2-D Dose-CT Mapping in Geant4

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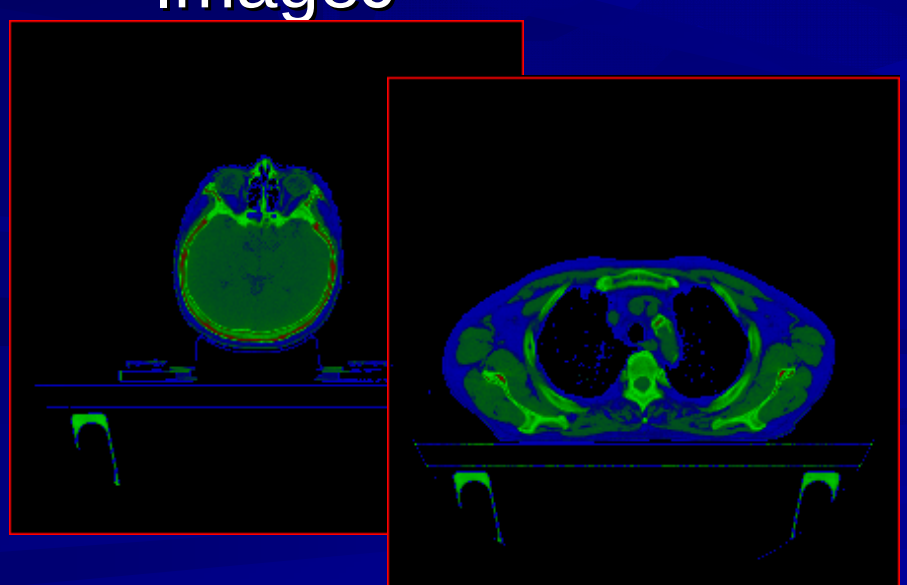
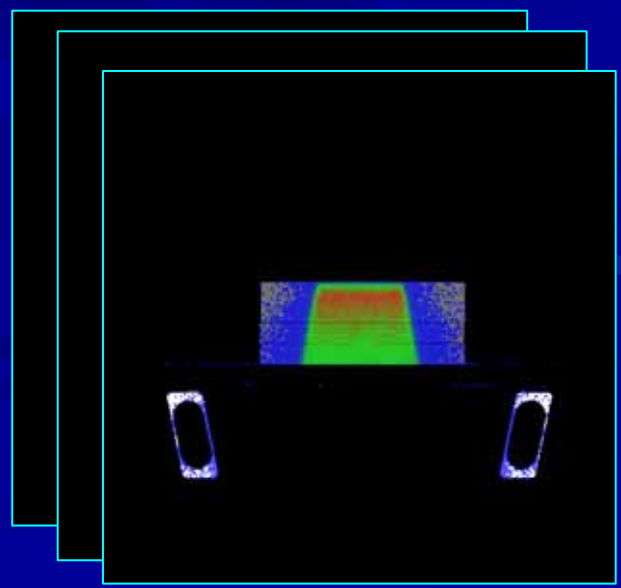
Background

- Recently, Monte Carlo simulation has been focused in medicine, especially in radiology department
- A detail of human volume data is needed in Monte Carlo simulation for medical applications
- A detail of human volume data can be obtained from CT images
- But there are not enough tools in medicine that can convert CT image to a format that can be processed in Monte Carlo simulation

Purpose

- We designed and developed 2-D Dose-CT Mapping software using Geant4 and ImageJ
  - To convert CT image to a format that can be processed in Geant4
  - To display dose mapping on CT image using ImageJ





Materials

- Monte Carlo Simulation Toolkit
  - Geant4(ver.4.8.1p01)

- 2-D Dose-CT Viewer
  - ImageJ(ver.1.37b)

    - a public domain Java image processing program
    - runs, either as an online applet or as a downloadable application, on any computer with a Java 1.1 or later virtual machine.
    - available for Windows, Mac OS, Mac OS X and Linux.
    - designed with an open architecture that provides extensibility via Java plugins.
    - Custom acquisition, analysis and processing plugins can be developed using ImageJ's built in editor and Java compiler.
    - User-written plugins make it possible to perform almost any image processing or analysis.

Methods in Monte Carlo simulation

- Target (Detector) construction
  - Load DICOM-CT images
  - Convert pixel to voxel
  - Set voxels
  - Convert CT value to “physical density” and “element composition”

- Beam data (X-ray Spectra)
  - X-ray spectrum used for radiation diagnosis (X-ray tube) Birch formula
  - X-ray spectrum used for radiotherapy (Linac) Load x-ray spectrum data

Methods in 2-D Dose-CT Mapping

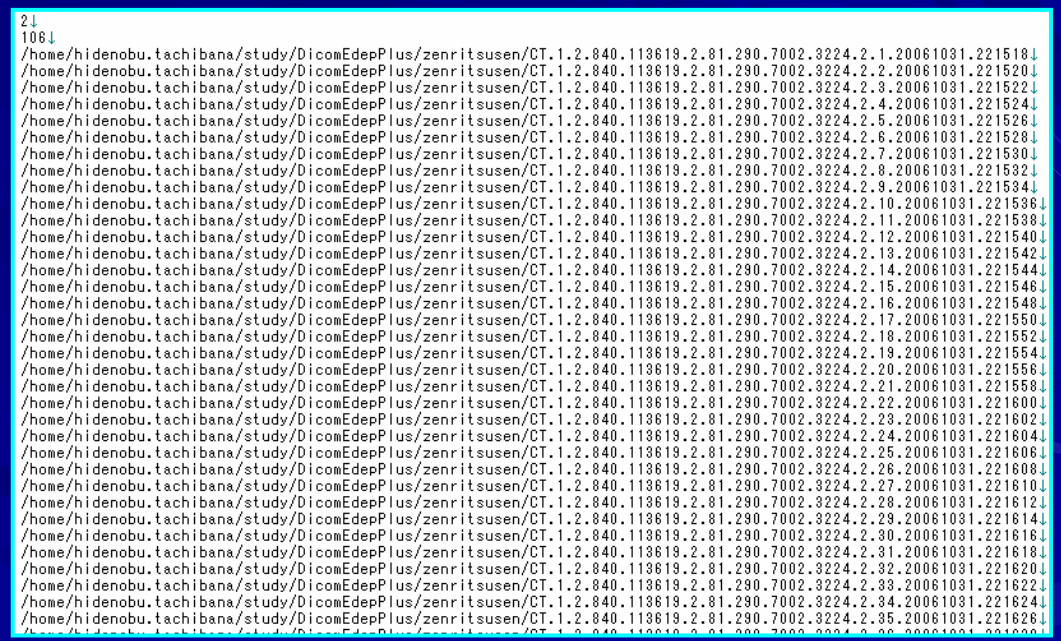
- CT data
  - Load DICOM-CT images

- Dose data
  - Load the data with energy deposition, voxel location (x, y, z), and voxel density.
  - Calculate Dose with energy deposition and its density
  - Create Dose images with color map
- 2-D dose map
  - Superimpose Dose image onto CT image

Process flow in Monte Carlo simulation

Pre-Process in Monte Carlo simulation

- Sort DICOM images by slice location
- Create “Data.dat” with names of DICOM images, the number of DICOM images, and compress ratio.



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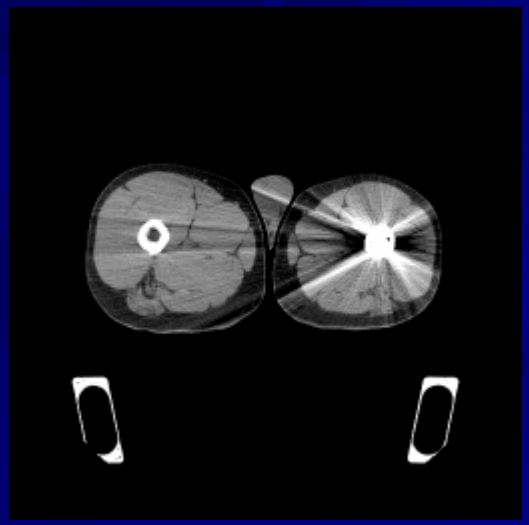
Process flow in Monte Carlo simulation (Detector construction)

- Load DICOM images



- Extract parameters in each DICOM image
  - Rows, Columns
  - Pixel Spacing (x, y)
  - Slice thickness
  - Slice location
  - Pixel Value (CT value)
- Create .g4 files and .dat files

```
Rows,columns(#):              512          512
PixelSpacing_X,Y(mm): 0.976562   0.976562
SliceThickness(mm):   3.000000
SliceLocation(mm):    -27.000000
```

.g4 file

00 40 EF 3F 00 00 00 00 00 00 08 40 00 00 00 00
00 00 3B C0 10 00 00 FC FF FF 00 FC FF FF 00 FC
FF FF 00 FC FF FF 00 FC FF FF 00 FC FF FF 00 FC
FF FF 00 FC FF FF 00 FC FF FF 00 FC FF FF 03 FC
FF FF 1B FC FF FF 1B FC FF FF 1B FC FF FF 17 FC
FF FF 13 FC FF FF 0C FC FF FF 03 FC FF FF 00 FC
FF FF 00 FC FF FF 00 FC FF FF 00 FC FF FF 00 FC

Pixel values (binary)....

