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ENDF-EXFOR:
Interactive Comparison of Evaluated (ENDF) and Measured (EXFOR) Nuclear Data

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Abstract

ENDF-EXFOR is designed to use the general purpose PLOTTAB plotting code to Interactively compare Evaluated (ENDF) and Measured (EXFOR) data. This system uses three computer codes. 1) **ENDF2PLOT** converts ENDF formatted data to PLOTTAB.CUR, continuous curves. 2) **X4TOC4** converts EXFOR formatted data to PLOTTAB.PNT, point data & uncertainty. 3) **PLOTTAB** produces graphic results; on-screen interactive graphics, or PDF hardcopy. The PLOTTAB code is designed to be easily used on any computer - not only today's computers, but also anything that comes along in the future.

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Introduction

ENDF-EXFOR is designed to use the general purpose PLOTTAB plotting code to Interactively compare Evaluated (ENDF) and Measured (EXFOR) data. This system uses three computer codes.
1)**ENDF2PLOT** convert ENDF formatted data to PLOTTAB.CUR, continuous curves.
2)**X4TOC4** convert EXFOR formatted data to PLOTTAB.PNT, point data & uncertainty.
3)**PLOTTAB** produces graphic results; on-screen interactive graphics, or PDF hardcopy.
The PLOTTAB code is designed to be easily used on any computer - not only today's computers, but also anything that comes along in the future.

Prologue

The original idea for ENDF-EXFOR came from **Jean-Christophe Sublet**, who expressed his need for a way to efficiently compare evaluated data, and experimentally measured data. I, **Dermott Cullen**, thought this need could be met by using my existing general purpose plotting code, PLOTTAB, that I have used for many years to display and allow me to interact with data for many of my applications. For evaluated data my more than 50 years' experience with the ENDF format allowed me to create a very simple code to convert ENDF data to the PLOTTAB.CUR format. For experimentally measured data, over 50 years ago while employed at the National Nuclear Data Center (NNDC) I invented the EXFOR format, to use in the Cross Section Information Storage and Retrieval System, CSISRS, so I naturally immediately thought of using this as the source of experimentally measured data. My problem was that I had not used the EXFOR format in many years. Fortunately, 50 years ago, I also invented the C4FOR format, and I

created the X4TOC4 code, which starts from the EXFOR general units (energy, cross section, etc.), and converts these to standard units that are the same as ENDF (eV, barns, etc.). I had not used this X4TOC4 code in many years, but over the years **Andrej Trkov** maintained X4TOC4 code, and he kindly supplied the most recent version for our use. In summary: This project could not have been completed without the true cooperative effort of the three authors; they all earned the right to be authors of this report.

Acknowledgement

I greatly acknowledge the work of the Nuclear Data Section, IAEA, Vienna, Austria for reviewing, improving and publishing this report. In particular, I must mention **Roberto Capote Noy**, who supervised the NDS work, and **Kira Nathani**, who edited my original paper. In addition to the cooperative work on ENDF-EXFOR, I should also acknowledge the suggestions that **Jean-Christophe Sublet** has made over the years to improve PLOTTAB and for providing MAC (old & new) executables for PLOTTAB. I must acknowledge that it was **Andrej Trkov** who proposed adding the alternative PLOTSAVE1 format to PLOTTAB; it can now produce hardcopy PDF files, with 1 plot per PDF file (PLOTSAVE), or ALL plots in 1 PDF file (PLOTSAVE1); the choice is strictly up to the code user. I thank **Bojan Zefran** for providing LINUX executables for PLOTTAB.

ENDF2PLOT

As an initial version I, Dermott Cullen, decided to keep this code as simple as possible by limiting the displayed evaluated ENDF data to only cross sections (ENDF MF=3). I also tried to keep the design and input/output as simple as possible. As background information I will mention that most EXFOR data is cross sections, and as far as ENDF, if we cannot get the cross sections (MF=3) correct, it does not matter very much what the secondary particle distributions are. Hopefully this will meet the initial needs.

The input and output file names are always the same,
ENDFB.IN = ENDF formatted data file to read
PLOTTAB.CUR = PLOTTAB curve data file to write
ENDF2PLOT.INP = Input parameters defining ENDF data to read

I have kept the input parameters as simple as possible. Each input line defines one ENDF MT and the title that the user defines to appear on a plot. You can request as many MTs as you want, one after the other. I suggest you limit this to not more than 10 to avoid the legend box on the plot being too large. Any MT that is not found will be skipped; e.g., do not worry about requesting Fission for non-fissile material. Below is a copy of the input file distributed with this package. Note, MT=18, Fission is included as input, and automatically ignored in the output, since 24-Cr is not fissionable.

```
    1 Total
    2 Elastic
  102 Capture
   18 Fission
    4 Inelastic
================(Only the above lines are read input)================
line. 1:Col. 1- 5: MT               I5
             7-26: PLOTTAB title   A20
 This one line can be repeated any number of times.
```

The corresponding output report is shown below; this is on-screen output.

```
=====================================================================
 ENDF2PLOT (2025-1): Create PLOTTAB.CUR
 ====================================================================
 ENDF Label
 --------------------------------------------------------------------
  24_Cr-Nat 300 K NJOY
 --------------------------------------------------------------------
   MT Title                 Points
 --------------------------------------------------------------------
    1 Total                 101763
    2 Elastic                101763
  102 Capture               101763
   18 Fission                    0 NOT found - Skipped
    4 Inelastic               5357
 ====================================================================
 End of Run
 ====================================================================
```

My idea/hope is that in order to retrieve any ENDF data to display users will only have to change the ENDFB.IN file (the ENDF data), to whatever evaluation they wish, and the above input will meet most needs. I have designed ENDF2PLOT as a very small code of only about 100 lines, about half being comments, defining what the code is doing. This code is so simple it should run on virtually any computer/system.

X4TOC$

ENDF2PLOT to translate the ENDF to PLOTTAB.CUR format, is new and I kept it as simple as possible. In contrast, X4TOC4 is a fairly complicated code with a long track record of many years, back to my original designed over 50 years ago. While I was employed at the National Nuclear Data Center (NNDC). I have not used this code in many years, but fortunately Andrej Trkov has maintained it since at least the year 2001. Andrej kindly supplied the most recent version for our use in this project.

