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Data Evaluation of Actinide Cross Sections: 238Pu, 237Pu, and 236Pu

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Introduction

This report documents the recent evaluation of the ^{236}Pu, ^{237}Pu, and ^{238}Pu cross section sets. Nuclear data evaluation is the fundamental interface that takes measured nuclear cross section data and turns them into a continuous curve that 1) is consistent with other measurements and nuclear reaction theory/models, and 2) is required by down-stream users. All experiments that generate nuclear data need to include an evaluation step for their data to be broadly useful to the end users.

In the research performed here, several neutron-induced nuclear reaction cross sections have been evaluated. These evaluations were then processed into a form suitable for end user codes, and the processed data underwent the verification and validation (V&V) step. Finally, the 'experimental' data libraries (ENDL2011.3-ex1 and EDL2011.3-ex2) were released for internal use within LLNL. This work made use of the unique capabilities that exist at LLNL in the Nuclear & Particle Physics and Nuclear Data & Theory groups, and leveraged existing NNSA/Defense Program investments in processing codes and V&V suites. The end-product is updated libraries that include the latest measurements of key cross sections.

All the steps in the evaluation, processing, validation and verification, and library release are described in the following sections. For completeness, the appendices contain all the parameters used in the evaluation for the ^{236}Pu, ^{237}Pu and ^{238}Pu cross sections.

Experimental Data

Above the resonance region, the available experimental data for neutron cross sections on ^{238}Pu, ^{237}Pu, and ^{236}Pu consists almost entirely of fission cross sections.

^{238}Pu Data

For ^{238}Pu, multiple direct measurements of the (n, f) cross section are available [1]-[14]. All were taken into account as part of the present evaluation, with the exception of the outlier data sets of Vorotnikov at al. [13] and Butler et al. [14], which were excluded. Also available for ^{238}Pu, are (n, f) data deduced from LLNL measurements of ^{239}Pu$(p, p'f)$ [15] and ^{239}Pu$(\alpha, \alpha' f)$ [16], as well as the data set from the surrogate measurements of Pal et al. [17], which have never been evaluated before. Following the recommendations of Refs. [15] and [16], we rejected the data of Ressler et al. below 5 MeV due to limitations of the Weiskopf-Ewing assumption for these energy-region, as well as the data of Hughes et al. above 11.9 MeV neutron energy, where it has been observed that surrogate measurements differ from directly measured (n, f) data due to energy of the corresponding outgoing proton falling below the nominal Coulomb barrier [15][18].

^{237}Pu Data

While there have been no direct measurements of the (n, f) cross section for ^{237}Pu, data in the neutron-energy range between 0.5 and 6 MeV are available from Britt and Wilhelmy, who deduced them from $(^3\mathrm{He}, xf)$ measurements [19]. In 2004, these data have been reanalyzed by Younes et al. [20], who introduced a correction to account for the spin mismatch between the neutron-induced and ^{3}He-induced reactions. In the present evaluation, we utilized the re-analyzed data of Younes et al. in place of the original data of Britt and Wilhelmy. Additionally, during the evaluation we also took into account the more recent (n,f) data of Hughes et al. [15] inferred from measurements of the ^{239}Pu(p,df) reaction. As before, we rejected data above 7.1 MeV due to the outgoing deuterium energy falling below the Coulomb barrier.

^{236}Pu Data

For the ^{236}Pu(n,f) cross section, limited direct data are available from work by Vorotnikov et al. [21] and Gramova et al. [22]. These two works apparently use the same data but with a shift in cross section of ~0.5 barn on each data point, and it is not clear which of these two data sets (if any) should be preferred. Also available are the derived data sets of Britt and Wilhelmy [19] and Hughes et al. [15]. The data from Britt and Wilhelmy were from $(^{3}\mathrm{He},xf)$ measurements, while those of Hughes et al. from the ^{239}Pu(p,tf) reaction. In the latter case, we rejected data above 7.4 MeV due to the outgoing tritium energies falling below the Coulomb barrier.

Evaluation Method

The evaluator carried out two sets of calculations of neutron cross sections on ^{238}Pu, ^{237}Pu, and ^{236}Pu for neutron energies above the resonance region and up to 20 MeV, using the TALYS-1.8 code [23]. TALYS is a NRG/CEA-developed software for simulations of nuclear reactions, which combines nuclear models for direct, compound, pre-equilibrium and fission reactions. In the following, we describe the models and parameters utilized to produce the two sets of evaluations, which we will refer to as 'ENDL2011.3-ex1' and 'ENDL2011.3-ex2'.

Coupled-channel optical model calculations

As a first step, the evaluator performed coupled-channel optical model calculations to obtain the compound-formation cross sections for neutrons impinging on the (deformed) ^{238}Pu, ^{237}Pu, and ^{236}Pu nuclei, and to obtain the neutron transmission coefficients for the Hauser-Feshbach calculations of the production and all decay channels of the relevant compound nuclear states. Specifically, the evaluator adopted the global optical model by Soukhovitskii et al. [24], which is one of the best available and was specifically tuned for ^{235}U, ^{238}U and ^{239}Pu. The same set of deformation parameters, $\beta_2 = 0.212$ and $\beta_4 = 0.066$, taken from the neighboring ^{239}Pu [24], was used for all three Pu isotopes considered here. The convergence of the coupled-channel calculation with respect to the number of included rotational states was tested for the case of the ^{238}Pu. This showed that a minimum of 8 rotational states is required to obtain stable results for the total cross section, particularly in the energy region below 5 MeV. For good measure, in all subsequent calculations for ^{238}Pu the evaluator opted for including 10 rotational states. All known states in the lowest rotational band i.e., 5 and 9 states, were included for ^{237}Pu and ^{236}Pu, respectively. A summary of the states employed in the coupled-channel calculations is shown in Table 1.

Table 1 Rotational states employed in the coupled-channel calculations

Rot. States	^{238}Pu		^{237}Pu		^{236}Pu	
	J^{π}	E_x (MeV)	J^{π}	E_{ex} (MeV)	J^{π}	E_{ex} (MeV)
g.s.	0^+	0.000	$7/2^-$	0.000	0^+	0.000
2	2^+	0.044	$9/2^-$	0.048	2^+	0.045
3	4^+	0.146	$11/2^-$	0.106	4^+	0.147

4	6^+	0.303	$13/2^-$	0.175	6^+	0.306
5	8^+	0.514	$15/2^-$	0.257	8^+	0.516
6	10^+	0.773	—	—	10^+	0.773
7	12^+	1.080	—	—	12^+	1.074
8	14^+	1.429	—	—	14^+	1.414
9	16^+	1.819	—	—	16^+	1.786
10	18^+	2.245	—	—	—	—

Table 2 Ground-state level density parameters. The same parameters where used in both sets of evaluations, unless otherwise highlighted through the 'ex1' and 'ex2' labels.

Nuclide	$a(S_n)$ (MeV^{-1})	$Pair$ (MeV)	P_{shift} (MeV)	δ_W (MeV)	T (MeV)	E_0 (MeV)	E_M (MeV)
^{239}Pu	15.66123	0.77622	-0.0500	-0.42820	0.38269	-0.00554	3.47184
^{238}Pu	15.43123	1.55569	0.0000	-0.60292	0.40399	-0.03640	4.50212
^{237}Pu (ex1)	15.92452	0.77948	0.0000	1.37937	0.38021	-0.74775	3.59285
^{237}Pu (ex2)	15.92452	0.77948	0.0000	1.87937	0.38021	-0.74775	3.59285
^{236}Pu (ex1)	11.77702	1.56227	0.0000	2.22529	0.50524	-0.29308	6.89854
^{236}Pu (ex2)	15.93948	1.56227	0.0000	2.22529	0.36524	2.09308	11.59854
^{235}Pu (ex1)	15.30221	0.78279	0.0000	1.97910	0.35133	-0.33101	3.01170
^{235}Pu (ex2)	15.30221	0.78279	0.0000	1.97910	0.60133	-3.23101	8.01170
^{234}Pu (ex1)	15.36743	1.56893	0.0000	2.17066	0.34887	0.46135	3.78986
^{234}Pu (ex2)	15.36743	1.56893	0.0000	2.17066	0.55887	2.46135	9.78986

Preequilibrium reactions calculations

Preequilibrium emission, which takes place after the first stage of the reaction but long before statistical equilibrium of the compound nucleus is attained, has been computed within the two-component exciton model of Koning and Duijvestijn [25].

Hauser Feshbach statistical model calculations

Fission, gamma, neutron, proton, deuteron, tritium, ^{3}He, and ^{4}He decay channels were included in the calculations. The neutron-transmission coefficients were taken from the coupled-channel optical model calculations, with the level scheme of the targets shown in Table 1. For the level densities, the evaluator used the constant temperature model of Gilbert and Cameron [26] with shell correction energy and collective enhancement. The fitted level density parameter at the neutron separation energy, $a(S_n)$, pairing energy, $Pair$, pairing shift for adjustment of the Fermi Gas level density, P_{shift}, shell correction energy, δ_W, temperature of the Gilbert-Cameron formula, T, 'back-shift' energy, E_0, and matching energy

E_M, for the ground-state level densities of ^{239}Pu, ^{238}Pu, ^{237}Pu, ^{236}Pu, ^{235}Pu, and ^{234}Pu are summarized in Table 2.

For the fission channel, the evaluator used the model based on the transition state hypothesis of Bohr and assumed double-humped fission barriers. The effective transmission coefficients for the double-humped barriers were computed starting from the Hill-Wheeler expression for the probability of tunneling through each barrier of height B_i and width $\hbar\omega_i$ $(i = 1{,}2)$. The fitted fission barrier parameters for ^{239}Pu, ^{238}Pu, ^{237}Pu, ^{236}Pu, ^{235}Pu, and ^{234}Pu are shown in Table 3. Above the fission barriers the evaluator assumed continuum states. The fitted level density parameters for the first and second barrier are shown in Table 4 and 5, respectively.

Table 3 Fission barrier parameters. The same parameters where used in both sets of evaluations, unless otherwise highlighted through the 'ex1' and 'ex2' labels.

Nuclide	B_1 (MeV)	$\hbar\omega_1$ (MeV)	B_2 (MeV)	$\hbar\omega_2$ (MeV)
^{239}Pu	5.920	0.600	5.930	0.650
^{238}Pu	5.550	0.400	4.900	2.000
^{237}Pu (ex1)	5.170	0.733	5.350	0.300
^{237}Pu (ex2)	5.169	0.733	5.400	0.300
^{236}Pu (ex1)	5.800	0.670	5.800	0.970
^{236}Pu (ex2)	5.850	1.100	5.900	0.720
^{235}Pu (ex1)	4.700	1.000	2.900	0.600
^{235}Pu (ex2)	4.800	1.100	2.900	0.500
^{234}Pu (ex1)	4.200	1.000	2.700	0.600
^{234}Pu (ex2)	4.800	0.600	2.700	0.600

Table 4 Parameters of the level density above the first barrier. The same parameters where used in both sets of evaluations, unless otherwise highlighted through the 'ex1' and 'ex2' labels.

Nuclide	P_{shift} (MeV)	δ_W (MeV)	T (MeV)	E_0 (MeV)	E_M (MeV)
^{239}Pu	0.00000	1.80000	0.33772	-1.15301	3.29458
^{238}Pu	0.00000	1.35000	0.35348	-0.45002	3.39879
^{237}Pu(ex1)	0.50000	1.50000	0.10226	-0.00003	2.39174
^{237}Pu(ex2)	0.00000	1.50000	0.25026	-0.00003	2.19174
^{236}Pu (ex1)	0.00000	1.50000	0.48937	-3.41273	2.04970
^{236}Pu (ex2)	2.50000	1.50000	0.40937	-2.41273	0.20970
^{235}Pu (ex1)	0.00000	1.50000	0.35133	-0.28632	2.90131
^{235}Pu (ex2)	0.00000	1.50000	0.35133	-0.28632	2.90131

^{234}Pu (ex1)	0.00000	1.50000	0.34887	0.53507	3.63662
^{234}Pu (ex2)	0.00000	1.50000	0.54887	0.53507	3.63662

Table 5 Parameters of the level density above the second barrier. The same parameters where used in both sets of evaluations, unless otherwise highlighted through the 'ex1' and 'ex2' labels.

