Report: LLNL-TR-2004415
January 2025

EPICS2025:
2025 Status Report

by

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DISCLAIMER

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PROLOGUE

This will be D. E. Cullen's final EPICS Report.
I am now 85 years old, and it is time for me to pass these data files on to the next generation to maintain.

All responsibility for maintaining and developing
EPICS is NOW assumed by

Caleb Mattoon
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ALL Feedback/Questions should be addressed to Caleb Mattoon

OVERVIEW

This will be my (D.E.Cullen) final EPICS report. I am now 85 years old, and it is time for me to pass these data files on to the next generation to maintain. Here I will concentrate on documenting the history of the EPICS data files (how we got here) and where I think/suggest we should be headed into the future (where we are going). Where we actually go is of course entirely in the hands of and based on the decisions of whoever inherits these data files. **This will be my (D.E.Cullen) last EPICS report; Caleb Mattoon is the "whoever" referred to herein: he has NOW assumed ALL responsibility for maintenance and development of EPICS. ALL feedback should be sent to Caleb Mattoon, Mattoon1@llnl.gov**

What is Different in 2025?

EPICS data has been documented extensively in the past. EPICS2025 **data** is identical to EPICS2023. Only the **format** has been updated for EPICS2025,

1) ENDL and ENDF data files are FORTRAN, C and C++ Compatible, e.g., no D+/- exponentials.
2) ENDF data each line is now 75 characters long; as per ENDF-102, no sequence numbers.

How we got here: History 101

By the mid-1960s there was no official U.S. national nuclear data. As an example, back then two well-known companies were both successfully designing different types of reactors, but the "nuclear data" they were using was more in the line of a few group diffusion parameters, based on fits to preceding designs, rather than measured nuclear data, i.e., fits rather than science based nuclear data. Each could design their type of nuclear reactor, but they could not design the other type of reactor. Obviously, dangerous.

Standard Nuclear Data

Henry Honeck addressed this problem by starting ENDF at the Brookhaven National Laboratory (BNL), with the intent of establishing a U.S. national **science based** nuclear data base that everyone could use for their **engineering applications**. ENDF was based largely on the British UKNDL system. The heart and soul of ENDF was ENDF-102, what I call "**The ENDF Bible**". The reason ENDF became such a great success was that ENDL-102 standardized definitions and kept things simple, e.g., ENDF-102 was based on **KISS** = Keep It Short and Simple. The focus of ENDF-102 was to serve as an **Engineering Manual**, rather than a **Physics Textbook.** ENDF used KISS and only included what is **needed in engineering problems** – let me repeat this extremely important point: **ENDF/B only included what is needed in engineering applications – NOT what physicists were interested in.**

For example, at the time it seemed that every textbook defined even simple Breit-Wigner resonances using a different equations. Henry standardized equations: initially in ENDF there were only two options: single or multi-level Breit-Wigner parameters, and all resonance peaks were observed (measured) peaks, with no shifts based on resonance spin. This made it simple for evaluators to use measured peaks directly in the ENDF format (the resonance energies included in ENDF were exactly the measured values), and for ENDF users to know the location of peaks, when reconstructing energy dependent cross sections.

Standard Atomic Photon Data?

Because it is important for engineering applications, Henry included atomic photon data in the ENDF-102 KISS tradition in a simple form including only four processes (ENDF MT numbers); photoelectric, coherent, incoherent and pair production. This atomic data is important because roughly 10% of the energy produced in fission is in the form of photons. There is more to the engineering applications of nuclear reactors than simply Keff. Designers must also consider energy deposits, radiation dose/damage to material and people, etc. At 10% of the fission energy released photon transport should be included in any realistic engineering applications for fission reactors.

Henry Honeck's ENDF system was a great success and led to establishing a U.S. National Nuclear Data Center (NNDC) at Brookhaven. This ENDF-102 KISS approach established communication between scientists to measure and/or calculate the nuclear and atomic data required for engineering applications, and data user testing and feedback to improve ENDF/B through successive generations of standard EENDF/B data. **This strict focus on meeting the NEEDS engineering applications allowed ENDF/B to improve within the strict confines of ENDF-102 rules through the first six generations of ENDF/B.**

The All Particle Method

In the late 1980s Lawerence Livermore National Laboratory (LLNL) started an ambitious project to produce a particle transport code that could transport ALL nuclear and atomic particles: neutrons, charged particles, photons, electrons, you name it the intent was that this one code would transport it; this project was named the All Particle Method (APM). Ted Perkins and I (D.E.Cullen) started to work on the data files needed by this new code, while another team worked on the actual transport code.

With the great success of ENDF/B we felt that neutron interaction data was well in hand, and we could rely on ENDF/B to supply neutron interaction data. So, Ted Perkins and I began to work on photon and electron interaction data; even after many years from its inception **ENDF/B still had a simple model for photon transport and no model for electron transport.** It took us several years to put together photon and electron interaction data bases. It is important for the reader to understand that Ted Perkins was the one who deserves recognition as the evaluator of our APM data files; he is the one who primarily researched available data, and my primary role was to translate the data Ted gave me to the Livermore ENDL format.