Basically, the code translates CSISRS data from the EXFOR format, where data can be in any units that any author publishes, to the fixed ENDF units (eV, barns, etc.). The biggest accuracy problem with the earlier experimental nuclear data system, Sigma Center Information Storage and Retrieval System, SCISRS, was that this system used fixed units, and whoever translated the data from the original published form to SCISRS by hand, was faced with an almost impossible task, i.e., trying to accurately translate by hand between published data and SCISRS fixed units. I recognized this problem when I designed the newer CSISRS and allowed coders to enter data into the system in whatever units it was published, and I relegated the translation from published to standard units to a computer code.

I then designed the C4FOR for use with CSISRS to translate the variable EXFOR units to standard ENDF units, so it could more easily be used in evaluation, i.e., ENDF. This was the origin of the X4TOC4 code over 50 years ago. This is a very complicated, and ever changing problem, as data is published in every changing forms and units. The results today is a complicated code of over 4,000 lines; far too complicated for me at my age to ever create today from scratch. Fortunately, because it has been maintained over the years by Andrej Trkov, for use in this current project all I had to add was a few lines of coding to output translated data to the PLOTTAB.PNT file format.

As with ENDF2PLOT, I have tried to keep the input and output as simple as possible,

The input and output file names are always the same,
X4TOC$.IN = X4TOC4 formatted data file to read
PLOTTAB.PNT = PLOTTAB point data and uncertainty file to write
There are no input parameters. It is the responsibility of the user to ensure that the cross section data from CSISRS is the cross section data corresponding to the ENDF evaluated data in ENDFB.IN that you want to compare to. The data X4TOC$ data distributed with this code correspond to measured total cross sections for elemental 24-Cr.

The output report is shown below; this is on-screen output. The X4TOC$.DAT includes 28 PLOTTAB.PNT sets of measured data points, as listed below. The last 2 numbers with each input line definition are the X4FOR accession and sub-accession numbers.

```
==================================
 X4TOC$ 2025-1: Create PLOTTAB.PNT
==================================
D.G.FOSTER JR,ET.AL. (71)10047 28
L.GREEN,ET.AL. (73)      10225 21
F.G.Perey,ET.AL. (73)    10342  4
T.W.BONNER,ET.AL. (54)   11012  4
L.S.Goodman (52)         11057 11
J.M.PETERSON,ET.AL. (60) 11108 17
A.BRATENAHL,ET.AL. (58)  11155 12
E.W.Bennett,ET.AL. (57)  11265  6
H.W.Newson,ET.AL. (61)   11368 11
J.F.Whalen,ET.AL. (66)   11540  3
R.E.COTE,ET.AL. (58)     11641 10
E.Melkonian,ET.AL. (53)  11670  2
C.T.HIBDON (57)          11674  2
J.H.Coon,ET.AL. (52)     12524 20
P.T.GUENTHER,ET.AL. (82) 12750  2
D.C.LARSON,ET.AL. (80)   12882  8
W.P.Abfalterer, (01)     13753 17
S.Cierjacks,ET.AL.       20012  3
F.MANERO (67)            20168  2
J.Cabe,ET.AL. (67)       20482  2
L.KOESTER,ET.AL. (78)    20813  8
K.TSUKADA,ET.AL. (66)    22628  7
Tran Ung,ET.AL. (72)     30149  3
F.Kropff Moreno, (76)    30311  2
M.Salama,ET.AL. (73)     30468  2
R.POLICRONIADES, (94)    31468  4
V.V.Filippov,ET.AL. (68) 40082  9
V.V.Filippov             40883  2
 ================================
 End of Run
 ================================
```

ALL data is in 11 Columns wide

ENDF and EXFOR both include data that is 11 columns wide, which is the same as the width of both PLOTTAB files, PLOTTAB.CUR and PLOTTAB.PNT; Henry Honeck designed the 11 column ENDF format. I, Dermott Cullen, designed X4FOR and PLOTTAB formats to be 11 columns wide, compatible with ENDF. In this case (ENDF MT=3) ENDF and C4FOR both use the same units (eV vs. barns), so these codes did not require any unit conversion. These codes (ENDF2PLOT and X4TOC4), read ALL numerical values as characters (A11) rather than numerical (E11) form. So that ALL of the data in both PLOTTAB.CUR (from ENDF) and PLOTTAB.PNT (from C4FOR) are exactly as they are represented in the original ENDF and C4FOR data, i.e. there is no change in precision between the original data and what is shown by PLOTTAB.

PLOTTAB

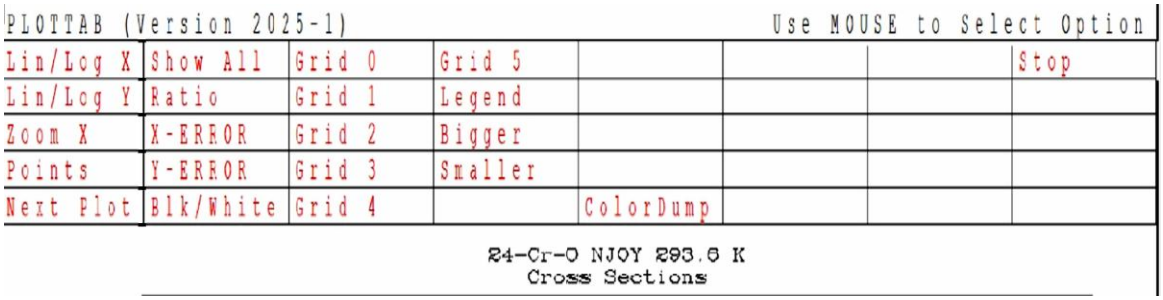
PLOTTAB is extensively documented elsewhere for general use, so that documentation will not be repeated here. Here we will only describe the PLOTTAB input parameters and plots included in the PLOTTAB 2025 distribution to display the ENDF (PLOTTAB.CUR), and X4TOC4 (PLOTTAB.PNT) data distributed with PLOTTAB 2025.

PLOTTAB input parameters are complicated to allow it to handle many different plots. But fortunately for this specific use, to compare ENDF and EXFOR data, you should be able to use the standard PLOTTAB.INP distributed with PLOTTAB2025, with very few changes – basically all you need change on each plot is the definition of the data you are comparing – in the below example: `24-Cr-0 NJOY 293.6 K,` and insure that the one ENDF MT you want to compare to is the first continuous curve in PLOTTAB.CUR; usually MT=1, Total.