Nuclide	P_{shift} (MeV)	δ_W (MeV)	T (MeV)	E_0 (MeV)	E_M (MeV)
^{239}Pu	1.07000	3.40000	0.45169	-1.92104	3.99940
^{238}Pu	0.00000	0.60000	0.34900	-0.10004	3.94849
^{237}Pu (ex1)	2.65000	0.60000	0.18662	-0.17501	1.21412
^{237}Pu (ex2)	3.70000	0.80000	0.19062	-0.22501	1.30412
^{236}Pu (ex1)	0.00000	0.60000	1.30186	-2.11865	2.14862
^{236}Pu (ex2)	0.00000	1.60000	0.50186	-2.11865	0.64862
^{235}Pu (ex1)	0.00000	0.60000	0.35133	-0.40594	2.67365
^{235}Pu (ex2)	0.00000	1.60000	0.55133	-0.20594	2.67365
^{234}Pu (ex1)	0.00000	0.60000	0.34887	0.41380	3.40936
^{234}Pu (ex2)	0.00000	0.60000	0.54887	0.41380	3.40936

For the gamma-ray strength functions the evaluator adopted the generalized Lorentzian form of Kopecky and Uhl [27] to describe E1 transitions, while for all other transition types used the Brink-Axel standard Lorentzian form [28]. The total radiative width (Γ_γ) and the strength ($\sigma_{1(2)}$), energy ($E_{1(2)}$) and width ($\Gamma_{1(2)}$) of the adopted gamma-ray strength functions for ^{239}Pu, ^{238}Pu, and ^{237}Pu are shown in Table 6, 7 and 8, respectively.

For other parameters not reported in the present Tables, the evaluator adopted the TALYS-1.8 default values. The TALYS input files and complete lists of model parameters are provided in Appendix.

Table 6 Gamma-ray strength functions for ^{239}Pu. The same parameters where used in both sets of evaluations, unless otherwise highlighted through the 'ex1' and 'ex2' labels.

Multipole	E_1 (MeV)	Γ_1 (mb)	σ_1 (mb)	E_2 (MeV)	Γ_2 (mb)	σ_2 (mb)
E1	11.280	2.480	325.000	13.730	4.250	384.000
M1	6.607	4.000	1.531	—	—	—
E2	10.152	3.242	0.624	—	—	—
M2	6.607	4.000	0.001	—	—	—
Γ_γ (eV)	0.034					

Table 7 Gamma-ray strength functions for ^{238}Pu. The same parameters where used in both sets of evaluations, unless otherwise highlighted through the 'ex1' and 'ex2' labels.

Multipole	E_1 (MeV)	Γ_1 (mb)	σ_1 (mb)	E_2 (MeV)	Γ_2 (mb)	σ_2 (mb)
E1 (ex1)	13.310	3.649	714.000	—	—	—
E1 (ex2)	10.900	2.500	300.000	13.800	4.700	450.000
M1	6.616	4.000	1.128	—	—	—
E2	10.166	3.254	0.624	—	—	—
M2	6.616	4.000	0.001	—	—	—
Γ_γ (eV)	0.030 (ex1)			0.040 (ex2)		

Table 8 Gamma-ray strength functions for 237Pu. The same parameters where used in both sets of evaluations, unless otherwise highlighted through the 'ex1' and 'ex2' labels.

Multipole	E_1 (MeV)	Γ_1 (mb)	σ_1 (mb)	E_2 (MeV)	Γ_2 (mb)	σ_2 (mb)
E1	10.90	2.500	300.000	13.800	4.700	450.000
M1	6.625	4.000	2.670	—	—	—
E2 (ex1)	10.18	3.266	6.800	—	—	—
E2 (ex2)	10.18	3.266	0.623	—	—	—
M2	6.625	4.000	0.001	—	—	—
Γ_γ (eV)	0.030 (ex1)			0.044 (ex2)		

Results from the data evaluation for ^{236}Pu

The computed fission cross sections obtained within the ENDL2011.3-ex1 and ENDL2011.3-ex2 evaluations for ^{236}Pu are shown in Figure 1 together with the available experimental data and existing evaluations. Note that the ENDL2011.3 and ENDF/B-VII.1 (not shown) ^{236}Pu(n,f) cross sections are equivalent and were taken from JENDL-4.0 (not shown). The lack of information about the S-wave level spacing (D_0) for the ^{237}Pu compound and ^{236}Pu target nuclei, and the ambiguity of the two available data sets from direct measurements, complicated the evaluation of the cross section below 2 MeV neutron incident energy. The works by Vorotnikov et al. [21] and Gramova et al. [22] use the same data but with a shift in cross section of ~0.5 barn on each data point. A possible explanation is that the data from Gramova et al. (which were published later) may have been a re-analysis of the data from Vorotnikov et al., however this is purely a speculation. In our first attempt at the evaluation (ENDL2011.3-ex1) we favored the data from Vorotnikov et al. as they appeared to fall more in line with the trend shown by the derived data sets of Britt and Wilhelmy [19] and Hughes et al. [15]. In particular, we preferred the data from Vorotnikov et al. in the incident energy region below ~1 MeV, where cross sections deduced via surrogate

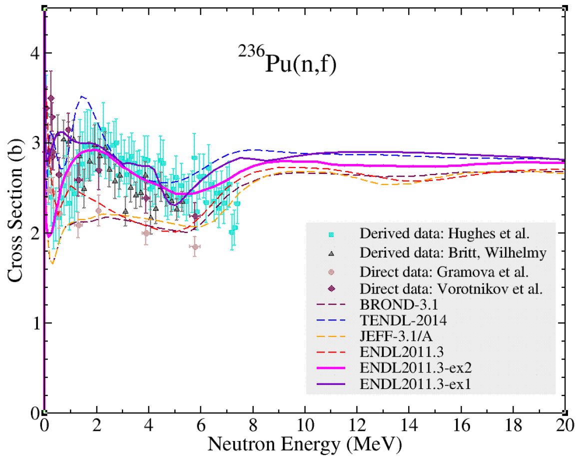

Figure 1 ENDL2011.3-ex1 (thin, indigo solid line) and ENDL2011.3-ex2 (thick, magenta solid line) evaluations for the ^{236}Pu(n,f) cross section compared to existing evaluations (dashed lines). Experimental data include the direct measurements of Refs. [21] (diamonds) and [22](circles), as well as experimental data deduced from surrogate reactions (squares [15], and triangles [19]).

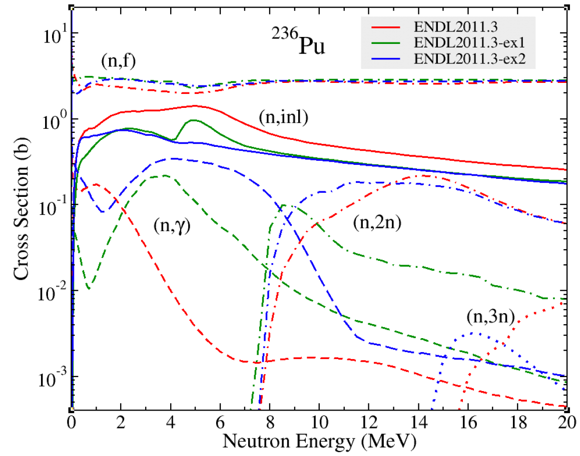

Figure 2 ENDL2011.3-ex1 (green curves) and ENDL2011.3-ex2 (blue curves) evaluations for the ^{236}Pu(n,f), (n,γ), (n,inl) or (n,n'), (n,2n), and (n,3n) cross sections compared to the corresponding ENDL2011.3 cross sections.

measurements have the potential of being unreliable due to the spin transfer mismatch between the neutron-induced and surrogate reaction. Further, the evaluator opted for adopting the default TALYS-1.8 structure parameters for the level densities and fission barriers of the ^{235}Pu and ^{234}Pu isotopes, which influence the ^{236}Pu(n,f) above ~7 MeV, i.e. where no fission nor other cross section data are available. This led the evaluator to overlook the cross sections in the weaker (n,γ), $(n,2n)$, and $(n,3n)$ channels (the latter of which had entirely disappeared), and resulted in substantial differences between the ENDL2011.3 and ENDL2011.3-ex1 evaluations as shown in Figure 2. These differences were highlighted by the V&V testing, as discussed in more detail later.

Therefore, upon feedback from the V&V testing and reconsideration of the data from Vorotnikov et al. and Gramova et al., the evaluator set out to produce a second, improved evaluation (ENDL2011.3-ex2) of the neutron cross sections on ^{236}Pu. To start with, the evaluator decided to disregard the data sets from both Vorotnikov et al. and Gramova et al., in favor of the surrogate data from Britt and Wilhelmy and Hughes et al., including in the low-energy region below ~1 MeV. For ^{236}Pu(n,f) this choice is justified by the fact that the ^{237}Pu compound is an odd-even nucleus (presenting a lower pairing gap). Therefore, it can be expected that the reaction is quickly dominated by a statistical distribution of angular momentum, lessening concerns about a spin transfer mismatch between the neutron-induced and surrogate reaction. It should also be noticed that inconsistences between fission data from Vorotnikov et al. and other direct measurements also exist in the case of ^{238}Pu. In addition, in this second and improved attempt, the evaluator varied the level-density and fission barrier parameters of the ^{235}Pu and ^{234}Pu isotopes to improve the $(n,2n)$ and $(n,3n)$ cross sections, and replaced the TALYS-1.8 default total radiative width (Γ_γ = 0.030 eV) with the systematic value of Mughabghab (Γ_γ = 0.044 eV) [30]. The resulting ENDL2011.3-ex2 cross sections are shown in Figure 1 (magenta line) and Figure 2 (blue lines). We found a noticeable improvement in the evaluated fission cross section, which now reproduces the trend of the surrogate data below 7 MeV, and is in line with previous evaluations at higher energies. The cross sections for the weaker reaction channels are also more in line with the previous, ENDL2011.3, evaluation. We note that the difference between the ENDL2011.3-ex2 and ENDL2011.3 evaluation in the (n, inl) [or (n, n')] channel is correlated with those in the (n, f) cross section, the evaluation of which in ENDL2011.3 seems to have been based on the Gramova data (the surrogate data were not available at the time that evaluation was carried out).

Results from the data evaluation for ^{237}Pu

The computed fission cross sections obtained within the ENDL2011.3-ex1 and ENDL2011.3-ex2 evaluations for ^{237}Pu are shown in Figure 3 together with the available experimental data and existing evaluations. Note that the ENDL2011.3 and ENDF/BVII.1 (not shown) ^{237}Pu(n, f) cross sections are equivalent and were taken from JENDL-AC-2008 (not shown). The evaluation was carried out using the recent (n, f) data of Hughes et al. [15] inferred from measurements of the ^{239}Pu(p, df) reaction, as well as the reanalyzed data from Younes et al. [20], who corrected the surrogate data from Britt and Wilhelmy [19] to account for the spin mismatch between the neutron-induced and ^{3}He-induced surrogate reaction. Due to this correction (which was not taken into account by Hughes et al.), we favored the latter data in the low-energy region below 2 MeV.

