Towards a new dosimetry library

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IAEA/NAPC Nuclear Data Section

Update of IRDF-2002 (release 2005)

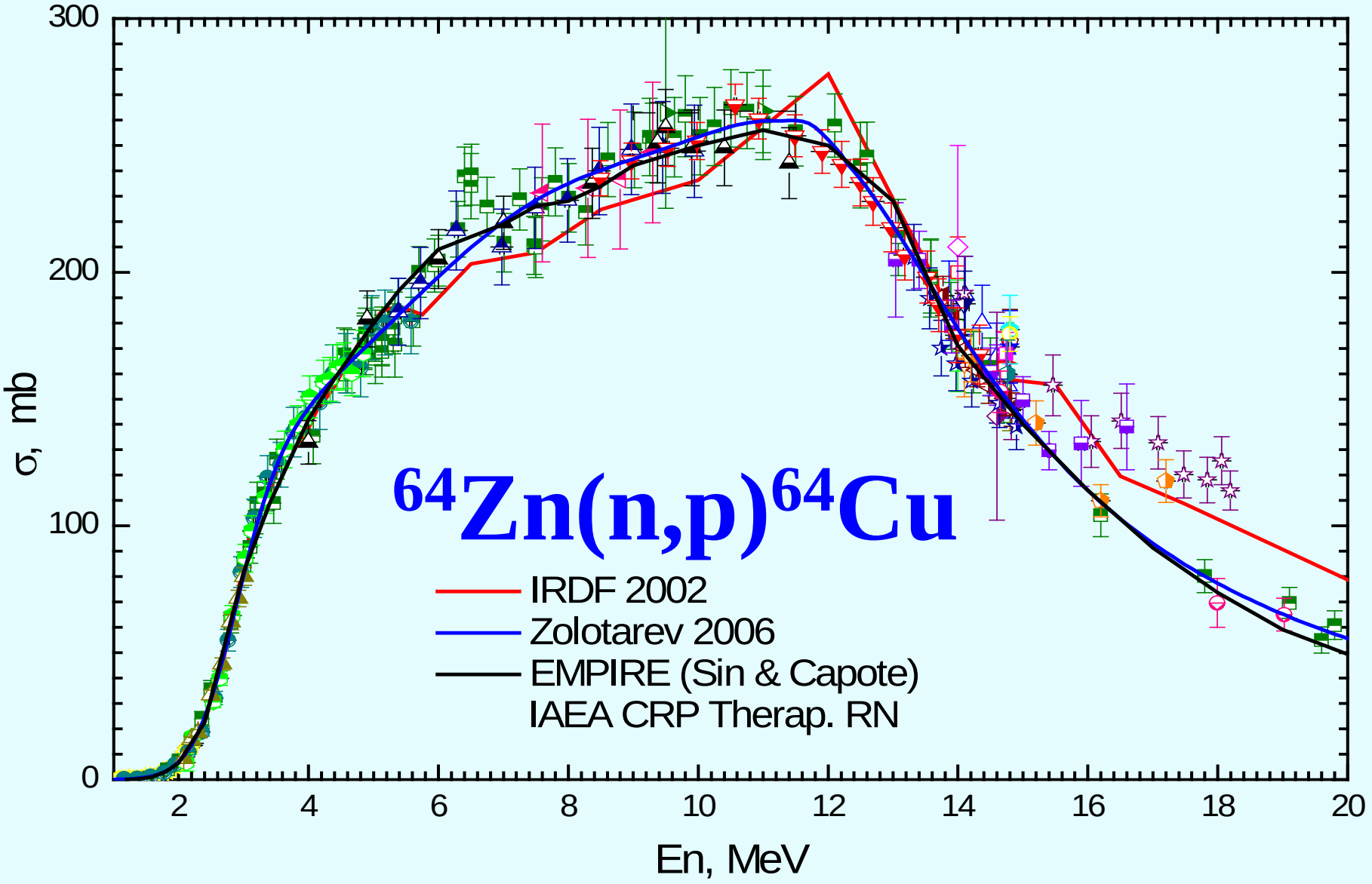
- IAEA CM held in 2007, 2010:
  INDC(NDS)-0575 (2010) and
  INDC(NDS)-507 (2007)
- Zolotarev evaluations
  (partially supported by IAEA/NDS)
  - INDC(NDS)-0526,
  - INDC(NDS)-0546,
  - INDC(NDS)-0584.
- IAEA Standards + ENDF/B-VII.0 + (cov)
- Model covariance calculations: TENDL
  Use for the extension of the energy range

	Dosimetry reaction	E_{max} [MeV]	Comments
1	^{24}Mg(n,p)	21	Fission
2	^{27}Al(n,p)	40	Fission+Fusion
3	^{27}Al(n,α)	40	Fission+Fusion
4	^{32}S(n,p)	21	Fission
5	^{47}Ti(n,p)	20	Fission
6	^{55}Mn(n,2n)	40	Fission+Fusion
7	^{55}Mn(n,γ)	20	Fission+Fusion
8	^{57}Fe(n,γ)	20	Fission
9	^{58}Fe(n,γ)	20	Fission
10	^{59}Co(n,2n)	60	Fission+Fusion
11	^{59}Co(n,p)	75	Fission+Fusion
12	^{60}Ni(n,p)	21	Fission
13	^{63}Cu(n,2n)	20	Fission
14	^{64}Zn(n,p)	20	Fission
15	^{65}Cu(n,2n)	20	Fission

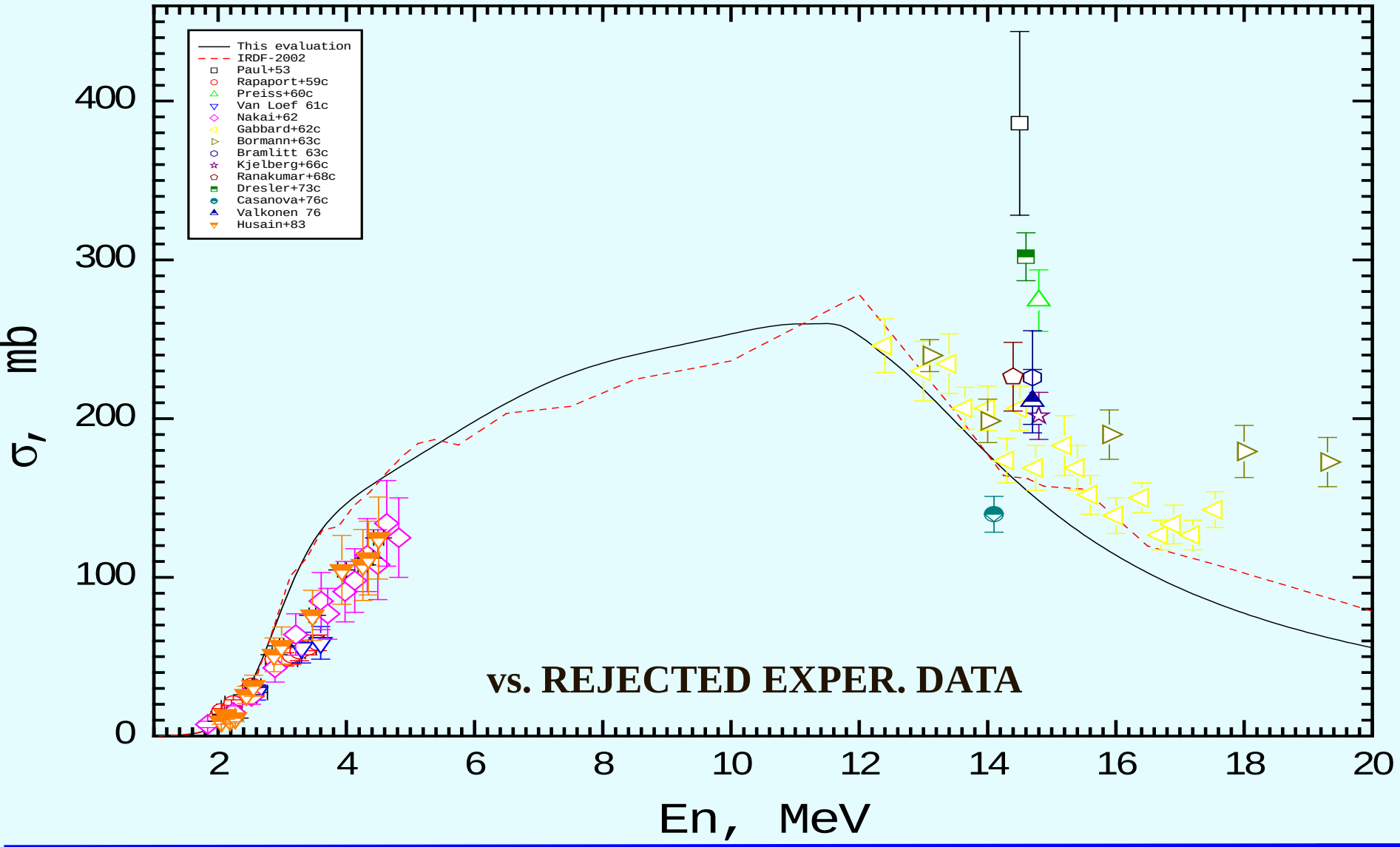
	Dosimetry reaction	E_{max} [MeV]	Comments
16	^{90}Zr(n,2n)	40	Fission+Fusion
17	^{115}In(n,2n)	20	Fission+Fusion
18	^{115}In(n,n′)	20	Fission+Fusion
19	^{115}In(n,γ)	20	Fission+Fusion
20	^{127}I(n,2n)	32	Fission
21	^{197}Au(n,2n)	40	Fission+Fusion
22	^{197}Au(n,γ)	30	Fission+Fusion
23	^{199}Hg(n,n′)^{199m}Hg	20	Fission
24	^{59}Co(n,3n)^{57}Co	85	Fusion
25	^{93}Nb(n,2n)^{92m}Nb	40	Fission+Fusion
26	^{89}Y(n,2n)^{88}Y	40	Fission+Fusion
27	^{169}Tm(n,2n)^{168}Tm	40	Fission+Fusion
28	^{209}Bi(n,3n)^{207}Bi	45	Fusion