Here are a few more details. Each plot uses 8 lines of input parameters, followed by a BLANK line, followed by another 8 lines for the next plot, etc., for as many plots as you want. Below I have included the complete input for the first 2 plots. To compare any ENDF and EXFOR data,, on each plot you will have to change the definition of what you are comparing. In the below example you can replace `24-Cr-0 NJOY 293.6 K`. The only other thing that varies is the first plot includes up to **8** continuous curves (ENDF data) and **0** sets of points (EXFOR data). All following plots repeat the first curve **-1** (ENDF data; usually MT=1, Total) and up to **8** sets of points (EXFOR). The standard input for all remaining plots is merely what you see below for the second plot, repeated many times to guarantee that all of the EXFOR data is plotted, compared to the first continuous curve (usually the total, MT=1). PLOTTAB will automatically stop when all of the EXFOR (PLOTTAB.PNT) data has been displayed, That is basically all you need to know = basically to compare any ENDF and EXFOR data, all you need change is definition of the data on the fifth line of input parameters for ALL plots.

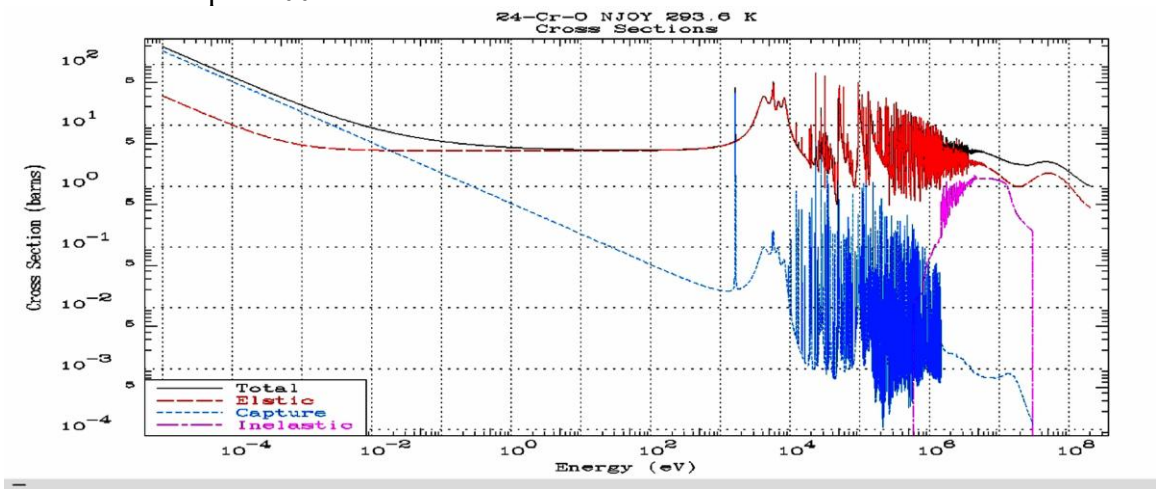
```
    -1.0000    15.0000    -0.5000    11.0000          1          1 1.5
          4           0           0          1          0          0   0
Energy (eV)
Cross Section (barns)
24-Cr-0 NJOY 293.6 K
Cross Sections
                                   2          2          0          0   0
                                   2          2          0          0   0

    -1.0000    15.0000    -0.5000    11.0000          1          1 1.5
         -1           8           0          1          0          0   0
Energy (eV)
Cross Section (barns)
24-Cr-0 NJOY 293.6 K
Cross Sections
                                   2          2          0          0   0
                                   2          2          0          0   0
```

You need not understand all of the other options, because they are defined in the output listing for PLOTTAB, i.e., PLOTTAB.LST, and also shown at the top of each Interactive plot, as you can see below.



