

Data inconsistencies in summation calculations

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How to calculate anti-neutrino rates

The nuclei in the core form a decay/processing network:

$$\frac{dN_i}{dt} = r(t)FY_i - \lambda_i N_i + \sum \lambda_{ik} N_k - \Phi_n(t)\sigma_i N_i + \Phi_n(t)\sum \sigma_{ik} N_k$$

Neglect processing as $\Phi_n \sigma \ll \lambda$ and consider an equilibrium situation:

$$\frac{dN_i}{dt} = 0 = rFY_i - \lambda_i N_i + \sum \lambda_{ik} N_k \quad \longrightarrow \quad N_i = rCFY_i / \lambda_i$$

Then the anti-neutrino rate per fission is:

$$S(E) = \sum \lambda_i N_i S_i(E) / r = \sum CFY_i S_i(E)$$

Needed: Decay data and fission yields

96Zr 2.35E+19 Y 2.80% 2β-	97Zr 16.749 H β-: 100.00%	98Zr 30.7 S β-: 100.00%
95Y 10.3 M β-: 100.00%	96Y 5.34 S β-: 100.00%	97Y 3.75 S β-: 100.00% γ: 36%
94Sr 75.3 S β-: 100.00%	95Sr 23.90 S β-: 100.00%	96Sr 1.07 S β-: 100.00%

Used by Vogel et al,
1981, ENDF/B-V

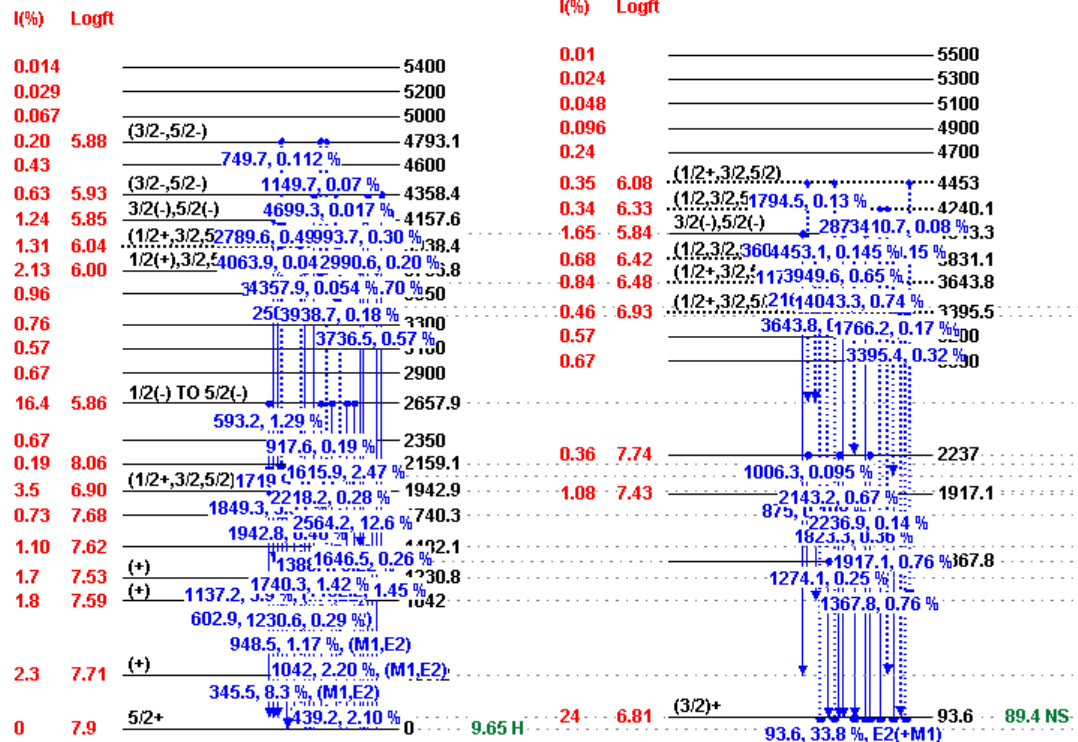
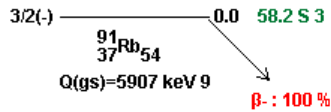
Example for ^{91}Rb

38	^{89}Y STABLE 100% 1.9E-9	^{90}Y 64.053 H β^- : 100.00% 4.E-8	^{91}Y 58.51 D β^- : 100.00% 1.6E-6	^{92}Y 3.54 H β^- : 100.00% 7.E-4	^{93}Y 10.18 H β^- : 100.00% 5.E-4	^{94}Y 18.7 M β^- : 100.00% 0.0039	^{95}Y 10.3 M β^- : 100.00% 0.011	^{96}Y 5.34 S β^- : 100.00% 0.020	^{97}Y 3.75 S β^- : 100.00% β^- -n: 0.06% 0.016
	^{88}Sr STABLE 82.58% 8.E-7	^{89}Sr 50.53 D β^- : 100.00% 1.8E-4	^{90}Sr 28.90 Y β^- : 100.00% 7.4E-4	^{91}Sr 9.63 H β^- : 100.00% 0.00250	^{92}Sr 2.66 H β^- : 100.00% 0.0108	^{93}Sr 7.43 M β^- : 100.00% 0.0257	^{94}Sr 75.3 S β^- : 100.00% 0.0451	^{95}Sr 23.90 S β^- : 100.00% 0.0454	^{96}Sr 1.07 S β^- : 100.00% 0.0357
37	^{87}Rb 4.81E+10 Y 27.83% β^- : 100.00% 2.5E-5	^{88}Rb 17.773 M β^- : 100.00% 2.23E-4	^{89}Rb 15.15 M β^- : 100.00% 0.00205	^{90}Rb 158 S β^- : 100.00% 0.007	^{91}Rb 58.4 S β^- : 100.00% 0.0222	^{92}Rb 4.482 S β^- : 100.00% 0.0166	^{93}Rb 5.91 S β^- : 100.00% β^- -n: 0.03% 0.0166	^{94}Rb 2.325 S β^- : 100.00% β^- -n: 1.95% 0.00486	^{95}Rb 277.3 MS β^- : 100.00% β^- -n: 1.11% 8.7E-4
	^{86}Kr STABLE 17.279% 8.7E-4	^{87}Kr 76.3 M β^- : 100.00% 0.0046	^{88}Kr 2.84 H β^- : 100.00% 0.0173	^{89}Kr 3.15 M β^- : 100.00% 0.0344	^{90}Kr 32.32 S β^- : 100.00% 0.0440	^{91}Kr 8.57 S β^- : 100.00% 0.0316	^{92}Kr 1.840 S β^- : 100.00% β^- -n: 0.03% 0.0166	^{93}Kr 1.286 S β^- : 100.00% β^- -n: 1.95% 0.00486	^{94}Kr 212 MS β^- : 100.00% β^- -n: 1.11% 8.7E-4
35	^{85}Br 2.90 M β^- : 100.00% 0.00235	^{86}Br 55.1 S β^- : 100.00% 0.0023	^{87}Br 55.65 S β^- : 100.00% β^- -n: 2.60% 0.0127	^{88}Br 16.29 S β^- : 100.00% β^- -n: 6.58% 0.0139	^{89}Br 4.40 S β^- : 100.00% β^- -n: 13.80% 0.0104	^{90}Br 1.91 S β^- : 100.00% β^- -n: 25.20% 0.0055	^{91}Br 0.541 S β^- : 100.00% β^- -n: 20.00% 0.00224	^{92}Br 0.343 S β^- : 100.00% β^- -n: 33.10% 2.7E-4	^{93}Br 102 MS β^- : 100.00% β^- -n: 68.00% 3.1E-5
	50	51	52	53	54	55	56	57	N