Improvements to TARTNP

By the time Ted and I finished the initial version of the photon and electron data files for APM, the team that was working on the APM transport code decided it was far too ambitious, and they abandoned the code and moved on to other projects. But all was not lost. We managed to use the detailed photon data in the Livermore TARTNP Monte Carlo transport code. Rather than simply the ENDF four reaction photon data, **Ted and I had added: ALL photon subshells, anomalous scattering, and triplet production**. This extension required that we also establish our Evaluated Atomic Data Library (EADL) that defines the binding energy for all subshells, and the transition probabilities of how a vacancy in any subshell relaxes back to neutrality. **The reason for adding atomic subshells to the photon data was a include fluorescence.** With only a total photoelectric (as defined in ENDF-102) each event led to all of the photon energy being deposited locally. In fact, in high Z elements, such as Uranium, roughly 90% of the K-edge binding energy is re-emitted as fluorescence, with energies up to in excess of 100 keV. **Tests with TARTNP demonstrated that including this additional photoelectric subshell detail improves the results of calculations of the effects of photons in real engineering applications.**

Improvements in ENDF

Based on our TARTNP results in using more detailed photon data there was interest in extending the ENDF format to include these details. A major problem was that Ted Perkins, and I did our evaluations in the Livermore ENDL format, and at the time (circa 2000) there were no ENDF-102 formats for this data,. Even after ENDF formats were defined the actual data had to be translated from the ENDL format to the new ENDF-102 formats. **See the presentation from a 2002 American Nuclear Society (ANS) meeting showing the difference in the ENDF data before the after introducing subshells.** In summary it took almost 40 years, from the start of ENDF in the 1960s to the photon subshell extension in 2000s. But this extension has led to improving the photon transport in many particle transport codes. At least to my mind this effort has paid off and should continue into the future, aimed at even further improvements in photon subshell cross sections (EPDL) and atomic relaxation data (EADL), e.g., again, I will mention **these extensions are required to define fluorescence**.

In contrast even though the electron interaction data (EEDL) that Ted Perkins and I did for APM in the ENDL format was translated to the ENDF format**, I am not aware of anyone who ever used this data in any actual applications, in either the original ENDL or ENDF format into which it was translated.**

Where we are Today

The reason for ENDF/B's GREAT success over the last 60 years is based on three important factors, namely: **EXPERIENCE, EXPERIENCE, EXPERIENCE**. Here I do not simply mean in creating data files; the real EXPERIENCE I refer to was creating, using/testing, and feedback to ensure the data met **our engineering needs**. It is that closed loop that has given us an abundance of useful EXPERIENCE.

For the first 40 years (1960s to 2000s) ENDF-102 for photons intersection data only included the basic four reactions described above. During these years ENDF-102 did not include any definitions for electron interaction data. The experience that we learned was that this simple photon model did not meet our needs. Since there was no electron data available for testing we did not gain any experience with electrons.

During the last twenty years (2000s to 2020s) the EPICS extended photon data including: photoelectric subshells, anomalous scatter and triplet production has been defined in ENDF-102, and the EPICS data has been available to users for testing. During these 20 ears I used this photon data in our TART Monte Carlo code, and it was also used in NJOY/MCNP, but I have no idea whether it was used in AMPX. **These days we need not guess**: if you are interested I suggest you contact code developers to find out what experience they have with this data. It is important to understand that I produced and used the data (photon and atomic relaxation data) in the ENDL format in which the evaluations were originally created, and that is what all of my personal experience is based on. I never used these data in the ENDF format, nor was I

even involved in the translation from ENDL to ENDF format. **My experience with the EPICS extended photon data in the TART Monte Carlo code has been that it did meet our needs, and once we realized this we considered this problem solved, a complete job**, and 20 years ago we moved on to address other problems/needs.

In contrast once the All Particle Method (APM) project was cancelled we lost interest in data for other particles, such as electrons and charged particles. By this time Ted Perkins and I had completed the photon and electron data ENDL format, and we used the extended photon data in TART, but not the electron data, i.e., TART has never transported electrons, and we have no plans to extend it to electrons. At one point I worked with Grady Hughes to try and add the electron data to MCNP, but Grady passed away before we completed this work, and since then I have no idea whether or not the EEDL electron data was ever actually used to MCNP; again, I suggest if you are interested ask the MCNP designers. **In summary, I have no experience using our EEDL electron date in either the original ENDL format or the ENDF formatted data, and I repeat, the ENDF formatting which was created by somebody else.**

Where Should we go in the Future?

Right now, we have three data files, EPDL, EEDL, EADL, that were developed/evaluated in the ENDL format some 30 years ago and converted to the ENDF format about 20 years ago. These files have changed little over these years. Atomic data is better known than nuclear data, and as such need not be re-evaluated as often. ENDF/B neutron data has is now in its VIII version after 60 years. **In comparison the atomic data has in these three data files has not been significantly improved in 20 years and by now it is well past when it should have been re-evaluated.** Since it was Ted Perkins who actually did the initial evaluations, and Ted passed away many years ago, I never had the experience of extensively updating these data files. I was only able to make minor changes in the data based mostly on user feedback; most of the changes in the files was only due to changes in the ENDL and ENDF formats, not the actual data.