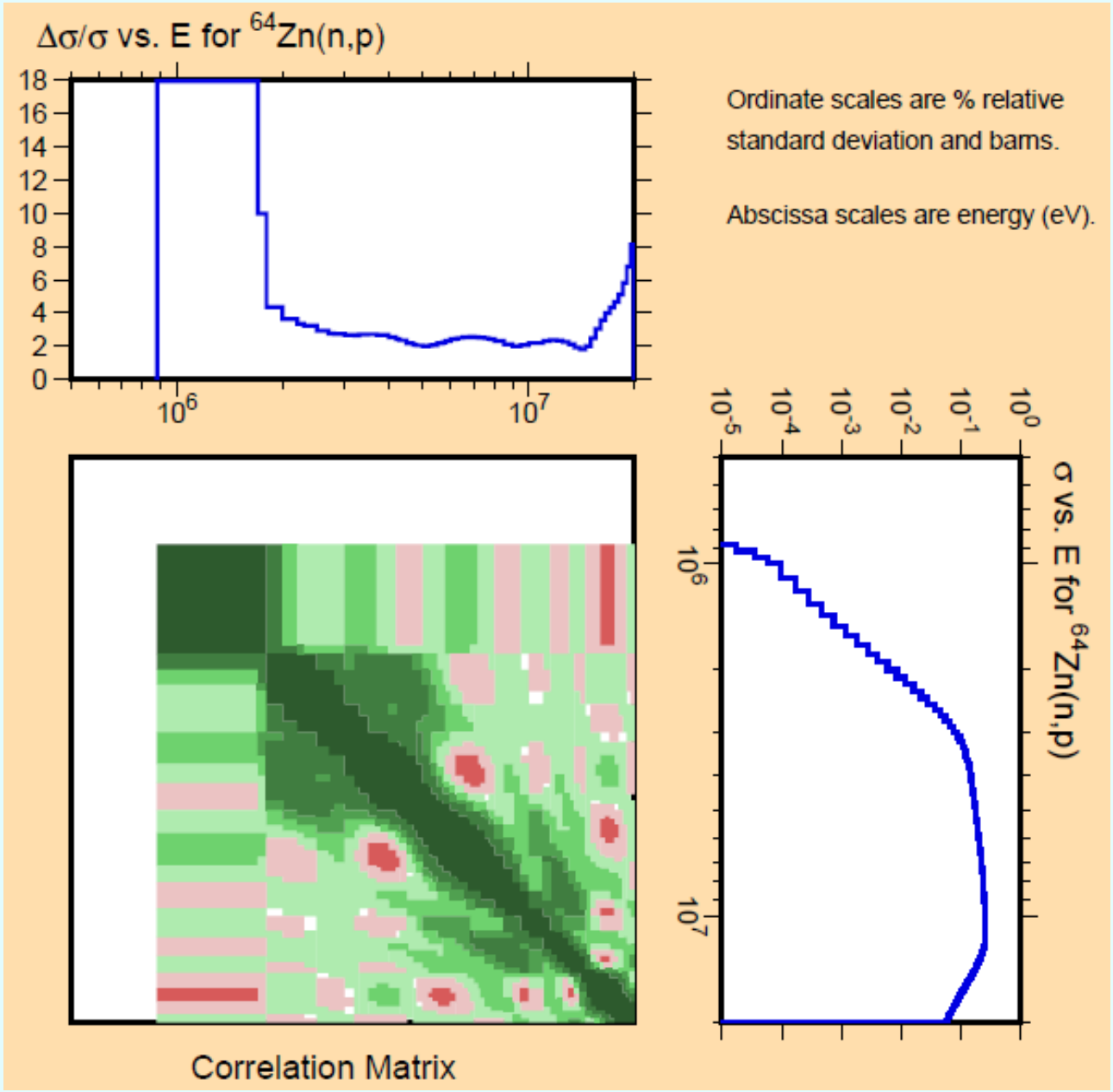
	Dosimetry reaction	E_{max} [MeV]	Comments
29	^{232}Th(n,f)	60	Fission
30	^{232}Th(n,γ)	60	Fission
31	^{235}U(n,f)	200	Fission
32	^{238}U(n,f)	200	Fission
33	^{238}U(n,γ)	30	Fission
34	^{239}Pu(n,f)	200	Fission
35	^{237}Np(n,f)	30	Fission
36	^{6}Li(n,t)	20	Fission
37	^{10}B(n,α)	20	Fission
	Cd-nat	20	Fission (no cov)

New evaluation vs EMPIRE



$^{64}Zn(n,p)^{64}Cu$


This evaluation
IRDF-2002
Paul+53
Rapaport+59c
Preiss+60c
Van Loef 61c
Nakai+62
Gabbard+62c
Bormann+63c
Bramlitt 63c
Kjelberg+66c
Ranakumar+68c
Dresler+73c
Casanova+76c
Valkonen 76
Husain+83
vs. REJECTED EXPER. DATA
σ, mb
En, MeV
0
100
200
300
400
2
4
6
8
10
12
14
16
18
20

