASOU(1)+ (WHASOU(2)- WHASOU(1))*
FLRNDM(XXX)
YFLK   (NPFLKA) = WHASOU(3)+ (WHASOU(4)- WHASOU(3))*
FLRNDM(XXY)
ZFLK   (NPFLKA) = WHASOU(5)+ (WHASOU(6)- WHASOU(5))*
FLRNDM(XXY)
```

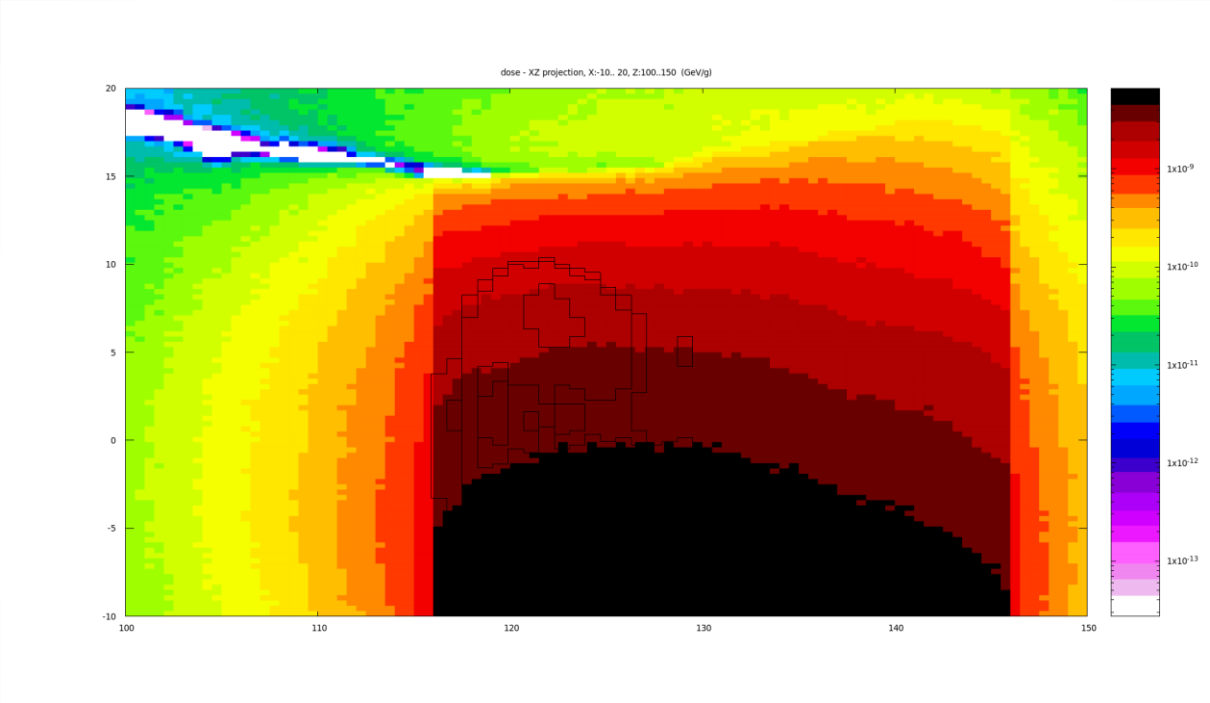
variables WHASOU(*)

Angle -45 degrees:

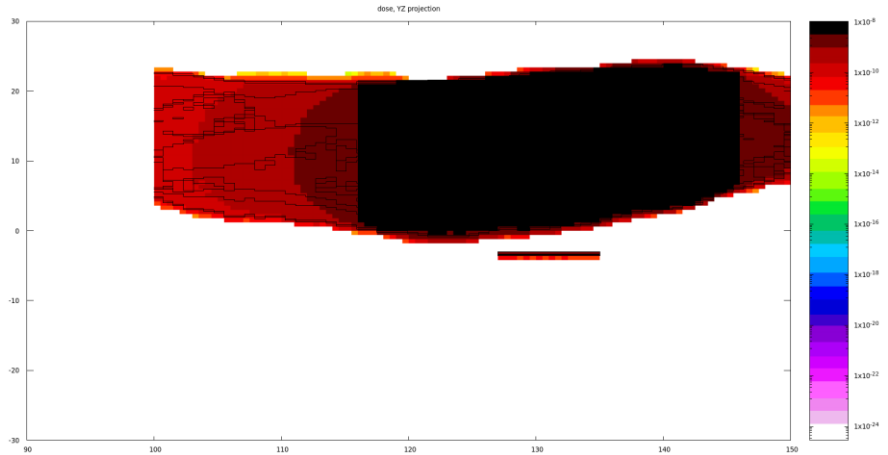
X: -45 .. -15
Y: 15 .. 45
Z: 116 .. 146



XY projection

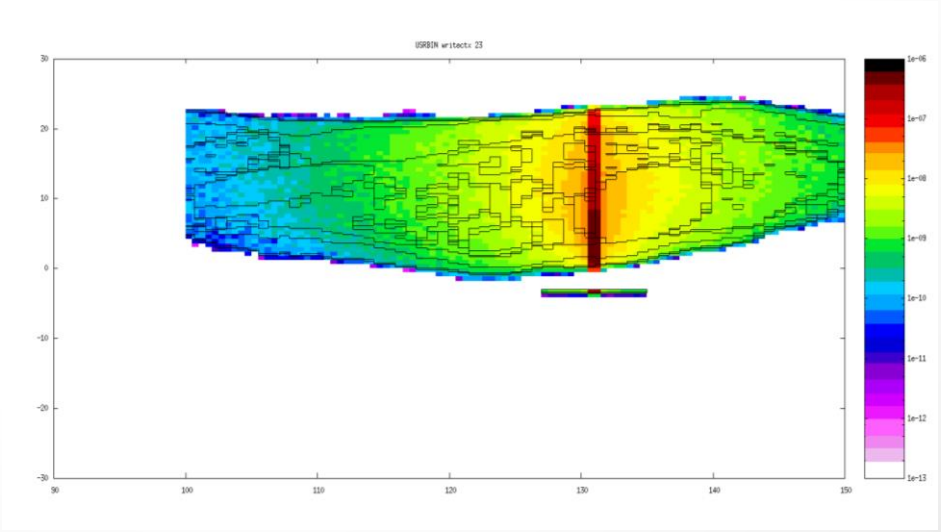


XZ projection



simplified model of the beam

YZ projection



thresholds were set by EMFCUT:

dose:

transport thresholds in all regions

for electrons were $1E^{-5}$ GeV (10 keV),

for gama $1E^{-6}$ GeV (1 keV)

production thresholds in all materials the same

kerma:

transport thresholds in all regions

for electrons were 0.002 GeV (2 MeV)