.dat file

Process flow in Monte Carlo simulation (Detector construction)

- Load .g4 files and .dat files

.g4 file

.dat file

Rows,columns(#): 512 512
PixelSpacing_X,Y(mm): 0.976562 0.976562
SliceThickness(mm): 3.000000
SliceLocation(mm): -27.000000

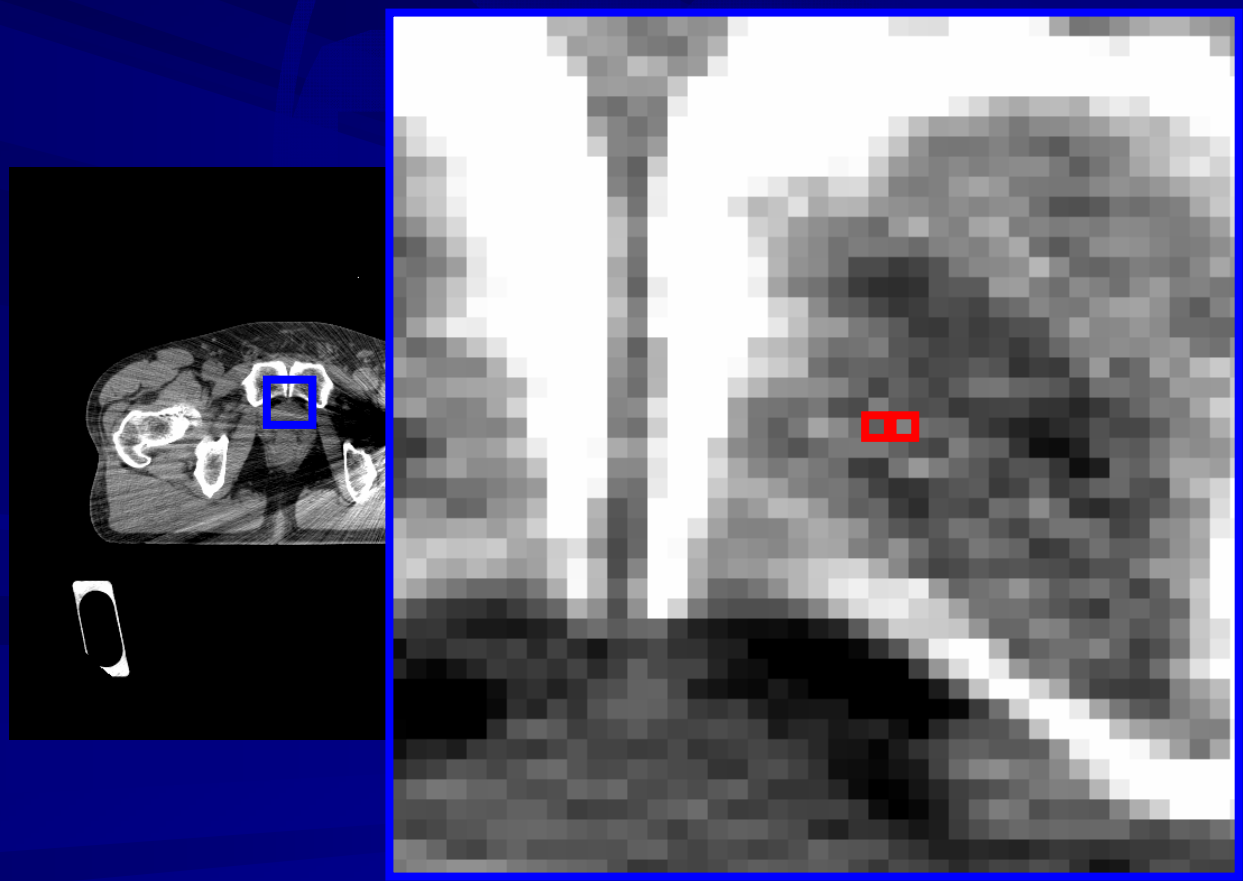
Pixel values
(binary)

Process flow in Monte Carlo simulation (Detector construction)

- Convert pixel to voxel

Pixel spacing (x,y)

Slice thickness

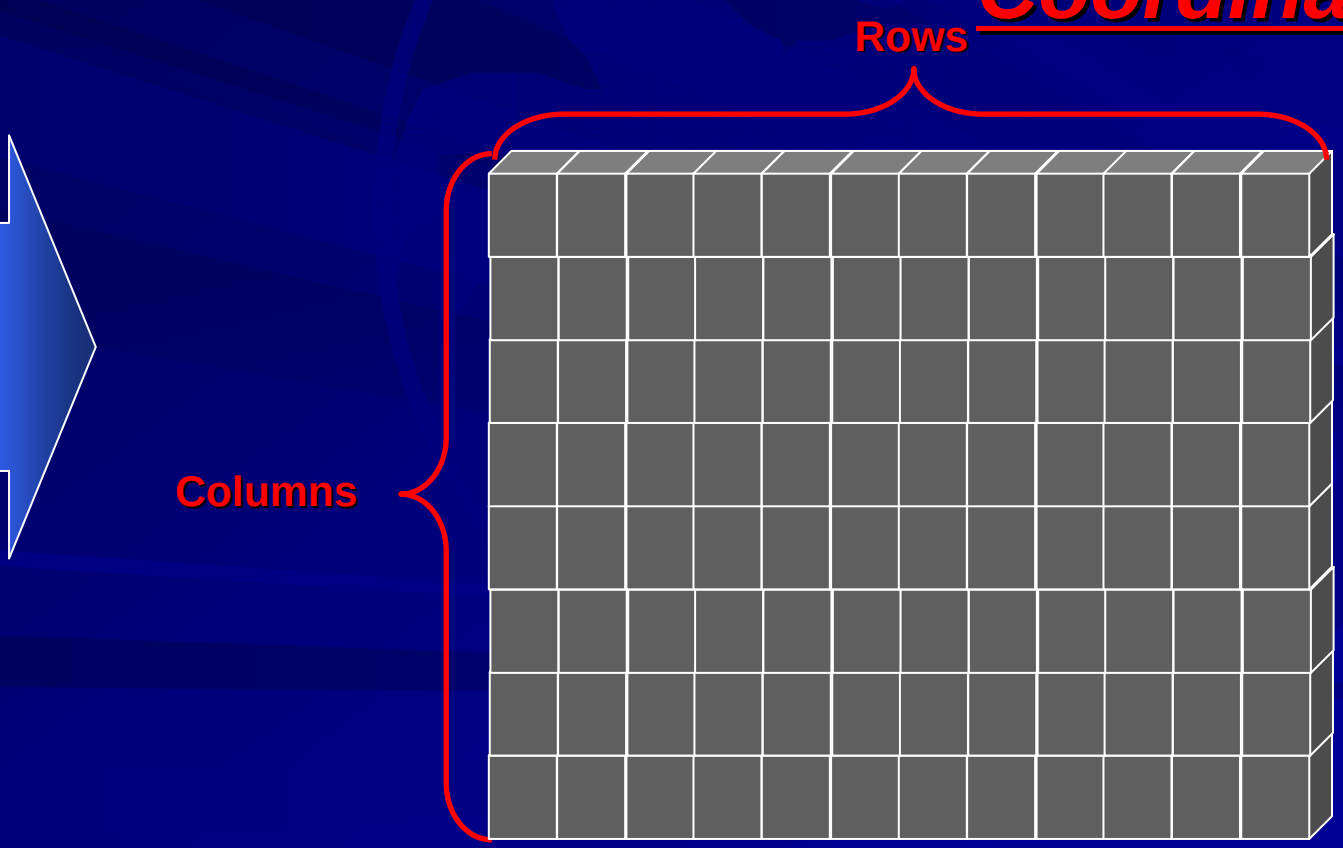


Process flow in Monte Carlo simulation (Detector construction)

- Set Voxels

Rows, Columns

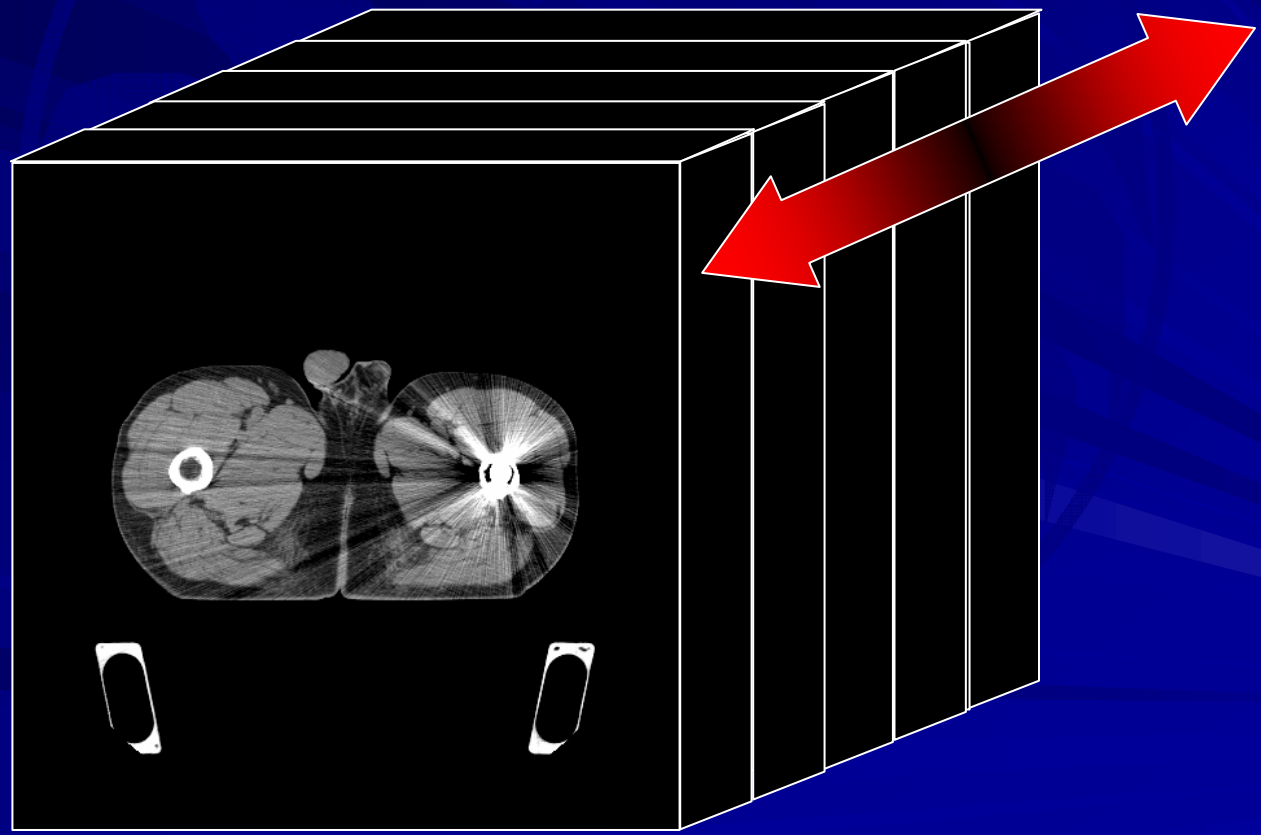
Coordinate (x, y)



Process flow in Monte Carlo simulation (Detector construction)