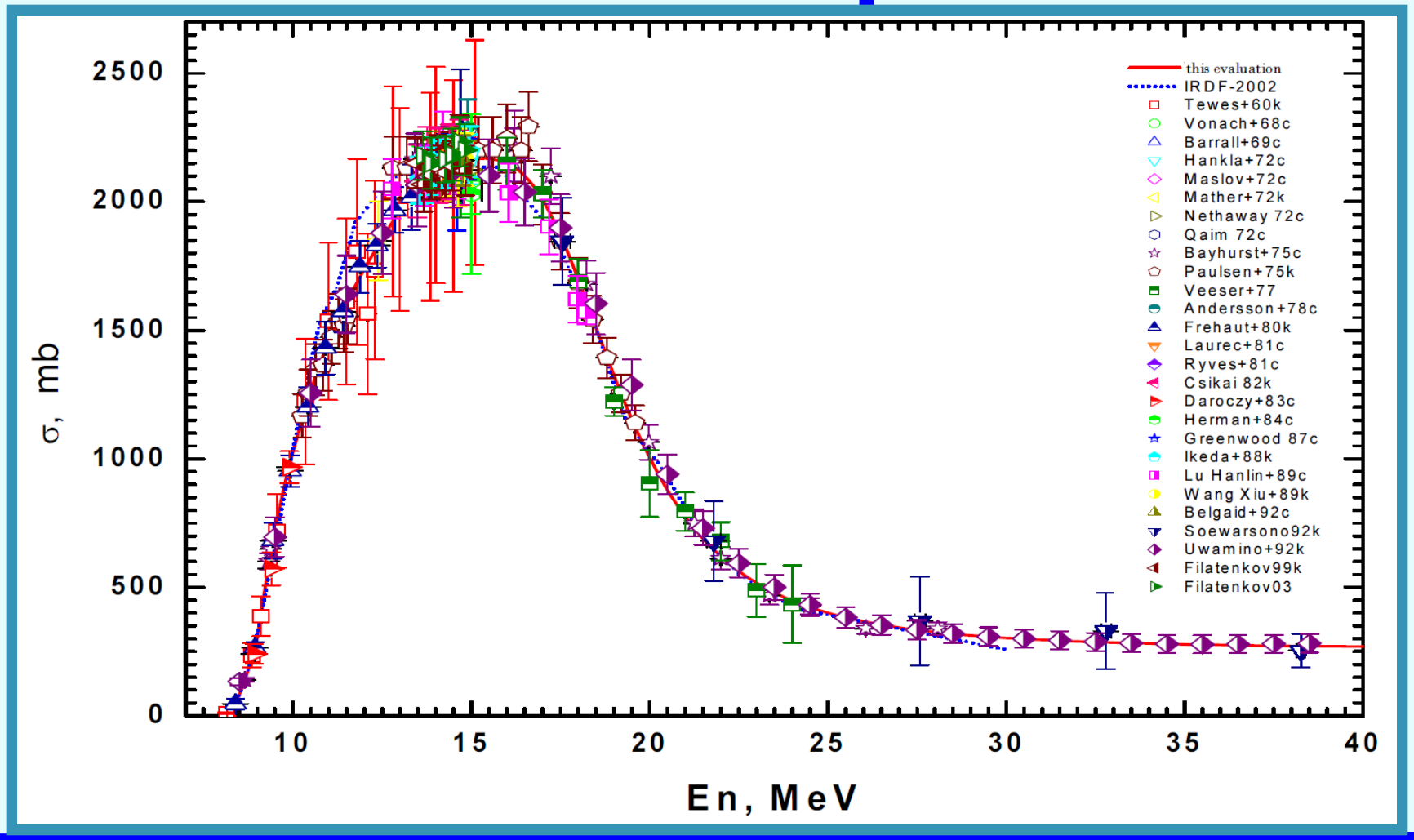

Δσ/σ vs. E for 64Zn(n,p)
18
16
14
12
10
8
6
4
2
0
10^6
10^7
Ordinate scales are % relative standard deviation and barns.
Abscissa scales are energy (eV).
Correlation Matrix
10^-5
10^-4
10^-3
10^-2
10^-1
10^0
10^6
10^7
σ vs. E for 64Zn(n,p)

$^{64}Zn(n,p)^{64}Cu$

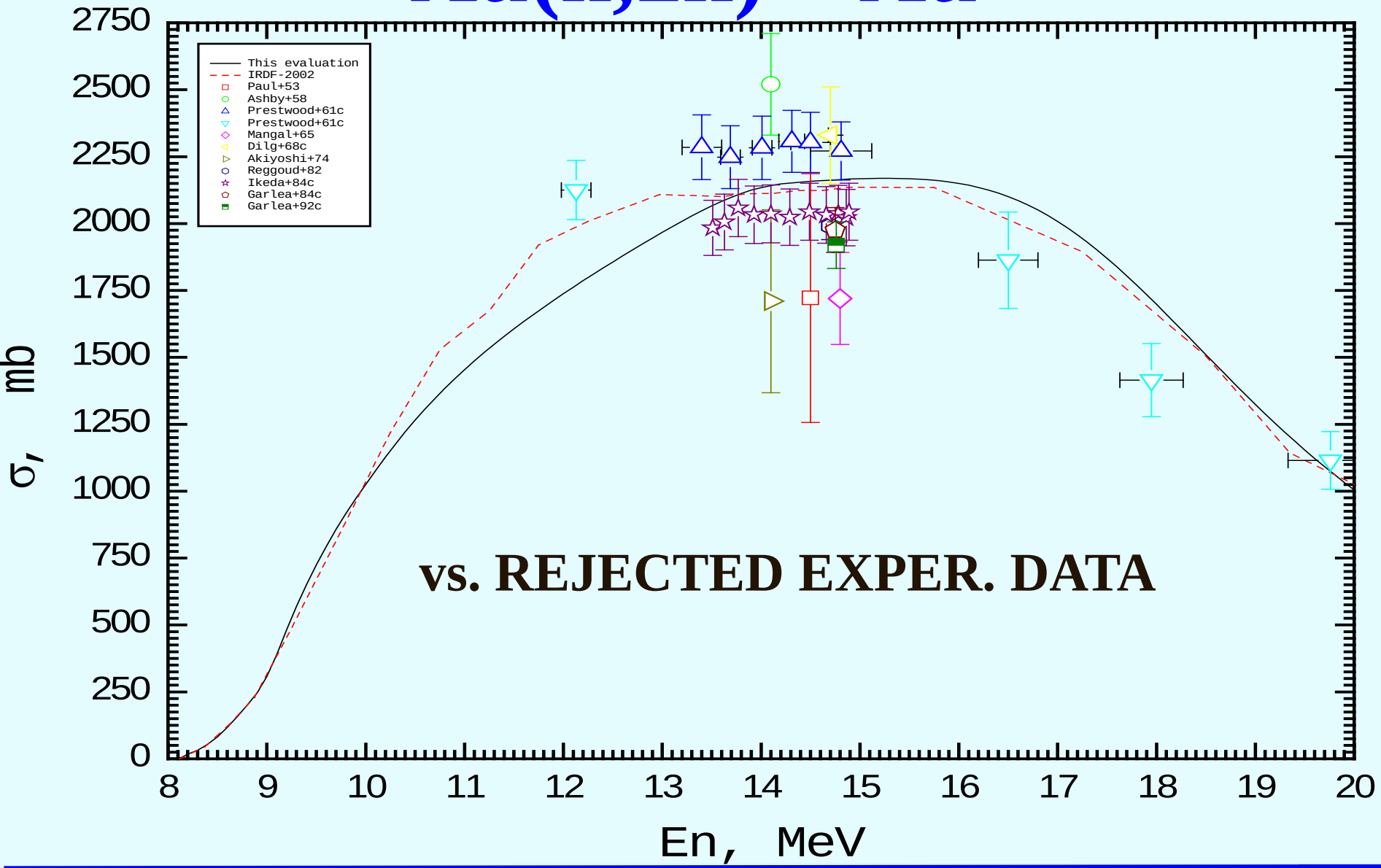
Type of neutron field	Average cross section, mb		C/E [**]
	Calculated	Measured	
^{235}U thermal fission neutron spectrum	38.9 ± 0.7 [A] 38.399 [B]	38.9 ± 2.8 [**]	1.000 0.987
^{252}Cf spontaneous fission neutron spectrum	42.7 ± 0.8 [A] 42.095 [B]	42.3 ± 0.9 [**]	1.009 0.994

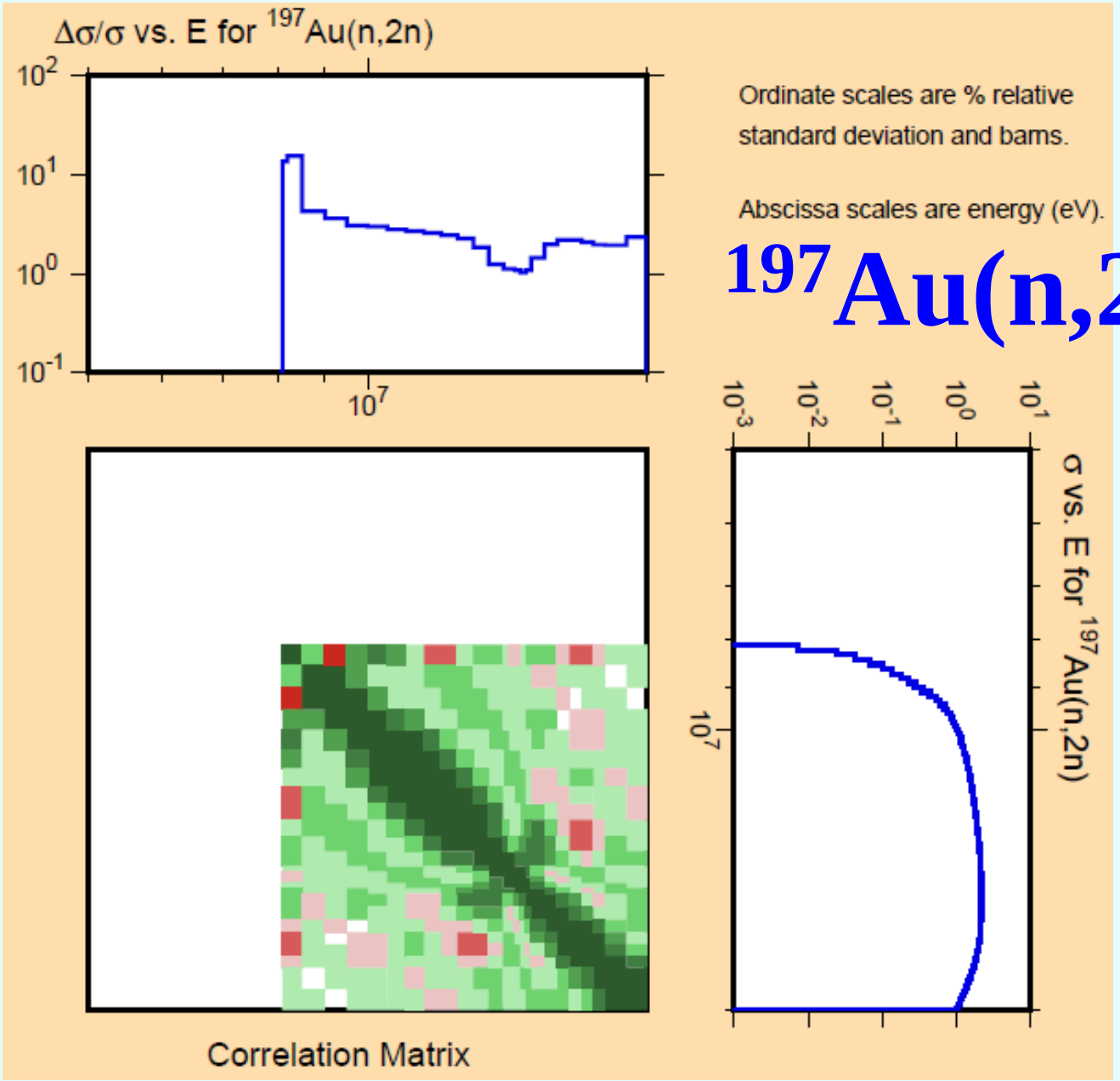
[A] – Present evaluation;
[B] – IRDF-2002 (IRDF-90v.2);
[**] – evaluated experimental cross section