In planning where these data files **NEED** to go from here it is important to realize that **Ted Perkins and I never intended our photon and electron data files to be general purpose data files**, which could be used for any application. We developed them to meet OUR needs for data in OUR engineering applications, particularly nuclear fission reactors. These files are only applicable to **COLD, NEUTRAL, ELEMENTAL** data, for which we produced 100 evaluations, for elements Z=1 through 100. This elemental data does not include any MOLECULAR effects, and as such is limits to energies above roughly 1 keV, which was adequate for OUR applications. To give but one example: one of the best known and quoted numbers is the binding energy of an electron in H_1 13.6 eV, but H_1 does not exist in nature, and the binding energy in H_2 is 16.4 eV; over 20% higher. Naturally, the binding energy in H_2O is different from either of these. If we consider hydrocarbons the variation of binding energies is too numerous to count, and even today I judge it to be beyond our ability to produce and use data for every possible molecule. More to the point: **This data is not NEEDED for our engineering application.** Any attempt to extend this data I think would be a terrible waste of our valuable time, as far as OUR APPLICATIONS are concerned.

In developing the photon and electron data for use the All Particle Method (APM) we extended the evaluation down to below the lowest electron binding energy (usually to 10 eV) only because **this data was needed to define the anomalous scattering cross section of photons**, which involves an integral over the entire energy range of the photoelectric cross section. In one version of EPICS, I experimented with excitation data, which is a low energy phenomenon. **Based on our experience using this data we found that excitation was not required for the important energy range of photons in our engineering applications**. Based on this experience, current EPICS data files does not include excitation data, and I suggest you do not waste time adding it.

My point**: the current elemental data meets all of our needs in a reasonable manner with 100 evaluations**. I strongly suggest that these data files NOT BE GENERALIZE; at least not in the ENDF-102 format. If you require more general data PLEASE use a different format or system. For example, as I stated above I personally have never used the electron data in either ENDL or ENDF format. For the few coupled photon-electron problems I have been interested in I have used the **PENELOPE** code, which more than met my every need. Therefore, I never had a need to develop my own electron transport code.

Now the punchline = the most difficult part for me to write/document. Because of my failing memory it has taken me some time to put this list together. But I am hoping that my spending a few days documenting my experience will save whoever inherits these files, man-years of effort. Here going,

1) In my mind the most important thing is: **Do not change ENDF-102 as it applies to this data**!!! Every time we change the rules we flush all of our EXPERIENCE down the toilet and have to start over from scratch. If you do change ENDF-102, my suggestions listed here may no longer be valid. **If you need different data for different applications PLEASE USE A DIFFERENT FORMAT; ENDF-102 now more than meets our needs, PLEASE DO NOT CHANGE IT!!**
2) Atomic data is much better known than nuclear, but **all three EPICS data files are way past when they should have been extensively re-evaluated**; Over the years I made small, incremental changes based of user feedback, and even this was dangerous and difficult for me a verify any changes; here I tried my best to be part of the solution, rather than the source of more errors.
3) Right now, the MASTER evaluations are in the ENDL format. **To truly integrate them into ENDF/B they must be accurately/reliably translated to ENDF format** – ALL 3 data files = photon, electron and atomic. There now seems to be an inconsistency between ENDL and ENDF formatted data (reported to me by users). I am no longer able to reliably verify the reported problems and fix them. **This should be a HIGH priority item for whoever inherits this data,**
4) EPICS includes three data files. EPDL and EEDL include photon and electron cross sections (basically they define what to expect before a collision). EADL defines atomic data (what happens after an atom is ionized); this applies to both electrons and photons, to relax the atom back to neutrality, e.g., **EADL is NECESSARY to define fluorescence.**
5) **The heart and sole of the three files is EADL, the Atomic Data,** which includes subshell edge energies and transition probabilities; this applies to both photons and electrons. The whole reason for extending the photon data in ENDF was so we can calculate fluorescence, and currently this can only be done using EADL data, and my RELAX code, that actually defines the fluorescence spectra, that I use in the TART Monte Carlo code. My RELAX code uses EADL data in the ENDL format. The EADL master should be in the ENDF format, and **we need the equivalent of my RELAX code to create fluorescence spectra starting from the ENDF format data**. I STRONGLY suggest that one verify that the fluorescence spectra produced starting from the current master in the ENDL format, and your new code using ENDF format, produce IDENTICAL results. If they do not produce EXACTLY the same results these files/codes are at best useless, and at worst inaccurate and misleading.
6) **KISS – stay with the current COLD, NEUTRAL, ELEMENTAL data**; 100 data files for Z=1 to 100. Trying to add MOLERCULAR data (a LOW ENERGY effect), would be the equivalent of a black hole, that you can pour any amount of effort into and not see any significant improvement in the results of our engineering applications, to calculate energy deposition,…
7) **Do not include EXCITATION** – a LOW ENERGY effect that my EXPERIENCE indicates we do not need. But you can feel free to verify this. But WARNING: the excitation data I added to an earlier version of the photon data was only for COLD, NEUTRAL, ELEMENTAL data – which is useless for actual MOLECULAR data – again, I will admit that my excitation data was

misleading, which is why I deleted it from the current photon data (see below).

