Evaluation of nuclear reaction cross sections with the TALYS code

Natalia Dzysiuk *, NRG, Petten, the Netherlands*

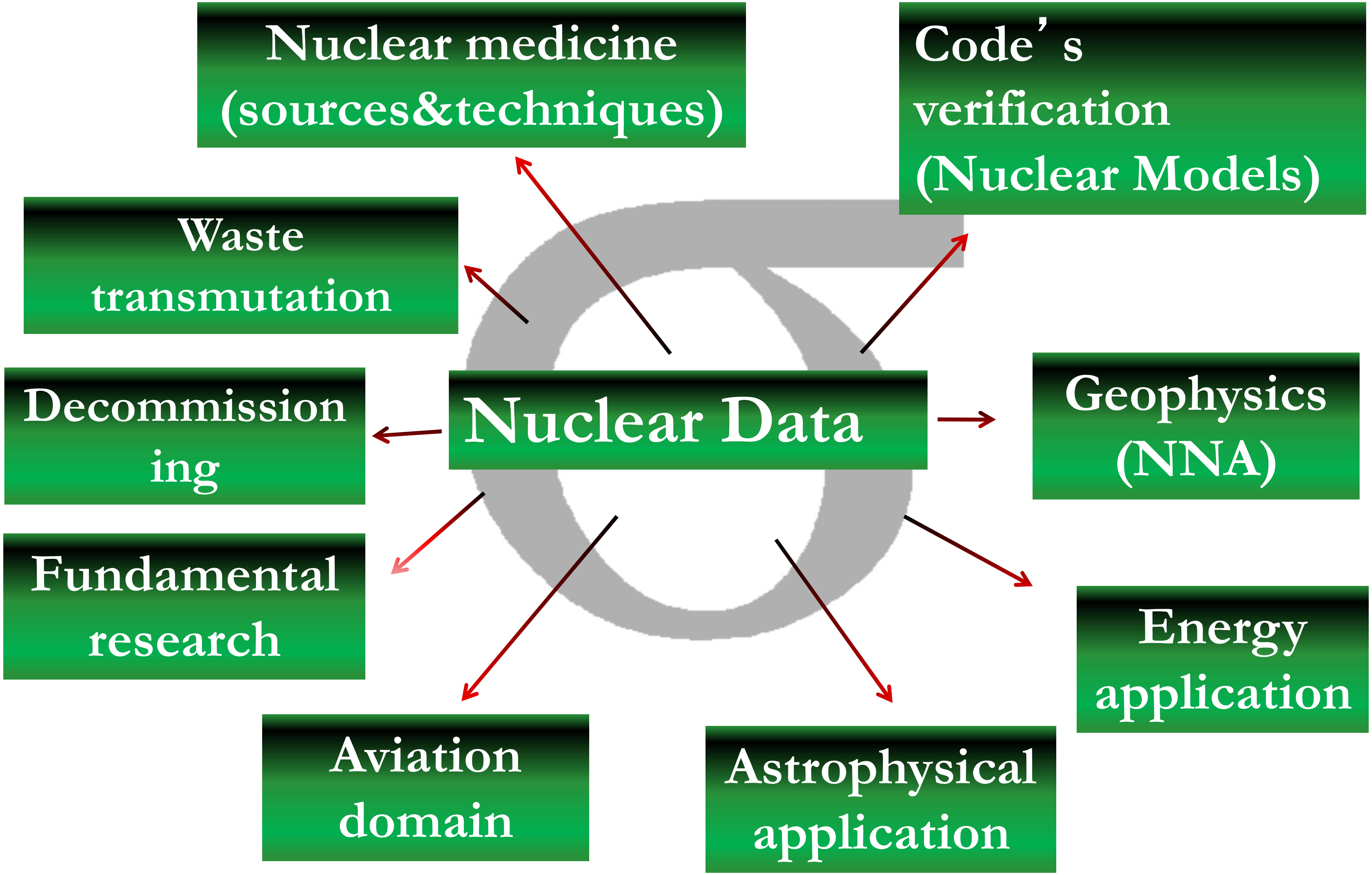
Arjan Koning*, NDS-IAEA, Austria*

IAEA

Overview

- Applications and Nuclear Data problems
- Objectives
- A fitting procedure (TALYS)
- Results
- Summary

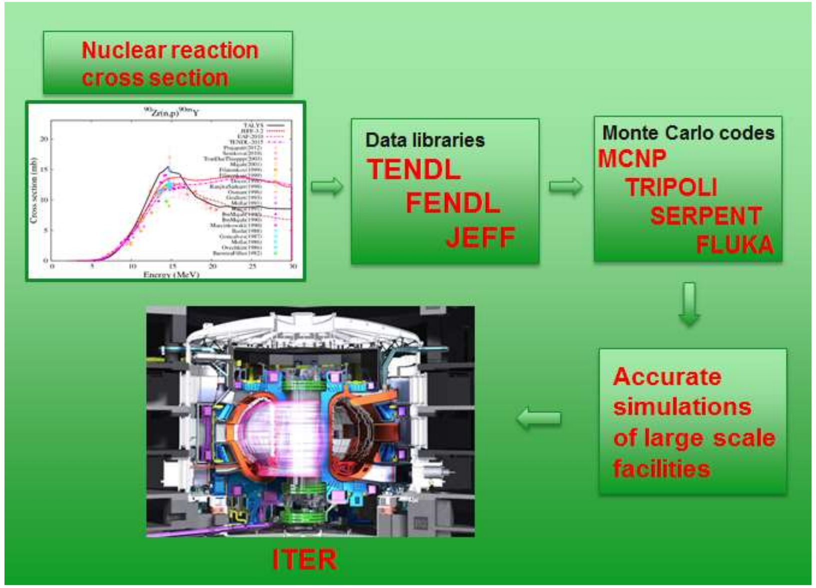
Applications

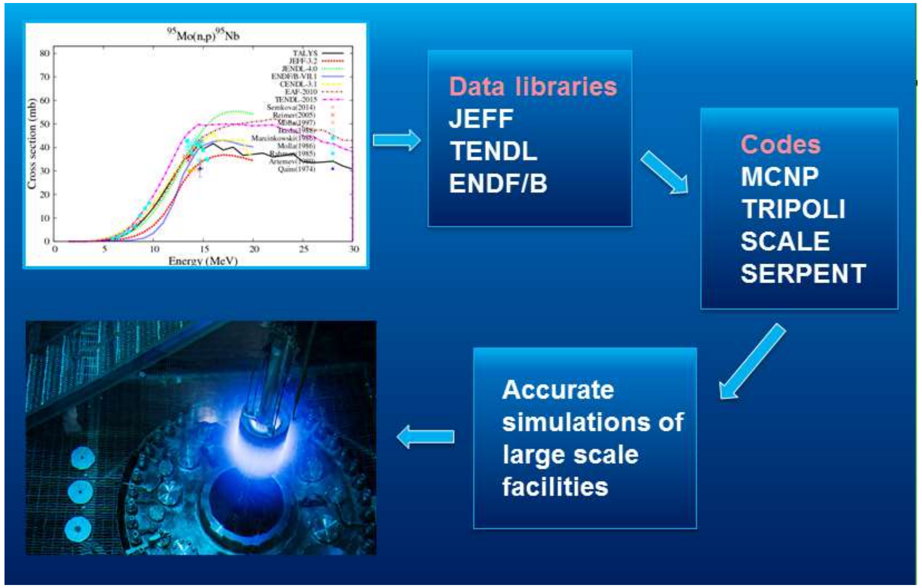


F4E & CHANDA

Fusion for **E**nergy
F4E

solving **CHA**llenges in **N**uclear **DA**ta
CHANDA





Fusion relevant reactions
TENDL

Fission products
JEFF/TENDL

Reliable data are needed for both fission and fusion: the approach is similar, the energy range is different!