$^{197}Au(n,2n)^{196}Au$ new evaluation vs selected exp. data



$^{197}Au(n,2n)^{196}Au$

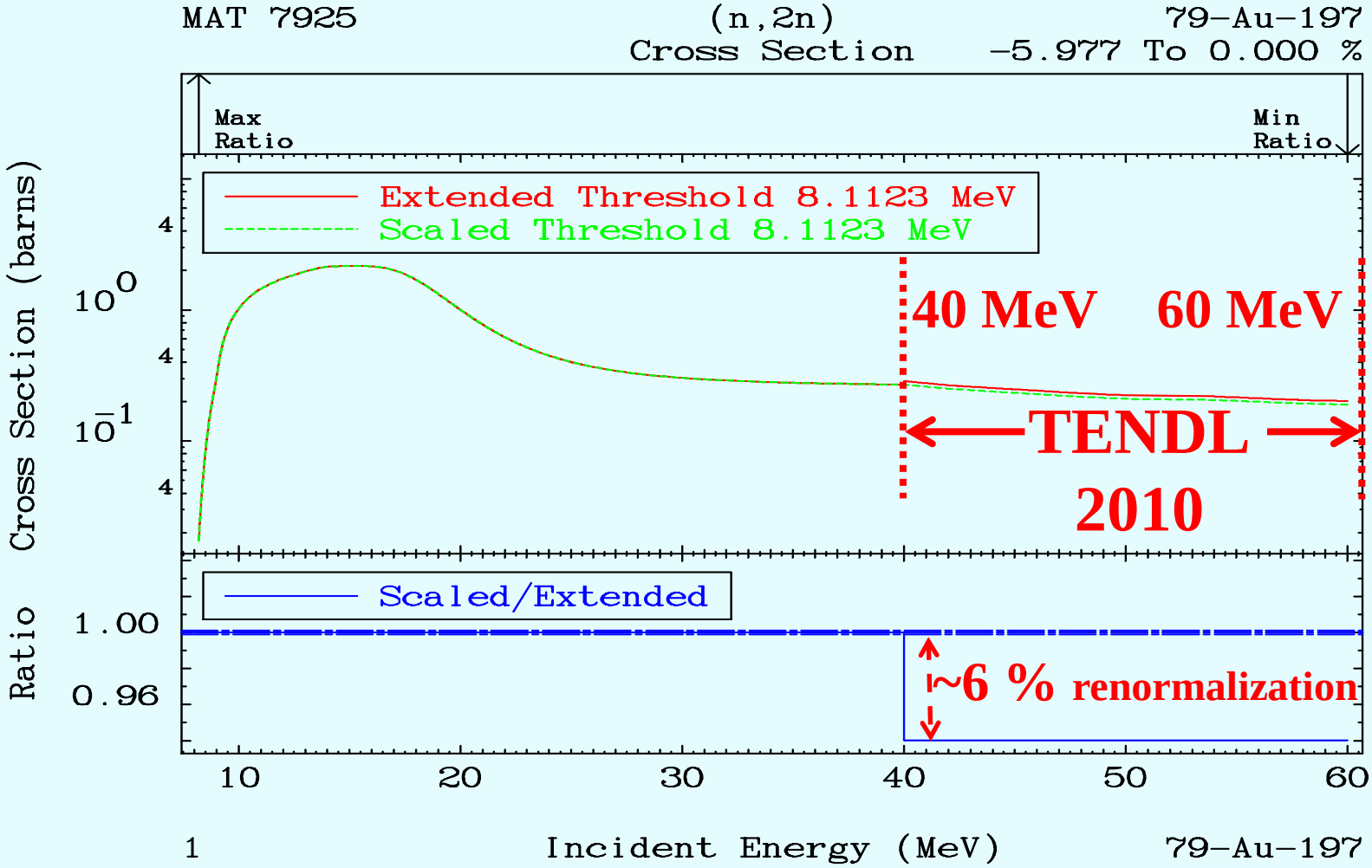




$^{197}Au(n,2n)^{196}Au$

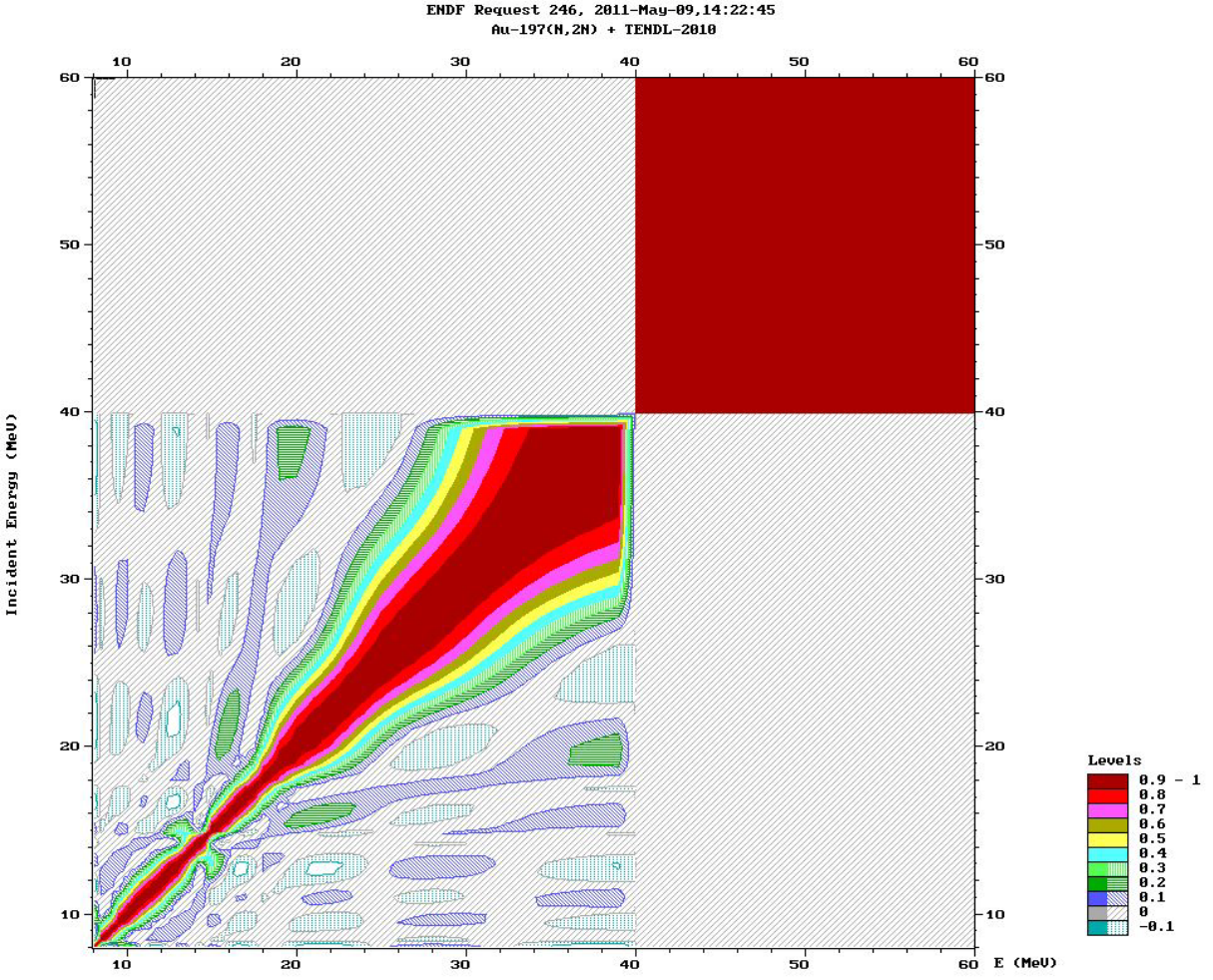
Extension to 60 MeV – TENDL- 2010

$^{197}Au(n,2n)^{196}Au$