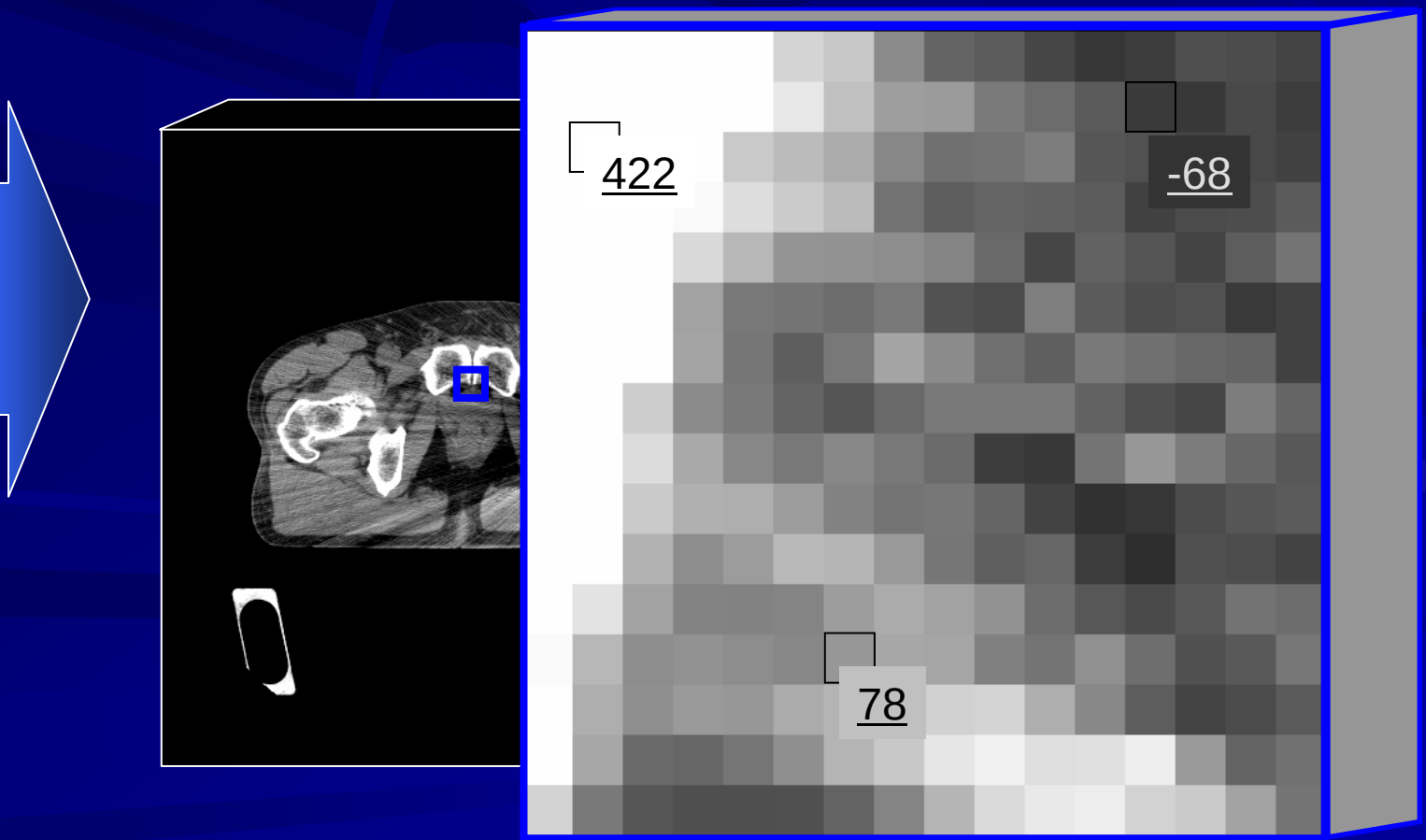
- Set Voxels

Slice location



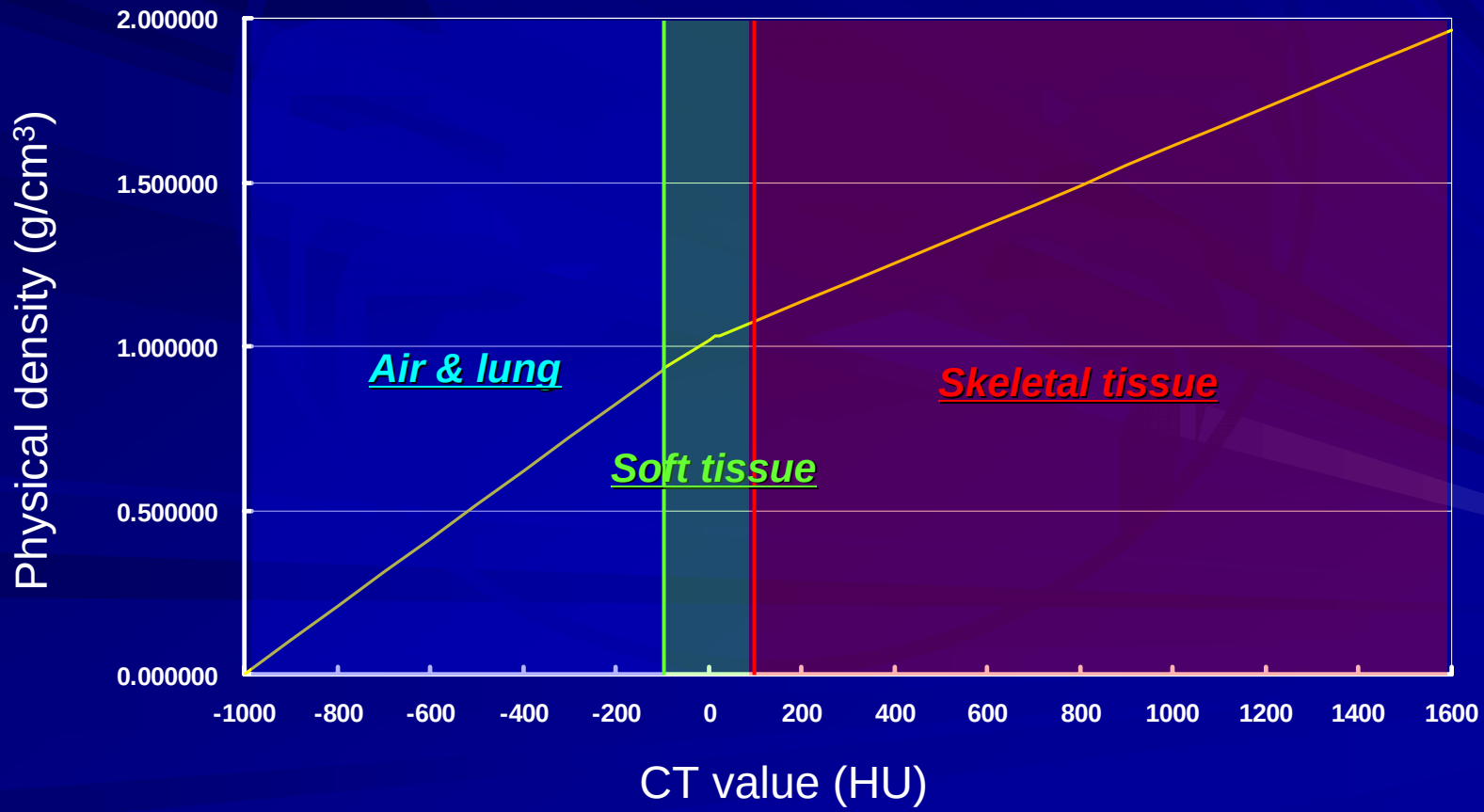
Process flow in Monte Carlo simulation (Detector construction)

- Convert CT value to “Physical Density” and “Element Composition”



Process flow in Monte Carlo simulation (Detector construction)

- Physical density (Ref. W Schneider et al, Phys. Med. Biol. 45 (2000))
  - CT value<-1000 1.29 mg/cm^3 Air
  - CT value>1600 default: 10g/cm^3 Ag



Process flow in Monte Carlo simulation (Detector Construction)

- Element Composition (Ref. W Schneider et al, Phys. Med. Biol. 45 (2000))

CT Low	CT High	H	C	N	O	Na	Mg	P	S	Cl	Ar	K	Ca	Ti	Fe	Ag
-1000	-950	0	0	75.5	23.2	0	0	0	0	0	1.3	0	0	0	0	0
-950	-120	10.3	10.5	3.1	74.9	0.2	0	0.2	0.3	0.3	0	0.2	0	0	0	0
-120	-83	11.6	68.1	0.2	19.8	0.1	0	0	0.1	0.1	0	0	0	0	0	0
-83	-53	11.3	56.7	0.9	30.8	0.1	0	0	0.1	0.1	0	0	0	0	0	0
-53	-23	11	45.8	1.5	41.1	0.1	0	0.1	0.2	0.2	0	0	0	0	0	0
-23	8	10.8	35.6	2.2	50.9	0	0	0.1	0.2	0.2	0	0	0	0	0	0
8	18	10.6	28.4	2.6	57.8	0	0	0.1	0.2	0.2	0	0.1	0	0	0	0
18	80	10.3	13.4	3	72.3	0.2	0	0.2	0.2	0.2	0	0.2	0	0	0	0
80	120	9.4	20.7	6.2	62.2	0.6	0	0	0.6	0.3	0	0	0	0	0	0
120	200	9.5	45.5	2.5	35.5	0.1	0	2.1	0.1	0.1	0	0.1	4.5	0	0	0
200	300	8.9	42.3	2.7	36.3	0.1	0	3	0.1	0.1	0	0.1	6.4	0	0	0
300	400	8.2	39.1	2.9	37.2	0.1	0	3.9	0.1	0.1	0	0.1	8.3	0	0	0
400	500	7.6	36.1	3	38	0.1	0.1	4.7	0.2	0.1	0	0	10.1	0	0	0
500	600	7.1	33.5	3.2	38.7	0.1	0.1	5.4	0.2	0	0	0	11.7	0	0	0
600	700	6.6	31	3.3	39.4	0.1	0.1	6.1	0.2	0	0	0	13.2	0	0	0
700	800	6.1	28.7	3.5	40	0.1	0.1	6.7	0.2	0	0	0	14.6	0	0	0
800	900	5.6	26.5	3.6	40.5	0.1	0.2	7.3	0.3	0	0	0	15.9	0	0	0
900	1000	5.2	24.6	3.7	41.1	0.1	0.2	7.8	0.3	0	0	0	17	0	0	0
1000	1100	4.9	22.7	3.8	41.6	0.1	0.2	8.3	0.3	0	0	0	18.1	0	0	0
1100	1200	4.5	21	3.9	42	0.1	0.2	8.8	0.3	0	0	0	19.2	0	0	0
1200	1300	4.2	19.4	4	42.5	0.1	0.2	9.2	0.3	0	0	0	20.1	0	0	0
1300	1400	3.9	17.9	4.1	42.9	0.1	0.2	9.6	0.3	0	0	0	21	0	0	0
1400	1500	3.6	16.5	4.2	43.2	0.1	0.2	10	0.3	0	0	0	21.9	0	0	0
1500	1600	3.4	15.5	4.2	43.5	0.1	0.2	10.3	0.3	0	0	0	22.5	0	0	0

