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Release of the 2008 Evaluated Nuclear Data Library (ENDL2008)

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Executive Summary

Livermore's N-Division is now releasing the first version of a major new nuclear data library. This includes some 500 evaluations (roughly four times the number in the previous standard) and many physics improvements important for calculating weapon performance, output effects, attribution signatures, key radiochemical diagnostics and performance of conventional and hybrid fission/fusion reactors. As this library is more extensive and on a much firmer nuclear physics footing than the previous ENDL99 it should become, after a period of trial use by the applied community, the new standard for programmatic applications at Livermore. This work was supported by ASC-PEM and Campaign 4.

Our basic philosophy in this release was to adopt the best work of the world's different nuclear data efforts. We have drawn heavily from the U.S. ENDF project (led by Brookhaven), the Japanese JENDL project (JAEA), and the European JEFF project (NEA). Because those efforts tend to focus on reactor applications they do not include an account of the charged particles emitted following a reaction. To enable broader applications we have used theory-based calculations to add a complete description of charged particles in all evaluations in the new library.

This release also includes results from the last ten years of theory and experimental work here at Livermore. Some of the most important results include the surrogate campaign for unstable uranium isotopes, the LLNL/LANL ^{239}Pu(n,2n) evaluation, the ^{241}Am(n,2n) evaluation validated by the recent Livermore-led experiments, and measurements of ^{48}Ti(n,2n). As well, we have adopted more than a hundred theory-based evaluations for radiochemical diagnostics completed by R. Hoffman and M. Mustafa and that use improved optical models, level densities, and decay scheme evaluations from the theory effort. These were extended to be transport complete (they now include a description of all of the particles emitted in reactions) to enable their use in neutronics simulations. There is an ongoing effort to provide all of these radiochemical evaluations, including isomers, in the next major ENDL release.

The new library has undergone extensive unclassified testing. All isotopes were required to pass a set of simple tests with both deterministic and Monte Carlo codes to ensure that, at a minimum, they do not cause problems for the transport codes. As well, the data was validated through simulations of historical integral experiments. Calculations for k eigenvalues for a broad array of bare and reflected critical assemblies show a marked improvement over ENDL99 and performance comparable to or better than any other currently available library. In particular, there is now excellent agreement with results for the bare plutonium Jezebel assembly (k=1.0007). Similarly, simulations of photon production and neutron time of flight show, with

some exceptions, excellent agreement with the LLNL pulsed sphere experiments. Our intention with this initial release is to engage the programmatic community to begin the process of testing with more complicated unclassified and classified problems. We would greatly appreciate recommendations and any reports of problems or oddities. These will be included in the final release of this database in 2009.

The new libraries can be found on LC in:

- `/usr/gapps/data/nuclear/endl_official/endl2008.2/ascii` for the ENDL ASCII formatted data,
- `/usr/gapps/data/nuclear/endl_official/endl2008.2/ndf` for deterministic data and
- `/usr/gapps/data/nuclear/endl_official/endl2008.2/mcf` for Monte-Carlo data.

Links to the following legacy paths have been maintained for backwards compatibility:

- `/usr/gapps/data/nuclear/processed/endl2008.2/ndf` for deterministic data and
- `/usr/gapps/data/nuclear/processed/endl2008.2/mcf` for Monte-Carlo data.

In addition, the data may be viewed in the Nuclear and Atomic Data System data viewer at http://nuclear.llnl.gov/NADS and the complete release history and project page can be found at https://sourceforge.llnl.gov/sf/projects/endl/.

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1. Introduction

LLNL's N Division is pleased to announce the 2008 release of the Evaluated Nuclear Data Library (ENDL2008) to LLNL users. This release is designed to enhance the laboratory's modeling of radiochemical diagnostics and structural materials in neutron-rich environments and modeling of energy generating reactions in the actinide mass region. ENDL2008 is the first major release of the ENDL library in over 9 years and includes 416 new isotopes and major improvements/replacements to many of the 110 legacy evaluations. In assembling this library, we have developed many new evaluations and taken evaluations from many different sources, including the ENDF/B-VII.0 and JENDL-Actinoid libraries and Rob Hoffman's Radiochemical library. Figure 1 illustrates the source composition of ENDL2008.

The goal of this release is to provide the best data to LLNL customers and, as a side-effect, this synchronizes ENDL with the ENDF/B-VII.0 library to some extent. This brings LANL and LLNL's floor nuclear data libraries into greater accord, allowing better cross-code comparisons between the labs. In addition, this enhances our collaboration with the external ENDF community: we now use many of the new ENDF/B-VII.0 evaluations. In return, we provide any new evaluations we develop to the US Nuclear Data Program and provide useful quality-control feedback to the ENDF community on the evaluations we adopt. By submitting our evaluations to ENDF, the ENDF community will have the opportunity to peer review our work.

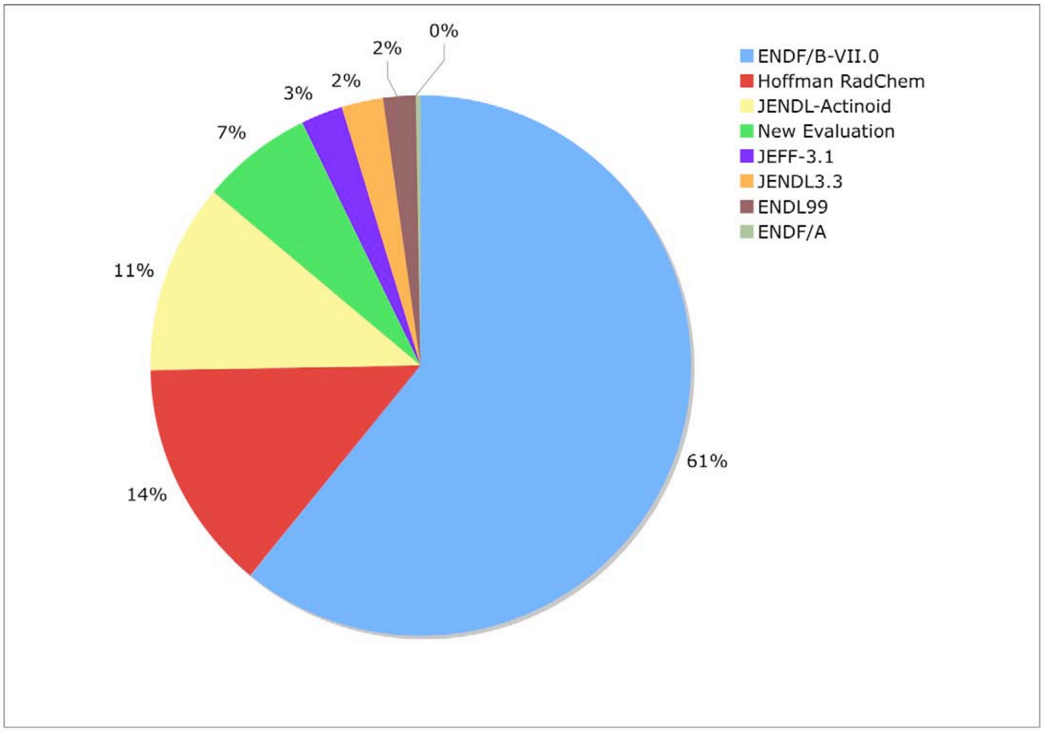

Figure 1: Pie chart showing the composition of the ENDL2008 library. Each wedge corresponds to the fraction of isotopic evaluations adopted from each source.

In the following section, we describe how the various sources of data were integrated into the library, including adopting evaluations from other ENDF libraries, integrating the Hoffman Radiochemistry library and developing several new evaluations. Next we detail the data testing used to validate this library release. We conclude with an outlook for an ENDL2009 release.

2. Review and Adoption of External (ENDF-formatted) Evaluations

The majority of the ENDL2008 evaluations are taken from other nuclear data libraries, all of which are distributed in the ENDF format. There are significant differences between the ENDF and ENDL formats, both in terms of complexity and scope of the formats. Translating ENDF-formatted data into ENDL-formatted data and then into processed `mcf` and `ndf` files suitable for use in LLNL applications is a complicated multi-step process. An overview of this process may be found in the documentation for the 2006 translated ENDF data release [Brown 2006]. Here we will outline our criteria for selecting evaluations for ENDL2008 and state what corrections we applied to the library, including how we ensure completeness of the evaluations.

We reviewed over 400 isotopes for inclusion in the ENDL2008 library. As each isotope has ~5-10 significant reaction channels and countless experimental data for comparison, we developed an automated tool to aid the comparison. This tool, based on the `Python` scripts used for the "Actinide Scorecard" website [Brown 2005b], automatically provides:

- A graphical comparison of all evaluations to all available data for all major reaction cross sections;
- Simple data-quality tests;

- Simple evaluation of statistical comparisons to data (e.g. χ^2).

With this tool, reviewing all of the evaluations becomes quite simple. Review of the evaluations only becomes difficult when the large set of available data obscures the plots. Our automated review did not check other observables such as outgoing angular distributions or fission neutron spectra; we rely on the data testing described later.

Once an evaluation is chosen, we check and repair it as needed. Evaluation fixes consist of synchronizing Q values and thresholds with the latest nuclear mass evaluation from Audi, Wapstra and Thibault [Audi 2003] and filling in missing data. The ENDL format specifications require that all ENDL evaluations be kinematically complete. This means that, for a given reaction, all outgoing particles must have complete angle and energy distributions. Furthermore, any outgoing particles whose multiplicity is not completely specified by the reaction **C** number (e.g. neutrons from fission or gammas from any reaction) must have multiplicity information provided. In practice, we filled in the outgoing particle tables from other libraries if possible or from automated `TALYS` runs using `geft`. This procedure works for all observables except the prompt and delayed fission nubar; ENDL requires only the prompt nubar. Since ENDF requires only the total nubar and `TALYS` has no capability of modeling nubar, we assume that the delayed nubar is zero and that the prompt nubar is equals to the total nubar, if we cannot locate suitable delayed nubar data.

3. Hoffman Radiochemical Evaluations

Three data sets from the Hoffman Radiochemical evaluations derived from `STAPRE` were included in this release: Ca-Fe [Kelley 2004]; Se-Rb [Hoffman 2004a]; and I-Xe [Hoffman 2004b]. The cross sections in these sets contained cross section data for specific reaction channels as well as for isomers. These evaluations, including outgoing particle spectra for all the particles in the channel cross sections, total and elastic cross sections with angular distributions, and gamma multiplicities for continuum and discrete gammas following particle emission, were incorporated into the ENDL2008 release. `TALYS` was used to provide any remaining data. The `geft` code was used to run the `TALYS` calculations while `fudge` was employed to combine the `STAPRE` and `TALYS` calculations using the methodology described below.

The `STAPRE` calculations included cross sections to final-state isomers as well as for reaction incident on isomers. Since the transport codes at present cannot handle isomers, the isomeric cross sections were summed to obtain a single isotope cross section and any reactions incident on isomeric targets. Inelastic cross sections from ground state targets to isomeric final states were removed and replaced later with total inelastic cross sections obtained from `TALYS`.

The Koning and Delaroche optical potential [Koning 2003] was used in both the `STAPRE` and `TALYS` calculations, providing consistent total and elastic cross sections along with the elastic angular distribution.

Specific outgoing particles were considered in the `STAPRE` calculations: neutrons, protons and gammas for the Se-Rb and I-Xe detector sets; deuterons and alphas were also included for the Ca-Fe sets. The Perey-Perey [Perey 1976] and McFadden-Satchler [McFadden 1966] optical potentials were used for deuterons and alphas respectively. Since the Perey-Perey deuteron optical potential was not an option in the TALYS-1.0 distribution, it was included in a local version of the code.

The level density and photon strength function systematics developed for the STAPRE calculations were imported into TALYS as closely as possible. More up to date systematics [Kelley 2006b] were used for the Ca-Fe set but, since they cover the same mass regions, the differences should be small. The asymptotic level density, the pairing energy and the shell correction were imported into TALYS from the tables of level density parameters in the reports. We used the TALYS implementation of the RIPL-2 level scheme and let TALYS handle the matching of the asymptotic level density onto the known level scheme. The spin cutoff parameter was also matched to known values. TALYS had options to use the two different spin cutoff parameterizations used in the different detector sets. The parameterization of the gamma shell correlations fall-off was also reproduced in TALYS.

The systematics for the average photon widths were included when there was no experimental data to constrain this variable, as for the STAPRE calculations.