8) Even though I recommend the ELEMENTAL files for energies above 1 keV**, keep the current ELEMENTAL data down to low energy, below the lowest energy subshell edge.** This data is needed to calculate the anomalous scattering, which involves an integral over the entire energy range of the photoelectric cross section. The data below 1 keV is less accurate, but adequate for our applications, and good enough to define the anomalous scattering where we need it. I calculated the current anomalous scattering 30 years ago for use in ATM (this code was never implemented). I do not have any record of the code that I used way back then to calculate anomalous scattering. **We need a new code to calculate consistent anomalous scattering starting from the ENDF format.** Without this code we cannot change/update the photoelectric and still have a consistent anomalous scatter.
9) Check with other code users, such as NJOY and AMPX. **They may already have the equivalent of my RELAX code and whatever I used to calculate anomalous scatter**. I started with the ENDL format; in their case they would be starting from the ENDF format. If you have to start from scratch to write and verify these two codes will not be easy.
10) **Keep ALL tabulated data as LINEARLY interpolable**. The original photon data was LOG interpolable, which confused many users and led to inaccurate results. Unfortunately, when I later converted the photon data to LINEAR interpolable, which should have increased the number of energy points to define cross sections, I also removed the excitation, which greatly decreased the number of energy points required. The net effect was that the current LINEAR interpolable data has fewer data points than the original LOG interpolable data. This led at least one major user of the photon data to ASSUME it must be LOG interpolable, which led to poor answers. **WRONG! WRONG! WRONG! I REPEAT – these days you need not ASSUME anything – use the internet/email to ask and verify.**
11) **Use your EXPERIENCE to judge feedback,** I keep stressing that currently most improvements to EPICS data are the result of feedback from users. But be WARNED – only about half of the feedback is useful. The other half of the feedback is due to users misinterpreting the data or formats, that I have had to explain to users. This is the crux of this report: **At 85 years old I have to admit to myself that I am no longer able to distinguish between good and bad feedback. In trying to distinguish good from bad feedback I am now not able to reliably maintain EPICS. That is why reluctantly I must admit that it is time for me to step aside and let the next generation maintain and improve EPICS. This is why Caleb Mattoon is NOW assuming ALL responsibility to maintain and develop EPICS.**
12) With the recent release of ENDF/B-VIII.1, including all three EPICS files in the ENDF format, **whoever inherits these files has plenty of time (years and years) to improve and test all of the data well before the next release of ENDF/B.** I suggest you use this time wisely, take your time and based on my EXPERIENCE-EXPERIENCE-EXPERRIENCE, follow as many of my suggestions, included here, as possible.

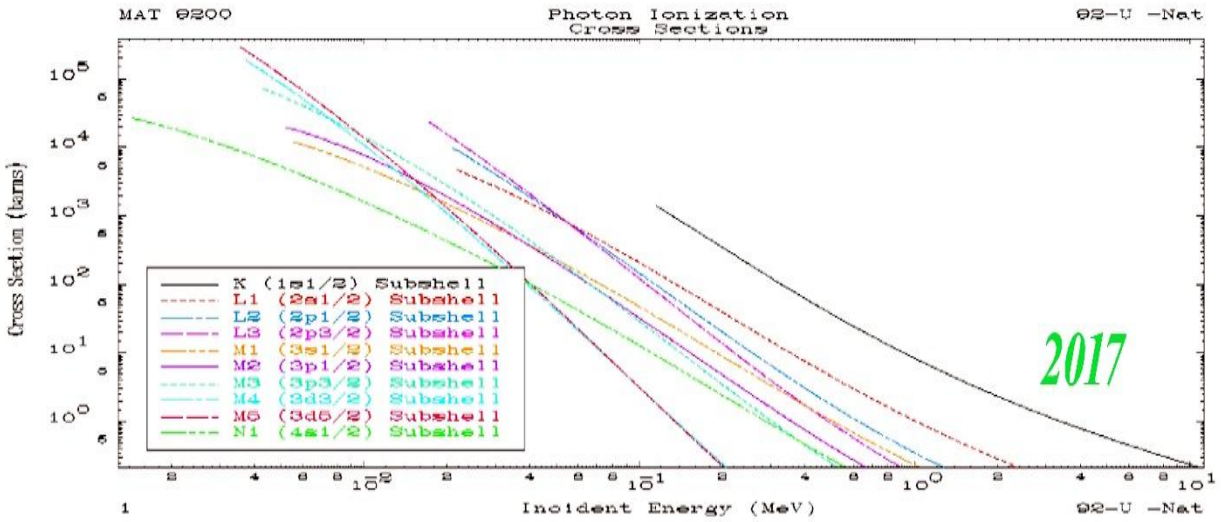
The Bottom Line to Caleb Mattoon inheriting EPICS

