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Preliminary n -bar Covariances for $^{238,242}\text{Pu}$ and $^{242,243,244,245}\text{Cm}$

by

D. Rochman, M. Herman, P. Oblozinsky,
S. F. Mughabghab

February 2007

Report prepared for WPEC Subgroup 26
"Nuclear Data Needs for Advanced Reactor Systems"
Proposed by P.J.Finck, coordinated by: M. Salvatores

**Energy Sciences & Technology Department
National Nuclear Data Center**

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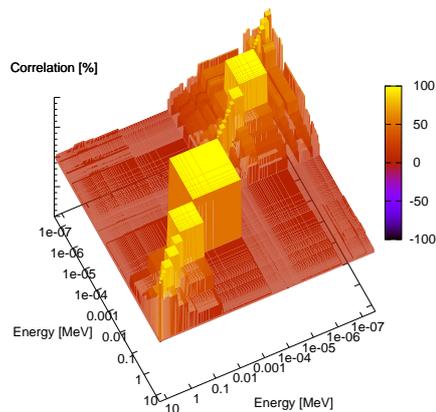
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**D. Rochman, M. Herman, P. Obložinský,
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We report preliminary new ν -bar covariances developed for the WPEC Subgroup 26 for 6 out of 19 requested actinides. For convenience, preliminary results for 10 other isotopes are also presented, taken from a previous report. The covariances were produced in 15-group representations as follows:

- 6 isotopes: $^{238,242}\text{Pu}$ and $^{242,243,244,245}\text{Cm}$ were evaluated using a simple methodology, presented in this report;
- 10 isotopes were taken from a previous report: ^{237}Np , $^{241,242m,243}\text{Am}$, $^{233,235,238}\text{U}$ and $^{239,240,241}\text{Pu}$.

Further work is needed to resolve some of the issues and to produce covariances for the full set of 19 materials.

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Chapter 1

Introduction

This report presents a set of preliminary ν -bar covariances produced for the OECD Nuclear Energy Agency, Working Party on International Nuclear Data Evaluation Co-operation (WPEC), Subgroup 26. Following the proposal by P. Finck, ANL (now INL), SG26 “Nuclear Data Needs for Advanced Reactor Systems” has been established in 2005. Its charge is to identify nuclear data needs for advanced nuclear power reactors (Gen-IV) using sensitivity analysis. To this end, a considerable amount of covariance data is needed.

SG26, chaired by M. Salvatores, CEA Cadarache and ANL, prepared a list of materials relevant to its charge. When translated into the list of isotopes, it consists of 19 actinides and 33 structural, coolant and moderator materials. SG26 is interested in ν -bar covariances for 19 actinides [1, 2]. These covariances should be provided in the 15-group representation, from the thermal energy up to 20 MeV.

Table 1.1 provides a complete list of covariances of interest to SG26 (52 in total), ordered by priority. The first two priority groups of isotopes will enable to complete the study for fast sodium cooled reactors. The third group should be available in order to complete Gen-IV system study foreseen by SG26. The last two priority groups are needed for more detailed analysis of advanced systems.

This report presents ν -bar covariances for 16 actinides out of the 19 requested (6 new and 10 taken from a previous report [3], see Table 1.1. The ν -bar covariances not finalized so far are indicated in underlined italic where further work is needed.

The present report is organized as follows: Chapter 2 is devoted to procedures and results for ν -bar covariances, with resulting plots and tables given in Appendix A. Our conclusions are given in Chapter 3.

Table 1.1: Priority list of WPEC SG26 materials for σ_{el} , σ_{inl} , $\sigma_{n,2n}$, σ_{capt} , σ_f cross section covariances in 15-energy groups. The cross section covariances not finalized so far are indicated in underlined *italic*, see Ref. [3]. The ν -bar covariances are required for all actinides. The ν -bar covariances not finalized so far are indicated in red.

Priority	Actinides	Sum	Structural Materials	Sum
1	<u>^{235}U</u> ^{238}U	2		
	^{239}Pu	1		
2	^{237}Np	1		
	^{240}Pu ^{241}Pu	2		
	^{241}Am ^{242m}Am ^{243}Am	3		
3			^{16}O	1
			^{23}Na	1
			^{52}Cr	1
			^{58}Ni	1
4			^1H	1
			<u>^{12}C</u>	1
			<u>^{28}Si</u>	1
			^{90}Zr ^{91}Zr ^{92}Zr	3
			^{94}Zr	1
			^{206}Pb ^{207}Pb ^{208}Pb	3
			^{209}Bi	1
5	<u>^{232}Th</u>	1	<u>^4He</u>	1
	^{233}U <u>^{234}U</u> <u>^{236}U</u>	3	<u>^6Li</u> <u>^7Li</u>	2
	^{238}Pu ^{242}Pu	2	<u>^9Be</u>	1
	^{242}Cm ^{243}Cm ^{244}Cm	3	<u>^{10}B</u>	1
	^{245}Cm	1	^{19}F	1
			^{27}Al	1
			^{56}Fe ^{57}Fe	2
			^{155}Gd ^{156}Gd ^{157}Gd	3
			^{158}Gd ^{160}Gd	2
			^{166}Er ^{167}Er ^{168}Er	3
			^{170}Er	1
Total		19		33
Presented in this report		18		27

Chapter 2

ν -bar Covariances

2.1 Procedure

The covariances for the average number of neutrons per fission (total ν -bar) were produced for 16 priority actinides listed in Table 1.1 following considerations listed below:

First, for $^{233,235,238}\text{U}$ and $^{239,240,241}\text{Pu}$ we used the data from the JENDL-3.3 library released in 2002. These data were processed by us in the 15-energy group representation with a constant flux.

Second, for ^{237}Np , $^{238,242}\text{Pu}$, $^{241,242m,243}\text{Am}$ and $^{242,243,244,245}\text{Cm}$, simple estimates were made. In doing so we made sure that our uncertainties agree reasonably well with the experimental data, while the correlations were assumed to be the same as those of the appropriately selected neighboring nuclei. Our procedure consisted of three steps:

- We took into account the odd-even effects and assumed that there is reasonable similarity between ν -bar covariances for corresponding nuclei. In other words, we assumed that the uncertainties for odd or even nuclei have similar shape respectively (if there are no experimental data) while the correlations are identical.
- We took thermal ν -bar uncertainties from the Atlas of Neutron Resonances [4] or estimated it from the spread of the evaluated values in different libraries. Then we used these thermal values to normalize energy dependence of the ν -bar uncertainties.
- The renormalized uncertainties were checked against the available data at higher energies and the ν -bar uncertainties were adjusted as necessary.

^{238}Pu .

At thermal energy, the uncertainty on ν -bar is equal to 2.4 %. This value is obtained from the spread of evaluated ν -bars for ^{238}Pu between ENDF/B-VII.0, JENDL-3.3, JEFF-3.1 and the Atlas. At higher energy, uncertainties gradually increase up to to the only available experimental datum at 1 MeV [5]. Above 1 MeV, the ν -bar

uncertainty is decreasing as the fission cross section increases.