Objective

- To elaborate the priority list of fusion relevant reactions
- To improve activation cross sections from the list
- To compare those cross sections to EAF-2010
- To update the current TENDL-2015
- To consider mass range 70-170 (isotopes from Ge to Lu)
- To analyze all stable isotopes of relevant materials
- For modernization of JEFF: Te, Nd, Ru, Pd, Xe, Sb, Cs, Pm, Ce, La, Pr, Sm, Tb, Dy, Ho
- To make an accent on construction materials: reflectors, shielding, absorber material (Sn, Nb, Y, Mo, Zr, Cd, In, Rh, Ba, I, Eu, Er, Gd)
- Validation procedure
- To prepare input files for TENDL-2017

Methodology of evaluation

NRG

TALYS TENDL

TALYS = **default** + "**best**" + "**bestbranch**" file

The fits were performed by varying nuclear model parameters

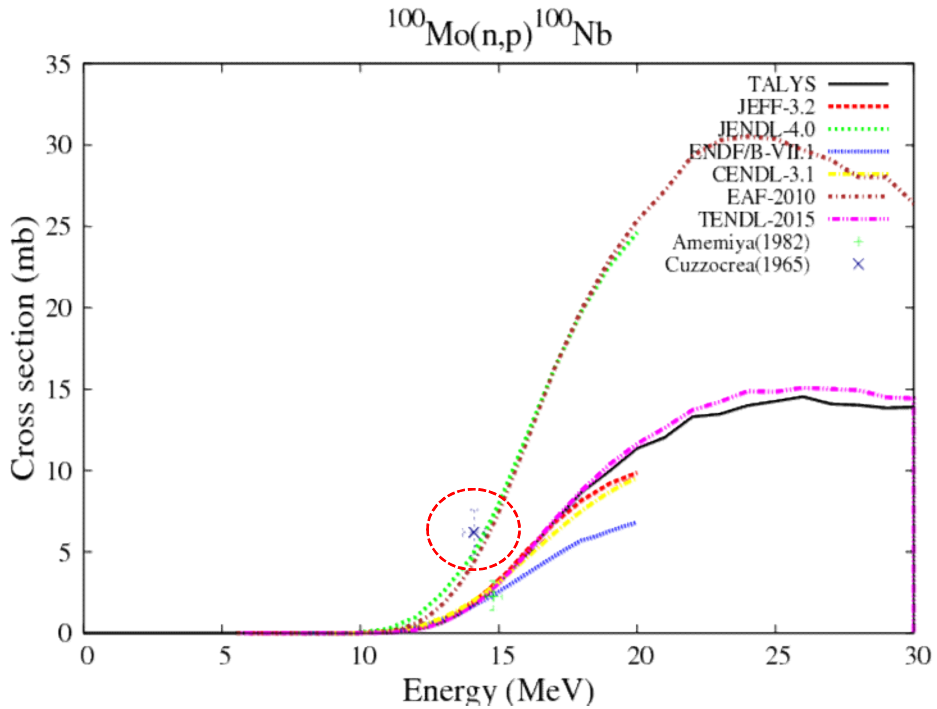
- Diffuseness of OMP (local adjustment)
- Radius of OMP
- Level density models
- Isomers (branching ratios)
- Gamma preequilibrium emission
- Radiative width
- Probability of α/d/t - particle formation

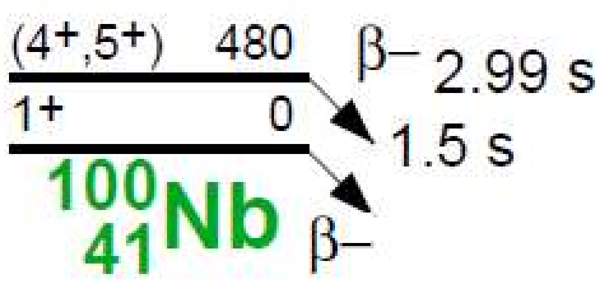
A general concept

- Fitting to the most recent experimental data if possible
- Compromise between a good C/E and reasonable shape of excitation function
- To vary adjustable parameters within acceptable margins
- To minimize the normalization factors

- **A correct choice of the experimental data set**
- **Differential and integral data validation (C/E, MACS)**

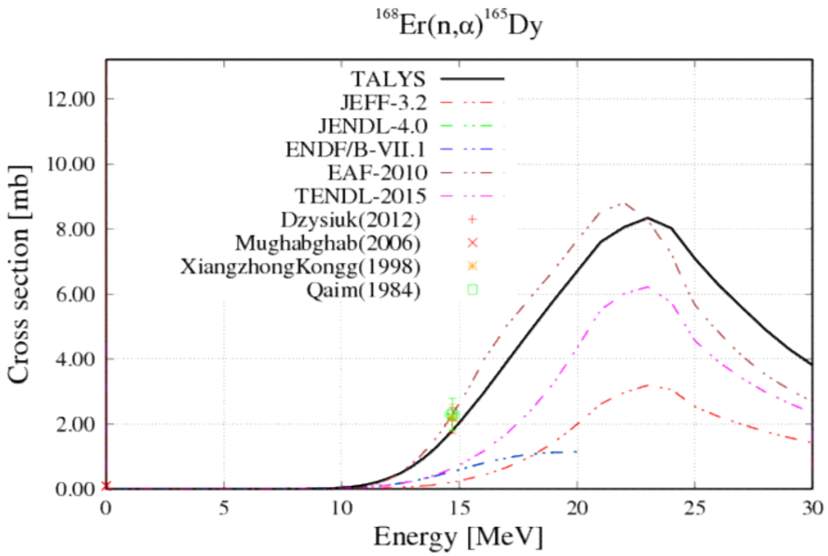
Analysis of experimental data (example)

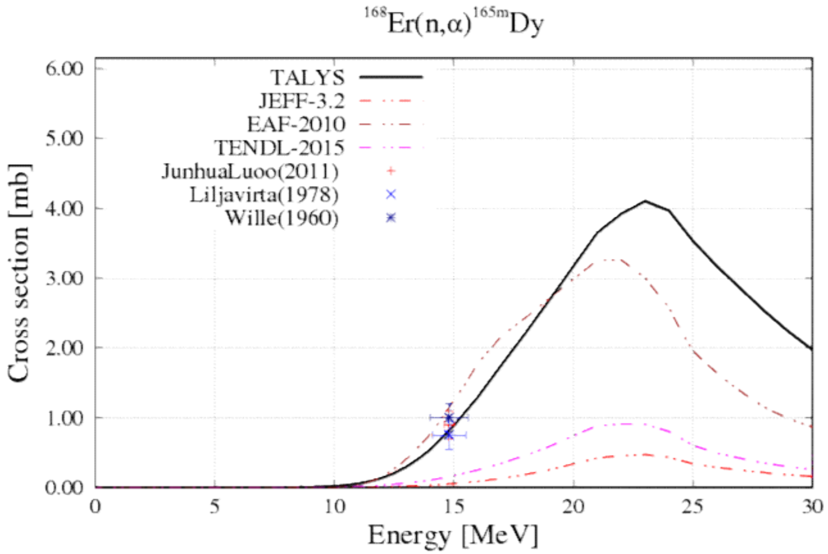


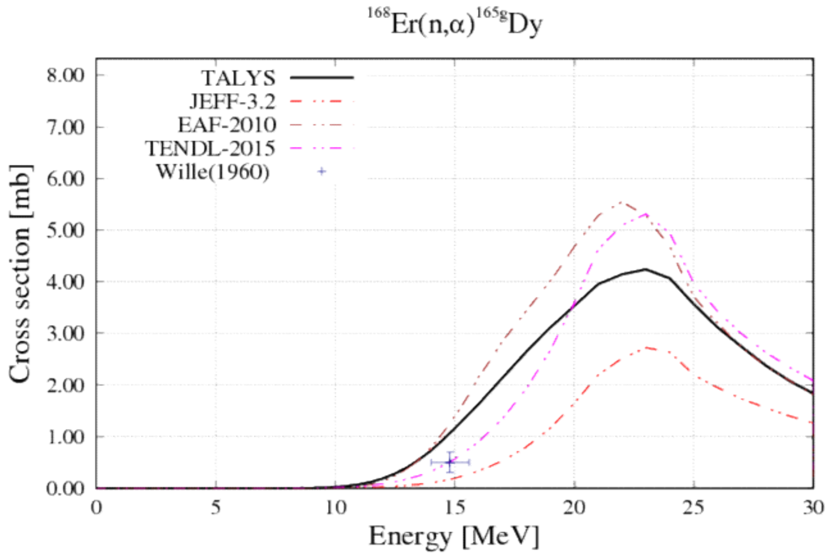


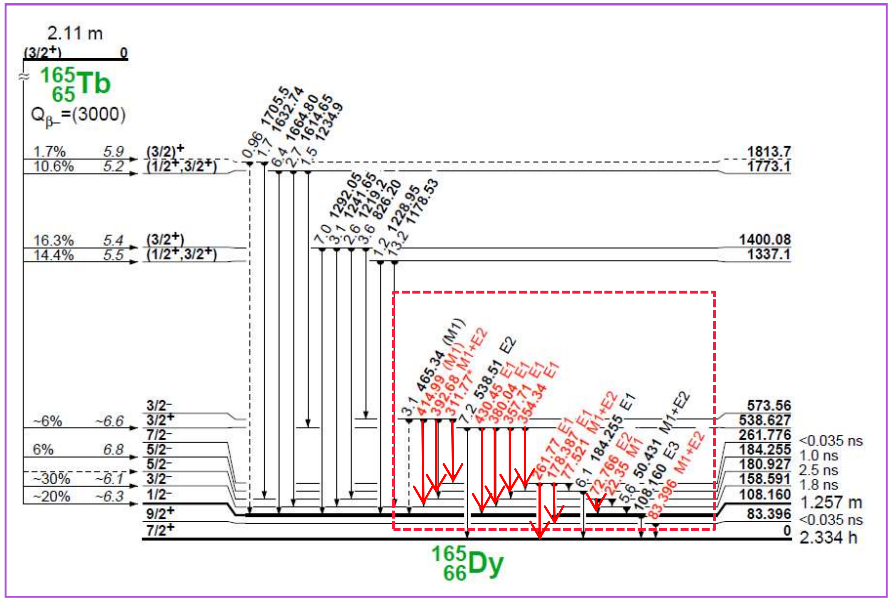
	EXFOR AUTHOR/ENTRY	Action
^{100}Mo(n,p)Nb^{100} Abundance: 9.63 %	1982 S. Amemiya 21840013	The fit was performed based on this data
	1965 P. Cuzzocrea 22503002	Data was not taken into evaluation. The authors used a wrong information on $T_{1/2}$
No integral data		

