SENSITIVITY STUDIES AND MTAS MEASUREMENTS FOR THE DECAY HEAT CALCULATION FOR ^{235}U

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ZFJ UW
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UNIVERSITAS VARSOVIENSIS

LANL FIESTA Fission School & Workshop, Sep. 17-22, 2017

DECAY HEAT – INTRODUCTION

Decay heat (DH) – heat released as a result of the (mainly β) decay of fission products.

For ^{235}U – app. 13 MeV/fission (7% of total released energy)

http://www.opensourceinvestigations.com/wp-content/uploads/2015/12/fukusima-accident.jpg

DH after reactor shutdown can be calculated with following equations:

$$DH(t) = \sum_i (\widetilde{E}_{\beta,i} + \widetilde{E}_{\gamma,i} + \widetilde{E}_{\alpha,i}) \cdot A_i(t)$$

average decay energies activity

$$A_i(t) = \lambda_i y_i e^{-\lambda_i t} + \lambda_i e^{-\lambda_i t} \otimes A_{i-1}(t)$$

decay constant

fission yield

ASSESMENTS

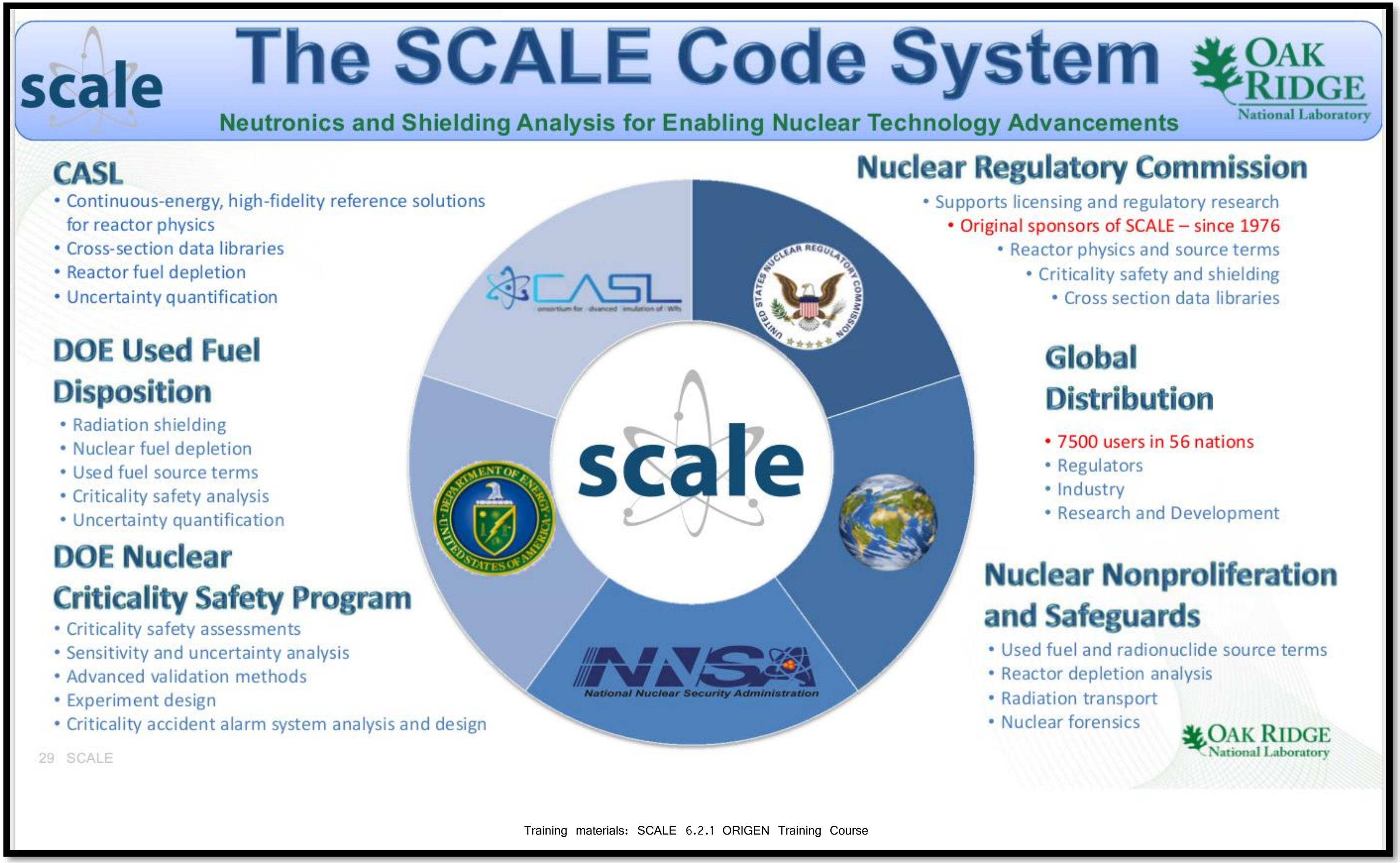
- ***Assessment of fission product decay data for decay heat calculations*, Nuclear Energy Agency Organisation for Economic Co-Operation and Development, OECD 2007**