Extension to 60 MeV – TENDL- 2010

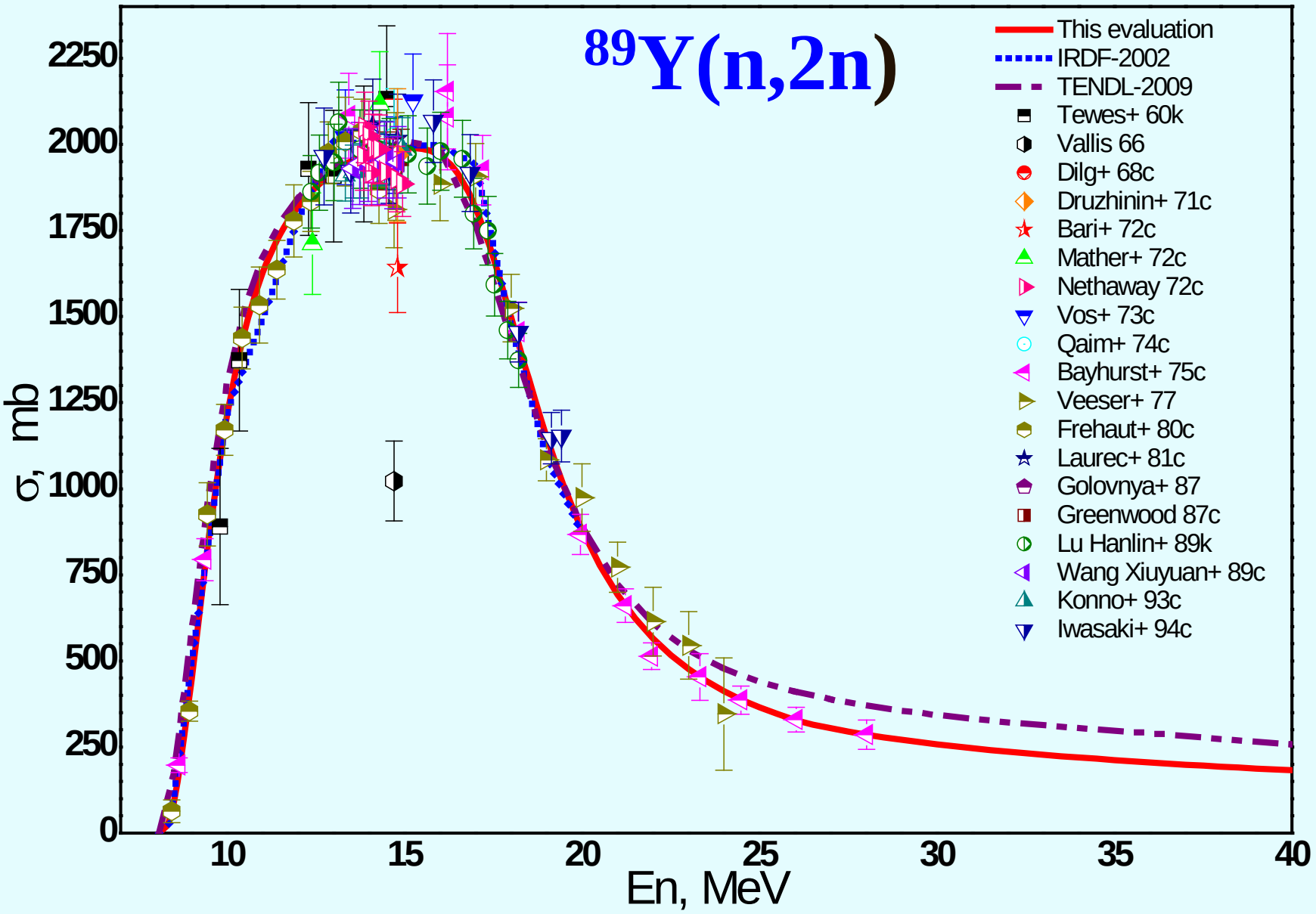
^{197}Au(n,2n)^{196}Au

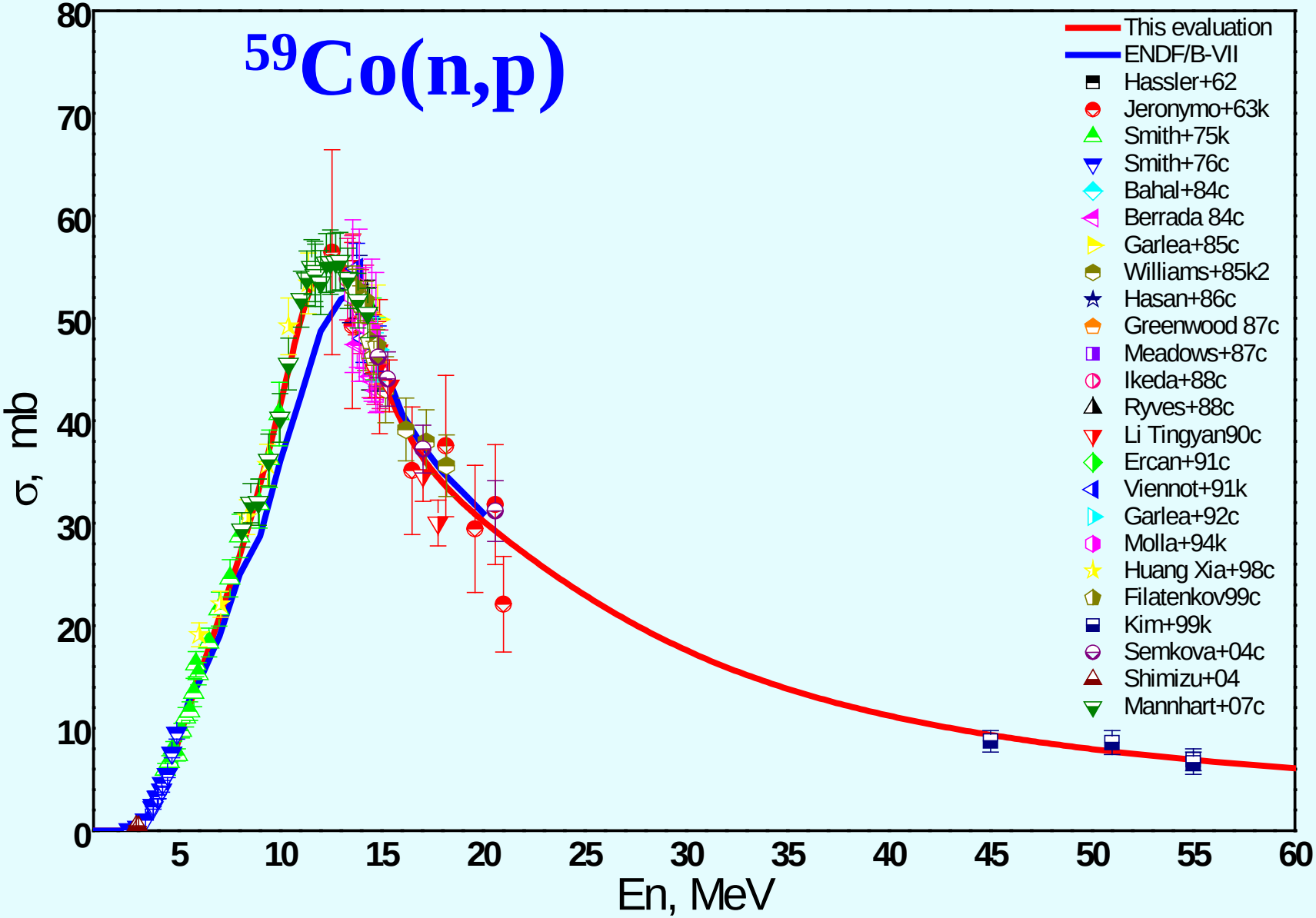


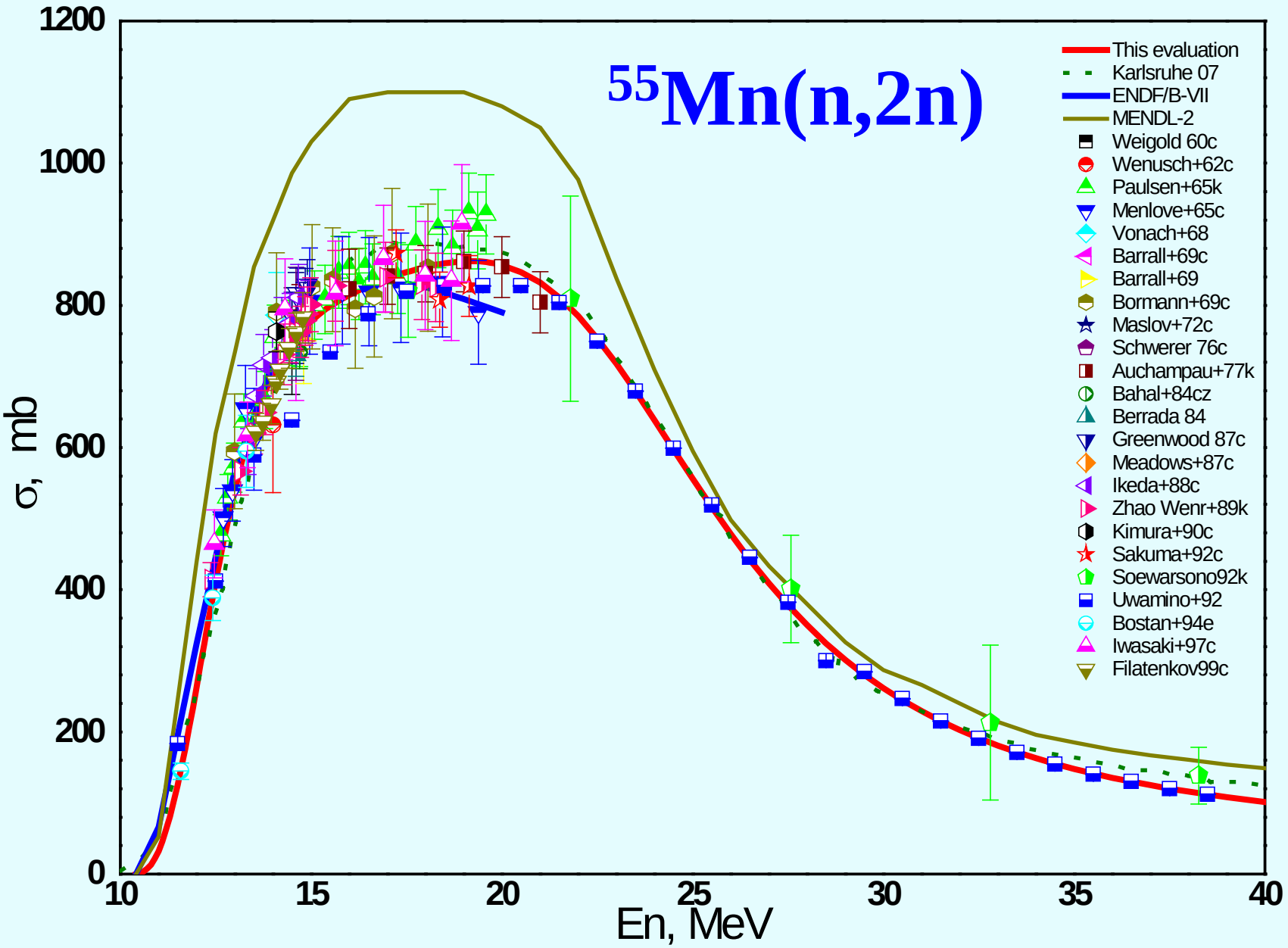
$^{197}Au(n,2n)^{196}Au$

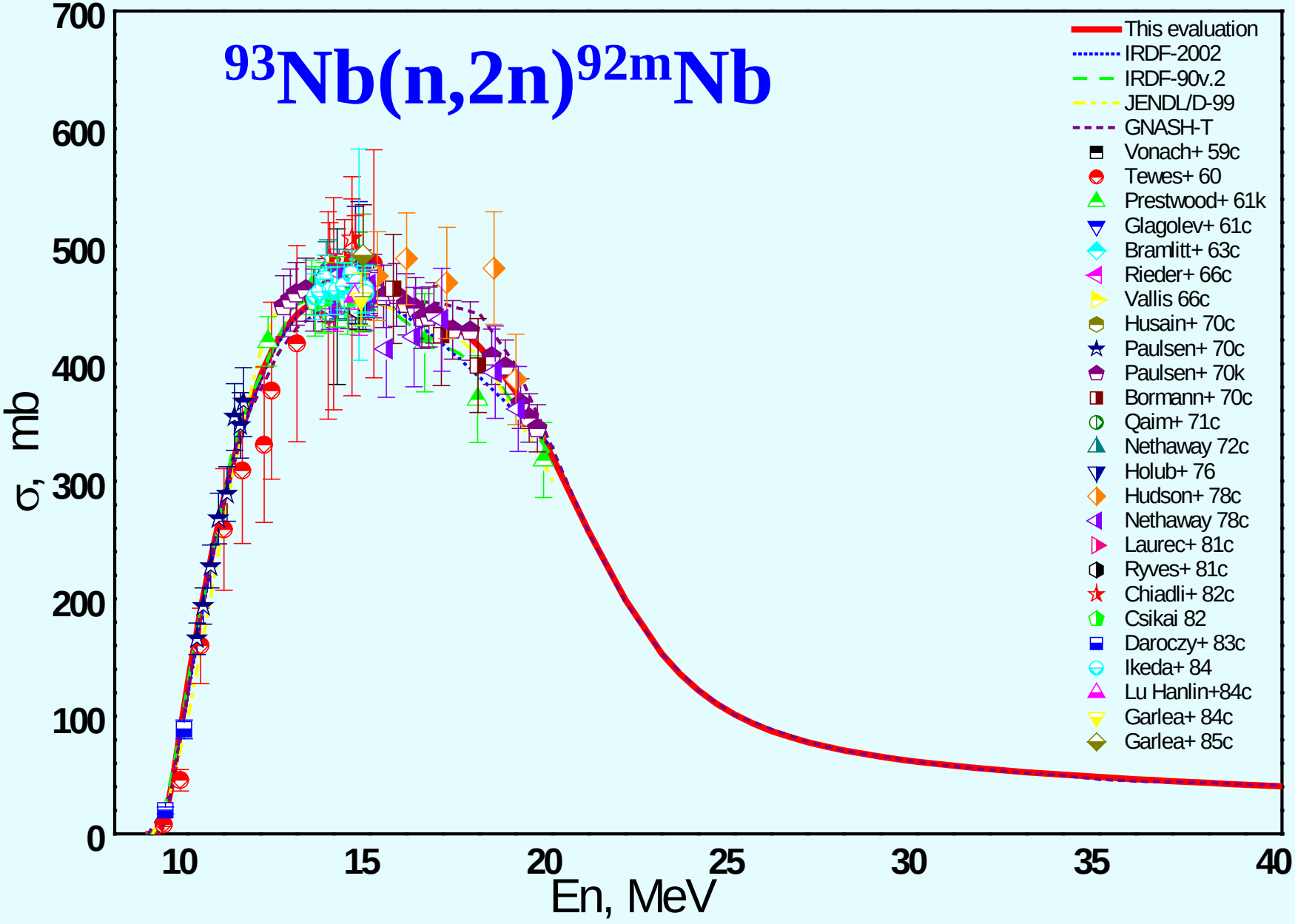
Type of neutron field	Average cross section, mb		C/E
	Calculated	Measured	
^{235}U thermal fission neutron spectrum	3.33 ± 0.07 [A] 3.4762 [B]	3.392 ± 0.080	0.988 1.025
^{252}Cf spontaneous fission neutron spectrum	5.53 ± 0.15 [A] 5.7469 [B]	5.506 ± 0.101	1.004 1.044

[A] – Present evaluation;
[B] – IRDF-2002 (IRDF-90v.2).