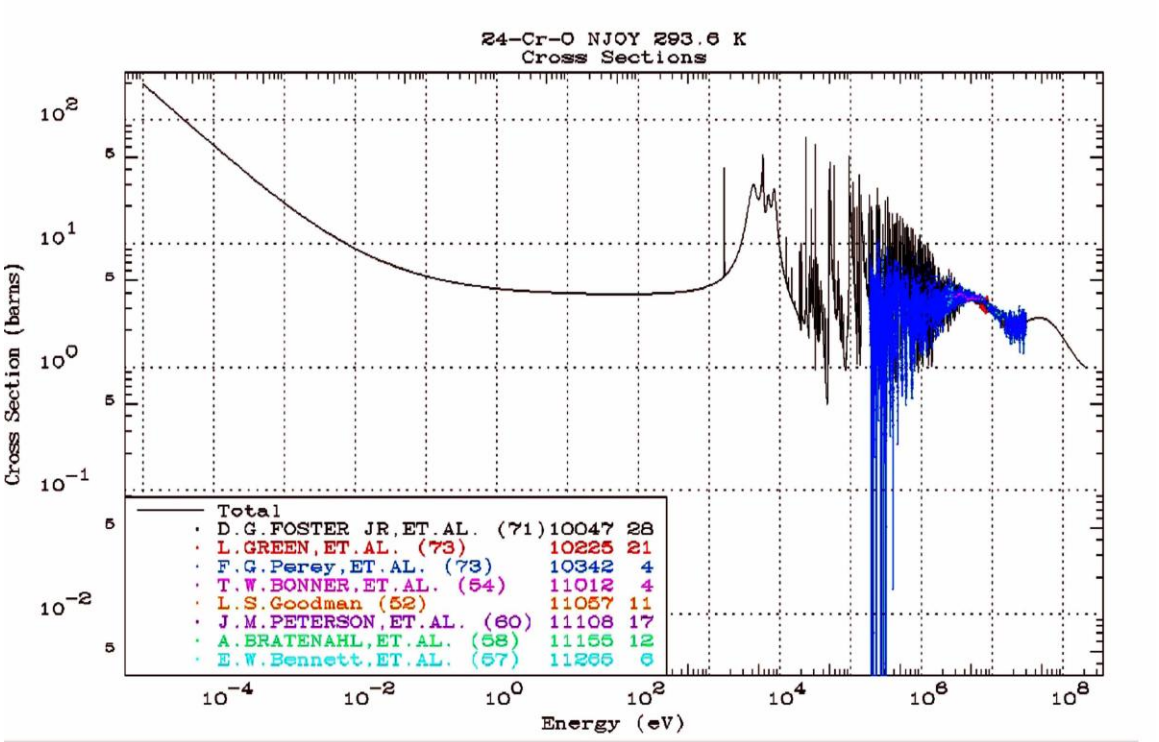
Example PLOTTAB Plots

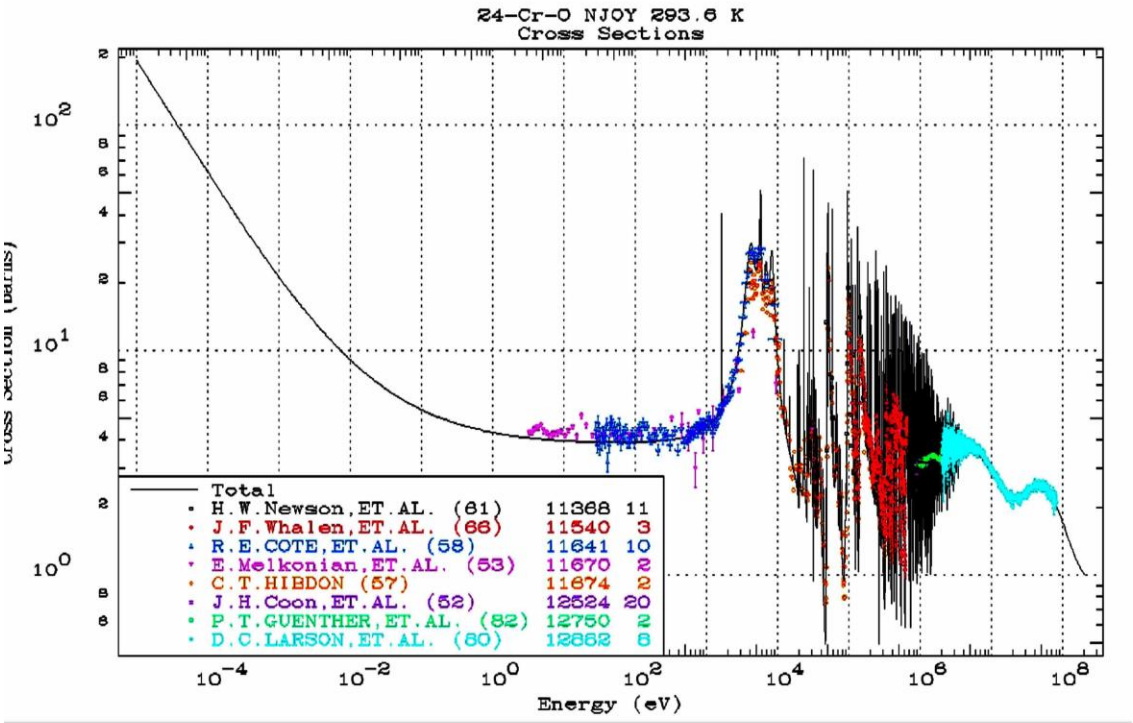
Below I show the first plot, which only included all of the PLOTTAB.CUR (ENDF) data; in this case 4 reactions are shown, because that is all I requested with the ENDF2PLOT input to create PLOTTAB.CUR. Note that the Inelastic, as defined by ENDF-102 (the ENDL Bible), Inelastic and Capture only extends up to 30 MeV, whereas Total and Elastic extend up to 200 MeV.

