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COMET/ZEUS Activation Foils Report for Irradiations IER-241 and IER-261

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Introduction

The goal of this work was to determine the internal neutron spectrum of the COMET/ZEUS assembly using activation foils. Similar measurements were performed on the COMET assembly when it was located at the Los Alamos Critical Experiments Facility (LACEF) at the Los Alamos National Laboratory (LANL) [1]. The present measurements were performed after the COMET assembly was moved to the National Criticality Experiments Research Center (NCERC) located in the Device Assembly Facility (DAF) at the Nevada National Security Site (NNSS). The December 2012 COMET/ZEUS irradiation was the first in a series of experiments, and the COMET/ZEUS assembly was selected because of operational readiness and authorization to run specific targets. The August 2013 irradiation was the second in the series and involved only small changes in the configuration. This report describes the unfolding of the activation foils to determine the internal neutron spectra.

Unfolding Codes

Activation foils can be used to measured neutron spectra when other techniques, such as time of flight or scintillation detectors, are not possible. The foil is exposed to the neutron flux for a period of time and then removed so that the induced radioactivity may be counted, typically using gamma and beta counting methods. The different materials in the foils respond differently because cross sections for the reactions on each material are different. These differences can be used to determine the neutron spectrum with unfolding analysis. Basically, a trial spectrum is varied, subject to some constraints, to give the best simultaneous fit to the induced activities in all of the foils. In many cases the code will calculate an acceptable spectrum when the trial spectrum is only a rough approximation of the expected finally fitted spectrum. However, the final spectrum may be more accurate when the trial spectrum is close to the final spectrum.

Several analysis methods with corresponding computer programs have been developed to do the unfolding. One of the early uses of activation foils was the measurement at Los Alamos of the spectra from the fission of 235U, 233U, and 239Pu [2]. In 1967, SAND-II, developed at the Kirkland Air Force Weapons Laboratory, was published [3]. In 1994, Sandia National Laboratory published an improved version of the SAND-II code and a user's manual [4]. The neutron spectrum at the Missouri University of Science and Technology Research Reactor was determined with the SAND II code [5]. The neutron spectrum from the Target-Moderator-Reflector-1 at the Indiana University was also characterized with the SAND-II code [6]. These early codes lacked adequate constraints on the fits, especially when the response functions contained resonances. More recently, several different codes and applications have been reported. GRAVEL is a slightly modified version of SAND-II and has been used for some measurements [7]. Dehimi et al. proposed unfolding with Fisher Regularisation [8]. Many of the codes, including SAND II, require a trial spectrum as a-prior input. The GAMCD (Genetic Algorithm and Monte Carlo Deconvolution) was developed by a group in India and does not require a-prior input. GAMCD was used to measure the neutron spectrum from the p+Be reaction at 20 MeV [9]. The MINUIT code in the CERN Cernlib, with smoothness and shape constraints, was used by researchers from Algeria to unfolded reactor data [10]. Tripathy et al. compare several different unfolding codes [11]. For the present report, we chose to use the Few Channel Maximum Entropy (MAXED) code, which was part of the U_M_G (Unfolding and Maxed and Gravel) version 3.3 code prepared by Reginatto et al. at the Physikalisch-Technische Bundesanstalt (PTB) in Germany because it was the only one readily available, except for the older code SAND II and its slight revised version GRAVEL [12]. The code and the manual were obtained from the Radiation Safety Information Computational Center (RSICC) at the Oak Ridge National Laboratory.

MAXED Unfolding Code

The MAXED code received from RSICC was a FORTRAN program. It contains 34 subroutines, and the most important one is the SA subroutine. SA implements the continuous simulated annealing global optimization algorithm by trying to find the global optimum of an N dimensional function. One limitation of the program was that it could not handle internally numbers less than 1.0E-26. It was necessary to multiple the response functions by 1.0E+06 and then multiple the output fit from the program by the same factor. The program can process an attempt at a fit of a set of foils data in approximately two minutes or less on a desk top computer. However, as discussed in the Analysis section below, many attempts are required to get a good fit.

The input MAXED files are the following.

1. Control file, which contains names of other files and fitting parameters
2. Measured data
3. Response functions
4. Output file name
5. Default spectrum

The Appendix provides some partial examples of these files.

Response Functions

The response function for a reaction is equal to the cross section for the reaction as a function of energy. For the present analysis, 640 energy bins were chosen in order to provide sufficient detail of structure in the spectrum. This choice is a standard that has been used in other published reports [4]. The MCNP code was used to bin the ENDF VII cross sections into 640 bins. MCNP was also used to bin the cross sections when the foils were covered with cadmium to eliminate low-energy reactions. Without a cadmium cover, the cross sections are just the binned ENDF VII cross sections. With a cadmium cover, the cross sections have been corrected by the attenuation of the neutrons by the cadmium to provide effective cross sections. The cross sections for the (n,γ) reactions at < 100 keV are very large, but the focus in this report is on the fast-energy range, especially at > 5 MeV.

Default Spectra

A 640 energy bin trial spectrum was calculated with an MCNP F4 tally using the detailed MCNP model for IER163 in reference [13]. The same spectrum was used for the December 2012 and the August 2013 data because the experimental configurations were only slightly different and the fits are not very sensitive to trial spectrum. The ^{235}U cross sections from ENDF/B-VI were used for the trial spectrum and differ only slightly from more recent ENDF cross sections. The trial spectrum is shown in Figures 2 and 3 below in the Analysis of the Foils section.

Analysis of the Foils

The unfolding of activation foil data is reported in the present report, and is based on the gamma-ray analysis of the foils performed by LANL teams [14,15]. The unfolding required more than 100 trial runs for IER-241 and IER-261 each because an acceptable fits could only be obtained if some of the activation foils were not included and the requested X^2 was not too small. Some possible reasons for these constraints are the following.

Foil Data

The reports containing the measurement data do not discuss the gamma-ray analysis and just provide final values of activation atoms per gram of the target with an uncertainty. Some of the corrections that should have been included are for the detector efficiency, gamma-ray branching ratio, decay during the irradiation (often negligible if the half-life is long), decay since the end of the irradiation, decay during the gamma-ray measurement, and decay of metastable states. Failure to include all of these corrections might be one reason not all of the measurement data could be included in the unfolding analysis. Figure 1 shows the decay of all the activation isotopes, including in particular, the eight with metastable states. Things to consider in the analysis of the measurement data for these isotopes are the following.

^{24}Na: The decay of the 20 ms metastable state, which decays to the ground state, is too short to have affected the gamma-ray measurement of the decay of the ground state.

^{46}Sc: The decay of the 18.75 s metastable state, which decays to the ground state, is too short to have affected the gamma-ray measurement of the decay of the ground state.

^{44}Sc: The decay of the 58.6 h metastable state via the emission of a 271 keV gamma ray was measured, and no correction was required.

^{58}Co: The ground state is fed by the decay of the 9.04 h metastable state at 24.95 keV, and an analysis correction would have been required if the measurement of the decay of the ground state was started within approximately 27 h after the end of the irradiation of the foil.