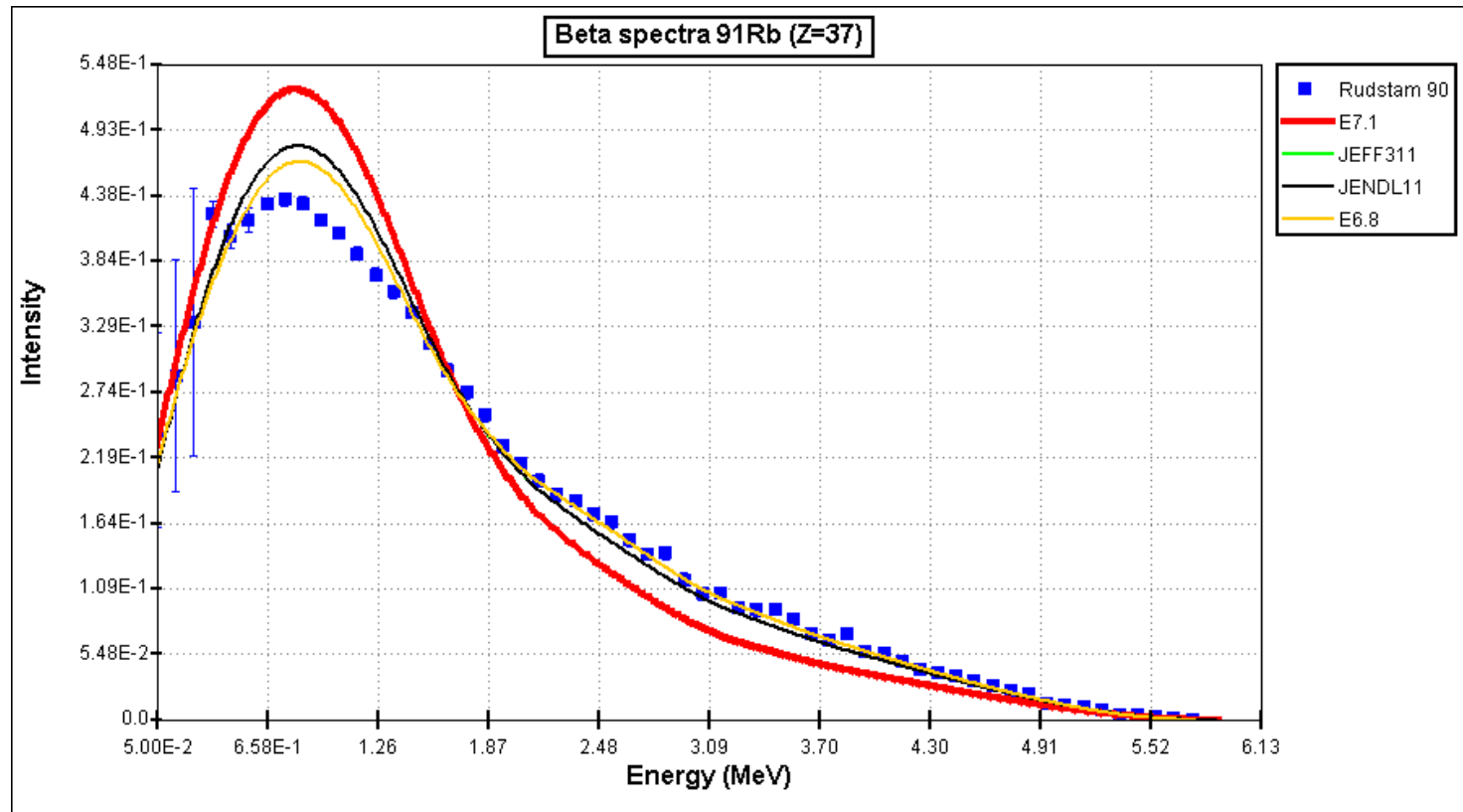
91Rb				
E(level)	J π	T $_{1/2}$	Decay Modes	235U FY
0.0	3/2(-)	58.4 s	β^- : 100.00 %	0.0222 3

FY 0.0222

Partial decay for ^{91}Rb



TAS – Comparison of Rudstam with INL

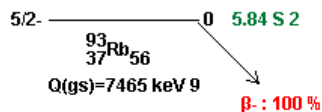


Example for ^{93}Rb

37	^{91}Y 58.51 D β^- : 100.00% 1.6E-6	^{92}Y 3.54 H β^- : 100.00% 7.E-4	^{93}Y 10.18 H β^- : 100.00% 5.E-4	^{94}Y 18.7 M β^- : 100.00% 0.0039	^{95}Y 10.3 M β^- : 100.00% 0.011	^{96}Y 5.34 S β^- : 100.00% 0.020	^{97}Y 3.75 S β^- : 100.00% β^-n : 0.06% 0.016	^{98}Y 0.548 S β^- : 100.00% β^-n : 0.33% 0.011	^{99}Y 1.484 S β^- : 100.00% β^-n : 1.70% 0.0195														
	^{90}Sr 28.90 Y β^- : 100.00% 7.4E-4	^{91}Sr 9.63 H β^- : 100.00% 0.00250	^{92}Sr 2.66 H β^- : 100.00% 0.0108	^{93}Sr 7.43 M β^- : 100.00% 0.0257	^{94}Sr 75.3 S β^- : 100.00% 0.0451	^{95}Sr 23.90 S β^- : 100.00% 0.0454	^{96}Sr 1.07 S β^- : 100.00% 0.0357	^{97}Sr 429 MS β^- : 100.00% β^-n : 0.05% 0.0172	^{98}Sr 0.653 S β^- : 100.00% β^-n : 0.25% 0.0081														
36	^{89}Rb 15.15 M β^- : 100.00% 0.00205	^{90}Rb 158 S β^- : 100.00% 0.007	^{91}Rb 58.4 S β^- : 100.00% 0.0222	^{92}Rb 4.492 S β^- : 100.00% β^-n : 0.01% 0.0313	^{93}Rb 5.84 S β^- : 100.00% β^-n : 1.39% 0.0307	^{94}Rb 2.702 S β^- : 100.00% β^-n : 10.50% 0.0157	^{95}Rb 377.7 MS β^- : 100.00% β^-n : 8.70% 0.0076	^{96}Rb 203 MS β^- : 100.00% β^-n : 13.30% 0.00168	^{97}Rb 169.1 MS β^- : 100.00% β^-n : 25.50% 3.8E-4														
	^{88}Kr 2.84 H β^- : 100.00% 0.0173	^{89}Kr 3.15 M β^- : 100.00% 0.0344	^{90}Kr 32.32 S β^- : 100.00% 0.0440	^{91}Kr 8.57 S β^- : 100.00% 0.0316	^{92}Kr 1.840 S β^- : 100.00% β^-n : 0.03% 0.0166	<table border="1"> <thead> <tr> <th colspan="5">93Rb</th> </tr> <tr> <th>E(level)</th> <th>Jπ</th> <th>T$_{1/2}$</th> <th>Decay Modes</th> <th>235U FY</th> </tr> </thead> <tbody> <tr> <td>0.0</td> <td>5/2-</td> <td>5.84 s ± 2</td> <td>β^-: 100.00 % β^-n: 1.39 %</td> <td>0.0307 4</td> </tr> </tbody> </table>				93Rb					E(level)	J π	T $_{1/2}$	Decay Modes	235U FY	0.0	5/2-	5.84 s ± 2	β^- : 100.00 % β^-n : 1.39 %
93Rb																							
E(level)	J π	T $_{1/2}$	Decay Modes	235U FY																			
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	52	53	54	55	56	57	58	59	N														