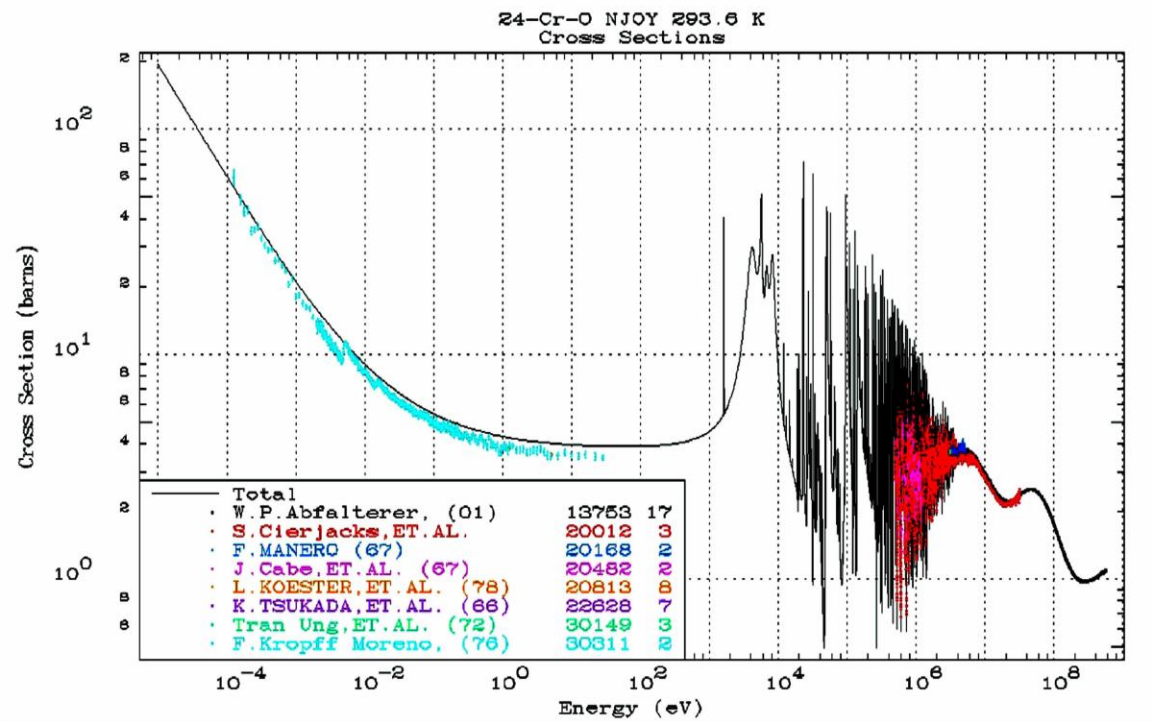


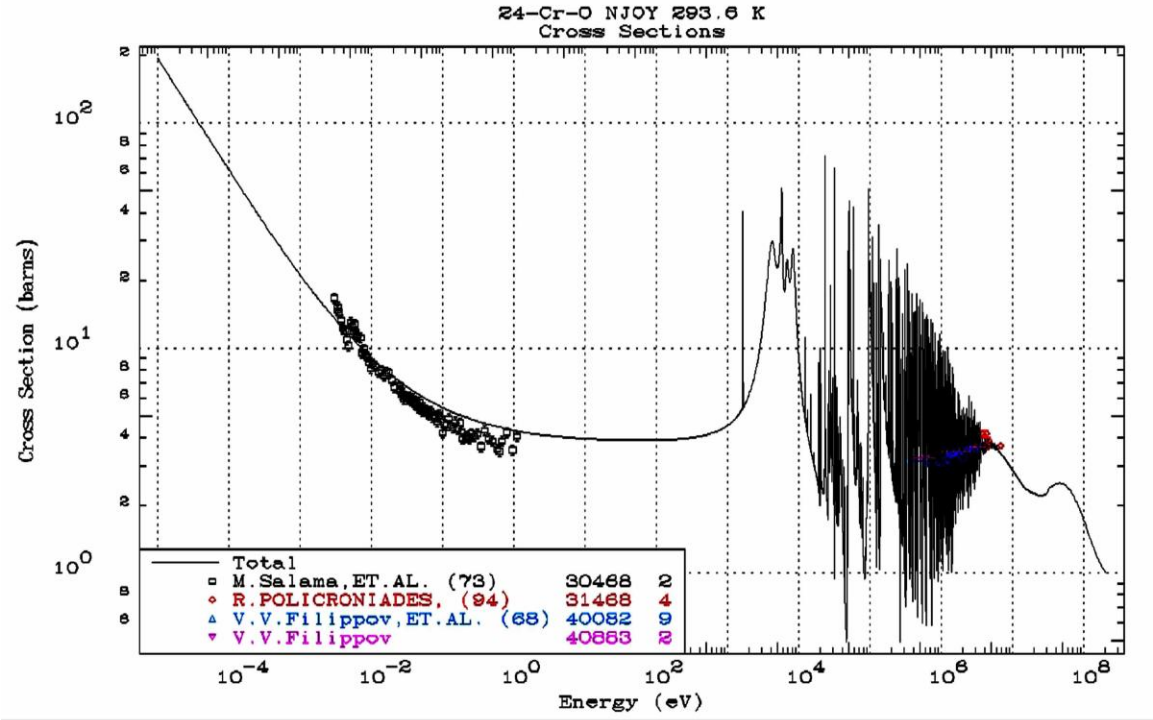
The following four (4) plots compare the first curve from PLOTTAB.CUR (ENDF), as selected by **-1** (first from preceding plot); in this case the Total Cross Section, compared to up to **8** sets of points from PLOTTAB.PNT (EXFOR). By the fourth plot all of the sets of points from PLOTTAB.PNT have been displayed and PLOTTAB automatically stops. If you are running the non-interactive version of PLOTTAB (PLOTSAVE or PLOTSSAVE1) that is all you will see.

In my jusdgement, these results do not tell me much about how well the ENDF evaluation agrees with the EXFOR measured data. So after these 4 plots I include a few examples of ZOOMed plots that any user of the on-screen interactive version of PLOTTAB can produce.


24-Cr-0 NJOY 293.6 K
Cross Sections
Cross Section (barns)
Energy (eV)
Total
D.G.FOSTER JR,ET.AL. (71)10047 28
L.GREEN,ET.AL. (73) 10225 21
F.G.Perey,ET.AL. (73) 10342 4
T.W.BONNER,ET.AL. (54) 11012 4
L.S.Goodman (52) 11057 11
J.M.PETERSON,ET.AL. (60) 11108 17
A.BRATENAHL,ET.AL. (58) 11155 12
E.W.Bennett,ET.AL. (57) 11265 6

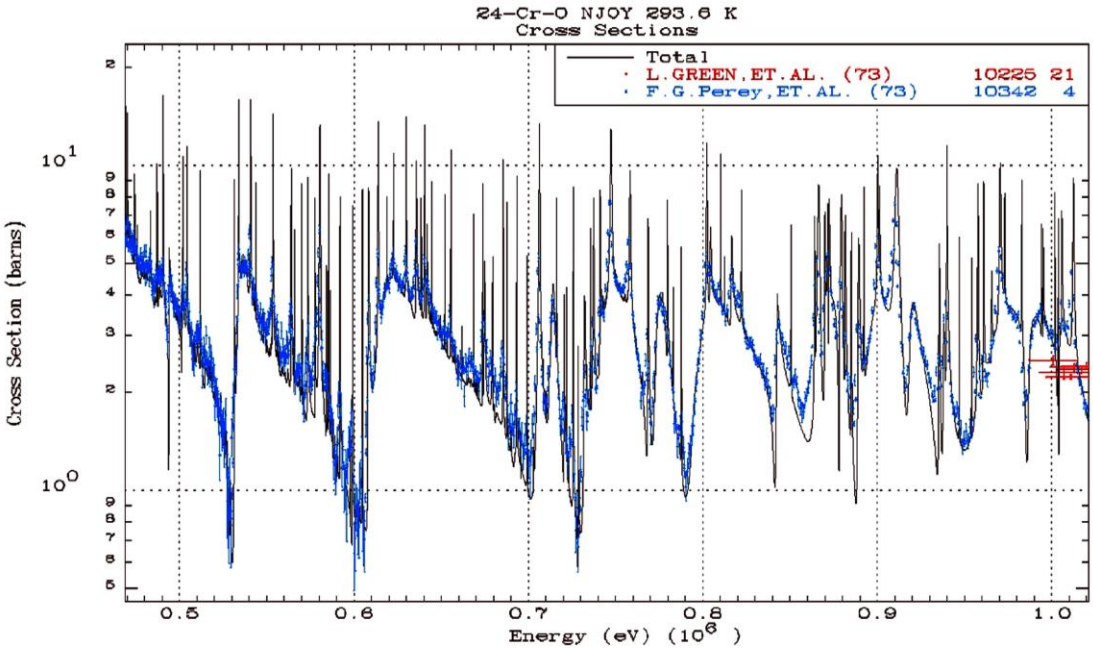

24-Cr-0 NJOY 293.6 K
Cross Sections
Energy (eV)
Total
H.W.Newson,ET.AL. (61) 11368 11
J.F.Whalen,ET.AL. (66) 11540 3
R.E.COTE,ET.AL. (58) 11641 10
E.Melkonian,ET.AL. (53) 11670 2
C.T.HIBDON (57) 11674 2
J.H.Coon,ET.AL. (52) 12524 20
P.T.GUENTHER,ET.AL. (82) 12750 2
D.C.LARSON,ET.AL. (60) 12862 8