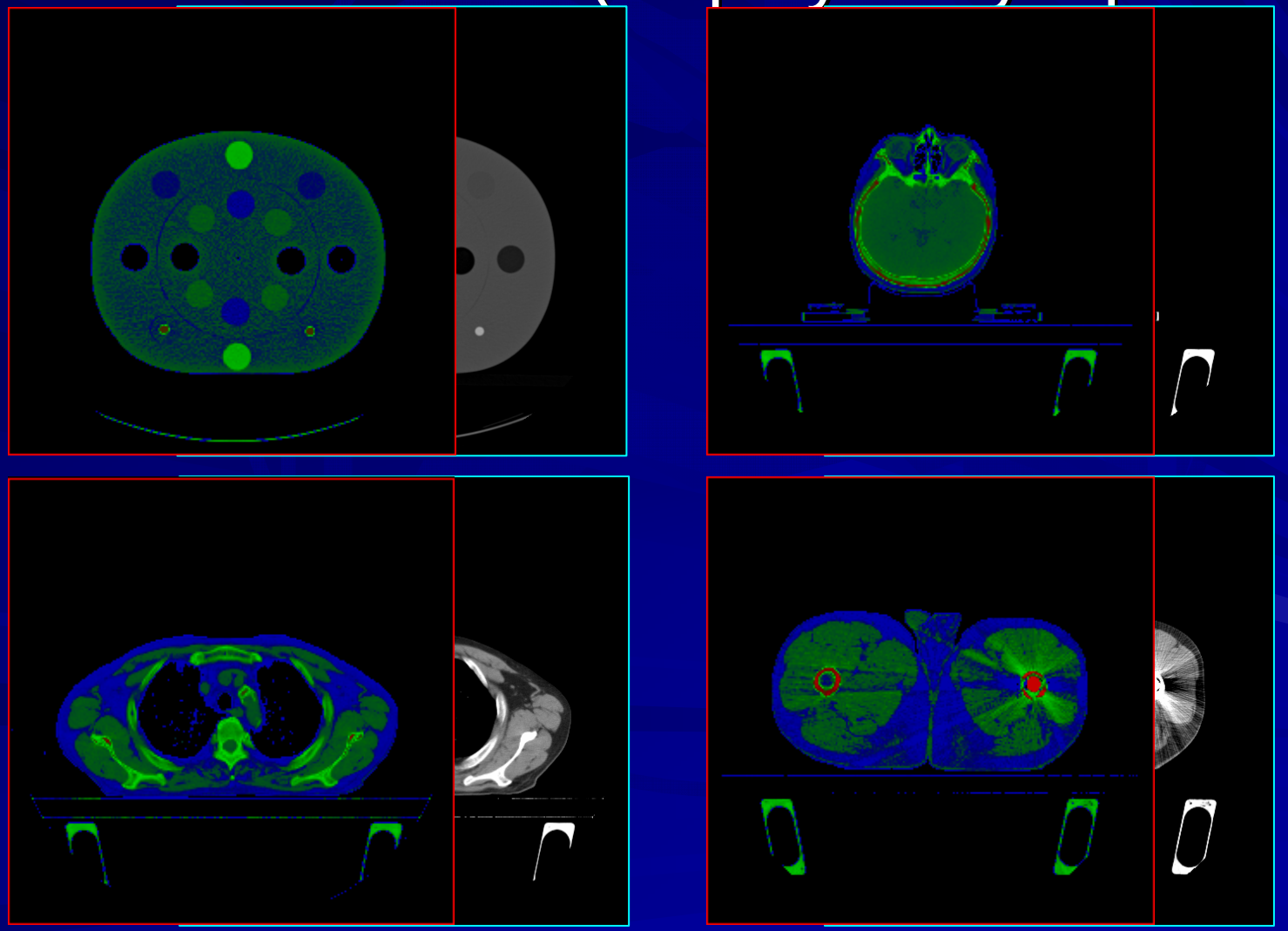
Air & lung

Soft tissue

Skeletal tissue

Process flow in Monte Carlo simulation (Detector construction)

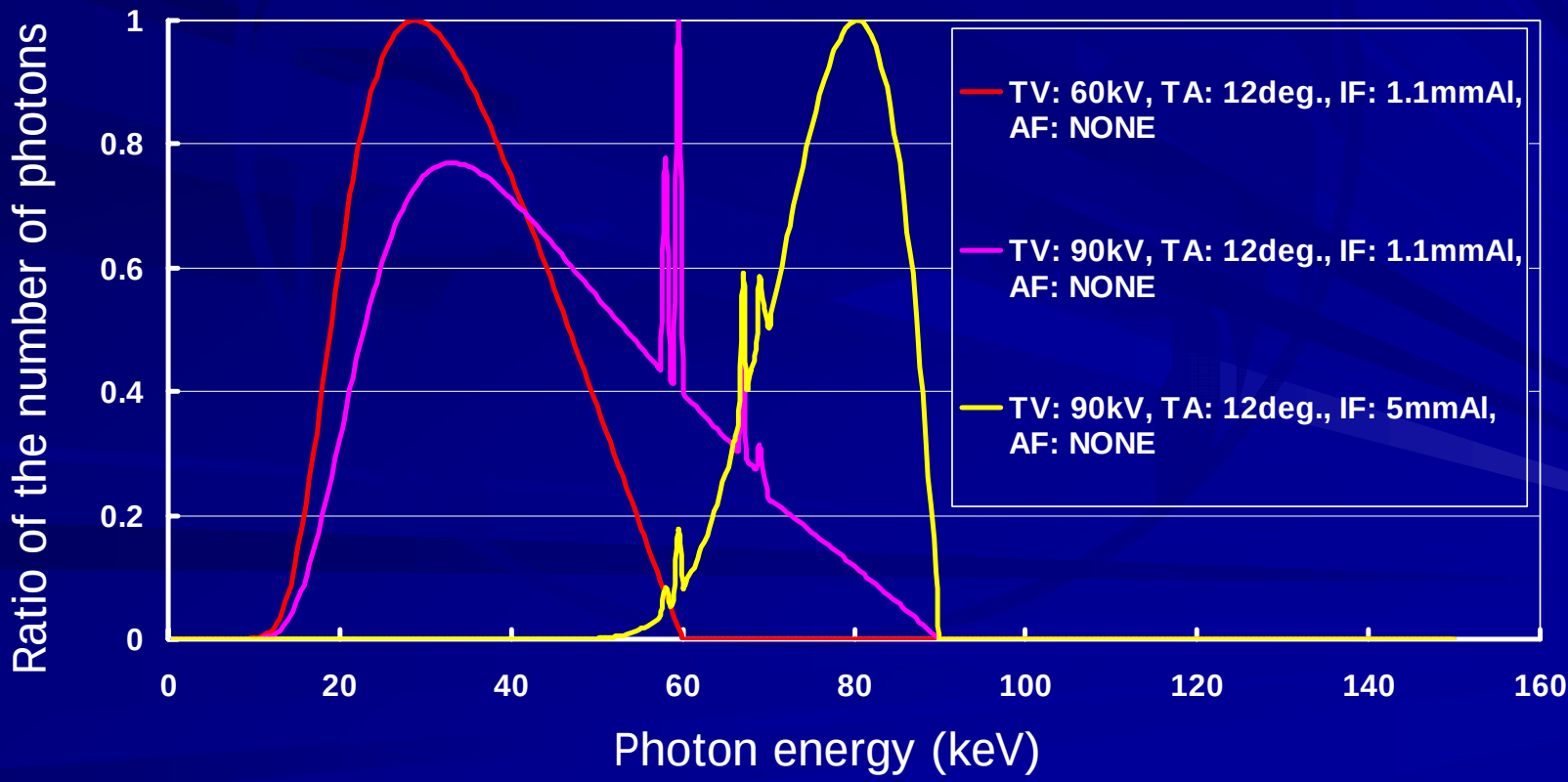
- Converted data (displayed by OpenGL)



Process flow in Monte Carlo simulation (Beam data)

- X-ray spectrum used for diagnosis (X-ray tube)
  - Tube voltage (TV, kV)
  - Inherent filter (IF, mmAl), Added filter (AF, mmAl, mmCu)
  - Target angle (TA, degree)