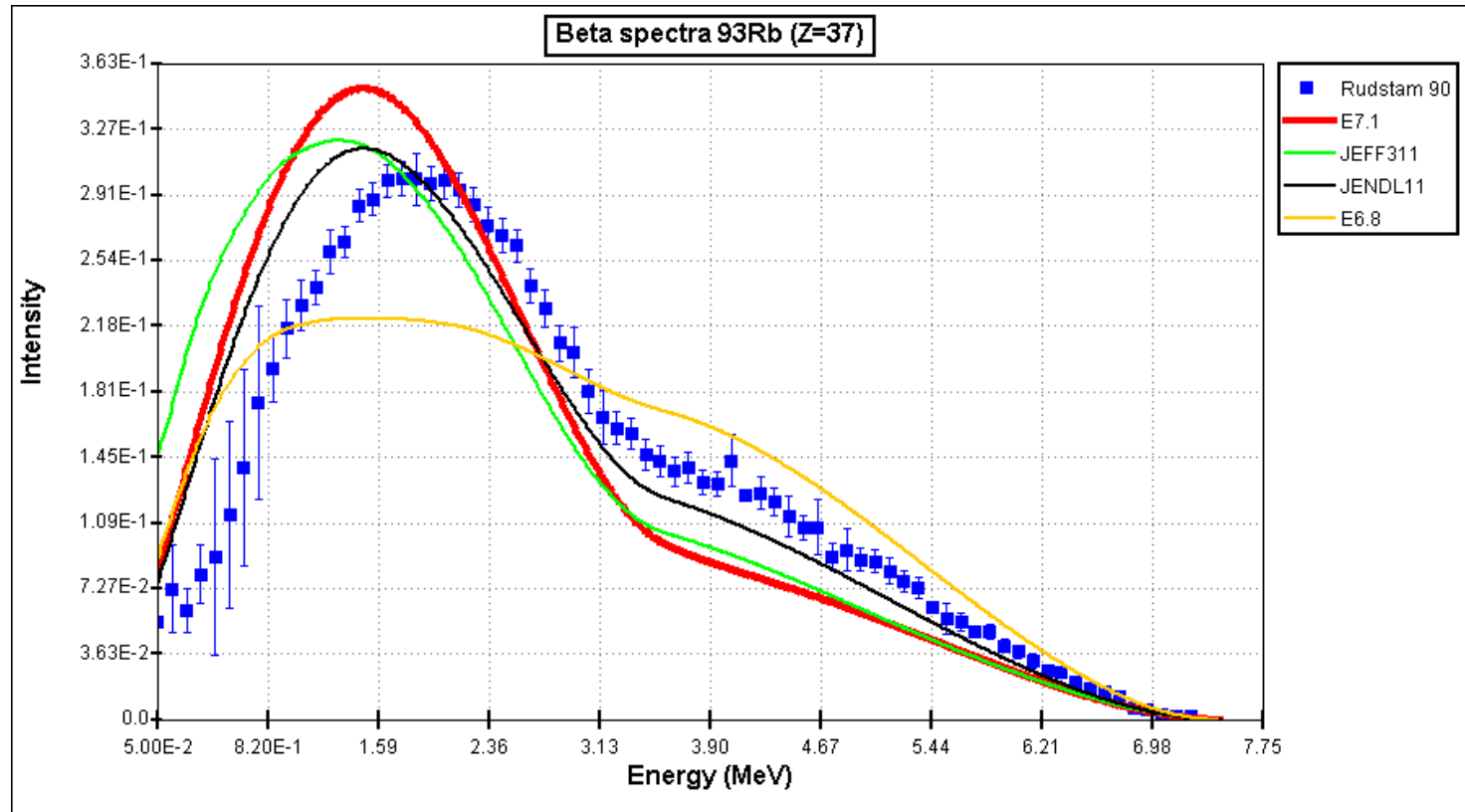
CFY 0.0355

Decay scheme for ^{93}Rb



I(%)	Logft	Energy (keV)	Spin/Parity	Transition	I(%)	Logft	Energy (keV)	Spin/Parity	Transition
0.038	5.0	6707.4		2903.6, 0.26 %					
0.019	6.0	6260.7		4250.9, 0.057 %					
0.027	6.2	6000.5		4387.9, 0.135 %	0.022	6.2	6096.7		2206.2, 0.21 %
				4899.4, 0.057 %					
0.037	6.5			3706.6, 0.085 %	0.075	6.2	631.2		4947.5, 0.081 %
				3547.2, 0.46 %	1.03	5.24			2398.3, 0.141 %
				3941.7, 0.13 %					4953.9, 0.042 %
0.74	≥ 5.5	5200		3224.8, 0.069 %					1507.8, 3172.1, 0.22 %
1.22	5.54	4913.1	(7/2)-	4648.7, 0.204 %	0.41	6.10	4790.4		2602.4, 0.413, 3338, 0.16 %
0.58	6.09	4577.6	3/2, 5/2, 7/2	2359.5, 0.38 %	0.46	6.23	4250.3		3/2(-), 5/2, 7/2 4645, 0.050 %
0.38	6.42	4236.1	(7/2-)	2620.2, 0.097 %	1.48	≥ 5.9	4250		7170, 3821.9, 0.113 %
2.09	5.82	4174.4	(7/2-)	3104.1, 0.08 %	1.62	6.05	3623.7		(5/2+, 7/2) 3366.0, 0.212, 353, 0.075 %
3.73	5.70	3847.6	(5/2+, 7/2)	1359.9, 3133.1, 0.10 %	0.41	6.78	3623.7		610.1, 0.20 %
0.67	6.57	3603.2		1745.7, 0.377, 0.4, 0.21 %	0.17	7.34			(7/2-, 9/2+) 1547.8, 0.33 %
≤ 0.020	≥ 8.0	311		1284, 0.295, 4.9, 0.53 %	0.50	7.03	2869.1		2724.6, 0.65 %
				1812.9	0.44, 0.053 %	0.44	7.19		776.4, 0.115 %
0.26	7.4	2782.2	(5/2+, 7/2, 9/2+)	3664.8, 0.64 %	0.56	7.21	2292.9		1115.8, 0.44 %
				1397.7, (3884, 0.52 %)	≤ 0.4	≥ 7.2	2054		(5/2+, 7/2, 9/2) 593.9, 0.175, 3.6, 0.109 %
				12349.6, 0.71 %	0.56	7.21	1452.7		(5/2+, 7/2, 9/2+) 1475.7, 0.091 %
≤ 0.4	≥ 7.2	2054		10325, 0.44 %	≤ 0.4	≥ 7.2	1142.6		1016, 2869.2, 0.51 %
≤ 0.3	≥ 7.3	1779.8	(11/2-)	101130.1, 0.22 %	≤ 0.8	≥ 7.0	98.5		(5/2+, 7/2, 9/2) 905.6, 0.011, 150.4, 0.54 %
≤ 0.25	≥ 7.5	529.3		1612.9, 1287, 0.13 %					205, 1306.9, 0.133 %
0.52	7.61	529.3	(7/2+)	1096.7, 1566.2, 0.07 %	> 1.6	> 6.8	1385.3		(5/2+, 7/2, 9/2+) 1822, 0.62 %
0.6	7.6	986.1	(9/2+)	1238.3, 1.72 %	≤ 0.9	≥ 7.1	1142.6		(5/2+, 7/2, 9/2+) 1385.2, 6.6 %
				986.1, 7.9 %					710, 6.2 %
≤ 3	≥ 6.8	432.6	(5/2, 7/2, 9/2)+	432.6, 20.2 %, M1, E2					929, 0.49 %
35	6.14	7.423 M	5/2+	432.6, 20.2 %, M1, E2	≤ 0.8	≥ 9.6	213.4	4.3 NS	(9/2)+ 1142.6, 0.37 %

TAS – Comparison of Rudstam with INL (cont)