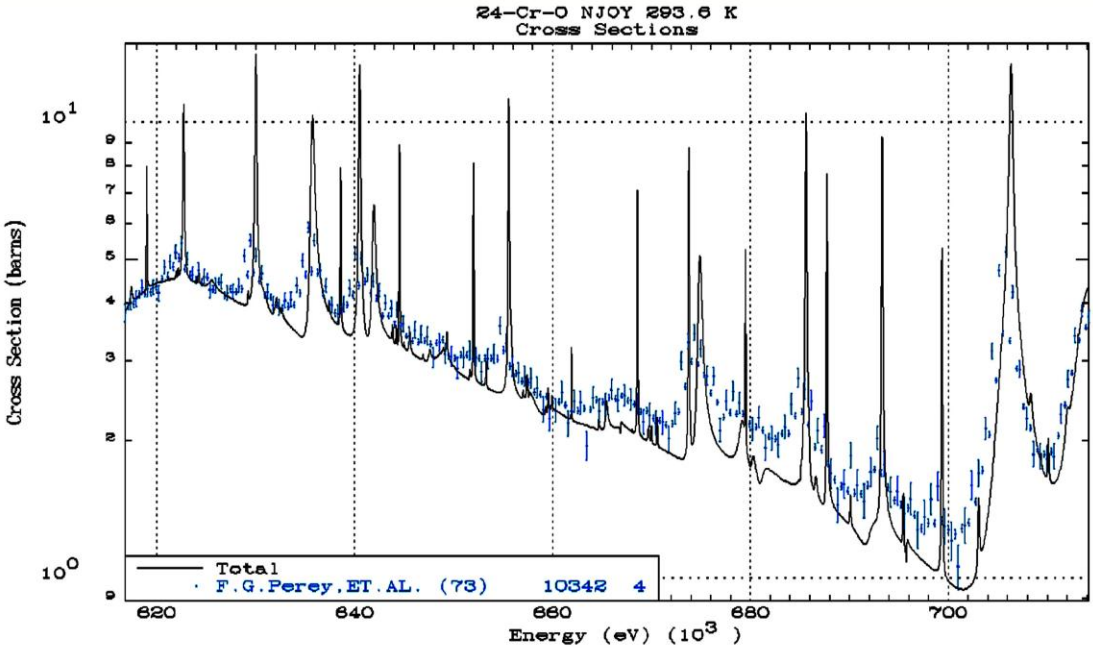

24-Cr-0 NJOY 293.6 K
Cross Sections
Cross Section (barns)
Energy (eV)
Total
W.P.Abfalterer, (01) 13753 17
S.Cierjacks,ET.AL. 20012 3
F.MANERO (67) 20168 2
J.Cabe,ET.AL. (67) 20482 2
L.KOESTER,ET.AL. (78) 20813 8
K.TSUKADA,ET.AL. (66) 22628 7
Tran Ung,ET.AL. (72) 30149 3
F.Kropff Moreno, (76) 30311 2


24-Cr-0 NJOY 293.6 K
Cross Sections
Cross Section (barns)
Energy (eV)
Total
M.Salama,ET.AL. (73) 30468 2
R.POLICRONIADES, (94) 31468 4
V.V.Filippov,ET.AL. (68) 40082 9
V.V.Filippov 40863 2

ZOOMed PLOTS

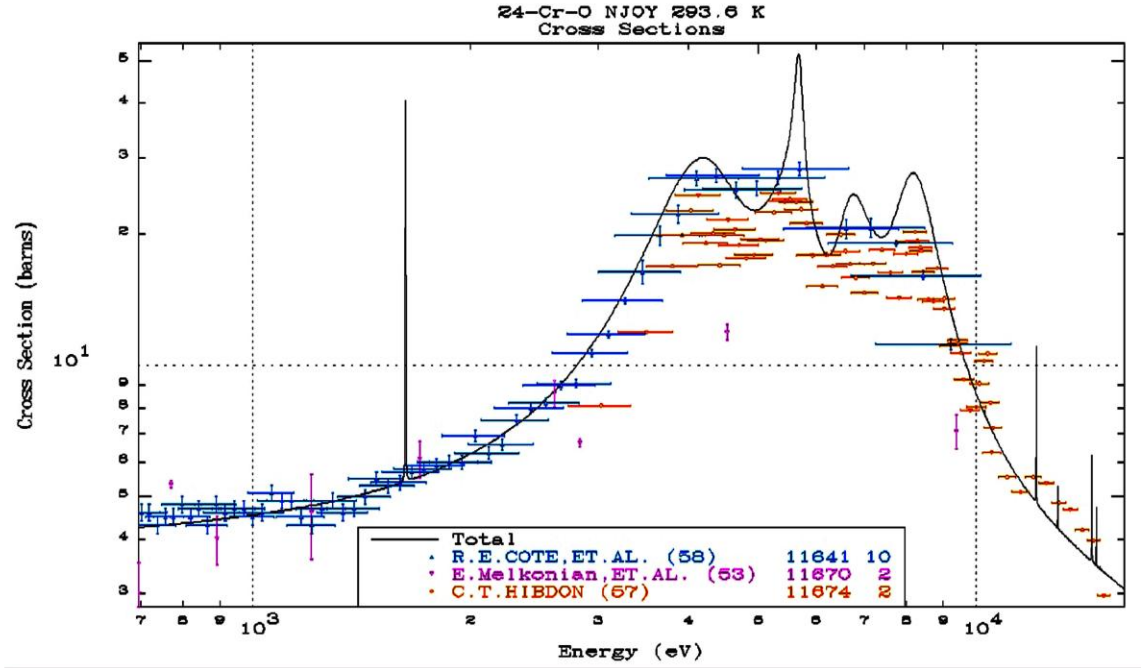
The below figures illustrate results using the PLOTTAB ZOOM option to select any X(energy) range, using your mouse to click on the lower and upper limits X you would like to see. The first figure shows roughly 0.5 to 1.0 MeV. The second shows a further zoom to roughly 620 to 720 MeV. Here we can see one set of experimental data in this energy range does not follow the detail included in the evaluaton, i.e., we obviously cannot simply use the experimentsal data an ENDF evauation. **That would not be real evaluations.**