Isomeric cross sections

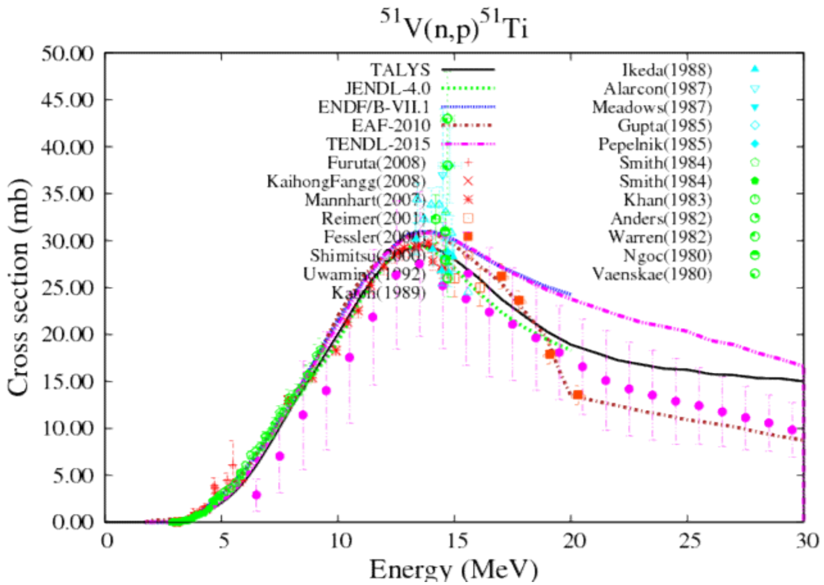


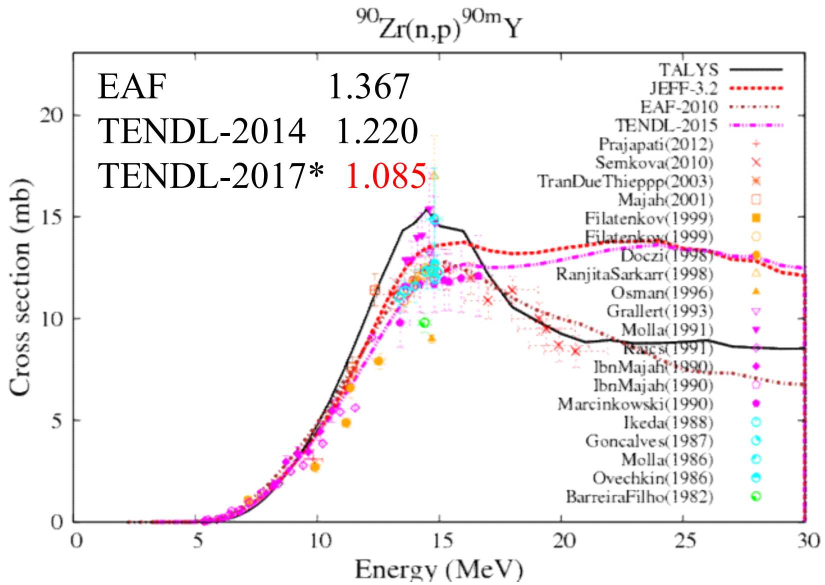


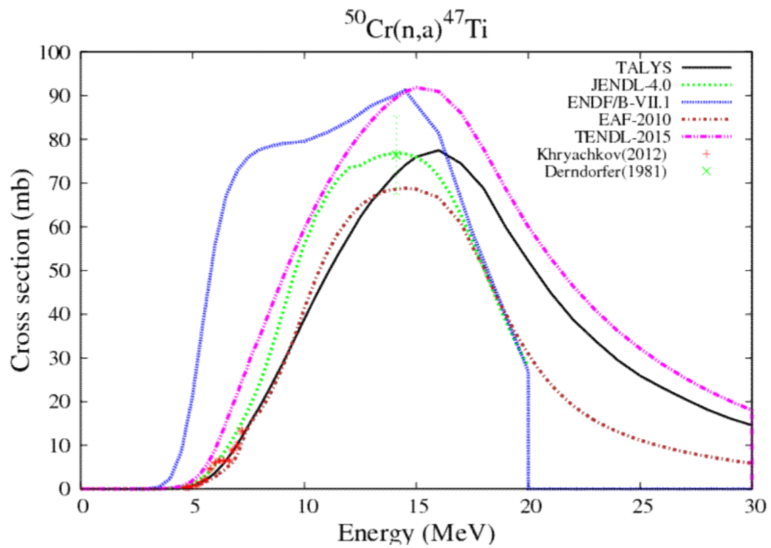


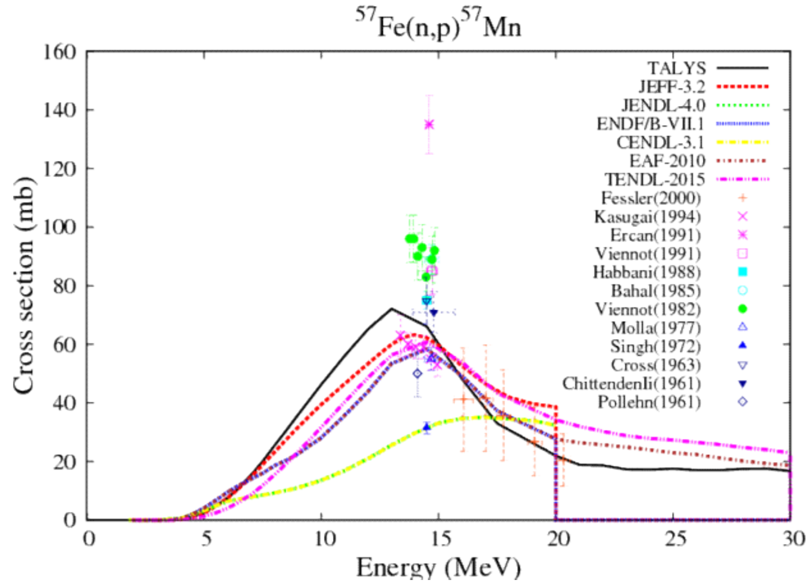


New evaluation (F4E)