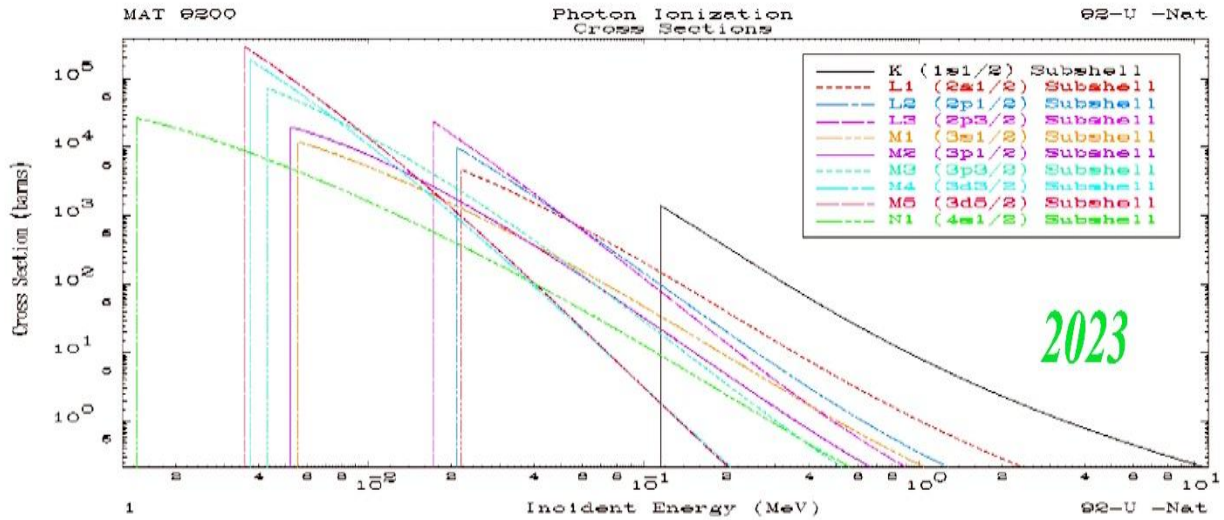
I hope that the above brief summary supplies YOU (in inheriting EPICS), with enough background information to allow you to NOW assume responsibility to maintain and develop EPICS – if you have any questions please feel free to contact me, **preferably in writing**, so we have a record. But I hope that the above summary makes it clear that at my age (85) you should expect some of my answers to be "I do not remember". I have tried with each version of EPICS to provide enough written background information so that YOU can carry on maintaining and improving these data files and build up **YOUR EXPERIENCE**. The list of references below is from the EPICS2023 report; I have left the references here as, I hope, valuable background information. **To data users: PLEASE SEND ALL FEEDBACK TO CALEB MATTOON.**

The remainder of this summary is a copy of a portion of the EPICS2023 report, which I hope will help those who inherit these files to maintenance and improves them. Some of this repeats what I wrote above, but I left it here in the hope that it further clarifies the status of the current data files, as of 2023.

Example of Detailed Photoelectric Data

Remember that up until circa 2000 ENDF-102 only included one photoelectric cross section. The extension to add subshell is illustrated below for Uranium, which in this plot included only the ten highest energy subshells/edges; the highest energy K edge is at over 100 keV. The two plots below show how we initially represented the cross section for each subshell up to 2017, with each edge starting "up in the air", which confused data users; they asked how this is defined below the edge. To keep these users happy by 2024 we started each subshell by adding a duplicate energy point at each edge with a ZERO cross section. Naturally, this satisfied one group of users but confused another group of users who complained about the duplicate energy, which they reported to me as an error. We do not seem to be able to keep everyone happy; all we can do is try. I add these plots here in the hope that they will help whoever inherits the EPICS will understand why there are duplicate energy points at each edge, just as Einstein predicted,





Duplicate Energy Points in EPDL

A number of EPICS users reported duplicate energy points in the EPDL data, i.e., same energy and cross sections. These appear in both the original ENDL format, in which the evaluations were performed, and the ENDF format, to which they were translated. These have now been deleted from both ENDL and ENDF formats. Note, that ENDL does not include SUM cross sections, which are included in ENDF; so that the number and values (cross sections) of duplicated points are more numerous in ENDF and naturally sums in ENDF will differ from the parts in ENDL (as we see below). To my knowledge, these duplicate points did not create any numerical problems, as far as calculated physical observable integrals are concerned.

ENDL format examples of duplicate points (energies in MeV)

```
 17000   7  0  35.453     2308032 2  0.0          0.0          0.0
73  0  0  0.0          0.0          0.0          0.0          0.0
 2.770000000D-04 3.249675230D+06
 2.770000000D-04 3.249675230D+06
 19000   7  0  39.102     2308032 2  0.0          0.0          0.0
73  0  0  0.0          0.0          0.0          0.0          0.0
 4.340000000D-06 3.495570000D+04
 4.340000000D-06 3.495570000D+04
 24000   7  0  51.996     2308032 2  0.0          0.0          0.0
73  0  0  0.0          0.0          0.0          0.0          0.0
 8.000000000D-05 5.039403760D+06
 8.000000000D-05 5.039403760D+06
```

