
Power Spectrum Normalization and Comparison

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10/18/1998

The goals of this notebook are twofold:

- First, to generate a set of normalized spectra for use by the CXrL ToolSet;
- Second, to analyze the spectral power distribution at the field sites.

Normalization

In this notebook we open the files created by GLOBAL_ANALYSIS and normalize them to a specific total power. The value is set the next line:

```
refpower = .100;
```

We recurse through the directory tree, compute the total power in the file and rescale to get the amount specified above. The only difference in the files (with a file specifier of "norm") will then be in the spectral distribution.

This step is taken because SHADOW does not generate power information directly, and the ToolSet requires that the input field be Watts/cm². In addition, in order to study the effect of spectral changes it is necessary to isolate the effect of dose variation and spectrum change. The dose variation can be introduced later, once the exposure latitude has been computed.

We also generate the difference between the spectra for further analysis

```
Clear@savedataD;  
savedata = Table@Table@0, 8i, 45<, 8j, 2<D, 8i, 9<, 8j, 3<D;  
Print@"-----"D  
Print@"-----"D  
Print@Date@DD  
Print@"-----"D  
For@k = 1, k < 10, k++,  
H* Define input directory *L  
Print@"-----"D  
Print@"Loop k= ", kD;  
Which@k == 1,  
workdir = "f:•sumitomo•tracing•top•central",
```

```
k == 2,
workdir = "f:•sumitomo•tracing•top•middle",
k == 3,
workdir = "f:•sumitomo•tracing•top•right",
k == 4,
workdir = "f:•sumitomo•tracing•center•central",
k == 5,
workdir = "f:•sumitomo•tracing•center•middle",
k == 6,
workdir = "f:•sumitomo•tracing•center•right",
k == 7,
workdir = "f:•sumitomo•tracing•bottom•central",
k == 8,
workdir = "f:•sumitomo•tracing•bottom•middle",
k == 9,
workdir = "f:•sumitomo•tracing•bottom•right"D
SetDirectory@workdirD;
Print@"Working in directory: ", workdirD;
For@j = 1, j < 4, j++,
Clear@data, ndata, powerD;
Which@j == 1,
infile = workdir <> "•spectrum.hist",
j == 2,
infile = workdir <> "•spectrum_Be.hist",
j == 3,
infile = workdir <> "•spectrum_M0.hist"
D;
Print@"Reading from file: ", infileD;
OpenRead@infileD;
data = Read@infileD;
Close@infileD;
nhisto = Length@dataD;
step = data@@2, 1DD - data@@1, 1DD;
Clear@powerD;
power = Sum@data@@jk, 2DD * step, 8jk, 1, nhisto<D;
Print@"Power found Ha.u.L: ", powerD;
ndata =
  Table@8data@@jk, 1DD, data@@jk, 2DD * power * refpower<, 8jk, 1, nhisto<D;
Which@j == 1,
name = "•spectrum.norm",
j == 2,
name = "•spectrum_Be.norm",
j == 3,
name = "•spectrum_M0.norm"
D;
outfile = workdir <> name;
Print@"Writing to output file: ", outfileD;
```

```
ostream = OpenWrite@outfileD;  
Write@ostream, ndataD;  
Close@ostreamD;  
savedata@@k, jDD = data;  
DH* J-loop: files *L  
D  
H* K-loop: directories *L
```

```
-----  
-----  
81998, 10, 14, 19, 15, 37<  
-----  
-----
```

```
Loop k= 1
```

```
Working in directory: f:•sumitomo•tracing•top•central
```

```
Reading from file: f:•sumitomo•tracing•top•central•spectrum.hist
```

```
Power found:  $2.51454 \times 10^8$ 
```

```
Writing to output file: f:•sumitomo•tracing•top•central•spectrum.norm
```

```
Reading from file: f:•sumitomo•tracing•top•central•spectrum_Be.hist
```

```
Power found:  $4.52117 \times 10^8$ 
```

```
Writing to output file: f:•sumitomo•tracing•top•central•spectrum_Be.norm
```

```
Reading from file: f:•sumitomo•tracing•top•central•spectrum_M0.hist
```

```
Power found:  $1.68036 \times 10^9$ 
```

```
Writing to output file: f:•sumitomo•tracing•top•central•spectrum_M0.norm  
-----
```

```
Loop k= 2
```

```
Working in directory: f:•sumitomo•tracing•top•middle
```

```
Reading from file: f:•sumitomo•tracing•top•middle•spectrum.hist
```

```
Power found:  $2.38674 \times 10^8$ 
```

```
Writing to output file: f:•sumitomo•tracing•top•middle•spectrum.norm
```

```
Reading from file: f:•sumitomo•tracing•top•middle•spectrum_Be.hist
```

```
Power found:  $4.28078 \times 10^8$ 
```

```
Writing to output file: f:•sumitomo•tracing•top•middle•spectrum_Be.norm
```

```
Reading from file: f:•sumitomo•tracing•top•middle•spectrum_M0.hist
```

```
Power found:  $1.67153 \times 10^9$ 
```

```
Writing to output file: f:•sumitomo•tracing•top•middle•spectrum_M0.norm  
-----
```

```
Loop k= 3
```

```
Working in directory: f:•sumitomo•tracing•top•right
```

```
Reading from file: f:•sumitomo•tracing•top•right•spectrum.hist
```

```
Power found:  $1.89144 \times 10^8$ 
```

```
Writing to output file: f:•sumitomo•tracing•top•right•spectrum.norm
```

```
Reading from file: f:•sumitomo•tracing•top•right•spectrum_Be.hist
```

```
Power found:  $3.37138 \times 10^8$ 
```

```
Writing to output file: f:•sumitomo•tracing•top•right•spectrum_Be.norm
```

```
Reading from file: f:•sumitomo•tracing•top•right•spectrum_M0.hist
```

```
Power found:  $1.63906 \times 10^9$ 
```

```
Writing to output file: f:\sumitomo\tracing\top\right\spectrum_M0.norm
-----
Loop k= 4
Working in directory: f:\sumitomo\tracing\center\central
Reading from file: f:\sumitomo\tracing\center\central\spectrum.hist
Power found:  $2.71052 \times 10^8$ 
Writing to output file: f:\sumitomo\tracing\center\central\spectrum.norm
Reading from file: f:\sumitomo\tracing\center\central\spectrum_Be.hist
Power found:  $4.86993 \times 10^8$ 
Writing to output file: f:\sumitomo\tracing\center\central\spectrum_Be.norm
Reading from file: f:\sumitomo\tracing\center\central\spectrum_M0.hist
Power found:  $1.74553 \times 10^9$ 
Writing to output file: f:\sumitomo\tracing\center\central\spectrum_M0.norm
-----
Loop k= 5
Working in directory: f:\sumitomo\tracing\center\middle
Reading from file: f:\sumitomo\tracing\center\middle\spectrum.hist
Power found:  $2.57266 \times 10^8$ 
Writing to output file: f:\sumitomo\tracing\center\middle\spectrum.norm
Reading from file: f:\sumitomo\tracing\center\middle\spectrum_Be.hist
Power found:  $4.61252 \times 10^8$ 
Writing to output file: f:\sumitomo\tracing\center\middle\spectrum_Be.norm
Reading from file: f:\sumitomo\tracing\center\middle\spectrum_M0.hist
Power found:  $1.73504 \times 10^9$ 
Writing to output file: f:\sumitomo\tracing\center\middle\spectrum_M0.norm
-----
Loop k= 6
Working in directory: f:\sumitomo\tracing\center\right
Reading from file: f:\sumitomo\tracing\center\right\spectrum.hist
Power found:  $2.04303 \times 10^8$ 
Writing to output file: f:\sumitomo\tracing\center\right\spectrum.norm
Reading from file: f:\sumitomo\tracing\center\right\spectrum_Be.hist
Power found:  $3.64469 \times 10^8$ 
Writing to output file: f:\sumitomo\tracing\center\right\spectrum_Be.norm
Reading from file: f:\sumitomo\tracing\center\right\spectrum_M0.hist
Power found:  $1.69748 \times 10^9$ 
Writing to output file: f:\sumitomo\tracing\center\right\spectrum_M0.norm
-----
Loop k= 7
Working in directory: f:\sumitomo\tracing\bottom\central
Reading from file: f:\sumitomo\tracing\bottom\central\spectrum.hist
Power found:  $2.89766 \times 10^8$ 
Writing to output file: f:\sumitomo\tracing\bottom\central\spectrum.norm
Reading from file: f:\sumitomo\tracing\bottom\central\spectrum_Be.hist
Power found:  $5.19457 \times 10^8$ 
Writing to output file: f:\sumitomo\tracing\bottom\central\spectrum_Be.norm
Reading from file: f:\sumitomo\tracing\bottom\central\spectrum_M0.hist
Power found:  $1.80483 \times 10^9$ 
```

```
Writing to output file: f:\sumitomo\tracing\bottom\central\spectrum_M0.norm
-----
Loop k= 8
Working in directory: f:\sumitomo\tracing\bottom\middle
Reading from file: f:\sumitomo\tracing\bottom\middle\spectrum.hist
Power found: 2.74572×108
Writing to output file: f:\sumitomo\tracing\bottom\middle\spectrum.norm
Reading from file: f:\sumitomo\tracing\bottom\middle\spectrum_Be.hist
Power found: 4.91361×108
Writing to output file: f:\sumitomo\tracing\bottom\middle\spectrum_Be.norm
Reading from file: f:\sumitomo\tracing\bottom\middle\spectrum_M0.hist
Power found: 1.79133×109
Writing to output file: f:\sumitomo\tracing\bottom\middle\spectrum_M0.norm
-----
Loop k= 9
Working in directory: f:\sumitomo\tracing\bottom\right
Reading from file: f:\sumitomo\tracing\bottom\right\spectrum.hist
Power found: 2.18658×108
Writing to output file: f:\sumitomo\tracing\bottom\right\spectrum.norm
Reading from file: f:\sumitomo\tracing\bottom\right\spectrum_Be.hist
Power found: 3.89697×108
Writing to output file: f:\sumitomo\tracing\bottom\right\spectrum_Be.norm
Reading from file: f:\sumitomo\tracing\bottom\right\spectrum_M0.hist
Power found: 1.7498×109
Writing to output file: f:\sumitomo\tracing\bottom\right\spectrum_M0.norm
```