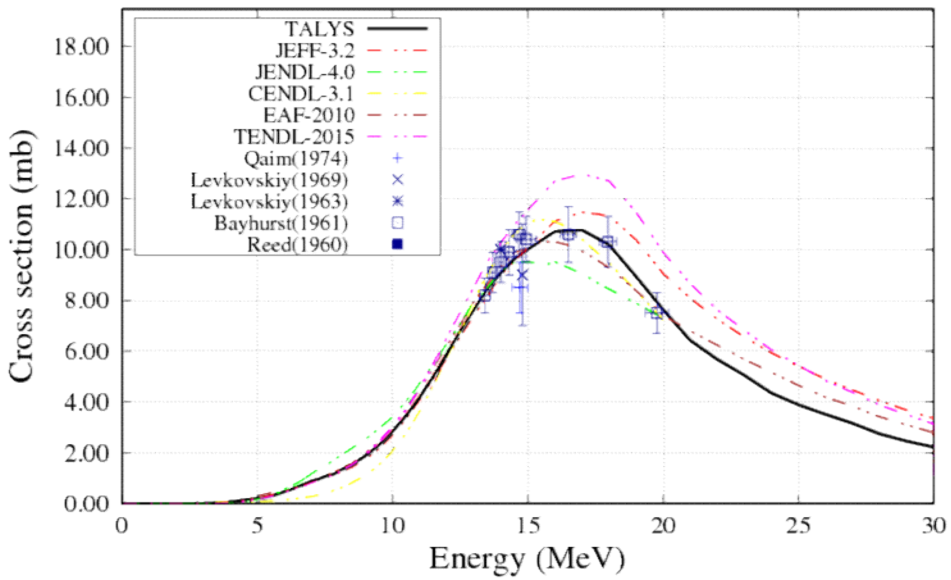




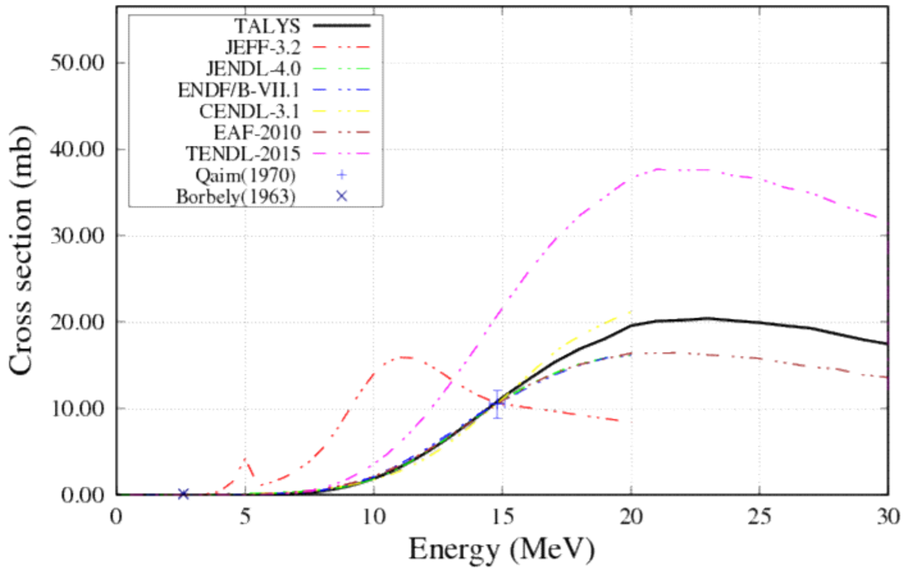


New evaluation (CHANDA)