ENDF format examples of duplicate points (energies in eV)

```
                                                                 MAT-MF- MT-#####
 277.000000 2924541.91 277.000000 3249831.91 277.000000 3249831.91    1700-23-501-  241
                      12345678901234567890 12
 4.34000000 34956.0067 4.34000000 34956.0067 4.35247133 33279.8352    1900-23-501-   36
1234567890123456789012
 80.0000000 5039457.02 80.0000000 5039457.02 80.4457625 5011959.88    2400-23-501-  191
1234567890123456789012
```

Bremsstrahlung Data Incorrectly Identified in EEDL ENDF Format

Bret Beck (LLNL) discovered and corrected a serious ERROR in the bremsstrahlung data in **the EEDL data in the ENDF format**; this ERROR does NOT appear in the original EEDL data in the ENDL format and appeared to be an ERROR introduced in the translation to the ENDF format. **WARNING** – if this data were used in any application assuming electrons, rather than photons were emitted, the results would be complete rubbish!!!! **Many thanks Bret.**

The ERROR is that ZAP ("particle" produced) is erroneously identified as an electron (ZAP=11),

```
                                                    MAT-MF- MT-#####
1000.00000 .999241400          0          0          2          0 100-26-527-    1
11.00000005.438673E-4          0          1          1          2 100-26-527-    2
```

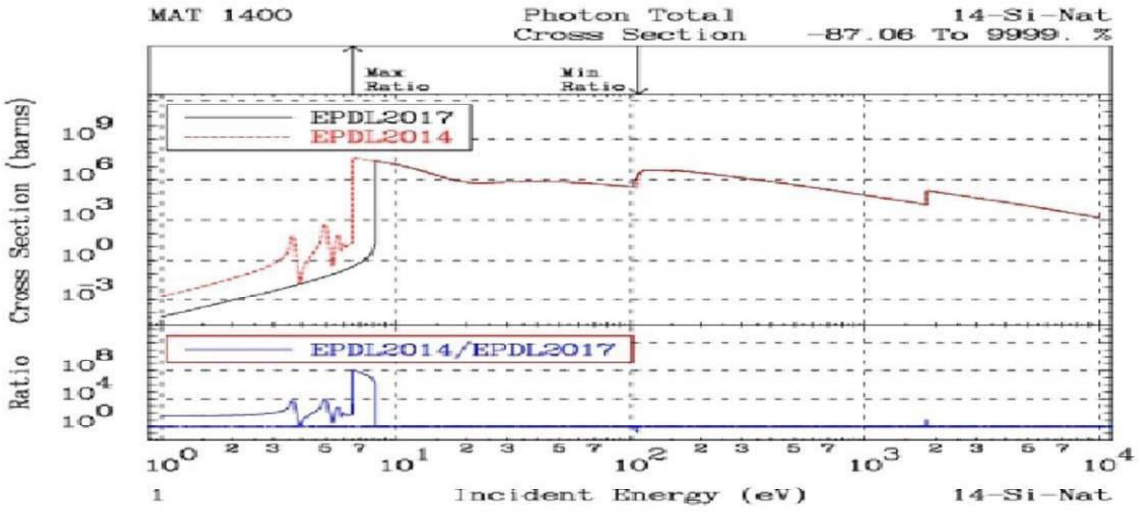
This has been corrected to photon (ZAP=0), by changing one number on the second line of each MF/MT = 26/527, for all 100 evaluations, Z – 1 to 100.

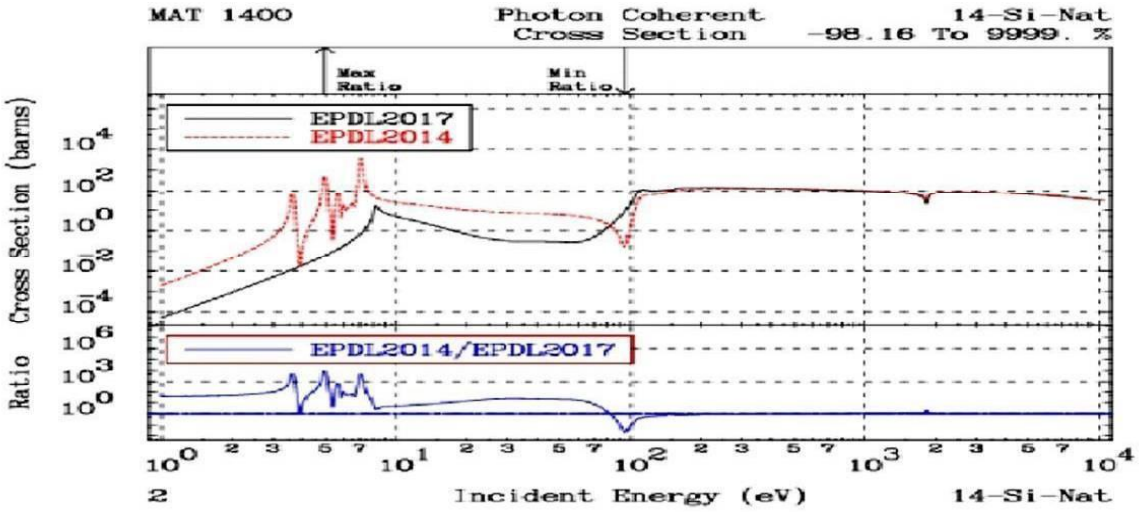
```
                                                     MAT-MF- MT-#####
1000.00000 .999241400          0          0          2          0  100-26-527-    1
 0.0       5.438673E-4          0          1          1          2  100-26-527-    2
```