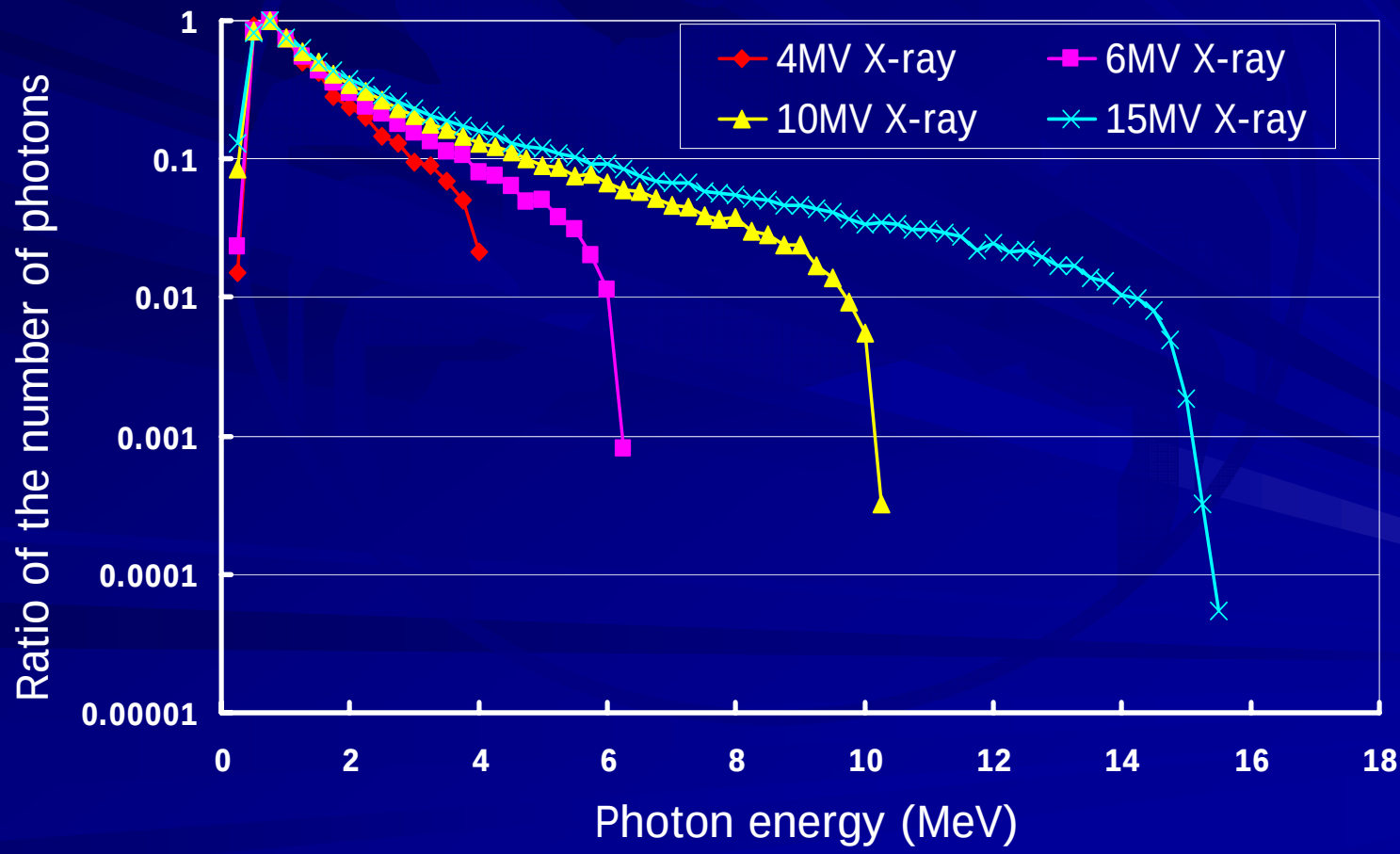
Birch formula



Process flow in Monte Carlo simulation (Beam data)

- X-ray spectrum used for treatment (Linac)

Load X-ray spectrum data from Monte Carlo



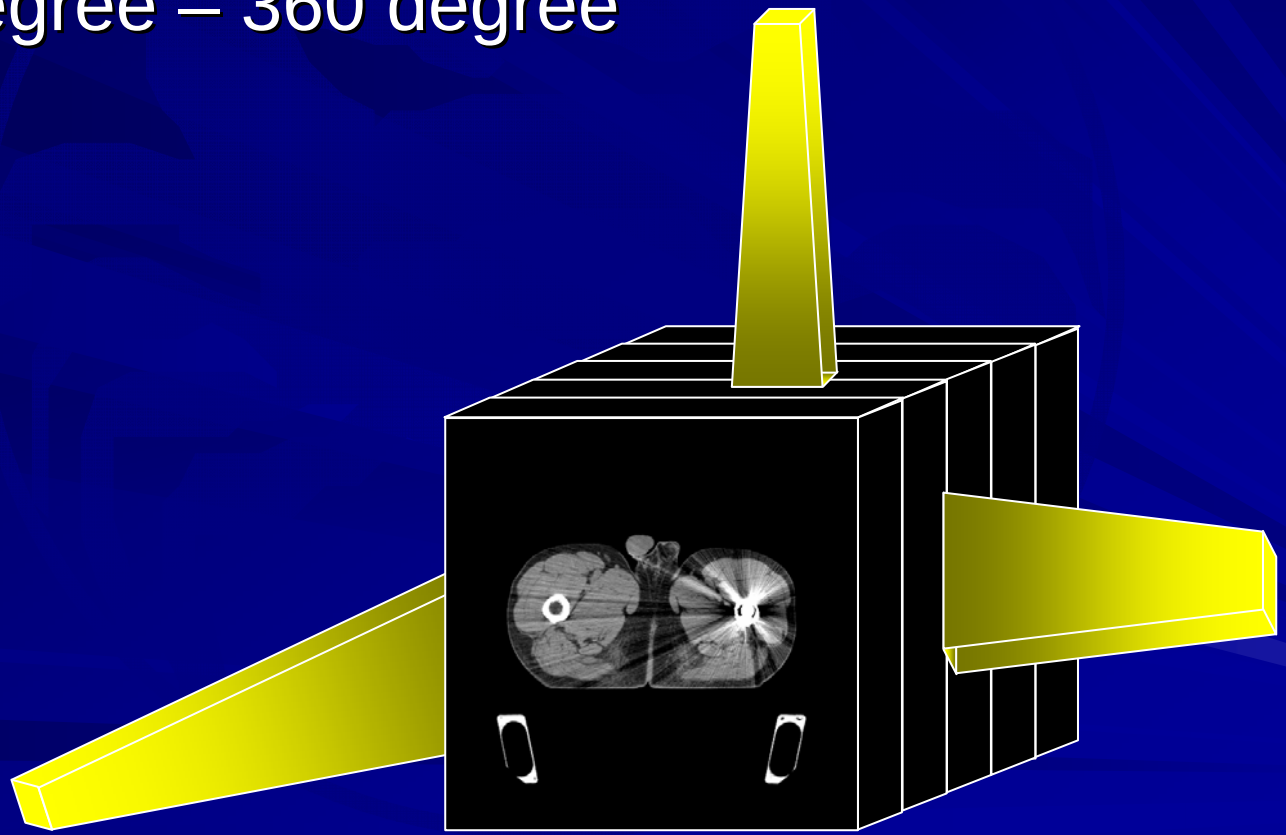
Process flow in Monte Carlo simulation (Beam Focus and Field)

- Source
  - The area of starting point
  - Shape: square

- Field
  - The are of destination point Shape: square

Process flow in Monte Carlo simulation (Beam Direction)

- Direction
  - 0 degree – 360 degree



Process flow in Monte Carlo simulation (Output data)

- Output the text file after calculation
  - Rows, Columns, Pixel Spacing (x, y), Slice thickness, etc
  - Copy Number, x coordinate, y coordinate, z coordinate, energy deposition, and physical density

run/beamOn 1000000↵
Event ID: 0
Event ID: 1
•
•
•
•
•
•
•

```
2↓
512↓
512↓
0.976562↓
0.976562↓
46↓
5↓
-5↓
1↓
↓
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1    4    146 0    0.456846    0.650951↓
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11   14   146 0    0    0.650951↓
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13   16   146 0    0    0.650951↓
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18   21   146 0    0.715906    0.650951↓
19   22   146 0    0.165669    0.650951↓
20   23   146 0    0.123649    0.650951↓
21   24   146 0    0.129785    0.650951↓
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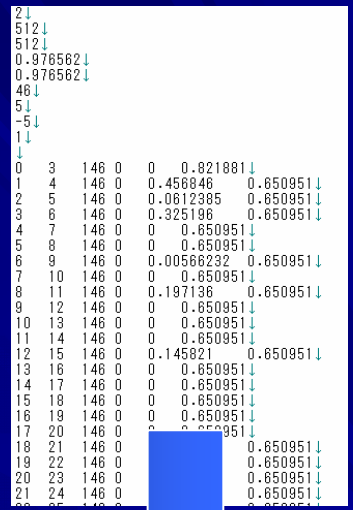
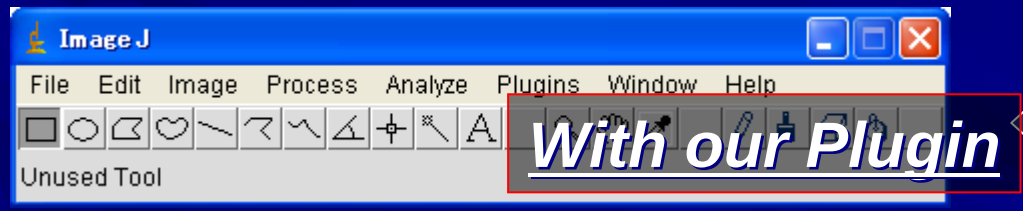
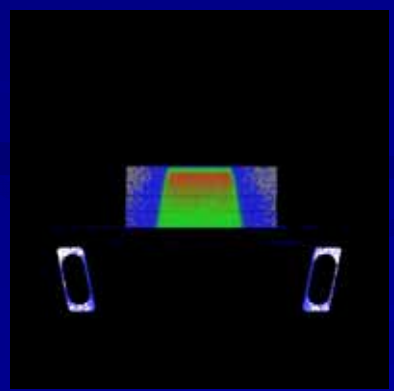
Process flow in 2-D Dose-CT Mapping

Process flow in 2-D Dose-CT Mapping

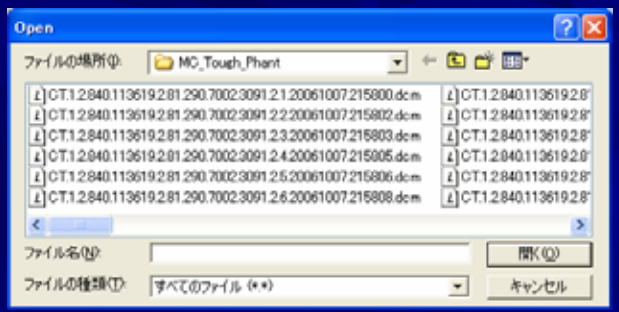




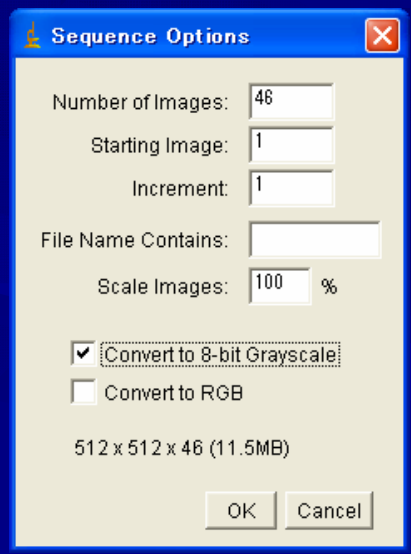


Process flow in 2-D Dose-CT Mapping (CT data)

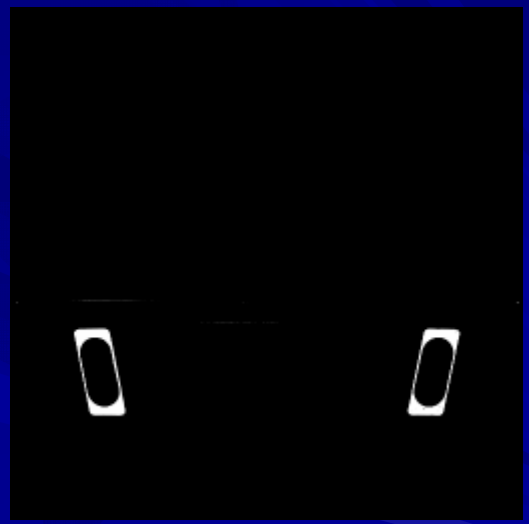
- Load CT images
  - Convert 16-bit to 8-bit gray scale



Load CT images



Convert 16-bit
to 8bit gray scale

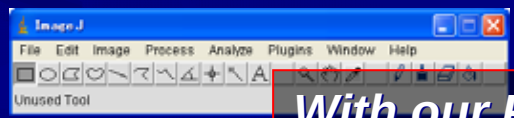


Phantom (Tough Water)

Process flow in 2-D Dose-CT Mapping (Dose data)

- Load output data

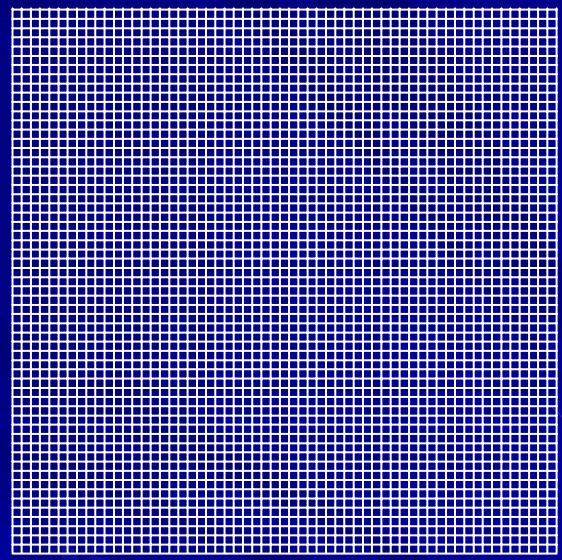
```
2↓
512↓
512↓
0.976562↓
0.976562↓
46↓
5↓
-5↓
1↓
↓
0    3    146 0    0    0.821881↓
1    4    146 0    0.456846    0.650951↓
2    5    146 0    0.0612385    0.650951↓
3    6    146 0    0.325196    0.650951↓
4    7    146 0    0    0.650951↓
5    8    146 0    0    0.650951↓
6    9    146 0    0.00566232    0.650951↓
7    10    146 0    0    0.650951↓
8    11    146 0    0.197136    0.650951↓
9    12    146 0    0    0.650951↓
10    13    146 0    0    0.650951↓
11    14    146 0    0    0.650951↓
12    15    146 0    0.145821    0.650951↓
13    16    146 0    0    0.650951↓
14    17    146 0    0    0.650951↓
15    18    146 0    0    0.650951↓
16    19    146 0    0    0.650951↓
17    20    146 0    0    0.650951↓
18    21    146 0    0.715906    0.650951↓
19    22    146 0    0.165669    0.650951↓
20    23    146 0    0.123649    0.650951↓
21    24    146 0    0.129785    0.650951↓
22    25    146 0    0.0621096    0.650951↓
23    26    146 0    0    0.650951↓
24    27    146 0    0.23512 0.650951↓
25    28    146 0    0.337658    0.650951↓
26    29    146 0    0.602522    0.650951↓
27    30    146 0    0    0.650951↓
28    31    146 0    0.305617    0.821881↓
29    32    146 0    0.109035    0.650951↓
30    33    146 0    0    0.650951↓
31    34    146 0    0    0.650951↓
32    35    146 0    0    0.650951↓
33    36    146 0    0.00361517    0.821881↓
34    37    146 0    0    0.650951↓
35    38    146 0    0.651383    0.821881↓
36    39    146 0    0    0.650951↓
37    40    146 0    0.0359235    0.650951↓
38    41    146 0    0    0.821881↓
39    42    146 0    0.68676 0.821881↓
40    43    146 0    0    0.650951↓
```



With our Plugin

512

512



Output data of phantom after calculation (Tough water)

Compress: 2

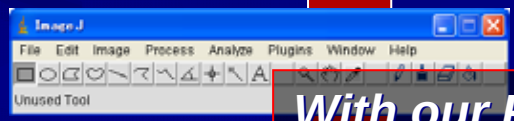
The number of slices: 46

Process flow in 2-D Dose-CT Mapping (Dose data)

- Load output data