outfile

f:\sumitomo\tracing\bottom\right\spectrum_M0.norm

```
ndata
```

```
88500, 0.00010065<, 8600, 0.0000912959<, 8700, 0.0000858799<,
 8800, 0.0000820131<, 8900, 0.0000753424<, 81000, 0.0000711823<,
 81100, 0.0000616736<, 81200, 0.0000609649<, 81300, 0.0000514746<,
 81400, 0.0000478138<, 81500, 0.0000462661<, 81600, 0.0000367676<,
 81700, 0.0000339641<, 81800, 0.0000310167<, 81900, 0.0000243958<,
 82000, 0.0000190702<, 82100, 6.64798 × 10-6<, 82200, 7.05367 × 10-6<,
 82300, 8.29373 × 10-6<, 82400, 6.8009 × 10-6<, 82500, 7.82866 × 10-6<,
 82600, 5.93386 × 10-6<, 82700, 5.40447 × 10-6<, 82800, 5.59411 × 10-6<,
 82900, 4.37739 × 10-6<, 83000, 4.39943 × 10-6<, 83100, 2.98777 × 10-6<,
 83200, 2.69129 × 10-6<, 83300, 2.81918 × 10-6<, 83400, 1.99983 × 10-6<,
 83500, 1.53231 × 10-6<, 83600, 1.41222 × 10-6<, 83700, 1.01658 × 10-6<,
 83800, 5.05518 × 10-7<, 83900, 8.11344 × 10-7<, 84000, 3.57305 × 10-7<,
 84100, 4.81534 × 10-7<, 84200, 3.14788 × 10-7<, 84300, 2.63826 × 10-7<,
 84400, 1.40797 × 10-7<, 84500, 1.84786 × 10-7<, 84600, 1.41295 × 10-7<,
 84700, 1.15614 × 10-7<, 84800, 5.25806 × 10-8<, 84900, 6.62811 × 10-8<<
```

And let's verify that the integral is indeed correct:

```
tpower = Sum@ndata@@jk, 2DD * step, 8jk, 1, nhisto<D
```

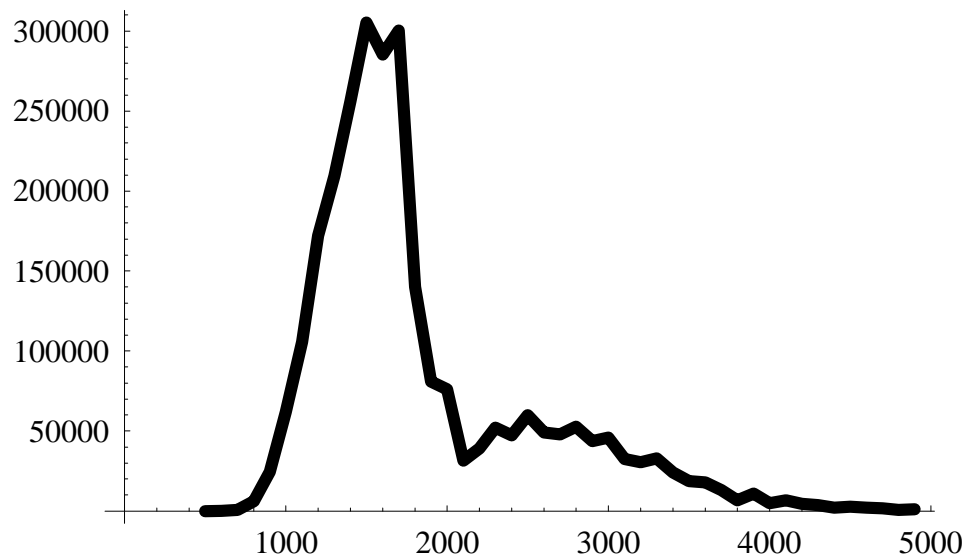
```
0.1
```

All done.

Analysis of Spectrum (No scaling).

Let's compute the difference between spectra in reference to the /Central/Center one; this is located in savedata[[4,1]]

```
ListPlot@savedata@@4, 1DD, PlotJoined -> True, PlotStyle -> Thickness@0.015DD;
```



```
difference = Table@8savedata@@4, 1, j, 1DD,  
  Hsavedata@@i, 1, j, 2DD - savedata@@4, 1, j, 2DDL • savedata@@4, 1, j, 2DD <,  
  8i, 9<, 8j, nhisto<D;
```

Let us test the output:

```
Dimensions@differenceD
```

```
89, 45, 2<
```

```
difference@@3DD
```

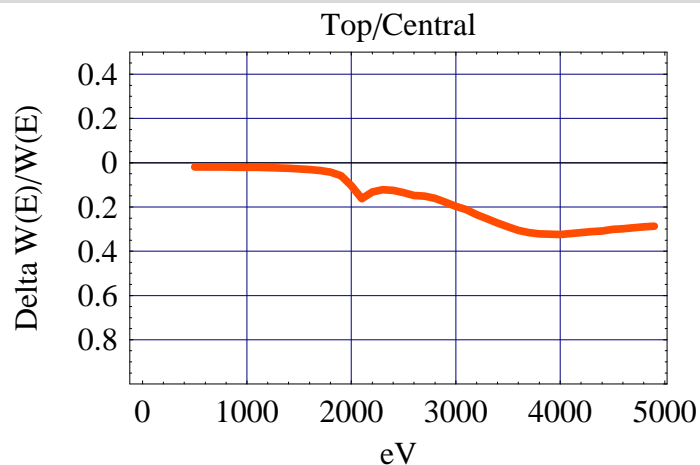
```
88500, -0.988147<, 8600, -0.945921<, 8700, -0.869093<, 8800, -0.769491<,
8900, -0.662744<, 81000, -0.561143<, 81100, -0.474778<, 81200, -0.401392<,
81300, -0.342076<, 81400, -0.294681<, 81500, -0.258111<, 81600, -0.230176<,
81700, -0.210301<, 81800, -0.200488<, 81900, -0.205561<, 82000, -0.261743<,
82100, -0.323002<, 82200, -0.272641<, 82300, -0.253343<, 82400, -0.252267<,
82500, -0.261395<, 82600, -0.277619<, 82700, -0.277432<, 82800, -0.290359<,
82900, -0.313093<, 83000, -0.336111<, 83100, -0.354559<, 83200, -0.382592<,
83300, -0.404186<, 83400, -0.426036<, 83500, -0.443443<,
83600, -0.459437<, 83700, -0.468687<, 83800, -0.473272<,
83900, -0.471804<, 84000, -0.47084<, 84100, -0.464042<, 84200, -0.458754<,
84300, -0.452564<, 84400, -0.445907<, 84500, -0.440452<,
84600, -0.435329<, 84700, -0.428897<, 84800, -0.423989<, 84900, -0.418351<<
```