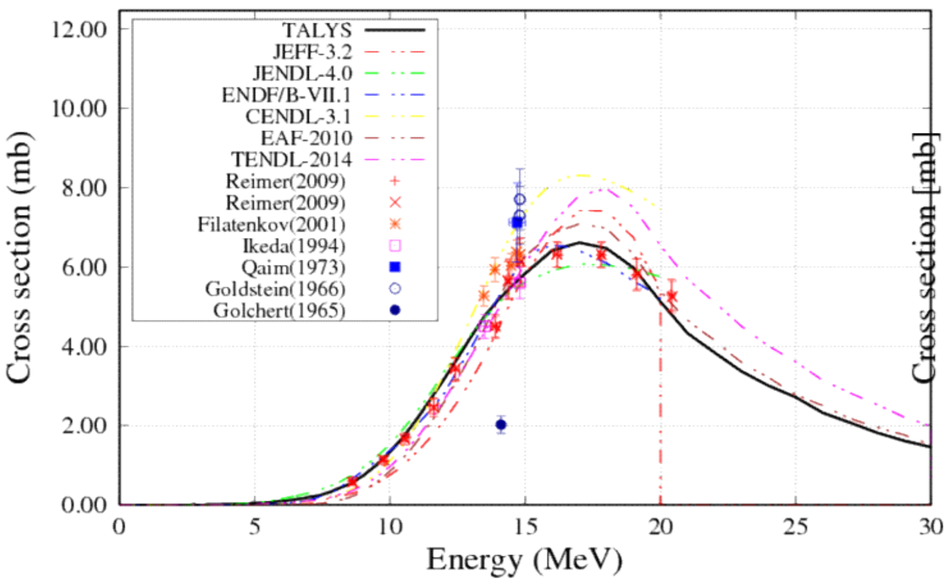
$^{92}Zr(n,\alpha)^{89}Sr$



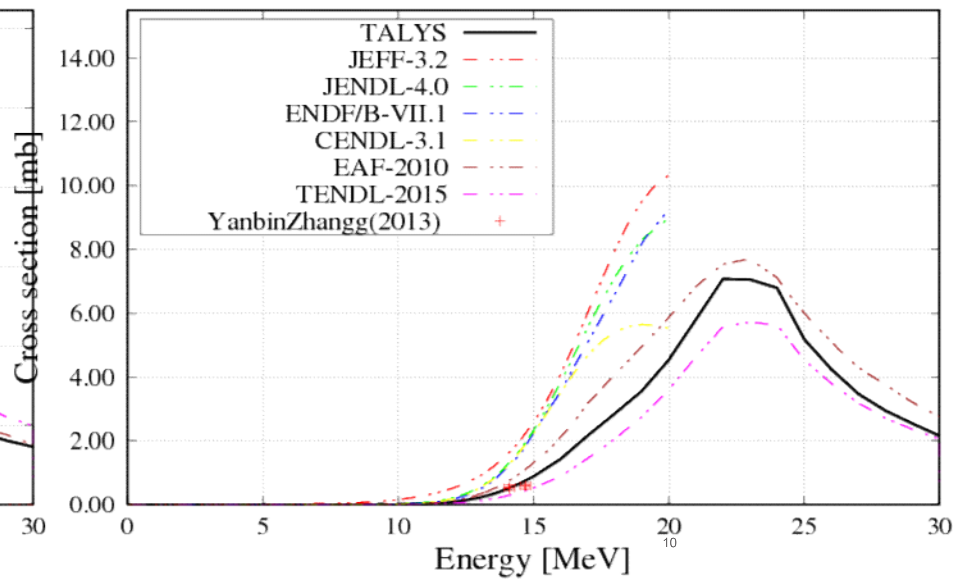
$^{133}Cs(n,p)^{133}Xe$



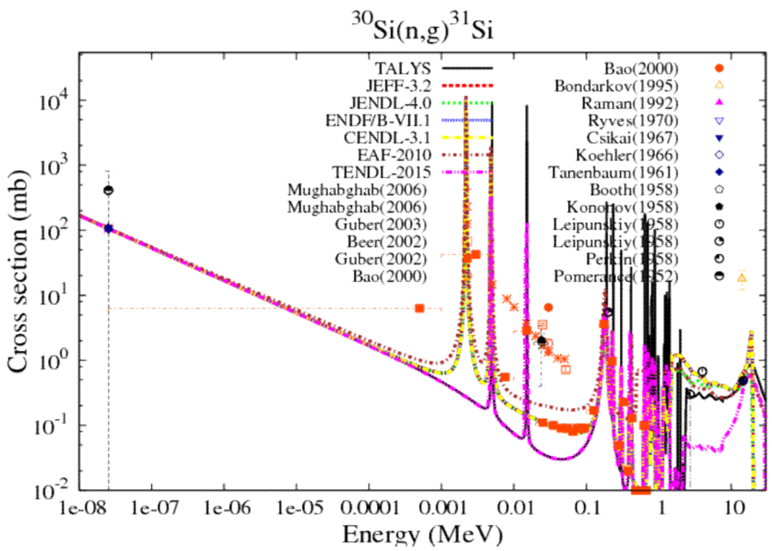
$^{99}Tc(n,\alpha)^{96}Nb$

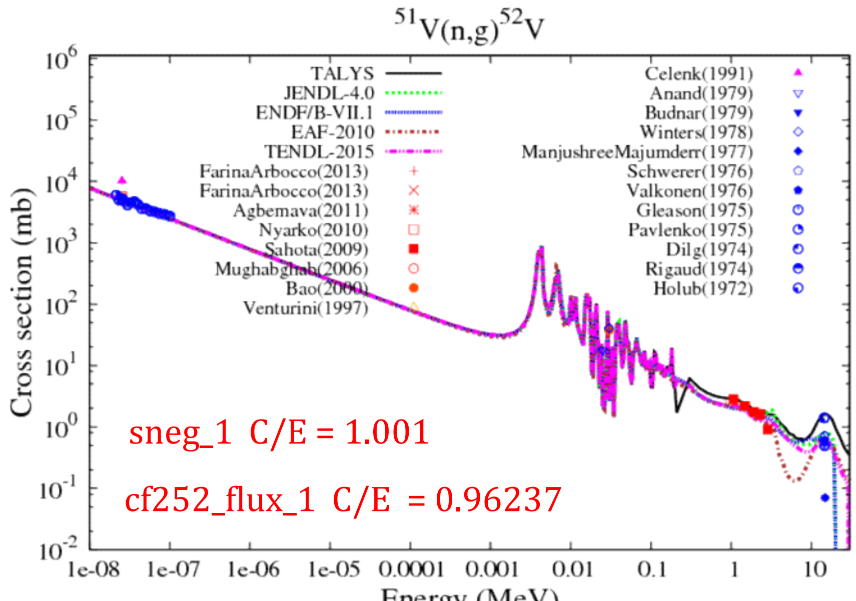


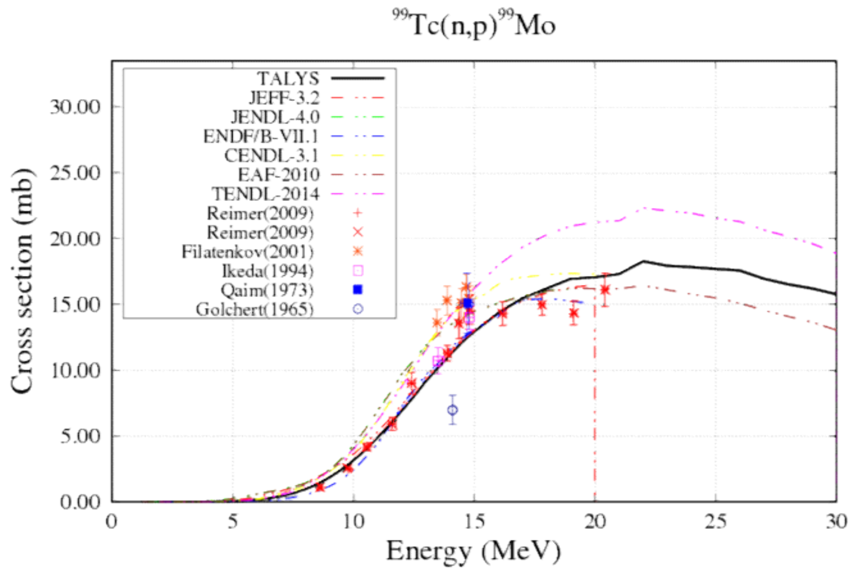
$^{160}Gd(n,\alpha)^{157}Sm$

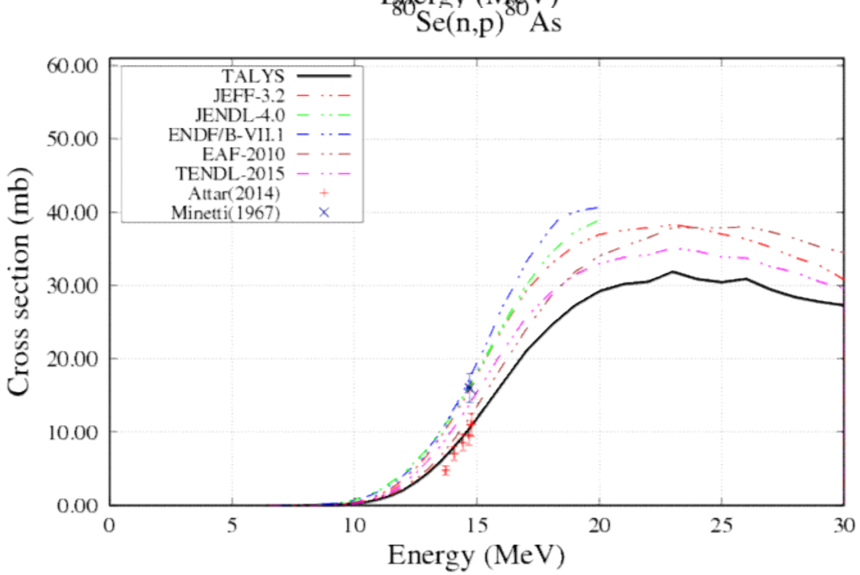


New evaluation









Integral validation (I)

Integral data validation implies getting the best C/E

	Reaction	Spectrum	σ(b)	C/E (EAF)	C/E (TENDL 2012)	C/E (TENDL 2014)	C/E (TENDL 2017)
1	$^{16}O(n,p)N^{16}$	fns_5min	3.23E-02	1.016	1.040	1.060	1.009*
2	$^{23}Na(n,p)Ne^{23}$	fns_5min	3.03E-02	1.190	1.189	1.190	1.163
3	$^{24}Mg(n,p)Na^{24}$	fns_5min	1.57E-01	1.165	1.000	–	0.984*
		cf252_flux_1	1.94E-03	1.347	1.238	–	1.107*
		cf252_flux_1	2.01E-03	1.300	1.283	–	1.068*
4	$^{32}S(n,t)P^{30}$	d-Be	4.13E-03	0.608	0.655	2.770	1.032
5	$^{34}S(n,\alpha)Si^{31}$	fns_5min	0.1160	1.019	1.019	0.940	1.001
6	$^{34}S(n,p)P^{34}$	fns_5min	0.0723	0.971	0.996	3.700	1.000
7	$^{37}Cl(n,p)S^{37}$	fns_5min	0.0179	1.368	0.871	0.970	0.971
8	$^{37}Cl(n,\alpha)P^{34}$	fns_5min	0.0275	0.980	1.305	0.940	1.011
9	$^{40}Ca(n,t)K^{38}$	d-Be	4.94E-03	0.338	0.571	–	1.007
10	$^{41}K(n,p)Ar^{41}$	fns_5min	3.63E-02	1.176	1.205	–	1.132
11	$^{46}Ti(n,2n)Ti^{45}$	sneg_1	5.82E-02	1.106	1.102	1.020	1.227
12	$^{48}Ca(n,2n)Ca^{47}$	fns_7hours	9.03E-01	0.885	0.885	0.930	1.007
13	$^{53}Cr(n,p)V^{53}$	sneg_1	5.95E-02	0.811	0.763	0.890	0.759
		cf252_flux_1	3.06E-04	1.880	1.699	1.610	1.137
		rez_DF	3.84E-04	3.256	3.610	3.740	2.930
14	$^{53}Cr(n,3n)Cr^{51}$	d-Be3	1.06E-02	0.769	0.769	0.750	0.945
15	$^{54}Fe(n,2n)Fe^{53}$	sneg_1	9.23E-03	2.039	1.754	1.440	2.420
16	$^{60}Ni(n,p)Co^{60m}$	fns_5min	6.90E-02	0.917	–	1.090	1.080
17	$^{60}Ni(n,2p)Fe^{59}$	fzk_ss316	8.62E-04	0.926	0.639	0.640	0.739
18	$^{61}Ni(n,p)Co^{61}$	fzk_2	1.88E-02	1.722	1.400	1.520	1.002
19	$^{74}Ge(n,p)Ga^{74}$	fns_5min	1.32E-03	1.389	1.059	1.110	1.006
20	$^{82}Se(n,2n)Se^{81}$	fns_5min	1.00E+00	1.305	1.118	1.180	1.006

Integral validation (MACS, C/E, RI)

	Reaction	MACS (EAF)	MACS (JEFF-3.3)	MACS (ENDF VIII)	MACS (TENDL-2012)	MACS (TENDL-2014)	MACS (TENDL-2017)
1	$^{107}Ag(n,\gamma)^{108}Ag$	1.02	0.900	0.900	1.150	0.880	0.960
2	$^{135}Ba(n,\gamma)^{136}Ba$	0.73	1.102	1.068	0.905	1.100	1.050
3	$^{136}Ce(n,\gamma)^{137}Ce$	1.43	0.884	1.147	1.430	0.960	1.000
4	$^{140}Ce(n,\gamma)^{141}Ce$	0.81	0.801	0.707	0.630	0.800	0.960
5	$^{162}Dy(n,\gamma)^{163}Dy$	0.83	1.025	1.024	0.810	1.110	1.060
6	$^{164}Dy(n,\gamma)^{165}Dy$	0.85	1.065	1.095	0.890	0.990	1.030
7	$^{154}Eu(n,\gamma)^{155}Eu$	0.62	0.789	0.789	1.070	1.200	1.010
8	$^{155}Eu(n,\gamma)^{156}Eu$	0.77	0.877	0.877	1.110	1.320	1.000
9	$^{164}Er(n,\gamma)^{165}Er$	0.59	1.786	1.787	0.430	1.230	1.060
10	$^{69}Ga(n,\gamma)^{70}Ga$	0.93	0.914	0.858	0.770	0.880	1.050
11	$^{71}Ga(n,\gamma)^{72}Ga$	0.91	0.796	1.011	0.750	0.800	1.070
12	$^{76}Ge(n,\gamma)^{77}Ge$	0.71	0.941	0.792	0.270	0.920	0.970
13	$^{155}Gd(n,\gamma)^{156}Gd$	1.02	1.253	1.092	0.930	1.060	1.000
14	$^{129}I(n,\gamma)^{130}I$	0.82	0.864	0.998	0.680	0.930	1.000
15	$^{163}Ho(n,\gamma)^{164}Ho$	0.64	2.820	–	2.510	2.810	1.030
16	$^{165}Ho(n,\gamma)^{166}Ho$	1.32	1.041	1.041	1.060	1.070	1.060
17	$^{83}Kr(n,\gamma)^{84}Kr$	1.00	1.464	1.111	0.900	1.440	1.000
18	$^{85}Kr(n,\gamma)^{86}Kr$	–	1.015	2.242	–	–	1.000
19	$^{100}Mo(n,\gamma)^{101}Mo$	0.66	0.789	0.802	0.680	0.990	1.010
20	$^{93}Nb(n,\gamma)^{94}Nb$	0.89	1.090	1.016	0.850	1.080	1.000
21	$^{95}Nb(n,\gamma)^{96}Nb$	–	1.820	1.307	–	–	1.000
22	$^{108}Pd(n,\gamma)^{109}Pd$	0.98	1.034	1.034	1.060	0.980	1.010
23	$^{110}Pd(n,\gamma)^{111}Pd$	0.68	1.060	1.077	0.920	1.070	1.000
24	$^{147}Pm(n,\gamma)^{148}Pm$	1.36	1.480	1.484	1.340	1.230	1.050
25	$^{141}Pr(n,\gamma)^{142}Pr$	0.95	0.987	0.987	0.950	0.870	0.990
26	$^{143}Pr(n,\gamma)^{144}Pr$	–	0.827	0.310	–	–	1.000
27	$^{103}Rh(n,\gamma)^{104}Rh$	0.96	1.060	0.992	1.020	1.260	1.110
28	$^{104}Ru(n,\gamma)^{105}Ru$	0.96	1.080	1.081	1.170	1.500	1.060
29	$^{121}Sb(n,\gamma)^{122}Sb$	0.95	0.985	0.965	1.060	1.000	1.130
30	$^{123}Sb(n,\gamma)^{124}Sb$	1.16	1.053	1.064	1.190	1.020	1.350
31	$^{74}Se(n,\gamma)^{75}Se$	0.72	0.969	0.775	0.850	0.960	1.020
32	$^{78}Se(n,\gamma)^{79}Se$	0.99	1.012	1.517	0.840	1.000	1.260
33	$^{82}Se(n,\gamma)^{83}Se$	–	0.458	3.464	–	–	1.010
34	$^{119}Sn(n,\gamma)^{120}Sn$	1.13	1.257	1.256	0.930	0.910	1.060
35	$^{88}Sr(n,\gamma)^{89}Sr$	0.92	0.882	0.882	0.780	0.880	1.000
36	$^{160}Tb(n,\gamma)^{161}Tb$	–	1.825	0.740	–	–	1.010
37	$^{120}Te(n,\gamma)^{121}Te$	0.68	0.953	0.543	0.510	0.980	1.060
38	$^{124}Te(n,\gamma)^{125}Te$	0.89	0.686	0.874	0.560	0.680	1.040
39	$^{126}Te(n,\gamma)^{127}Te$	1.01	0.833	0.982	0.520	0.860	1.000
40	$^{128}Te(n,\gamma)^{129}Te$	0.65	0.794	0.834	0.450	0.700	0.780