for gama $1E^{-6}$ GeV (1 keV)

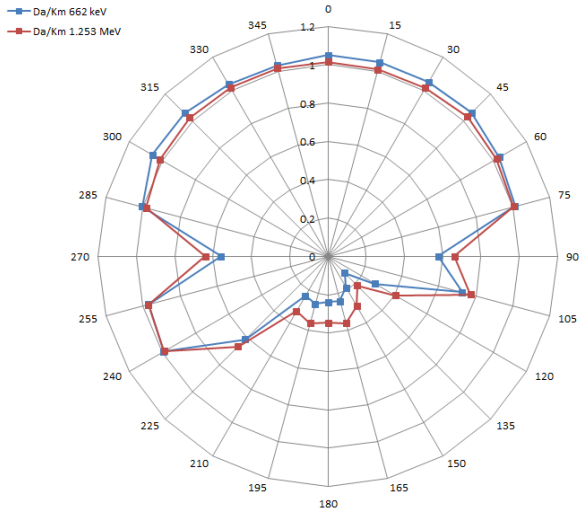
production thresholds in all materials the same

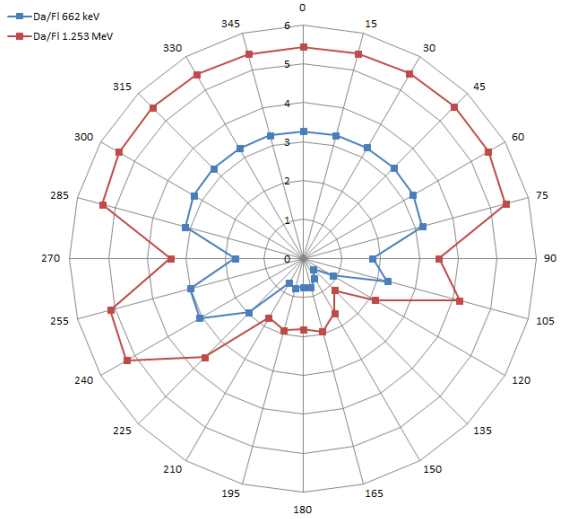
Dose per region (back glass) :

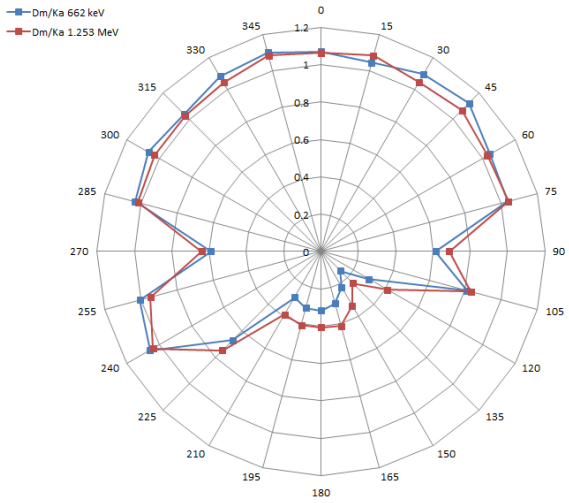
dose (GeV/g) in glass
fluence (particle/cm^2) in vacuum
kerma (GeV/g) in air

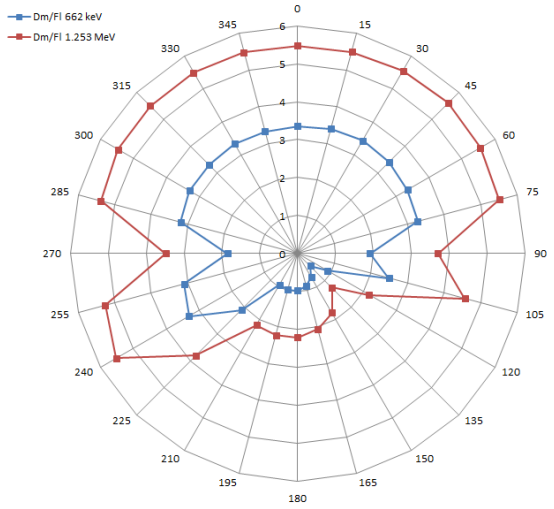
evaluated ratios:

Dose per fluence: (Gy.cm^2) … dose multiplied by a factor of 1.602176462E-7
 and
dose per kerma: (Gy/Gy)


Da/Km 662 keV
Da/Km 1.253 MeV
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
0
0.2
0.4
0.6
0.8
1
1.2


Da/Fl 662 keV
Da/Fl 1.253 MeV
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
0
1
2
3
4
5
6


Dm/Ka 662 keV
Dm/Ka 1.253 MeV
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
0
0.2
0.4
0.6
0.8
1
1.2


Dm/Fl 662 keV
Dm/Fl 1.253 MeV
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
0
1
2
3
4
5
6

Geometry	Energy (MeV)	$D_m/K_{a(ROT)}$ (Gy/Gy)	$D_m/Fl_{(ROT)}$ (pGy·cm²)
ROT	0.662	0.727±0.003	2.269±0.001
ROT	1.253	0.757±0.003	4.055±0.002

Table 4A. $D_m/K_{a\,(ROT)}$ and $D_m/F_{l\,(ROT)}$ in back display glass placed on the chest of reference voxel man phantom, rotational geometry, simplified model

Geometry	Energy (MeV)	$D_m/K_{a(ROT)}$ (Gy/Gy)	$D_m/Fl_{(ROT)}$ (pGy·cm²)
ROT	0.662	0.764±0.008	2.390±0.006
ROT	1.253	0.793±0.008	4.201±0.010

Table 4B. $D_m/K_{a\,(ROT)}$ a $D_m/F_{l\,(ROT)}$ in back display glass placed on the chest of the reference voxel man phantom, rotational geometry

Fig. 1: Experimental setup.