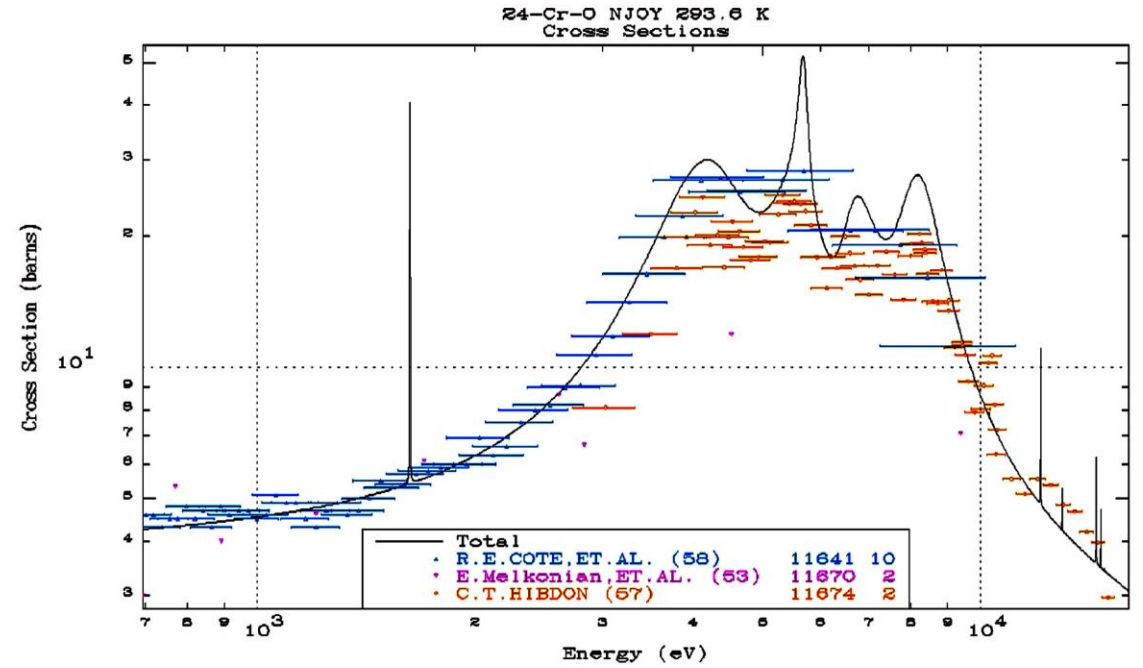


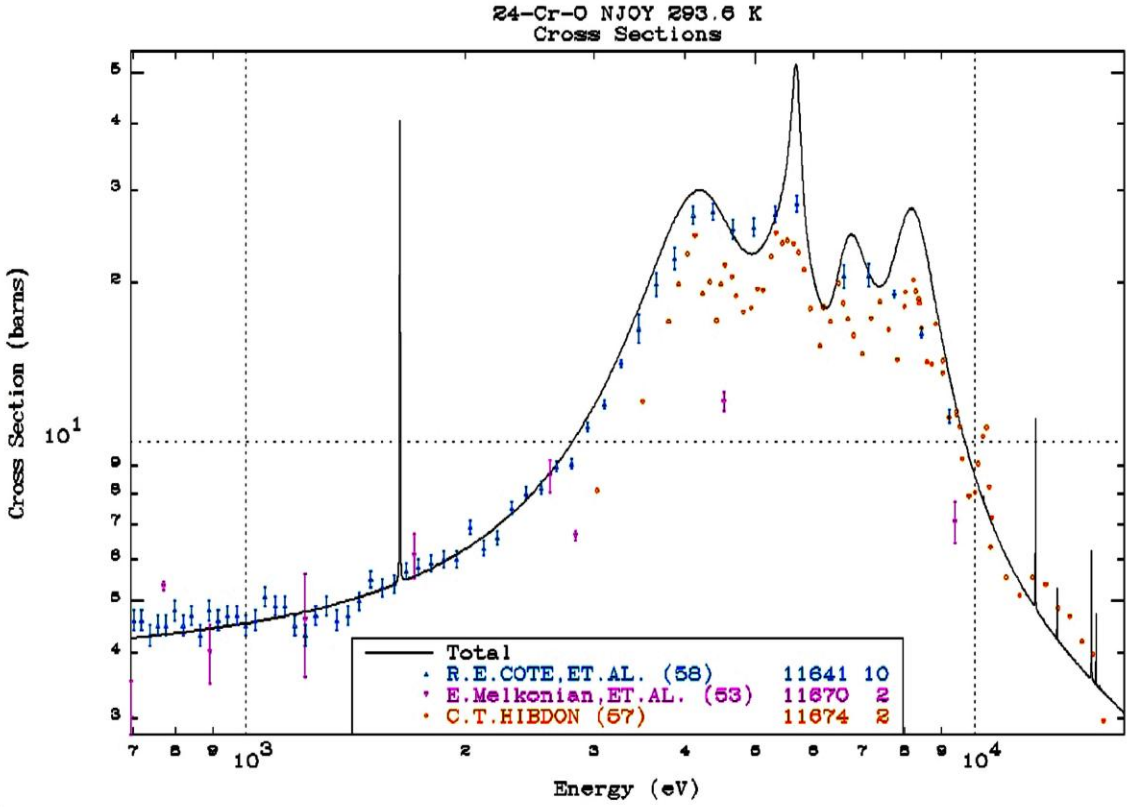


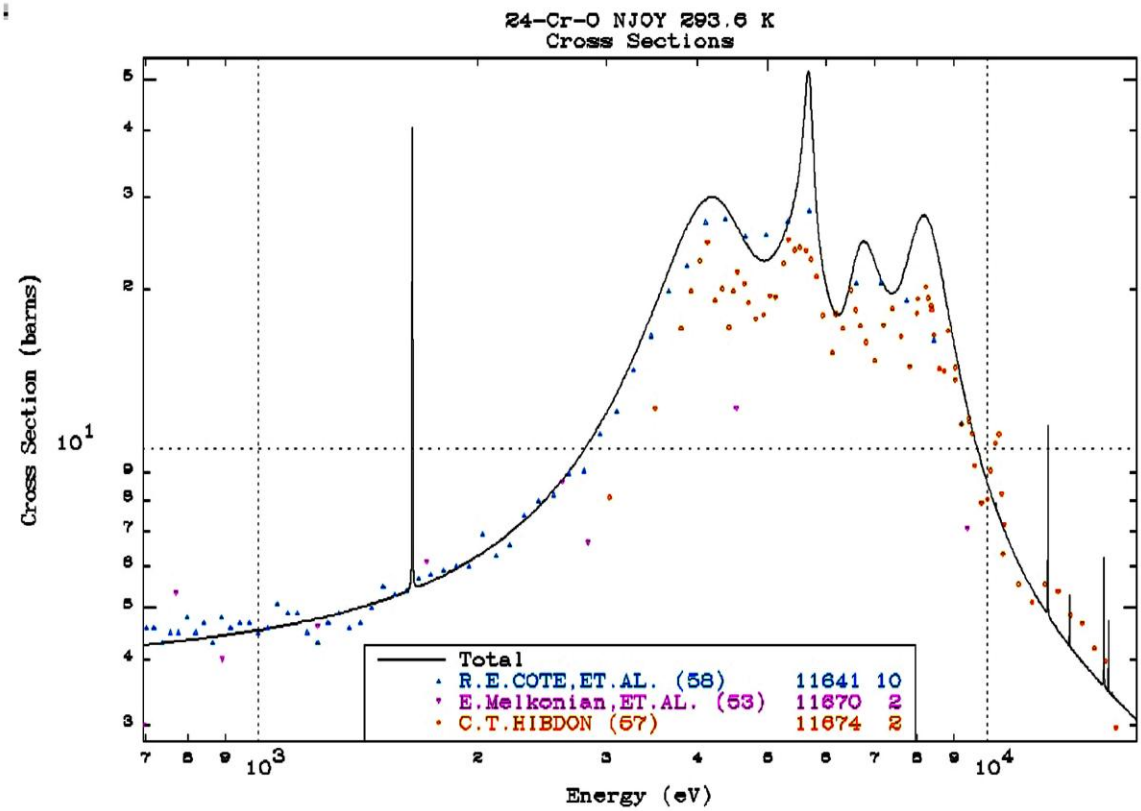
Uncertainty: (X, Y) (energy, cross section) ERROR

The following 4 figures illustrate how displaying or omiting X and Y (energy, cross section) uncertainty of the sets of PLOTTAB/PNT (EXFOR) data can greatly affect the ENDF-EXFOR comparisons. The first figure shows results including both X and Y (energy, cross setion) uncertainty. In the second figure I omit the Y (cross section) uncertainty. In the thrid I omit the X (energy) uncertainty. In the fourth I omit both X and Y (enerrgy, cross section) uncerainties. To my eye there are an enormous differences.






24-Cr-0 NJOY 293.6 K
Cross Sections
Cross Section (barns)
Energy (eV)
Total
R.E.COTE,ET.AL. (58) 11641 10
E.Melkonian,ET.AL. (53) 11670 2
C.T.HIBDON (57) 11674 2


24-Cr-0 NJOY 293.6 K
Cross Sections
Cross Section (barns)
Energy (eV)
Total
R.E.COTE,ET.AL. (58) 11641 10
E.Melkonian,ET.AL. (53) 11670 2
C.T.HIBDON (57) 11674 2

Serendipity

Serendipity means an unexpected fortunate discovery or encounter. In this case I was surprised that the very first test of ENDF-EXFOR selected by Jean-Christophe Sublet is natural 24-Cr total cross section, resulting in serendipity. The first PLOTTAB plot that I produced using the 24-Cr total cross section EXFOR data showed a measurement by Francis Perey. I was familiar with his measurements from 50 years ago when he copied one of his measurements to the ENDF format and claimed that was an evaluation, this created a problem. Regardless of how fine the experimental resolution any **differential** measurement will not "see" very narrow resonances that theory tells us to expect, and **integral** measurements, such as Bramblett-Czirr, transmission measurements prove are real. **Copying resonance measurements to the ENDF format didn't work 50 years ago, and it doesn't work today.**

The serendipity enters here because unfortunately today I see evaluators who are new to ENDF making the same mistake and copying resonance measurements to ENDF and think this is evaluation that meets our needs. Henry Honeck carefully designed the ENDF-102 format, to only include: 1) a resolved resonance region where we can define ALL resonances (not just L=0), 2) an unresolved resonance region where we do not EXPLICTLY define any