```
2↓
512↓
512↓
0.976562↓
0.976562↓
46↓
5↓
-5↓
1↓
↓
0   3   146 0   0   0.821881↓
1   4   146 0   0.456846    0.650951↓
2   5   146 0   0.0612385   0.650951↓
3   6   146 0   0.325196    0.650951↓
4   7   146 0   0   0.650951↓
5   8   146 0   0   0.650951↓
6   9   146 0   0.00566232  0.650951↓
7   10  146 0   0   0.650951↓
8   11  146 0   0.197136    0.650951↓
9   12  146 0   0   0.650951↓
10  13  146 0   0   0.650951↓
11  14  146 0   0   0.650951↓
12  15  146 0   0.145821    0.650951↓
13  16  146 0   0   0.650951↓
14  17  146 0   0   0.650951↓
15  18  146 0   0   0.650951↓
16  19  146 0   0   0.650951↓
17  20  146 0   0   0.650951↓
18  21  146 0   0.715906    0.650951↓
19  22  146 0   0.165669    0.650951↓
20  23  146 0   0.123649    0.650951↓
21  24  146 0   0.129785    0.650951↓
22  25  146 0   0.0621096   0.650951↓
23  26  146 0   0   0.650951↓
24  27  146 0   0.23512 0.650951↓
25  28  146 0   0.337658    0.650951↓
26  29  146 0   0.602522    0.650951↓
27  30  146 0   0   0.650951↓
28  31  146 0   0.305617    0.821881↓
29  32  146 0   0.109035    0.650951↓
30  33  146 0   0   0.650951↓
31  34  146 0   0   0.650951↓
32  35  146 0   0   0.650951↓
33  36  146 0   0.00361517  0.821881↓
34  37  146 0   0   0.650951↓
35  38  146 0   0.651383    0.821881↓
36  39  146 0   0   0.650951↓
37  40  146 0   0.0359235   0.650951↓
38  41  146 0   0   0.821881↓
39  42  146 0   0.68676 0.821881↓
40  43  146 0   0   0.650951↓
```

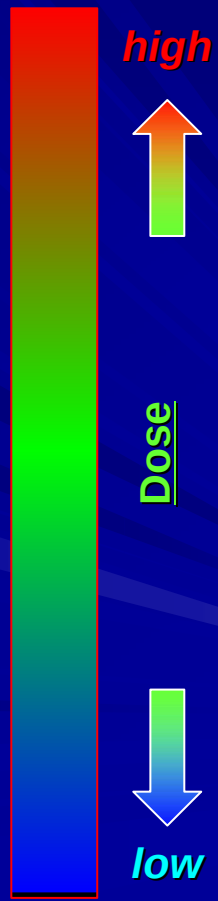
x	y	z	Energy deposition	physical density
15	146	0	0.145821	0.650951



With our Plugin

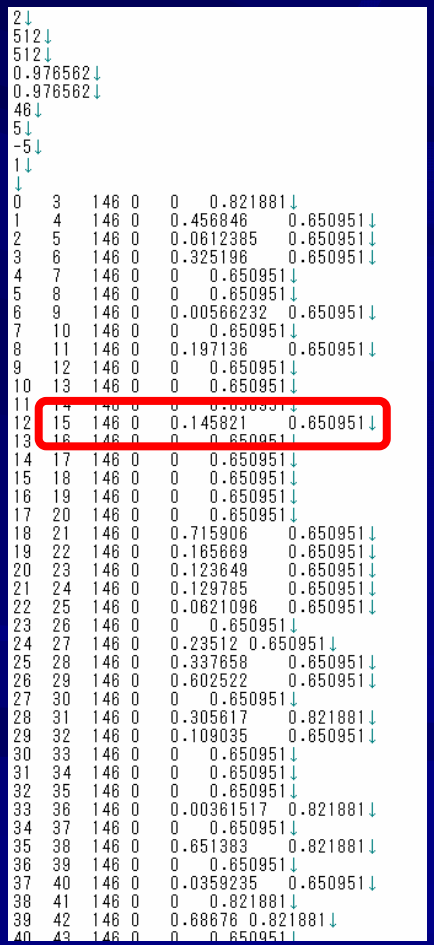
$$\text{Dose} = \frac{\text{Energy deposition}}{\text{Physical density}}$$

Compress: 2
The number of slices: 46



Process flow in 2-D Dose-CT Mapping (Dose data)

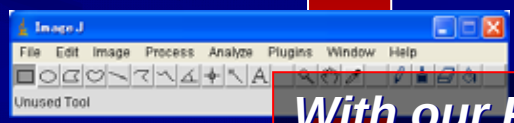
- Load output data



2↓
512↓
512↓
0.976562↓
0.976562↓
46↓
5↓
-5↓
1↓
↓

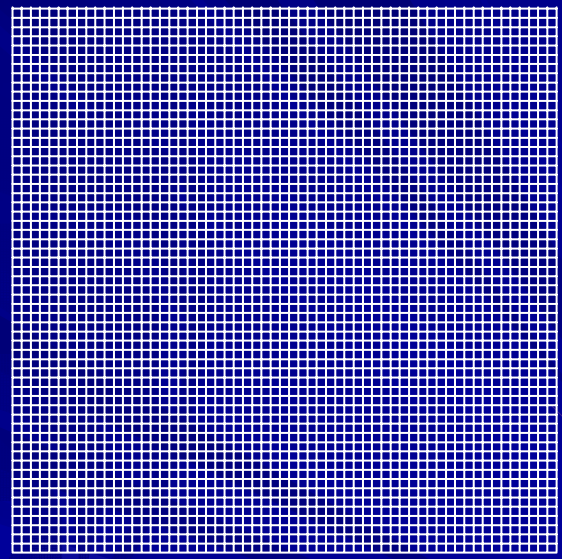
0	3	146	0	0	0.821881	↓
1	4	146	0	0.456846	0.650951	↓
2	5	146	0	0.0612385	0.650951	↓
3	6	146	0	0.325196	0.650951	↓
4	7	146	0	0	0.650951	↓
5	8	146	0	0	0.650951	↓
6	9	146	0	0.00566232	0.650951	↓
7	10	146	0	0	0.650951	↓
8	11	146	0	0.197136	0.650951	↓
9	12	146	0	0	0.650951	↓
10	13	146	0	0	0.650951	↓
11	14	146	0	0	0.650951	↓
12	15	146	0	0.145821	0.650951	↓
13	16	146	0	0	0.650951	↓
14	17	146	0	0	0.650951	↓
15	18	146	0	0	0.650951	↓
16	19	146	0	0	0.650951	↓
17	20	146	0	0	0.650951	↓
18	21	146	0	0.715906	0.650951	↓
19	22	146	0	0.165669	0.650951	↓
20	23	146	0	0.123649	0.650951	↓
21	24	146	0	0.129785	0.650951	↓
22	25	146	0	0.0621096	0.650951	↓
23	26	146	0	0	0.650951	↓
24	27	146	0	0.23512	0.650951	↓
25	28	146	0	0.337658	0.650951	↓
26	29	146	0	0.602522	0.650951	↓
27	30	146	0	0	0.650951	↓
28	31	146	0	0.305617	0.821881	↓
29	32	146	0	0.109035	0.650951	↓
30	33	146	0	0	0.650951	↓
31	34	146	0	0	0.650951	↓
32	35	146	0	0	0.650951	↓
33	36	146	0	0.00361517	0.821881	↓
34	37	146	0	0	0.650951	↓
35	38	146	0	0.651383	0.821881	↓
36	39	146	0	0	0.650951	↓
37	40	146	0	0.0359235	0.650951	↓
38	41	146	0	0	0.821881	↓
39	42	146	0	0.68676	0.821881	↓
40	43	146	0	0	0.650951	↓

x	y	z	Energy deposition	physical density
15	146	0	0.145821	0.650951



With our Plugin

$$\text{Dose} = \frac{\text{Energy deposit}}{\text{Physical density}}$$



Compress: 2
The number of slices: 46

Process flow in 2-D Dose-CT Mapping (Dose data)

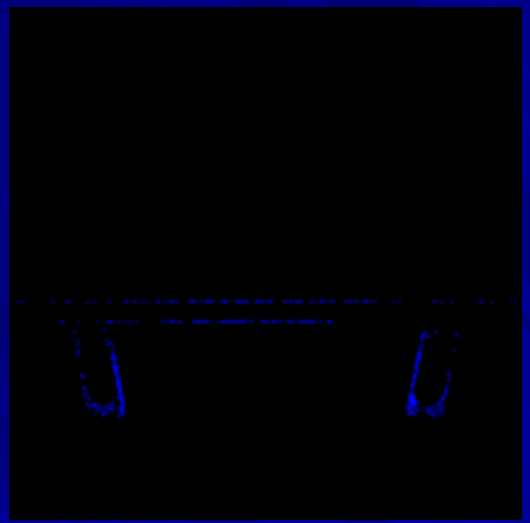
- Load output data