^{60}Co: The ground state is fed by the decay of the 10.467 m metastable state, and an analysis correction would have been required if the measurement of the decay of the ground state was started within 30 minutes of the end of the irradiation.

^{92}Nb: The decay of the 10.15 d metastable state of ^{92}Nb to ^{92}Mo with the emission of a 934 keV gamma ray was measured, and no correction was required.

^{99}Mo: This isotope with a half-life of 65.94 h decays to the 6.01 h metastable state in ^{99}Tc, which decays to the ground state with the emission of a 142.6833 keV gamma ray. An analysis correction would have been required if the measurement was started within approximately 18 h before the system reached secular equilibrium.

^{196}Au: This isotope has two metastable states, the 9.6 h state at 595.66 keV and the 8.1 s state at 84.660 keV. These states feed into the ground state of ^{196}Au, which has a half-life of 6.183 d and decays by emitting gamma rays that were measured. The 595.66 keV state has a high spin of 12^- and may not have been strongly populated in the irradiation. How strongly it is populated could be determined from its 147.780 keV decay gamma ray. An analysis correction would have been required if the 9.6 h state was significantly populated and the measurement was started within approximately 30 h after the end of the irradiation.

^{198}Au: This isotope has a metastable state at 811.7 keV with half-life of 2.27 d. It decays to the ground state, which then decays with a half-life of 2.69517 d. The 811.7 keV metastable state has a high spin of 12^- and may not be strongly populated in the irradiation. How strongly it is populated could be determined from its decay gamma rays. An analysis correction would have been required if it was significantly populated.

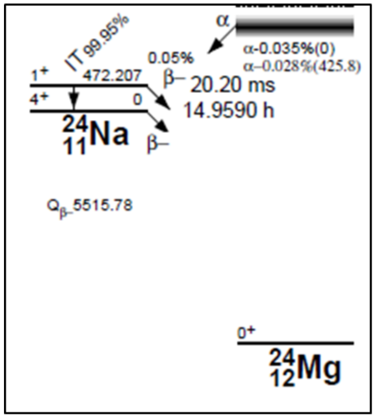
In summary, five of the foils, ^{58}Co, ^{60}Co, ^{99}Mo, ^{196}Au, and ^{198}Au, might have required corrections for the metastable states.

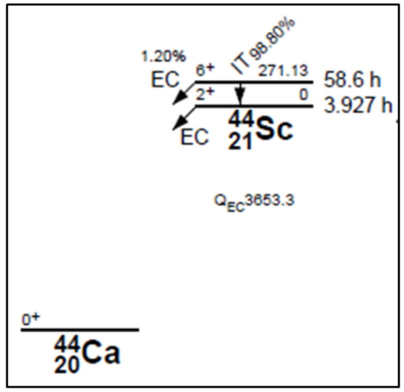
X^2

Requiring a small X^2, such as $X^2 = 1$, usually resulted in large oscillations, especially above 8 MeV, in neutron flux vs energy, and a search on X^2 was required. This is consistent with the warning in the instructions for MAXED: "The choice of this parameter requires some care. In particular, if the value is set too low, there might not be a solution consistent with the data." This might be an inherent limitation of MAXED.

Cross Sections

The response functions for the foils are basically just the cross sections for the nuclear reactions producing the activated nuclei. Cross sections at low neutron energies are very accurately known because time of flight measurements have been used. However, at higher energies, say >8 MeV, other technique are required and the cross sections are less accurately known. This loss of accuracy at high energy might have been the reason some foils were no included in the final analysis.


α
α-0.035%(0)
α-0.028%(425.8)
IT 99.95%
0.05%
1+ 472.207
β−
20.20 ms
4+ 0
14.9590 h
24 11 Na
β−
Qβ-5515.78
0+
24 12 Mg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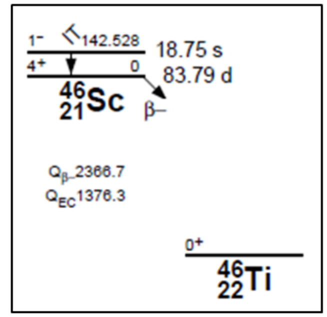
EC
6+
IT 98.80%
271.13
58.6 h
2+ 0
3.927 h
EC
44 21 Sc
QEC3653.3
0+
44 20 Ca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4+ 0
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β−
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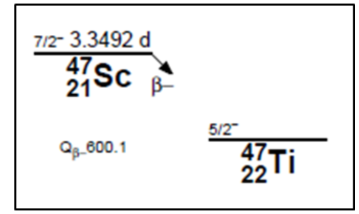
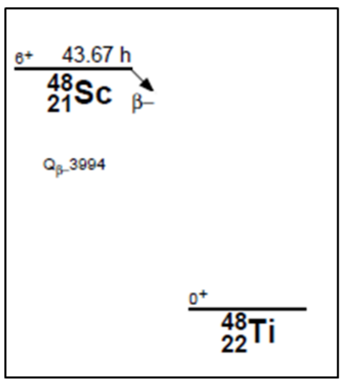
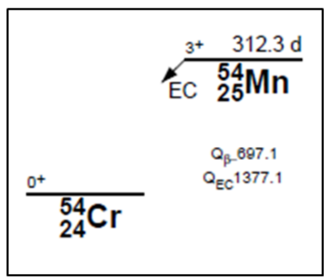
QEC1376.3
0+
46 22 Ti


7/2− 3.3492 d
47 21 Sc
β−
5/2−
Qβ-600.1
47 22 Ti


6+ 43.67 h
48 21 Sc
β−
Qβ-3994
0+
48 22 Ti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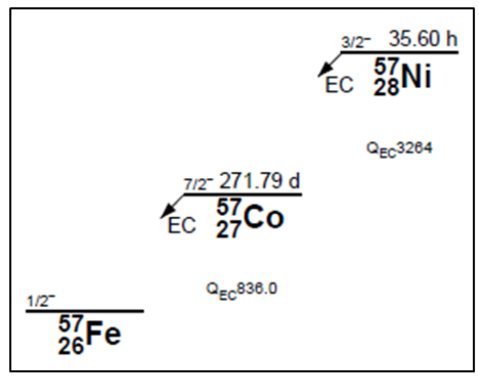
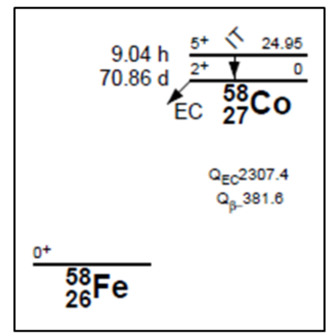
EC
54 25 Mn
Qβ-697.1
QEC1377.1
0+
54 24 Cr


3/2− 35.60 h
EC
57 28 Ni
QEC3264
7/2− 271.79 d
EC
57 27 Co
QEC836.0
1/2−
57 26 Fe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5+
IT
24.95
70.86 d
2+ 0
EC
58 27 Co
QEC2307.4
Qβ-381.6
0+
58 26 Fe