89Y(n,2n)
This evaluation
IRDF-2002
TENDL-2009
Tewes+ 60k
Vallis 66
Dilg+ 68c
Druzhinin+ 71c
Bari+ 72c
Mather+ 72c
Nethaway 72c
Vos+ 73c
Qaim+ 74c
Bayhurst+ 75c
Veeser+ 77
Frehaut+ 80c
Laurec+ 81c
Golovnya+ 87
Greenwood 87c
Lu Hanlin+ 89k
Wang Xiuyuan+ 89c
Konno+ 93c
Iwasaki+ 94c
σ, mb
0
250
500
750
1000
1250
1500
1750
2000
2250
10
15
20
25
30
35
40
En, MeV


59Co(n,p)
This evaluation
ENDF/B-VII
Hassler+62
Jeronymo+63k
Smith+75k
Smith+76c
Bahal+84c
Berrada 84c
Garlea+85c
Williams+85k2
Hasan+86c
Greenwood 87c
Meadows+87c
Ikeda+88c
Ryves+88c
Li Tingyan90c
Ercan+91c
Viennot+91k
Garlea+92c
Molla+94k
Huang Xia+98c
Filatenkov99c
Kim+99k
Semkova+04c
Shimizu+04
Mannhart+07c
σ, mb
En, MeV
0
10
20
30
40
50
60
70
80
5
10
15
20
25
30
35
40
45
50
55
60


55Mn(n,2n)
σ, mb
En, MeV
0
200
400
600
800
1000
1200
10
15
20
25
30
35
40
This evaluation
Karlsruhe 07
ENDF/B-VII
MENDL-2
Weigold 60c
Wenusch+62c
Paulsen+65k
Menlove+65c
Vonach+68
Barrall+69c
Barrall+69
Bormann+69c
Maslov+72c
Schwerer 76c
Auchampau+77k
Bahal+84cz
Berrada 84
Greenwood 87c
Meadows+87c
Ikeda+88c
Zhao Wenr+89k
Kimura+90c
Sakuma+92c
Soewarsono92k
Uwamino+92
Bostan+94e
Iwasaki+97c
Filatenkov99c


^{93}Nb(n,2n)^{92m}Nb
σ, mb
En, MeV
0
100
200
300
400
500
600
700
10
15
20
25
30
35
40
This evaluation
IRDF-2002
IRDF-90v.2
JENDL/D-99
GNASH-T
Vonach+ 59c
Tewes+ 60
Prestwood+ 61k
Glagolev+ 61c
Bramlitt+ 63c
Rieder+ 66c
Vallis 66c
Husain+ 70c
Paulsen+ 70c
Paulsen+ 70k
Bormann+ 70c
Qaim+ 71c
Nethaway 72c
Holub+ 76
Hudson+ 78c
Nethaway 78c
Laurec+ 81c
Ryves+ 81c
Chiadli+ 82c
Csikai 82
Daroczy+ 83c
Ikeda+ 84
Lu Hanlin+84c
Garlea+ 84c
Garlea+ 85c

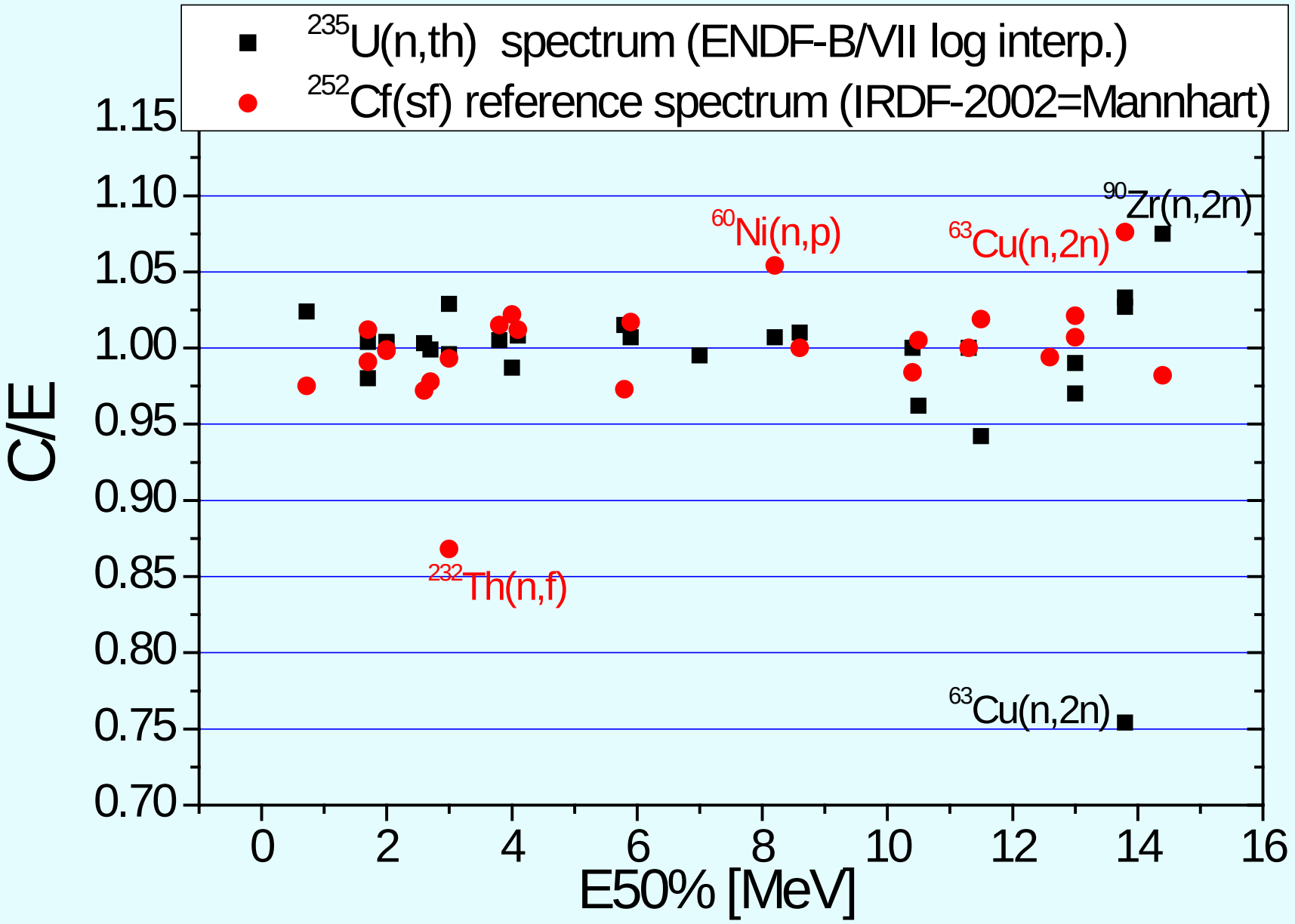
UPDATED REACTIONS	$E_{50\%}$ (MeV)	Calculated <σ>, mb	Experiment <σ>, mb	C/E	Calculated <σ>, mb	Experiment <σ>, mb	C/E
$^{6}Li(n,t)^{4}He$ ENDF/B-VII.1β2	0.66	323.2 ± 2.1 (0.6%)	--	--	321.3 ± 2.8 (0.9%)	--	--
$^{197}Au(n,\gamma)^{198}Au$	0.72	75.8 ± 0.4 (0.6%)	74.0 ± 3.0 (4.0%)	1.024	74.9 ± 0.7 (0.9%)	76.8 ± 1.2 (1.59%)	0.975
$^{58}Fe(n,\gamma)^{58}Fe$ JEFF 3.1	0.72	2.0 ± 0.2 (10%)	--	--	2.0 ± 0.2 (10%)	--	--
$^{10}B(n,\alpha_0+\alpha_1)$ ENDF/B-VII.1β2	0.84	447 ± 8 (1.8%)	--	--	446 ± 7 (1.6%)	--	--
$^{232}Th(n,\gamma)^{233}Th$ ENDF/B-VII.0	0.88	91.9 ± 2.6 (2.8%)	--	--	90.0 ± 2.6 (2.8%)	[87.8 ± 4.0] (4.6%)	1.025
$^{238}U(n,\gamma)^{239}U$	0.88	69.0 ± 0.7 (1.0%)	--	--	67.5 ± 0.7 (1.0%)	--	--
$^{55}Mn(n,\gamma)^{56}Mn$	0.88	**2.60 ± 0.25 (10%)**	--	--	**2.60 ± 0.25 (10%)**	**[2.96 ± 0.21] (7%)**	**0.878**
$^{235}U(n,f)$	1.70	1222 ± 5 (0.4%)	1217 ± 14 (1.1%)	1.004	1225 ± 5 (0.4%)	1210 ± 14 (1.20%)	1.012
$^{239}Pu(n,f)$	1.70	1795 ± 9 (0.5%)	1831 ± 32 (1.7%)	0.980	1796 ± 9 (0.5%)	1812 ± 25 (1.37%)	0.991
$^{237}Np(n,f)$	2.00	1356 ± 22 (1.7%)	1350 ± 24 (1.8%)	1.004	1360 ± 23 (1.7%)	1361 ± 22 (1.59%)	0.999
$^{237}Np(n,f)$ - ENDF/B-VII.1β2	2.00	1354 ± 36 (2.7%)	1350 ± 24 (1.8%)	1.003	1359 ± 36 (2.7%)	1361 ± 22 (1.59%)	0.998