The single-component exciton model, employed in STAPRE, was used for the pre-equilibrium model. The TALYS default options for multiple pre-equilibrium, surface and complex pre-equilibrium were all turned off to reproduce the STAPRE calculations as far as possible. The remaining parameter in the STAPRE calculations was used to scale the matrix element. Since the simple energy dependence in STAPRE could not be reproduced with the complex energy dependence employed in TALYS, the default values were used. Comparison of the STAPRE and TALYS cross sections and showed very similar results. Since the overall cross sections were scaled to match the reaction cross section, as discussed later, the agreement was deemed to be reasonable.

When the STAPRE and TALYS calculations were combined, the original STAPRE cross sections were retained and other significant cross sections imported from TALYS were scaled to preserve the overall reaction cross section. The elastic and total cross sections were taken from TALYS. Note that the compound elastic cross section – which should be included in the reaction cross section – was not rescaled since scaling this small contribution proved problematic. Below 1 MeV the sum of the STAPRE calculations was sometimes slightly larger than the reaction cross section calculated in TALYS. In this case, the reaction cross section (and therefore the total cross section) was increased to account for this discrepancy. The STAPRE calculations were extrapolated down to 10^{-5} MeV. Using the TALYS implementation for the low energy extrapolation (see TALYS manual for details), the STAPRE cross sections were extended down to 10^{-11} MeV.

4. New Evaluations

The ENDL2008 library contains many new evaluations developed explicitly for LLNL users. All of these evaluations have been or are in the process of being packaged for submission to the US Nuclear Data Program for possible inclusion in the ENDF/B library. We divide these new evaluations up into several categories: actinide evaluations, structural material evaluations and radiochemical diagnostic evaluations. In addition, we have added a new feature: energy dependent *Q* values for fission. We discuss each of these below.

Actinides

We developed two new evaluations in the actinide mass range, described in detail elsewhere, for this ENDL release: ^{237}U [Brown 2008a] and ^{240}Am [Brown 2007a]. In both cases, the final evaluations were also submitted to the US Nuclear Data Program for possible inclusion in a future ENDF/B release. Here we present a few highlights from these evaluations.

A well-known shortcoming of Hauser-Feshbach models is their inability to reliably predict fission cross sections. While we relied on `TALYS` to provide all of the cross sections and most of the outgoing particle data for both ^{237}U and ^{240}Am, we needed an alternate approach to develop the fission cross sections. In both cases, we chose to fit to recent surrogate (n,f) measurements [Burke 2006] or re-evaluations or older surrogate (n,f) measurements [Younes 2004]. We then rescaled the other associated reaction cross sections from `TALYS` to be consistent with the experimental fits. As shown in the right panel of Fig. 2, this strategy clearly works: we were able to nearly reproduce the ^{237}U(n,2n) measured data [Bernstein 2006]. In both cases, we adopted the fission neutron spectra, nubar and resonance data from other evaluations. We used the JEFF-3.1 evaluation of ^{237}U. Since there is no other ^{240}Am evaluation, we took these data from the nearest odd-*Z*, even-*A* nucleus, ^{242}Am. The quality of the matching onto ^{242}Am is evident in Fig. 3.

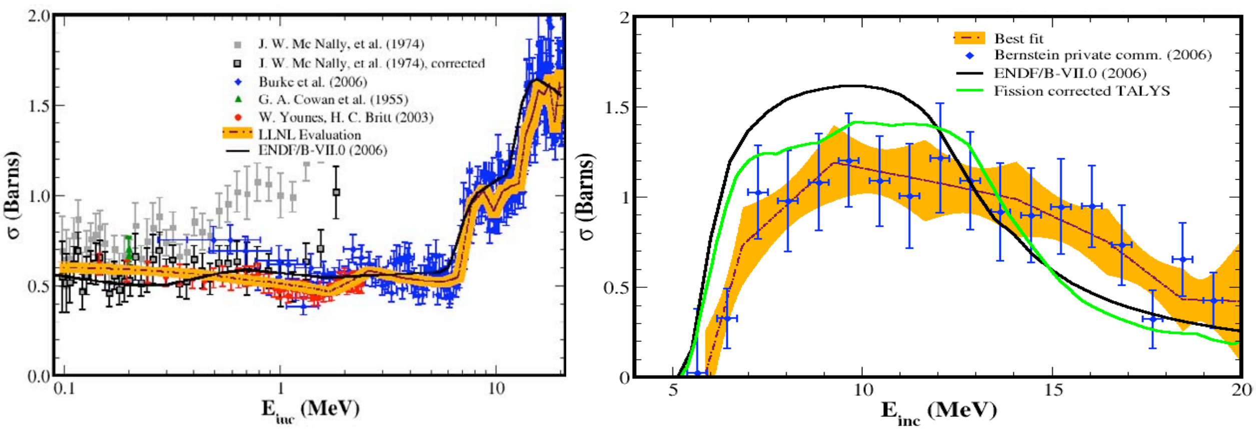

Figure 2: Illustrations of the ENDL2008 ^{237}U evaluation [Brown 2008a]. On the left panel, we show the ^{237}U(n,f) cross section. The ENDL2008 evaluation is the fit indicated by the dot-dashed line with the orange error band. On the right panel, we show the ^{237}U(n,2n) cross section with the fit to the surrogate data [Burke 2006]. As these data are still being analyzed, we chose to employ the `TALYS` cross section calculation after appropriate corrections for the fitted fission cross section shown in the left panel.

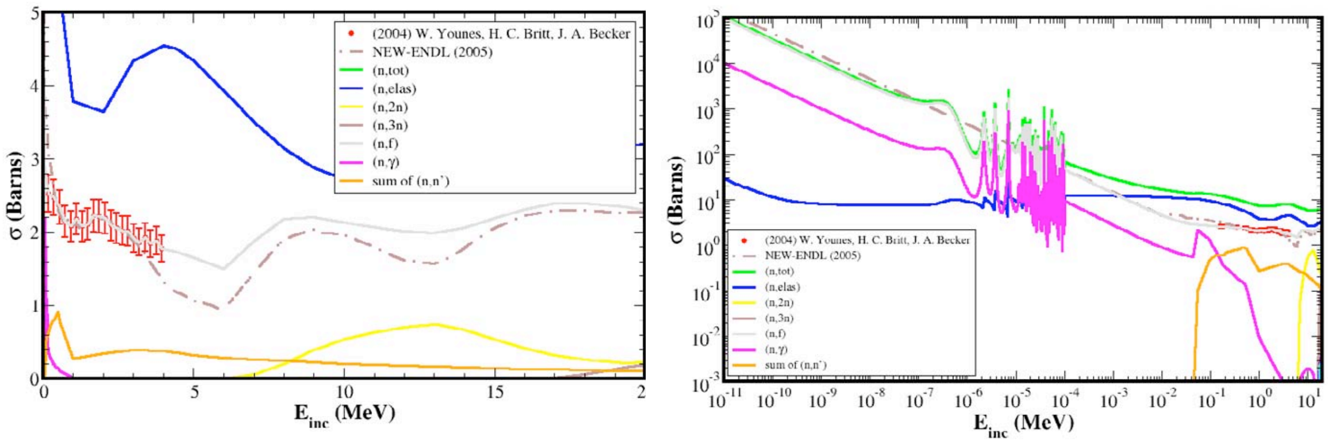

Figure 3: Plots of the ^{240}Am cross sections. On the left, all open channels are shown on a linear scale to highlight the agreement of our fission cross section with the surrogate reaction data analyzed by Younes, Britt and Becker [Younes 2004]. The same plot is shown on a logarithmic scale on the right-hand side to emphasize both the matching onto the resonance region and the thermal cross sections.

Structural Materials

As part of the ENDL2008 release, we developed evaluations for isotopes found in many common structural materials: cobalt, nickel, copper, zinc and gallium. Figure 4 shows the reaction network in this mass range. The copper, nickel and gallium evaluations simply fill in the gaps in the existing ENDF/B-VII.0 reaction network. Our cobalt and zinc evaluations entirely replace existing ENDF/B-VII.0 evaluations. In all cases, the legacy ENDL99 release contains only elemental evaluations. We maintain these evaluations only for backwards compatibility.

The structural material evaluations in ENDL2008 were produced using a version of `TALYS` [TALYS 2007] with input from the regional systematic nuclear properties [Kelley 2006a], as benchmarked to experimental data where available. The ENDL files were generated from the `TALYS` output using `geft`.

A modified version of `TALYS` was constructed where the spin cut-off parameter could be specified separately for each nucleus by introducing a new input variable for each isotope. The asymptotic value of the level density parameter *a* was either found from global systematics or by fitting to known values of the average resonance spacing for low-energy neutrons. Pre-equilibrium particle emission was calculated with a two-component exciton model, using numerical transition rates with energy-dependent matrix elements [Koning 2004]. The photon capture width was derived from a linear fit for $50 < A < 70$ instead of the default spline fit in `TALYS` which over predicts the photo-emission cross sections by factors of 2-3.

When good resonance data were available, they were added to our ENDL evaluations, replacing the low energy extrapolation from `TALYS`. This was done for isotopes such as ^{64}Zn, ^{66}Zn, ^{67}Zn, ^{68}Zn, ^{70}Zn, ^{58}Co and ^{59}Co.

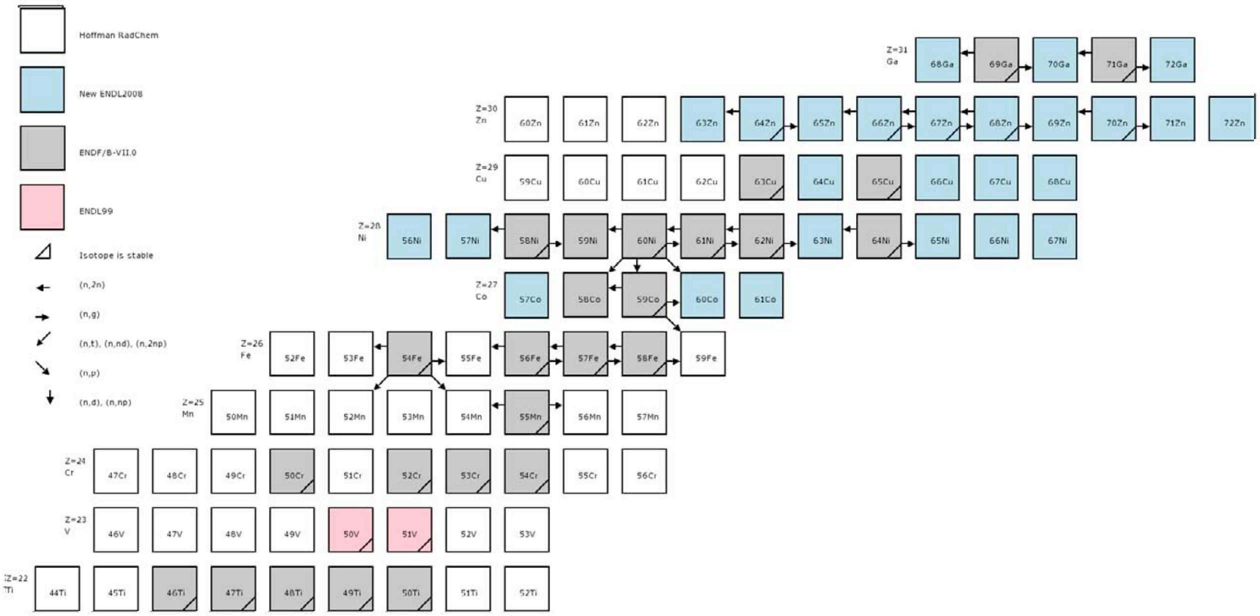

Figure 4: Reaction network of isotopes in the range $22 \leq Z \leq 31$, corresponding to commonly used structural materials. The arrows denote important creation/destruction reactions. Evaluations of the isotopes in blue were specially created for ENDL2008 while those in white are taken from the Hoffman Radiochemistry library, as described in the previous section. The grey and red isotopes employ evaluations from ENDF/B-VII.0 and ENDL99 respectively.

Radiochemical Diagnostics

We produced new evaluations for $^{76-78}$Kr. These isotopic evaluations were based on the Hoffman Radiochemistry evaluations described previously. The ^{78}Kr resonance region was adopted from ENDF/B-VII.0. These evaluations are a significant improvement over ENDF/B-VII.0 for an important radiochemical diagnostic. We show ^{78}Kr cross sections in Fig. 5.