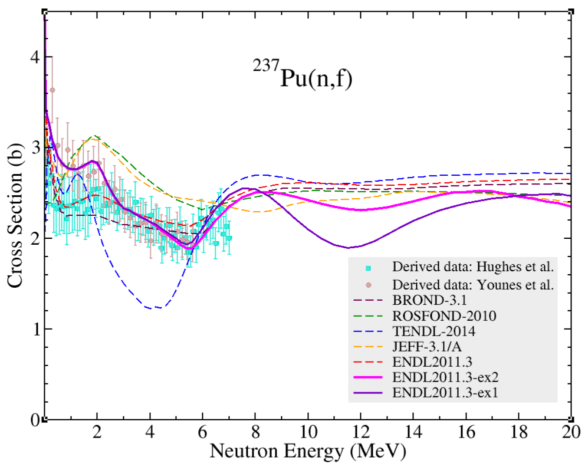

Figure 3 ENDL2011.3-ex1 (thin solid line) and ENDL2011.3-ex2 (thick solid line) evaluations for the ^{237}Pu(n,f) cross section compared to existing evaluations (dashed lines) and experimental data deduced from surrogate reactions (squares [15], and circles [20]).

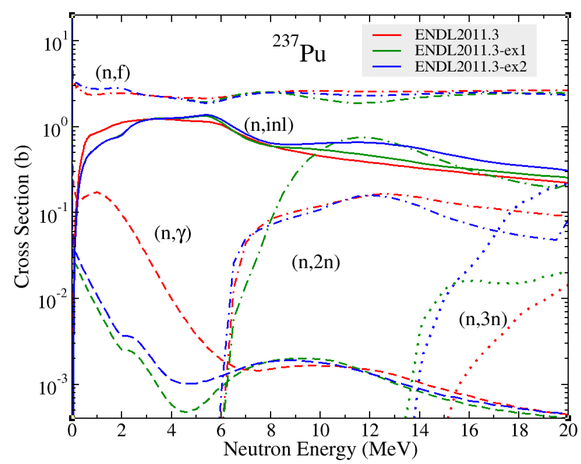

Figure 4 ENDL2011.3-ex1 (green curves) and ENDL2011.3-ex2 (blue curves) evaluations for the ^{237}Pu(n,f), (n,γ), (n,inl) or (n,n'), (n,2n), and (n,3n) cross sections compared to the corresponding ENDL2011.3 cross sections.

Similar to the case of ^{236}Pu, discussed in the previous section, the V&V test highlighted substantial differences between the ENDL2011.3 and ENDL2011.3-ex1 evaluations for the cross sections in the weaker (n, γ), and $(n, 2n)$ channels, as shown in Figure 4. The new choice of ^{237}Pu and ^{236}Pu parameters, introduced to improve the ^{236}Pu cross sections in the ENDL2011.3-ex2 evaluation, automatically fixed the ^{237}Pu$(n, 2n)$ cross section. It also improved the agreement of the computed (n, f) cross section with the surrogate data at the onset of the second chance fission, and with previous evaluations at higher energies. At the same time, the ^{237}Pu evaluation could be further improved in the energy range above ~13 MeV, where the $(n, 3n)$ channel has taken away some strength from the tail of the $(n, 2n)$ cross section. Concerning the (n, γ) channel, the differences between the ENDL2011.3-ex1 and ENDL2011.3-ex2 stem from the use of two rather than one (TALYS-1.8 default) Lorentzians in the modeling of the E1 strength function of ^{238}Pu and the replacement of the TALYS-1.8 default total radiative width (Γ_γ = 0.030 eV) with

Γ_γ = 0.040 eV, a value chosen between the total radiative widths reported by Mughabghab [30] for the ^{239}Pu and ^{237}Pu nuclei. Nevertheless, the ENDL2011.3-ex2 ^{237}Pu(n,γ) cross section remains smaller than in the ENDL2011.3 evaluation, particularly in the region below 3 MeV. This is correlated with the fact that, in that same energy range the new evaluation presents a higher fission cross section in agreement with the data of Younes et al.

Results from the data evaluation for ^{238}Pu

The computed fission cross sections obtained within the ENDL2011.3-ex1 and ENDL2011.3-ex2 evaluations for ^{238}Pu are shown in Figure 5 together with the available experimental data and existing evaluations. Note that the ENDL2011.3 ^{238}Pu(n,f) cross section was taken from JENDL-AC-2008 (not shown). The evaluation was carried out using the direct measurements from Refs. [1]-[12], the data deduced from LLNL measurements of ^{239}Pu$(p,p'f)$ [15] and ^{239}Pu$(\alpha,\alpha'f)$ [16], as well as the data set from the surrogate measurements of Pal et al. [17]. In general, when possible we favored the direct over the surrogate measurements, particularly in the energy region below ~5 MeV. Different from the ^{236}Pu, ^{238}Pu cases, the S-wave level spacing for the compound ^{239}Pu nucleus is known and is reported in the RIPL-3 library to be $D_0 = 8.3 \pm 0.5$ eV. Our computed value of $D_0 = 8.37$ eV is in good agreement.

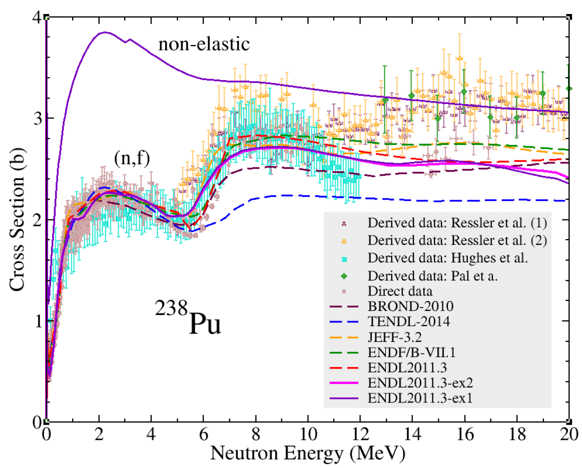

Figure 5 ENDL2011.3-ex1 (thin solid line) and ENDL2011.3-ex2 (thick solid line) evaluations for the ^{238}Pu(n,f) cross section compared to existing evaluations (dashed lines). Experimental data include the direct measurements of Refs. [1]-[12] (circles), as well as data deduced from surrogate reactions (squares [15], triangles [16], and diamonds [15]). Also shown is the computed total non-elastic cross section.

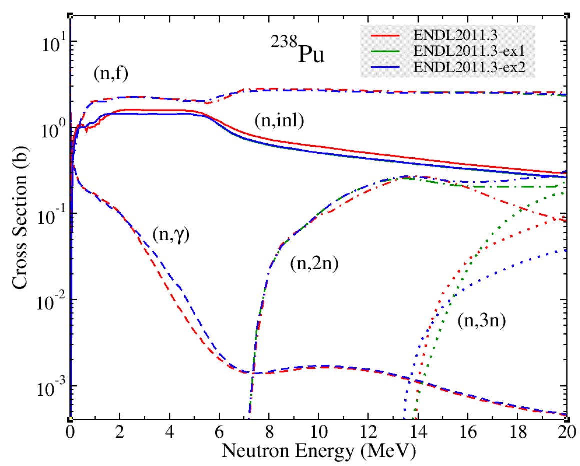

Figure 6 ENDL2011.3-ex1 (green curves) and ENDL2011.3-ex2 (blue curves) evaluations for the ^{238}Pu(n,f), (n,γ), (n,inl) or (n,n'), (n,2n), and (n,3n) cross sections compared to the corresponding ENDL2011.3 cross sections.

As shown in Figure 5 and Figure 6, the ENDL2011.3-ex1 and ENDL2011.3-ex2 calculations are almost identical and in good agreement with the available data below 12 MeV and the existing ENDL2011.3 evaluation in all reaction channels. Minor differences can be noticed above 15 MeV neutron incident energy, where the $(n,2n)$ channel is taking away some of the $(n,3n)$ cross section. Above ~11 MeV, the computed (n,f) cross sections lie well below the surrogate measurements of Ressler et al. and Pal et al. above ~11 MeV. Obtaining a larger fission cross section in this energy rage has proven extremely difficult within the adopted model, in which the total non-elastic cross section (also shown in Figure 5) lies between 3.2 b and 3.0 b in the energy region above 11 MeV. Forcing a larger fission cross section at such energies would result in the disappearance of the $(n,2n)$ and $(n,3n)$ reaction channels, as well as generate larger ^{237}Pu(n,f) and ^{236}Pu(n,f) cross sections in disagreement with the available data. In this respect, we note that our coupled-channel calculations were based on the same optical model by Soukhovitskii et al. and deformation parameters specifically tuned for the neighboring ^{239}Pu, and should therefore produce a reliable non-elastic cross section. We feel that ^{238}Pu$(n,2n)$ measurements are needed for a conclusive answer on the magnitude of the ^{238}Pu(n,f) cross section above 11 MeV.

Recommended evaluation

Based on the discussion above, the evaluator found the ENDL2011.3-ex2 evaluation to be overall of better quality than the initial ENDL2011.3-ex1, which should be disregarded. The evaluator therefore recommended the ENDL2011.3-ex2 evaluation.

Data Processing and Release Procedures for Nuclear Evaluations

The evaluations as provided by the evaluator (Sofia Quaglioni) are in the form of output files from TALYS runs, for the several target nuclei reacting with incident neutrons. The evaluator has found the parameters of Hauser-Feshbach calculations that match the cross sections for neutrons from about ~0.1 to 20 MeV. For each neutron incident energy, files are provided for the cross sections and angular distributions of outgoing neutrons, alpha particles, and gamma rays when residual nuclei are in specific final states. As well, cross sections and exit energy distributions are provided for exit neutrons, alphas, protons, deuterons, tritons, helions (^{3}He) and gammas for the remaining processes when the residual nuclear states are unspecified. These files include the direct, pre-equilibrium and compound contributions to each exit channel.

These files are read into the code GEFT (Get ENDL From TALYS), that was written at LLNL by Neil Summers and subsequently developed by Eric Jurgenson. This is a python code that reads the TALYS output, stores it using FUDGE data structures as developed at LLNL, and writes out ENDL-format files for use by applications at LLNL. These files can also be translated into ENDF format for use by the national data community, and into GNDS format for use by the very recently developed GIDI processing methods at LLNL.

At present TALYS runs do not give angular distributions for unspecified ('continuum') final states. These can be extracted with extra work, and GEFT can be modified to translate that data. These changes should be feasible within FY2018.

The data from the TALYS output, however, is not fully sufficient for application use, and has to be supplemented by further information for low-energy reactions, and for specifying the products of fission reactions. Low-energy reactions of neutrons (below about 1 to 10 keV) are dominated by resonances, and these have to be specifically measured by time-of-flight neutron experiments. Similarly, the products of fission processes (prompt neutron multiplicities, prompt neutron energy distributions, total fission energy production, fission product distributions) were not fitted by the evaluator. In the present work for Pu isotopes, the resonance data and fission product data were adopted unchanged from the previous evaluations in the ENDL2011.3 library (sourced from JENDL and subsequently ENDF/B-VII). For ^{236}Pu and ^{237}Pu, the resonances were included from 0-10 eV, corresponding to the lower extent of the new evaluation and the previous point of splicing evident in the existing data. For ^{238}Pu the existing data was included up to 10 keV, where resonances were available, and did not overlap the new data points and evaluation.

Finally, we have ENDL files for evaluations for ^{236}Pu, ^{237}Pu, and ^{238}Pu nuclei as targets for neutrons. In order for these evaluations to be tested, this set of files must be supplemented by data for all the other nuclei in critical assemblies and other applications. In the present work, we simply made experimental evaluations based on our most recent LLNL library ENDL2011.3, which is currently a release candidate library. Thus, we made ENDL2011.3-ex1 and ENDL2011.3-ex2 libraries, where the ^{236}Pu, ^{237}Pu, and ^{238}Pu data in ENDL2011.3 library was replaced by the new files we have just produced. The combination was then processed for deterministic and Monte Carlo simulations using the multigroup codes NDFGEN and MCFGEN, respectively. These also process cross sections that have been broadened by Maxwellian distributions to a range of temperatures suitable for applications. The new evaluations were then tested by comparing results from the 'ex' evaluations with those from the ENDL2011.2 library (the latest officially released ENDL library). Note that no Pu cross sections where changed between ENDL2011.2 and ENDL2011.3.