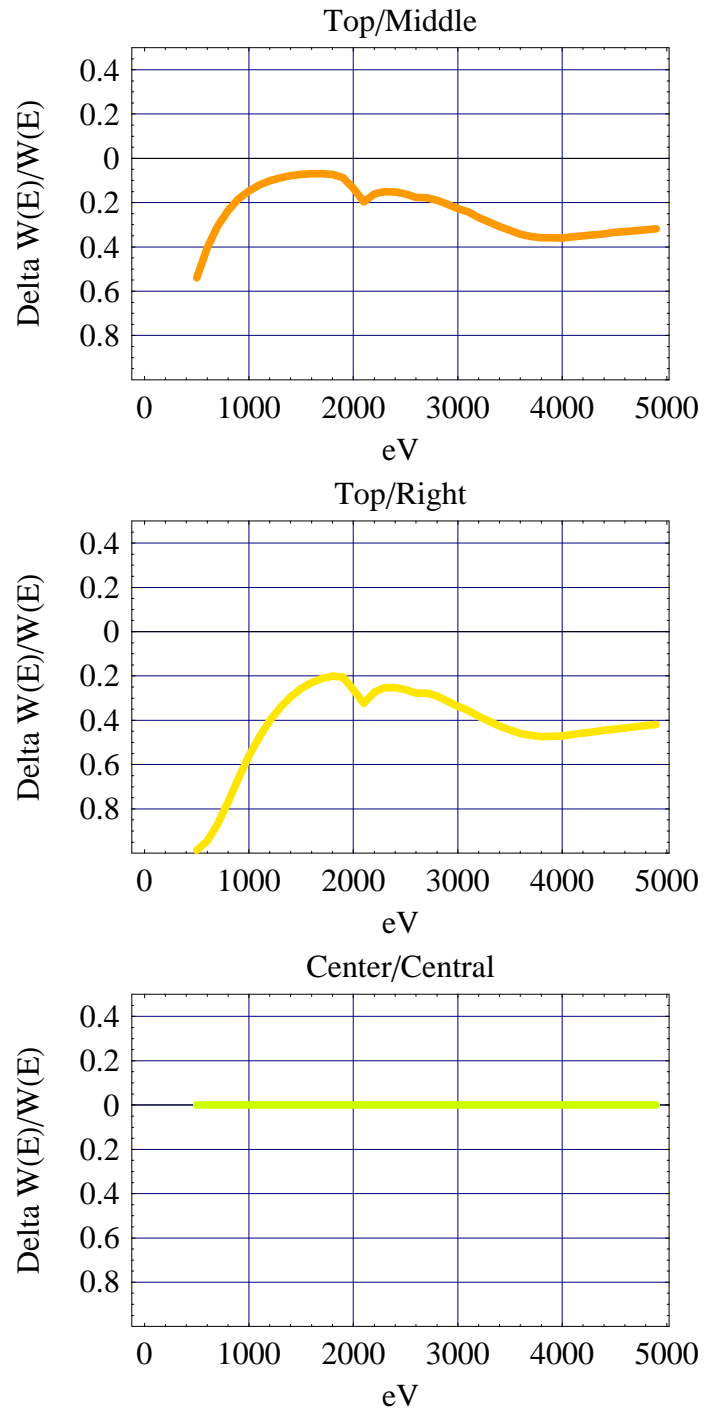
Define labels for plots:

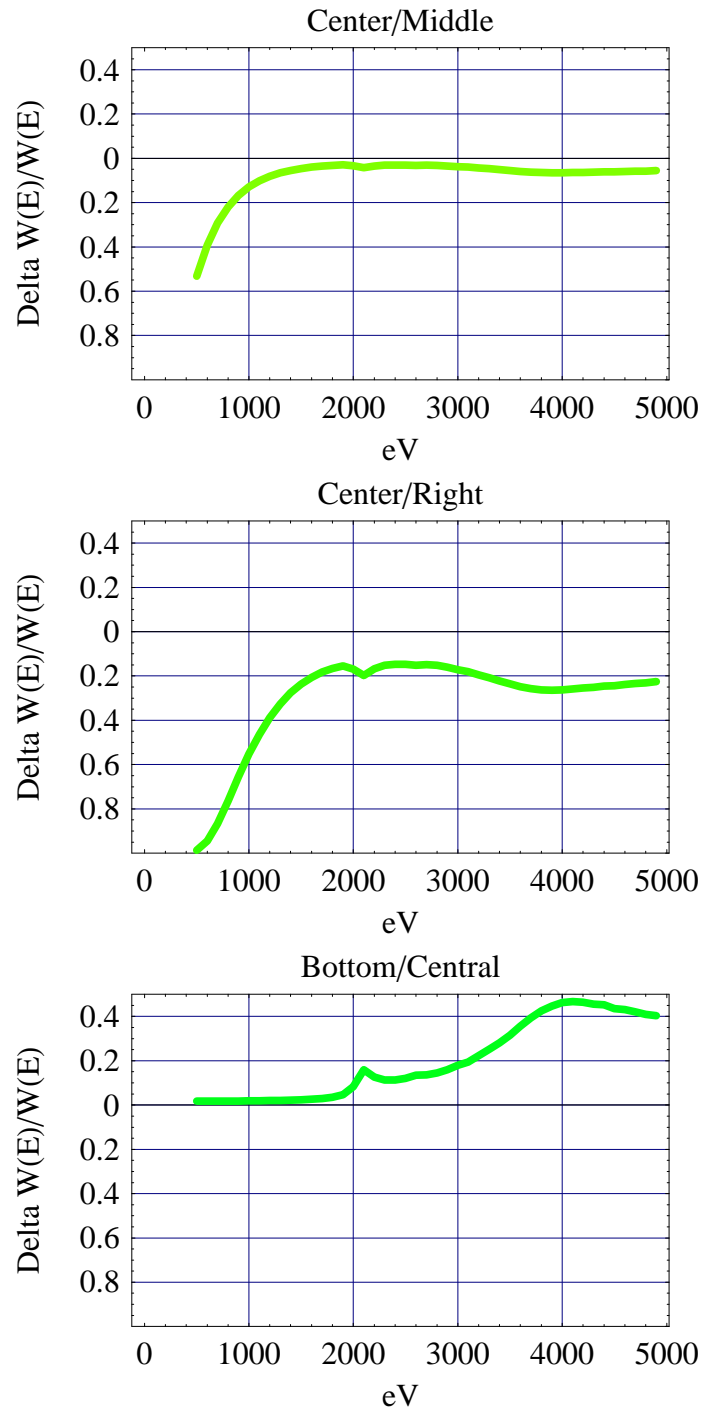
```
labelPlot = Flatten@Table@Take@8"Top•", "Center•", "Bottom•"<, 8i, i<D<>
  Take@8"Central", "Middle", "Right"<, 8j, j<D, 8i, 3<,
  8j, 3<DD
```

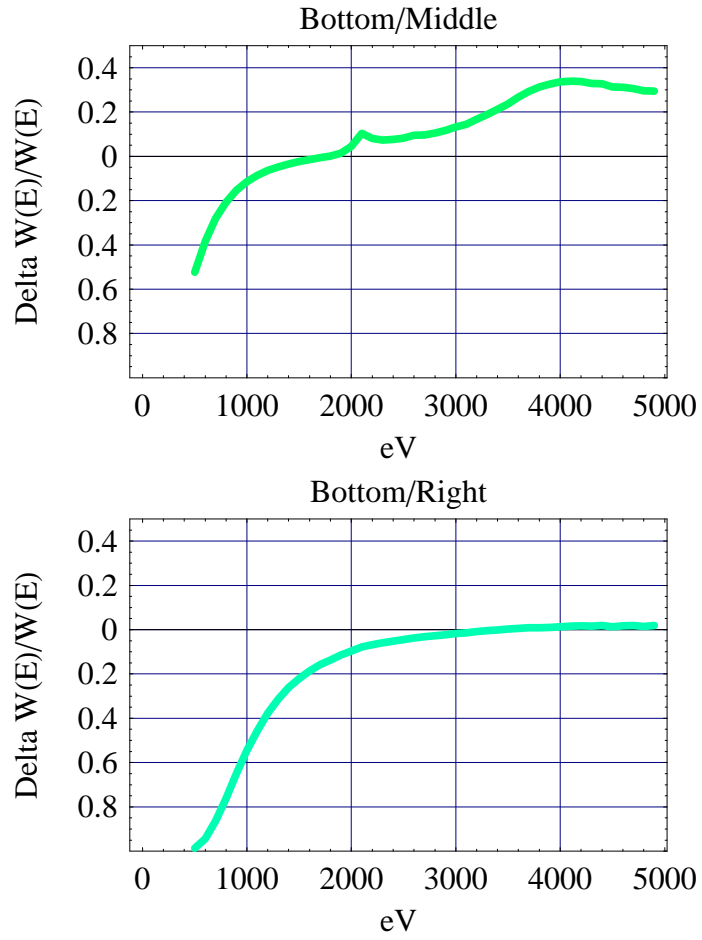
```
8Top•Central, Top•Middle, Top•Right, Center•Central, Center•Middle,
Center•Right, Bottom•Central, Bottom•Middle, Bottom•Right<
```

```
gplot = Table@ListPlot@difference@@iDD,
  PlotStyle -> 8Thickness@0.015D, Hue@i • 20D<, Frame -> True,
  PlotLabel -> labelPlot@@iDD, FrameLabel -> 8"eV", "Delta WHEL•WHEL"<,
  GridLines -> Automatic, PlotJoined -> True, PlotRange -> 8-1, 0.5<D,
  8i, 9<D;
```