Energy Dependent *Q* Values for Actinide Fission

We have produced a general formula for energy-dependent *Q* values based on Madland's parameterization of the energy deposited in the fission of ^{235}U, ^{238}U and ^{239}Pu [Madland 2006], as described in [Vogt 2007]. Based on the formulas in [Madland 2006] and the existing actinide evaluations (the **I=10)** files for prompt neutron and gamma emission and using a Coulomb approximation of the total fission product kinetic energy, it is possible to obtain energy-dependent *Q* values for all the actinides in ENDL2008. The energy dependence of our model *Q(E)* for ^{235}U, ^{238}U and ^{239}Pu is shown in Fig. 6. The results differ from Ref. [Madland 2006] by less than 1% at thermal energies and less than 3% at 20 MeV. The difference at higher energies is primarily due to the choice of which prompt gamma emission evaluation to parameterize. Typically, the *Q* value decreases about 10% from 0 to 20 MeV. Details of the generalized model can be found in Ref. [Vogt 2008], along with tables of the coefficients *a, b*, and *c* in the formula $Q(E) = c + b\,E + a\,E^2$.

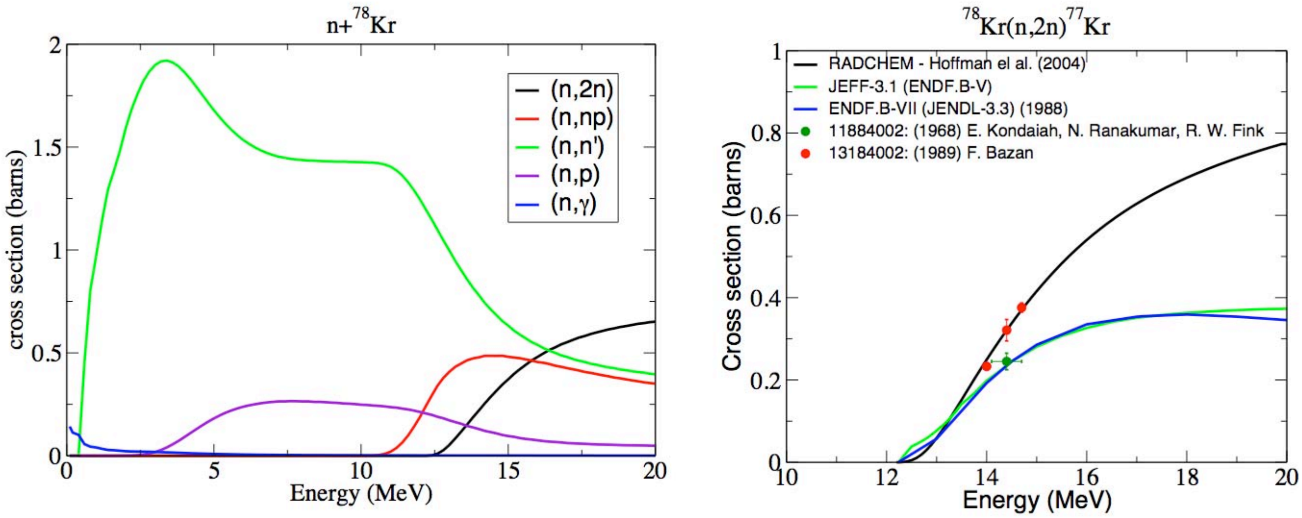

Figure 5: Cross sections of several neutron-induced reactions on ^{78}Kr. The left panel shows all the reaction cross sections on the same plot while the right panel focuses on the (n,2n) reaction, the only one with available experimental data for benchmarking the ENDL2008 evaluation.

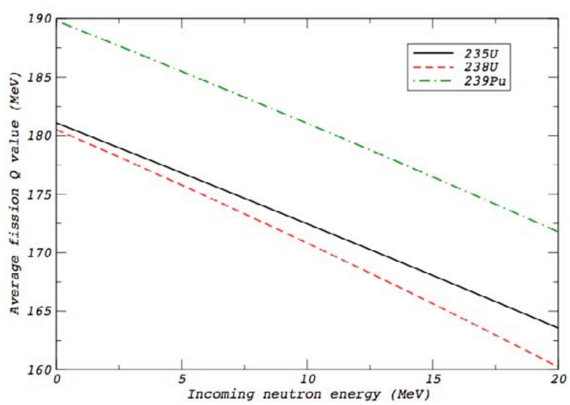

Figure 6: Example of the energy-dependent *Q(E)* in ENDL2008 for ^{235}U, ^{238}U and ^{239}Pu.

5. Testing

Before release, ENDL2008 was submitted to a formal testing program comprised of the four components described below: simple sanity tests; benchmark critical assemblies; gamma production and LLNL pulsed-spheres.

The first step was a set of basic checks and physics tests in `fudge` before processing the data for use in applications. Format checks ensured that all the data headers matched for an isotope, that the energy points were in order with no steps or double values, and that the given Q matched the Q value computed for the reaction designation (**C** number) and the particle masses. The completeness checks ensured that all emitted particles have outgoing energy-angle distributions, gamma multiplicities were given and the fission nubar was provided. We also checked that the energy balance was maintained so that the outgoing energy E' obeyed $E' \leq E + Q$, and that the threshold matched with the Q values. Finally, we checked that probabilities were correctly normalized, that the cross sections, multiplicities and probability densities were positive definite, and that the cross sections obeyed relevant sum-rules.

Once the data was processed, the ENDL2008 library went through several simple tests to ensure that each isotope or element ran normally and did not lead to a core dump of the application code. The `mcf` file was tested using `Mercury`, a 3D particle-transport Monte Carlo code, by running a dynamic simulation of a sphere of material made of a single isotope with a neutron source in the middle. Gamma production was studied with a similar test that tallied the average gamma energy leaking out of a 40 cm ball of the material with a 14 MeV neutron source in its center. The `ndf` file was tested using `AMTRAN`, a deterministic code. A fast k_{eff} simulation was run for each isotope with a ^{239}Pu core inside a reflector made of the isotope.

ENDL2008 was then tested using k_{eff} benchmark simulations taken from the criticality safety benchmark handbook [NEA 2006]. The `mcf` and `ndf` libraries were tested through an automated suite of 27 `Mercury` and 15 `AMTRAN` benchmark calculations respectively. In Fig. 7, the k_{eff} values for ^{235}U, ^{239}Pu, and ^{233}U assemblies simulated with these two codes are compared to benchmark values and `MCNP4C3` calculations using ENDF/B-VII.0. ENDL2008 performs well in most assemblies and the deviations are under control. Most discrepancies are understood and can be traced back to four main factors:

- Poor performance for thermal assemblies (PST11) and thermalizing-reflector assemblies (HMF19, PMF11, PMF23, PMF24) due to poor $S_{\alpha\beta}$ support in ENDL2008.
- The unresolved resonance region(s) is not yet treated in either the production code or the data library.
- The Ni, W, and Be evaluations are poor in *all* libraries.
- The difference in k_{eff} for the Thor assembly (PMF8), a plutonium core with a ^{232}Th reflector, is due to a mistake in the library assembly resulting in nubar being set to 1. This has been fixed in endl2008.1 and later releases.

For the two well-known bare assemblies, Godiva and Jezebel, the ENDL2008 performance is comparable to ENDF/B-VII.0, as shown in Fig. 8. The Godiva k_{eff} is in excellent agreement with ENDF/B-VII.0 for both ENDL99 and ENDL2008. The Jezebel k_{eff} has improved dramatically over ENDL99 primarily because the ENDL99 239Pu evaluation was replace with the GENIE-based evaluation in ENDF/B-VII.0 developed by a LLNL-LANL collaboration. In addition, there was set of interesting and noticeable improvements between ENDL2008 β2 and β3:

1. The ENDL99 elemental Ga evaluation was replaced with ENDF/B-VII.0 isotopic .
2. The ENDL99 240Pu evaluation was replaced with the JENDL-Actinoid ^{240}Pu evaluation.

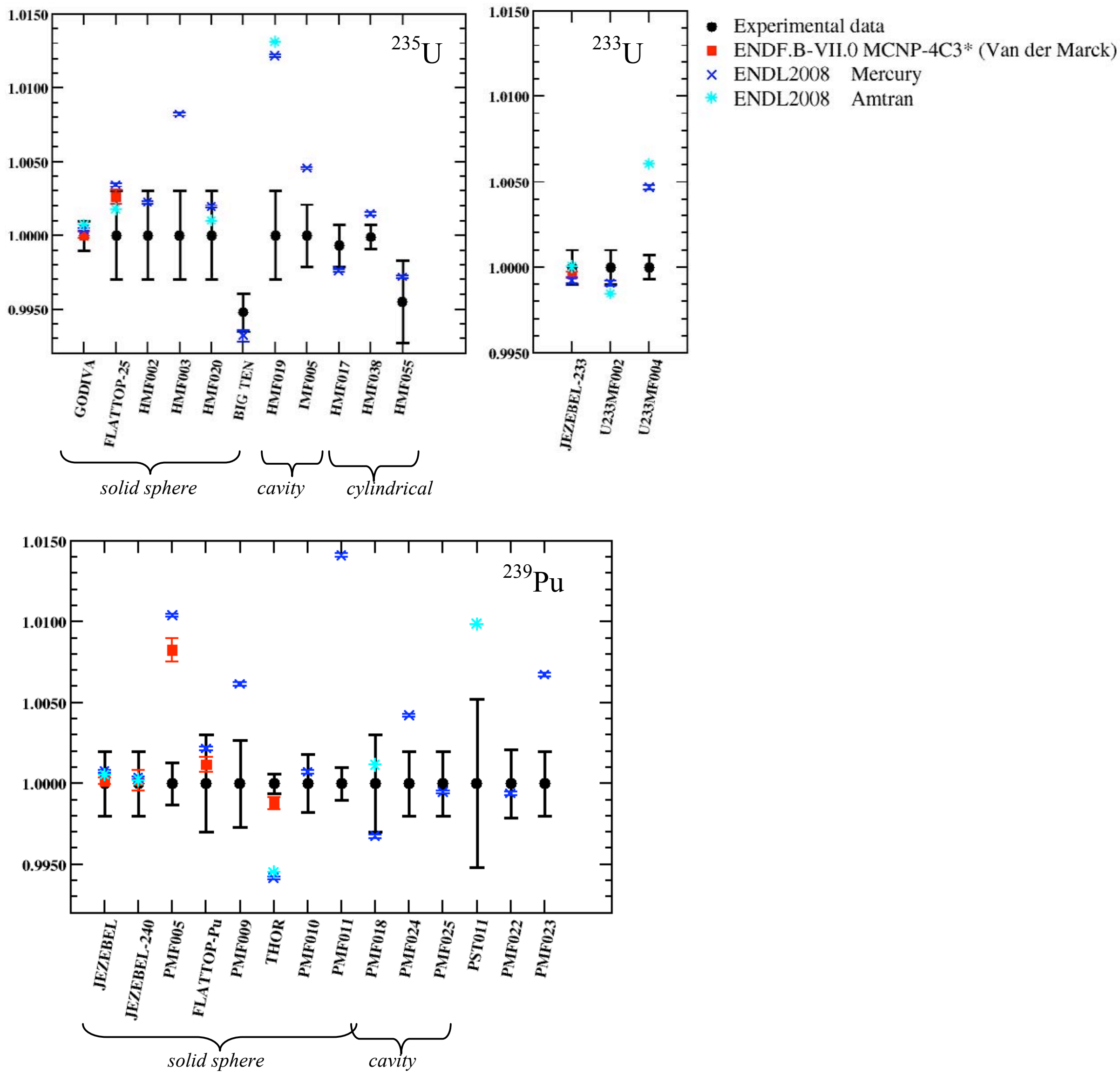

Figure 7: The k_{eff} for ^{235}U, ^{233}U, and ^{239}Pu benchmark critical assemblies simulated using ENDL2008.β3 with `Mercury` (x) and `AMTRAN` (*) compared to experiments (●) and `MCNP5`-ENDF/B-VII.0 calculations (■). The assemblies are grouped according to their geometry. Spherical assemblies with a cavity in the center have their own category regardless of cavity size.