	Experimental data			Computed data	
geometry	reference K_a [Gy]	D_a/K_a	D_a/D_b	D_a/K_a	D_a/D_b
AP	0.7	1.00	1.05	1.07	1.11
	2	1.11	1.15		
	4	0.86	0.89		
ROT	0.7	0.74	0.95	0.76	0.97
	2	0.81	1.04		

Table 1: Experimental results in the form of ratios to the applied reference air kerma values are shown in the third column. These values were compared with whole body doses taken from [2], which is shown in the fourth column. The last two columns contain the corresponding results obtained from simulations.

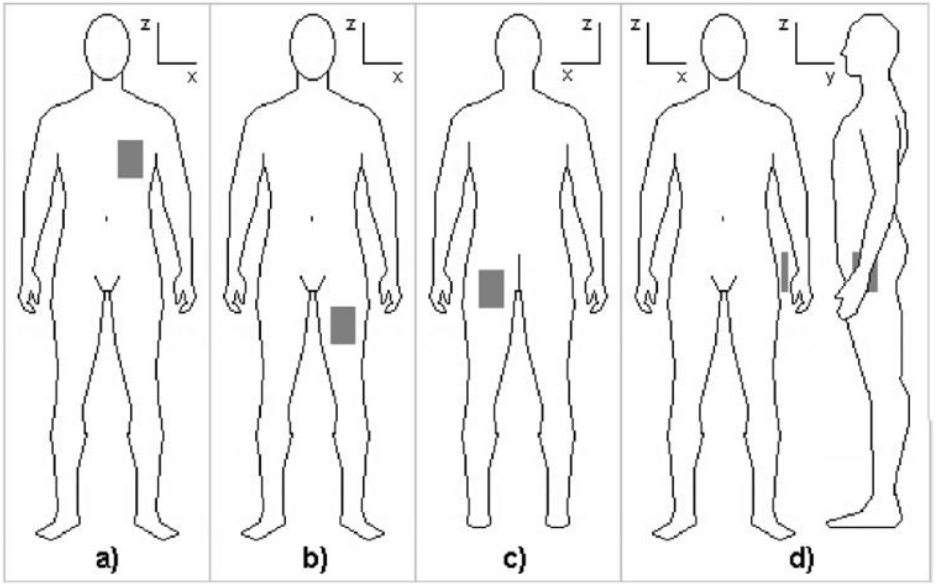


Figure 6. Illustration of the approximate locations of the phones (grey rectangles) in the four geometries of interest: (*a*) Chest, (*b*) Leg, (*c*) Back and (*d*) Hip.

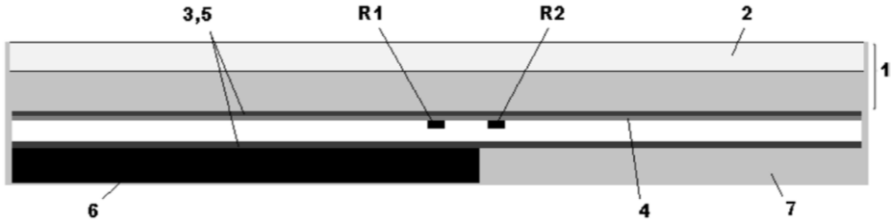


Figure 1. Side view of a simulated mobile phone consisting of (1) front and (7) back plastic case, (2) glass screen, (3, 5) aluminium covers, (4) circuit board, (6) battery, and two resistor components with Al_2O_3 substrates (R1 and R2).

