Unfolding of measurements with the Neutron Generator from Purdue, May/June 2016

(prepared by Andreas Zimbal, PTB, 2016-10-28)

NE213 Detector No. 19 (PTB internal number), HV = 1867 V
PH-ADC, 4k => rebined to 2k spectrum by software to improve statistics in channels and get around 5 keVee/Chn as energy scale.

Spectrum from Eric used:

Phs_a_c.phs

phs_acc_cor.phs from Eric 2016-10-14

```
         2          1
         1       2047        2047   9.761294e+00
-1.313125e-02          0.000000e+00          0.000000e+00
-8.356250e-03          0.000000e+00          0.000000e+00
-3.581250e-03          0.000000e+00          0.000000e+00
1.193750e-03           0.000000e+00          0.000000e+00
5.968750e-03           0.000000e+00          0.000000e+00
1.074375e-02           0.000000e+00          0.000000e+00
1.551875e-02           0.000000e+00          0.000000e+00
2.029375e-02           0.000000e+00          0.000000e+00
2.506875e-02           0.000000e+00          0.000000e+00
2.984375e-02           0.000000e+00          0.000000e+00
3.461875e-02           0.000000e+00          0.000000e+00
3.939375e-02           0.000000e+00          0.000000e+00
4.416875e-02           0.000000e+00          0.000000e+00
4.894375e-02           0.000000e+00          0.000000e+00
5.371875e-02           0.000000e+00          0.000000e+00
5.849375e-02           0.000000e+00          0.000000e+00
6.326875e-02           0.000000e+00          0.000000e+00
6.804375e-02           0.000000e+00          0.000000e+00
7.281875e-02           0.000000e+00          0.000000e+00
7.759375e-02           0.000000e+00          0.000000e+00
8.236875e-02           0.000000e+00          0.000000e+00
8.714375e-02           0.000000e+00          0.000000e+00
9.191875e-02           0.000000e+00          0.000000e+00
9.669375e-02           0.000000e+00          0.000000e+00
1.014687e-01           1.666081e-01          5.914515e-03
1.062438e-01           9.324355e-02          4.105231e-03
1.110188e-01           5.973582e-02          3.101044e-03
1.157938e-01           4.509709e-02          2.535171e-03
1.205688e-01           4.449398e-02          2.364510e-03
1.253438e-01           4.704877e-02          2.281742e-03
```

Spectrum contains a factor of two less events/channels compared to spectrum 50-2-5-bg.phs which was used for first unfolding by Andreas, probably due to rebinning. Andreas has done the rebinning by adding always two channels to keep the same number of events in ths PHS.

If this is considered, the two spectra are very similar:

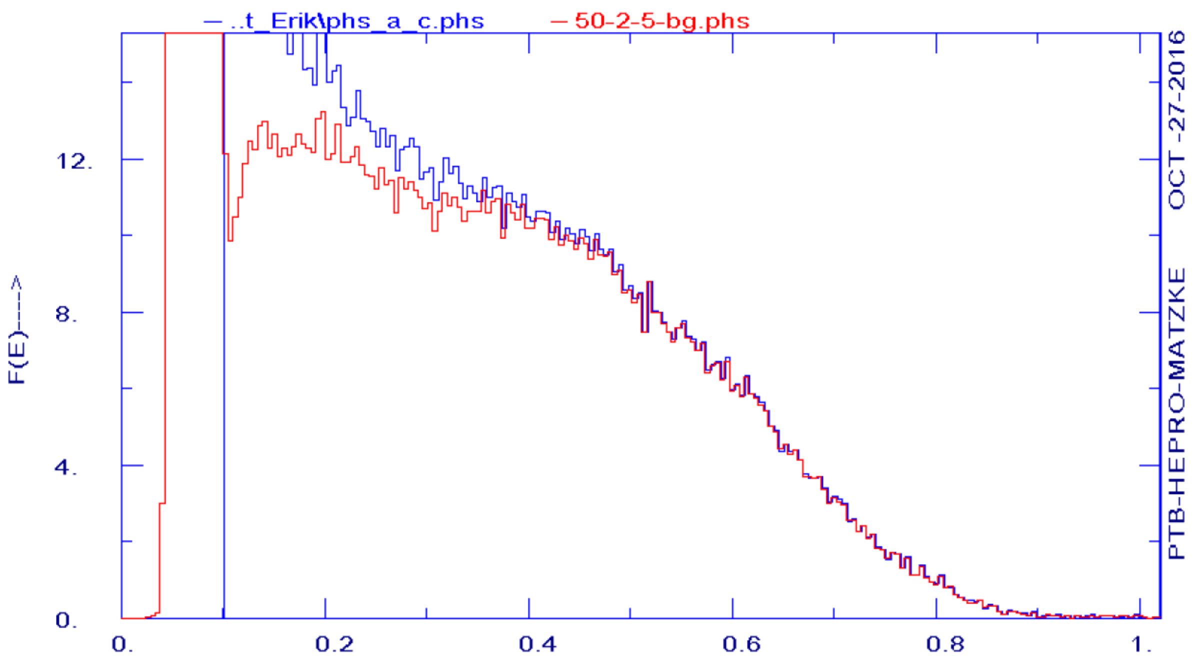

Figure 1: Comparison of PHS previously used (Andreas “bye eye” cut, red) and data from Eric (blue)

Both spectra show in the third column of the PHS-file, which is the absolute uncertainty of the number of events/channel and needed for the unfolding, the same relative uncertainty, which indicates that it is not a problem and both spectra are equivalent in this respect.

Unfolding done with Gavel and Maxed, with calculated and experimentally determined response functions. First Gravel was used to determine Chi2, which was used as input parameter for Maxed. The Gravel results gave to many structures/peaks which is a known feature (overfitting of the data).

Input parameter for Gravel for calculated response function:

phs_a_c.phs	*file with data*
n100cm25nl50.rsp	*file with response functions (RF)*
gv	*name of output file*
flat_fin.flu	*file with default spectrum (DS)*
0.35,0.95	*lowest, highest MC E bin edges (MeV)*
1.49,2.92	*lowest, highest RF E bin edges (MeV)*
0.8	*chi-square factor*
50000,10000	*Maximum number of iter. in L-BFGS-B*
3,1	*3 = use RF bin structure, 1 = dF/dE*
1	*1 = use a scale factor for the DS*
1	*0 = use MAXED scale factor*
0.1	

Out parameter of Gravel for calculated response function:

Chi-squared P.D.F. Using the Default Spectrum	=	*230.2678241*
Final Chi-squared P.D.F.	=	*1.0911988*
NOTE: Chi-squared Per Degree of Freedom was set to:		*0.800*

Input parameter for Maxed for calculated response function:

phs_a_c.phs	*file with data*
n100cm25nl50.rsp	*file with response functions (RF)*
mx	*name of output file*
flat_fin.flu	*file with default spectrum (DS)*
0.35,0.95	*lowest, highest MC E bin edges (MeV)*
1.49,2.92	*lowest, highest RF E bin edges (MeV)*
1.08	*chi-square factor*
200000	*Maximum number of iter. in L-BFGS-B*
3,1	*3 = use RF bin structure, 1 = dF/dE*
1	*1 = use a scale factor for the DS*
1	*0 = use MAXED scale factor*
0.10	

Input parameter for Gravel for experimentally determined response function:

phs_a_c.phs	*file with data*
expresp8.rsp	*file with response functions (RF)*
gv_e	*name of output file*
flat_fin.flu	*file with default spectrum (DS)*
0.35,0.95	*lowest, highest MC E bin edges (MeV)*
1.49,2.92	*lowest, highest RF E bin edges (MeV)*
0.8	*chi-square factor*
50000,10000	*Maximum number of iter. in L-BFGS-B*
3,1	*3 = use RF bin structure, 1 = dF/dE*
1	*1 = use a scale factor for the DS*
1	*0 = use MAXED scale factor*
0.1	

Out parameter of Gravel for experimentally determined response function:

Chi-squared P.D.F. Using the Default Spectrum	=	*232.1210973*
Final Chi-squared P.D.F.	=	*0.9933604*
NOTE: Chi-squared Per Degree of Freedom was set to:		*0.800*

Input parameter for Maxed for experimentally determined response function:

phs_a_c.phs	*file with data*
expresp8.rsp	*file with response functions (RF)*
mx_e	*name of output file*
flat_fin.flu	*file with default spectrum (DS)*
0.35,0.95	*lowest, highest MC E bin edges (MeV)*
1.49,2.92	*lowest, highest RF E bin edges (MeV)*
1.04	*chi-square factor*
200000	*Maximum number of iter. in L-BFGS-B*
3,1	*3 = use RF bin structure, 1 = dF/dE*
1	*1 = use a scale factor for the DS*
1	*0 = use MAXED scale factor*
0.10	

Results:

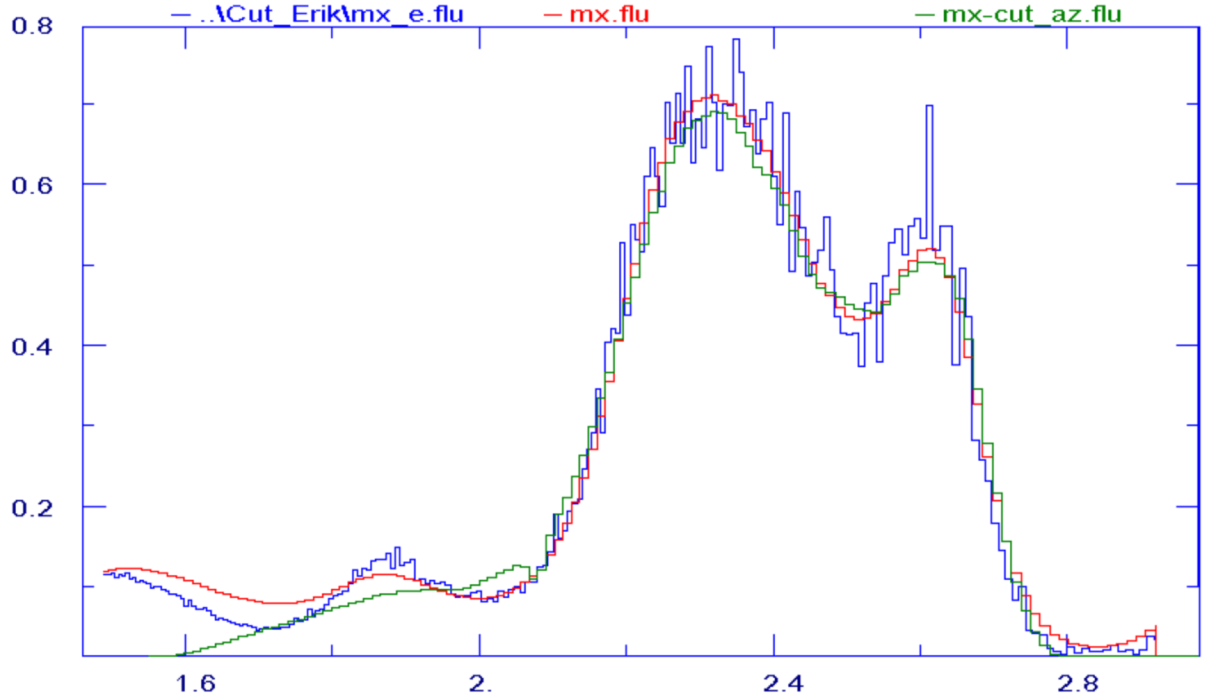

Figure 2: Output spectra as explained in the text.

The pulse height scale energy range was limited from 350 keVee to 950 keVee for all unfoldings. In the pulse height spectrum, the contribution from 14 MeV is clearly visible, but the number of counts is not sufficient to perform a "free unfolding". As start spectrum for the unfolding, a flat spectrum was used. This default spectrum was scaled manually with a factor which is a factor 3 smaller than the intrinsically determined scaling factor (Maxed, calculated response function):

Scaling Factor/Default Spectrum for best fit = 2.8892E-01
Scaling Factor/Default Spectrum used = 1.0000E-01

The neutron energy range was limited from 1.49 MeV to 2.92 MeV. These energies correspond to the proton light output of the selected pulse height energies. The selection of the scaling factor results in a flat distribution on the low energy side of the 2.5 MeV, with some fluctuations. The selection of a scaling factor 100 times smaller than the intrinsically determined scaling factor resulted in a spectrum which drops nearly to zero at around 1.6 MeV (green curve).

In the **figure 2** , three plots are shown:

mx_e.flu	Unfolding with Maxed, experimentally dertermined response function
mx.flu	Unfolding with Maxed, calculated response function
mx-cut_az.flu	Unfolding with Maxed, calculated response function, "bye eye" cut between neutron and gammas done by Andreas.

The remaining structure at about 3 MeV neutron energy is an artifact from misinterpreted 14 MeV neutrons resulting in events with energies higher than about 1 MeVee.