²⁴²Pu.

At thermal energy, the uncertainty on ν -bar is equal to 4.0 %. This value is obtained from the normalization of the ²⁴⁰Pu ν -bar shape to the only available set of experimental data above 300 keV [6]. The resulting thermal value is higher than the 2.0 % spread between ENDF/B-VII.0, and JENDL-3.3. This uncertainty is propagated up to 500 keV. Above 500 keV, the ν -bar uncertainty is decreasing to reach values about 1 % above the data from Ref. [6]. We attribute this excess to possible uncertainty on ν -bar for ²⁵²Cf(sf), used as a monitor during the experiment.

^{242,244}Cm.

For both isotopes the uncertainty on ν -bar at thermal energy is equal to 5.6 %. This value is obtained from the spread of evaluated ν -bars for ²⁴²Cm between ENDF/B-VII.0, and JENDL-3.3. For ²⁴⁴Cm, the same evaluated value is found in the three libraries and no value is given in the Atlas. No experimental data exist at higher energies. The 5.6 % uncertainty is propagated up to 1 MeV. Above 1 MeV, the uncertainty is a factor of two larger than at thermal neutron energy.

²⁴³Cm.

At thermal energy, the uncertainty on ν -bar is equal to 1.3 %. This value is obtained from the spread of evaluated ν -bars between ENDF/B-VII.0, JEFF-3.1 and the Atlas. This uncertainty is propagated up to 6 MeV. Above 6 MeV, the uncertainty increases up to 10 % in the absence of experimental data.

²⁴⁵Cm.

At thermal energy, the uncertainty on ν -bar is equal to 3.0 %. This value is obtained from the difference of ν -bars in ENDF/B-VII.0 and in the Atlas. This uncertainty is propagated up to 6 MeV, while for higher energies it increases up to 10 %, in good agreement with experimental uncertainties [6, 7, 8].

2.2 Results

The ν -bar covariances are provided only for the first 16 actinides, listed in Table 2.1. The plots and tables are given in Appendix A for $^{233,235,238}\text{U}$, $^{238,239,240,241,242}\text{Pu}$, ^{237}Np , $^{241,242m,243}\text{Am}$, and $^{242,243,244,245}\text{Cm}$. The remaining ν -bar covariances (3 actinides, all priority 5) will be produced later in 2007.

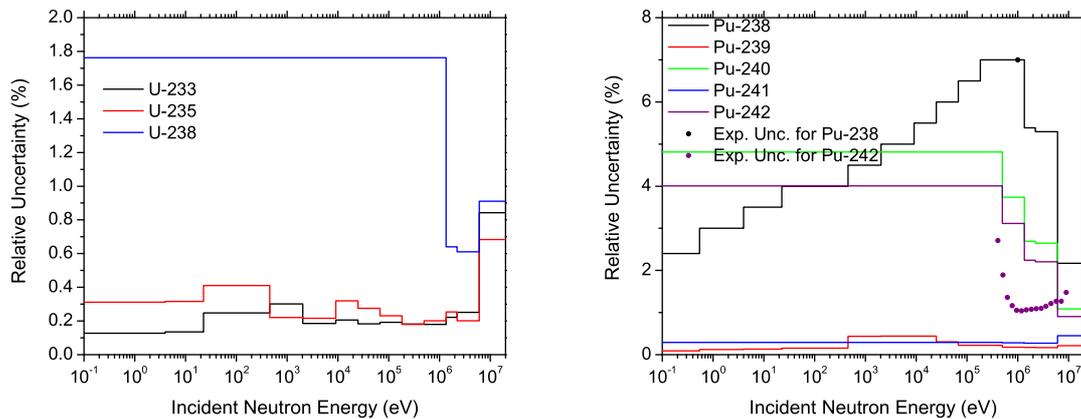


Figure 2.1: ν -bar uncertainties for uranium isotopes (left) and plutonium isotopes (right).

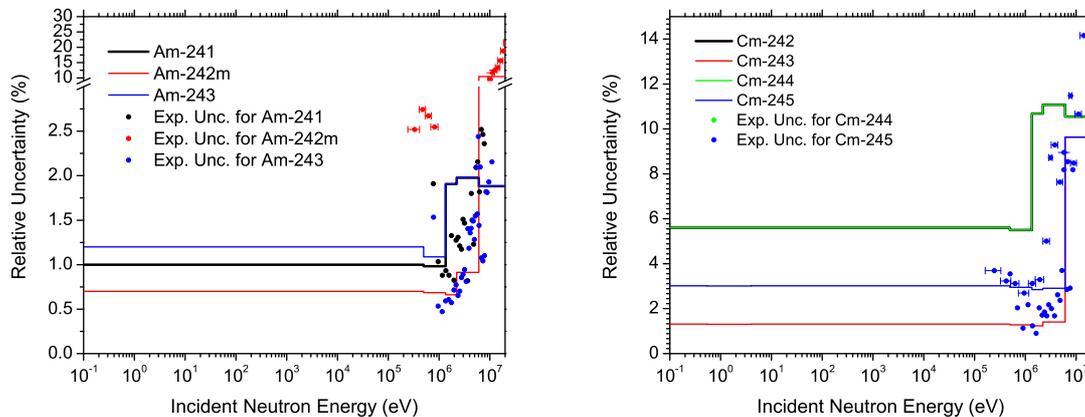


Figure 2.2: ν -bar uncertainties for americium isotopes (left) and curium isotopes (right).