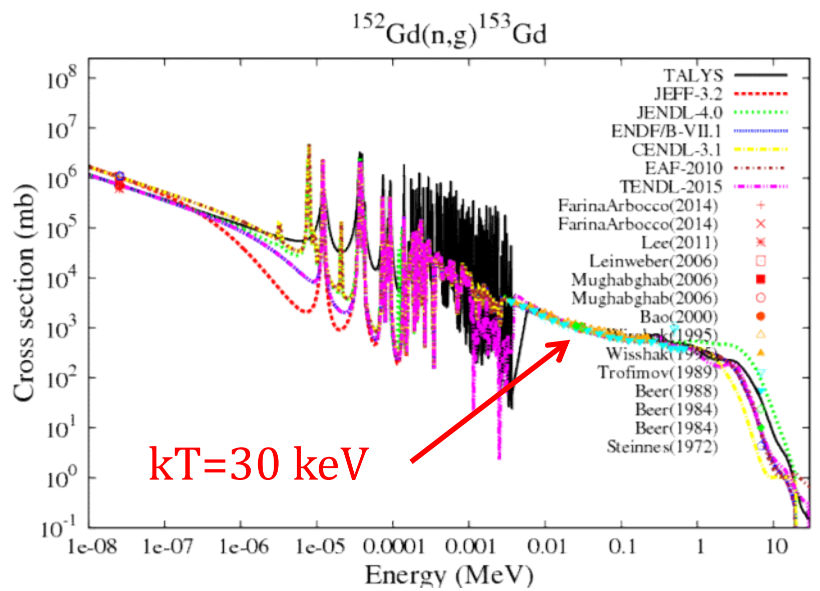
	Reaction	C/E_thermal JEFF-3.3	C/E_thermal TENDL-2017
1	$^{10}B(n,\gamma)^{10}B$	1.693	0.308
2	$^{23}Na(n,\gamma)^{24}Na$	1.309	1.293
3	$^{46}Sc(n,\gamma)^{47}Sc$	1.163	0.998
4	$^{62}Ni(n,\gamma)^{63}Ni$	0.953	0.953
5	$^{90}Sr(n,\gamma)^{91}Sr$	3.316	3.950
6	$^{90}Zr(n,\gamma)^{91}Zr$	0.129	0.138
7	$^{91}Zr(n,\gamma)^{92}Zr$	1.465	1.465
8	$^{92}Zr(n,\gamma)^{93}Zr$	0.881	1.000
9	$^{93}Zr(n,\gamma)^{94}Zr$	0.694	0.996
10	$^{92}Mo(n,\gamma)^{93}Mo$	0.766	1.012
11	$^{105}Rh(n,\gamma)^{106}Rh$	1.310	1.306
12	$^{107}Pd(n,\gamma)^{108}Pd$	0.790	0.995
13	$^{108}Pd(n,\gamma)^{109}Pd$	1.120	0.996
14	$^{108}Cd(n,\gamma)^{109}Cd$	1.256	0.994
15	$^{109}Cd(n,\gamma)^{110}Cd$	0.752	0.996
16	$^{127}I(n,\gamma)^{128}I$	0.943	0.998
17	$^{140}La(n,\gamma)^{141}La$	4.922	0.996
18	$^{147}Nd(n,\gamma)^{148}Nd$	1.798	0.996
19	$^{151}Pm(n,\gamma)^{152}Pm$	0.300	0.995
20	$^{148}Gd(n,\gamma)^{149}Gd$	0.223	0.772
21	$^{156}Gd(n,\gamma)^{157}Gd$	0.853	0.986
22	$^{158}Gd(n,\gamma)^{159}Gd$	1.136	1.002
23	$^{160}Gd(n,\gamma)^{161}Gd$	0.550	1.008
24	$^{161}Gd(n,\gamma)^{162}Gd$	0.618	0.995
25	$^{171}Er(n,\gamma)^{172}Er$	1.739	0.995

Reaction	σ(b)	Δσ(b)	RI (EAF)	RI (JEFF-3.3)	RI (TENDL 2014)	RI (ENDF VIII)	RI (TENDL 2017)
$^{107}Ag(n,\gamma)^{108}Ag$	1.07E+02	5.00E+00	1.000	0.762	0.920	0.763	0.927
$^{135}Ba(n,\gamma)^{136}Ba$	4.65E-01	7.00E-02	0.520	1.353	0.380	1.056	1.026
$^{140}Ce(n,\gamma)^{141}Ce$	5.40E-01	5.00E-02	0.490	0.554	0.510	0.551	0.553
$^{162}Dy(n,\gamma)^{163}Dy$	2.74E+03	2.70E+02	1.010	1.000	1.000	1.006	1.002
$^{164}Dy(n,\gamma)^{165}Dy$	3.42E+02	2.00E+01	1.010	1.000	1.000	1.005	1.004
$^{129}I(n,\gamma)^{130}I$	3.38E+01	1.40E+00	0.900	0.999	1.000	0.851	1.011
$^{165}Ho(n,\gamma)^{166}Ho$	6.65E+02	2.00E+01	1.020	1.025	1.040	1.025	1.037
$^{110}Pd(n,\gamma)^{111g}Pd$	2.30E+00	3.00E-01	0.850	0.954	1.220	0.999	0.929
$^{147}Pm(n,\gamma)^{148m}Pm$	7.90E+02	1.00E+00	1.240	1.023	0.880	1.07	1.024
$^{141}Pr(n,\gamma)^{142}Pr$	1.74E+01	2.00E+00	1.030	1.025	1.010	1.025	1.012
$^{103}Rh(n,\gamma)^{104}Rh$	1.01E+03	5.00E+01	1.020	0.959	0.960	0.958	0.961
$^{104}Ru(n,\gamma)^{105}Ru$	6.30E+00	2.00E-01	1.020	1.047	1.170	1.047	1.078
$^{121}Sb(n,\gamma)^{122}Sb$	2.02E+02	2.00E+01	1.020	1.059	1.020	1.019	1.021
$^{123}Sb(n,\gamma)^{124}Sb$	1.26E+02	2.00E+01	0.950	0.970	1.010	1.014	1.015
$^{78}Se(n,\gamma)^{79m}Se$	3.70E+00	6.00E-01	1.008	1.062	0.730	1.0629	1.055
$^{126}Te(n,\gamma)^{127}Te$	8.00E+00	6.00E-01	1.130	0.949	0.940	0.949	0.954
$^{128}Te(n,\gamma)^{129m}Te$	7.75E-02	5.00E-03	1.630	1.054	0.320	1.083	1.034