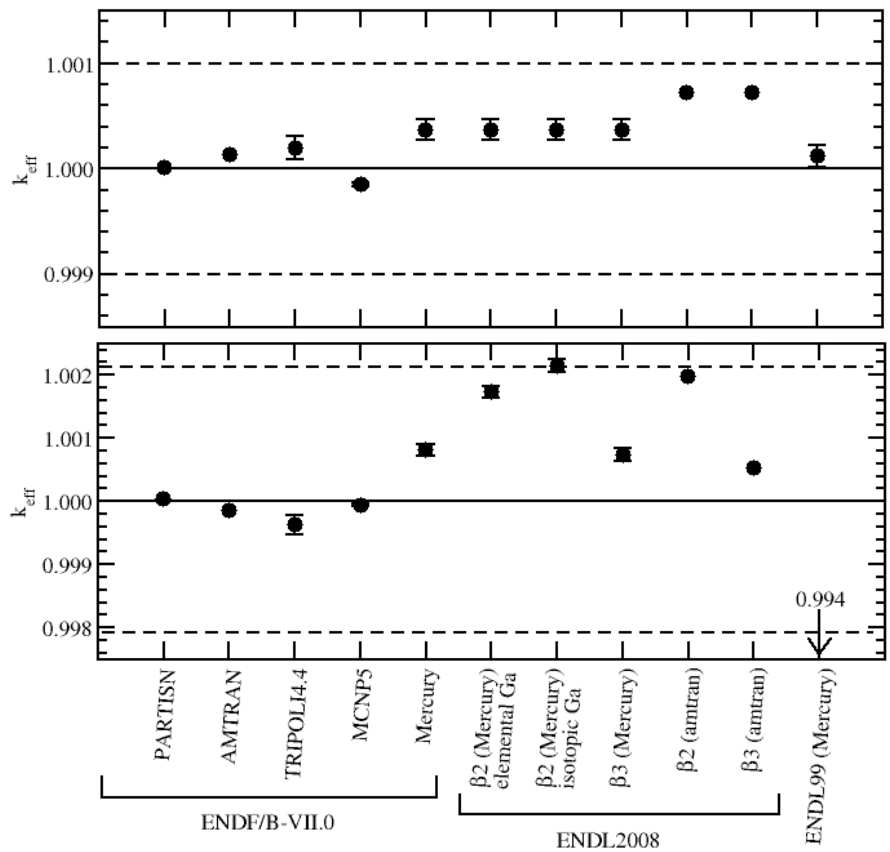

Figure 8: The Godiva (top) and Jezebel (bottom) critical assembly k_{eff} for ENDF/B-VII.0 and several versions of the ENDL2008 library. The ENDL99 k_{eff} is shown for reference. The benchmark k_{eff} values are 1.0000±001 for Godiva and 1.0000±002 for Jezebel. The dashed line represents a one standard deviation uncertainty.

ENDL2008 was also tested against LLNL pulsed-sphere experiments, a set of fusion-shielding benchmarks. The pulsed-sphere program, from the 70's to the early 90's, consisted of measuring neutron time-of-flight (TOF) and gamma spectra after a 14 MeV neutron pulse was emitted from a deuterium-tritium source placed in a sphere of material [Wong 1972]. TOF spectra were measured for a variety of materials. `Mercury` models of the LLNL pulsed-sphere experiments were developed for the materials reported in Goldberg et al. [Goldberg 1990, Marchetti 1998]. Thirteen plots of experimental and simulated TOF spectra are shown in Appendix B. Overall, ENDL2008 matches the data quite well. These plots highlight the need for better tungsten, nitrogen, carbon and thorium evaluations. We also note that the nitrogen data in ENDL99 appears to perform better than that of the ENDF/B-VII.0 evaluation.

Since electron transport is not yet implemented in `Mercury`, we did not simulate electron recoil spectra. Instead, we used values of the published average leaked gamma energy [Goldberg 1990], based on simulations, for our comparisons. The ENDL2008 performance for the average leaked gamma energy is better than ENDL99 and ENDF/B-VII.0 except for ^{19}F and ^{14}N, as shown in Fig. 9. This will be corrected in the future since ^{19}F will be re-evaluated – the ENDL99 and ENDF/B-VII.0 evaluations are considered obsolete - and ^{14}N will be taken from ENDF/B-VII.0 once the translation of the break-up data is resolved.

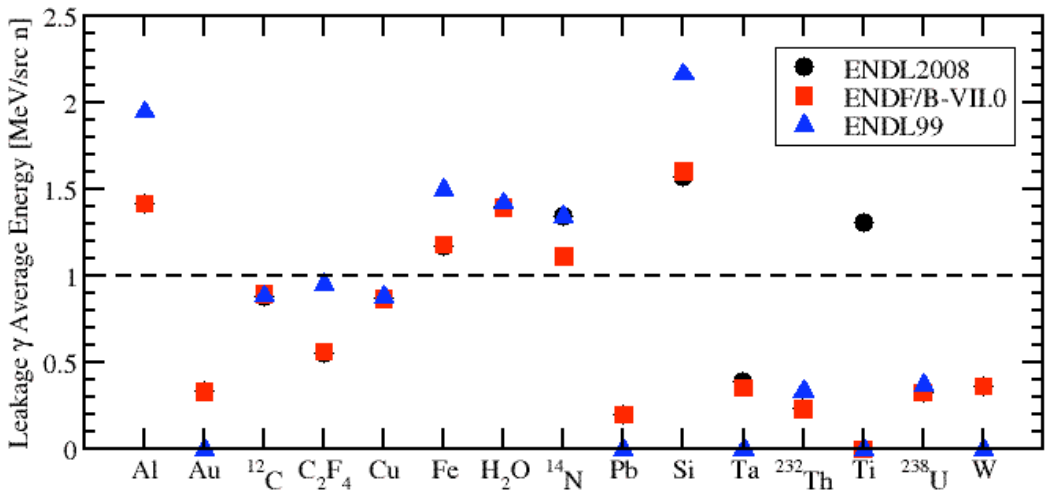

Figure 9: Average leaked gamma energy per source neutron in [MeV/# source neutrons] simulated with `Mercury` employing ENDL99 (▲), ENDF/B-VII.0 (■) and ENDL2008.β3(●), compared to published simulations [Goldberg 1990].

6. Outlook

While the release of ENDL2008 is a dramatic improvement over the legacy ENDL99 data library, our data users can expect to encounter some "bumps" in the changeover. Our extensive data testing, described above, should smooth out most of these bumps. The change from elemental evaluations to isotopic evaluations may prove to be a large challenge for users. In this release, all 27 elemental evaluations in ENDL99 have been replaced with isotopic evaluations. To ease the changeover, we have left the ENDL99 elemental evaluations in the library. *These evaluations are not synchronized with the newer isotopic evaluations.* This is the last ENDL release in which we will keep these legacy elemental evaluations. In the future, the deterministic and Monte Carlo application code data interfaces will provide "on-the-fly" elemental evaluations by combining isotopic evaluations in the access routines.

The ENDL2009 library, due at the end of FY2009 should provide even more significant improvements. The biggest change will be the addition of many more neutron-induced data, including deformed nuclei from the Hoffman Radiochemistry library, more structural materials, isomer targets, $S_{\alpha\beta}$ data, and fission spectra re-evaluations for ^{235}U, ^{238}U and ^{239}Pu. The isomer target and $S_{\alpha\beta}$ data will be enabled by changes to `MCAPM` and `libndf` which will allow users to access Monte-Carlo or deterministic data for particular isotopes by a string rather an inflexible integer. We will also add charged particle and photonuclear data from the world's libraries much as we did for neutrons in the 2008 release. Finally, the ENDL2009 release will receive even greater testing than the ENDL2008 release, including an expanded set of critical assembly tests, Bethe sphere, Oktavian sphere tests and a variety of classified tests.

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Appendix A: Library sources for each evaluation

Here we present an accounting of the source for each isotope in the ENDL2008 release. More detail can be found in the `documentation.txt` file in each evaluation directory under `endl2008/ascii/yi01/` on Livermore's computer cluster. In this table, we list the fractional natural abundances for only naturally-occurring elements. In the column "Evaluation source," "JENDL-AC" refers to the JENDL-Actinoid library [JENDL 2008], "H. RadChem" refers to the Hoffman Radiochemistry library [Hoffman 2004a, Hoffman2004b, Kelly 2004, Kelley 2006a, Kelley 2006b, Brown 2005a], "ENDF/A" refers to the ENDF/A library used by the National Nuclear Data Center to store evaluations for possible inclusion in a major ENDF/B release [ENDF/A 2007] and "New Eval" refers to evaluations generated specifically for the ENDL2008 library. An entry of "N/A" in the Evaluation source column indicates that there is no evaluation for an isotope and the evaluation was included in this table for the sake of completeness.

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
n	za000001	0	Y	New Eval
natH	za001000			
1H	za001001	99.985	Y	ENDF/B-VII.0
2H	za001002	0.015	Y	ENDF/B-VII.0
3H	za001003	0	Y	ENDF/A
natHe	za002000			
3He	za002003	0.000137	Y	ENDF/B-VII.0
4He	za002004	99.99986	Y	JENDL-3.3
natLi	za003000			
6Li	za003006	7.59	Y	ENDL99
7Li	za003007	93.41	Y	ENDL99
natBe	za004000			
7Be	za004007	0	Y	ENDF/B-VII.0
8Be	za004008	0		N/A
9Be	za004009	100	Y	ENDF/B-VII.0
natB	za005000			
10B	za005010	19.8	Y	ENDL99
11B	za005011	80.2	Y	ENDF/B-VII.0
natC	za006000			
12C	za006012	98.89	Y	ENDL99
13C	za006013	1.11	Y	ENDL99
natN	za007000			
14N	za007014	99.634	Y	ENDL99
15N	za007015	0.366	Y	ENDL99
natO	za008000			
16O	za008016	99.762	Y	ENDF/B-VII.0
17O	za008017	0.038		N/A
18O	za008018	0.2		N/A
natF	za009000			
19F	za009019	100	Y	ENDF/B-VII.0
natNe	za010000			
20Ne	za010020	90.48	Y	ENDL99
21Ne	za010021	0.27		N/A
22Ne	za010022	9.25		N/A
natNa	za011000			N/A
22Na	za011022	0		ENDF/B-VII.0
23Na	za011023	100	Y	JENDL-3.3
natMg	za012000			
24Mg	za012024	78.99		ENDF/B-VII.0
25Mg	za012025	10		ENDF/B-VII.0
26Mg	za012026	11.01		ENDF/B-VII.0
natAl	za013000			N/A
27Al	za013027	100	Y	ENDF/B-VII.0
natSi	za014000		Y	
28Si	za014028	92.23		ENDF/B-VII.0
29Si	za014029	4.683		ENDF/B-VII.0
30Si	za014030	3.087		ENDF/B-VII.0
natP	za015000			N/A
31P	za015031	100	Y	ENDF/B-VII.0
natS	za016000			N/A
32S	za016032	95.02	Y	ENDF/B-VII.0
33S	za016033	0.75		ENDF/B-VII.0
34S	za016034	4.21		ENDF/B-VII.0
35S	za016035	0		N/A

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
36S	za016036	0.02		ENDF/B-VII.0
natCl	za017000		Y	
35Cl	za017035	75.77		ENDF/B-VII.0
36Cl	za017036	0		N/A
37Cl	za017037	24.23		ENDF/B-VII.0
natAr	za018000		Y	
36Ar	za018036	0.3365		ENDF/B-VII.0
37Ar	za018037	0		N/A
38Ar	za018038	0.0632		ENDF/B-VII.0
39Ar	za018039	0		N/A
40Ar	za018040	99.6003		ENDF/B-VII.0
natK	za019000		Y	
39K	za019039	93.2581		ENDF/B-VII.0
40K	za019040	0.0117		ENDF/B-VII.0
41K	za019041	6.7302		ENDF/B-VII.0
natCa	za020000		Y	
40Ca	za020040	96.94		ENDF/B-VII.0
41Ca	za020041	0		H. RadChem
42Ca	za020042	0.647		ENDF/B-VII.0
43Ca	za020043	0.135		ENDF/B-VII.0
44Ca	za020044	2.09		ENDF/B-VII.0
45Ca	za020045	0		H. RadChem
46Ca	za020046	0.004		ENDF/B-VII.0
47Ca	za020047	0		H. RadChem
48Ca	za020048	0.187		ENDF/B-VII.0
natSc	za021000			N/A
41Sc	za021041	0		H. RadChem
42Sc	za021042	0		H. RadChem
43Sc	za021043	0		H. RadChem
44Sc	za021044	0		H. RadChem
45Sc	za021045	100		JEFF-3.1
46Sc	za021046	0		H. RadChem
47Sc	za021047	0		H. RadChem
48Sc	za021048	0		H. RadChem
49Sc	za021049	0		H. RadChem
50Sc	za021050	0		H. RadChem
natTi	za022000		Y	
44Ti	za022044	0		H. RadChem
45Ti	za022045	0		H. RadChem
46Ti	za022046	8.25		JENDL-3.3
47Ti	za022047	7.44		JENDL-3.3
48Ti	za022048	73.72		JENDL-3.3
49Ti	za022049	5.41		JENDL-3.3
50Ti	za022050	5.18		JENDL-3.3