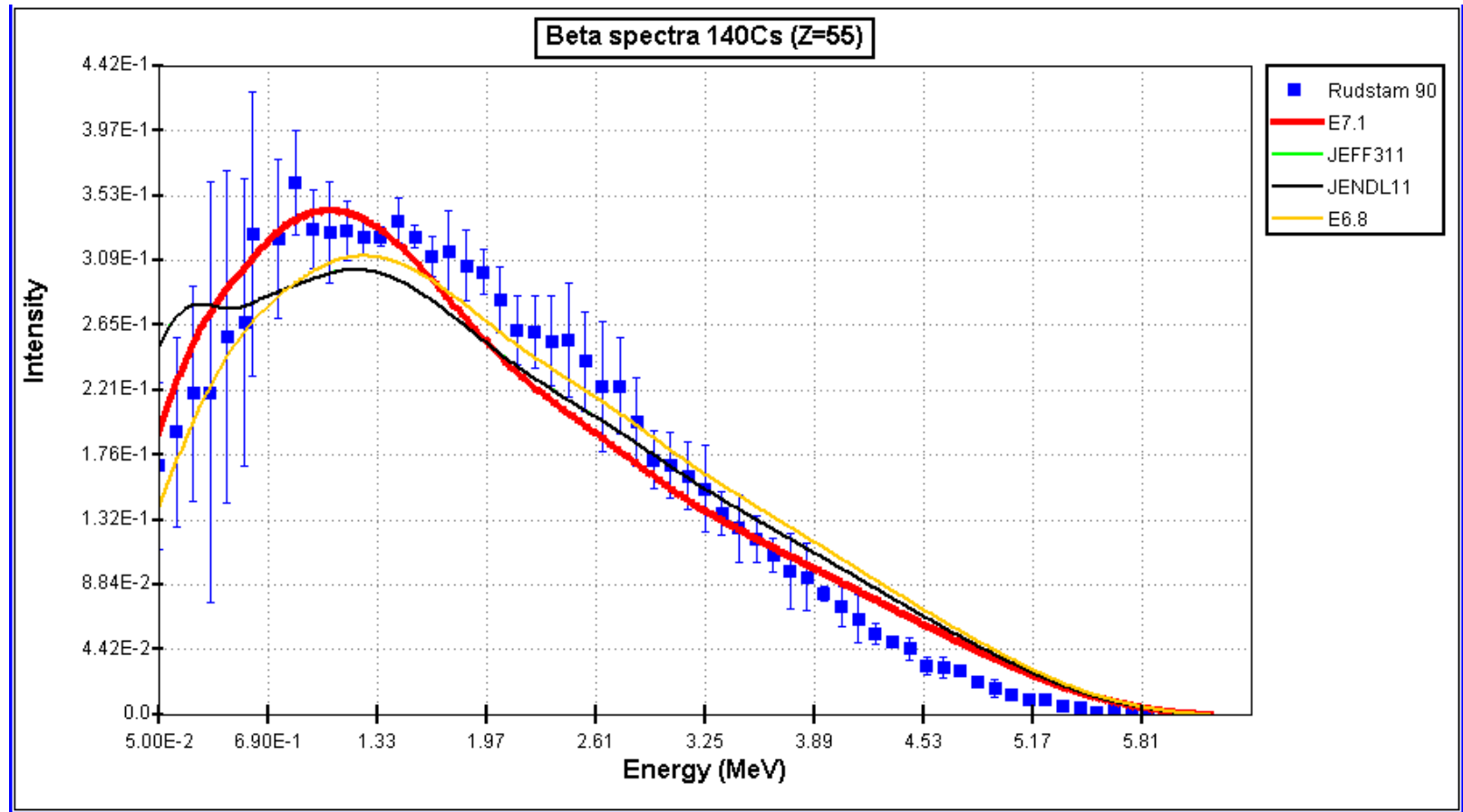
Example for ^{140}Cs

Z	138La 1.02E+11 Y 0.08881% ϵ : 65.60% β^- : 34.40% 3.2E-7	139La STABLE 99.9119% 2.3E-7	140La 1.67855 D β^- : 100.00% 5.E-5	141La 3.92 H β^- : 100.00% 1.8E-4	142La 91.1 M β^- : 100.00% 1.0E-3	143La 14.2 M β^- : 100.00% 0.0038	144La 40.8 S β^- : 100.00% 0.0107	145La 24.8 S β^- : 100.00% 0.0191	146La 6.27 S β^- : 100.00% 0.007
	56	137Ba STABLE 11.232% 1.3E-6	138Ba STABLE 71.698% 4.E-5	139Ba 83.06 M β^- : 100.00% 7.E-4	140Ba 12.7527 D β^- : 100.00% 0.0049	141Ba 18.27 M β^- : 100.00% 0.0166	142Ba 10.6 M β^- : 100.00% 0.0301	143Ba 14.5 S β^- : 100.00% 0.0410	144Ba 11.5 S β^- : 100.00% 0.0397
55	136Cs 13.04 D β^- : 100.00% 2.8E-5	137Cs 30.08 Y β^- : 100.00% 6.0E-4	138Cs 33.41 M β^- : 100.00% 0.00223	139Cs 9.27 M β^- : 100.00% 0.0131	140Cs 63.7 S β^- : 100.00% 0.0207	141Cs 24.84 S β^- : 100.00% 0.0000	142Cs 1.684 S β^- : 100.00% 0.03%	143Cs 1.791 S β^- : 100.00% 0.42%	144Cs 0.994 S β^- : 100.00% 0.42%
	54	135Xe 9.14 H β^- : 100.00% 0.00178	136Xe >2.4E+21 Y 8.8573% 2 β^- 0.022	137Xe 3.818 M β^- : 100.00% 0.0319	138Xe 14.08 M β^- : 100.00% 0.0481	139Xe 39.68 S β^- : 100.00% 0.0432	140Xe 13.84 S β^- : 100.00% 0.0351	141Xe 12.24 S β^- : 100.00% β -n: 0.04% 0.0122	142Xe 12.74 S β^- : 100.00% β -n: 0.21% 0.0043
53	134I 52.5 M β^- : 100.00% 0.0036	135I 6.58 H β^- : 100.00% 0.0293	136I 83.4 S β^- : 100.00% 0.0125	137I 24.5 S β^- : 100.00% β -n: 7.14% 0.0262	138I 6.23 S β^- : 100.00% β -n: 5.56% 0.0142	139I 2.280 S β^- : 100.00% β -n: 10.00% 0.0077	140I 0.86 S β^- : 100.00% β -n: 9.30% 0.0014	141I 0.43 S β^- : 100.00% β -n: 21.20% 4.1E-4	142I 222 MS β^- : 100.00% β -n 6.E-5
	81	82	83	84	85	86	87	88	N

Ground and isomeric state information for $^{140}_{55}\text{Cs}$

FY 0.0207

TAS – Comparison of Rudstam with INL (cont)

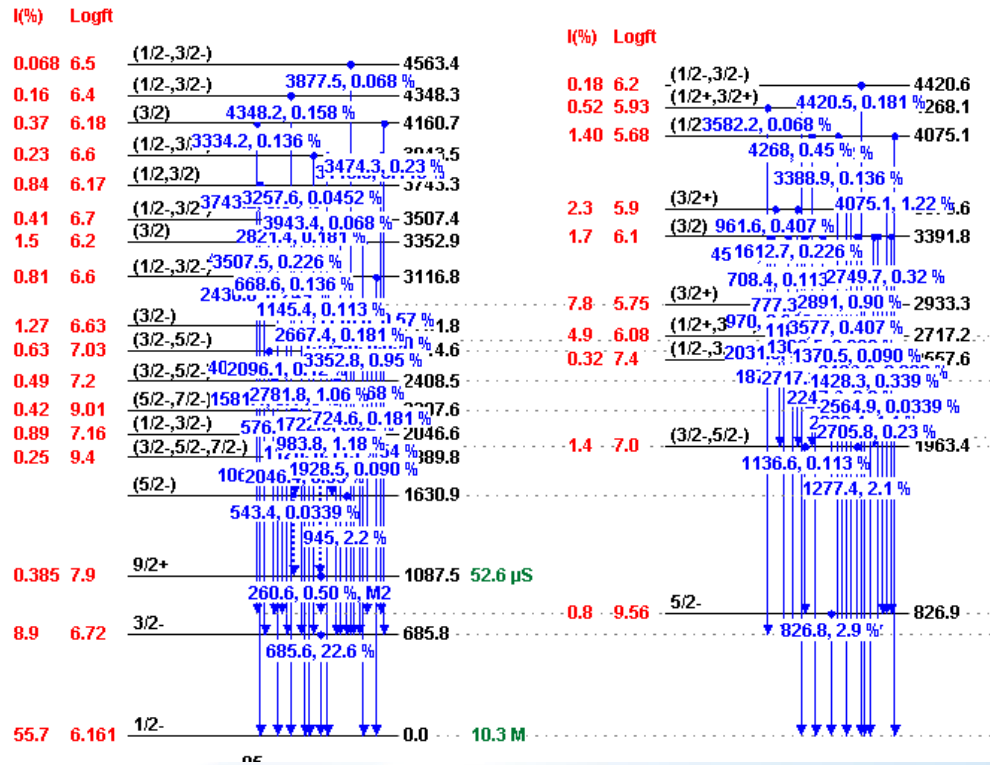
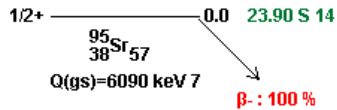