Maxwellian Average Cross Section

Reaction	MACS ratio	
$^{46}Ca(n,\gamma)Ca^{47}$	EAF-2010	1.347
	TENDL-2014	1.160
	TENDL-2016*	1.005
$^{54}Fe(n,\gamma)Fe^{55}$	EAF-2010	0.659
	TENDL-2014	0.730
	TENDL-2016*	1.040
$^{74}Ge(n,\gamma)Ge^{75}$	EAF-2010	0.334
	TENDL-2014	0.960
	TENDL-2016*	1.039
$^{88}Sr(n,\gamma)Sr^{89}$	EAF-2010	0.918
	TENDL-2014	0.880
	TENDL-2016*	1.009
$^{92}Mo(n,\gamma)Mo^{93}$	EAF-2010	0.844
	TENDL-2014	0.760
	TENDL-2016*	1.002
$^{144}Sm(n,\gamma)Sm^{145}$	EAF-2010	0.951
	TENDL-2014	0.480
	TENDL-2016*	1.006
$^{152}Gd(n,\gamma)Gd^{153}$	EAF-2010	0.845
	TENDL-2014	1.040
	TENDL-2016*	1.002
$^{163}Ho(n,\gamma)Ho^{164}$	EAF-2010	0.643
	TENDL-2014	2.810
	TENDL-2016*	1.031
$^{180}W(n,\gamma)W^{181}$	EAF-2010	0.903
	TENDL-2014	0.850
	TENDL-2016*	1.009
$^{186}W(n,\gamma)W^{187}$	EAF-2010	0.842
	TENDL-2014	0.850
	TENDL-2016*	1.007
$^{207}Pb(n,\gamma)Pb^{208}$	EAF-2010	0.740
	TENDL-2014	1.190
	TENDL-2016*	1.001

MACS ratio = TALYS (mb) / KADoNIS (mb)



Summary

- A set of new evaluations has been performed for the F4E and CHANDA projects
  - F4E: 120 reaction channels (~60 nuclides)
  - CHANDA: 280 reaction channels (~150 nuclides)

- **TALYS** is a good platform for improving the consistency and reliability of nuclear data. Evaluation has been done including the experimental data analysis.

- The obtained results ("best files") are going to be used for production of the latest **TENDL** data library and available for a worldwide use

- Validation of current evaluations was done by integral data testing (C/E, IR, MACS)

- The first part of results was published:

  - N. Dzysiuk, A. Koning "Improving activation cross section data with TALYS", *Proceedings of the International Conference on Nuclear Data for Science and Technology*, September 11-16, 2016, Bruges, Belgium, EPJ, 146, 02047 (2017)
  - N. Dzysiuk, D. Rochman, A. Koning, U. Fisher, "Improving activation cross sections for fusion applications", *Fusion Science and Technology* (2017), DOI: 10.1080/15361055.2017.1372682

TALYS Evaluated Nuclear Data Library

^{107}Ag(n,γ)^{108}Ag, ^{135}Ba(n,γ)^{136}Ba, ^{115}Cd(n,γ)^{116}Cd, ^{136}Ce(n,γ)^{137}Ce, ^{140}Ce(n,γ)^{141}Ce, ^{141}Ce(n,γ)^{142}Ce, ^{134}Cs(n,γ)^{135}Cs, ^{158}Dy(n,γ)^{159}Dy, ^{162}Dy(n,γ)^{163}Dy, ^{164}Dy(n,γ)^{165}Dy, ^{154}Eu(n,γ)^{155}Eu, ^{155}Eu(n,γ)^{156}Eu, ^{164}Er(n,γ)^{165}Er, ^{69}Ga(n,γ)^{70}Ga, ^{71}Ga(n,γ)^{72}Ga, ^{76}Ge(n,γ)^{77}Ge, ^{153}Gd(n,γ)^{154}Gd, ^{155}Gd(n,γ)^{156}Gd, ^{163}Ho(n,γ)^{164}Ho, ^{165}Ho(n,γ)^{166}Ho, ^{129}I(n,γ)^{130}I, ^{129}I(n,γ)^{130m}I, ^{131}I(n,γ)^{132}I, ^{83}Kr(n,γ)^{84}Kr, ^{85}Kr(n,γ)^{86}Kr, ^{99}Mo(n,γ)^{100}Mo, ^{100}Mo(n,γ)^{101}Mo, ^{93}Nb(n,γ)^{94}Nb, ^{94}Nb(n,γ)^{95}Nb, ^{95}Nb(n,γ)^{96}Nb, ^{142}Nd(n,γ)^{143}Nd, ^{108}Pd(n,γ)^{109m}Pd, ^{110}Pd(n,γ)^{111}Pd, ^{147}Pm(n,γ)^{148}Pm, ^{148}Pm(n,γ)^{149}Pm, ^{149}Pm(n,γ)^{150}Pm, ^{141}Pr(n,γ)^{142}Pr, ^{143}Pr(n,γ)^{144}Pr, ^{86}Rb(n,γ)^{87}Rb, ^{103}Rh(n,γ)^{104}Rh, ^{104}Ru(n,γ)^{105}Ru, ^{121}Sb(n,γ)^{122}Sb, ^{123}Sb(n,γ)^{124}Sb, ^{74}Se(n,γ)^{75}Se, ^{119}Sn(n,γ)^{120}Sn, ^{121}Sn(n,γ)^{122}Sn, ^{125}Sn(n,γ)^{126}Sn, ^{126}Sn(n,γ)^{127}Sn, ^{153}Sm(n,γ)^{154}Sm, ^{78}Se(n,γ)^{79}Se, ^{79}Se(n,γ)^{80}Se, ^{82}Se(n,γ)^{83g}Se, ^{88}Sr(n,γ)^{89}Sr, ^{90}Sr(n,γ)^{91}Sr, ^{160}Tb(n,γ)^{161}Tb, ^{120}Te(n,γ)^{121}Te, ^{123}Te(n,γ)^{124}Te, ^{124}Te(n,γ)^{125}Te, ^{126}Te(n,γ)^{127}Te, ^{126}Te(n,γ)^{127g}Te, ^{128}Te(n,γ)^{129}Te, ^{128}Te(n,γ)^{129g}Te, ^{130}Te(n,γ)^{131g}Te, ^{126}Xe(n,γ)^{127}Xe, ^{130}Xe(n,γ)^{131}Xe, ^{131}Xe(n,γ)^{132}Xe, ^{132}Xe(n,γ)^{133}Xe, ^{89}Y(n,γ)^{90}Y, ^{95}Zr(n,γ)^{96}Zr, ^{96}Zr(n,γ)^{97}Zr.

^{107}Ag(n,2n)^{106}Ag, ^{107}Ag(n,2n)^{106m}Ag, ^{107}Ag(n,2n)^{106g}Ag, ^{130}Ba(n,2n)^{129}Ba, ^{81}Br(n,2n)^{80}Br, ^{164}Er(n,2n)^{163}Er, ^{69}Ga(n,2n)^{68}Ga, ^{154}Gd(n,2n)^{153}Gd, ^{72}Ge(n,2n)^{71}Ge, ^{129}I(n,2n)^{128}I, ^{82}Kr(n,2n)^{81m}Kr, ^{86}Kr(n,2n)^{85m}Kr, ^{142}Nd(n,2n)^{141}Nd, ^{142}Nd(n,2n)^{141m}Nd, ^{142}Nd(n,2n)^{141g}Nd, ^{146}Nd(n,2n)^{145}Nd, ^{148}Nd(n,2n)^{147}Nd, ^{150}Nd(n,2n)^{148}Nd, ^{110}Pd(n,2n)^{109}Pd, ^{110}Pd(n,2n)^{109m}Pd, ^{141}Pr(n,2n)^{140}Pr, ^{87}Rb(n,2n)^{86}Rb, ^{96}Ru(n,2n)^{95}Ru, ^{98}Ru(n,2n)^{97}Ru, ^{104}Ru(n,2n)^{103}Ru, ^{74}Se(n,2n)^{73}Se, ^{74}Se(n,2n)^{73g}Se, ^{78}Se(n,2n)^{77}Se, ^{150}Sm(n,2n)^{149}Sm, ^{114}Sn(n,2n)^{113}Sn, ^{86}Sr(n,2n)^{85}Sr, ^{86}Sr(n,2n)^{85g}Sr, ^{120}Te(n,2n)^{119}Te, ^{120}Te(n,2n)^{119g}Te, ^{124}Te(n,2n)^{123m}Te, ^{126}Xe(n,2n)^{125}Xe, ^{132}Xe(n,2n)^{131m}Xe, ^{134}Xe(n,2n)^{133}Xe, ^{134}Xe(n,2n)^{133g}Xe, ^{136}Xe(n,2n)^{135}Xe, ^{136}Xe(n,2n)^{135m}Xe, ^{96}Zr(n,2n)^{95}Zr