Validation & Verification testing

The ENDL2011.3-ex1 mcf Monte Carlo library file with the new evaluations for ^{238}Pu, ^{237}Pu, and ^{236}Pu, were tested using the Nuclear Data Group Automated Verification and Validation test suite [31]. A verification test, often referred to as a 'Broomstick' problem, was added to the test suite since there is no integral criticality benchmarks in the International Criticality Safety Benchmark Evaluation Project (ISCBEP) with significant amount of these isotopes [32].

The test consists of a thin cylinder of material made of a single isotope of density 1.0 g/cm^3. The cylinder is 10^5 cm long with a radius of 10^{-5} cm, long enough to be considered semi-infinite so that all incident neutrons interact once in the material, and thin enough to ensure once-scattered and secondary particles escape without interactions. A monoenergetic pencil beam of 1 or 14 MeV neutrons is directed along the cylinder axis. Currently, available tallies include the number of reactions per reaction type within the cylinder and leakage spectra as a function of energy or angular emission. The decks were formatted to be easily added to and queried in the test suite database of problems and to be run automatically on Livermore Computing (LC) systems.

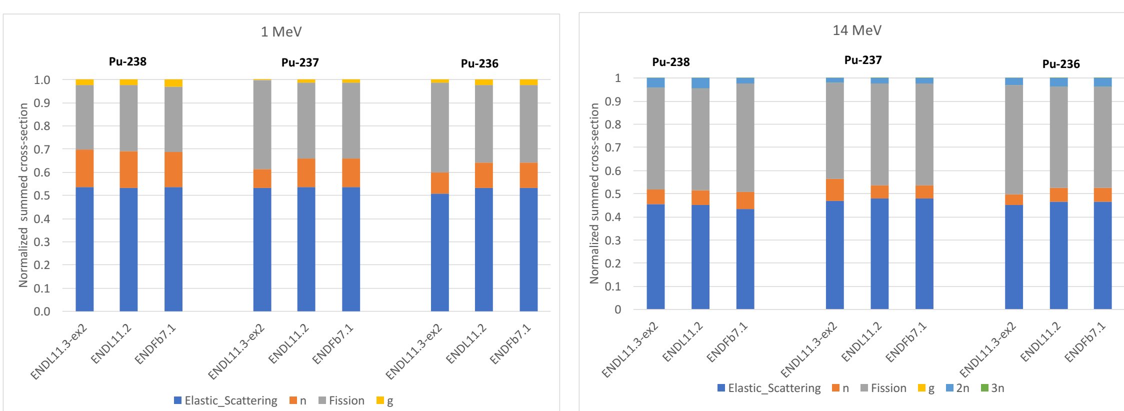

Figure 7 Normalized summed cross-section contributions obtained from Mercury simulations for 1 MeV (left) and 14 MeV (right) neutrons incident on a thin cylinder of ^{238}Pu, ^{237}Pu and ^{236}Pu. Results are shown for ENDL2011.3-ex2, ENDL2011.2, and ENDF/b-VII.1 cross-section libraries.

Simulations were run using Mercury, LLNL's Monte Carlo particle transport code and, initially, the ENDL2011.3-ex1 library [33][34]. Results were compared to those obtained with two officially released cross section libraries, namely ENDL2011.2 and ENDF/b-VII.1, which contains ^{238}Pu, ^{237}Pu, and ^{236}Pu evaluations from JENDL-AC-2008 and LANL/JENDL4.0, respectively [35] [36]. We note that ENDL2011.3 is currently a release candidate, but has not been officially released yet. No Pu cross sections where changed between ENDL2011.2 and ENDL2011.3. Several differences were observed between the new evaluations and those in the released libraries. For ^{236}Pu and ^{237}Pu, contributions from the (n,n') and (n,γ) channels were smaller at 1 MeV. At 14 MeV, the ^{237}Pu evaluation showed an increase in (n,n'), $(n,2n)$ and $(n,3n)$ reactions while the ^{236}Pu evaluation shows a decrease in (n,n') and$(n,2n)$ and an increase in (n,γ). These differences observed in the weaker channels were consistent with the initial model developed for ENDL2011.3-ex1 evaluations and informed modifications implemented in the revised evaluations included in ENDL2011.3-ex2. Contributions from the ^{236}Pu(n,n') and (n,γ) channels at 1 MeV and (n,n') and $(n,2n)$ channels at 14 MeV, and from the ^{237}Pu$(n,2n)$ channel at 14 MeV are now closer to those given by the two released libraries (see Figure 7) for the simulations adopting the ENDL2011.3-ex2 library. Note that no experimental data is available for these channels.

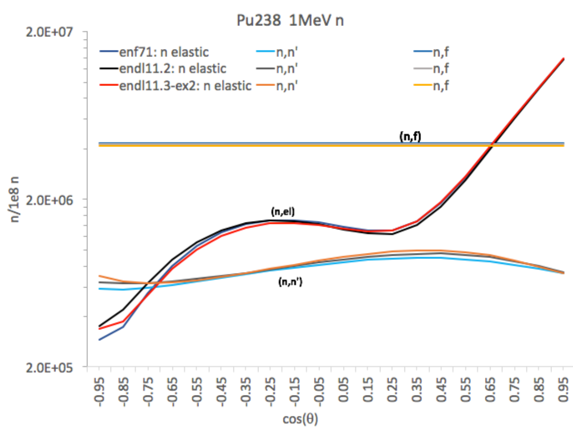

Figure 8 Simulated angular distribution of outgoing neutrons by reaction type for 1 MeV neutrons on ^{238}Pu

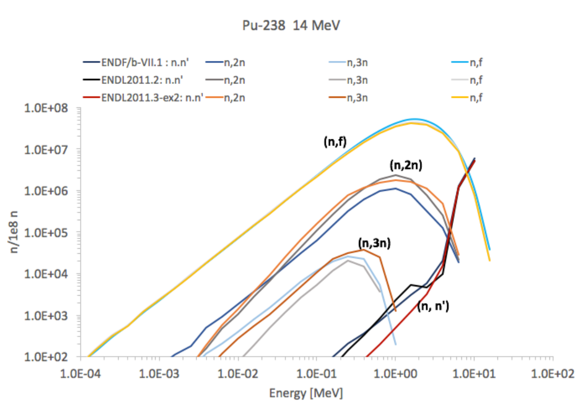

Figure 9 Simulated leakage spectra by reaction type for 14 MeV neutrons on ^{238}Pu.

The angular and energy distributions of outgoing neutrons after a single interaction simulated with the ENDL2011.3-ex2, ENDL20011.2, and ENDF/b-VII.1 cross section libraries are shown in Figure 8 and 9. These are typical examples of V&V results that can provide feedback on specific evaluations.

Internal Library Release

Following the V&V tests, the new recommended 'experimental' library ENDL2011.3-ex2, including the new evaluations of the ^{236}Pu, ^{237}Pu and ^{238}Pu cross sections, was released for internal use within LLNL.

Conclusion

We have performed a new data evaluation of ^{236}Pu, ^{237}Pu and ^{238}Pu cross sections using newly obtained fission cross section data. The new evaluations (ENDL2011.3-ex1 and ENDL2011.3-ex2) include the nuclear cross sections for (n,γ), (n,n'), $(n,2n)$, $(n,3n)$, (n,f) and all their associated distributions. The evaluations were then translated into ENDL format using GEFT, and processed into accessible libraries for Monte Carlo and Deterministic simulation codes WITH MCFGEN and NDFGEN, respectively. The ENDL2011.3-ex1mcf Monte Carlo library was then used for a simulation on a "broomstick" example to verify the integrity of the library and check the functionality of the results. The ENDL2011.3-ex2mcf library has now been released as an "experimental" version for internal access. All results have been documented within this report, through the associated references and the appendices at the end of this report.

References

[1] B. I. Fursov, V. N. Polynov, B. F. Samylin, V. S. Shorin, Proc. Intern. on Nuclear Data for Science and Technology, Trieste, Italy, 19-24 May, 1997, G.Reffo, A.Ventura, C.Grandi, Eds., Editrice Compositori, Italy, Pt. 1, 488 (1997).
[2] B. Alam, R. C. Block, R. E. Slovacek, R. W. Hoff, Nucl. Sci. Eng. **99**, 267 (1988)
[3] C. Budtz-Joergensen, H.-H. Knitter, D. L. Smith, Conf. on Nucl. Data for Science and Technology, Antwerp 1982, 206 (1982), Belgium.
[4] M. G. Silbert, A. Moat, T. E. Young, Nucl. Sci. Eng. **52**, 176 (1973).
[5] D. M. Drake, C. D. Bowman, M. S. Coops, R. W. Hoff, Los Alamos Scientific Lab. Reports, No. 4420, 101 (1970).
[6] S. B. Ermagambetov, G. N. Smirenkin, At. Energ. (USSR) **29**, 422 (1970); Sov. At. Energy **29**, 1190 (1970).
[7] E. F. Fomushkin, E. K. Gutnikova, Yadern. Fiz. **10**, 917 (1969); Soviet J. Nucl. Phys. **10**, 529 (1970).
[8] S. B. Ermagambetov, G. N. Smirenkin, Sov. At. Energy **25**, 1364 (1968).
[9] W. F. Stubbins, C. D. Bowman, G. F. Auchampaugh, M. S. Coops, Phys. Rev. **154**, 1111 (1967).
[10] D. M. Barton, P. G. Koontz, Phys. Rev. **162**, 1070 (1967).
[11] E. F. Fomushkin, eta l., Yad. Fiz. **5**, 966 (1967); Soviet J. of Nucl. Phys. **5**, 689 (1967).
[12] V. F. Gerasimov, Yad.Fiz. **4**, 985 (1966); Soviet J. of Nucl. Phys. **4**, 706 (1967).
[13] P. E. Vorotnikov, S. M. Dubrovina, G. A. Otroshchenko, V. A. Shigin, Yadern.Fiz. **3**, 479 (1966); Soviet J. Nucl. Phys. **3**, 348 (1966).
[14] D. K. Butler, R. K. Sjoblom, Bulletin of the American Physical Society **8**, 369(RA7) (1963).
[15] R. O. Hughes et a., Physical Review C 90, 014304 (2014).
[16] J. J. Ressler et al., Physical Review C 83, 054610 (2011).
[17] A. Pal et al., Phys.Rev. C 91, 054618 (2015).
[18] R. O Hughes et al., Phys. Rev C 85, 024613 (2012).
[19] H. C. Britt and J. B. Wilhelmy, Nucl. Sci. Eng. **72**, 222 (1979).
[20] W. Younes, H. C. Britt, and J. A. Becker, Tech. Rep. UCRL-TR-201913, LLNL (2004).
[21] P. E. Vorotnikov et al., in Proceedings of the First International Conference on Neutron Physics, Kiev, September 14-18, 1987 (TSNIIatominform, Moscow, 1988) **4**, 76.
[22] E. A. Gromova et al., At. Energ. **68**, 223 (1990).