individual resonances; only the distribution of resonance is defined based on a model, and lastly 3) smooth – I repeat smooth - tabulated higher energy cross sections above the resonance regions. Henry also allowed for what he called background corrections tabulated in ENDF MF=3, to be added to the cross section calculated from resonance parameters (resolved and unresolved). Experimentally measured differential resonance data does not fit into any of these three definitions. Unfortunately, it looks like history is repeating itself – if this isn't serendipity nothing is – seeing this Perey measurement as the very first reference in our initial test of ENDF-EXFOR was so unexpected – I hope this is useful to those who plan in the future to do ENDF evaluations; **true evaluation requires more than copying differential measurements.**

Conclusions

The original idea for ENDF-EXFOR came from **Jean-Christophe Sublet**, who expressed his need for a way to efficiently compare evaluated data, and experimentally measured data. I, **Dermott Cullen**, thought this need could be met by using my existing general purpose plotting code, PLOTTAB, that I have used for many years to display and allow me to interact with data for many of my applications. For evaluated data my over 50 years' experience with the ENDF format allowed me to create a very simple code to convert ENDF data to the PLOTTAB.CUR format. For experimentally measured data, over 50 years ago while employed at the National Nuclear Data Center (NNDC) I invented the EXFOR format, to use in the Cross Section Information Storage and Retrieval System, CSISRS, so I naturally immediately thought of using this as the source of experimentally measured data. My problem was that I had not used the EXFOR format in many years. Fortunately, 50 years ago, I also invented the C4FOR format, and I created the X4TOC4 code, which starts from the EXFOR general units (energy, cross section, etc.), and converts these to standard units that are the same as ENDF (eV, barns, etc.). I had not used this X4TOC4 code in many years, but over the years **Andrej Trkov**

maintained X4TOC4 code, and kindly supplied the most recent version for use. In summary: This project could not have been completed without the true cooperative effort of the three authors; they all earned the right to be authors of this report.