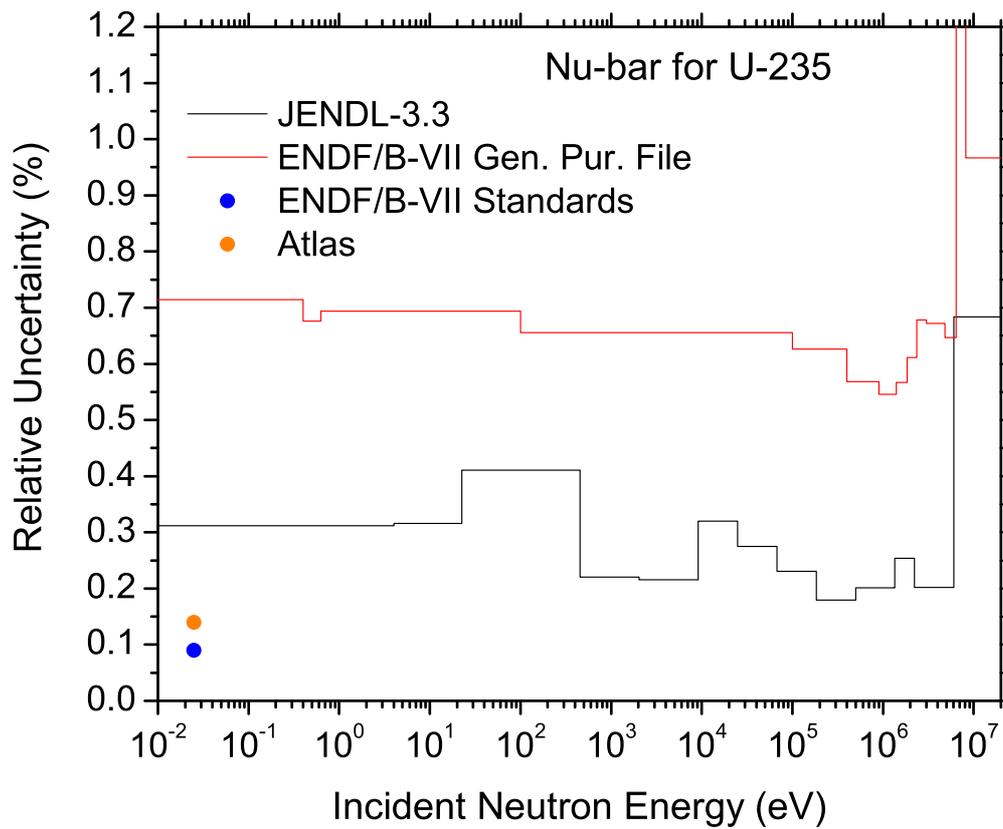


Figure 2.3: ν -bar uncertainties for uranium-235 from JENDL-3.3, ENDF/B-VII.0 general purpose file, from the standards file and the Atlas of Neutron Resonances.

Table 2.1: Total ν -bar at thermal energy (0.0253 eV). ^(p) means prompt.

$\bar{\nu}_{tot}$	Standards	ENDF/B-VII.0	JENDL-3.3	JEFF-3.1	Atlas	This work
²³³ U	2.497 ± 0.14 %	2.497	2.48771 ± 0.13 %	2.4877 ± 0.13 %	2.493 ± 0.16 %	± 0.13 %
²³⁵ U	2.4355 ± 0.09 %	2.4367 ± 0.71 %	2.43633 ± 0.32 %	2.4362	2.4251 ± 0.14 %	± 0.31 %
²³⁸ U	—	2.2921	2.48754 ± 1.76 %	2.4076	—	± 1.76 %
²³⁷ Np		2.63561	2.6014	2.6014	2.525 ^(p) ± 0.63 %	± 0.60 %
²³⁸ Pu		2.895	2.8447	2.8947	2.900 ^(p) ± 0.69 %	± 2.40 %
²³⁹ Pu	2.8836 ± 0.16 %	2.8789	2.88432 ± 0.10 %	2.8778	2.879 ± 0.21 %	± 0.09 %
²⁴⁰ Pu		2.803	2.78391 ± 4.81 %	2.881		± 4.81 %
²⁴¹ Pu	2.9479 ± 0.18 %	2.9453	2.9313 ± 0.29 %	2.9313	2.924 ± 0.24 %	± 0.29 %
²⁴² Pu		2.810	2.8594	2.8595	—	± 4.00 %
²⁴¹ Am		3.08027	3.0599	3.2388	3.213 ^(p) ± 1.00 %	± 1.00 %
^{242m} Am		3.2705	3.2705	3.2705	3.260 ^(p) ± 0.73 %	± 0.70 %
²⁴³ Am		3.2728	3.2085	3.2085	3.214 ^(p) ± 1.18 %	± 1.20 %
²⁴² Cm		3.44	3.252	3.44	—	± 5.60 %
²⁴³ Cm		3.432	3.432	3.433	3.430 ^(p) ± 1.37 %	± 1.30 %
²⁴⁴ Cm		3.244	3.244	3.244	—	± 5.60 %
²⁴⁵ Cm		3.5964	3.596	3.5964	3.717 ± 1.61 %	± 3.00 %

Chapter 3

Conclusions, Bibliography

The preliminary covariances for ν -bar are reported for 16 actinides. For 6 materials we used the recent evaluated data libraries, the other 10 materials are based on simple estimates. The latter should be reevaluated using proper tools and techniques applied to the specific isotopes.

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Appendix A

In the following, plots for the relative ν -bar uncertainties and correlations are given in the 15-energy group representation.

Table A.1: Definition of the 15-energy groups

Group no.	Energy Max (eV)	Energy Min (eV)
1	19.6 E+06	6.07 E+06
2	6.07 E+06	2.23 E+06
3	2.23 E+06	1.35 E+06
4	1.35 E+06	4.98 E+05
5	4.98 E+05	1.83 E+05
6	1.83 E+05	6.74 E+04
7	6.74 E+04	2.48 E+04
8	2.48 E+04	9.12 E+03
9	9.12 E+03	2.04 E+03
10	2.04 E+03	4.54 E+02
11	4.54 E+02	2.26 E+01
12	2.26 E+01	4.00 E+00
13	4.00 E+00	5.40 E-01
14	5.40 E-01	1.00 E-01
15	1.00 E-01	1.00 E-05

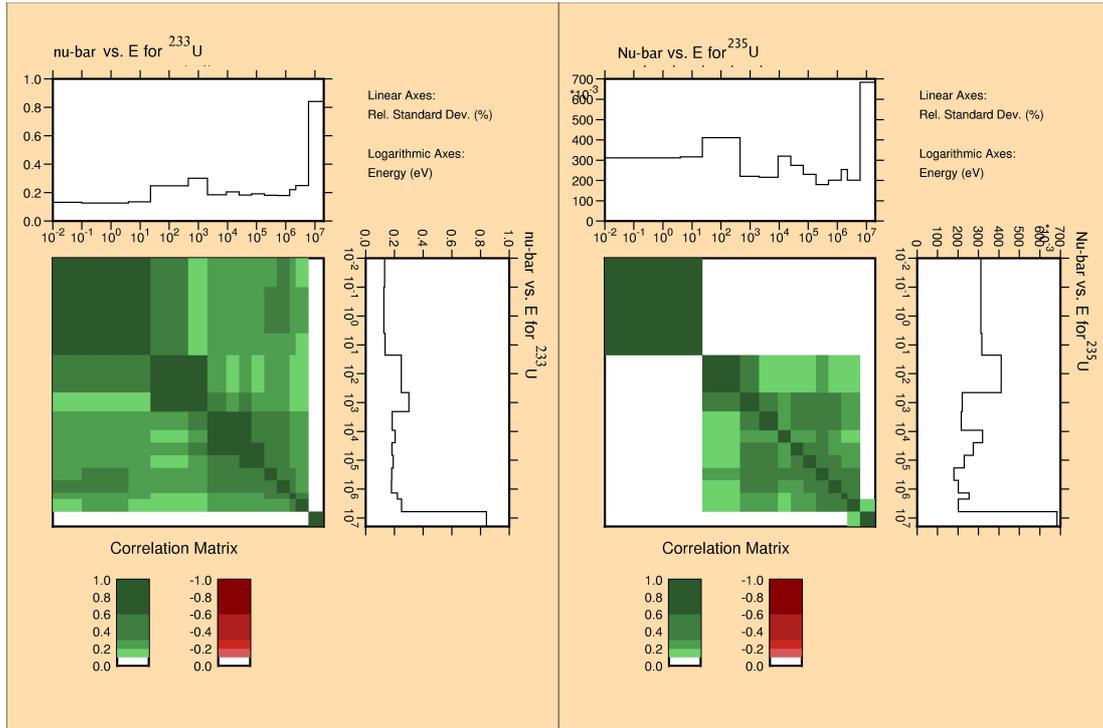


Figure A.1: Correlation and uncertainties for $\bar{\nu}$ in 15 groups for the ^{233}U (left) and ^{235}U (right).