One more example: ^{95}Sr

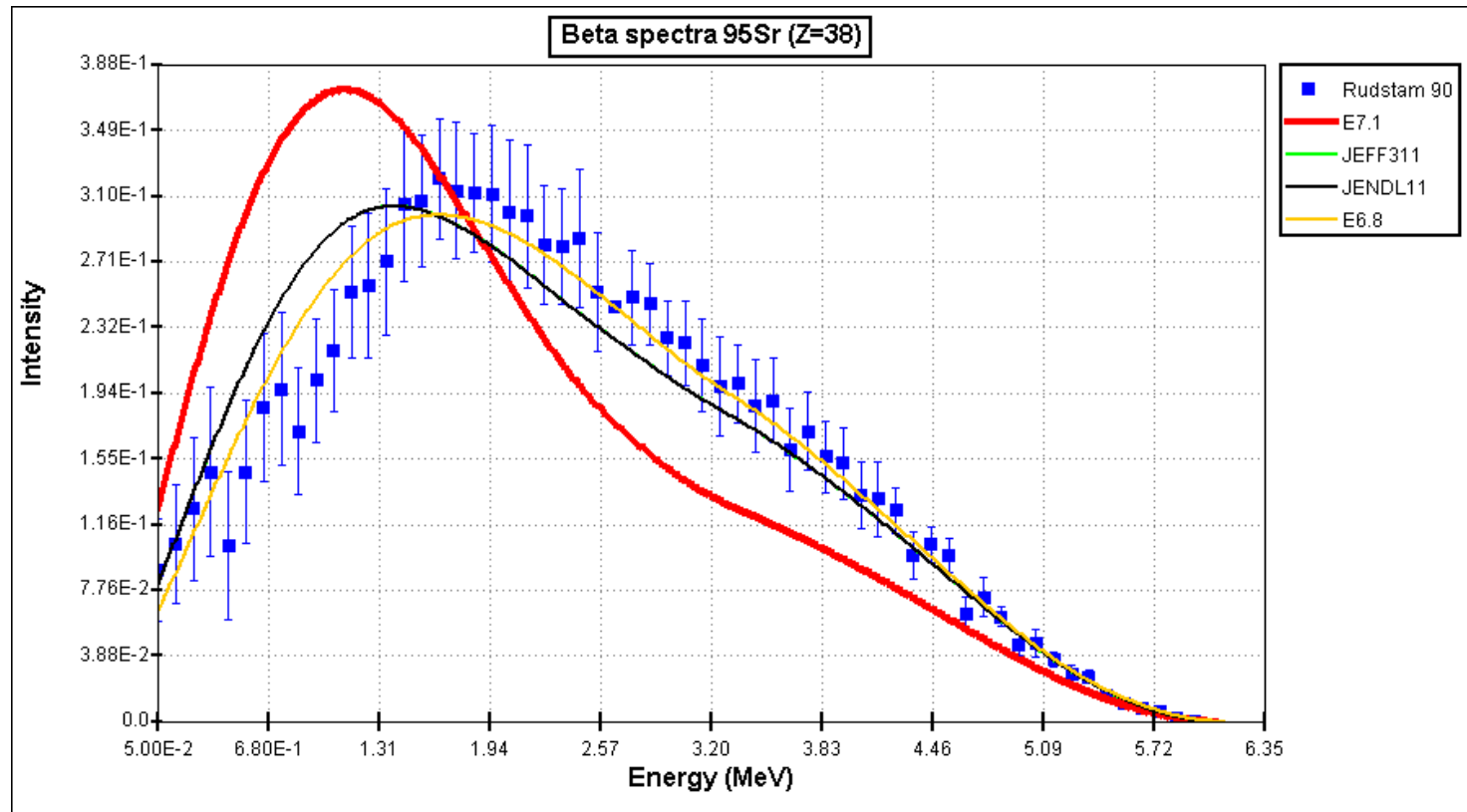
38	93Zr 1.61E+6 Y β^- : 100.00% 1.4E-6	94Zr STABLE 17.38% 1.9E-4	95Zr 64.032 D β^- : 100.00% 0.00127	96Zr 2.35E+19 Y 2.80% $2\beta^-$ 0.0034	97Zr 16.749 H β^- : 100.00% 0.0109	98Zr 30.7 S β^- : 100.00% 0.026	99Zr 2.1 S β^- : 100.00% 0.036	100Zr 7.1 S β^- : 100.00% 0.050	101Zr 2.3 S β^- : 100.00% 0.0279	
	39	92Y 3.54 H β^- : 100.00% 7.E-4	93Y 10.18 H β^- : 100.00% 5.E-4	94Y 18.7 M β^- : 100.00% 0.0039	95Y 10.3 M β^- : 100.00% 0.011	96Y 5.34 S β^- : 100.00% 0.020	97Y 3.75 S β^- : 100.00% β^- -n: 0.06% 0.016	98Y 0.548 S β^- : 100.00% β^- -n: 0.33% 0.011	99Y 1.484 S β^- : 100.00% β^- -n: 1.70% 0.0195	100Y 735 MS β^- : 100.00% β^- -n: 0.92% 0.006
37	91Sr 9.63 H β^- : 100.00% 0.00250	92Sr 2.66 H β^- : 100.00% 0.0108	93Sr 7.43 M β^- : 100.00% 0.0257	94Sr 75.3 S β^- : 100.00% 0.0451	95Sr 23.90 S β^- : 100.00% 0.0454	96Sr 1.07 S β^- : 100.00% 0.0357	97Sr 429 MS β^- : 100.00% β^- -n: 0.05% 0.0172	98Sr 0.653 S β^- : 100.00% β^- -n: 0.25% 0.0081	99Sr 0.269 S β^- : 100.00% β^- -n: 0.10% 0.00133	
	36	90Rb 158 S β^- : 100.00% 0.007	91Rb 58.4 S β^- : 100.00% 0.0222	92Rb 4.492 S β^- : 100.00% β^- -n: 0.01% 0.0313	93Rb 5.84 S β^- : 100.00% β^- -n: 1.39% 0.0307	94Rb 2.702 S β^- : 100.00% β^- -n: 10.50% 0.0157	^{95}Sr			
						E(level)	J π	T $_{1/2}$	Decay Modes	235U FY
						0.0	1/2+	23.90 s 14	β^- : 100.00 %	0.0454 9
						0.0076		0.00168	3.8E-4	2.4E-5
	89Kr 3.15 M β^- : 100.00% 0.0344	90Kr 32.32 S β^- : 100.00% 0.0440	91Kr 8.57 S β^- : 100.00% 0.0316	92Kr 1.840 S β^- : 100.00% β^- -n: 0.03% 0.0166	93Kr 1.286 S β^- : 100.00% β^- -n: 1.95% 0.00486	94Kr 212 MS β^- : 100.00% β^- -n: 1.11% 8.7E-4	95Kr 0.114 S β^- : 100.00% β^- -n: 2.87% 7.E-5	96Kr 80 MS β^- : 100.00% β^- -n: 3.70% 3.6E-4	97Kr 63 MS β^- : 100.00% β^- -n: 6.70% 3.0E-7	
	53	54	55	56	57	58	59	60	N	