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
51Ti	za022051	0		H. RadChem
52Ti	za022052	0		H. RadChem
natV	za023000			JENDL-3.3
46V	za023046	0		H. RadChem
47V	za023047	0		H. RadChem
48V	za023048	0		H. RadChem
49V	za023049	0		H. RadChem
50V	za023050	0.25	Y	ENDL99
51V	za023051	99.75	Y	ENDL99
52V	za023052	0		H. RadChem
53V	za023053	0		H. RadChem
natCr	za024000		Y	ENDL99
47Cr	za024047	0		H. RadChem
48Cr	za024048	0		H. RadChem
49Cr	za024049	0		H. RadChem
50Cr	za024050	4.345		ENDF/B-VII.0
51Cr	za024051	0		H. RadChem
52Cr	za024052	83.789		ENDF/B-VII.0
53Cr	za024053	9.501		ENDF/B-VII.0
54Cr	za024054	2.365		ENDF/B-VII.0
55Cr	za024055	0		H. RadChem
56Cr	za024056	0		H. RadChem
natMn	za025000			N/A
50Mn	za025050	0		H. RadChem
51Mn	za025051	0		H. RadChem
52Mn	za025052	0		H. RadChem
53Mn	za025053	0		H. RadChem
54Mn	za025054	0		H. RadChem
55Mn	za025055	100	Y	ENDF/B-VII.0
56Mn	za025056	0		H. RadChem
57Mn	za025057	0		H. RadChem
natFe	za026000		Y	
52Fe	za026052	0		H. RadChem
53Fe	za026053	0		H. RadChem
54Fe	za026054	5.845		ENDF/B-VII.0
55Fe	za026055	0		H. RadChem
56Fe	za026056	91.754		ENDF/B-VII.0
57Fe	za026057	2.119		ENDF/B-VII.0 + JENDL-3.3
58Fe	za026058	0.282		ENDF/B-VII.0
59Fe	za026059	0		H. RadChem
natCo	za027000			N/A
57Co	za027057	0		New Eval
58Co	za027058	0		New Eval

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
59Co	za027059	100	Y	New Eval
60Co	za027060	0		New Eval
61Co	za027061	0		New Eval
natNi	za028000		Y	
56Ni	za028056	0		New Eval
57Ni	za028057	0		New Eval
58Ni	za028058	68.077	Y	ENDF/B-VII.0
59Ni	za028059	0		ENDF/B-VII.0
60Ni	za028060	26.223		ENDF/B-VII.0
61Ni	za028061	1.14		ENDF/B-VII.0
62Ni	za028062	3.634		ENDF/B-VII.0
63Ni	za028063	0		New Eval
64Ni	za028064	0.926		ENDF/B-VII.0
65Ni	za028065	0		New Eval
66Ni	za028066	0		New Eval
67Ni	za028067	0		New Eval
natCu	za029000		Y	
62Cu	za029062	0		New Eval
63Cu	za029063	69.17		ENDF/B-VII.0
64Cu	za029064	0		New Eval
65Cu	za029065	30.83		ENDF/B-VII.0
66Cu	za029066	0		New Eval
67Cu	za029067	0		New Eval
68Cu	za029068	0		New Eval
natZn	za030000		Y	
62Zn	za030062	0		New Eval
63Zn	za030063	0		New Eval
64Zn	za030064	48.63		New Eval
65Zn	za030065	0		New Eval
66Zn	za030066	27.9		New Eval
67Zn	za030067	4.1		New Eval
68Zn	za030068	18.75		New Eval
69Zn	za030069	0		New Eval
70Zn	za030070	0.62		New Eval
71Zn	za030071	0		New Eval
72Zn	za030072	0		New Eval
73Zn	za030073	0		New Eval
natGa	za031000		Y	
68Ga	za031068	0		New Eval
69Ga	za031069	60.108		ENDF/B-VII.0
70Ga	za031070	0		New Eval
71Ga	za031071	39.892		ENDF/B-VII.0
72Ga	za031072	0		New Eval
natGe	za032000			N/A

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
70Ge	za032070	20.37		ENDF/B-VII.0
71Ge	za032071	0		N/A
72Ge	za032072	27.31		ENDF/B-VII.0
73Ge	za032073	7.76		ENDF/B-VII.0
74Ge	za032074	36.73		ENDF/B-VII.0
75Ge	za032075	0		N/A
76Ge	za032076	7.83		ENDF/B-VII.0
natAs	za033000			N/A
73As	za033073	0		New Eval
74As	za033074	0	Y	ENDF/B-VII.0
75As	za033075	100	Y	ENDF/B-VII.0
natSe	za034000			N/A
74Se	za034074	0.89		ENDF/B-VII.0
75Se	za034075	0		H. RadChem
76Se	za034076	9.37		ENDF/B-VII.0
77Se	za034077	7.63		ENDF/B-VII.0
78Se	za034078	23.77		ENDF/B-VII.0
79Se	za034079	0		ENDF/B-VII.0
80Se	za034080	49.61		ENDF/B-VII.0
81Se	za034081	0		H. RadChem
82Se	za034082	8.73		ENDF/B-VII.0
natBr	za035000			N/A
75Br	za035075	0		H. RadChem
76Br	za035076	0		H. RadChem
77Br	za035077	0		H. RadChem
78Br	za035078	0		H. RadChem
79Br	za035079	50.69		ENDF/B-VII.0
80Br	za035080	0		H. RadChem
81Br	za035081	49.31		ENDF/B-VII.0
82Br	za035082	0		H. RadChem
natKr	za036000			N/A
76Kr	za036076	0		H. RadChem
77Kr	za036077	0		H. RadChem
78Kr	za036078	0.35		New Eval
79Kr	za036079	0		H. RadChem
80Kr	za036080	2.28		ENDF/B-VII.0
81Kr	za036081	0		H. RadChem
82Kr	za036082	11.58		ENDF/B-VII.0
83Kr	za036083	11.49		ENDF/B-VII.0
84Kr	za036084	57		ENDF/B-VII.0
85Kr	za036085	0		ENDF/B-VII.0
86Kr	za036086	17.3		ENDF/B-VII.0
natRb	za037000			N/A
77Rb	za037077	0		H. RadChem

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
78Rb	za037078	0		H. RadChem
79Rb	za037079	0		H. RadChem
80Rb	za037080	0		H. RadChem
81Rb	za037081	0		H. RadChem
82Rb	za037082	0		H. RadChem
83Rb	za037083	0		H. RadChem
84Rb	za037084	0		H. RadChem
85Rb	za037085	72.17		ENDF/B-VII.0
86Rb	za037086	0		ENDF/B-VII.0
87Rb	za037087	27.83		ENDF/B-VII.0
natSr	za038000			N/A
84Sr	za038084	0.56		ENDF/B-VII.0
85Sr	za038085	0		N/A
86Sr	za038086	9.86		ENDF/B-VII.0
87Sr	za038087	7		ENDF/B-VII.0
88Sr	za038088	82.58		ENDF/B-VII.0
89Sr	za038089	0		ENDF/B-VII.0
90Sr	za038090	0		ENDF/B-VII.0
natY	za039000			N/A
86Y	za039086	0		N/A
87Y	za039087	0		N/A
88Y	za039088	0	Y	ENDL99
89Y	za039089	100	Y	ENDF/B-VII.0
90Y	za039090	0		ENDF/B-VII.0
91Y	za039091	0		ENDF/B-VII.0
92Y	za039092	0		N/A
natZr	za040000		Y	
87Zr	za040087	0		N/A
88Zr	za040088	0		N/A
89Zr	za040089	0		N/A
90Zr	za040090	51.45		ENDF/B-VII.0
91Zr	za040091	11.22		ENDF/B-VII.0
92Zr	za040092	17.15		ENDF/B-VII.0
93Zr	za040093	0		ENDF/B-VII.0
94Zr	za040094	17.38		ENDF/B-VII.0
95Zr	za040095	0		ENDF/B-VII.0
96Zr	za040096	2.8		ENDF/B-VII.0
natNb	za041000			N/A
91Nb	za041091	0		N/A
92Nb	za041092	0		N/A
93Nb	za041093	100	Y	ENDF/B-VII.0
94Nb	za041094	0		ENDF/B-VII.0
95Nb	za041095	0		ENDF/B-VII.0
natMo	za042000		Y	

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
91Mo	za042091	0		N/A
92Mo	za042092	14.84		ENDF/B-VII.0
93Mo	za042093	0		N/A
94Mo	za042094	9.25		ENDF/B-VII.0
95Mo	za042095	15.92		ENDF/B-VII.0
96Mo	za042096	16.68		ENDF/B-VII.0
97Mo	za042097	9.55		ENDF/B-VII.0
98Mo	za042098	24.13		ENDF/B-VII.0
99Mo	za042099	0		ENDF/B-VII.0
100Mo	za042100	9.63		ENDF/B-VII.0
natTc	za043000			N/A
99Tc	za043099	0		JEFF-3.1
natRu	za044000			N/A
96Ru	za044096	5.54		ENDF/B-VII.0
97Ru	za044097	0		N/A
98Ru	za044098	1.87		ENDF/B-VII.0
99Ru	za044099	12.76		ENDF/B-VII.0
100Ru	za044100	12.6		ENDF/B-VII.0
101Ru	za044101	17.06		ENDF/B-VII.0
102Ru	za044102	31.55		ENDF/B-VII.0
103Ru	za044103	0		ENDF/B-VII.0
104Ru	za044104	18.62		ENDF/B-VII.0
105Ru	za044105	0		ENDF/B-VII.0
106Ru	za044106	0		ENDF/B-VII.0
natRh	za045000			N/A
103Rh	za045103	100		JEFF-3.1
104Rh	za045104	0		N/A
105Rh	za045105	0		ENDF/B-VII.0
natPd	za046000			N/A
102Pd	za046102	1.02		JENDL-3.3
103Pd	za046103	0		N/A
104Pd	za046104	11.14		ENDF/B-VII.0
105Pd	za046105	23.33		ENDF/B-VII.0
106Pd	za046106	27.33		ENDF/B-VII.0
107Pd	za046107	0		ENDF/B-VII.0
108Pd	za046108	26.46		ENDF/B-VII.0
109Pd	za046109	0		N/A
110Pd	za046110	11.72		ENDF/B-VII.0
natAg	za047000			N/A
107Ag	za047107	51.839	Y	ENDF/B-VII.0
108Ag	za047108	0		N/A
109Ag	za047109	48.161	Y	ENDF/B-VII.0
110Ag	za047110	0		N/A
111Ag	za047111	0		ENDF/B-VII.0

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
natCd	za048000		Y	
106Cd	za048106	1.25		ENDF/B-VII.0
107Cd	za048107	0		N/A
108Cd	za048108	0.89		ENDF/B-VII.0
109Cd	za048109	0		N/A
110Cd	za048110	12.49		JENDL-3.3
111Cd	za048111	12.8		ENDF/B-VII.0
112Cd	za048112	24.13		ENDF/B-VII.0
113Cd	za048113	12.22		ENDF/B-VII.0
114Cd	za048114	28.73		ENDF/B-VII.0
115Cd	za048115	0		N/A
116Cd	za048116	7.49		ENDF/B-VII.0
natIn	za049000		Y	
113In	za049113	4.29		ENDF/B-VII.0
114In	za049114	0		N/A
115In	za049115	95.71		ENDF/B-VII.0
natSn	za050000		Y	
112Sn	za050112	0.97		ENDF/B-VII.0
113Sn	za050113	0		ENDF/B-VII.0
114Sn	za050114	0.66		ENDF/B-VII.0
115Sn	za050115	0.34		ENDF/B-VII.0
116Sn	za050116	14.54		ENDF/B-VII.0
117Sn	za050117	7.68		ENDF/B-VII.0
118Sn	za050118	24.22		ENDF/B-VII.0
119Sn	za050119	8.59		ENDF/B-VII.0
120Sn	za050120	32.58		ENDF/B-VII.0
121Sn	za050121	0		N/A
122Sn	za050122	4.63		ENDF/B-VII.0
123Sn	za050123	0		ENDF/B-VII.0
124Sn	za050124	5.79		ENDF/B-VII.0
125Sn	za050125	0		ENDF/B-VII.0
126Sn	za050126	0		ENDF/B-VII.0
natSb	za051000		Y	
121Sb	za051121	57.21		ENDF/B-VII.0
122Sb	za051122	0		N/A
123Sb	za051123	42.79		ENDF/B-VII.0
124Sb	za051124	0		ENDF/B-VII.0
125Sb	za051125	0		ENDF/B-VII.0
126Sb	za051126	0		ENDF/B-VII.0
natTe	za052000			N/A
120Te	za052120	0.09		ENDF/B-VII.0
121Te	za052121	0		N/A
122Te	za052122	2.55		ENDF/B-VII.0
123Te	za052123	0.89		ENDF/B-VII.0