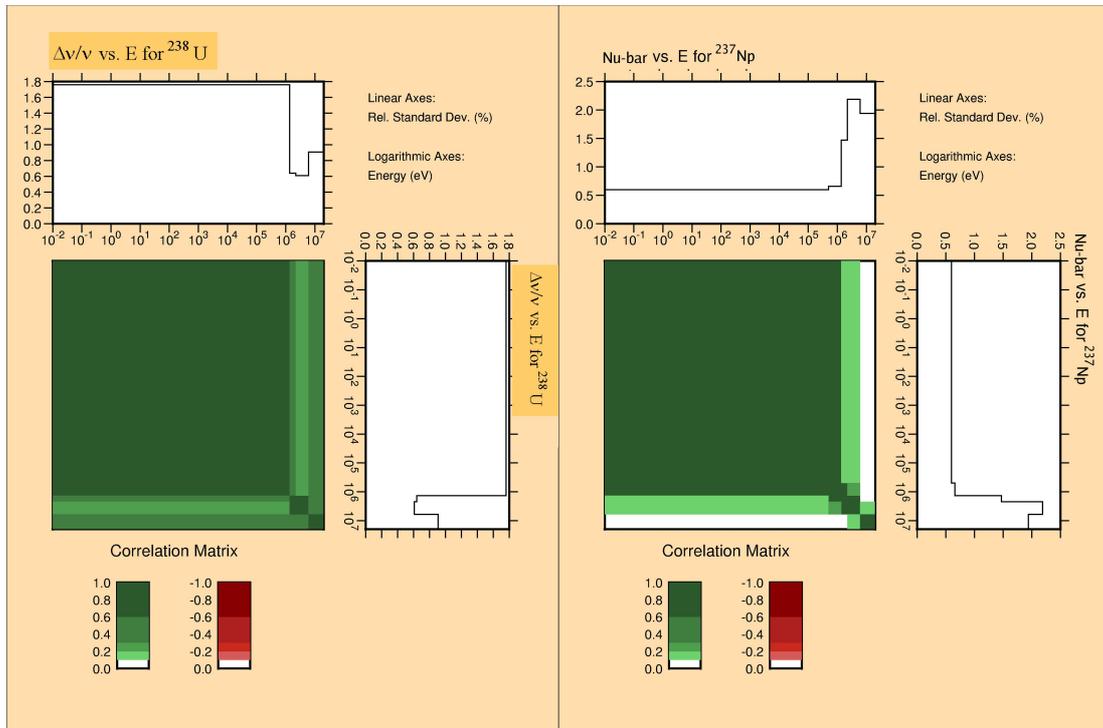


Figure A.2: Correlation and uncertainties for $\bar{\nu}$ in 15 groups for the ^{238}U (left) and ^{237}Np (right).

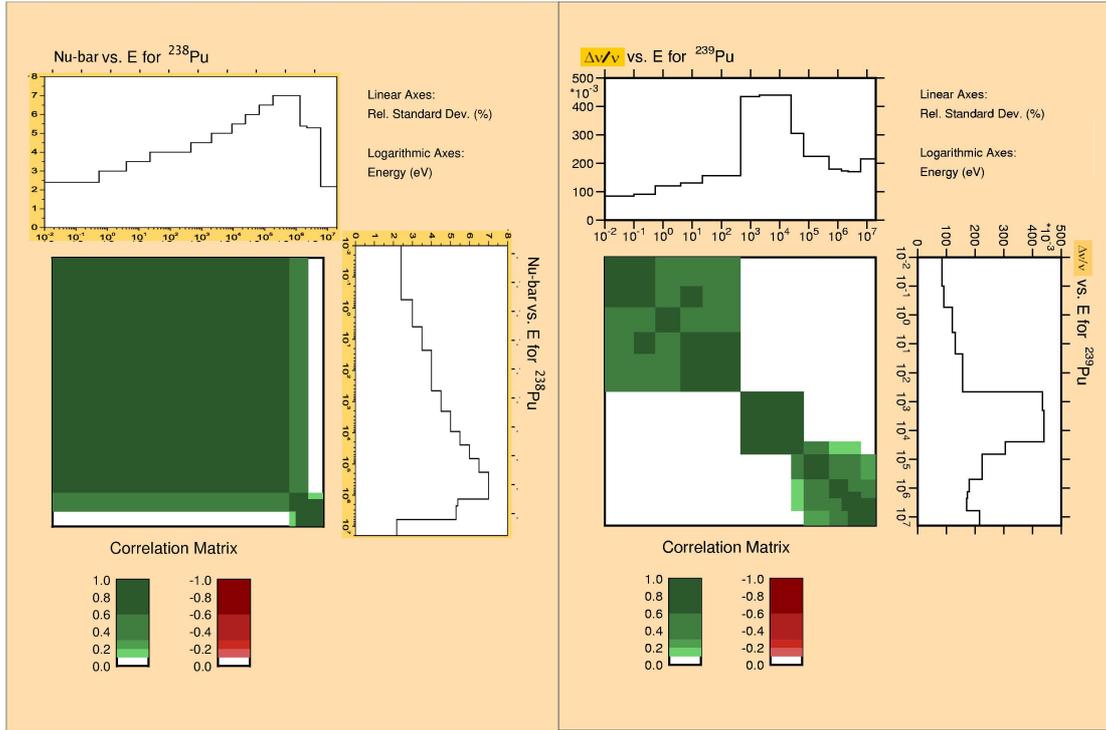


Figure A.3: Correlation and uncertainties for $\bar{\nu}$ in 15 groups for the ^{238}Pu (left) and ^{239}Pu (right).