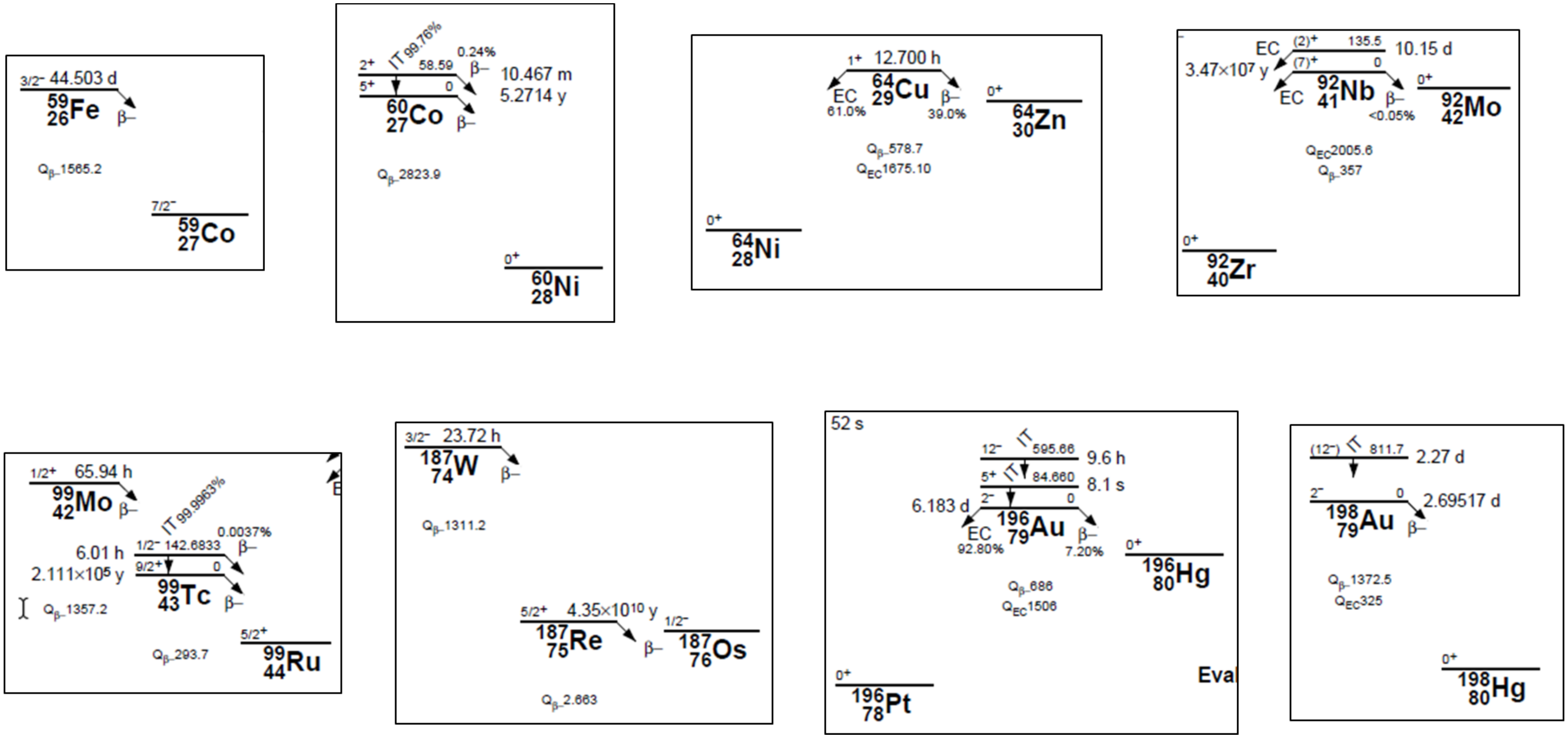

Figure 1. Decay schemes of the activated nuclei [16].

IER-241

Table 1 lists the data for the gamma-ray measurements of the activated foils. All of the foils, except for four gold foils and one aluminum foil, were covered with a thin cadmium foil to minimize the low-energy thermal neutron reactions, which have large cross sections for some reactions. The ID, Act/g, and ±Act/g(%) are the identification, activations per gram of foil, and the activations per gram of foil uncertainty, respectively, from the measurements reported in reference [14]. The ratio Act/Tgt is the number of activated nuclei divided by the number of target nuclei for the reaction, and ±Act/Tgt is the corresponding uncertainty calculated from the reference [14] data.

Table 1. IER-241 Foil Data

Foil	Reaction	Cd Cover?	ID	Act/g	±Act/g(%)	Isotopic Abundance (%)	Half-life	Act/Tgt	±Act/Tgt (%)
Sc	Sc45(n,2n)Sc44m	yes	4145-1-44	8.60E+07	25	100	2.44 d	6.420E-15	25.00
Sc	Sc45(n,g)Sc46	yes	4145-1-44	2.11E+11	2.6	100	85 d	1.575E-11	2.60
Ti	Ti46(n,p)Sc46	yes	4145-1-46	4.80E+09	4.5	8.25	85 d	4.625E-12	4.50
Ti	Ti47(n,p)Sc47	yes	4145-1-46	8.00E+09	5.1	7.44	3.43 d	8.547E-12	5.10
Ti	Ti48(n,p)Sc48	yes	4145-1-46	1.02E+09	3.3	73.72	44 h	1.100E-13	3.30
V	V51(n,α)Sc48	yes	4145-1-51	8.90E+07	24	99.75	44 h	7.548E-15	24.00
Ni	Ni58(n,p)Co58	yes	4145-1-57	3.16E+11	2.5	68.08	72 d	4.524E-11	2.50
Ni	Ni60(n,p)Co60	yes	4145-1-57	4.20E+09	31	26.22	5.27 y	1.561E-12	31.00
Ni	Ni58(n,2n)Ni57	yes	4145-1-57	2.10E+08	6.4	68.08	1.50 d	3.006E-14	6.40
Fe	Fe54(n,p)Mn54	yes	4145-1-59	2.37E+10	3.3	5.85	310 d	3.757E-11	3.30
Mo	Mo92(n,p)Nb92m	yes	4145-1-99	3.20E+09	4.8	14.84	10.2 d	3.435E-12	4.80
Mo	Mo98(n,γ)Mo99	yes	4145-1-99	6.10E+10	4.8	24.13	2.75 d	4.027E-11	4.80
W	W186(n,γ)W187	yes	4145-1-187	2.74E+12	3.2	28.43	23.9 h	2.942E-09	3.20
Au	Au197((n,2n)Au196	no	4145-1-198	6.20E+09	28	100	6.18 h	2.028E-12	28.00
Au	Au197(n,γ)Au198	no	4145-1-198	7.50E+11	5.5	100	2.69 d	2.453E-10	5.50
Al	Al27(n,α)Na24	no	4145-1-198	6.50E+09	4.7	100	15.06 h	2.912E-13	4.70
Au	Au197((n,2n)Au196	yes	4145-2-198	4.50E+09	26	100	6.18 h	1.472E-12	26.00
Au	Au197(n,γ)Au198	yes	4145-2-198	7.30E+11	5.7	100	2.69 d	2.388E-10	5.70
Au	Al27(n,α)Na24	yes	4145-2-198	6.20E+09	5.7	100	15.06 h	2.778E-13	5.70
Au	Au197((n,2n)Au196	no	4145-3-198	3.90E+09	4	100	6.18 h	1.276E-12	4.00
Au	Au197(n,γ)Au198	no	4145-3-198	6.00E+11	2.5	100	2.69 d	1.962E-10	2.50
Au	Au197((n,2n)Au196	yes	4145-4-198	3.90E+09	7.1	100	6.18 h	1.276E-12	7.10
Au	Au197(n,γ)Au198	yes	4145-4-198	5.90E+11	2.5	100	2.69 d	1.930E-10	2.50

The MAXED unfolding code was run with these foil data. As noted above in the Analysis of the Foils section above, data for some of the foils could not be included because they resulted in unreasonable oscillations or large deviations from the smooth trial spectrum. The foil data that were not included in the final fit are specified in the Appendix.