	thick (mm)	width (mm)	length (mm)
glass	1	100	80
plastic	3	100	80
aluminium	0.5	100	80
board	0.5	100	80
aluminium	0.5	100	80
plasitc	4	100	80

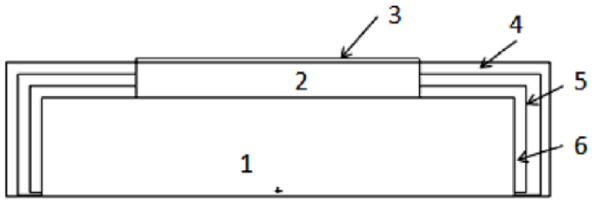


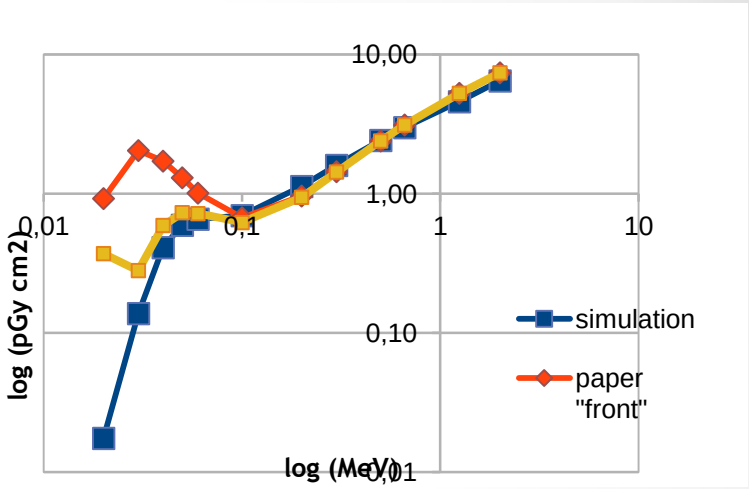
Figure 2. Model of a '0805' type SMR. The material compositions of parts 1–6 are explained in table 1.

Table 1. Dimensions and material compositions of the various parts of an SMR.

	Dimensions (cm)			
Resistor part	Length	Width	Thickness	Material
1. Ceramic substrate	0.2	0.125	0.04	Alumina (Al_2O_3)
2. Resistive element	0.1	0.125	0.015	Ruthenium oxide (RuO_2)
3. Insulating coating	0.1	0.125	0.0005	Epoxy
4. Outer termination	0.06	0.125	0.005	Tin-Silver (Sn-Ag)
5. Middle termination	0.06	0.125	0.005	Nickel (Ni)
6. Inner termination	0.06	0.125	0.005	Palladium-Silver (Pd-Ag)

Area no. 1:
Al_2O_3 - OSL/TL

MeV	Dose (GeV/g)	Fluence (particle/cm²)	pGy cm² (simulation)	pGy cm² (paper „front“)
0.02	1.13E-7 (1.0%)	1.04 (0.1%)	1.75	9.20
0.03	8.93E-7 (1.0%)	1.04 (0.1%)	1.41	2.04
0.04	2.66E-6 (0.7%)	1.04 (0.1%)	4.28	1.71
0.05	3.86E-6 (1.0%)	1.04 (0.1%)	5.95	1.30
0.06	4.26E-6 (0.7%)	1.04 (0.1%)	6.66	1.01
0.1	4.53E-6 (1.0%)	1.04 (0.1%)	6.98	6.70
0.2	7.32E-6 (1.0%)	1.04 (0.1%)	1.14	9.60
0.3	1.04E-5 (0.8%)	1.04 (0.1%)	1.60	1.44
0.5	1.57E-5 (0.9%)	1.04 (0.1%)	2.42	2.39
0.66	1.94E-5 (1.0%)	1.04 (0.1%)	2.99	3.11
1.25	2.98E-5 (0.8%)	1.04 (0.1%)	4.59	5.27
2	4.16E-5 (0.7%)	1.04 (0.1%)	6.41	7.39



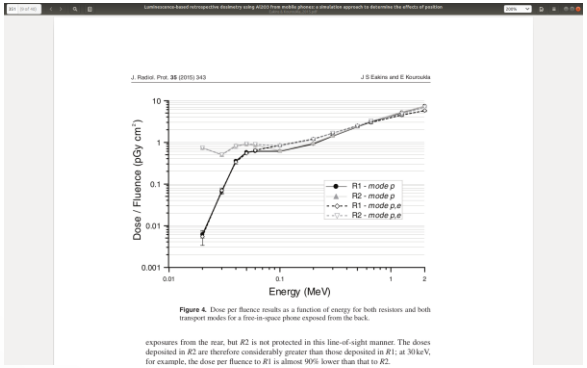


Figure 4. Dose per fluence results as a function of energy for both resistors and both transport modes for a free-in-space phone exposed from the back.