Ground and isomeric state information for $^{95}_{38}\text{Sr}$

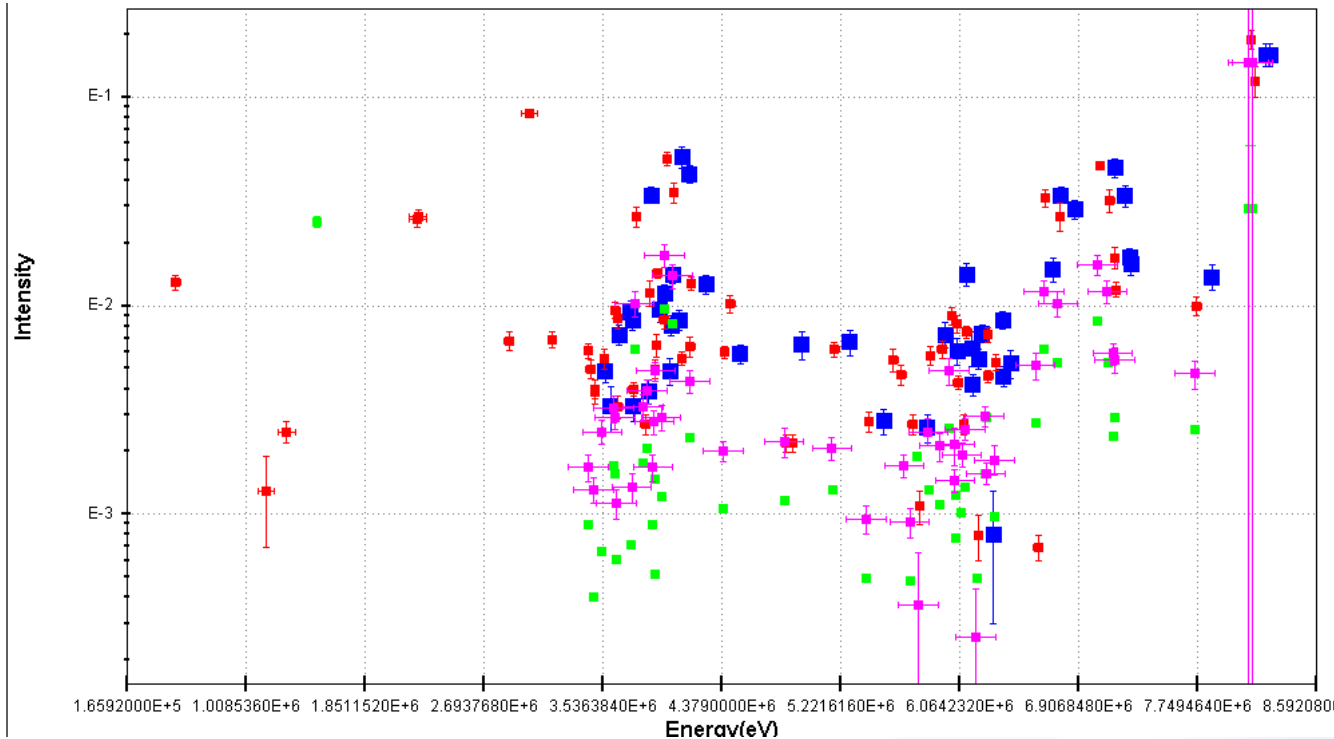
^{95}Sr decay



TAS – Comparison of Rudstam with INL (cont)