Figure 2 shows a comparison of the fitted spectrum with the trial spectrum calculated with MCNP. The statistical uncertainty increases at high energies in both the fitted spectrum and the trial spectrum. The fitted spectrum closely matches the trial spectrum below 12000 keV, but above 12000 keV, the fitted spectrum is lower. The reason for this difference may be due to the difficulties in obtaining a good fit discussed in the Analysis of the Foils section above or due to the possibility that the model for the trial, based on IER-163, did not accurately match the configuration that was measured.

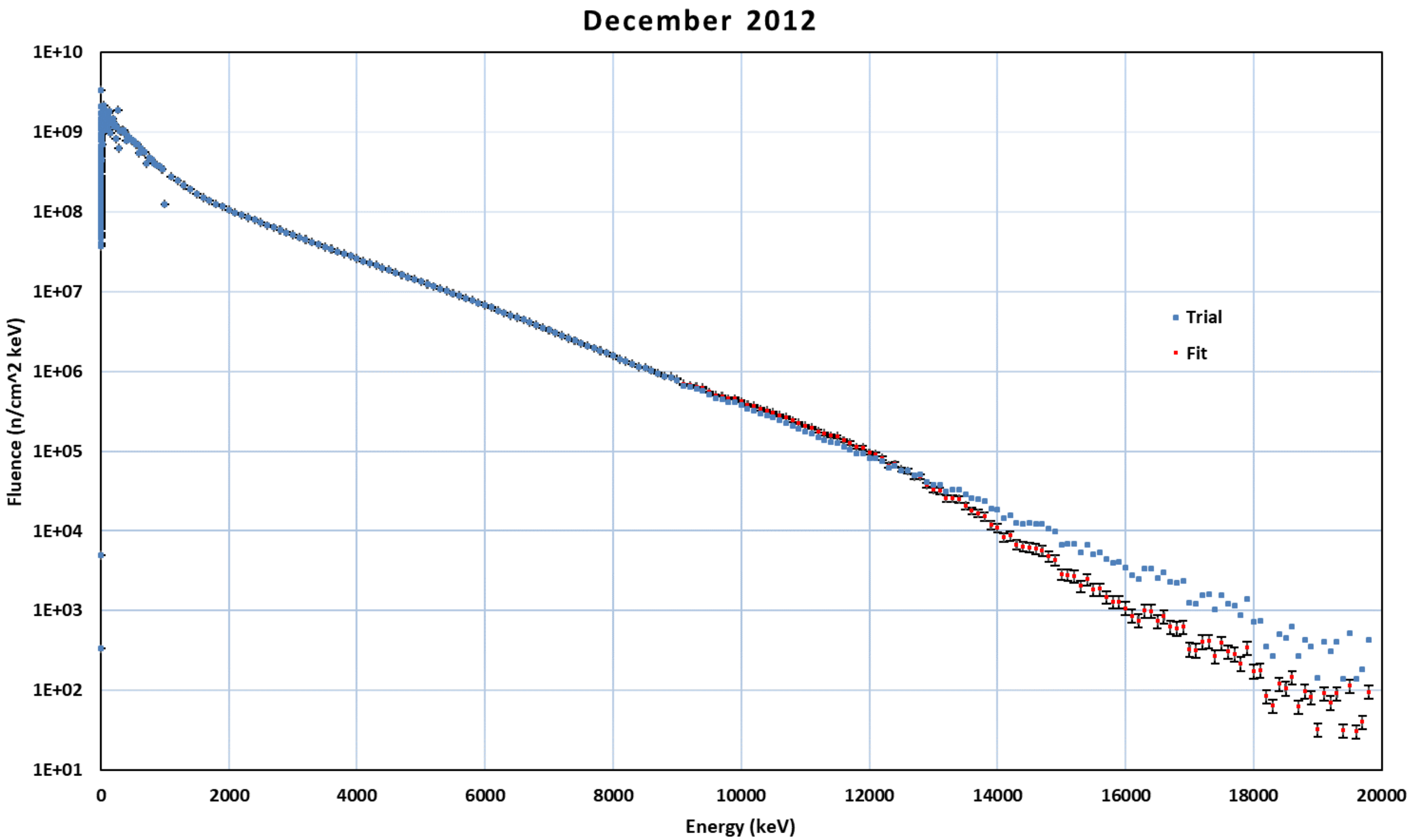

Figure 2. Comparison of the MCNP trial spectrum and the spectrum determined by unfolding the activation foils data for irradiation IER241.

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Table 2 lists the data for the gamma-ray measurements of the activated foils. All of the foils, except for two gold foils and one aluminum foil, were covered with a thin cadmium foil to minimize the low-energy thermal neutron reactions, which have large cross sections for some reactions. The ID, Act/g, and ±Act/g(%) are the identification, activations per gram of foil, and the activations per gram of foil uncertainty, respectively, from the measurements reported in reference [15]. The ratio Act/Tgt is the number of activated nuclei divided by the number of target nuclei for the reaction, and ±Act/Tgt is the corresponding uncertainty calculated from the reference [15] data.