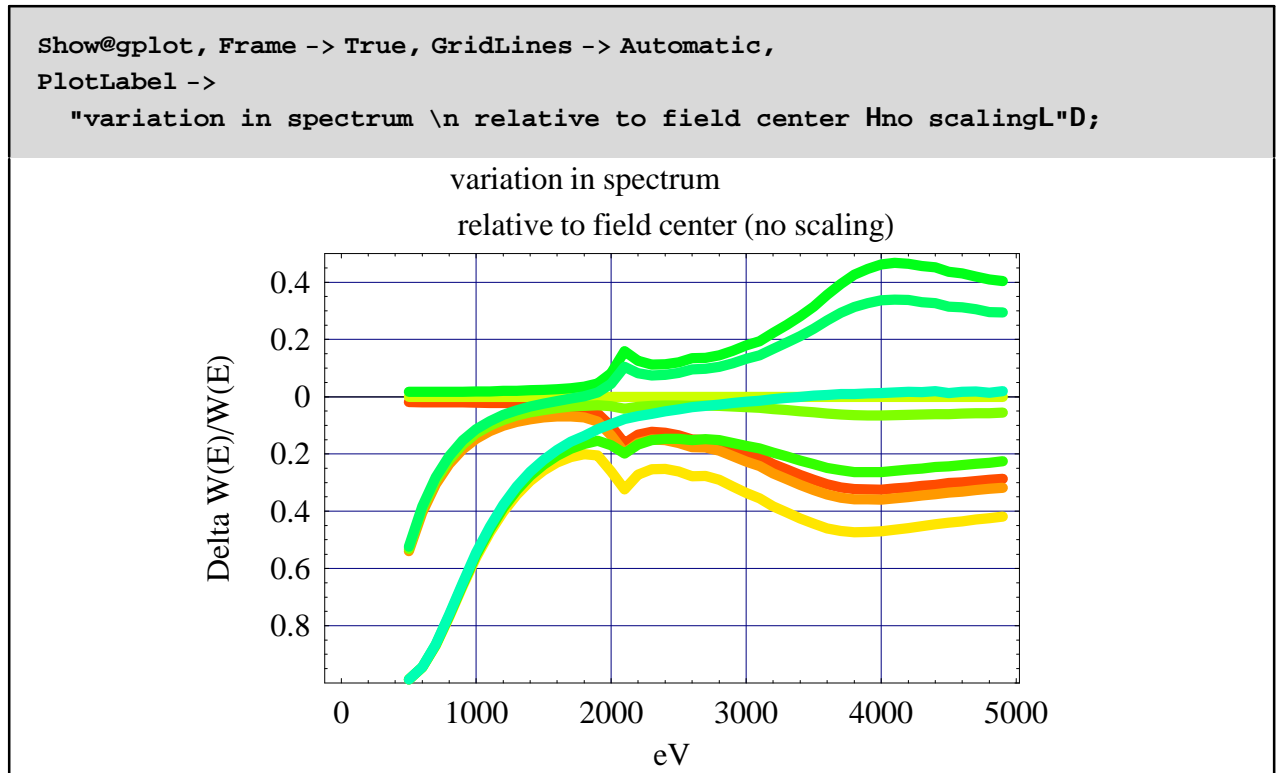








Needs@"Graphics`Legend`"D



The spectrum variation is asymmetric, as expected. It is easy to recognize the 3 cases; at low energy, the three "right" filed positions correspond to the lowest 3 curves (thicker Be suppresses lower energies).

Analysis of Spectrum (Scaling)

Compute power in each field site as stored in the data arrays:

```
snorm = Table@Sum@savedata@@@j, 1, i, 2DD, 8i, 45<D, 8j, 9<D
```

```
82.51454 × 106, 2.38674 × 106, 1.89144 × 106, 2.71052 × 106, 2.57266 × 106,
2.04303 × 106, 2.89766 × 106, 2.74572 × 106, 2.18658 × 106<
```

Read in the corrected power from Global Analysis:

```
temp = << "f:sumitomoPower_At_Field_Sites.dat";
```

Convert to expression, and rescale it so that we have correction factor of 1 for the field center:

```

scalingPower = Flatten@ToExpression@tempDD
temp = scalingPower@@4DD
scalingPower = scalingPower * temp

80.2690590779364057, 0.2735309985476516, 0.2844877582719838,
0.2789953590218849, 0.2839401911942135, 0.2969658688023587,
0.2878157519781886, 0.2929701589501116, 0.3080277924186272<

```

```
0.2789953590218849
```

```
80.964385, 0.980414, 1.01969, 1., 1.01772, 1.06441, 1.03161, 1.05009, 1.10406<
```

We now scale the spectra so that the data array of the center/central is not changed, and the others are renormalized to the value computed by Global_Analysis, i.e., including effect of scanning and Be transmission. In effect we discard the area of the spectra, and rescale them so that the new area is in agreement with Global_Analysis.

```

scalingFactor = scalingPower * snorm * snorm@@4DD

81.03955, 1.11342, 1.46126, 1., 1.07226, 1.41217, 0.964989, 1.03662, 1.36861<

```

We build a table of the spectral difference relative to the center of field spectrum:

```

difference =
Table@8savedata@@4, 1, j, 1DD, Hsavedata@@i, 1, j, 2DD scalingFactor@@iDD -
  savedata@@4, 1, j, 2DD scalingFactor@@4DDL *
  Hsavedata@@4, 1, j, 2DD scalingFactor@@4DDL<, 8i, 9<,
8j, nhisto<D;

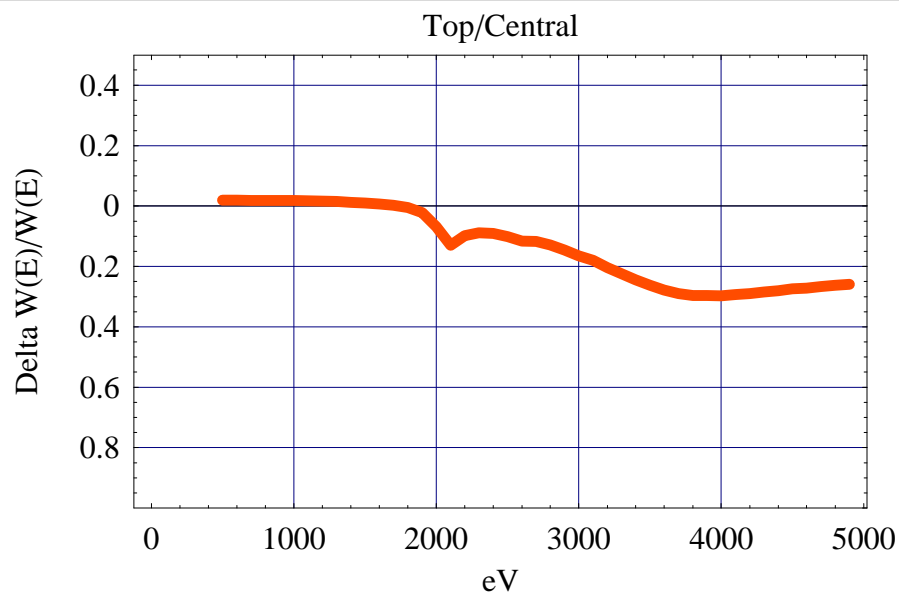
```