[23] A.J. Koning and D. Rochman, Nuclear Data Sheets **113**, 2841 (2012).
[24] E. Sh Soukhovitskii, S. Chiba, J.-Y. Lee, O. Iwamoto and T. Fukahori, J. Phys. G: Nucl. Part. Phys. **30**, 905 (2004).
[25] J. Koning and M.C. Duijvestijn, Nucl. Phys. A **744**, 15 (2004).
[26] A. Gilbert and A.G.W. Cameron, Can. J. Phys. **43**, 1446 (1965).
[27] J. Kopecky, M. Uhl and R.E. Chrien, Phys. Rev. C **47**, 312 (1993).
[28] D.M. Brink, Nucl. Phys. 4, 215 (1957); P. Axel, Phys. Rev. **126**, 671 (1962).
[29] J. E. Escher and F. S. Dietrich, Phys. Rev. C **74**, 054601 (2006).
[30] S. F. Mughabghab, *Atlas of Neutron Resonances: Resonance Parameters and Thermal Cross Sections Z=1-100*, 5th Edition, Elsevier (2006).
[31] P. Vranas et a., LLNL-SM-733021 (2017)
[32] International Criticality Safety Benchmark Evaluation Project (ISCBEP), International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC/(95)03, September 2011 Edition [CD-ROM], Nuclear Energy Agency (2011).
[33] "Mercury web site," accessed: 2017-09-22. [Online]. Available: https://wci.llnl.gov/simulation/computer-codes/mercury
[34] P. S. Brantley et al., Mercury User Guide: Version d.8, LLNL-SM-560687, Lawrence Livermore National Laboratory (2012).
[35] B. Beck et al., 2011.2 Revision of the Evaluated Nuclear Data Library (ENDL2011.2) Technical report (private communication) (2016)
[36] M.B. Chadwick, et al., Nucl. Data Sheets, **112**, 2887(2011).

Appendix A

The following TALYS-1.8 input is for the recommended ENDL2011.3-ex2 evaluation. The output files can be made available upon request.

Input file for deformation parameters

```
 94 236   9   R   B             236Pu
  0   R   0          0.21200  0.06600
  1   R   0
  2   R   0
  3   R   0
  4   R   0
  7   R   0
  9   R   0
 13   R   0
 14   R   0
 94 237   8   R   B             237Pu
  0   R   0          0.21200  0.06600
  1   R   0
  2   R   0
  5   R   0
  8   R   0
 31   R   0
 37   R   0
 48   R   0
 94 238  10   R   B             238Pu
  0   R   0          0.21200  0.06600
  1   R   0
  2   R   0
  3   R   0
  4   R   0
  8   R   0
 17   R   0
 28   R   0
 38   R   0
 40   R   0
```

Input file for ^{238}Pu ENDL2011.3-ex2 TALYS-1.8 evaluation

```
#
# General
#
projectile n
element     Pu
mass        238
energy      energies
#
# Parameters
#
localomp n
deformfile 94 z094_deform.loc
autorot y
maxrot 10
maxlevelstar 30
preeqmode 2
twocomponent y
gammax 2
asys n
hbstate n
class2 n
inccalc y
eciscalc y
ecissave y
partable y
#
# Output
#
outdensity y
channels y
filechannels y
outgamma y
###
##-------------------------------------------
##
## Parameters for 239Pu
##
## Level density
##
a                 94 239   15.66123
Pshift            94 239   -0.05000    0
deltaW            94 239   -0.42820    0
T                 94 239    0.38269    0
E0                94 239   -0.00554    0
Exmatch           94 239    3.47184    0
Ntop              94 239   15    0
Nlow              94 239    4    0
Pshift            94 239    0.00000    1
deltaW            94 239    1.80000    1
T                 94 239    0.33772    1
E0                94 239   -1.15301    1
Exmatch           94 239    3.29458    1
Pshift            94 239    1.07000    2
deltaW            94 239    3.40000    2
T                 94 239    0.45169    2
E0                94 239   -1.92104    2
Exmatch           94 239    3.99940    2
##
## Gamma-ray
##
gamgam            94 239    0.03400
sgr               94 239  325.000 E1
egr               94 239   11.280 E1
ggr               94 239    2.480 E1
sgr               94 239  384.000 E1 2
egr               94 239   13.730 E1 2
ggr               94 239    4.250 E1 2
sgr               94 239    1.531 M1
egr               94 239    6.607 M1
ggr               94 239    4.000 M1
sgr               94 239    0.624 E2
egr               94 239   10.152 E2
ggr               94 239    3.242 E2
sgr               94 239    0.001 M2
egr               94 239    6.607 M2
ggr               94 239    4.000 M2
##
## Fission parameters
##
fisbar            94 239    5.92000  1
fishw             94 239    0.60000  1
fisbar            94 239    5.93000  2
fishw             94 239    0.65000  2
##
```

```
##-----------------------------------------
##
## Parameters for 238Pu
##
## Level density
##
a                94 238  15.43123
Pshift           94 238   0.00000   0
deltaW           94 238  -0.60292   0
T                94 238   0.40399   0
E0               94 238  -0.03640   0
Exmatch          94 238   4.50212   0
Ntop             94 238  16   0
Nlow             94 238   2   0
Pshift           94 238   0.00000   1
deltaW           94 238   1.35000   1
T                94 238   0.35348   1
E0               94 238  -0.45002   1
Exmatch          94 238   3.39879   1
Pshift           94 238   0.00000   2
deltaW           94 238   0.60000   2
T                94 238   0.34900   2
E0               94 238  -0.10004   2
Exmatch          94 238   3.94849   2
##
## Gamma-ray
##
gamgam           94 238   0.04000
sgr              94 238 300.000 E1
egr              94 238  10.900 E1
ggr              94 238   2.500 E1
sgr              94 238 450.000 E1 2
egr              94 238  13.800 E1 2
ggr              94 238   4.700 E1 2
sgr              94 238   1.128 M1
egr              94 238   6.616 M1
ggr              94 238   4.000 M1
sgr              94 238   0.624 E2
egr              94 238  10.166 E2
ggr              94 238   3.254 E2
sgr              94 238   0.001 M2
egr              94 238   6.616 M2
ggr              94 238   4.000 M2
##
## Fission parameters
##
fisbar           94 238   5.55000  1
fishw            94 238   0.40000  1
fisbar           94 238   4.90000  2
fishw            94 238   2.00000  2
##-----------------------------------------
##
## Parameters for 237Pu
##
## Level density
##
a                94 237  15.92452
Pshift           94 237   0.00000   0
deltaW           94 237   1.87937   0
T                94 237   0.38021   0
E0               94 237  -0.74775   0
Exmatch          94 237   3.59285   0
Ntop             93 237  18   0
Nlow             93 237   8   0
Pshift           94 237   0.00000   1
deltaW           94 237   1.50000   1
T                94 237   0.25026   1
E0               94 237  -0.00003   1
Exmatch          94 237   2.19174   1
Pshift           94 237   3.70000   2
deltaW           94 237   0.80000   2
T                94 237   0.19062   2
E0               94 237  -0.22501   2
Exmatch          94 237   1.30412   2
##
## Gamma-ray
##
gamgam           94 237   0.04400
sgr              94 237 300.000 E1
egr              94 237  10.900 E1
ggr              94 237   2.500 E1
sgr              94 237 450.000 E1 2
egr              94 237  13.800 E1 2
ggr              94 237   4.700 E1 2
sgr              94 237   2.670 M1
egr              94 237   6.625 M1
ggr              94 237   4.000 M1
sgr              94 237   0.623 E2
egr              94 237  10.180 E2
ggr              94 237   3.266 E2
sgr              94 237   0.001 M2
egr              94 237   6.625 M2
ggr              94 237   4.000 M2
##
## Fission parameters
##
fisbar           94 237   5.16900  1
fishw            94 237   0.73300  1
fisbar           94 237   5.40000  2
fishw            94 237   0.30000  2
##-----------------------------------------
##
## Parameters for 236Pu
##
## Level density
##
a                94 236  15.93948
Pshift           94 236   0.00000   0
deltaW           94 236   2.22529   0
T                94 236   0.36524   0
E0               94 236   2.09308   0
Exmatch          94 236  11.59854   0
Ntop             94 236  14   0
Nlow             94 236   2   0
Pshift           94 236   2.50000   1
deltaW           94 236   1.50000   1
T                94 236   0.40937   1
E0               94 236  -2.41273   1
Exmatch          94 236   0.20970   1
Pshift           94 236   0.00000   2
deltaW           94 236   1.60000   2
T                94 236   0.50186   2
E0               94 236  -2.11865   2
Exmatch          94 236   0.64862   2
##
## Gamma-ray
##
gamgam           94 236   0.04400
sgr              94 236 707.911 E1
egr              94 236  13.335 E1
ggr              94 236   3.662 E1
sgr              94 236   1.115 M1
egr              94 236   6.635 M1
ggr              94 236   4.000 M1
sgr              94 236   0.623 E2
egr              94 236  10.195 E2
ggr              94 236   3.278 E2
sgr              94 236   0.001 M2
egr              94 236   6.635 M2
ggr              94 236   4.000 M2
##
## Fission parameters
##
fisbar           94 236   5.85000  1
fishw            94 236   1.10000  1
fisbar           94 236   5.90000  2
```

```
fishw            94 236   0.72000   2
##-----------------------------------------
##
## Parameters for 235Pu
##
## Level density
##
a                94 235  15.30221
Pshift           94 235   0.00000    0
deltaW           94 235   1.97910    0
T                94 235   0.60133    0
E0               94 235  -3.23101    0
Exmatch          94 235   8.01170    0
Ntop             94 235  10    0
Nlow             94 235   2    0
Pshift           94 235   0.50000    1
deltaW           94 235   1.50000    1
T                94 235   0.55133    1
E0               94 235  -0.15632    1
Exmatch          94 235   0.90131    1
Pshift           94 235   0.00000    2
deltaW           94 235   1.60000    2
T                94 235   0.55133    2
E0               94 235  -0.20594    2
Exmatch          94 235   2.67365    2
##
## Fission parameters
##
fisbar           94 235   4.80000   1
fishw            94 235   1.10000   1
fisbar           94 235   2.90000   2
fishw            94 235   0.50000   2
```

```
##-----------------------------------------
##
## Parameters for 234Pu
##
## Level density
##
a                94 234  15.36743
Pshift           94 234   0.00000    0
deltaW           94 234   2.17066    0
T                94 234   0.55887    0
E0               94 234   2.46135    0
Exmatch          94 234   9.78986    0
Ntop             94 234  10    0
Nlow             94 234   2    0
Pshift           94 234   0.00000    1
deltaW           94 234   1.50000    1
T                94 234   0.54887    1
E0               94 234   0.53507    1
Exmatch          94 234   3.63662    1
Pshift           94 234   0.00000    2
deltaW           94 234   0.60000    2
T                94 234   0.54887    2
E0               94 234   0.41380    2
Exmatch          94 234   3.40936    2
##
## Fission parameters
##
fisbar           94 234   4.80000   1
fishw            94 234   0.60000   1
fisbar           94 234   2.70000   2
fishw            94 234   0.60000   2
```