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
124Te	za052124	4.74		ENDF/B-VII.0
125Te	za052125	7.07		ENDF/B-VII.0
126Te	za052126	18.84		ENDF/B-VII.0
127Te	za052127	0		H. RadChem
128Te	za052128	31.74		ENDF/B-VII.0
129Te	za052129	0		N/A
130Te	za052130	34.08		ENDF/B-VII.0
131Te	za052131	0		N/A
132Te	za052132	0		ENDF/B-VII.0
natI	za053000			N/A
124I	za053124	0		H. RadChem
125I	za053125	0		H. RadChem
126I	za053126	0		H. RadChem
127I	za053127	100	Y	ENDF/B-VII.0
128I	za053128	0		H. RadChem
129I	za053129	0		ENDF/B-VII.0
130I	za053130	0		ENDF/B-VII.0
131I	za053131	0		ENDF/B-VII.0
132I	za053132	0		N/A
133I	za053133	0		N/A
134I	za053134	0		N/A
135I	za053135	0		ENDF/B-VII.0
natXe	za054000		Y	
123Xe	za054123	0		ENDF/B-VII.0
124Xe	za054124	0.095		ENDF/B-VII.0
125Xe	za054125	0		H. RadChem
126Xe	za054126	0.089		ENDF/B-VII.0
127Xe	za054127	0		H. RadChem
128Xe	za054128	1.91		ENDF/B-VII.0
129Xe	za054129	26.4		ENDF/B-VII.0
130Xe	za054130	4.071		JENDL-3.3
131Xe	za054131	21.232		ENDF/B-VII.0
132Xe	za054132	26.909		ENDF/B-VII.0
133Xe	za054133	0		ENDF/B-VII.0
134Xe	za054134	10.436	Y	ENDF/B-VII.0
135Xe	za054135	0		ENDF/B-VII.0
136Xe	za054136	8.857		ENDF/B-VII.0
natCs	za055000			N/A
133Cs	za055133	100		ENDF/B-VII.0
134Cs	za055134	0		ENDF/B-VII.0
135Cs	za055135	0		ENDF/B-VII.0
136Cs	za055136	0		ENDF/B-VII.0
137Cs	za055137	0		ENDF/B-VII.0
natBa	za056000			N/A

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
130Ba	za056130	0.106		ENDF/B-VII.0
131Ba	za056131	0		N/A
132Ba	za056132	0.101		ENDF/B-VII.0
133Ba	za056133	0		ENDF/B-VII.0
134Ba	za056134	2.417		ENDF/B-VII.0
135Ba	za056135	6.592		ENDF/B-VII.0
136Ba	za056136	7.854		ENDF/B-VII.0
137Ba	za056137	11.232		ENDF/B-VII.0
138Ba	za056138	71.698	Y	ENDF/B-VII.0
139Ba	za056139	0		N/A
140Ba	za056140	0		JENDL-3.3
natLa	za057000			N/A
138La	za057138	0.09		ENDF/B-VII.0
139La	za057139	99.91		ENDF/B-VII.0
140La	za057140	0		ENDF/B-VII.0
natCe	za058000			N/A
136Ce	za058136	0.185		ENDF/B-VII.0
137Ce	za058137	0		N/A
138Ce	za058138	0.251		ENDF/B-VII.0
139Ce	za058139	0		ENDF/B-VII.0
140Ce	za058140	88.45		ENDF/B-VII.0
141Ce	za058141	0		ENDF/B-VII.0
142Ce	za058142	11.114		ENDF/B-VII.0
143Ce	za058143	0		ENDF/B-VII.0
144Ce	za058144	0		ENDF/B-VII.0
natPr	za059000			N/A
141Pr	za059141	100		ENDF/B-VII.0
142Pr	za059142	0		ENDF/B-VII.0
143Pr	za059143	0		ENDF/B-VII.0
natNd	za060000			N/A
142Nd	za060142	27.2		ENDF/B-VII.0
143Nd	za060143	12.2		ENDF/B-VII.0
144Nd	za060144	23.8		ENDF/B-VII.0
145Nd	za060145	8.3		ENDF/B-VII.0
146Nd	za060146	17.2		ENDF/B-VII.0
147Nd	za060147	0		ENDF/B-VII.0
148Nd	za060148	5.7		ENDF/B-VII.0
149Nd	za060149	0		N/A
150Nd	za060150	5.6		ENDF/B-VII.0
natPm	za061000			N/A
147Pm	za061147			ENDF/B-VII.0
148Pm	za061148			ENDF/B-VII.0
149Pm	za061149			ENDF/B-VII.0
150Pm	za061150			N/A

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
151Pm	za061151			ENDF/B-VII.0
natSm	za062000			N/A
144Sm	za062144	3.07		ENDF/B-VII.0
145Sm	za062145	0		N/A
146Sm	za062146	0		N/A
147Sm	za062147	14.99		ENDF/B-VII.0
148Sm	za062148	11.24		ENDF/B-VII.0
149Sm	za062149	13.82		ENDF/B-VII.0
150Sm	za062150	7.38		ENDF/B-VII.0
151Sm	za062151	0		ENDF/B-VII.0
152Sm	za062152	26.75		ENDF/B-VII.0
153Sm	za062153	0		ENDF/B-VII.0
154Sm	za062154	22.75		ENDF/B-VII.0
155Sm	za062155	0		N/A
natEu	za063000		Y	
145Eu	za063145	0		N/A
146Eu	za063146	0		N/A
147Eu	za063147	0		N/A
148Eu	za063148	0		N/A
149Eu	za063149	0		N/A
150Eu	za063150	0		N/A
151Eu	za063151	47.81		ENDF/B-VII.0
152Eu	za063152	0		ENDF/B-VII.0
153Eu	za063153	52.19		ENDF/B-VII.0
154Eu	za063154	0		ENDF/B-VII.0
155Eu	za063155	0		ENDF/B-VII.0
156Eu	za063156	0		ENDF/B-VII.0
157Eu	za063157	0		ENDF/B-VII.0
natGd	za064000		Y	
146Gd	za064146	0		N/A
147Gd	za064147	0		N/A
148Gd	za064148	0		N/A
149Gd	za064149	0		N/A
150Gd	za064150	0		N/A
151Gd	za064151	0		N/A
152Gd	za064152	0.2		ENDF/B-VII.0
153Gd	za064153	0		ENDF/B-VII.0
154Gd	za064154	2.18		ENDF/B-VII.0
155Gd	za064155	14.8		ENDF/B-VII.0
156Gd	za064156	20.47		ENDF/B-VII.0
157Gd	za064157	15.65		ENDF/B-VII.0
158Gd	za064158	24.84		ENDF/B-VII.0
159Gd	za064159	0		N/A
160Gd	za064160	21.86		ENDF/B-VII.0

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
natTb	za065000			N/A
159Tb	za065159	100		ENDF/B-VII.0
160Tb	za065160	0		ENDF/B-VII.0
natDy	za066000			N/A
156Dy	za066156	0.06		ENDF/B-VII.0
157Dy	za066157	0		N/A
158Dy	za066158	0.1		ENDF/B-VII.0
159Dy	za066159	0		N/A
160Dy	za066160	2.34		ENDF/B-VII.0
161Dy	za066161	18.91		ENDF/B-VII.0
162Dy	za066162	25.51		ENDF/B-VII.0
163Dy	za066163	24.9		ENDF/B-VII.0
164Dy	za066164	28.18		ENDF/B-VII.0
natHo	za067000			N/A
165Ho	za067165	100	Y	ENDF/B-VII.0
166Ho	za067166	0		N/A
natEr	za068000			N/A
162Er	za068162	0.139		ENDF/B-VII.0
163Er	za068163	0		N/A
164Er	za068164	1.601		ENDF/B-VII.0
165Er	za068165	0		N/A
166Er	za068166	33.503		ENDF/B-VII.0
167Er	za068167	22.869		ENDF/B-VII.0
168Er	za068168	26.978		ENDF/B-VII.0
169Er	za068169	0		N/A
170Er	za068170	14.91		ENDF/B-VII.0
natTm	za069000			N/A
166Tm	za069166	0		N/A
167Tm	za069167	0		N/A
168Tm	za069168	0		N/A
169Tm	za069169	100		N/A
170Tm	za069170	0		N/A
171Tm	za069171	0		N/A
172Tm	za069172	0		N/A
173Tm	za069173	0		N/A
natYb	za070000			N/A
168Yb	za070168	0.13		N/A
169Yb	za070169	0		N/A
170Yb	za070170	3.04		N/A
171Yb	za070171	14.28		N/A
172Yb	za070172	21.83		N/A
173Yb	za070173	16.13		N/A
174Yb	za070174	31.83		N/A
175Yb	za070175	0		N/A

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
176Yb	za070176	12.76		N/A
natLu	za071000			N/A
170Lu	za071170	0		N/A
171Lu	za071171	0		N/A
172Lu	za071172	0		N/A
173Lu	za071173	0		N/A
174Lu	za071174	0		N/A
175Lu	za071175	97.41		ENDF/B-VII.0
176Lu	za071176	2.59		ENDF/B-VII.0
177Lu	za071177	0		N/A
178Lu	za071178	0		N/A
179Lu	za071179	0		N/A
natHf	za072000		Y	
174Hf	za072174	0.16		JEFF-3.1
175Hf	za072175	0		N/A
176Hf	za072176	5.26		JEFF-3.1
177Hf	za072177	18.6		JEFF-3.1
178Hf	za072178	27.28		JEFF-3.1
179Hf	za072179	13.62		JEFF-3.1
180Hf	za072180	35.08		JEFF-3.1
natTa	za073000			N/A
179Ta	za073179	0		N/A
180Ta	za073180	0.012		N/A
181Ta	za073181	99.988	Y	JEFF-3.1
182Ta	za073182	0		ENDF/B-VII.0
183Ta	za073183	0		N/A
184Ta	za073184	0		N/A
natW	za074000		Y	
179W	za074179	0		N/A
180W	za074180	0.12		N/A
181W	za074181	0		N/A
182W	za074182	26.5		ENDF/B-VII.0
183W	za074183	14.31		ENDF/B-VII.0
184W	za074184	30.64		ENDF/B-VII.0
185W	za074185	0		N/A
186W	za074186	28.43		ENDF/B-VII.0
187W	za074187	0		N/A
natRe	za075000			N/A
185Re	za075185	37.4	Y	ENDF/B-VII.0
186Re	za075186	0		N/A
187Re	za075187	62.6	Y	ENDF/B-VII.0
natOs	za076000			JEFF-3.1
184Os	za076184	0.02		N/A
185Os	za076185	0		N/A

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
186Os	za076186	1.59		N/A
187Os	za076187	1.6		N/A
188Os	za076188	13.29		N/A
189Os	za076189	16.21		N/A
190Os	za076190	26.36		N/A
191Os	za076191	0		N/A
192Os	za076192	40.93		N/A
natIr	za077000			N/A
187Ir	za077187	0		N/A
188Ir	za077188	0		N/A
189Ir	za077189	0		N/A
190Ir	za077190	0		N/A
191Ir	za077191	37.3		ENDF/B-VII.0
192Ir	za077192	0		N/A
193Ir	za077193	62.7		ENDF/B-VII.0
194Ir	za077194	0		N/A
195Ir	za077195	0		N/A
natPt	za078000		Y	JEFF-3.1
192Pt	za078192	0.782		N/A
193Pt	za078193	0		N/A
194Pt	za078194	32.967		N/A
195Pt	za078195	33.832		N/A
196Pt	za078196	25.242		N/A
197Pt	za078197	0		N/A
198Pt	za078198	7.163		N/A
natAu	za079000			N/A
193Au	za079193	0		N/A
194Au	za079194	0		N/A
195Au	za079195	0		N/A
196Au	za079196	0		N/A
197Au	za079197	100	Y	ENDF/B-VII.0
198Au	za079198	0		N/A
199Au	za079199	0		N/A
natHg	za080000		Y	N/A
196Hg	za080196	0.15		ENDF/B-VII.0
197Hg	za080197	0		N/A
198Hg	za080198	9.97		ENDF/B-VII.0
199Hg	za080199	16.87		ENDF/B-VII.0
200Hg	za080200	23.1		ENDF/B-VII.0
201Hg	za080201	13.18		ENDF/B-VII.0
202Hg	za080202	29.86		ENDF/B-VII.0
203Hg	za080203	0		N/A
204Hg	za080204	6.87		ENDF/B-VII.0
natTl	za081000		FALSE	JEFF-3.1