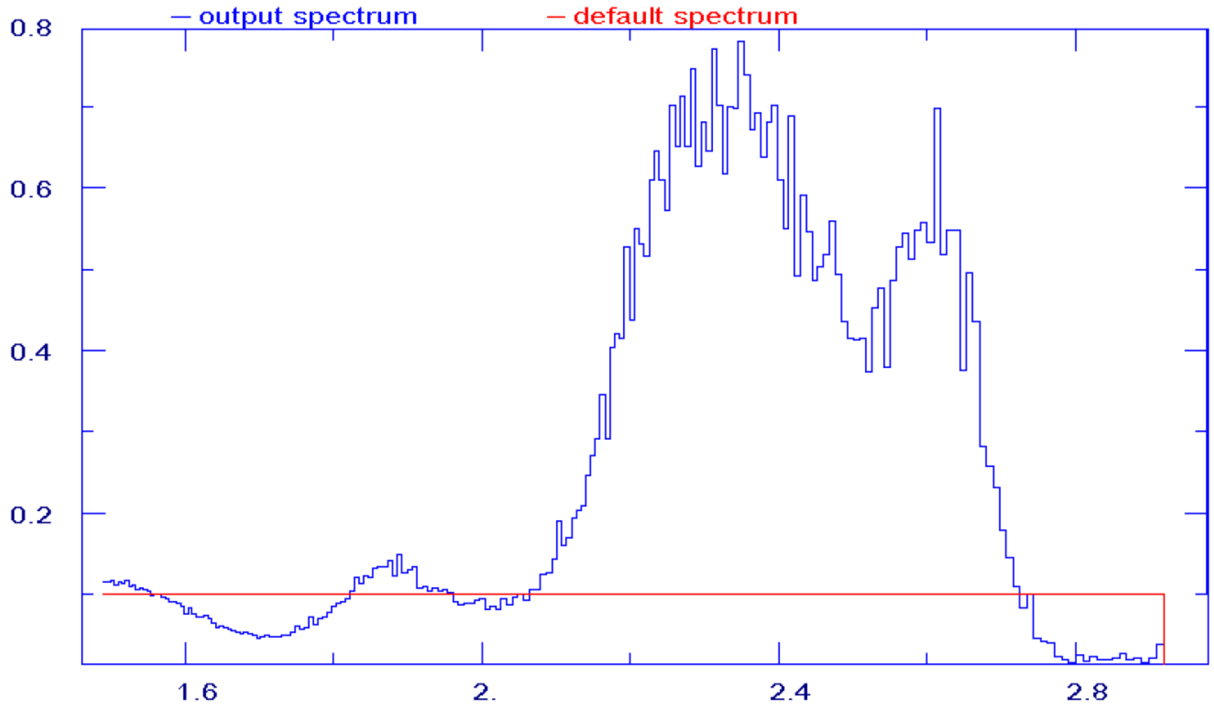

Figure 3: Comparison of Maxed output spectrum (experimentally determined response function) with the scaled flat default spectrum.

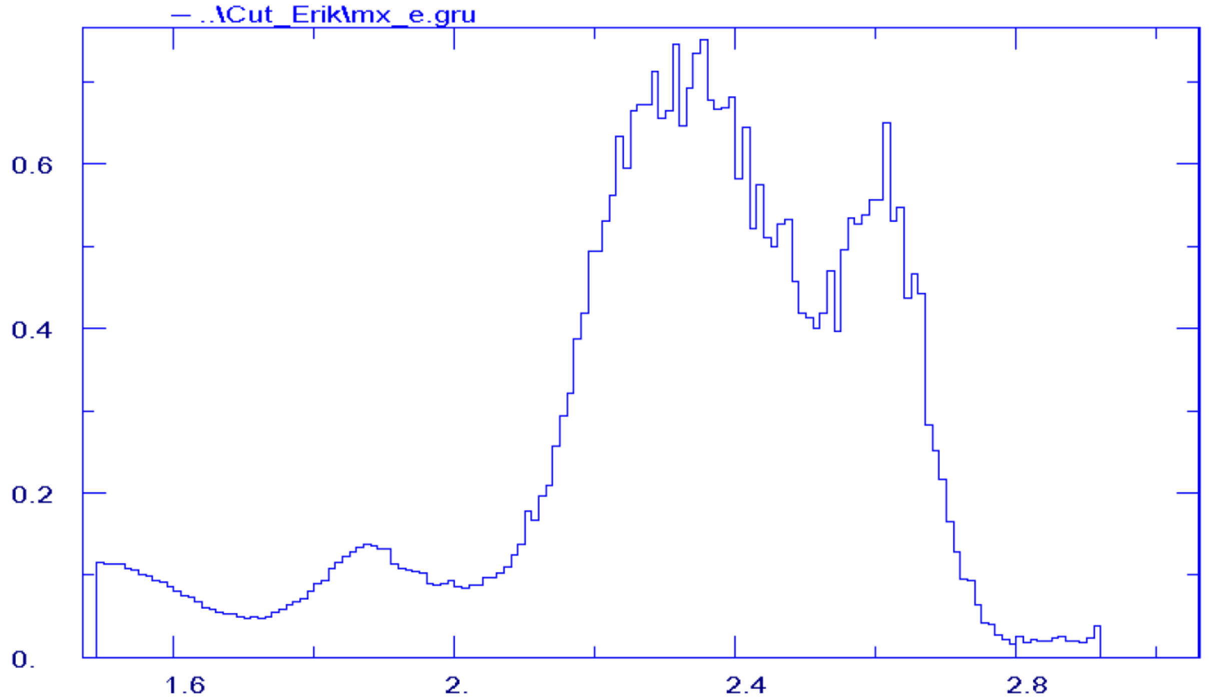

Figure 4: Final output spectrum (mx_e.gru): Unfolding with Maxed with the experimentally determined response, rebinned within Maxed to the default spectrum bin structure (10 keV/bin).