Table 2. IER-261 Foil Data

Foil	Reaction	Cd Cover?	ID	Act/g	±Act/g(%)	Isotopic Abundance (%)	Half-life	Act/Tgt	±Act/Tgt (%)
Sc	Sc45(n,2n)Sc44m	yes	4165-1-44	1.30E+08	58.00	100	2.44 d	9.705E-15	58.00
Sc	Sc45(n,g)Sc46	yes	4165-1-44	2.61E+11	2.90	100	85 d	1.948E-11	2.90
Ti	Ti46(n,p)Sc46	yes	4165-1-46	6.40E+09	13.10	8.25	85 d	6.166E-12	13.10
Ti	Ti47(n,p)Sc47	yes	4165-1-46	9.90E+09	4.90	7.44	3.43 d	1.058E-11	4.90
Ti	Ti48(n,p)Sc48	yes	4165-1-46	1.54E+09	3.00	73.72	44 h	1.660E-13	3.00
Ni	Ni58(n,p)Co58	yes	4165-1-57	4.25E+11	3.20	68.08	72 d	6.084E-11	3.20
Ni	Ni58(n,2n)Ni57	yes	4165-1-57	4.20E+07	33.00	68.08	1.50 d	6.013E-15	33.00
Fe	Fe54(n,p)Mn54	yes	4165-1-59	3.43E+10	2.40	5.85	310 d	5.437E-11	2.40
Fe	Fe58(n,γ)Fe59	yes	4165-1-59	2.10E+08	12.00	0.28	44.5 d	6.955E-12	12.00
Cu	Cu63(n,α)Co60	yes	4165-1-64	1.50E+09	33.00	69.17	5.27 y	2.288E-13	33.00
Cu	Cu63(n,γ)Cu64	yes	4165-1-64	2.22E+11	4.10	69.17	12.7 h	3.387E-11	4.10
W	W186(n,γ)W187	yes	4165-1-187	9.78E+11	3.20	28.43	23.9 h	1.050E-09	3.20
Au	Au197((n,2n)Au196	no	4165-1-198	5.00E+09	14.00	100	6.18 h	1.635E-12	14.00
Au	Au197(n,γ)Au198	no	4165-1-198	1.02E+12	2.40	100	2.69 d	3.336E-10	2.40
Au	Al27(n,α)Na24	no	4165-1-198	9.50E+09	2.80	100	15.06 h	4.257E-13	2.80
Au	Au197((n,2n)Au196	yes	4165-2-198	4.50E+09	15.00	100	6.18 h	1.472E-12	15.00
Au	Au197(n,γ)Au198	yes	4165-2-198	1.01E+12	2.40	100	2.69 d	3.303E-10	2.40
Au	Al27(n,α)Na24	yes	4165-2-198	9.20E+09	2.90	100	15.06 h	4.122E-13	2.90

The MAXED unfolding code was run with these foil data. As noted above in the Analysis of the Foils section above, data for some of the foils could not be included because they resulted in unreasonable oscillations or large deviations from the smooth trial spectrum. The foil data that were not included in the final fit are specified in the Appendix.

Figure 3 shows a comparison of the fitted spectrum with the trial spectrum. The results are similar to the results for IER-241. The statistical uncertainty increases at high energies in both the fitted spectrum and the trial spectrum. The fitted spectrum closely matches the trial spectrum below 12000 keV, but above 12000 keV, the fitted spectrum is lower. The reason for this difference may be due to the difficulties in obtaining a good fit discussed in the Analysis of the Foils section above or due to the possibility that the model, based on IER-163, for the trial did not accurately match the configuration that was measured.

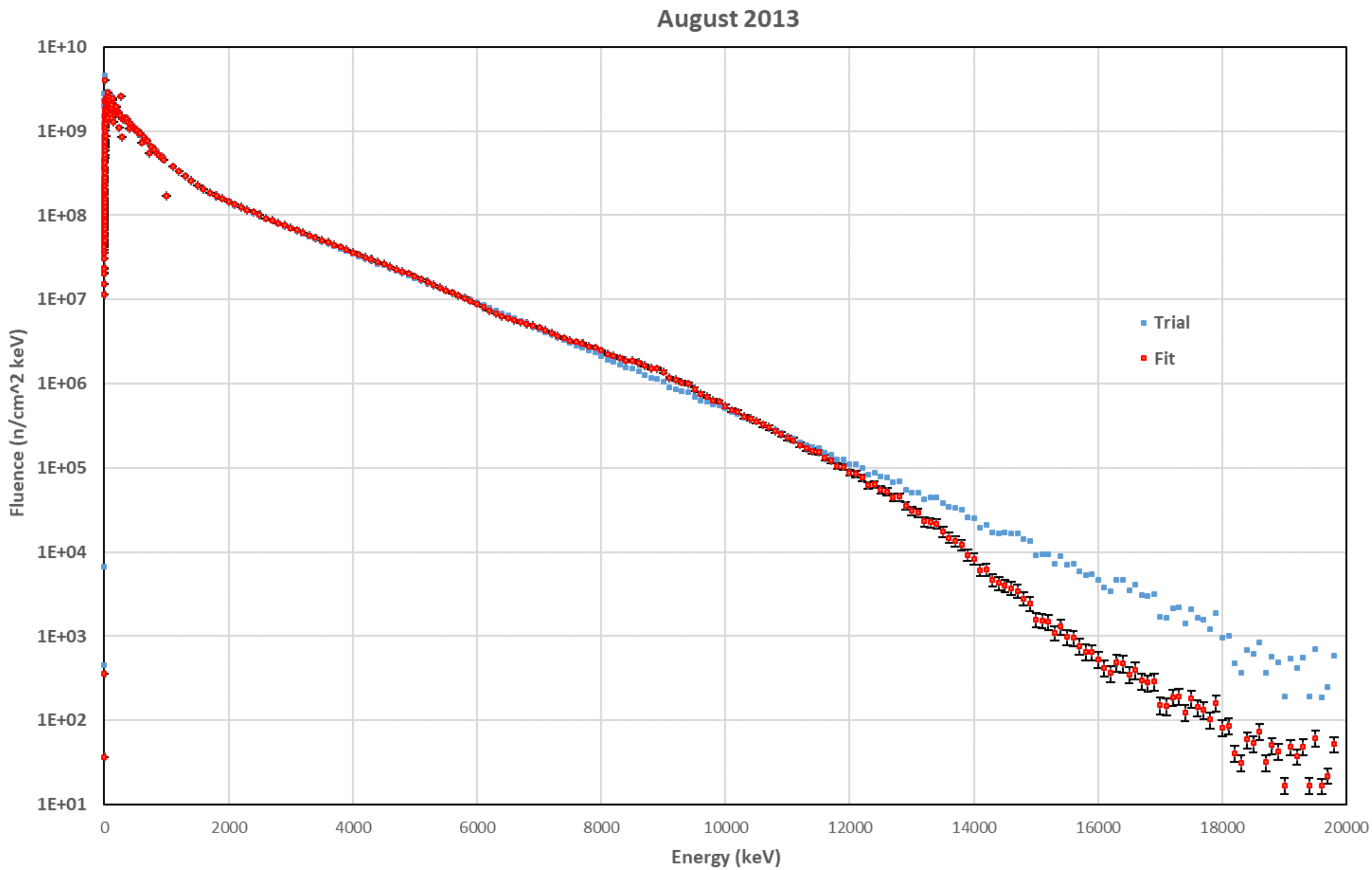

Figure 3. Comparison of the spectrum determined by unfolding the activation foils data and the MCNP trial spectrum for irradiation IER-261.

Conclusions

The Maximum Entropy (MAXED) code has been used to unfold the COMET ZEUS activation foil data taken in December 2012 and August 2013 to determine the internal neutron spectra in COMET operating near critical. The fitted spectra for both dates closely match the trial spectrum below 12000 keV, but above 12000 keV, the fitted spectrum is lower. The reason for this difference may be due to problems with the reported activation data, inherent problems with the MAXED code, inaccuracies in the ENDF cross sections at higher energies, or failure of the MCNP model, based on IER-163, to accurately match the configurations that were measured IER-241 and IER-261. Analysis of these data and other data with different unfolding codes is needed to better understand the unfolding. MAXED is very labor intensive because all of the input and output files are in strict FORTRAN format and many runs are required to exclude data from the foils that do not provide reasonable neutron spectra and to select MAXED starting parameters. Hopefully, other codes will be less labor intensive. Finally, if the primary interest is above 8 MeV, more foils with threshold energies in this region with accurately known cross sections should be included.