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
203Tl	za081203	29.524		N/A
204Tl	za081204	0		N/A
205Tl	za081205	70.476		N/A
natPb	za082000		Y	
203Pb	za082203	0		N/A
204Pb	za082204	1.4		ENDF/B-VII.0
205Pb	za082205	0		N/A
206Pb	za082206	24.1		ENDF/B-VII.0
207Pb	za082207	22.1		ENDF/B-VII.0
208Pb	za082208	52.4		ENDF/B-VII.0
209Pb	za082209	0		N/A
210Pb	za082210	0		N/A
natBi	za083000			N/A
204Bi	za083204	0		N/A
205Bi	za083205	0		N/A
206Bi	za083206	0		N/A
207Bi	za083207	0		N/A
208Bi	za083208	0		N/A
209Bi	za083209	100	Y	JEFF-3.1
210Bi	za083210	0		N/A
natPo	za084000			N/A
natAt	za085000			N/A
natRn	za086000			N/A
natFr	za087000			N/A
natRa	za088000			N/A
223Ra	za088223			ENDF/B-VII.0
224Ra	za088224			ENDF/B-VII.0
225Ra	za088225			ENDF/B-VII.0
226Ra	za088226			ENDF/B-VII.0
natAc	za089000			N/A
225Ac	za089225			JENDL-AC
226Ac	za089226			JENDL-AC
227Ac	za089227			JENDL-AC
natTh	za090000			N/A
227Th	za090227	0		JENDL-AC
228Th	za090228	0		JENDL-AC
229Th	za090229	0		JENDL-AC
230Th	za090230	0		JENDL-AC
231Th	za090231	0	Y	JENDL-AC
232Th	za090232	100	Y	ENDF/B-VII.0
233Th	za090233	0	Y	ENDF/B-VII.0
234Th	za090234	0		JENDL-AC
natPa	za091000			N/A
229Pa	za091229			JENDL-AC

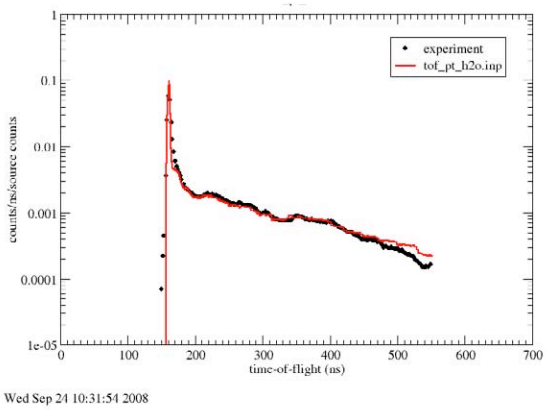
Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
230Pa	za091230			JENDL-AC
231Pa	za091231			JENDL-AC
232Pa	za091232			JENDL-AC
233Pa	za091233		Y	ENDF/B-VII.0
natU	za092000			N/A
230U	za092230	0		JENDL-AC
231U	za092231	0		JENDL-AC
232U	za092232	0		ENDF/B-VII.0
233U	za092233	0	Y	ENDF/B-VII.0
234U	za092234	0.0054	Y	ENDF/B-VII.0
235U	za092235	0.7204	Y	ENDF/B-VII.0
236U	za092236	0	Y	ENDF/B-VII.0
237U	za092237	0	Y	New Eval
238U	za092238	99.2742	Y	ENDF/B-VII.0
239U	za092239	0	Y	ENDF/B-VII.0
240U	za092240	0	Y	ENDF/B-VII.0
241U	za092241	0		ENDF/B-VII.0
natNp	za093000			N/A
234Np	za093234			JENDL-AC
235Np	za093235		Y	JENDL-AC
236Np	za093236		Y	JENDL-AC
237Np	za093237		Y	JENDL-AC
238Np	za093238		Y	JENDL-AC
239Np	za093239			JENDL-AC
natPu	za094000			N/A
236Pu	za094236			JENDL-AC
237Pu	za094237		Y	JENDL-AC
238Pu	za094238		Y	JENDL-AC
239Pu	za094239		Y	ENDF/B-VII.0
240Pu	za094240		Y	JENDL-AC
241Pu	za094241		Y	JENDL-AC
242Pu	za094242		Y	JENDL-AC
243Pu	za094243		Y	N/A
244Pu	za094244			JENDL-AC
245Pu	za094245			N/A
246Pu	za094246			JENDL-AC
natAm	za095000			N/A
240Am	za095240			New Eval
241Am	za095241		Y	ENDF/B-VII.0
242Am	za095242			ENDF/B-VII.0

Symbol	za	Natural abund. (%)	ENDL99 isotope	Evaluation source
243Am	za095243		Y	ENDF/B-VII.0
244Am	za095244			ENDF/B-VII.0
natCm	za096000			N/A
240Cm	za096240			JENDL-AC
241Cm	za096241			JENDL-AC
242Cm	za096242		Y	JENDL-AC
243Cm	za096243		Y	JENDL-AC
244Cm	za096244		Y	JENDL-AC
245Cm	za096245		Y	JENDL-AC
246Cm	za096246		Y	JENDL-AC
247Cm	za096247		Y	JENDL-AC
248Cm	za096248		Y	JENDL-AC
249Cm	za096249			JENDL-AC
250Cm	za096250			JENDL-AC
natBk	za097000			N/A
245Bk	za097245			JENDL-AC
246Bk	za097246			JENDL-AC
247Bk	za097247			JENDL-AC
248Bk	za097248			JENDL-AC
249Bk	za097249		Y	JENDL-AC
250Bk	za097250			JENDL-AC
natCf	za098000			N/A
246Cf	za098246			JENDL-AC
247Cf	za098247			N/A
248Cf	za098248			JENDL-AC
249Cf	za098249		Y	JENDL-AC
250Cf	za098250		Y	JENDL-AC
251Cf	za098251		Y	JENDL-AC
252Cf	za098252		Y	JENDL-AC
253Cf	za098253			JENDL-AC
254Cf	za098254			JENDL-AC
natEs	za099000			N/A
FF	za099120		Y	ENDL99
FF	za099121			ENDL99
FF	za099122			ENDL99
FF	za099125		Y	ENDL99
253Es	za099253			N/A
254Es	za099254			N/A
255Es	za099255			N/A

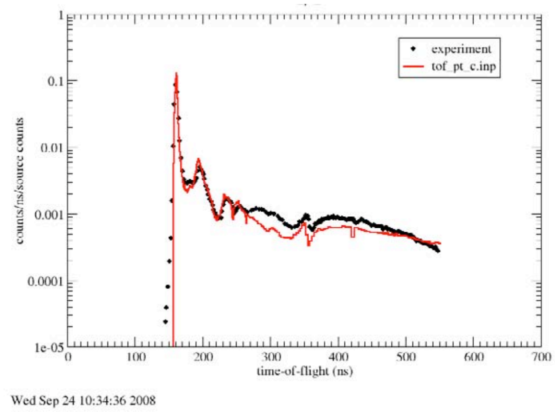
Appendix B: `Mercury` TOF simulations for ENDL2008.β3

The LLNL pulsed-sphere experiments are fusion-shielding benchmarks commonly used to test cross section evaluations. ENDL2008 was tested against 13 experiments/materials (H_2O, natural C, N_2, teflon, Al, Si, Ti, Fe, Cu, Ta, W, Au, and ^{232}Th) with `Mercury`. The results are compared to LLNL pulsed-sphere neutron time-of-flight (TOF) measurements [Goldberg 1990].