Comparing Decay Sublibraries ^{89}Br



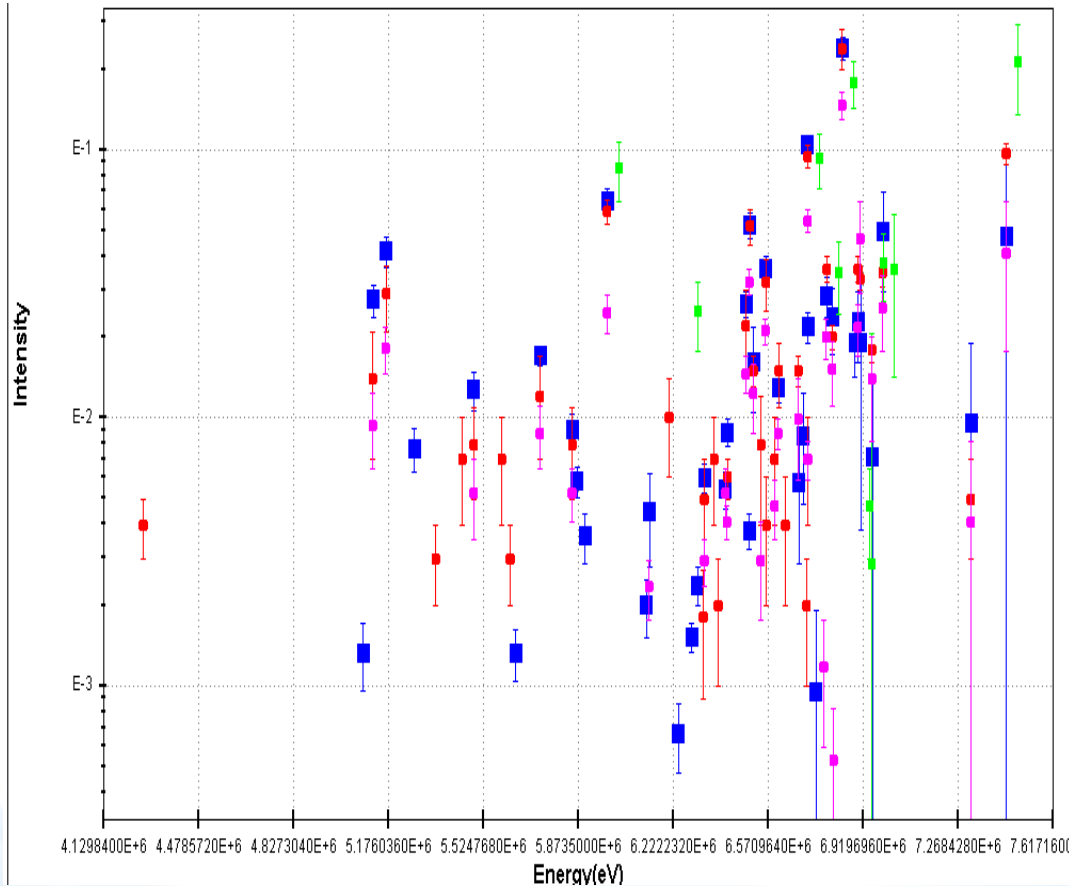
Blue: ENDF VII.1

Green: Jeff 3.1

Red: ENDF 6.8

Magenta: JENDL
4.0

Comparing Decay Sublibraries ^{99}Y



Blue: ENDF VII.1

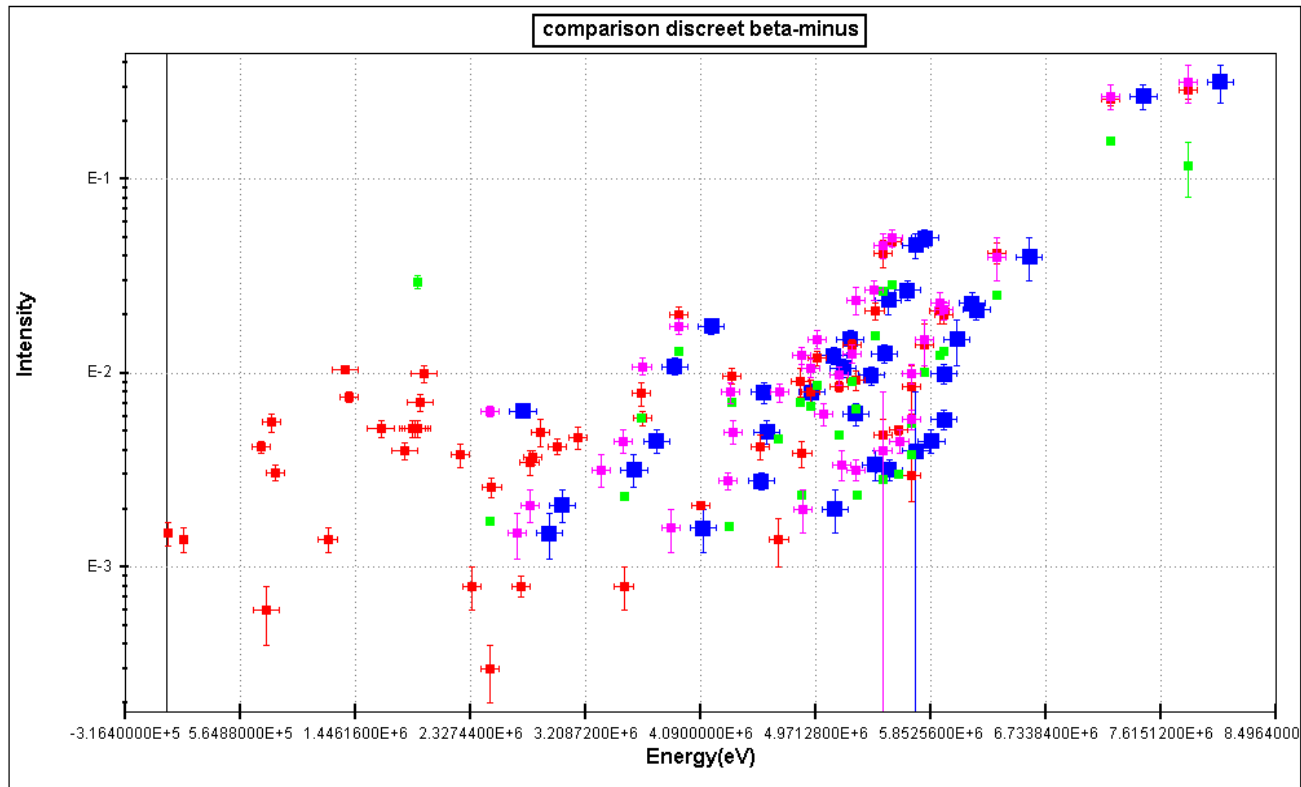
Green: Jeff 3.1

Red: ENDF 6.8

Magenta: JENDL 4.0

Comparing Decay Sublibraries

¹³⁸I



Blue: ENDF VII.1

Green: Jeff 3.1

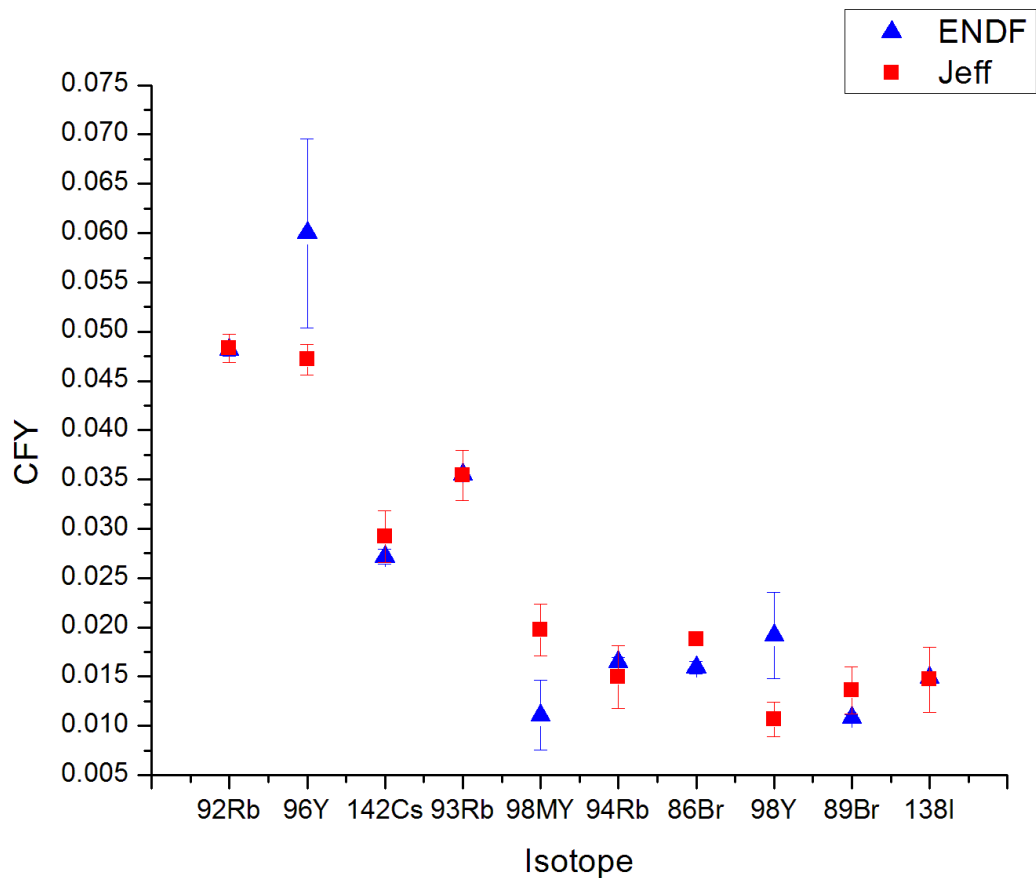
Red: ENDF 6.8

Magenta:
JENDL 4.0

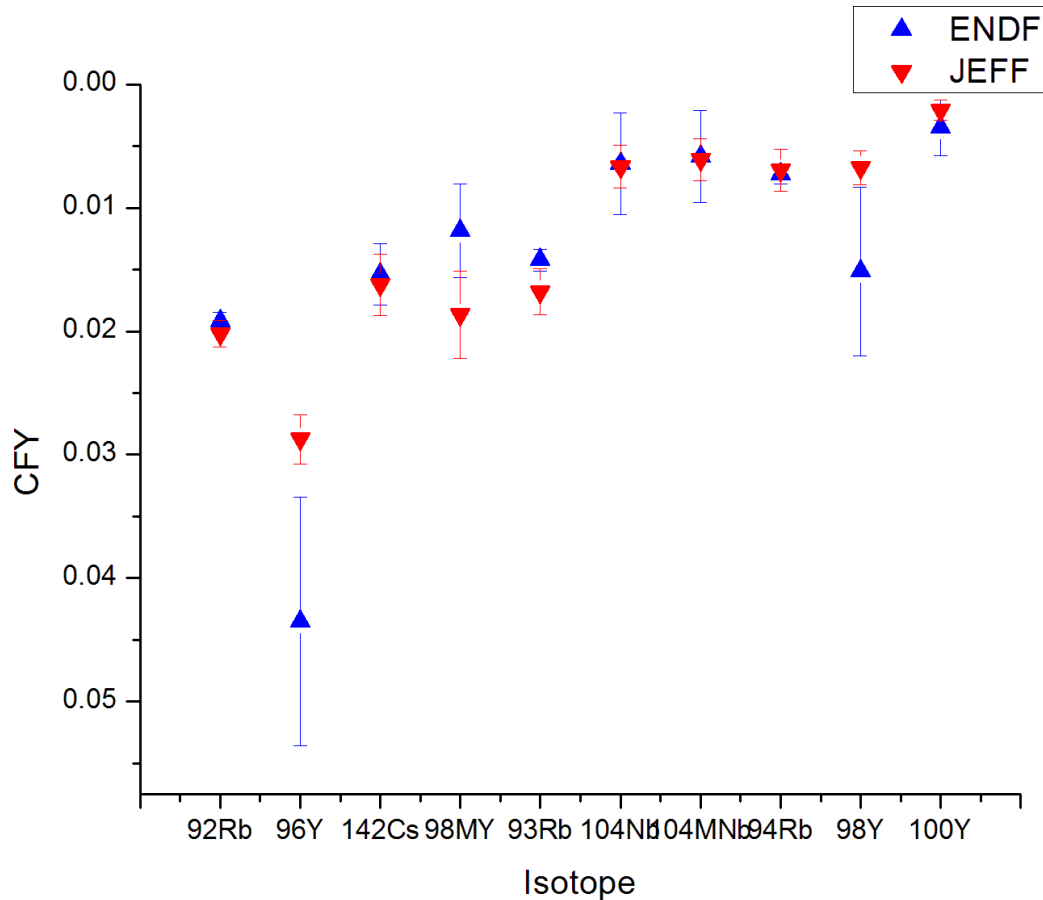
How do fission yields compare?