exposures from the rear, but R2 is not protected in this line-of-sight manner. The doses deposited in R2 are therefore considerably greater than those deposited in R1; at 30 keV, for example, the dose per fluence to R1 is almost 90% lower than that to R2.

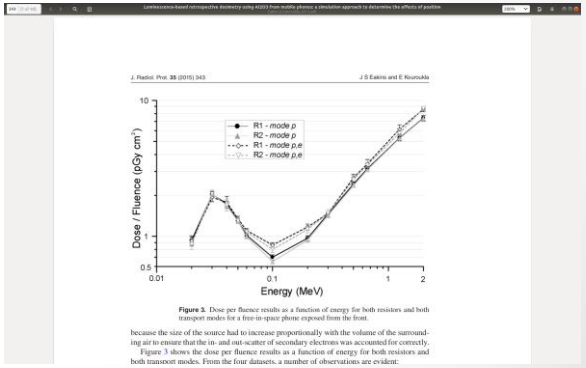
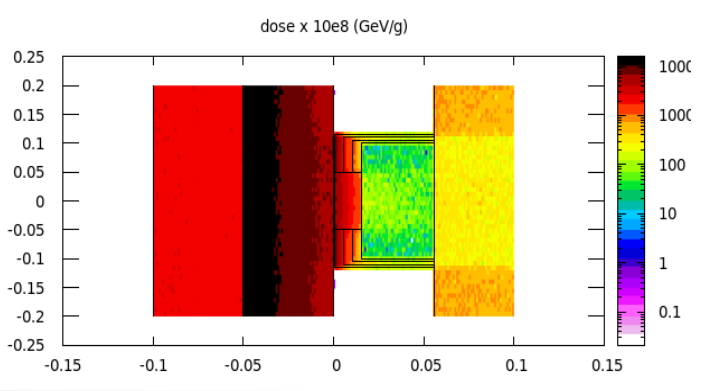
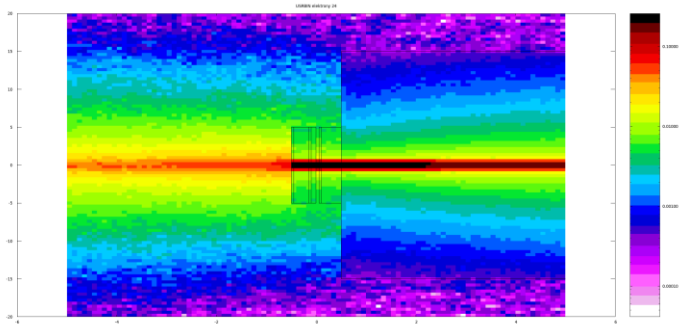


Figure 3. Dose per fluence results as a function of energy for both resistors and both transport modes for a free-in-space phone exposed from the front.