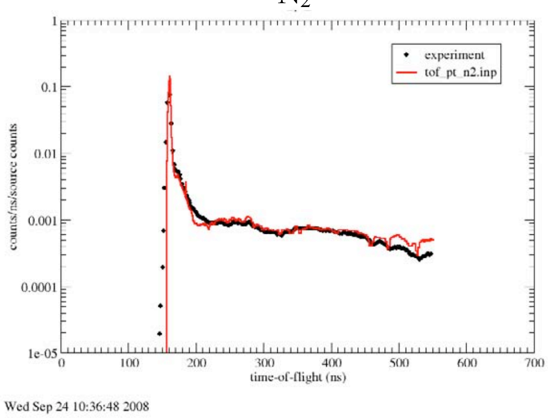
H_20



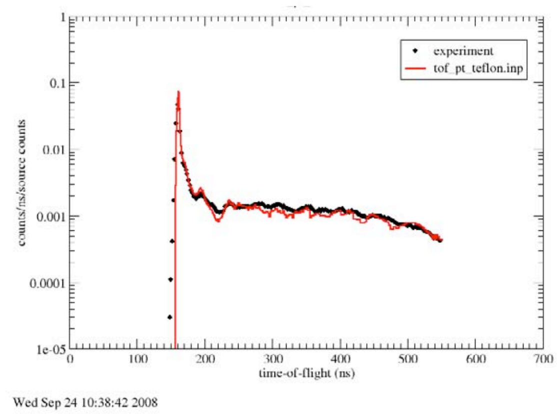
Natural C



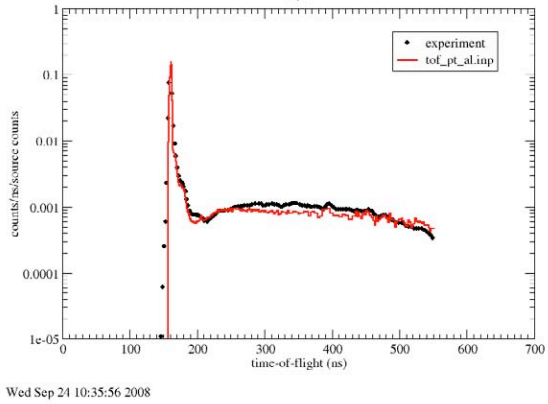
N_2



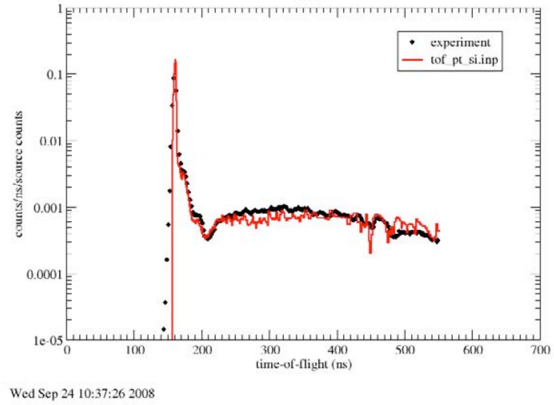
Teflon



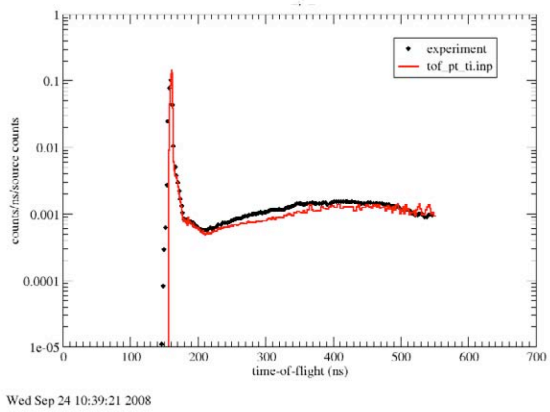
Al



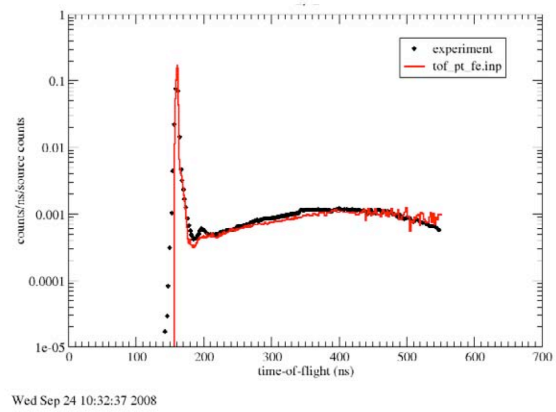
Si



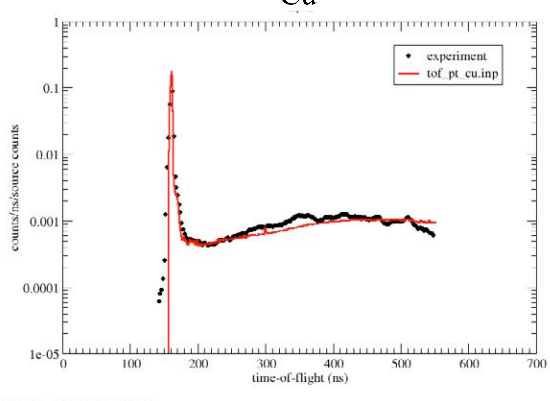
Ti



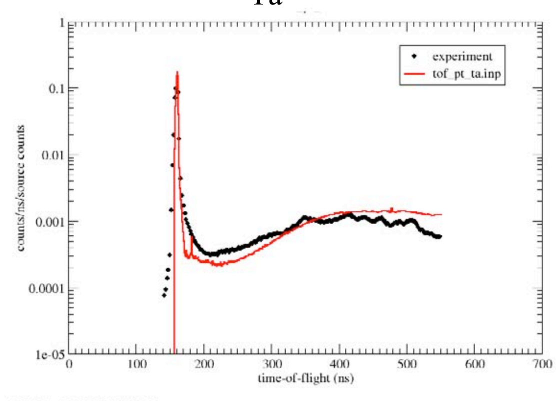
Fe



Cu

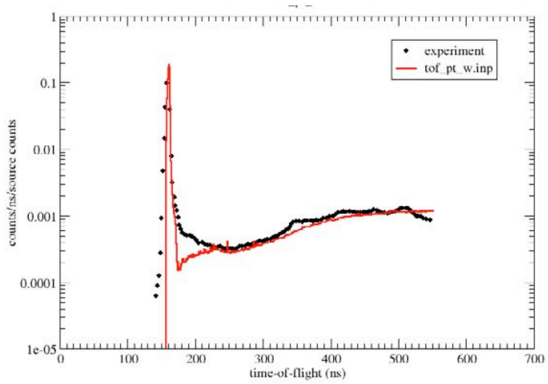


Ta

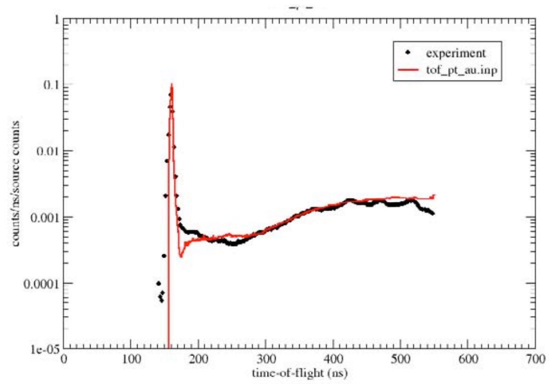


W

Au

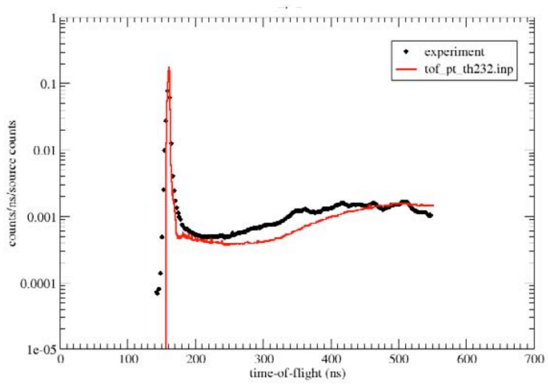


Wed Sep 24 10:39:57 2008



Wed Sep 24 10:35:14 2008

^{232}Th



Wed Sep 24 10:54:17 2008

Appendix C: Tools Used to Develop ENDL2008

To assemble ENDL2008, we developed and used a variety of tools. In addition to the Hauser-Feshbach reaction codes `TALYS` [TALYS 2007] and `STAPRE` [STAPRE 1976] and the ENDF format translator `fete` [Fete 2006], we used the `fudge` code framework [Beck 2008] to prepare the evaluations. All of these tools are described elsewhere. In this section, we will describe the two new tools used to develop ENDL2008: `geft` [Summers 2008] and `endl2endf` [Brown 2008b].

`geft` [Summers 2008] is a set of `Python` scripts that can be used to create evaluations using the reaction code `TALYS` [TALYS 2007]. The scripts can create input files for `TALYS`, run `TALYS` and parse the output files and convert them into ENDL formatted files with the help of `fudge` [Beck 2008]. These scripts can also be used in conjunction with `pyMPI` [Miller 2002], so that multiple `TALYS` runs may be performed in parallel on Livermore Computing. The following ENDL **I** files are constructed from the `TALYS` output: total cross sections; elastic cross sections and angular distributions (**I=1**); cross sections for all outgoing channels; outgoing particle spectra for the channel cross sections (**I=4)** files, assuming $L=0$ isotropic distributions; gamma multiplicities (**I=9**), and gamma distributions (**I=4,** files containing both continuum and discrete gammas).

`endl2endf` [Brown 2008b] is a second set of `Python` scripts which are used to assemble final ENDF-formatted evaluations from ENDL-formatted data. Since LLNL processing codes require data in the ENDL format, this might appear not to be a very useful. However, the ENDL format has no provision for the ENDF resonance data. To include resonances in ENDL, these data must be expanded into point-wise cross section tables. In many cases, we found that we needed to merge the resonance region from one evaluation into another, a difficult task to do properly with point-wise tables. In these cases, it was often easier to read the ENDF evaluations into `endl2endf` and recombine sections of different ENDF evaluations before translating them into the ENDL format.

Appendix D: Errata (ENDL2008.1 and ENDL2008.2 bug-fix releases)

Here we list all of the issues resolved in the endl2008.1 and endl2008.2 releases. These issues are logged in the ENDL project on LLNL's sourceforge server https://sourceforge.llnl.gov/sf/projects/endl.

ENDL2008.1

Artifact ID	Title	Description	Fixed in Release	Submitter
artf11083	Unphysical gamma multiplicity for 48Ti	Gamma multiplicity is greater than 100	1	David Brown
artf11084	Missing Q(E) in all actinides	Q(E) is not present in any actinide evaluation	1	Ramona Vogt
artf11085	232Th: nubar set to 1	nubar should be bigger!	1	Ramona Vogt
artf11086	233Pa: nubar set to 1	nubar should be bigger than 1!	1	Ramona Vogt
artf11090	d(n,2n) off by factor of 2	Outgoing neutron multiplicity 2x too high; extra outgoing particle distributions	1	George Zimmerman

ENDL2008.2

Artifact ID	Title	Description	Fixed in Release	Submitter
artf10954	Natural elements having outgoing particles with only I = 1 data	The following is a list of natural element, channel and outgoing particle for which there is only I = 1 data: ZA C yo 23000 41 3 23000 42 4 76000 40 2 76000 45 6 81000 40 2 81000 41 3 81000 42 4 81000 45 6	2	Bret Beck
artf11051	Unphysical gamma multiplicity for 41Sc	Gamma multiplicity is greater than 100	2	Frank Daffin
artf11050	Unphysical gamma multiplicity for 103Rh	Gamma multiplicity is greater than 100	2	Frank Daffin

artf11049	Unphysical gamma multiplicity for 125Sn	Gamma multiplicity is greater than 100	2	Frank Daffin
artf11030	11B has way too many outgoing particle distributions	Somehow there are I=1+3 and I=4 data for several outgoing particles in several channels: C = 11, yo = 1; C = 12, yo = 1; C = 40, yo = 2; C = 45, yo = 45.	2	Bret Beck
artf11029	73As has no data below 80 keV	Evaluation was default EMPIRE run & so has no resonance data. We thought it was OK since access routines extrapolate from 80 keV on down. However, relying on a behavior of the access routines is what got us in trouble before...	2	Jason Pruet
artf10951	70Zn(n,t) missing outgoing t distributions	Has I=0 S=0, but no outgoing distributions	2	David Brown
artf10949	63Ni(n,t) has no t distribution	Has I=0 S=0, but no outgoing distributions	2	David Brown
artf10953	72Ga(n,t) missing outgoing t distributions	Has I=0 S=0, but no outgoing distributions	2	David Brown
artf10952	71Zn(n,t) missing outgoing t distributions	Has I=0 S=0, but no outgoing distributions	2	David Brown
artf10950	66Cu(n,t) missing outgoing t distributions	Has I=0 S=0, but no outgoing distributions	2	David Brown
artf10948	61Co(n,t) missing t distribution	Has I=0 S=0, but no outgoing distributions	2	David Brown
artf10733	7Be: extra S=0, C=45 file	za004007 has an S = 0 and S = 1 for C = 45. The S = 0 is the same as in endl99, so this should have been deleted and replaced with the S = 1.	2	Bret Beck
artf10702	240Am gamma multiplicities messed up	Major set of bugs in fete, endl2endf and talys ensure that the gammas in 240Am are totally nuts.	2	David Brown

artf10690	240Am capture, fission set to zero below 0.4 MeV	The capture and fission for Am240 is currently set to zero below 40 keV.	2	Jason Pruet
artf10689	11B(n,t) missing outgoing t distributions	11B(n,t) S=0 has I=1 triton distribution, but needs either I=3 or 4. MCFGEN assigns a kintype 0 in this case.	2	Chris Hagmanm
artf11087	Missing energy depositions	There are no energy depositions in the processed mcf files	2	Jason Pruet
artf11088	Wrong bdfls file was used in processing	Used the wrong bdfls file in generating mcf file	2	David Brown
artf11091	t: header mismatch	Header mismatch in diff files	2	David Brown
artf11092	7Be: header mismatch	Header mismatch in diff files	2	David Brown
artf11093	103Rh: mu grid mismatch	I = 1 & 3 files didn't have same mu's	2	Bret Beck
artf11094	27Al: mu grid mismatch	I = 1 & 3 files didn't have same mu's	2	Bret Beck

Appendix E: Known Issues

Here we list all of the known issues in the endl2008.2 release. These issues are logged in the ENDL project on LLNL's sourceforge server https://sourceforge.llnl.gov/sf/projects/endl.

Artifact ID	Title	Description	Submitter
artf1105	12C has old gamma data	12C has old gamma data and needs to be updated	David Brown
artf10901	1H: total cross section not equal to the sum of the partial cross sections	The problem appears to be partially an artifact of interpolation. The elastic cross-section does not have many points at the total and neither the total nor elastic cross-sections have near as many points at the capture. In between interpolation points one can expect large differences in this case.	Ed Lent
artf10691	58Co missing resonances	58Co missing resonances	David Brown
artf10692	59Co missing resonances	59Co missing resonances	David Brown
artf10693	60Co missing resonances	60Co missing resonances	David Brown
artf10734	6Li: S=0→S=1 reassignment	The isotopes za002003 and za003006 should have the offending S = 0 data/files converted to S = 1.	Bret Beck
artf10735	3He: S=0→S=1 reassignment	The isotopes za002003 and za003006 should have the offending S = 0 data/files converted to S = 1.	Bret Beck
artf10910	n: xs not heated	neutron cross-section wasn't heated	George Zimmerman
artf10916	Too much energy deposition for capture on 98254	The energy deposition for gammas in the capture reaction on 98254 (i.e., n + ^{254}Cf → g + ^{255}Cf) produce too much energy. For example, the E = 10e-11, the total gamma energy should be 4.6 MeV, while it is 2.361 MeV = 5.129 * 4.6 MeV as the multiplicity is 5.129.	Bret Beck
artf10918	Too much energy deposition for capture on 96250	This is like the za098254 gamma energy problem (maybe too much multiplicity), but there also seems to be a problem with the gamma I = 4 distribution. For example, the following E, E' data calculated from the I = 4 (i.e., multiplicity = 1), shows a jump up and then back down in E' as E increases.	Bret Beck
artf11035	232Th (n,f) xs and Q(E) are inconsistent	The xs 1st starts being non-zero at 4e-3 MeV while Q(E) is non-zero all the way down to 1e-11 MeV. Affects group collapses in MCAPM.	Chris Hagmann
artf11074	75As (n,tot) grid doesn't have enough energy points	The total cross section (MF3 MT1) does not contain enough energy points. This section should have all energy points appeared in each partial cross sections, such as the threshold energies. (note: effects ENDF file, not ENDL files in use at LLNL)	Toshihiko Kawano

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