Input file for ^{237}Pu ENDL2011.3-ex2 TALYS-1.8 evaluation

```
#
# General
#
projectile n
element     Pu
mass        237
energy      energies
#
# Parameters
#
localomp n
deformfile 94 z094_deform.loc
autorot y
maxrot 5
maxlevelstar 30
preeqmode 2
twocomponent y
gammax 2
asys n
hbstate n
class2 n
inccalc y
eciscalc n
ecissave y
partable y
endf y
endfecis n
#
# Output
#
outdensity y
channels y
filechannels y
outgamma y
###
##-----------------------------------------
```

```
##
## Parameters for 238Pu
##
## Level density
##
a                94 238  15.43123
Pshift           94 238   0.00000    0
deltaW           94 238  -0.60292    0
T                94 238   0.40399    0
E0               94 238  -0.03640    0
Exmatch          94 238   4.50212    0
Ntop             94 238  16    0
Nlow             94 238   2    0
Pshift           94 238   0.00000    1
deltaW           94 238   1.35000    1
T                94 238   0.35348    1
E0               94 238  -0.45002    1
Exmatch          94 238   3.39879    1
Pshift           94 238   0.00000    2
deltaW           94 238   0.60000    2
T                94 238   0.34900    2
E0               94 238  -0.10004    2
Exmatch          94 238   3.94849    2
##
## Gamma-ray
##
gamgam           94 238   0.04000
sgr              94 238 300.000 E1
egr              94 238  10.900 E1
ggr              94 238   2.500 E1
sgr              94 238 450.000 E1  2
egr              94 238  13.800 E1  2
ggr              94 238   4.700 E1  2
sgr              94 238   1.128 M1
egr              94 238   6.616 M1
ggr              94 238   4.000 M1
```

```
sgr              94 238   0.624 E2
egr              94 238  10.166 E2
ggr              94 238   3.254 E2
sgr              94 238   0.001 M2
egr              94 238   6.616 M2
ggr              94 238   4.000 M2
##
## Fission parameters
##
fisbar           94 238   5.55000  1
fishw            94 238   0.40000  1
fisbar           94 238   4.90000  2
fishw            94 238   2.00000  2
##-----------------------------------------
##
## Parameters for 237Pu
##
## Level density
##
a                94 237  15.92452
Pshift           94 237   0.00000   0
deltaW           94 237   1.87937   0
T                94 237   0.38021   0
E0               94 237  -0.74775   0
Exmatch          94 237   3.59285   0
Ntop             93 237  18   0
Nlow             93 237   8   0
Pshift           94 237   0.00000   1
deltaW           94 237   1.50000   1
T                94 237   0.25026   1
E0               94 237  -0.00003   1
Exmatch          94 237   2.19174   1
Pshift           94 237   3.70000   2
deltaW           94 237   0.80000   2
T                94 237   0.19062   2
E0               94 237  -0.22501   2
Exmatch          94 237   1.30412   2
##
## Gamma-ray
##
gamgam           94 237   0.04400
sgr              94 237 300.000 E1
egr              94 237  10.900 E1
ggr              94 237   2.500 E1
sgr              94 237 450.000 E1 2
egr              94 237  13.800 E1 2
ggr              94 237   4.700 E1 2
sgr              94 237   2.670 M1
egr              94 237   6.625 M1
ggr              94 237   4.000 M1
sgr              94 237   0.623 E2
egr              94 237  10.180 E2
ggr              94 237   3.266 E2
sgr              94 237   0.001 M2
egr              94 237   6.625 M2
ggr              94 237   4.000 M2
##
## Fission parameters
##
fisbar           94 237   5.16900  1
fishw            94 237   0.73300  1
fisbar           94 237   5.40000  2
fishw            94 237   0.30000  2
##-----------------------------------------
##
## Parameters for 236Pu
##
## Level density
##
a                94 236  15.93948
Pshift           94 236   0.00000   0
deltaW           94 236   2.22529   0
T                94 236   0.36524   0
E0               94 236   2.09308   0
Exmatch          94 236  11.59854   0
Ntop             94 236  14   0
Nlow             94 236   2   0
Pshift           94 236   2.50000   1
deltaW           94 236   1.50000   1
T                94 236   0.40937   1
E0               94 236  -2.41273   1
Exmatch          94 236   0.20970   1
Pshift           94 236   0.00000   2
deltaW           94 236   1.60000   2
T                94 236   0.50186   2
E0               94 236  -2.11865   2
Exmatch          94 236   0.64862   2
##
## Gamma-ray
##
gamgam           94 236   0.04400
sgr              94 236 707.911 E1
egr              94 236  13.335 E1
ggr              94 236   3.662 E1
sgr              94 236   1.115 M1
egr              94 236   6.635 M1
ggr              94 236   4.000 M1
sgr              94 236   0.623 E2
egr              94 236  10.195 E2
ggr              94 236   3.278 E2
sgr              94 236   0.001 M2
egr              94 236   6.635 M2
ggr              94 236   4.000 M2
##
## Fission parameters
##
fisbar           94 236   5.85000  1
fishw            94 236   1.10000  1
fisbar           94 236   5.90000  2
fishw            94 236   0.72000  2
##-----------------------------------------
##
## Parameters for 235Pu
##
## Level density
##
a                94 235  15.30221
Pshift           94 235   0.00000   0
deltaW           94 235   1.97910   0
T                94 235   0.60133   0
E0               94 235  -3.23101   0
Exmatch          94 235   8.01170   0
Ntop             94 235  10   0
Nlow             94 235   2   0
Pshift           94 235   0.50000   1
deltaW           94 235   1.50000   1
T                94 235   0.55133   1
E0               94 235  -0.15632   1
Exmatch          94 235   0.90131   1
Pshift           94 235   0.00000   2
deltaW           94 235   1.60000   2
T                94 235   0.55133   2
E0               94 235  -0.20594   2
Exmatch          94 235   2.67365   2
##
## Fission parameters
##
fisbar           94 235   4.80000  1
fishw            94 235   1.10000  1
fisbar           94 235   2.90000  2
fishw            94 235   0.50000  2
##-----------------------------------------
##
## Parameters for 234Pu
##
## Level density
```

```
##
a                94 234  15.36743
Pshift           94 234   0.00000   0
deltaW           94 234   2.17066   0
T                94 234   0.55887   0
E0               94 234   2.46135   0
Exmatch          94 234   9.78986   0
Ntop             94 234  10    0
Nlow             94 234   2    0
Pshift           94 234   0.00000   1
deltaW           94 234   1.50000   1
T                94 234   0.54887   1
E0               94 234   0.53507   1
Exmatch          94 234   3.63662   1
Pshift           94 234   0.00000   2
deltaW           94 234   0.60000   2
T                94 234   0.54887   2
E0               94 234   0.41380   2
Exmatch          94 234   3.40936   2
##
## Fission parameters
##
fisbar           94 234   4.80000  1
fishw            94 234   0.60000  1
fisbar           94 234   2.70000  2
fishw            94 234   0.60000  2
```

Input file for ^{236}Pu ENDL2011.3-ex2 TALYS-1.8 evaluation

```
#
# General
#
projectile n
element    Pu
mass       236
energy     energies
#
# Parameters
#
localomp n
deformfile 94 z094_deform.loc
autorot y
maxrot 9
maxlevelstar 16
preeqmode 2
twocomponent y
gammax 2
asys n
hbstate n
class2 n
inccalc y
eciscalc y
ecissave y
partable y
endf y
endfecis n
#
# Output
#
outdensity y
channels y
filechannels y
outgamma y
###
##-------------------------------------------
##
## Parameters for 237Pu
##
## Level density
##
a                94 237  15.92452
Pshift           94 237   0.00000   0
deltaW           94 237   1.87937   0
T                94 237   0.38021   0
E0               94 237  -0.74775   0
Exmatch          94 237   3.59285   0
Ntop             93 237  18    0
Nlow             93 237   8    0
Pshift           94 237   0.00000   1
deltaW           94 237   1.50000   1
T                94 237   0.25026   1
E0               94 237  -0.00003   1
Exmatch          94 237   2.19174   1
Pshift           94 237   3.70000   2
deltaW           94 237   0.80000   2
T                94 237   0.19062   2
E0               94 237  -0.22501   2
Exmatch          94 237   1.30412   2
##
## Gamma-ray
##
gamgam           94 237   0.04400
sgr              94 237 300.000 E1
egr              94 237  10.900 E1
ggr              94 237   2.500 E1
sgr              94 237 450.000 E1 2
egr              94 237  13.800 E1 2
ggr              94 237   4.700 E1 2
sgr              94 237   2.670 M1
egr              94 237   6.625 M1
ggr              94 237   4.000 M1
sgr              94 237   0.623 E2
egr              94 237  10.180 E2
ggr              94 237   3.266 E2
sgr              94 237   0.001 M2
egr              94 237   6.625 M2
ggr              94 237   4.000 M2
##
## Fission parameters
##
fisbar           94 237   5.16900  1
fishw            94 237   0.73300  1
fisbar           94 237   5.40000  2
fishw            94 237   0.30000  2
##--------------------------------------------
##
## Parameters for 236Pu
##
## Level density
##
a                94 236  15.93948
Pshift           94 236   0.00000   0
deltaW           94 236   2.22529   0
T                94 236   0.36524   0
E0               94 236   2.09308   0
Exmatch          94 236  11.59854   0
Ntop             94 236  14    0
Nlow             94 236   2    0
Pshift           94 236   2.50000   1
deltaW           94 236   1.50000   1
T                94 236   0.40937   1
E0               94 236  -2.41273   1
Exmatch          94 236   0.20970   1
Pshift           94 236   0.00000   2
deltaW           94 236   1.60000   2
T                94 236   0.50186   2
E0               94 236  -2.11865   2
Exmatch          94 236   0.64862   2
##
```

```
## Gamma-ray
##
gamgam          94 236   0.04400
sgr             94 236 707.911 E1
egr             94 236  13.335 E1
ggr             94 236   3.662 E1
sgr             94 236   1.115 M1
egr             94 236   6.635 M1
ggr             94 236   4.000 M1
sgr             94 236   0.623 E2
egr             94 236  10.195 E2
ggr             94 236   3.278 E2
sgr             94 236   0.001 M2
egr             94 236   6.635 M2
ggr             94 236   4.000 M2
##
## Fission parameters
##
fisbar          94 236   5.85000  1
fishw           94 236   1.10000  1
fisbar          94 236   5.90000  2
fishw           94 236   0.72000  2
##----------------------------------------
##
## Parameters for 235Pu
##
## Level density
##
a               94 235  15.30221
Pshift          94 235   0.00000   0
deltaW          94 235   1.97910   0
T               94 235   0.60133   0
E0              94 235  -3.23101   0
Exmatch         94 235   8.01170   0
Ntop            94 235  10    0
Nlow            94 235   2    0
Pshift          94 235   0.50000   1
deltaW          94 235   1.50000   1
T               94 235   0.55133   1
E0              94 235  -0.15632   1
Exmatch         94 235   0.90131   1
Pshift          94 235   0.00000   2
deltaW          94 235   1.60000   2
T               94 235   0.55133   2
E0              94 235  -0.20594   2
Exmatch         94 235   2.67365   2
##
## Fission parameters
##
fisbar          94 235   4.80000  1
fishw           94 235   1.10000  1
fisbar          94 235   2.90000  2
fishw           94 235   0.50000  2
##----------------------------------------
##
## Parameters for 234Pu
##
## Level density
##
a               94 234  15.36743
Pshift          94 234   0.00000   0
deltaW          94 234   2.17066   0
T               94 234   0.55887   0
E0              94 234   2.46135   0
Exmatch         94 234   9.78986   0
Ntop            94 234  10    0
Nlow            94 234   2    0
Pshift          94 234   0.00000   1
deltaW          94 234   1.50000   1
T               94 234   0.54887   1
E0              94 234   0.53507   1
Exmatch         94 234   3.63662   1
Pshift          94 234   0.00000   2
deltaW          94 234   0.60000   2
T               94 234   0.54887   2
E0              94 234   0.41380   2
Exmatch         94 234   3.40936   2
##
## Fission parameters
##
fisbar          94 234   4.80000  1
fishw           94 234   0.60000  1
fisbar          94 234   2.70000  2
fishw           94 234   0.60000  2
```

Complete list TALYS parameters for ^{238}Pu ENDL2011.3-ex2 TALYS-1.8 evaluation[*]

```
##
## Parameters for 239Pu
##
## Level density
##
a               94 239  15.66123
aadjust         94 239   1.00000
gammald         94 239   0.07632
pair            94 239   0.77622
Pshift          94 239  -0.05000   0
Pshiftadjust    94 239   0.00000   0
deltaW          94 239  -0.42820   0
T               94 239   0.38269   0
E0              94 239  -0.00554   0
Exmatch         94 239   3.47184   0
Tadjust         94 239   1.00000   0
E0adjust        94 239   1.00000   0
Exmatchadjust   94 239   1.00000   0
Ntop            94 239  15    0
Nlow            94 239   4    0
s2adjust        94 239   1.00000   0
ctable          94 239   0.00000
ptable          94 239   0.00000
Krotconstant    94 239   1.00000   0
Pshift          94 239   0.00000   1
Pshiftadjust    94 239   0.00000   1
deltaW          94 239   1.80000   1
T               94 239   0.33772   1
E0              94 239  -1.15301   1
Exmatch         94 239   3.29458   1
Tadjust         94 239   1.00000   1
E0adjust        94 239   1.00000   1
Exmatchadjust   94 239   1.00000   1
Ntop            94 239   1    1
Nlow            94 239   0    1
s2adjust        94 239   1.00000   1
ctable          94 239   0.00000
ptable          94 239   0.00000
Krotconstant    94 239   1.00000   1
Pshift          94 239   1.07000   2
```