```
2↓
512↓
512↓
0.976562↓
0.976562↓
46↓
5↓
-5↓
1↓
↓
0   3   146 0   0   0.821881↓
1   4   146 0   0.456846    0.650951↓
2   5   146 0   0.0612385   0.650951↓
3   6   146 0   0.325196    0.650951↓
4   7   146 0   0   0.650951↓
5   8   146 0   0   0.650951↓
6   9   146 0   0.00566232  0.650951↓
7   10  146 0   0   0.650951↓
8   11  146 0   0.197136    0.650951↓
9   12  146 0   0   0.650951↓
10  13  146 0   0   0.650951↓
11  14  146 0   0   0.650951↓
12  15  146 0   0.145821    0.650951↓
13  16  146 0   0   0.650951↓
14  17  146 0   0   0.650951↓
15  18  146 0   0   0.650951↓
16  19  146 0   0   0.650951↓
17  20  146 0   0   0.650951↓
18  21  146 0   0.715906    0.650951↓
19  22  146 0   0.165669    0.650951↓
20  23  146 0   0.123649    0.650951↓
21  24  146 0   0.129785    0.650951↓
22  25  146 0   0.0621096   0.650951↓
23  26  146 0   0   0.650951↓
24  27  146 0   0.23512 0.650951↓
25  28  146 0   0.337658    0.650951↓
26  29  146 0   0.602522    0.650951↓
27  30  146 0   0   0.650951↓
28  31  146 0   0.305617    0.821881↓
29  32  146 0   0.109035    0.650951↓
30  33  146 0   0   0.650951↓
31  34  146 0   0   0.650951↓
32  35  146 0   0   0.650951↓
33  36  146 0   0.00361517  0.821881↓
34  37  146 0   0   0.650951↓
35  38  146 0   0.651383    0.821881↓
36  39  146 0   0   0.650951↓
37  40  146 0   0.0359235   0.650951↓
38  41  146 0   0   0.821881↓
39  42  146 0   0.68676 0.821881↓
40  43  146 0   0   0.650951↓
```

x	y	z	energy deposit	physical density
15	146	0	0.145821	0.650951

With our Plugin

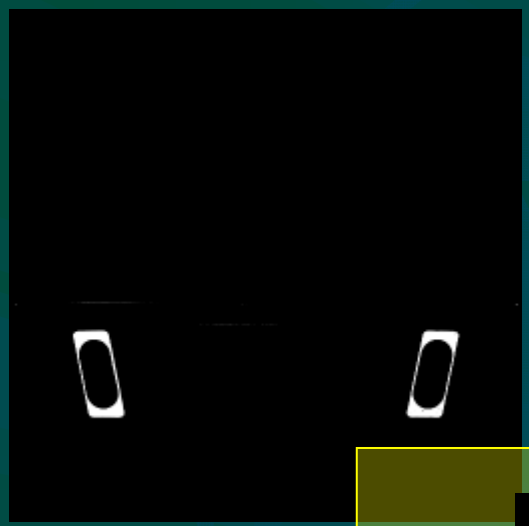
$$\text{Dose} = \frac{\text{Energy deposit}}{\text{Physical density}}$$



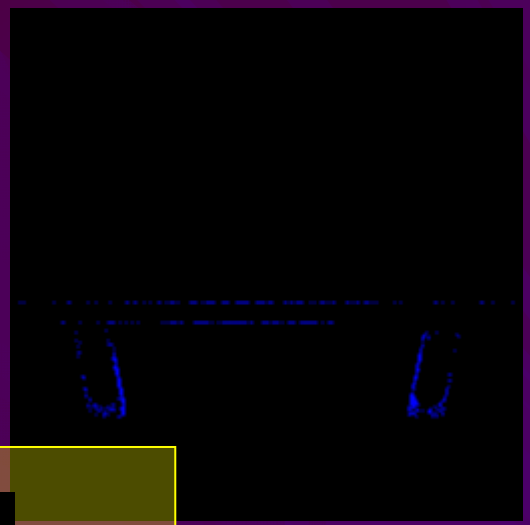
Compress: 2

The number of slices: 46