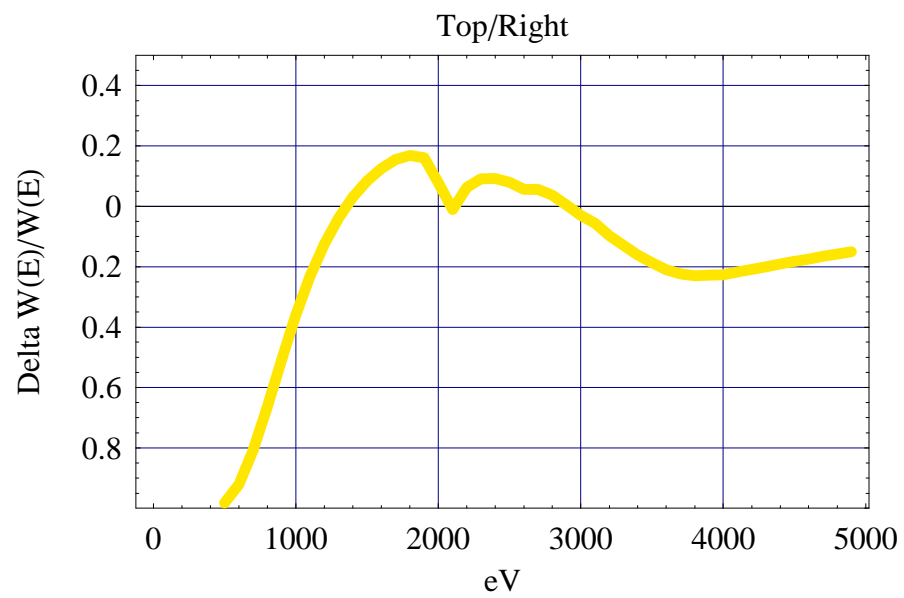
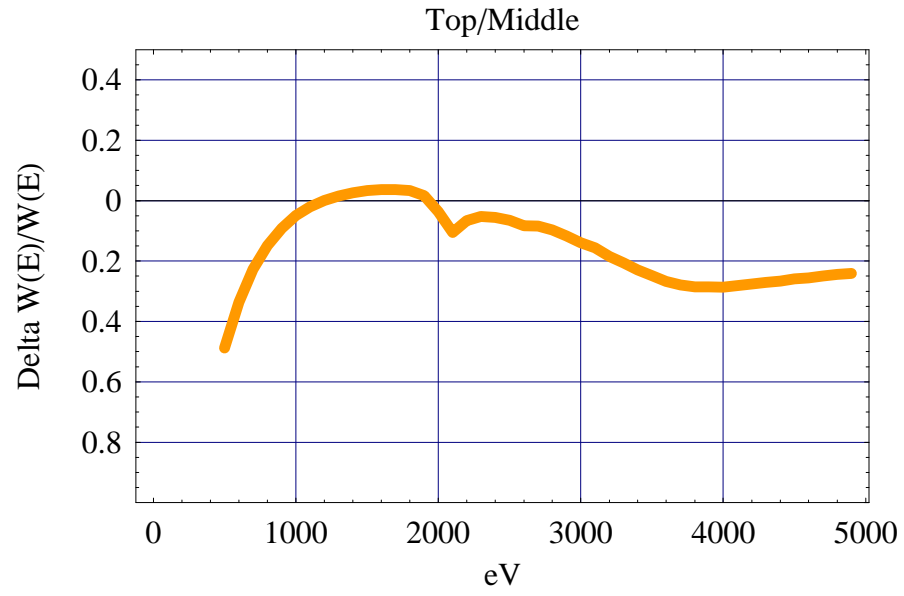
```
difference@@1DD
```

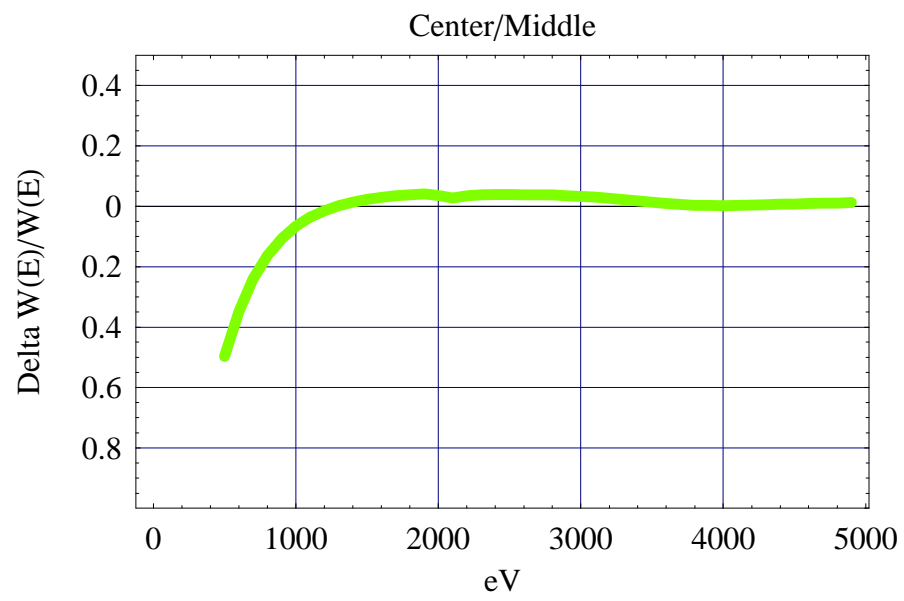
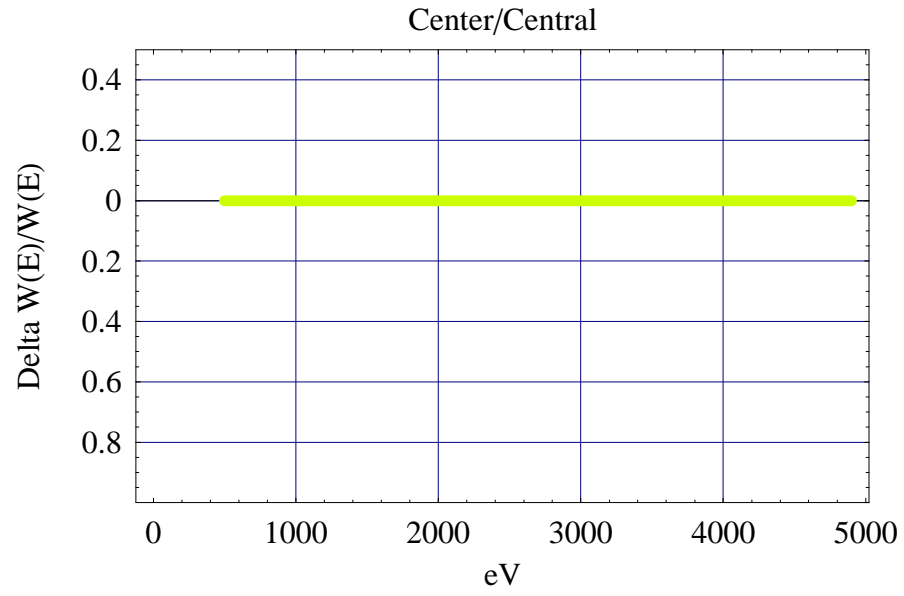
```
88500, 0.0197345<, 8600, 0.0196026<, 8700, 0.0188788<, 8800, 0.0188415<,
8900, 0.0185155<, 81000, 0.0179369<, 81100, 0.0172199<, 81200, 0.0160992<,
81300, 0.0147144<, 81400, 0.0128123<, 81500, 0.010374<, 81600, 0.00705608<,
81700, 0.00221913<, 81800, -0.00433131<, 81900, -0.021259<,
82000, -0.068321<, 82100, -0.129507<, 82200, -0.0980274<, 82300, -0.0880781<,
82400, -0.0909317<, 82500, -0.100639<, 82600, -0.115518<, 82700, -0.117553<,
82800, -0.128496<, 82900, -0.146011<, 83000, -0.164902<, 83100, -0.179876<,
83200, -0.204442<, 83300, -0.224313<, 83400, -0.244225<, 83500, -0.262183<,
83600, -0.278774<, 83700, -0.289753<, 83800, -0.296022<,
83900, -0.296739<, 84000, -0.2975<, 84100, -0.293475<, 84200, -0.289494<,
84300, -0.284423<, 84400, -0.280868<, 84500, -0.274337<,
84600, -0.271403<, 84700, -0.266425<, 84800, -0.262084<, 84900, -0.259054<<
```

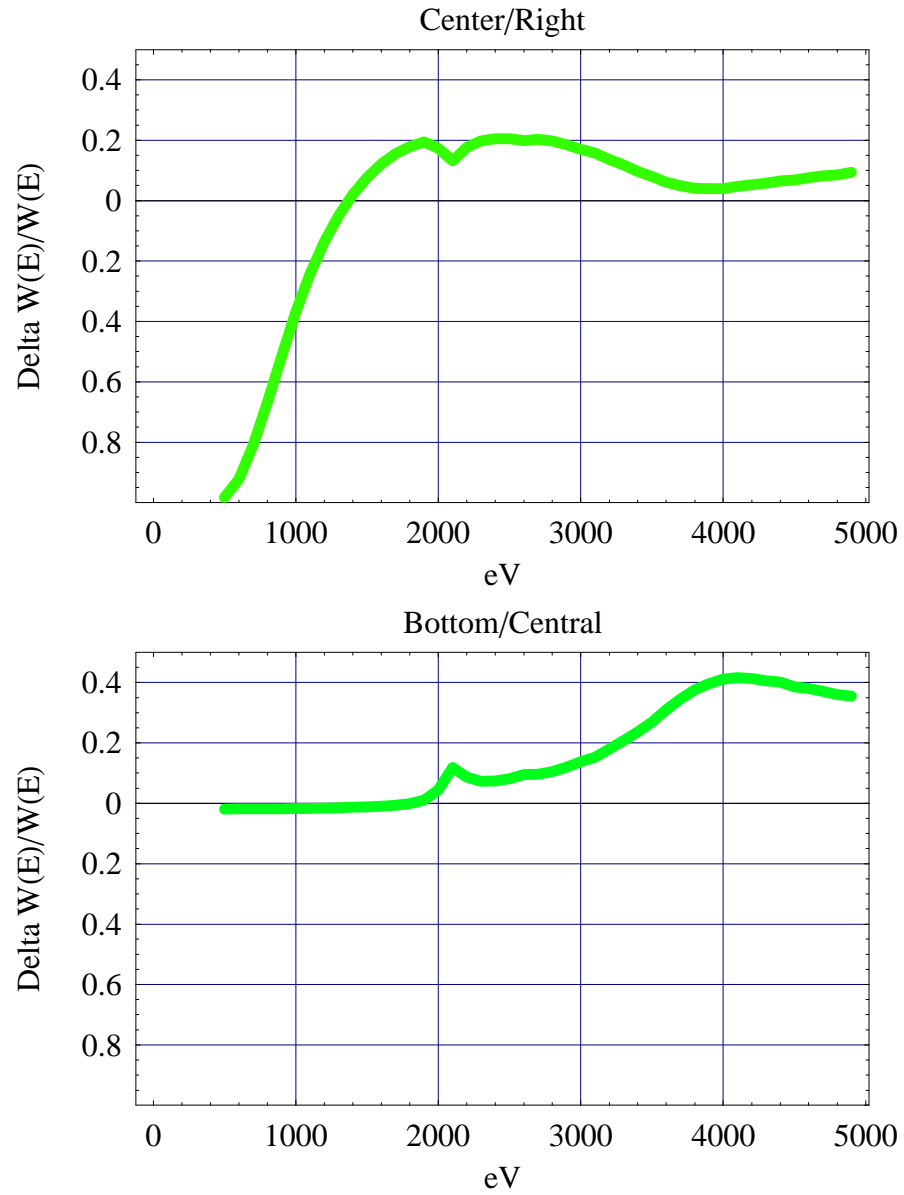
And we plot it:

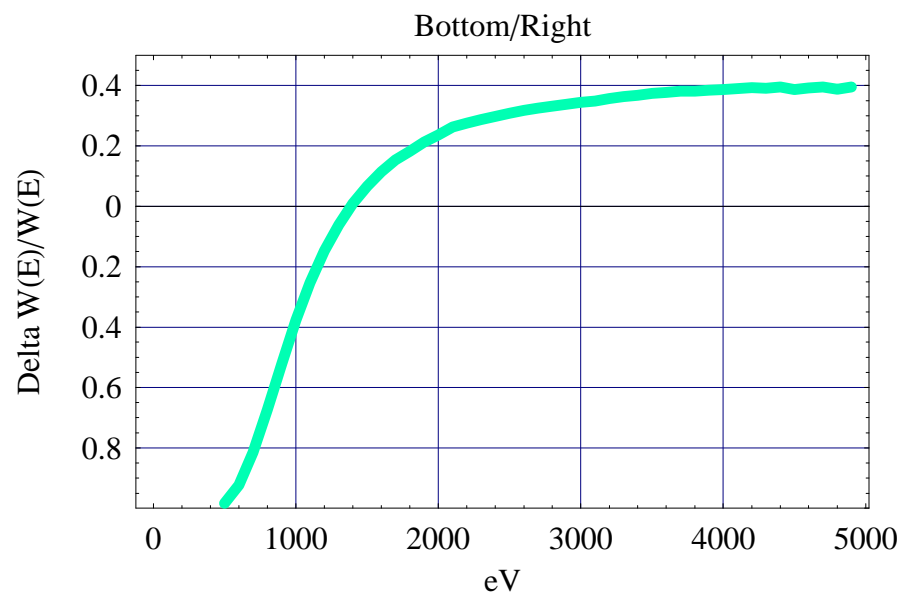
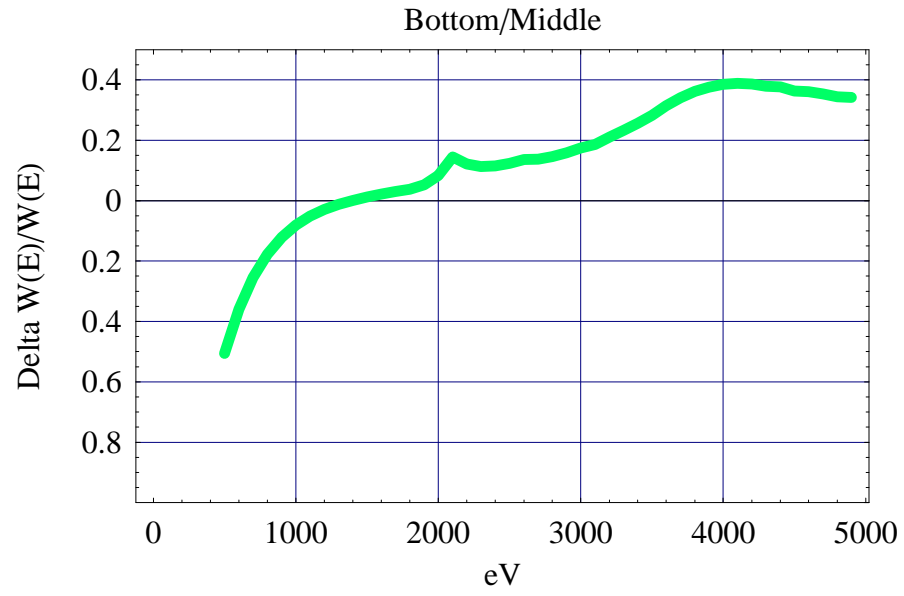
```
gplot = Table@ListPlot@difference@@iDD,
PlotStyle -> 8Thickness@0.015D, Hue@i * 20D<, Frame -> True,
PlotLabel -> labelPlot@@iDD, FrameLabel -> 8"eV", "Delta WHEL*WHEL"<,
GridLines -> Automatic, PlotJoined -> True, PlotRange -> 8-1, 0.5<D,
8i, 9<D;
```

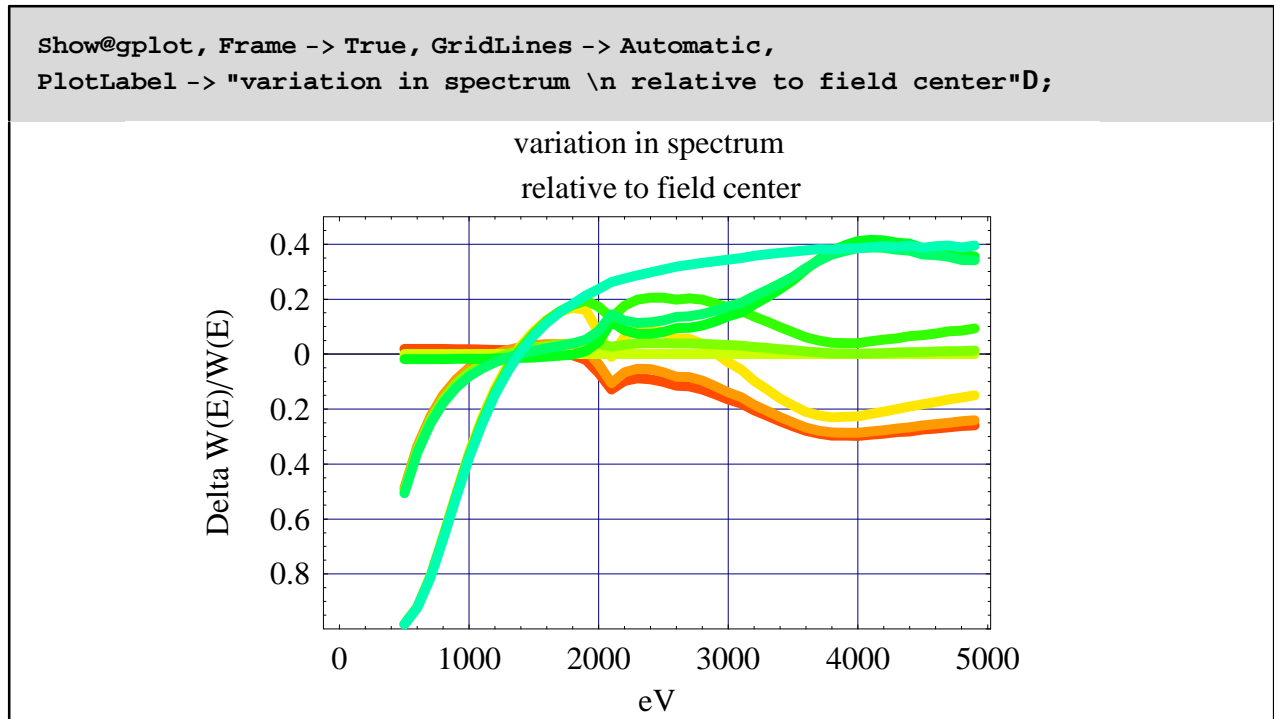












Spectra Histogram Comparison (Scaling)

Plot now the spectra using a color coding for the bars to show the difference from the central/center case. First, we rewrite the labels so that they are more readable:

```
histoLabels = Table@"", 8i, 45<D;
Do@
histoLabels@@iDD = N@HHi - 1L * 1 + 5L * 10D,
8i, 1, 45, 10<D;
Print@histoLabelsD
```

```
80.5, , , , , , , , , , 1.5, , , , , , , , , , 2.5, , , , , , , , , , 3.5, , ,
, , , , , , , , , , 4.5, , , , , <
```

We define the reference spectrum and some easy-to-plot arrays:

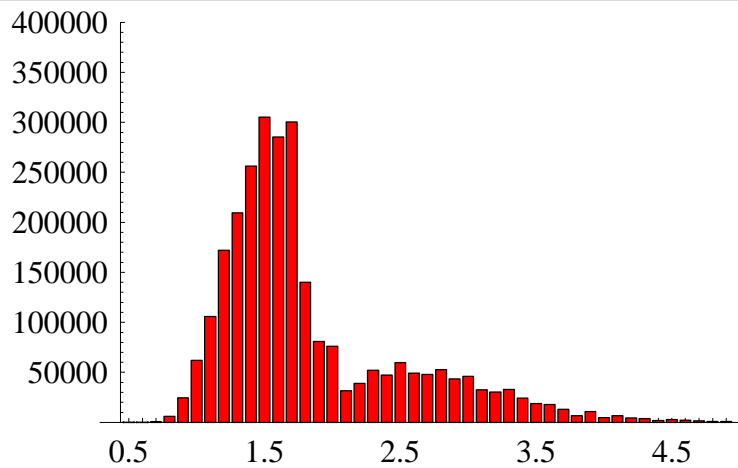
```
reference = Table@savedata@@4, 1DD@@i, 2DD scalingFactor@@4DD, 8i, nhisto<D;
spectraPlot = Table@
Table@savedata@@j, 1DD@@i, 2DD scalingFactor@@jDD, 8i, nhisto<D, 8j, 9<D;
```

```
Dimensions@spectraPlotD
```

```
89, 45<
```

As an example, let's look at the reference spectrum:

```
BarChart@reference, BarLabels -> histoLabels, PlotRange -> 80, 400000<D;
```



Initialize a plot holding variable and the colormap:

```
savePlot = Table@"", 8i, 9<D;
colorSpectra = Table@"", 8i, 9<D;
```

```
Do@
colorSpectra @@iDD = Table@ savedata@@i, 1DD@@j, 2DD scalingFactor@@iDD -
reference@@jDD scalingFactor@@4DD, 8j, nhisto<D
, 8i, 9<D
```

Normalize the colortable between 0 and 0.5 (from red to blue):

```
maxval = Max@colorSpectraD
minval = Min@colorSpectraD
range = maxval - minval;
colorBars = HcolorSpectra - minvalL * range * 2;
Min@testD
Max@testD

46869.9
```

```
-26808.
```

```
0.
```

```
0.5
```

We now compute a normalization factor, so that we can display the reference spectrum between 0 and 100:

```
temp = scalingFactor@@4DD
normSpectra = Max@spectraPlot@@4DD D * temp
maxColorScale = Floor@maxval * normSpectra * 100 + 0.5D
minColorScale = Floor@minval * normSpectra * 100 + 0.5D

1.
```

```
305238.
```

```
15
```

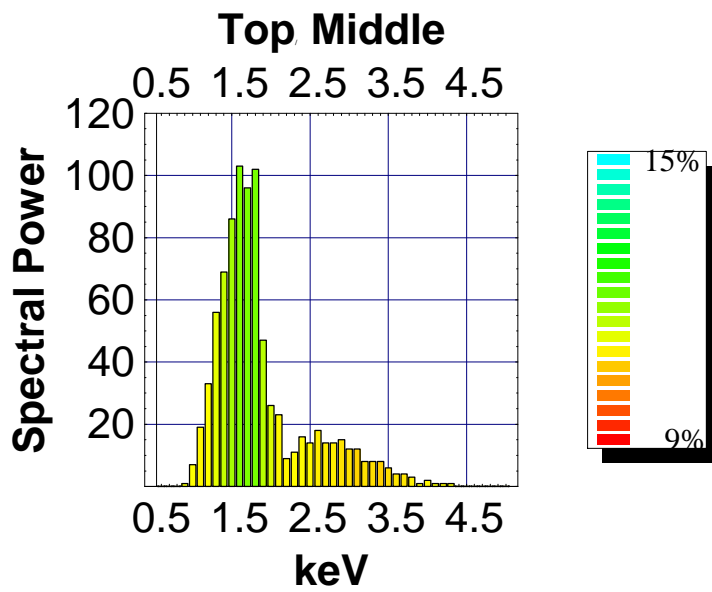
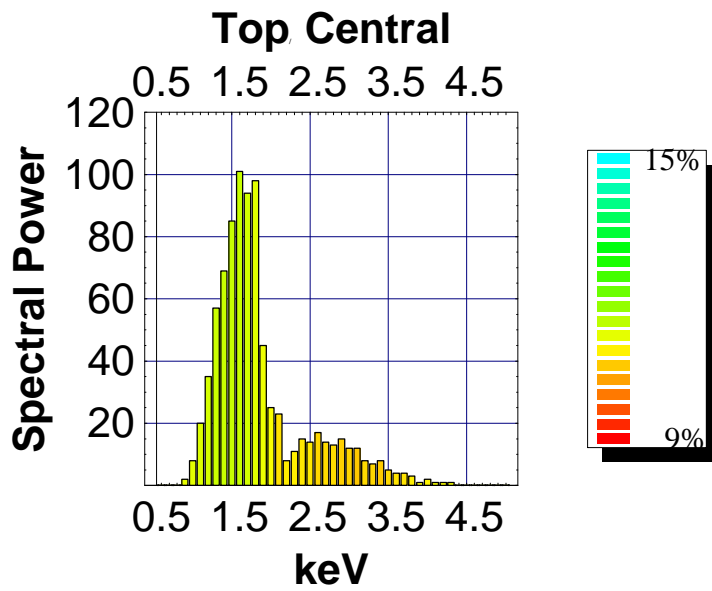
```
-9
```

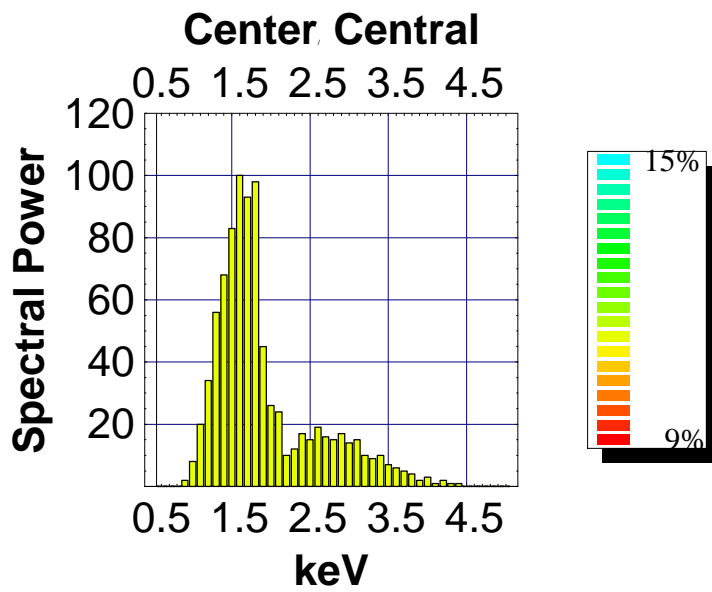
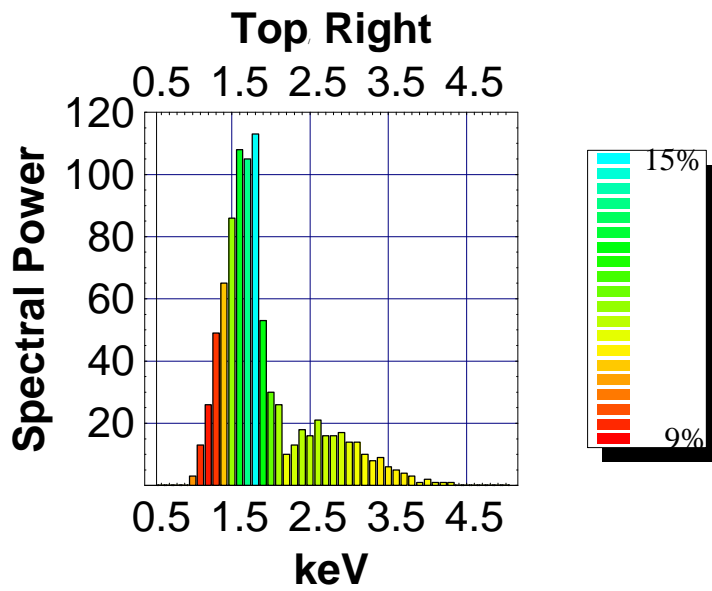
```
spectraPlot@@4DD • normSpectra
```