because the size of the source had to increase proportionally with the volume of the surrounding air to ensure that the in- and out-scatter of secondary electrons was accounted for correctly. Figure 3 shows the dose per fluence results as a function of energy for both resistors and both transport modes. From the four datasets, a number of observations are evident:



30 keV: dose 8.93 e-7 GeV/g



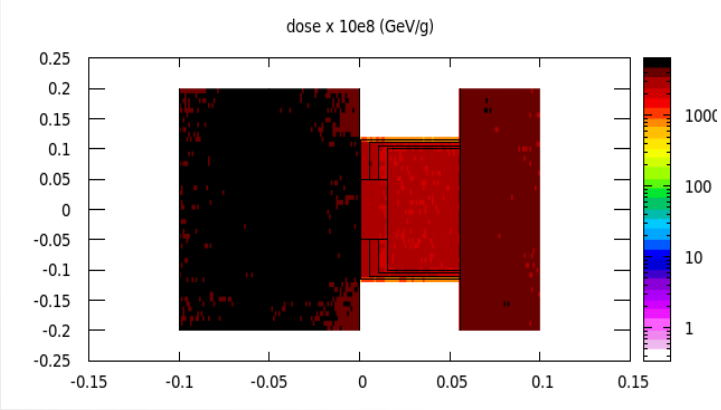
Source: E=300 keV ΔX, ΔY = 1 cm

0.1

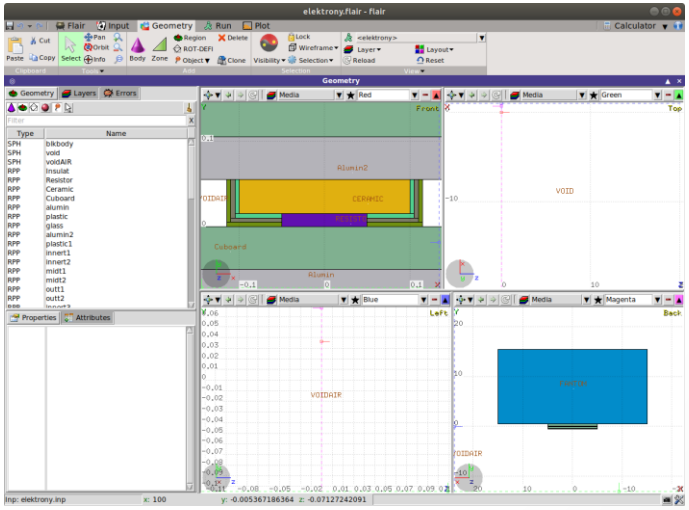
0.01

0.001

0.0001



2 MeV: dose 4.16 e-5 GeV/g



water phantom in air, AP orientation, out (board replaced by= plastic)
resistor volume 0.001 cm^3

MeV	Dose (GeV.cm3/g)	Fluence ($particle.cm^3/cm^2$)	pGy cm^2 (simulation)	pGy cm^2 (paper)
0.05	5.21E-09 (0.6%)	1.01E-03 (0.1%)	**0.82**	**1.39**
0.1	4.80E-09 (0.8%)	1.02E-03 (0.1%)	**7.52**	**9.60**
0.2	7.23E-09 (0.7%)	1.02E-03 (0.1%)	**1.13**	**1.28**
0.3	1.03E-08 (0.9%)	1.03E-03 (0.1%)	**1.60**	**1.73**
0.662	1.92E-08 (1.0%)	1.03E-03(0.1%)	**2.98**	**3.37**
1.253	2.99E-08 (1.0%)	1.03E-03(0.1%)	**4.67**	**5.50**

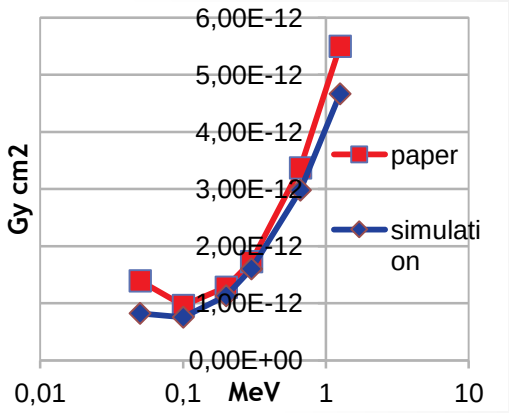


Table 2. Board – composition (2)

	Weight ratio %	Density g/cm3	Metal: 63 %
Metal	63 (59.34)	5.83	Cu -20% (12.6%)
Ceramics	24 (24)	3.72	Fe – 8% (5.04%)
Polymer	13 (16.66)	1.17	Zn – 2% (1.26%)

(2) Yamane LH, Morales, VT, Espinosa DCR, Tenorio JAS , Waste Manag. 31 (2011) 2553-8