Appendix

Partial Examples of MAXED Files

The required FORTRAN formats are specified in the MAXED instructions.

IER-241

1. Control File

CMTZDc93.dat	File with measured data
Dec12RF5.txt	File with response functions (RF)
DecOut93	Name of output file
Z163mod3.flu	File with default spectrum (DS)
20000000.	Highest energy (use energy units of RF)
5	requested final CHI^2 P.D.F.
0.001,0.85	temperature, temp. reduction fact.
3,1	3 = use the RF energy bins, 1 = dF/dE
1	1 = scale DS
0	0 = use the GRAVEL DS scale factor

2. Measured Data

Dec 2012 COMET/ZEUS   number of activated nuclei per target nuclei

23   0

Foil	Measurement	Mea stat uncer	% stat uncer	% syst uncer	flag
Sc45n2Cd	6.420E-15	1.605E-15	25.00	2.0	1
Sc45ngCd	1.575E-11	4.095E-13	2.60	2.0	-2
Ti46npCd	4.625E-12	2.081E-13	4.50	2.0	-3
Ti47npCd	8.547E-12	4.359E-13	5.10	2.0	-4
Ti48npCd	1.100E-13	3.629E-15	3.30	2.0	5
V51naCd	7.548E-15	1.811E-15	24.00	2.0	6
Ni58npCd	4.524E-11	1.131E-12	2.50	2.0	7
Ni60npCd	1.561E-12	4.840E-13	31.00	2.0	8
Ni58n2Cd	3.006E-14	1.924E-15	6.40	2.0	-9
Fe54npCd	3.757E-11	1.240E-12	3.30	2.0	-10
Mo92npCd	3.435E-12	1.649E-13	4.80	2.0	-11
Mo98ngCd	4.027E-11	1.933E-12	4.80	2.0	-12
W186ngCd	2.942E-09	9.415E-11	3.20	2.0	-13
Au197n2n	2.028E-12	5.678E-13	28.00	2.0	14
Au197ng	2.453E-10	1.349E-11	5.50	2.0	-15
Al27na	2.912E-13	1.369E-14	4.70	2.0	16
Aun2nCd1	1.472E-12	3.827E-13	26.00	2.0	17
AungCd1	2.388E-10	1.361E-11	5.70	2.0	-18
Al27naCd	2.778E-13	1.583E-14	5.70	2.0	19
Aun2n	1.276E-12	5.102E-14	4.00	2.0	20
Aung	1.962E-10	4.906E-12	2.50	2.0	-21
Aun2nCd2	1.276E-12	9.057E-14	7.10	2.0	22
AungCd2	1.930E-10	4.824E-12	2.50	2.0	-23

Note: Entries with negative in the last column were not included in the final fit for Figure 2.

3. Response Functions

The first block is a partial listing of the bin energies in eV. The second block is a partial listing of 1.0E+06 times the response cross section for the reaction Sc45(n,g)Sc46. The 1.0E+06 is necessary because the MAXED code cannot handle internally numbers less than 1.0E-26. The fit must be multiplied by 1.0E+06. Similar response cross sections for all of the target foils followed the one for Sc45(n,g)Sc46.

June 6, 2018 Based on cross sections calculated with MCNP6
Neutron Response Functions for Dec 2012 Comet_Zeus_IER-261.xlsx
641 0

1.000E-04	1.050E-04	1.100E-04	1.150E-04	1.200E-04	1.275E-04	1.350E-04	1.425E-04
1.500E-04	1.600E-04	1.700E-04	1.800E-04	1.900E-04	2.000E-04	2.100E-04	2.200E-04
2.300E-04	2.400E-04	2.550E-04	2.700E-04	2.800E-04	3.000E-04	3.200E-04	3.400E-04
3.600E-04	3.800E-04	4.000E-04	4.250E-04	4.500E-04	4.750E-04	5.000E-04	5.250E-04
5.500E-04	5.750E-04	6.000E-04	6.300E-04	6.600E-04	6.900E-04	7.200E-04	7.600E-04
8.000E-04	8.400E-04	8.800E-04	9.200E-04	9.600E-04	1.000E-03	1.050E-03	1.100E-03
1.150E-03	1.200E-03	1.275E-03	1.350E-03	1.425E-03	1.500E-03	1.600E-03	1.700E-03
1.800E-03	1.900E-03	2.000E-03	2.100E-03	2.200E-03	2.300E-03	2.400E-03	2.550E-03
2.700E-03	2.800E-03	3.000E-03	3.200E-03	3.400E-03	3.600E-03	3.800E-03	4.000E-03
4.250E-03	4.500E-03	4.750E-03	5.000E-03	5.250E-03	5.500E-03	5.750E-03	6.000E-03
6.300E-03	6.600E-03	6.900E-03	7.200E-03	7.600E-03	8.000E-03	8.400E-03	8.800E-03
9.200E-03	9.600E-03	1.000E-02	1.050E-02	1.100E-02	1.150E-02	1.200E-02	1.275E-02
1.350E-02	1.425E-02	1.500E-02	1.600E-02	1.700E-02	1.800E-02	1.900E-02	2.000E-02
2.100E-02	2.200E-02	2.300E-02	2.400E-02	2.550E-02	2.700E-02	2.800E-02	3.000E-02
3.200E-02	3.400E-02	3.600E-02	3.800E-02	4.000E-02	4.250E-02	4.500E-02	4.750E-02
5.000E-02	5.250E-02	5.500E-02	5.750E-02	6.000E-02	6.300E-02	6.600E-02	6.900E-02
7.200E-02	7.600E-02	8.000E-02	8.400E-02	8.800E-02	9.200E-02	9.600E-02	1.000E-01
1.050E-01	1.100E-01	1.150E-01	1.200E-01	1.275E-01	1.350E-01	1.425E-01	1.500E-01
1.600E-01	1.700E-01	1.800E-01	1.900E-01	2.000E-01	2.100E-01	2.200E-01	2.300E-01
2.400E-01	2.550E-01	2.700E-01	2.800E-01	3.000E-01	3.200E-01	3.400E-01	3.600E-01
3.800E-01	4.000E-01	4.250E-01	4.500E-01	4.750E-01	5.000E-01	5.250E-01	5.500E-01
5.750E-01	6.000E-01	6.300E-01	6.600E-01	6.900E-01	7.200E-01	7.600E-01	8.000E-01
8.400E-01	8.800E-01	9.200E-01	9.600E-01	1.000E+00	1.050E+00	1.100E+00	1.150E+00
1.200E+00	1.275E+00	1.350E+00	1.425E+00	1.500E+00	1.600E+00	1.700E+00	1.800E+00
1.900E+00	2.000E+00	2.100E+00	2.200E+00	2.300E+00	2.400E+00	2.550E+00	2.700E+00
2.800E+00	3.000E+00	3.200E+00	3.400E+00	3.600E+00	3.800E+00	4.000E+00	4.250E+00
4.500E+00	4.750E+00	5.000E+00	5.250E+00	5.500E+00	5.750E+00	6.000E+00	6.300E+00
6.600E+00	6.900E+00	7.200E+00	7.600E+00	8.000E+00	8.400E+00	8.800E+00	9.200E+00
9.600E+00	1.000E+01	1.050E+01	1.100E+01	1.150E+01	1.200E+01	1.275E+01	1.350E+01
1.425E+01	1.500E+01	1.600E+01	1.700E+01	1.800E+01	1.900E+01	2.000E+01	2.100E+01
2.200E+01	2.300E+01	2.400E+01	2.550E+01	2.700E+01	2.800E+01	3.000E+01	3.200E+01
3.400E+01	3.600E+01	3.800E+01	4.000E+01	4.250E+01	4.500E+01	4.750E+01	5.000E+01
5.250E+01	5.500E+01	5.750E+01	6.000E+01	6.300E+01	6.600E+01	6.900E+01	7.200E+01