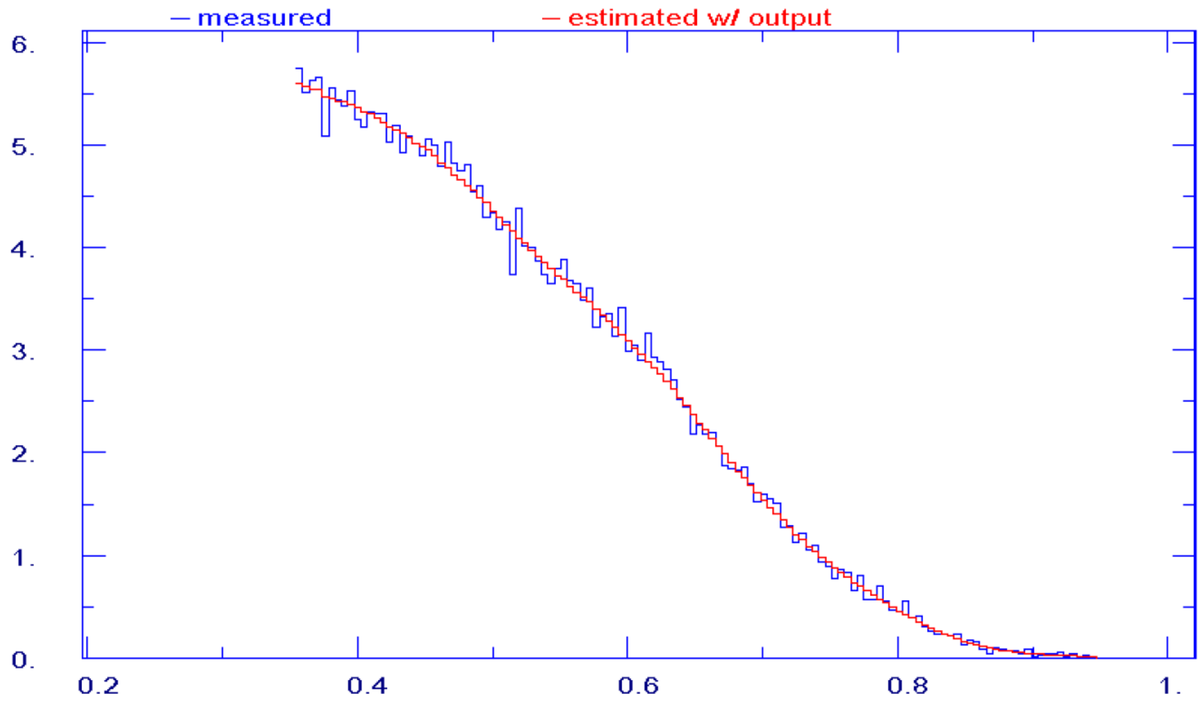

Figure 5: Result of folding the output spectrum with the response matrix.

From the output spectrum (mx_e.gru) the calculated fluence rate at the detector position is the following:

Phi (2 MeV < E < 2.8 MeV) = 0.643 1/ (s cm^2)

The contribution from 14 MeV neutrons was calculated from the counts in the pulse height spectrum (50-2-5-BG.phs) in the range from 2 MeV to 10 MeV and the response of the scintillation detector.

Number of Counts (2 MeV < PH < 10 MeV) = 0.0735 1/s

The response of the scintillation detector for 14 MeV for the pulse height range > 2 MeVee is:

R(E_n = 14 MeV, PH > 2 MeVee) = 2.0668 cm^2

From these numbers, the fluence rate of 14 MeV can be calculated:

Phi (14 MeV) = $Counts_{14MeV}$ / $R_{14\ MeV}$ = 0.03556 1/ (s cm^2)

The ratio of neutrons with energies of 14 MeV and 2.5 MeV is therefore:

Ratio (14 MeV / 2.5 MeV) = (0.03556 / 0.643) = 0.055 (= 5.5 %)