Process flow in 2-D Dose-CT Mapping (Dose mapping on CT image)



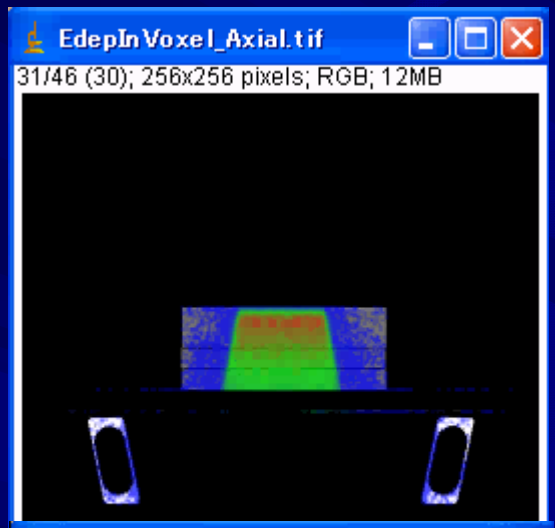
CT images

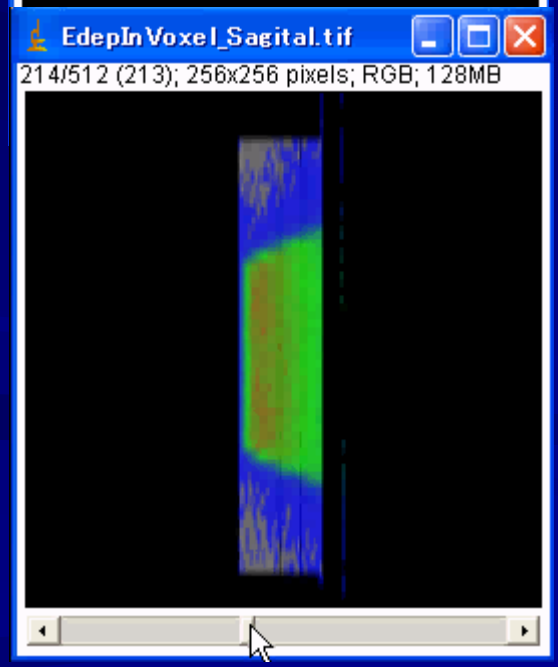


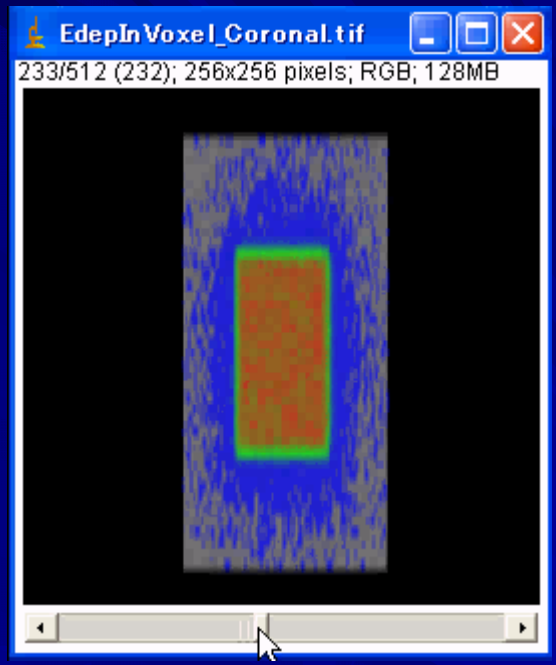
Dose images

2-D Dose-CT images

Process flow in 2-D Dose-CT Mapping (2-D dose map)

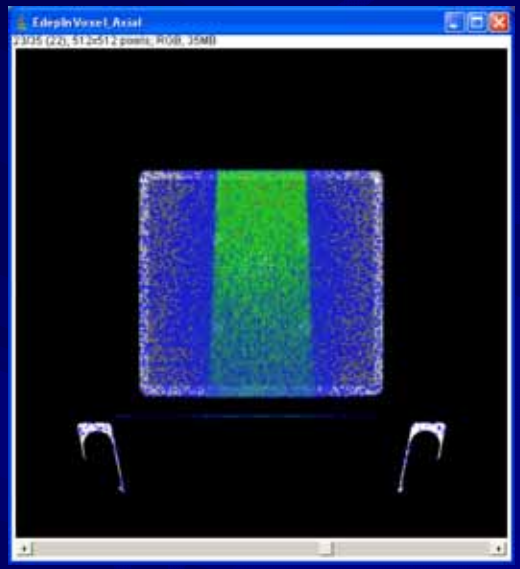


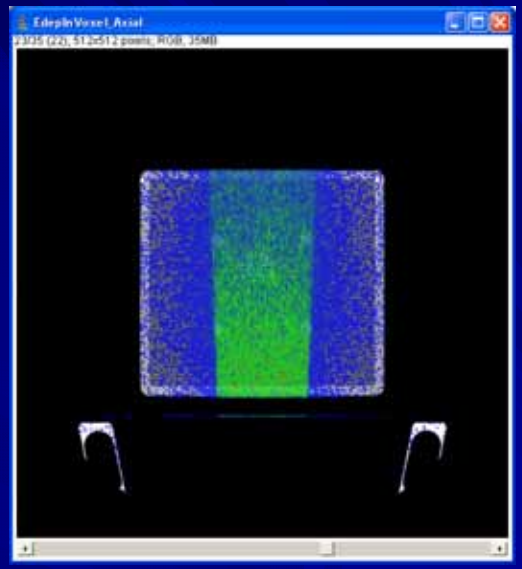


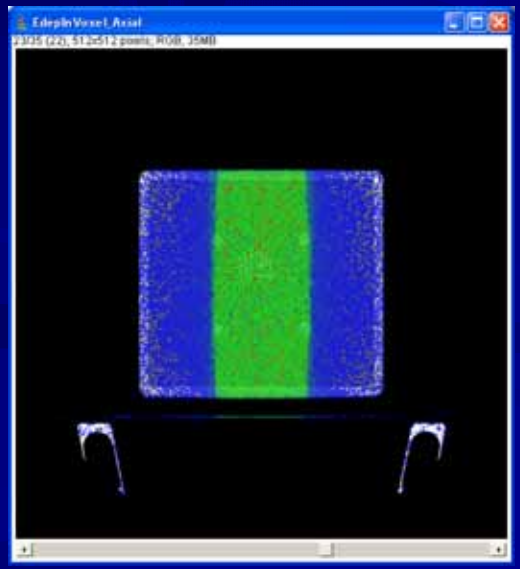


Axial	Coronal
Sagittal	

Process flow in 2-D Dose-CT Mapping (2-D dose map)

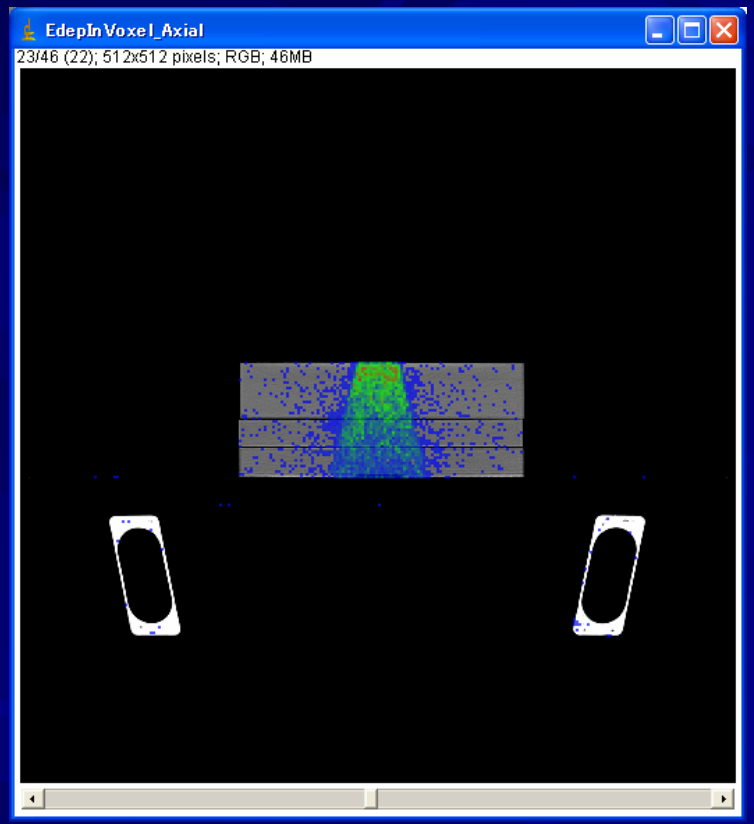




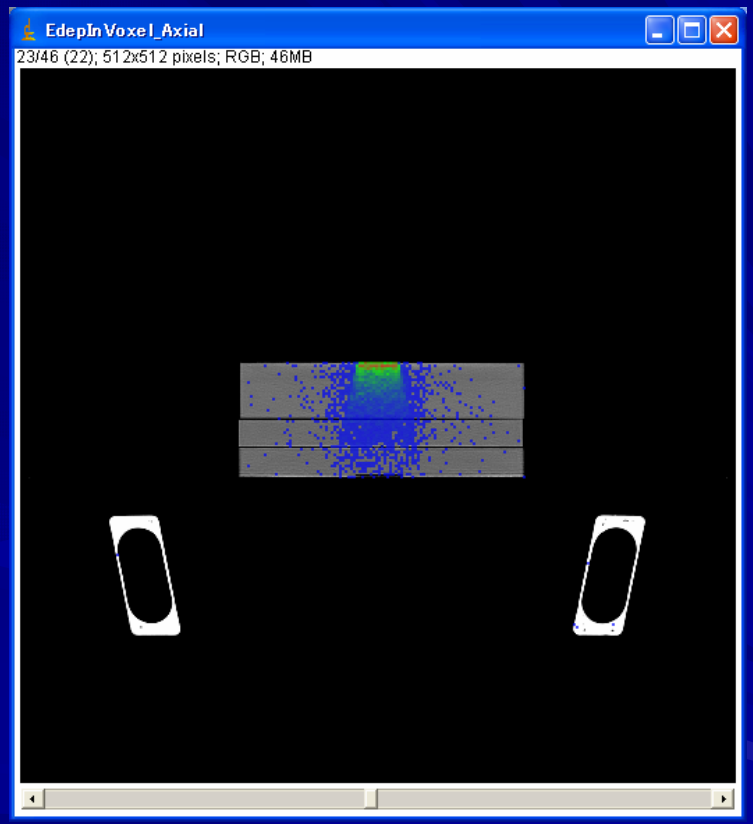


1	1
2	

Process flow in 2-D Dose-CT Mapping
(Difference between high-energy and low-energy)



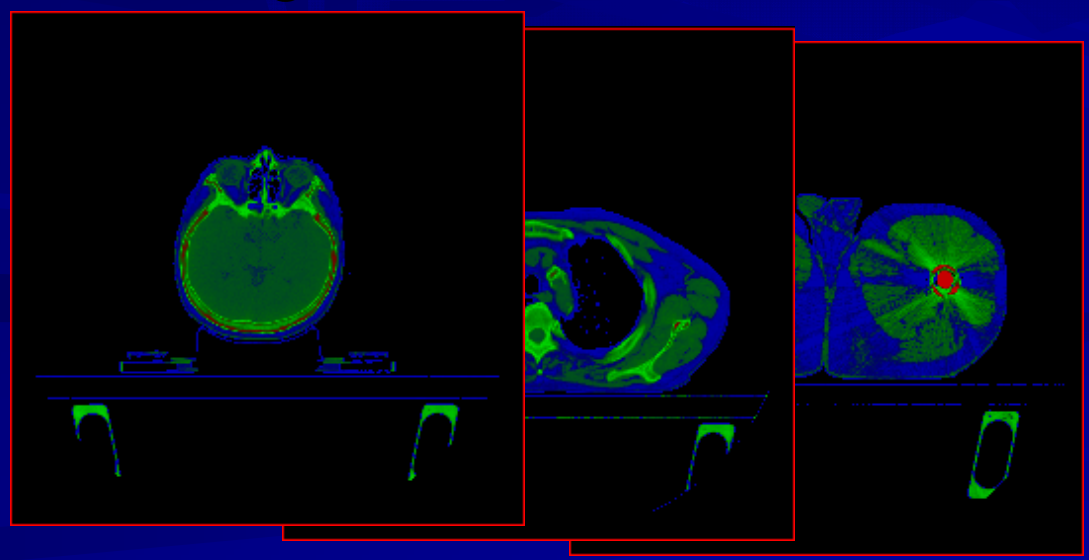
4MV X-ray

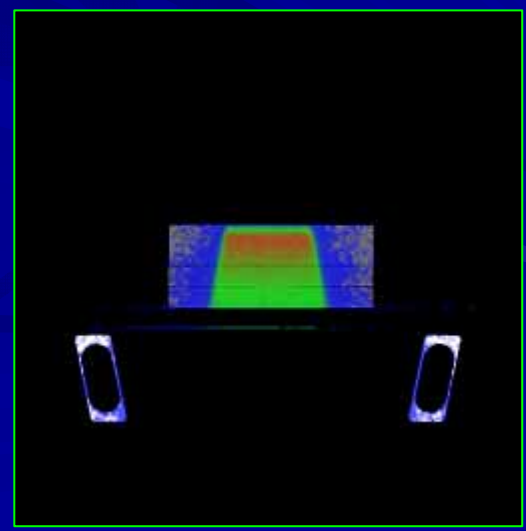


40KV X-ray

Summary

- We designed and developed 2-D Dose-CT Mapping software using Geant4 and ImageJ
  - To convert CT image to a format that can be processed in Geant4
  - To display dose mapping on CT image using ImageJ





Future work

- To optimize radiation therapy verification tool
  - The enormous amount of time necessary to calculate dose by CT images
    - Remove extra voxel ex) Air outside body
  - Dose Analysis Tool
    - Dose Volume Histogram
    - etc…
  - Irregular Shape Field
  - Dynamic Wedge
  - Dynamic Multi-Leaf Collimator

Acknowledgement

Satoko Saotome [*1], Yutaka Takahashi [*2], Iori Sumida [*2,3], Teruo Ito [*1], Minoru Yoshioka [*1], Takeo Hashimoto [*1], Tomoharu Sato [*1], Takayuki Nose [*2,3], Akio Kuramoto [*1], Akira Ito [*2], Takashi Yamashita [*2,3]

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***2 The Cancer Institute of JFCR, Physics Dept.**

***3 The Cancer Institute Hospital of JFCR, Radiation Oncology Dept.**