[*] To limit the size of the Appendix, only the parameters for the most relevant ^{239}Pu, ^{238}Pu, ^{237}Pu, ^{236}Pu, ^{235}Pu, and ^{234}Pu isotopes are reported here. The list of parameters for other isotopes can be made available upon request.

```
Pshiftadjust     94 239   0.00000   2
deltaW           94 239   3.40000   2
T                94 239   0.45169   2
E0               94 239  -1.92104   2
Exmatch          94 239   3.99940   2
Tadjust          94 239   1.00000   2
E0adjust         94 239   1.00000   2
Exmatchadjust    94 239   1.00000   2
Ntop             94 239   1   2
Nlow             94 239   0   2
s2adjust         94 239   1.00000   2
ctable           94 239   0.00000
ptable           94 239   0.00000
Krotconstant     94 239   1.00000   2
D0               94 239 8.30000E-03
g                94 239  15.93333
gp               94 239   6.26667
gn               94 239   9.66667
gnadjust         94 239   1.00000
gpadjust         94 239   1.00000
##
## Gamma-ray
##
gamgam           94 239   0.03400
gamgamadjust     94 239   1.00000
sgr              94 239 325.000 E1
egr              94 239  11.280 E1
ggr              94 239   2.480 E1
sgradjust        94 239   1.000 E1
egradjust        94 239   1.000 E1
ggradjust        94 239   1.000 E1
sgr              94 239 384.000 E1 2
egr              94 239  13.730 E1 2
ggr              94 239   4.250 E1 2
sgradjust        94 239   1.000 E1 2
egradjust        94 239   1.000 E1 2
ggradjust        94 239   1.000 E1 2
sgr              94 239   1.531 M1
egr              94 239   6.607 M1
ggr              94 239   4.000 M1
sgradjust        94 239   1.000 M1
egradjust        94 239   1.000 M1
ggradjust        94 239   1.000 M1
sgr              94 239   0.624 E2
egr              94 239  10.152 E2
ggr              94 239   3.242 E2
sgradjust        94 239   1.000 E2
egradjust        94 239   1.000 E2
ggradjust        94 239   1.000 E2
sgr              94 239   0.001 M2
egr              94 239   6.607 M2
ggr              94 239   4.000 M2
sgradjust        94 239   1.000 M2
egradjust        94 239   1.000 M2
ggradjust        94 239   1.000 M2
##
## Fission parameters
##
fisbar           94 239   5.92000  1
fishw            94 239   0.60000  1
fisbaradjust     94 239   1.00000  1
fishwadjust      94 239   1.00000  1
class2width      94 239   0.20000  1
Rtransmom        94 239   0.60000  1
Rclass2mom       94 239   1.00000  1
fisbar           94 239   5.93000  2
fishw            94 239   0.65000  2
fisbaradjust     94 239   1.00000  2
fishwadjust      94 239   1.00000  2
Rtransmom        94 239   1.00000  2
Rclass2mom       94 239   1.00000  2
##--------------------------------------------
--
```

```
##
## Parameters for 238Pu
##
## Level density
##
a                94 238  15.43123
aadjust          94 238   1.00000
gammald          94 238   0.07643
pair             94 238   1.55569
Pshift           94 238   0.00000   0
Pshiftadjust     94 238   0.00000   0
deltaW           94 238  -0.60292   0
T                94 238   0.40399   0
E0               94 238  -0.03640   0
Exmatch          94 238   4.50212   0
Tadjust          94 238   1.00000   0
E0adjust         94 238   1.00000   0
Exmatchadjust    94 238   1.00000   0
Ntop             94 238  16   0
Nlow             94 238   2   0
s2adjust         94 238   1.00000   0
ctable           94 238   0.00000
ptable           94 238   0.00000
Krotconstant     94 238   1.00000   0
Pshift           94 238   0.00000   1
Pshiftadjust     94 238   0.00000   1
deltaW           94 238   1.35000   1
T                94 238   0.35348   1
E0               94 238  -0.45002   1
Exmatch          94 238   3.39879   1
Tadjust          94 238   1.00000   1
E0adjust         94 238   1.00000   1
Exmatchadjust    94 238   1.00000   1
Ntop             94 238   1   1
Nlow             94 238   0   1
s2adjust         94 238   1.00000   1
ctable           94 238   0.00000
ptable           94 238   0.00000
Krotconstant     94 238   1.00000   1
Pshift           94 238   0.00000   2
Pshiftadjust     94 238   0.00000   2
deltaW           94 238   0.60000   2
T                94 238   0.34900   2
E0               94 238  -0.10004   2
Exmatch          94 238   3.94849   2
Tadjust          94 238   1.00000   2
E0adjust         94 238   1.00000   2
Exmatchadjust    94 238   1.00000   2
Ntop             94 238   1   2
Nlow             94 238   0   2
s2adjust         94 238   1.00000   2
ctable           94 238   0.00000
ptable           94 238   0.00000
Krotconstant     94 238   1.00000   2
D0               94 238 3.50000E-03
g                94 238  15.86667
gp               94 238   6.26667
gn               94 238   9.60000
gnadjust         94 238   1.00000
gpadjust         94 238   1.00000
##
## Gamma-ray
##
gamgam           94 238   0.04000
gamgamadjust     94 238   1.00000
sgr              94 238 300.000 E1
egr              94 238  10.900 E1
ggr              94 238   2.500 E1
sgradjust        94 238   1.000 E1
egradjust        94 238   1.000 E1
ggradjust        94 238   1.000 E1
sgr              94 238 450.000 E1 2
egr              94 238  13.800 E1 2
```

```
ggr              94 238   4.700 E1 2
sgradjust        94 238   1.000 E1 2
egradjust        94 238   1.000 E1 2
ggradjust        94 238   1.000 E1 2
sgr              94 238   1.128 M1
egr              94 238   6.616 M1
ggr              94 238   4.000 M1
sgradjust        94 238   1.000 M1
egradjust        94 238   1.000 M1
ggradjust        94 238   1.000 M1
sgr              94 238   0.624 E2
egr              94 238  10.166 E2
ggr              94 238   3.254 E2
sgradjust        94 238   1.000 E2
egradjust        94 238   1.000 E2
ggradjust        94 238   1.000 E2
sgr              94 238   0.001 M2
egr              94 238   6.616 M2
ggr              94 238   4.000 M2
sgradjust        94 238   1.000 M2
egradjust        94 238   1.000 M2
ggradjust        94 238   1.000 M2
##
## Fission parameters
##
fisbar           94 238   5.55000  1
fishw            94 238   0.40000  1
fisbaradjust     94 238   1.00000  1
fishwadjust      94 238   1.00000  1
class2width      94 238   0.20000  1
Rtransmom        94 238   0.60000  1
Rclass2mom       94 238   1.00000  1
fisbar           94 238   4.90000  2
fishw            94 238   2.00000  2
fisbaradjust     94 238   1.00000  2
fishwadjust      94 238   1.00000  2
Rtransmom        94 238   1.00000  2
Rclass2mom       94 238   1.00000  2
##--------------------------------------------
##
## Parameters for 237Pu
##
## Level density
##
a                94 237  15.92452
aadjust          94 237   1.00000
gammald          94 237   0.07653
pair             94 237   0.77948
Pshift           94 237   0.00000   0
Pshiftadjust     94 237   0.00000   0
deltaW           94 237   1.87937   0
T                94 237   0.38021   0
E0               94 237  -0.74775   0
Exmatch          94 237   3.59285   0
Tadjust          94 237   1.00000   0
E0adjust         94 237   1.00000   0
Exmatchadjust    94 237   1.00000   0
Ntop             94 237  15   0
Nlow             94 237   7   0
s2adjust         94 237   1.00000   0
ctable           94 237   0.00000
ptable           94 237   0.00000
Krotconstant     94 237   1.00000   0
Pshift           94 237   0.00000   1
Pshiftadjust     94 237   0.00000   1
deltaW           94 237   1.50000   1
T                94 237   0.25026   1
E0               94 237  -0.00003   1
Exmatch          94 237   2.19174   1
Tadjust          94 237   1.00000   1
E0adjust         94 237   1.00000   1
Exmatchadjust    94 237   1.00000   1
Ntop             94 237   1   1
Nlow             94 237   0   1
s2adjust         94 237   1.00000   1
ctable           94 237   0.00000
ptable           94 237   0.00000
Krotconstant     94 237   1.00000   1
Pshift           94 237   3.70000   2
Pshiftadjust     94 237   0.00000   2
deltaW           94 237   0.80000   2
T                94 237   0.19062   2
E0               94 237  -0.22501   2
Exmatch          94 237   1.30412   2
Tadjust          94 237   1.00000   2
E0adjust         94 237   1.00000   2
Exmatchadjust    94 237   1.00000   2
Ntop             94 237   1   2
Nlow             94 237   0   2
s2adjust         94 237   1.00000   2
ctable           94 237   0.00000
ptable           94 237   0.00000
Krotconstant     94 237   1.00000   2
D0               94 237 4.90000E-03
g                94 237  15.80000
gp               94 237   6.26667
gn               94 237   9.53333
gnadjust         94 237   1.00000
gpadjust         94 237   1.00000
##
## Gamma-ray
##
gamgam           94 237   0.04400
gamgamadjust     94 237   1.00000
sgr              94 237 300.000 E1
egr              94 237  10.900 E1
ggr              94 237   2.500 E1
sgradjust        94 237   1.000 E1
egradjust        94 237   1.000 E1
ggradjust        94 237   1.000 E1
sgr              94 237 450.000 E1 2
egr              94 237  13.800 E1 2
ggr              94 237   4.700 E1 2
sgradjust        94 237   1.000 E1 2
egradjust        94 237   1.000 E1 2
ggradjust        94 237   1.000 E1 2
sgr              94 237   2.670 M1
egr              94 237   6.625 M1
ggr              94 237   4.000 M1
sgradjust        94 237   1.000 M1
egradjust        94 237   1.000 M1
ggradjust        94 237   1.000 M1
sgr              94 237   0.623 E2
egr              94 237  10.180 E2
ggr              94 237   3.266 E2
sgradjust        94 237   1.000 E2
egradjust        94 237   1.000 E2
ggradjust        94 237   1.000 E2
sgr              94 237   0.001 M2
egr              94 237   6.625 M2
ggr              94 237   4.000 M2
sgradjust        94 237   1.000 M2
egradjust        94 237   1.000 M2
ggradjust        94 237   1.000 M2
##
## Fission parameters
##
fisbar           94 237   5.16900  1
fishw            94 237   0.73300  1
fisbaradjust     94 237   1.00000  1
fishwadjust      94 237   1.00000  1
class2width      94 237   0.20000  1
Rtransmom        94 237   0.60000  1
Rclass2mom       94 237   1.00000  1
fisbar           94 237   5.40000  2
fishw            94 237   0.30000  2
```

```
fisbaradjust     94 237   1.00000  2
fishwadjust      94 237   1.00000  2
Rtransmom        94 237   1.00000  2
Rclass2mom       94 237   1.00000  2
##-----------------------------------------
##
## Parameters for 236Pu
##
## Level density
##
a                94 236  15.93948
aadjust          94 236   1.00000
gammald          94 236   0.07664
pair             94 236   1.56227
Pshift           94 236   0.00000   0
Pshiftadjust     94 236   0.00000   0
deltaW           94 236   2.22529   0
T                94 236   0.36524   0
E0               94 236   2.09308   0
Exmatch          94 236  11.59854   0
Tadjust          94 236   1.00000   0
E0adjust         94 236   1.00000   0
Exmatchadjust    94 236   1.00000   0
Ntop             94 236  14   0