UPDATED REACTIONS	$E_{50\%}$ (MeV)	Calculated <σ>, mb	Experiment <σ>, mb	C/E	Calculated <σ>, mb	Experiment <σ>, mb	C/E
$^{115}In(n,n')^{115m}In$	2.60	188.4 ± 3.2 (1.7%)	187.8 ± 2.3 (1.2%)	1.003	191.8 ± 3.3 (1.7%)	197.4 ± 2.7 (1.37%)	0.972
$^{238}U(n,f)$	2.70	309.2 ± 1.6 (0.5%)	309.4 ± 3.5 (1.1%)	0.999	318.5 ± 2.1 (0.6%)	325.7 ± 5.3 (1.64%)	0.978
$^{99}Hg(n,n')^{199m}Hg$	3.00	286 ± 10 (3.7%)	278 ± 16 (5.3%)	1.029	296 ± 11 (3.6%)	298 ± 5 (1.81%)	0.993
$^{232}Th(n,f)$ ENDF/B-VII.0	3.00	74.1 ± 1.5 (2.1%)	74.5 ± 3.1 (4.2%)	0.996	77.6 ± 1.6 (2.1%)	76.9 ± 2.9 (3.8%) **[89.4 ± 2.7] (3.0%)**	1.009 **0.868**
$^{47}Ti(n,p)^{47}Sc$	3.80	18.1 ± 0.5 (2.8%)	18.0 ± 0.8 (4.6%)	1.005	19.56 ± 0.55 (2.8%)	19.27 ± 0.32 (1.66%)	1.015
$^{32}S(n,p)^{32}P$	4.00	68.2 ± 1.7 (2.5%)	69.1 ± 1.4 (2.0%)	0.987	74.1 ± 1.90 (2.6%)	72.5 ± 2.5 (3.49%)	1.022
$^{64}Zn(n,p)^{64}Cu$	4.10	38.9 ± 0.7 (1.7%)	38.6 ± 1.6 (4.3%)	1.008	42.7 ± 0.80 (1.9%)	42.2 ± 1.0 (2.3%)[4]	1.012
$^{27}Al(n,p)^{27}Mg$	5.80	3.96 ± 0.08 (2.%)	3.90 ± 0.07 (1.8%)	1.015	4.75 ± 0.11 (2.4%)	4.88 ± 0.10 (2.14%)	0.973
$^{59}Co(n,p)^{59}Fe$	5.90	1.41 ± 0.05 (3.6%)	1.40 ± 0.03 (2.4%)	1.007	1.72 ± 0.06 (3.6%)	1.69 ± 0.04 (2.48%)	1.017
$^{60}Ni(n,p)^{60}Co$	7.00	2.17 ± 0.04 (2.0%)	2.18 ± 0.10 (4.8%)	0.995	2.80 ± 0.06 (2.3%)	**[2.180 ± .104] (4.7%)**	**1.171**

UPDATED REACTIONS	$E_{50\%}$ (MeV)	Calculated <σ>, mb	Experiment <σ>, mb	C/E	Calculated <σ>, mb	Experiment <σ>, mb	C/E
$^{24}Mg(n,p)^{24}Na$	8.20	1.50 ± 0.01 (0.8%)	1.49 ± 0.03 (1.8%)	1.007	2.10 ± 0.04 (1.8%)	1.996 ± 0.049 (2.44%)	1.054
$^{27}Al(n,\alpha)^{24}Na$	8.60	0.707 ± 0.005 (0.7%)	0.701 ± 0.009 (1.3%)	1.010	1.02 ± 0.02 (1.8%)	1.02 ± 0.01 (1.28%)	1.000
$^{169}Tm(n,2n)^{168}Tm$	10.4	3.74 ± .10 (2.6%)	3.74 ± .16 (4.2%)	1.000	6.3 ± 0.2 (3.1%)	6.4 ± 0.4 (6.4%)	0.984
$^{197}Au(n,2n)^{196}Au$	10.5	3.33 ± 0.06 (2.0%)	3.39 ± 0.08 (5.1%)	0.962	5.531 ± 0.15 (2.8%)	5.506 ± 0.101 (1.83%)	1.005
$^{93}Nb(n,2n)^{92m}Nb$	11.3	0.435 ± 0.004 (0.9%)	0.435 ± 0.010 (2.3%)	1.000	.791 ± 0.019 (2.4%)	.791 ± 0.035 (4.5%)	1.000

UPDATED REACTIONS	$E_{50\%}$ (MeV)	Calculated <σ>, mb	Experiment <σ>, mb	C/E	Calculated <σ>, mb	Experiment <σ>, mb	C/E
$^{127}I(n,2n)^{126}I$	11.5	1.13 ± 0.04 (3.2%)	1.20 ± 0.04 (3.4%)	0.942	2.11 ± 0.080 (3.8%)	2.07 ± 0.06 (2.73%)	1.019
$^{65}Cu(n,2n)^{64}Cu$	12.6	0.322 ± 0.006 (2%)	--	--	0.654 ± 0.022 (3.5%)	0.658 ± 0.015 (2.22%)	0.994
$^{55}Mn(n,2n)^{54}Mn$	13.0	0.198 ± 0.004 (2.0%)	0.20 ± 0.07 (3.6%)	0.990	0.420 ± 0.020 (3.7%)	0.407 ± 0.009 (2.33%)	1.021
$^{59}Co\ (n,2n)^{58}Co$	13.0	0.194 ± 0.003 (1.7%)	0.20 ± 0.08 (2.5%)	0.970	0.408 ± 0.020 (3.6%)	0.405 ± 0.010 (2.51%)	1.007
$^{89}Y(n,2n)^{88}Y$	13.8	0.154 ± 0.002 (1.3%)	.150 ± 0.005 (3.3%)	1.027	0.346 ± 0.015 (4.4%)	--	--
$^{89}Y(n,2n)^{88}Y$ - ENDF/B-VII.0	13.8	0.155 ± 0.004 (2.7%)	0.150 ± 0.005 (3.3%)	1.033	0.349 ± 0.017 (5.0%)	--	--
$^{63}Cu(n,2n)^{62}Cu$	13.8	**0.089 ± 0.001 (1.5%)**	**0.118 ± 0.007 (5.9%)**	**0.754**	**0.198 ± 0.009 (4.4%)**	**0.184 ± 0.007 (3.98%)**	**1.076**
$^{90}Zr(n,2n)^{89}Zr$	14.4	0.092 ± 0.009 (.9%)	0.086 ± .005 (5.8%) 0.103 ± 0.003 (2.7%)	1.075 0.893	0.217 ± 0.010 (5.2%)	0.221 ± 0.006 (2.89%)	0.982

IRDFF extension, 37 new evaluations



Conclusions

- International Reactor Dosimetry File IRDF-2002 released in 2005 [1]; library contains 66 dosimetry reactions. Update is needed.
- New suitable evaluations including covariances became available
  - IAEA neutron cross-section standards [2] combined with ENDF-B/VII.1 evaluations [3],
  - Zolotarev evaluations [4-6].
- 37 dosimetry reactions updated and compared to measurements in ENDF-B/VII.0 ^{235}U thermal and ^{252}Cf fast neutron fields.
- Formal extension of all evaluations up to 60 MeV of incident neutron energy using TENDL-2010 [7] done.
- New IAEA dosimetry library will be released for testing in December 2011

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[1] O. Bersillon *et al.*, IRDF-2002, International Atomic Energy Agency, Vienna, Austria, TRS 452 (2006).

[2] A. D. Carlson, *et al, Nucl. Data Sheets* 110 (2009) 3215-3324.

[3] L. Leal, Evaluations in the ENDF/B-VII.1 library with covariances, priv. comm., 2010.

[4] K. I. Zolotarev, INDC(NDS)-0526, IAEA, Vienna, August 2008.

[5] K. I. Zolotarev, INDC(NDS)-0546, IAEA, Vienna, April 2009.

[6] K. I. Zolotarev, INDC(NDS)-0584, IAEA, Vienna, November 2010.

[7] A. J. Koning and D. Rochman, TENDL-2010, The Netherlands.

Acknowledgements

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