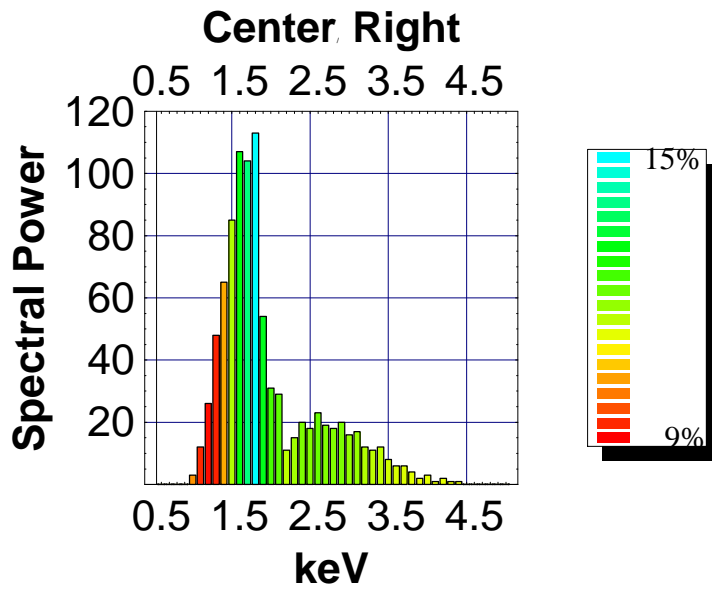
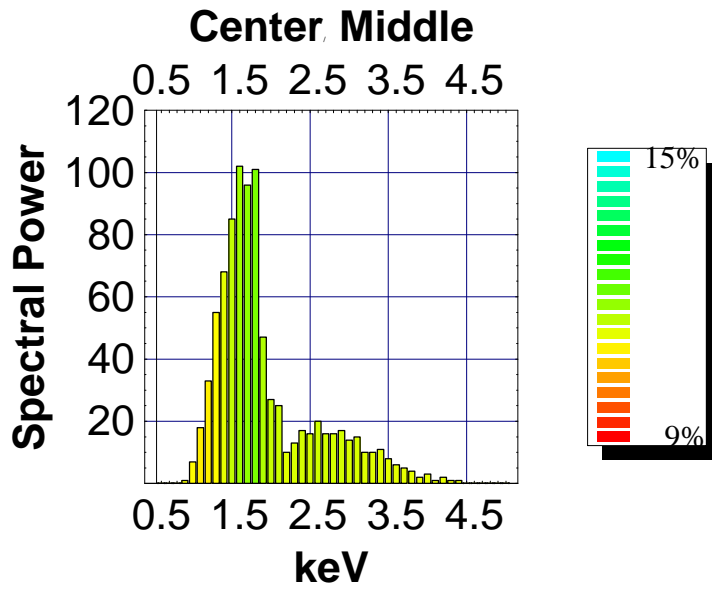
```
82.62463 × 10-7, 0.0000753633, 0.00234447, 0.0202639, 0.0804855, 0.202903,
0.346193, 0.563699, 0.686164, 0.839452, 1., 0.935179, 0.984215,
0.458631, 0.264644, 0.249104, 0.103381, 0.127677, 0.170305, 0.154789,
0.196179, 0.160854, 0.157124, 0.172387, 0.142841, 0.150604, 0.106563,
0.0994632, 0.107662, 0.0786983, 0.0616367, 0.0583456, 0.0428434,
0.0218079, 0.0355507, 0.0158968, 0.0217856, 0.0144023, 0.0122465,
0.00659903, 0.00880221, 0.00678273, 0.00558874, 0.00257747, 0.0032613<
```

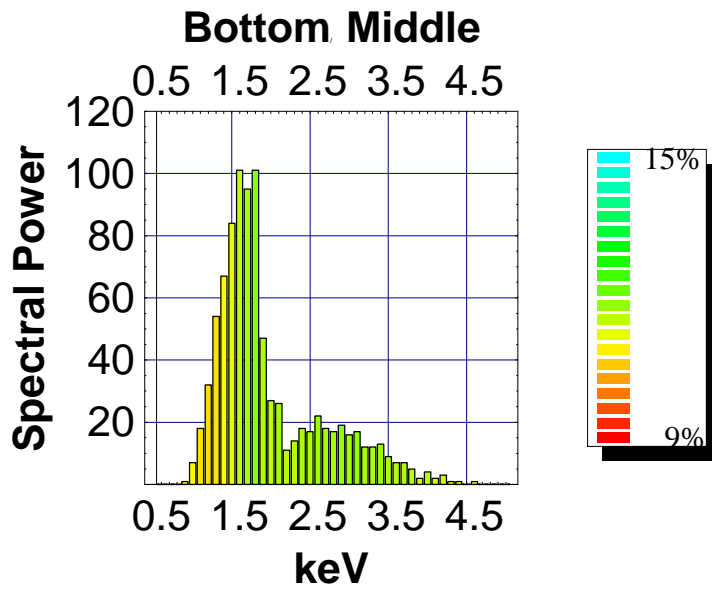
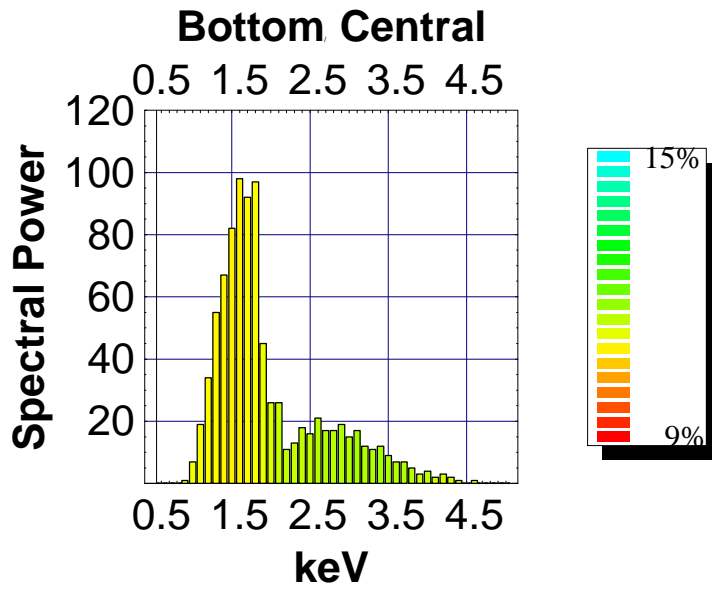
Ready to plot:

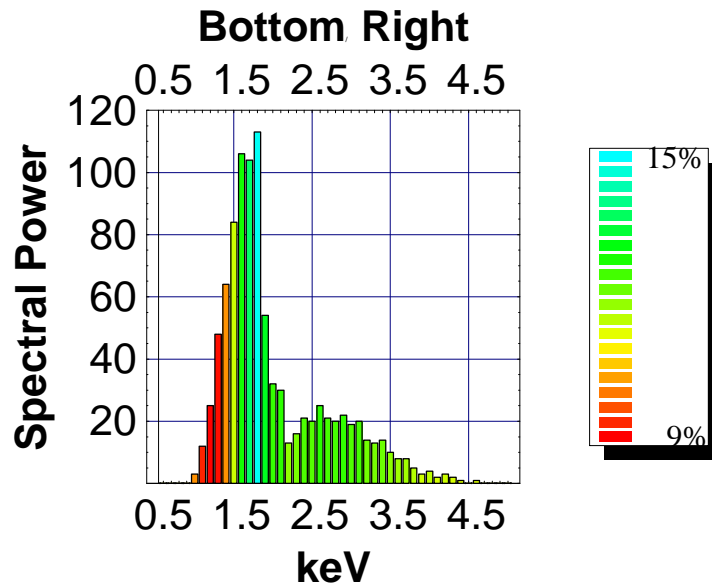
```
Do@
savePlot@@iDD = ShowLegend@
BarChart@IntegerPart@spectraPlot@@iDD • normSpectra * 100 D,
  BarStyle -> Map@Hue, colorBars@@iDD D,
  GridLines -> Automatic, AspectRatio -> 1, PlotRange -> 80, 120<,
  TextStyle -> 8FontFamily -> "Helvetica"<, BarLabels -> histoLabels,
  Frame -> True, FrameLabel -> 8StyleForm@"keV", FontWeight -> "Bold"D,
  StyleForm@"Spectral Power", FontWeight -> "Bold"D<,
  PlotLabel -> StyleForm@labelPlot@@iDD, FontWeight -> "Bold"D,
  DisplayFunction -> IdentityD,
8Hue@0.5 - # • 2D&, 20, ToString@maxColorScaleD<> "%",
  ToString@minColorScaleD<> "%", LegendSize -> 80.4, 1<, LegendSpacing -> 0.2,
  LegendTextSpace -> 2.0, LegendPosition -> 81.1, -0.5<<,
  ImageSize -> 300, Background -> NoneD
, 8i, 9<
D
```











Discussion

The spectra presented as histograms have not been corrected for the total intensity, as obtained in Global Analysis for Flat Be. We have to be careful about the various normalizations that we had to do in order to compare the spectral distributions.

We notice that while the spectral changes may be quite large, the total power is changed less because of the cancellation of contributions of opposite sign. This is in turn true for the total absorbed dose, but not for the changes in the image formation that are dependent on the spectrum: two images may have the same total dose, but the shape may be different because of the spectral contributions.