...

0
23
Sc45ngCd
1.000E+00 cm^2 0 0 3 1 1 0

0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.645E-22	0.000E+00	5.401E-22
5.229E-22	5.172E-22	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.470E-22	4.234E-22
4.173E-22	2.451E-21	3.589E-21	1.535E-21	3.401E-21	4.038E-21	3.971E-21	3.876E-21
3.446E-21	4.368E-21	5.908E-21	1.093E-20	7.209E-21	7.649E-21	1.305E-20	1.401E-20
1.674E-20	1.617E-20	2.118E-20	1.815E-20	2.543E-20	2.628E-20	2.963E-20	2.855E-20
3.765E-20	4.692E-20	4.420E-20	5.298E-20	5.615E-20	6.058E-20	6.391E-20	6.660E-20
7.744E-20	7.692E-20	7.943E-20	7.982E-20	8.645E-20	8.366E-20	8.783E-20	9.554E-20
9.125E-20	9.797E-20	8.925E-20	8.957E-20	9.032E-20	8.423E-20	8.283E-20	8.172E-20
7.661E-20	6.675E-20	5.908E-20	5.419E-20	5.184E-20	4.221E-20	3.665E-20	3.343E-20

2.542E-20	2.279E-20	1.385E-20	1.131E-20	1.144E-20	5.871E-21	4.728E-21	2.423E-21
2.101E-21	9.043E-22	4.832E-22	7.879E-23	7.661E-23	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.552E-22	1.106E-21	3.886E-21
1.872E-20	8.048E-20	1.869E-19	4.283E-19	8.752E-19	1.430E-18	1.994E-18	2.547E-18
3.000E-18	3.442E-18	3.810E-18	4.082E-18	4.303E-18	4.438E-18	4.541E-18	4.613E-18
4.649E-18	4.664E-18	4.665E-18	4.646E-18	4.624E-18	4.584E-18	4.528E-18	4.457E-18
4.397E-18	4.325E-18	4.258E-18	4.191E-18	4.124E-18	4.040E-18	3.963E-18	3.880E-18
3.808E-18	3.705E-18	3.609E-18	3.518E-18	3.429E-18	3.326E-18	3.235E-18	3.146E-18
3.069E-18	2.992E-18	2.922E-18	2.861E-18	2.789E-18	2.726E-18	2.651E-18	2.575E-18
2.519E-18	2.433E-18	2.358E-18	2.289E-18	2.225E-18	2.163E-18	2.105E-18	2.042E-18
1.983E-18	1.931E-18	1.882E-18	1.836E-18	1.793E-18	1.752E-18	1.711E-18	1.672E-18
1.630E-18	1.592E-18	1.555E-18	1.513E-18	1.472E-18	1.437E-18	1.402E-18	1.370E-18
1.338E-18	1.309E-18	1.276E-18	1.245E-18	1.213E-18	1.183E-18	1.145E-18	1.111E-18
1.078E-18	1.046E-18	1.010E-18	9.774E-19	9.392E-19	9.202E-19	8.946E-19	8.700E-19
8.481E-19	8.252E-19	8.023E-19	7.762E-19	6.532E-19	7.286E-19	7.026E-19	6.767E-19
6.527E-19	6.311E-19	6.100E-19	5.898E-19	5.680E-19	5.481E-19	5.297E-19	5.125E-19
4.966E-19	4.807E-19	4.672E-19	4.533E-19	4.347E-19	3.913E-19	4.110E-19	3.979E-19
3.829E-19	3.721E-19	3.772E-19	2.811E-19	3.317E-19	3.133E-19	3.100E-19	2.949E-19
2.886E-19	2.862E-19	2.481E-19	2.540E-19	2.401E-19	2.303E-19	2.192E-19	2.025E-19
1.962E-19	1.884E-19	1.737E-19	1.683E-19	1.594E-19	1.503E-19	1.421E-19	1.388E-19
1.297E-19	1.226E-19	1.167E-19	1.083E-19	1.008E-19	9.388E-20	9.011E-20	8.487E-20

…

4. Output File

The output needs to be multiplied by 1.0E+06 because the response was multiplied by this factor.

```
Fluence spectrum from program MXD_FC33
       1          0
       1        638        638   19900000.0              0
  1.04999999E-04  0.00000000       0.00000000
  1.10000001E-04  0.00000000       0.00000000
  1.15000003E-04  0.00000000       0.00000000
  1.19999997E-04  0.00000000       0.00000000
  1.27499996E-04  0.00000000       0.00000000
  1.34999995E-04  0.00000000       0.00000000
  1.42499994E-04  0.00000000       0.00000000
  1.50000007E-04  0.00000000       0.00000000
  1.59999996E-04  0.00000000       0.00000000
  1.69999999E-04  0.00000000       0.00000000
  1.80000003E-04  0.00000000       0.00000000
  1.90000006E-04  0.00000000       0.00000000
  1.99999995E-04  0.00000000       0.00000000
  2.09999998E-04  0.00000000       0.00000000
  2.20000002E-04  0.00000000       0.00000000
  …
  5000000.00      13.3822212       0.00000000
  5100000.00      12.4111462       0.00000000
  5200000.00      11.6772184       0.00000000
  5300000.00      10.9504662       0.00000000
  5400000.00      10.2391443       0.00000000
  5500000.00      9.53618145       0.00000000
  5600000.00      8.91266346       0.00000000
  5700000.00      8.26978111       0.00000000
  5800000.00      7.85534763       0.00000000
  5900000.00      7.27341938       0.00000000
  6000000.00      6.77801609       0.00000000

  …
```