Comparison of ENDF VII.1 and Jeff 3.1

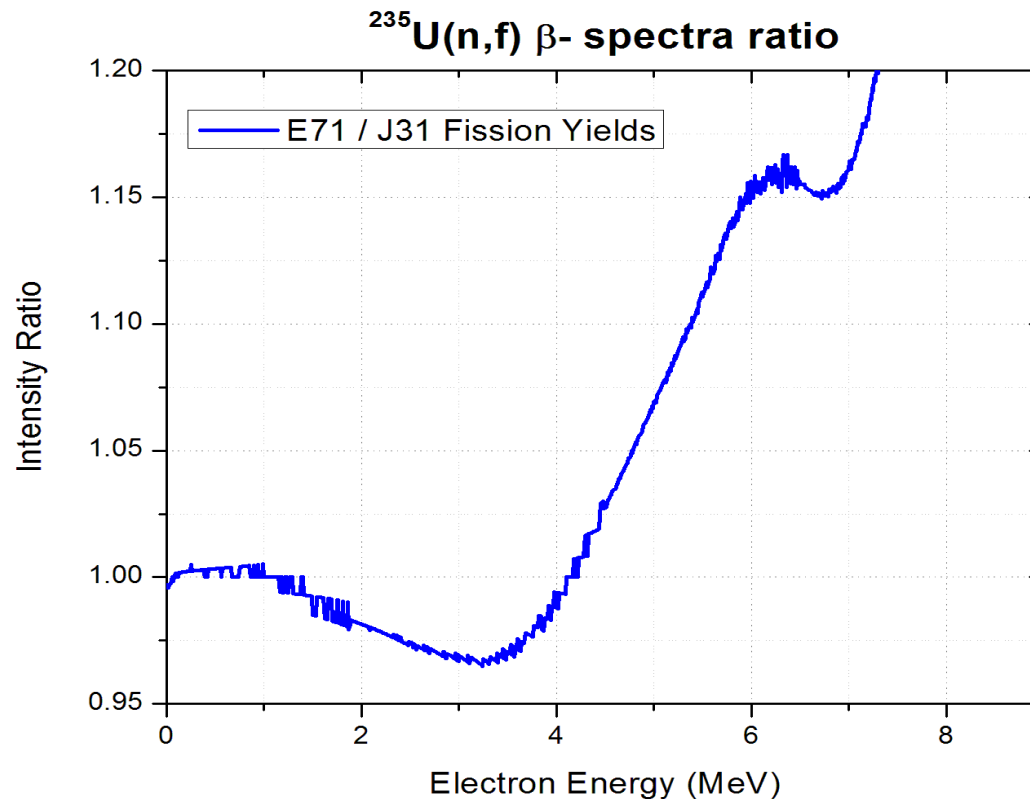
(top 10 contributors to beta spectra at 6 MeV for ^{235}U)



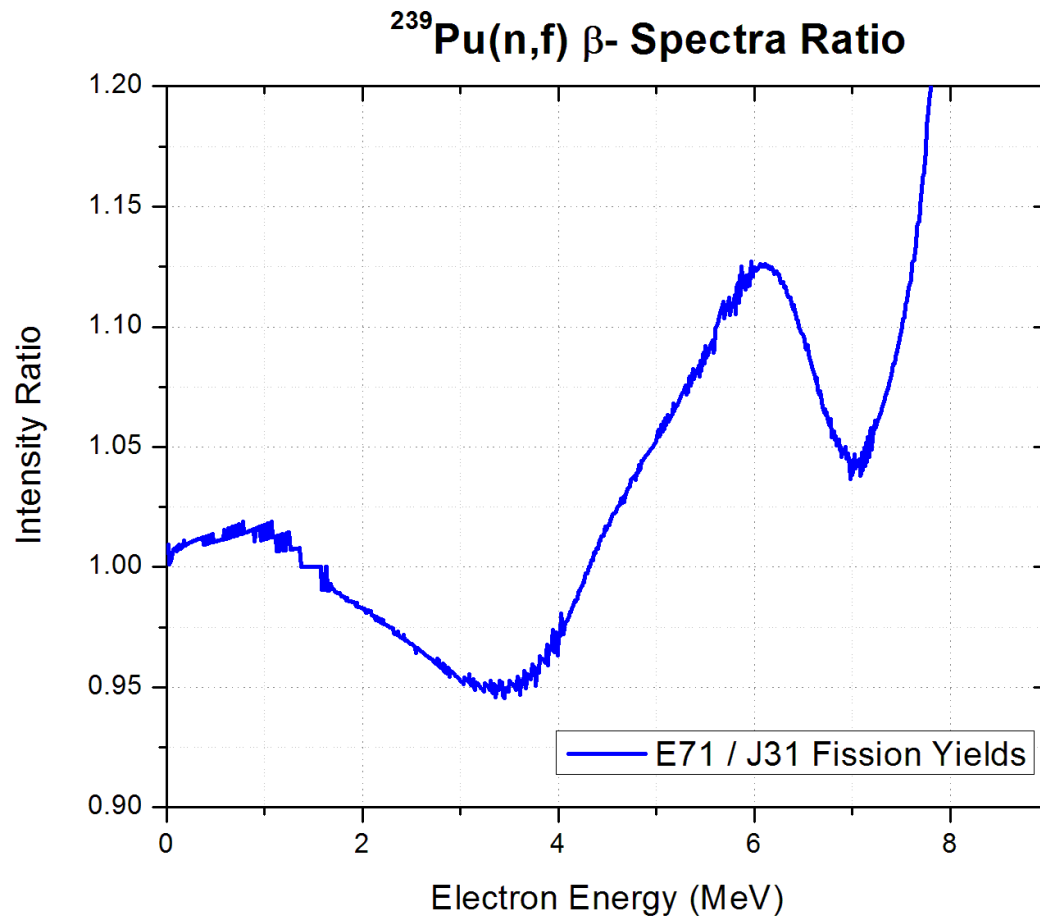
Comparison of ENDF VII.1 and Jeff 3.1 (top 10 contributors to beta spectra at 6 MeV, ^{239}Pu)



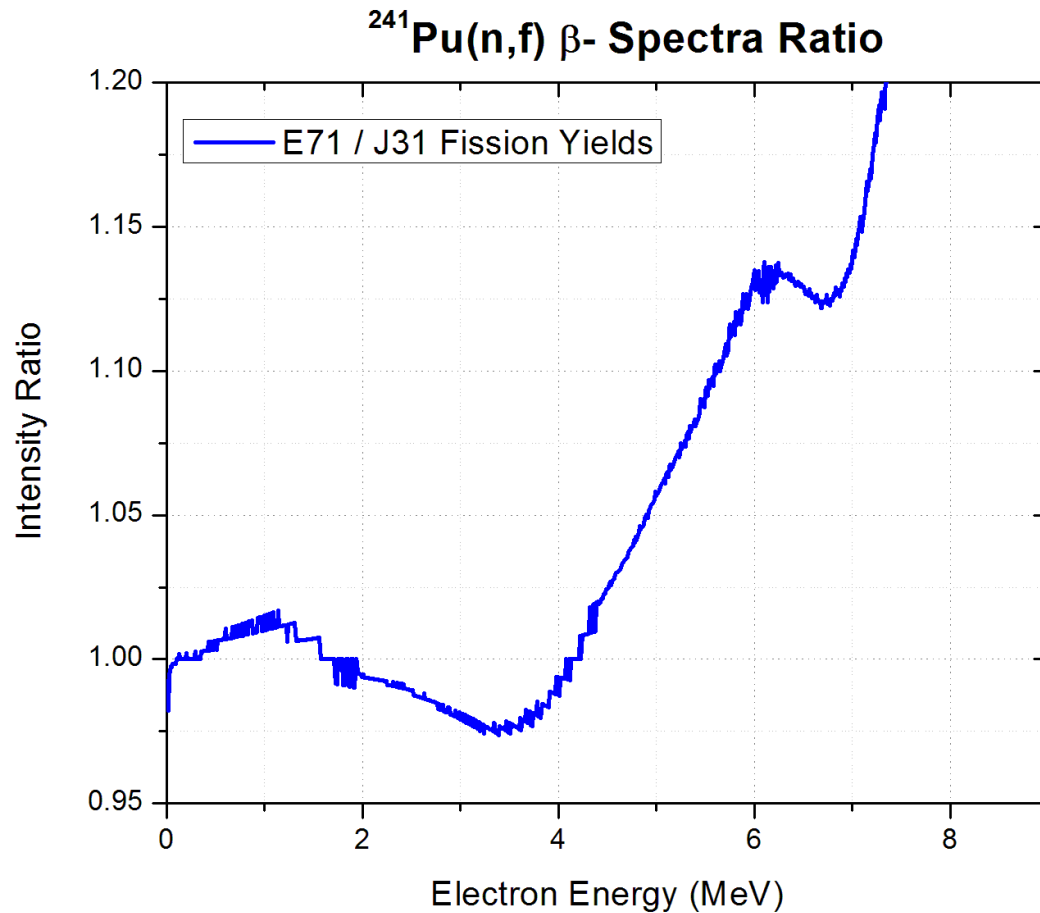
Effect of different yields on beta spectra



Effect of different yields on beta spectra (cont)



Effect of different yields on beta spectra (cont)



Wish List

- High resolution data corresponding to TAS when possible
- Common library of codes and data that all can use
 - Open source model?
- Centralized document with all equations, references, etc.

Next Meeting....?