Reminder: EPDL does not currently include EXCITATION

Below is but one example showing that as of **EPICS2017, EPDL has not included EXCITATION** (this figure is a copy of what appears in the earlier EPDL report). Hopefully, this example will illustrate that the combination of changing from log-log to lin-lin interpolation (tends to increase the number of energy points) AND removing excitation (tends to decrease the number of energy points), can results in a net decrease in the number of energy points in EPICS2017. Removing the excitation particularly simplifies the anomalous scattering, which in turn simplifies the coherent scatter, greatly **reducing the number of tabulated energy points required to accurately define the data even using lin-lin interpolation.**

Also, hopefully this example illustrates that **excitation need not be included in EPDL** because it is a lower energy phenomenon, below the keV and above energy range that EPICS is designed to accurately model.





For Coupled Photon-Electron Calculations

The **TART** [8] Monte Carlo code performs coupled neutron-photon calculation, but it does NOT perform electron transport; all electron energy is deposited at the space point they are produced. If you have applications that really require coupled photon-electron calculations or are outside the designed range of EPICS (keV and above), I make the following recommendations.

For **lower energy** applications, or those in which molecular, chemical, density effects are important consider using **PENELOPE** [10], which is designed, and has an excellent reputation, for accurately calculating coupled photon-electron applications.

For **medium energy** applications, in the keV to MeV range, consider using **MCNP** [11], which I believe can now handle coupled photon-electron applications.

For **higher energy** applications, consider using one of the higher energy codes, such as **GEANT** [12] and **FLUKA** [13]. These include PHOTONUCLEAR physics that is not included in EPICS; EPICS only includes ATOMIC, not NUCLEAR data.

Below the keV energy range there are atomic binding effects not considered by the EPICS data. For example, the currently BEST estimate of the K shell electron in H_1 is 13.6 eV. The good news is that this is a well-known value and is what is included in EPICS2023. The bad news is that H_1 does not exist in nature; the binding energy for H_2 is 16.4 eV, 21% higher. And for something that might seem like a simple change from H_2 to H_2O (water) the binding has a completely different value. Let me again, here stress: EPICS only includes ELEMENTAL data (for elements with atomic number, Z = 1 through 100), e.g., there is no data for H_2, H_2O, or any other materials; only elemental data. The good news is that this molecular effect has a major effect only at lower energies, below keV energy range where EPICS data should be used, so **EPICS meets our current ENDF needs.**

Above the MeV range that we normally encounter in ENDL and ENDF applications, **photonuclear** events become progressively more important. Again, we stress EPICS2017 included **ATOMIC, no NUCLEAR** data, and there are no plans, or indeed, need to extend it to include photonuclear data in EPICS. There is no need because ENDF already includes a separate file of **photonuclear** data, which can be used in conjunction with EPICS **photo-atomic** data to model particle transport; see the NNDC website for details.

Use ONLY the Most Recent EPICS Data

The official **EPICS2025** data will soon be FREELY available ON-LINE at: Lawerence Livermore National Laboratory, nuclear.llnl.gov. It can also be accessed through the National Nuclear Data Center, Brookhaven National Laboratory, the Nuclear Data Section, IAEA, Vienna, Austria, and NEA/DB, Paris, France. But the BEST place to ensure that you have the most recent data is at my (Red Cullen) website,

http://redcullen1.net/homepage.new/

Conclusions

Usually, my conclusions mostly repeat my introductory remarks, in line with my normal approach: 1) tell them what you are about to explain, 2) explain it, 3) tell them what you have explained. In this case I will present different closing remarks: **a plea for YOU the reader to help in maintaining, verifying, and improving our data and codes.**

First some background. By the time I completed my thesis on integral particle transport, it was obvious to me that regardless of how accurate I designed and implemented any transport code, I was in a "garbage in = garbage out" situation unless I had good nuclear and atomic data. In an attempt to help improve our data, I initially took a post at what later became the National Nuclear Data Center (NNDC), Brookhaven National Laboratory, where the Evaluated National Data File (ENDF) was in its infancy. There I quickly realized that the potential of ENDF could only be fully exploited if it had software to support the effort, so I began to work on what today are the ENDF Pre-Processing Codes, PREPRO2023 [6]. My second position was at the Lawrence Livermore National Laboratory (LLN), where I continued to work on nuclear and atomic data, but also could return to my first true love: particle transport, working on the TART2022 code [8].