5. Default Spectrum

1.05E-04	1.10E-04	1.15E-04	1.20E-04	1.28E-04	1.35E-04	1.43E-04
1.50E-04	1.60E-04	1.70E-04	1.80E-04	1.90E-04	2.00E-04	2.10E-04
2.20E-04	2.30E-04	2.40E-04	2.55E-04	2.70E-04	2.80E-04	3.00E-04
3.20E-04	3.40E-04	3.60E-04	3.80E-04	4.00E-04	4.25E-04	4.50E-04
4.75E-04	5.00E-04	5.25E-04	5.50E-04	5.75E-04	6.00E-04	6.30E-04
6.60E-04	6.90E-04	7.20E-04	7.60E-04	8.00E-04	8.40E-04	8.80E-04
9.20E-04	9.60E-04	1.00E-03	1.05E-03	1.10E-03	1.15E-03	1.20E-03

1.28E-03	1.35E-03	1.43E-03	1.50E-03	1.60E-03	1.70E-03	1.80E-03
1.90E-03	2.00E-03	2.10E-03	2.20E-03	2.30E-03	2.40E-03	2.55E-03
2.70E-03	2.80E-03	3.00E-03	3.20E-03	3.40E-03	3.60E-03	3.80E-03
4.00E-03	4.25E-03	4.50E-03	4.75E-03	5.00E-03	5.25E-03	5.50E-03
5.75E-03	6.00E-03	6.30E-03	6.60E-03	6.90E-03	7.20E-03	7.60E-03
8.00E-03	8.40E-03	8.80E-03	9.20E-03	9.60E-03	1.00E-02	1.05E-02
1.10E-02	1.15E-02	1.20E-02	1.28E-02	1.35E-02	1.43E-02	1.50E-02
1.60E-02	1.70E-02	1.80E-02	1.90E-02	2.00E-02	2.10E-02	2.20E-02
2.30E-02	2.40E-02	2.55E-02	2.70E-02	2.80E-02	3.00E-02	3.20E-02
3.40E-02	3.60E-02	3.80E-02	4.00E-02	4.25E-02	4.50E-02	4.75E-02
5.00E-02	5.25E-02	5.50E-02	5.75E-02	6.00E-02	6.30E-02	6.60E-02
6.90E-02	7.20E-02	7.60E-02	8.00E-02	8.40E-02	8.80E-02	9.20E-02
9.60E-02	1.00E-01	1.05E-01	1.10E-01	1.15E-01	1.20E-01	1.28E-01

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2.04E+02	2.02E+02	1.23E+02	5.70E+02	1.38E+02	2.08E+02	3.70E+02
1.14E+02	2.18E+02	2.23E+02	1.83E+02	1.85E+02	1.58E+02	2.46E+02
2.03E+02	1.83E+02	1.36E+02	2.42E+02	1.94E+02	9.71E+01	2.11E+02
2.74E+02	1.93E+02	9.76E+01	9.09E+01	1.88E+02	2.37E+02	6.11E+01
1.28E+02	1.79E+02	1.01E+02	1.32E+02	1.14E+02	9.84E+01	1.18E+02
1.12E+02	1.66E+02	1.33E+02	1.08E+02	7.53E+01	8.11E+01	5.32E+01
1.19E+02	8.30E+01	1.05E+02	8.22E+01	9.93E+01	1.53E+02	1.15E+02
1.65E+02	9.77E+01	9.80E+01	1.31E+02	1.29E+02	3.87E+01	7.39E+01
5.42E+01	5.18E+01	7.29E+01	8.11E+01	5.01E+01	6.78E+01	4.99E+01
6.70E+01	6.54E+01	8.23E+01	5.51E+01	6.13E+01	7.11E+01	8.02E+01
1.06E+02	1.19E+02	4.01E+01	9.25E+01	4.76E+01	9.41E+01	1.07E+02
8.32E+01	6.65E+01	8.49E+01	9.52E+01	1.03E+02	7.78E+01	9.73E+01
8.13E+01	1.18E+02	3.89E+01	1.37E+02	1.48E+02	1.44E+02	1.14E+02
1.52E+02	1.47E+02	1.91E+02	1.88E+02	2.18E+02	2.02E+02	1.88E+02
2.07E+02	1.94E+02	2.43E+02	1.71E+02	2.63E+02	2.72E+02	3.16E+02
2.52E+02	3.43E+02	3.54E+02	3.83E+02	3.13E+02	1.39E+02	3.72E+01
1.15E+02	1.84E+02	1.91E+02	2.34E+02	1.80E+02	1.06E+02	2.68E+02
3.30E+02	3.72E+02	4.58E+02	5.25E+02	2.59E+02	5.48E+02	5.55E+02
6.72E+02	5.32E+02	8.77E+02	3.57E+02	5.92E+02	5.08E+02	9.39E+02
7.99E+02	1.12E+03	1.27E+03	3.40E+03	4.49E+02	4.20E+02	8.68E+02

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IER-261

1. Control File

Z_Ag103.dat	File with measured data
Aug13RF4.txt	File with response functions (RF)
AgOut103	Name of output file
Z163mod3.flu	File with default spectrum (DS)
20000000.	Highest energy (use energy units of RF)
5	requested final CHI^2 P.D.F.
1.0,0.85	temperature, temp. reduction fact.
3,1	3 = use the RF energy bins, 1 = dF/dE
1	1 = scale DS
0	0 = use the GRAVEL DS scale factor

2. Measured Data

0 * Zeus Aug 2013 config, number of activated nuclei per target nuclei

18 0

Sc45n2Cd	9.706E-15	5.629E-15	58.00	2.0	1
Sc45ngCd	1.949E-11	5.651E-13	2.90	2.0	2
Ti46npCd	6.165E-12	8.077E-13	13.10	2.0	3

Ti47npCd	1.058E-11	5.182E-13	4.90	2.0	4
Ti48npCd	1.660E-13	4.981E-15	3.00	2.0	5
Ni58npCd	6.084E-11	1.947E-12	3.20	2.0	6
Ni58n2Cd	6.012E-15	1.984E-15	33.00	2.0	-7
Fe54npCd	5.438E-11	1.305E-12	2.40	2.0	-8
Fe58ngCd	6.956E-12	8.347E-13	12.00	2.0	-9
Cu63naCd	2.288E-13	7.552E-14	33.00	2.0	10
Cu63ngCd	3.387E-11	1.389E-12	4.10	2.0	11
W186ngCd	1.050E-09	3.361E-11	3.20	2.0	-12
Aun2n	1.680E-12	2.352E-13	14.00	2.0	13
Aung	3.428E-10	8.227E-12	2.40	2.0	-14
Al27na	4.373E-13	1.224E-14	2.80	2.0	15
Aun2nCd	1.433E-12	2.149E-13	15.00	2.0	16
AungCd	3.505E-10	8.412E-12	2.40	2.0	-17
Al27naCd	4.012E-13	1.163E-14	2.90	2.0	18
Foil	Measurement	Mea stat	% stat	% syst	
	uncer	uncer	uncer		flag

Note: Entries with negative in the last column were not included in the final fit for Figure 3.

3. Response Functions

The file of response functions for IER-261 is similar to the file of response functions for IER-241. When the reactions are the same, the data are identical. See the response functions for IER-241 above.

4. Output File

The format of the output file is identical to the format for the IER-241 output above.

5. Default Spectrum

The default spectrum was the same as the one used for IER-241 above.

References

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