^{107}Ag(n,p)^{107m}Pd, ^{75}As(n,p)^{75}Ge, ^{132}Ba(n,p)^{132}Cs, ^{134}Ba(n,p)^{134}Cs, ^{136}Ba(n,p)^{136}Cs, ^{138}Ba(n,p)^{138}Cs, ^{81}Br(n,p)^{81}Se, ^{81}Br(n,p)^{81g}Se, ^{110}Cd(n,p)^{110}Ag, ^{111}Cd(n,p)^{111}Ag, ^{113}Cd(n,p)^{113}Ag, ^{114}Cd(n,p)^{114}Ag, ^{140}Ce(n,p)^{140}La, ^{142}Ce(n,p)^{142}La, ^{133}Cs(n,p)^{133}Xe, ^{133}Cs(n,p)^{133m}Xe, ^{133}Cs(n,p)^{133g}Xe, ^{158}Dy(n,p)^{158}Tb, [illegible], [illegible]Dy(n[illegible], [illegible]b, [illegible], [illegible], [illegible], [illegible]Ga[illegible], [illegible]Ga(n[illegible]Zn, [illegible], [illegible], [illegible], ^{157}Gd(n,p)^{157}Eu, ^{72}Ge[illegible],p)^{72}Ga, ^{73}Ge(n,p)^{73}Ga, [illegible]Ge(n,p)^{74}Ga, ^{74}Ge(n,p)^{74g}Ga, ^{80}Kr(n,p)^{80m}Br, ^{82}Kr(n,p)^{82}Br, ^{84}Kr(n,p)^{84g}Br, ^{139}La(n,p)^{139}Ba, ^{94}Mo(n,p)^{94}Nb, ^{94}Mo(n,p)^{94m}Nb, ^{95}Mo(n,p)^{95}Nb, ^{95}Mo(n,p)^{95m}Nb, ^{95}Mo(n,p)^{95g}Nb, ^{96}Mo(n,p)^{96}Nb, ^{97}Mo(n,p)^{97}Nb, ^{97}Mo(n,p)^{97m}Nb, ^{98}Mo(n,p)^{98}Nb, ^{98}Mo(n,p)^{98m}Nb, ^{100}Mo(n,p)^{100}Nb, ^{142}Nd(n,p)^{142}Pr, ^{146}Nd(n,p)^{146}Pr, ^{102}Pd(n,p)^{102g}Rh, ^{102}Pd(n,p)^{102m}Rh, ^{105}Pd(n,p)^{105}Rh, ^{105}Pd(n,p)^{105m}Rh, ^{106}Pd(n,p)^{106}Rh, ^{106}Pd(n,p)^{106m}Rh, ^{106}Pd(n,p)^{106g}Rh, ^{108}Pd(n,p)^{108}Rh, ^{103}Rh(n,p)^{103}Ru, ^{96}Ru(n,p)^{96}Tc, ^{100}Ru(n,p)^{100}Tc, ^{101}Ru(n,p)^{101}Tc, ^{123}Sb(n,p)^{123}Sn, ^{74}Se(n,p)^{74}As, ^{76}Se(n,p)^{76}As, ^{77}Se(n,p)^{77}As, ^{78}Se(n,p)^{78}As, ^{80}Se(n,p)^{80}As, ^{114}Sn(n,p)^{114m}In, ^{116}Sn(n,p)^{116g}In, ^{115}Sn(n,p)^{115m}In, ^{116}Sn(n,p)^{116m}In, ^{117}Sn(n,p)^{117}In, ^{117}Sn(n,p)^{117g}In, ^{118}Sn(n,p)^{118}In, ^{118}Sn(n,p)^{118m}In, ^{120}Sn(n,p)^{120}In, ^{144}Sm(n,p)^{144}Pm, ^{148}Sm(n,p)^{148}Pm, ^{88}Sr(n,p)^{88}Rb, ^{99}Tc(n,p)^{99}Mo, ^{128}Xe(n,p)^{128}I, ^{131}Xe(n,p)^{131}I, ^{89}Y(n,p)^{89}Sr, ^{90}Zr(n,p)^{90}Y, ^{90}Zr(n,p)^{90m}Y, ^{91}Zr(n,p)^{91}Y, ^{91}Zr(n,p)^{91m}Y, ^{92}Zr(n,p)^{92}Y, ^{94}Zr(n,p)^{94}Y, ^{107}Ag(n,α)^{103m}Rh, ^{107}Ag(n,α)^{104g}Rh, ^{75}As(n,α)^{72}Ga, ^{138}Ba(n,α)^{135}Xe, ^{79}Br(n,α)^{76}As, ^{81}Br(n,α)^{78}As, ^{140}Ce(n,α)^{137m}Ba, ^{106}Cd(n,α)^{135}Pd, ^{112}Cd(n,α)^{109}Pd, ^{114}Cd(n,α)^{111}Pd, ^{114}Cd(n,α)^{111m}Pd, ^{114}Cd(n,α)^{111g}Pd, ^{142}Ce(n,α)^{139}Ba, ^{133}Cs(n,α)^{130}I, ^{69}Ga(n,α)^{66}Cu, ^{71}Ga(n,α)^{68m}Cu, ^{164}Dy(n,α)^{161}Gd, ^{168}Er(n,α)^{165}Dy, ^{170}Er(n,α)^{167}Dy, ^{156}Gd(n,α)^{153}Sm, ^{160}Gd(n,α)^{157}Sm, ^{72}Ge(n,α)^{69m}Zn, ^{74}Ge(n,α)^{71m}Zn, ^{76}Ge(n,α)^{73}Zn, ^{127}I(n,α)^{124g}Sb, ^{86}Kr(n,α)^{83g}Se, ^{139}La(n,α)^{136}Cs, ^{92}Mo(n,α)^{89}Zr, ^{92}Mo(n,α)^{89g}Zr, ^{95}Mo(n,α)^{92}Zr, ^{98}Mo(n,α)^{95}Zr, ^{100}Mo(n,α)^{97}Zr, ^{93}Nb(n,α)^{90}Y, ^{93}Nb(n,α)^{90m}Y, ^{93}Nb(n,α)^{90g}Y, ^{106}Pd(n,α)^{103}Ru, ^{110}Pd(n,α)^{107}Ru, ^{141}Pr(n,α)^{138}La, ^{85}Rb(n,α)^{82}Br, ^{103}Rh(n,α)^{100}Tc, ^{102}Ru(n,α)^{99}Mo, ^{104}Ru(n,α)^{101}Mo, ^{78}Se(n,α)^{75}Ge, ^{144}Sm(n,α)^{141m}Nd, ^{114}Sn(n,α)^{111m}Cd, ^{118}Sn(n,α)^{115}Cd, ^{88}Sr(n,α)^{85m}Kr, ^{159}Tb(n,α)^{156}Eu, ^{99}Tc(n,α)^{96}Nb, ^{128}Te(n,α)^{125m}Sn, ^{89}Y(n,α)^{86}Rb, ^{89}Y(n,α)^{86g}Rb, ^{90}Zr(n,α)^{87m}Sr, ^{92}Zr(n,α)^{89}Sr, ^{94}Zr(n,α)^{91}Sr, ^{96}Zr(n,α)^{93}Sr

^{107}Ag(n,tot), ^{107}Ag(n,el), ^{107}Ag(n,n)^{107m}Ag, ^{133}Cs(n,3n)^{131}Cs, ^{160}Gd(n,3n)^{158}Gd, ^{139}La(n,t)^{137}Ba, ^{92}Mo(n,d)^{91}Nd, ^{94}Mo(n,d)^{93}Nb, ^{95}Mo(n,np)^{94m}Nb, ^{96}Mo(n,d)^{95}Nb, ^{98}Mo(n,np)^{97}Nb, ^{93}Nb(n,t)^{91}Zr, ^{105}Pd(n,np)^{104m}Rh, ^{106}Pd(n,np)^{105}Rh, ^{141}Pr(n,3n)^{139}Pr, ^{141}Pr(n,t)^{139}Ce, ^{103}Rh(n,nα)^{99m}Tc, ^{103}Rh(n,t)^{101}Ru, ^{96}Ru(n,np)^{95g}Tc, ^{151}Sm(n,tot), ^{87}Sr(n,n)^{87m}Sr, ^{87}Sr(n,np)^{86}Rb, ^{99}Tc(n,n)^{99m}Tc, ^{99}Tc(n,nα)^{95}Nb, ^{91}Zr(n,nα)^{87m}Sr, ^{91}Zr(n,np)^{90m}Y, ^{94}Zr(n,np)^{93}Y.

Thank you for your attention!