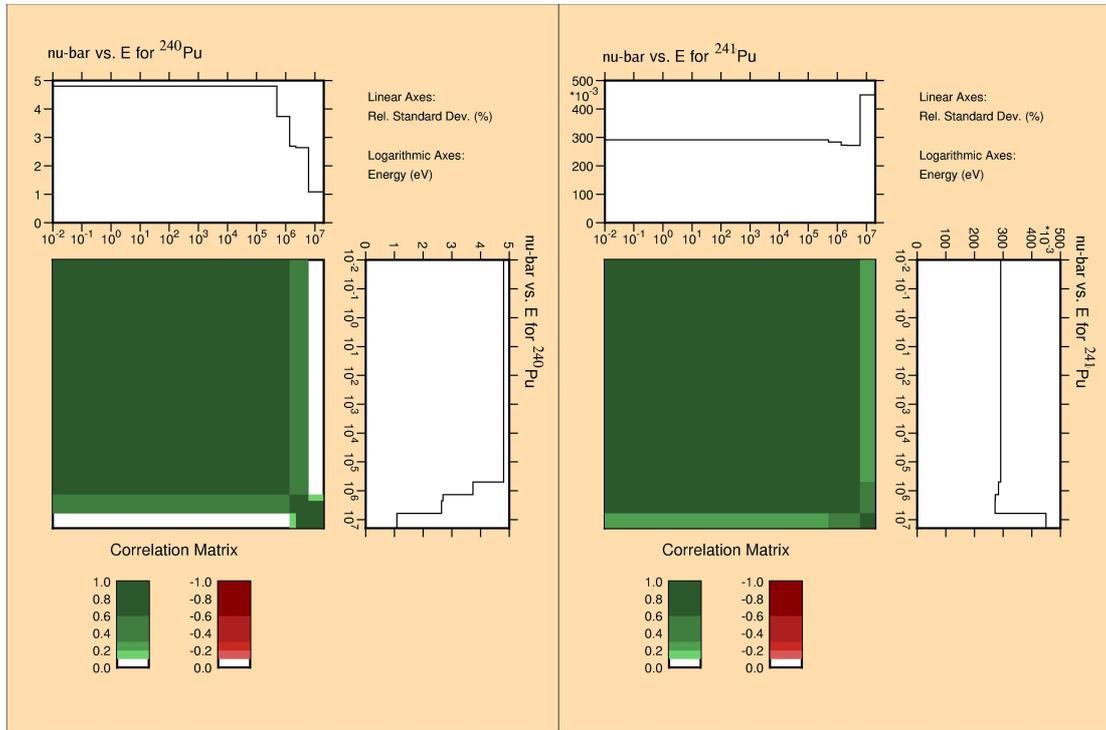


Figure A.4: Correlation and uncertainties for $\bar{\nu}$ in 15 groups for the ^{240}Pu (left) and ^{241}Pu (right).

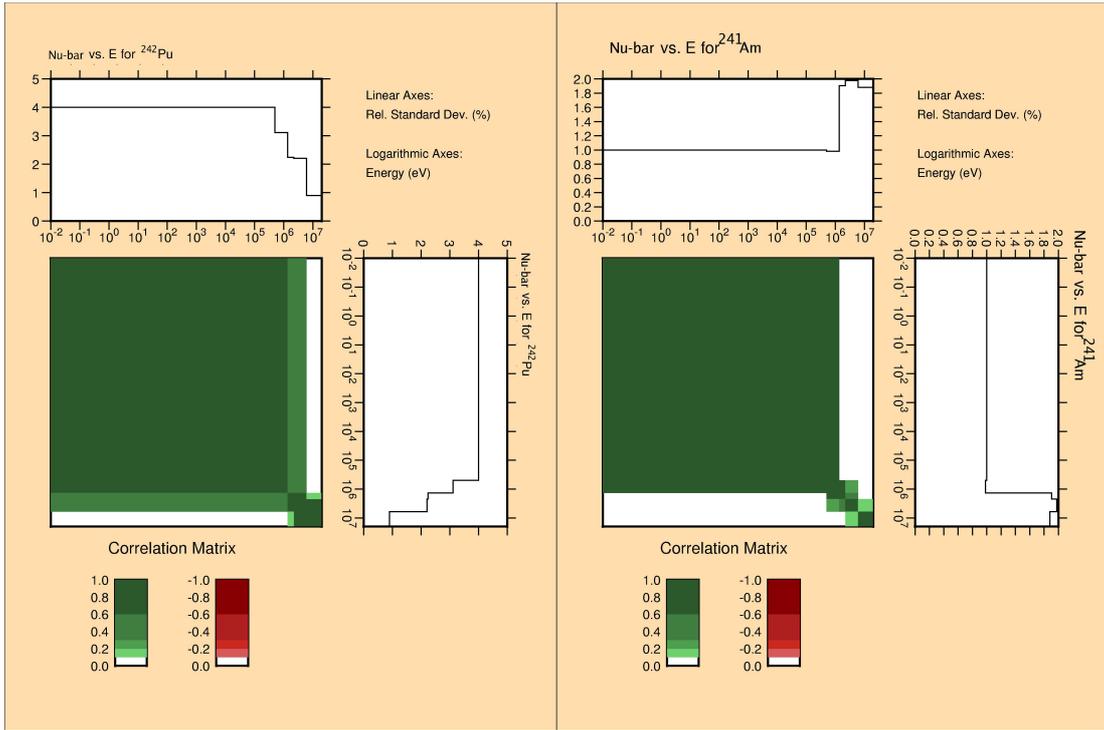


Figure A.5: Correlation and uncertainties for ν -bar in 15 groups for the ^{242}Pu (left) and ^{241}Am (right).

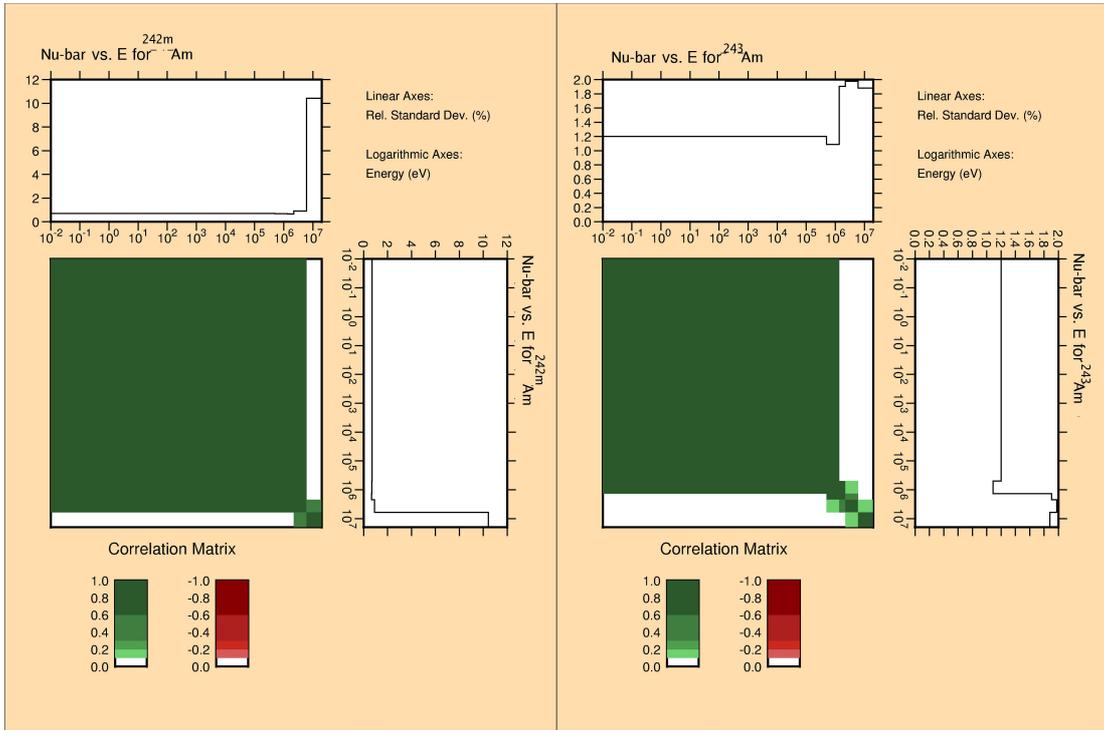


Figure A.6: Correlation and uncertainties for ν -bar in 15 groups for the ^{242m}Am (left) and ^{243}Am (right).