Nlow             94 236   2   0
s2adjust         94 236   1.00000   0
ctable           94 236   0.00000
ptable           94 236   0.00000
Krotconstant     94 236   1.00000   0
Pshift           94 236   2.50000   1
Pshiftadjust     94 236   0.00000   1
deltaW           94 236   1.50000   1
T                94 236   0.40937   1
E0               94 236  -2.41273   1
Exmatch          94 236   0.20970   1
Tadjust          94 236   1.00000   1
E0adjust         94 236   1.00000   1
Exmatchadjust    94 236   1.00000   1
Ntop             94 236   1   1
Nlow             94 236   0   1
s2adjust         94 236   1.00000   1
ctable           94 236   0.00000
ptable           94 236   0.00000
Krotconstant     94 236   1.00000   1
Pshift           94 236   0.00000   2
Pshiftadjust     94 236   0.00000   2
deltaW           94 236   1.60000   2
T                94 236   0.50186   2
E0               94 236  -2.11865   2
Exmatch          94 236   0.64862   2
Tadjust          94 236   1.00000   2
E0adjust         94 236   1.00000   2
Exmatchadjust    94 236   1.00000   2
Ntop             94 236   1   2
Nlow             94 236   0   2
s2adjust         94 236   1.00000   2
ctable           94 236   0.00000
ptable           94 236   0.00000
Krotconstant     94 236   1.00000   2
D0               94 236 4.70000E-03
g                94 236  15.73333
gp               94 236   6.26667
gn               94 236   9.46667
gnadjust         94 236   1.00000
gpadjust         94 236   1.00000
##
## Gamma-ray
##
gamgam           94 236   0.04400
gamgamadjust     94 236   1.00000
sgr              94 236 707.911 E1
egr              94 236  13.335 E1
ggr              94 236   3.662 E1
sgradjust        94 236   1.000 E1
egradjust        94 236   1.000 E1
ggradjust        94 236   1.000 E1
sgr              94 236   1.115 M1
egr              94 236   6.635 M1
ggr              94 236   4.000 M1
sgradjust        94 236   1.000 M1
egradjust        94 236   1.000 M1
ggradjust        94 236   1.000 M1
sgr              94 236   0.623 E2
egr              94 236  10.195 E2
ggr              94 236   3.278 E2
sgradjust        94 236   1.000 E2
egradjust        94 236   1.000 E2
ggradjust        94 236   1.000 E2
sgr              94 236   0.001 M2
egr              94 236   6.635 M2
ggr              94 236   4.000 M2
sgradjust        94 236   1.000 M2
egradjust        94 236   1.000 M2
ggradjust        94 236   1.000 M2
##
## Fission parameters
##
fisbar           94 236   5.85000  1
fishw            94 236   1.10000  1
fisbaradjust     94 236   1.00000  1
fishwadjust      94 236   1.00000  1
class2width      94 236   0.20000  1
Rtransmom        94 236   0.60000  1
Rclass2mom       94 236   1.00000  1
fisbar           94 236   5.90000  2
fishw            94 236   0.72000  2
fisbaradjust     94 236   1.00000  2
fishwadjust      94 236   1.00000  2
Rtransmom        94 236   1.00000  2
Rclass2mom       94 236   1.00000  2
##-----------------------------------------
##
## Parameters for 235Pu
##
## Level density
##
a                94 235  15.30221
aadjust          94 235   1.00000
gammald          94 235   0.07675
pair             94 235   0.78279
Pshift           94 235   0.00000   0
Pshiftadjust     94 235   0.00000   0
deltaW           94 235   1.97910   0
T                94 235   0.60133   0
E0               94 235  -3.23101   0
Exmatch          94 235   8.01170   0
Tadjust          94 235   1.00000   0
E0adjust         94 235   1.00000   0
Exmatchadjust    94 235   1.00000   0
Ntop             94 235  10   0
Nlow             94 235   2   0
s2adjust         94 235   1.00000   0
ctable           94 235   0.00000
ptable           94 235   0.00000
Krotconstant     94 235   1.00000   0
Pshift           94 235   0.50000   1
Pshiftadjust     94 235   0.00000   1
deltaW           94 235   1.50000   1
T                94 235   0.55133   1
E0               94 235  -0.15632   1
Exmatch          94 235   0.90131   1
Tadjust          94 235   1.00000   1
E0adjust         94 235   1.00000   1
Exmatchadjust    94 235   1.00000   1
Ntop             94 235   1   1
Nlow             94 235   0   1
```

```
s2adjust         94 235   1.00000   1
ctable           94 235   0.00000
ptable           94 235   0.00000
Krotconstant     94 235   1.00000   1
Pshift           94 235   0.00000   2
Pshiftadjust     94 235   0.00000   2
deltaW           94 235   1.60000   2
T                94 235   0.55133   2
E0               94 235  -0.20594   2
Exmatch          94 235   2.67365   2
Tadjust          94 235   1.00000   2
E0adjust         94 235   1.00000   2
Exmatchadjust    94 235   1.00000   2
Ntop             94 235   1   2
Nlow             94 235   0   2
s2adjust         94 235   1.00000   2
ctable           94 235   0.00000
ptable           94 235   0.00000
Krotconstant     94 235   1.00000   2
g                94 235  15.66667
gp               94 235   6.26667
gn               94 235   9.40000
gnadjust         94 235   1.00000
gpadjust         94 235   1.00000
##
## Gamma-ray
##
gamgam           94 235   0.03000
gamgamadjust     94 235   1.00000
sgr              94 235 704.602 E1
egr              94 235  13.348 E1
ggr              94 235   3.669 E1
sgradjust        94 235   1.000 E1
egradjust        94 235   1.000 E1
ggradjust        94 235   1.000 E1
sgr              94 235   1.108 M1
egr              94 235   6.644 M1
ggr              94 235   4.000 M1
sgradjust        94 235   1.000 M1
egradjust        94 235   1.000 M1
ggradjust        94 235   1.000 M1
sgr              94 235   0.622 E2
egr              94 235  10.209 E2
ggr              94 235   3.290 E2
sgradjust        94 235   1.000 E2
egradjust        94 235   1.000 E2
ggradjust        94 235   1.000 E2
sgr              94 235   0.001 M2
egr              94 235   6.644 M2
ggr              94 235   4.000 M2
sgradjust        94 235   1.000 M2
egradjust        94 235   1.000 M2
ggradjust        94 235   1.000 M2
##
## Fission parameters
##
fisbar           94 235   4.80000  1
fishw            94 235   1.10000  1
fisbaradjust     94 235   1.00000  1
fishwadjust      94 235   1.00000  1
class2width      94 235   0.20000  1
Rtransmom        94 235   0.60000  1
Rclass2mom       94 235   1.00000  1
fisbar           94 235   2.90000  2
fishw            94 235   0.50000  2
fisbaradjust     94 235   1.00000  2
fishwadjust      94 235   1.00000  2
Rtransmom        94 235   1.00000  2
Rclass2mom       94 235   1.00000  2
##-----------------------------------------
##
## Parameters for 234Pu
##
## Level density
##
a                94 234  15.36743
aadjust          94 234   1.00000
gammald          94 234   0.07686
pair             94 234   1.56893
Pshift           94 234   0.00000   0
Pshiftadjust     94 234   0.00000   0
deltaW           94 234   2.17066   0
T                94 234   0.55887   0
E0               94 234   2.46135   0
Exmatch          94 234   9.78986   0
Tadjust          94 234   1.00000   0
E0adjust         94 234   1.00000   0
Exmatchadjust    94 234   1.00000   0
Ntop             94 234  10   0
Nlow             94 234   2   0
s2adjust         94 234   1.00000   0
ctable           94 234   0.00000
ptable           94 234   0.00000
Krotconstant     94 234   1.00000   0
Pshift           94 234   0.00000   1
Pshiftadjust     94 234   0.00000   1
deltaW           94 234   1.50000   1
T                94 234   0.54887   1
E0               94 234   0.53507   1
Exmatch          94 234   3.63662   1
Tadjust          94 234   1.00000   1
E0adjust         94 234   1.00000   1
Exmatchadjust    94 234   1.00000   1
Ntop             94 234   1   1
Nlow             94 234   0   1
s2adjust         94 234   1.00000   1
ctable           94 234   0.00000
ptable           94 234   0.00000
Krotconstant     94 234   1.00000   1
Pshift           94 234   0.00000   2
Pshiftadjust     94 234   0.00000   2
deltaW           94 234   0.60000   2
T                94 234   0.54887   2
E0               94 234   0.41380   2
Exmatch          94 234   3.40936   2
Tadjust          94 234   1.00000   2
E0adjust         94 234   1.00000   2
Exmatchadjust    94 234   1.00000   2
Ntop             94 234   1   2
Nlow             94 234   0   2
s2adjust         94 234   1.00000   2
ctable           94 234   0.00000
ptable           94 234   0.00000
Krotconstant     94 234   1.00000   2
g                94 234  15.60000
gp               94 234   6.26667
gn               94 234   9.33333
gnadjust         94 234   1.00000
gpadjust         94 234   1.00000
##
## Gamma-ray
##
gamgam           94 234   0.03000
gamgamadjust     94 234   1.00000
sgr              94 234 701.281 E1
egr              94 234  13.362 E1
ggr              94 234   3.676 E1
sgradjust        94 234   1.000 E1
egradjust        94 234   1.000 E1
ggradjust        94 234   1.000 E1
sgr              94 234   1.177 M1
egr              94 234   6.653 M1
ggr              94 234   4.000 M1
sgradjust        94 234   1.000 M1
egradjust        94 234   1.000 M1
ggradjust        94 234   1.000 M1
```

```
sgr              94 234   0.622 E2
egr              94 234  10.224 E2
ggr              94 234   3.302 E2
sgradjust        94 234   1.000 E2
egradjust        94 234   1.000 E2
ggradjust        94 234   1.000 E2
sgr              94 234   0.001 M2
egr              94 234   6.653 M2
ggr              94 234   4.000 M2
sgradjust        94 234   1.000 M2
egradjust        94 234   1.000 M2
fisbar           94 234   2.70000  2
fishw            94 234   0.60000  2
fisbaradjust     94 234   1.00000  2
fishwadjust      94 234   1.00000  2
Rtransmom        94 234   1.00000  2
Rclass2mom       94 234   1.00000  2
##
## General parameters
##
## Level density
##
alphald           0.02073
betald            0.22954
gammashell1       0.47363
gammashell2       0.00000
pairconstant     12.00000
pshiftconstant    0.00000
Rspincut          1.00000
cglobal         1.00000E-20
pglobal         1.00000E-20
Ufermi           30.00000
cfermi            5.00000
Ufermibf         45.00000
cfermibf          5.00000
ggradjust        94 234   1.000 M2
##
## Fission parameters
##
fisbar           94 234   4.80000  1
fishw            94 234   0.60000  1
fisbaradjust     94 234   1.00000  1
fishwadjust      94 234   1.00000  1
class2width      94 234   0.20000  1
Rtransmom        94 234   0.60000  1
Rclass2mom       94 234   1.00000  1
Kph              15.00000
##
## Gamma-ray
##
gnorm             2.63912
xscaptherm      5.40000E+05
##
## Pre-equilibrium
##
M2constant        1.00000
M2limit           1.00000
M2shift           1.00000
Rpipi             1.00000
Rnunu             1.50000
Rpinu             1.00000
Rnupi             1.00000
Rgamma            2.00000
Esurf            13.76215
Cstrip        d   1.00000
Cstrip        t   1.00000
Cstrip        h   1.00000
Cstrip        a   1.00000
Cknock        a   1.00000
```