Today it is 58 years since I started working at NNDC, BNL, and over 50 years since I moved to LLNL. As you can see by this report, and the references in this report, I have continued my work on: ENDF support codes, PREPRO2023 [6], and Monte Carlo Transport, TART2022 [8], and Atomic Electron-Photon Interaction Cross Sections, EPICS2023, **even though I retired in 2009, over 14 years ago**. **I have carried on this effort without financial or facility support because I felt I could still make an important contribution, and to keep myself mentally active.**

Since I retired I have been more of a spectator than a participant in any projects at any research facility. In order to keep this effort going I need YOUR support – not financial support – I need support from the READER of this report, and USERS of my codes and data. Specifically, I need feedback from YOU – both PRO and CON feedback help. PRO feedback demonstrates that these data and codes are useful and accurate in your applications and encourage me to carry on. CON feedback demonstrates that we can still make improvements in our applications. **Effectively immediately, PLEASE SEND ALL FEEDBACK TO CALEB MATTOON; he has now assumed ALL responsibility for maintaining and developing EPICS.**

We do not read minds, and I do not have the time nor the energy to search for many publications. What is needed is for **YOU TO SEND CALEB MATTOON COPIES OF YOUR REPORTS** – plus any additional background information, as to how you judge the quality of our codes and data – or lack thereof. The future of this work is in your hands **– PLEASE BECOME PART OF OUR VILLAGE AND HELP!!!!**

References

A reminder that the references listed here actually refer to the EPICS2023 documentation, I have left them here in the hope that they will be useful to whoever inherits the EPICS data files,

[1] **EADL2017**: Survey of Atomic Binding Energies for use in EPICS2017, Report IAEA-NDS-224, September 2017, IAEA, Vienna, Austria.
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[2] **EPDL2017**: Survey of Atomic Photon Cross Section Data for use in EPICS2017, Report IAEA-NDS-225, November 2017, IAEA, Vienna, Austria.
EPDL2017: Survey of Atomic Photon Cross Section Data for use in EPICS2017, Report IAEA-NDS225, Rev. 1, February 2018, IAEA, Vienna, Austria.

[3] **EEDL2017**: Survey of Electron Cross Section Data for use in EPICS2017, Report IAEA-NDS-226, December 2017, IAEA, Vienna, Austria.

[4] **ENDL Format.** ENDL Type Formats for the LLNL Evaluated Atomic Data Library (EADL), Evaluated Electron Data Library (EEDL), and Evaluated Photon Data Library (EPDL), Lawrence Livermore National Laboratory, UCRL-ID-117796, Rev. 1, May 2002.

[5] **ENDF Format.** ENDF-6 Formats Manual: Data Formats and Procedures for the Evaluated Nuclear Data Files ENDF/B-VI, ENDF/B-VI, and ENDF/B-VIII, CSEWG Document ENDF-102, Report BNL-203218-2018-INRE, Rev. 215, February 2018, Brookhaven National Laboratory (Eds, A. Trkov, M. Herman, D.A. Brown).

[6] **PREPRO 2023**: 2023 ENDF/B Pre-processing Codes (ENDF/B-VIII.0 Improved Precision), Report IAEA-NDS- 0241, IAEA, Vienna, Austria, June 2023.

[7] **Private Communication**, Robert J. Howerton, circa 1972.

[8] **TART 2022**: An Overview of A Coupled Neutron-Photon 3-D, Combinatorial Geometry Time Dependent Monte Carlo Transport Code, Report: LLNL-SM-835527, Code Release: LLNL-CODE-836321, May 2022.

[9] Program **EPICSHOW**: A Computer Code to Allow Interactive viewing of the EPIC Data Libraries (Version 94-1), UCRL-ID-116819, February 1994.

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[11] **MCNP:** T. Goorley et al., Initial MCNP6 release overview, Nucl. Technol. **180**/3 (2012) 298-315.

[12] **GEANT4:** J. Allison et al., Recent developments in Geant4, Nucl. Instrum. Methods A **835** (2016) 186-225.

[13] **FLUKA:** T.T. Böhlen et al., The FLUKA code: Developments and challenges for high energy and medical applications, Nucl. Data Sheets **120** (2014) 211-214.

EXTRA References to Original Data Files

[14] **EPDL:** D.E.Cullen, M.H. Chen, J.H. Hubbell, S.T. Perkins, E.F. Plechaty, J.A. Rathkopf and J.H. Scofield "Tables and Graphs of Photon-Interaction Cross Sections from 10 eV to 100 GeV Derived from the LLNL Evaluated Photon Data Library (EPDL), UCRL-50400, Vol. 6, Rev. 4, Part A: Z = 1 to 50, October 1989

[15] **EPDL:** D.E.Cullen, M.H. Chen, J.H. Hubbell, S.T. Perkins, E.F. Plechaty, J.A. Rathkopf and J.H. Scofield "Tables and Graphs of Photon-Interaction Cross Sections from 10 eV to 100 GeV Derived from the LLNL Evaluated Photon Data Library (EPDL), UCRL-50400, Vol. 6, Rev. 4, Part B: Z = 51 to 100, October 1989

[16] **EEDL:** D.E.Cullen, S.T. Perkins, and S.M. Seltzer, "Tables and Graphs of Electron Interaction Cross 10 eV to 100 GeV Derived from the LLNL Evaluated Electron Data Library (EEDL), Z = 1 - 100", Lawrence Livermore National Laboratory, UCRL-50400, Vol. 31, November 1991.

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