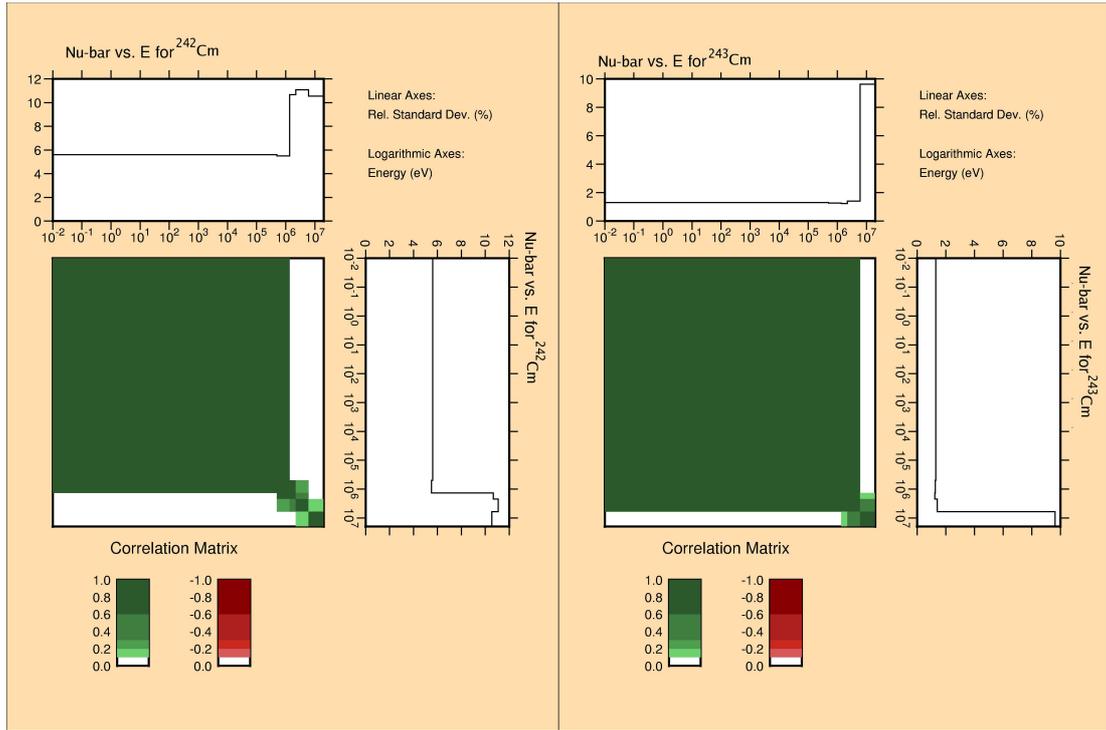


Figure A.7: Correlation and uncertainties for $\bar{\nu}$ in 15 groups for the ^{242}Cm (left) and ^{243}Cm (right).

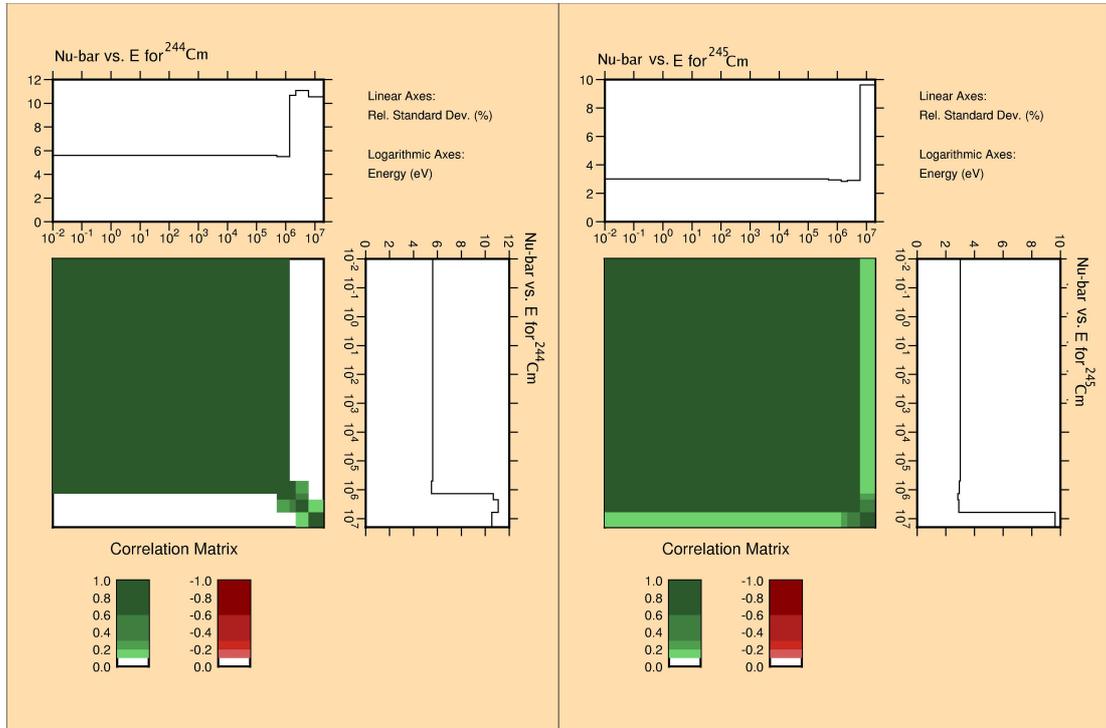


Figure A.8: Correlation and uncertainties for $\bar{\nu}$ in 15 groups for the ^{244}Cm (left) and ^{245}Cm (right).

Table A.2: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{233}U

group	rel.s.d.	-----														
1	8.4211E-03	1000	37	38	55	62	61	68	62	68	43	28	32	35	35	33
2	2.5122E-03	37	1000	385	268	232	213	229	206	225	139	122	187	204	204	193
3	2.2163E-03	38	385	1000	347	309	267	278	246	270	166	160	261	284	284	269
4	1.7977E-03	55	268	347	1000	445	390	415	369	404	254	210	299	324	324	307
5	1.8181E-03	62	232	309	445	1000	465	457	412	451	282	212	280	305	305	289
6	1.9268E-03	61	213	267	390	465	1000	615	417	457	280	192	247	268	268	254
7	1.8345E-03	68	229	278	415	457	615	1000	956	722	313	206	252	274	274	259
8	2.0560E-03	62	206	246	369	412	417	956	1000	715	287	185	221	240	240	227
9	1.8495E-03	68	225	270	404	451	457	722	715	1000	580	202	243	264	264	250
10	3.0187E-03	43	139	166	254	282	280	313	287	580	1000	820	145	158	158	149
11	2.4814E-03	28	122	160	210	212	192	206	185	202	820	1000	443	415	415	401
12	1.3557E-03	32	187	261	299	280	247	252	221	243	145	443	1000	919	919	891
13	1.2690E-03	35	204	284	324	305	268	274	240	264	158	415	919	1000	1000	946
14	1.2690E-03	35	204	284	324	305	268	274	240	264	158	415	919	1000	1000	946
15	1.3294E-03	33	193	269	307	289	254	259	227	250	149	401	891	946	946	1000

Table A.3: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{235}U

group	rel.s.d.	-----														
1	6.8355E-03	1000	132	80	74	67	50	41	35	54	51	23	0	0	0	0
2	2.0161E-03	132	1000	429	360	368	279	230	195	298	284	131	0	0	0	0
3	2.5371E-03	80	429	1000	419	353	250	204	171	268	254	117	0	0	0	0
4	2.0122E-03	74	360	419	1000	550	347	287	246	369	359	175	0	0	0	0
5	1.7967E-03	67	368	353	550	1000	492	358	304	465	445	208	0	0	0	0
6	2.3035E-03	50	279	250	347	492	1000	319	268	385	370	164	0	0	0	0
7	2.7486E-03	41	230	204	287	358	319	1000	235	325	319	152	0	0	0	0
8	3.2002E-03	35	195	171	246	304	268	235	1000	293	275	121	0	0	0	0
9	2.1589E-03	54	298	268	369	465	385	325	293	1000	435	186	0	0	0	0
10	2.2034E-03	51	284	254	359	445	370	319	275	435	1000	359	0	0	0	0
11	4.1079E-03	23	131	117	175	208	164	152	121	186	359	1000	58	53	53	53
12	3.1620E-03	0	0	0	0	0	0	0	0	0	0	58	1000	916	916	916
13	3.1200E-03	0	0	0	0	0	0	0	0	0	0	53	916	1000	1000	1000
14	3.1200E-03	0	0	0	0	0	0	0	0	0	0	53	916	1000	1000	1000
15	3.1200E-03	0	0	0	0	0	0	0	0	0	0	53	916	1000	1000	1000

Table A.4: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{238}U

group	rel.s.d.	-----														
1	9.1066E-03	1000	411	349	308	308	308	308	308	308	308	308	308	308	308	308
2	6.1098E-03	411	1000	923	278	278	278	278	278	278	278	278	278	278	278	278
3	6.4020E-03	349	923	1000	550	550	550	550	550	550	550	550	550	550	550	550
4	1.7627E-02	308	278	550	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
5	1.7627E-02	308	278	550	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
6	1.7627E-02	308	278	550	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
7	1.7627E-02	308	278	550	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
8	1.7627E-02	308	278	550	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
9	1.7627E-02	308	278	550	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
10	1.7627E-02	308	278	550	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
11	1.7627E-02	308	278	550	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
12	1.7627E-02	308	278	550	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
13	1.7627E-02	308	278	550	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
14	1.7627E-02	308	278	550	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
15	1.7627E-02	308	278	550	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

Table A.5: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{237}Np

group	rel.s.d.	-----														
1	1.9421E-02	1000	132	27	0	0	0	0	0	0	0	0	0	0	0	0
2	2.1886E-02	132	1000	511	197	71	71	71	71	71	71	71	71	71	71	71
3	1.4704E-02	27	511	1000	605	76	76	76	76	76	76	76	76	76	76	76
4	6.6175E-03	0	197	605	1000	818	818	818	818	818	818	818	818	818	818	818
5	6.0000E-03	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
6	6.0000E-03	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
7	6.0000E-03	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
8	6.0000E-03	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
9	6.0000E-03	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
10	6.0000E-03	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
11	6.0000E-03	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
12	6.0000E-03	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
13	6.0000E-03	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
14	6.0000E-03	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
15	6.0000E-03	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

Table A.6: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{238}Pu

group	rel.s.d.	-----														
1	2.1714E-02	1000	672	138	0	0	0	0	0	0	0	0	0	0	0	0
2	5.2957E-02	672	1000	625	390	303	303	303	303	303	303	303	303	303	303	303
3	5.3853E-02	138	625	1000	508	309	309	309	309	309	309	309	309	309	309	309
4	7.0000E-02	0	390	508	1000	975	975	975	975	975	975	975	975	975	975	975
5	7.0000E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
6	6.5000E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
7	6.0000E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
8	5.5000E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
9	5.0000E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
10	4.5000E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
11	4.0000E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
12	3.5000E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
13	3.0000E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
14	2.4000E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
15	2.4000E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

Table A.7: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{239}Pu

group	rel.s.d.	-----														
1	2.1524E-03	1000	740	513	334	217	217	79	26	26	26	21	25	21	35	35
2	1.7031E-03	740	1000	914	588	382	382	134	41	41	41	34	42	35	58	59
3	1.7340E-03	513	914	1000	640	415	415	143	42	42	42	36	45	37	61	63
4	1.7900E-03	334	588	640	1000	550	550	185	51	51	52	29	36	29	48	49
5	2.2400E-03	217	382	415	550	1000	1000	303	58	58	58	18	22	18	31	31
6	2.2400E-03	217	382	415	550	1000	1000	303	58	58	58	18	22	18	31	31
7	3.0540E-03	79	134	143	185	303	303	1000	969	969	969	6	8	6	11	11
8	4.3980E-03	26	41	42	51	58	58	969	1000	1000	1000	2	2	2	3	3
9	4.3980E-03	26	41	42	51	58	58	969	1000	1000	1000	2	2	2	3	3
10	4.3509E-03	26	41	42	52	58	58	969	1000	1000	1000	6	5	4	5	5
11	1.5633E-03	21	34	36	29	18	18	6	2	2	6	1000	730	447	521	485
12	1.3122E-03	25	42	45	36	22	22	8	2	2	5	730	1000	585	640	595
13	1.2082E-03	21	35	37	29	18	18	6	2	2	4	447	585	1000	531	492
14	9.1368E-04	35	58	61	48	31	31	11	3	3	5	521	640	531	1000	819
15	8.5168E-04	35	59	63	49	31	31	11	3	3	5	485	595	492	819	1000

Table A.8: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{240}Pu

group	rel.s.d.	-----														
1	1.0857E-02	1000	672	138	0	0	0	0	0	0	0	0	0	0	0	0
2	2.6479E-02	672	1000	625	390	303	303	303	303	303	303	303	303	303	303	303
3	2.6926E-02	138	625	1000	508	309	309	309	309	309	309	309	309	309	309	309
4	3.7373E-02	0	390	508	1000	975	975	975	975	975	975	975	975	975	975	975
5	4.8100E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
6	4.8100E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
7	4.8100E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
8	4.8100E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
9	4.8100E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
10	4.8100E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
11	4.8100E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
12	4.8100E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
13	4.8100E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
14	4.8100E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
15	4.8100E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

Table A.9: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{241}Pu

group	rel.s.d.	-----														
1	4.4976E-03	1000	581	531	358	288	288	288	288	288	288	288	288	288	288	288
2	2.7245E-03	581	1000	998	968	946	946	946	946	946	946	946	946	946	946	946
3	2.7345E-03	531	998	1000	981	964	964	964	964	964	964	964	964	964	964	964
4	2.8414E-03	358	968	981	1000	997	997	997	997	997	997	997	997	997	997	996
5	2.9154E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
6	2.9154E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
7	2.9154E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
8	2.9154E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
9	2.9154E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
10	2.9154E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
11	2.9154E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
12	2.9154E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
13	2.9146E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
14	2.9154E-03	288	946	964	996	999	999	999	999	999	999	999	999	999	1000	1000
15	2.9154E-03	288	946	964	996	999	999	999	999	999	999	999	999	999	1000	1000

Table A.10: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{242}Pu

group	rel.s.d.	-----														
1	9.0473E-03	1000	672	138	0	0	0	0	0	0	0	0	0	0	0	0
2	2.2066E-02	672	1000	625	390	303	303	303	303	303	303	303	303	303	303	303
3	2.2439E-02	138	625	1000	508	309	309	309	309	309	309	309	309	309	309	309
4	3.1144E-02	0	390	508	1000	975	975	975	975	975	975	975	975	975	975	975
5	4.0083E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
6	4.0083E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
7	4.0083E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
8	4.0083E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
9	4.0083E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
10	4.0083E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
11	4.0083E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
12	4.0083E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
13	4.0083E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
14	4.0083E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
15	4.0083E-02	0	303	309	975	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

Table A.11: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{241}Am

group	rel.s.d.	-----														
1	1.8823E-02	1000	132	27	0	0	0	0	0	0	0	0	0	0	0	0
2	1.9772E-02	132	1000	511	197	71	71	71	71	71	71	71	71	71	71	71
3	1.9067E-02	27	511	1000	605	76	76	76	76	76	76	76	76	76	76	76
4	9.8185E-03	0	197	605	1000	818	818	818	818	818	818	818	818	818	818	818
5	1.0000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
6	1.0000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
7	1.0000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
8	1.0000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
9	1.0000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
10	1.0000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
11	1.0000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
12	1.0000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
13	1.0000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
14	1.0000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
15	1.0000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

Table A.12: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{242m}Am

group	rel.s.d.	-----														
1	1.0428E-01	1000	581	531	358	288	288	288	288	288	288	288	288	288	288	288
2	9.1295E-03	581	1000	998	968	946	946	946	946	946	946	946	946	946	946	946
3	6.6162E-03	531	998	1000	981	964	964	964	964	964	964	964	964	964	964	964
4	6.8430E-03	358	968	981	1000	997	997	997	997	997	997	997	997	997	996	996
5	6.9995E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	999	999
6	6.9995E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	999	999
7	6.9995E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	999	999
8	6.9995E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	999	999
9	6.9995E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	999	999
10	6.9995E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	999	999
11	6.9995E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	999	999
12	6.9995E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	999	999
13	6.9965E-03	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
14	6.9995E-03	288	946	964	996	999	999	999	999	999	999	999	999	999	1000	1000
15	6.9995E-03	288	946	964	996	999	999	999	999	999	999	999	999	999	1000	1000

Table A.13: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{243}Am

group	rel.s.d.	-----														
1	1.8823E-02	1000	132	27	0	0	0	0	0	0	0	0	0	0	0	0
2	1.9772E-02	132	1000	511	197	71	71	71	71	71	71	71	71	71	71	71
3	1.9067E-02	27	511	1000	605	76	76	76	76	76	76	76	76	76	76	76
4	1.0880E-02	0	197	605	1000	818	818	818	818	818	818	818	818	818	818	818
5	1.2000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
6	1.2000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
7	1.2000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
8	1.2000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
9	1.2000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
10	1.2000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
11	1.2000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
12	1.2000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
13	1.2000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
14	1.2000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
15	1.2000E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

Table A.14: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{242}Cm

group	rel.s.d.	-----														
1	1.0547E-01	1000	132	27	0	0	0	0	0	0	0	0	0	0	0	0
2	1.1079E-01	132	1000	511	197	71	71	71	71	71	71	71	71	71	71	71
3	1.0684E-01	27	511	1000	605	76	76	76	76	76	76	76	76	76	76	76
4	5.5019E-02	0	197	605	1000	818	818	818	818	818	818	818	818	818	818	818
5	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
6	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
7	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
8	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
9	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
10	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
11	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
12	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
13	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
14	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
15	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

Table A.15: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{243}Cm

group	rel.s.d.	-----														
1	9.6361E-02	1000	581	531	358	288	288	288	288	288	288	288	288	288	288	288
2	1.4075E-02	581	1000	998	968	946	946	946	946	946	946	946	946	946	946	946
3	1.2378E-02	531	998	1000	981	964	964	964	964	964	964	964	964	964	964	964
4	1.2802E-02	358	968	981	1000	997	997	997	997	997	997	997	997	997	997	996
5	1.3095E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
6	1.3095E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
7	1.3095E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
8	1.3095E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
9	1.3095E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
10	1.3095E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
11	1.3095E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
12	1.3095E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
13	1.3089E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
14	1.3095E-02	288	946	964	996	999	999	999	999	999	999	999	999	999	1000	1000
15	1.3095E-02	288	946	964	996	999	999	999	999	999	999	999	999	999	1000	1000

Table A.16: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{244}Cm

group	rel.s.d.	-----														
1	1.0547E-01	1000	132	27	0	0	0	0	0	0	0	0	0	0	0	0
2	1.1079E-01	132	1000	511	197	71	71	71	71	71	71	71	71	71	71	71
3	1.0684E-01	27	511	1000	605	76	76	76	76	76	76	76	76	76	76	76
4	5.5019E-02	0	197	605	1000	818	818	818	818	818	818	818	818	818	818	818
5	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
6	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
7	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
8	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
9	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
10	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
11	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
12	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
13	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
14	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
15	5.6036E-02	0	71	76	818	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

Table A.17: Relative uncertainty (relative standard deviation) and correlation (normalized to 1000) for ν -bar for ^{245}Cm

group	rel.s.d.	-----														
1	9.6361E-02	1000	581	531	358	288	288	288	288	288	288	288	288	288	288	288
2	2.9088E-02	581	1000	998	968	946	946	946	946	946	946	946	946	946	946	946
3	2.8496E-02	531	998	1000	981	964	964	964	964	964	964	964	964	964	964	964
4	2.9473E-02	358	968	981	1000	997	997	997	997	997	997	997	997	997	997	996
5	3.0147E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
6	3.0147E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
7	3.0147E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
8	3.0147E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
9	3.0147E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
10	3.0147E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
11	3.0147E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
12	3.0147E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
13	3.0134E-02	288	946	964	997	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
14	3.0147E-02	288	946	964	996	999	999	999	999	999	999	999	999	999	1000	1000
15	3.0147E-02	288	946	964	996	999	999	999	999	999	999	999	999	999	1000	1000