Collaboration of world experts; Goal: assesment and improvement of the evaluated decay data sub-libraries in order to obtain more accurate estimations of DH; List of 37 radionuclides in 3 priority groups recommended for TAGS measurements provided.

- ***Decay Data Comparisons for Decay Heat and Inventory Simulations of Fission Events*, Fleming M., Sublet J.-C., CCFE-R(15)28/S1, June 2015**
- ***Fission Yield Comparisons for Decay Heat and Inventory Simulations of Fission Events*, Fleming M., Sublet J.-C., CCFE-R(15)28/S2, June 2015**

Calculations provide detailed data of fission pulse events from 15 fissile nuclides (including U-235) for five cooling times (10,100,1000,5011,10000s);
Simulation tool: FISPACT-II;
List of main contributors in each time after shutdown provided.

SCALE/ORIGEN



ORIGEN – Oak Ridge Isotope Generation code; calculates time-dependent concentrations, activities and radiation source terms for a huge number of nuclides simultaneously generated/depleted by neutron transmutation, fission and radioactive decay.

DATABASES

DATASET 1 (SCALE/ORIGEN)

ENDF/B-VII.0
adjusted independent fission yields

ENDF/B-VII.1 (2011)
with updates and calculations

- experimental data
- theoretical predictions

FISSION YIELDS

DECAY PROPERTIES

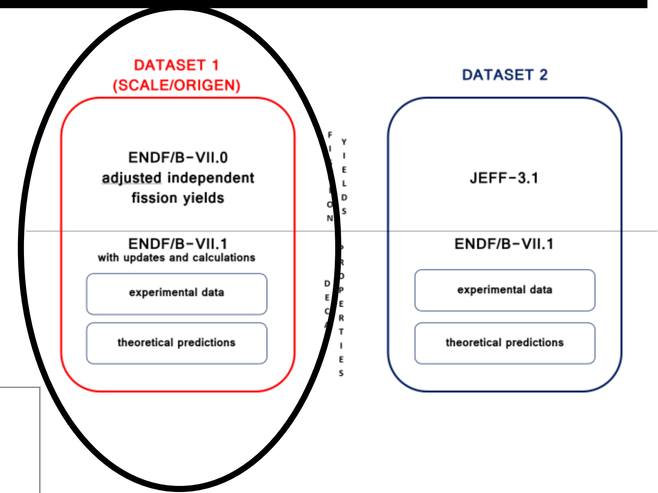
DATASET 2

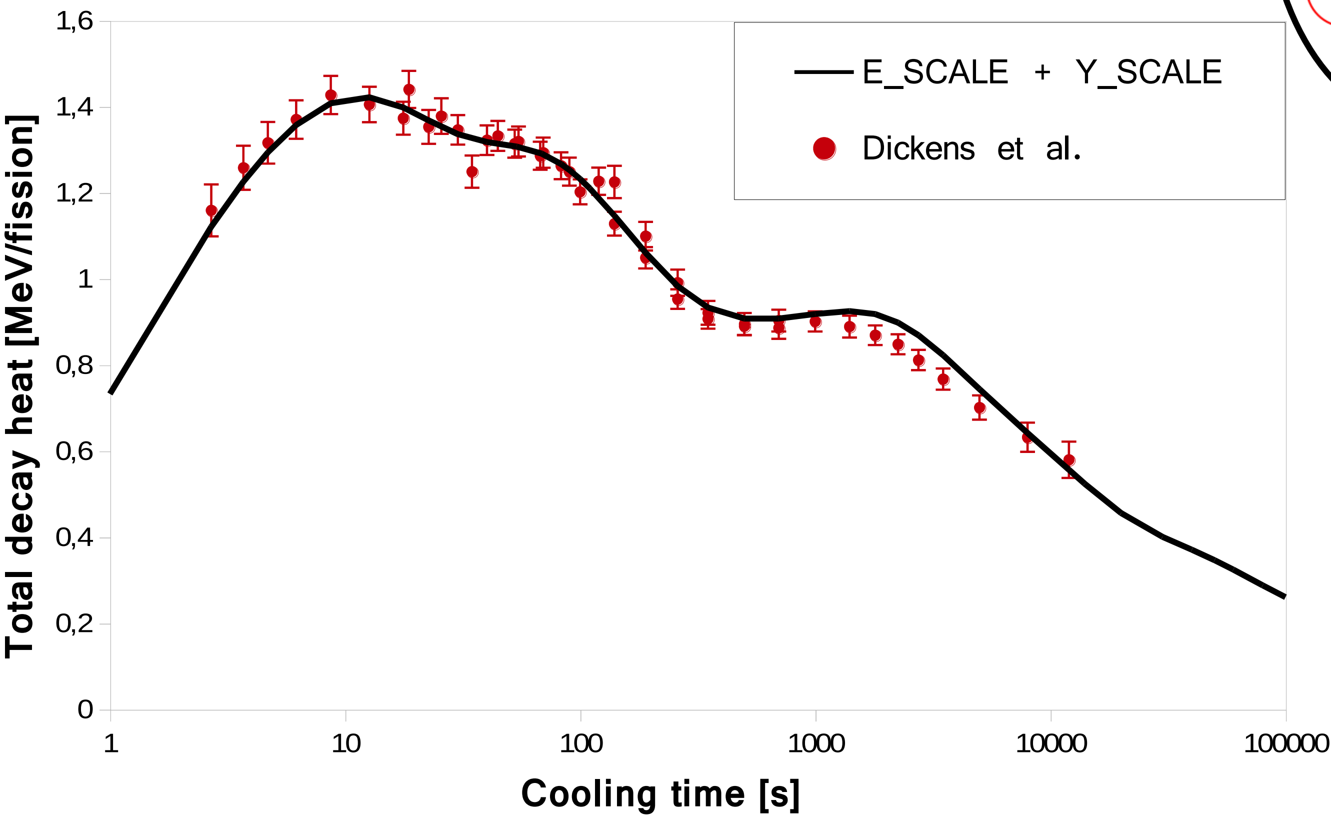
JEFF-3.1

ENDF/B-VII.1 (2011)

- experimental data
- theoretical predictions

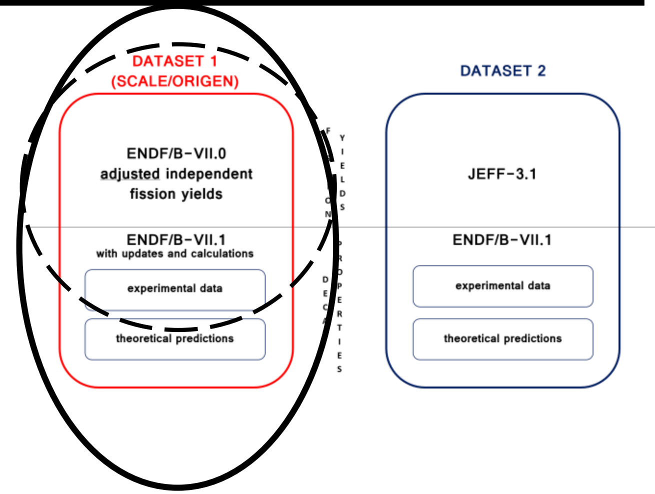
SCALE/ORIGEN SIMULATION

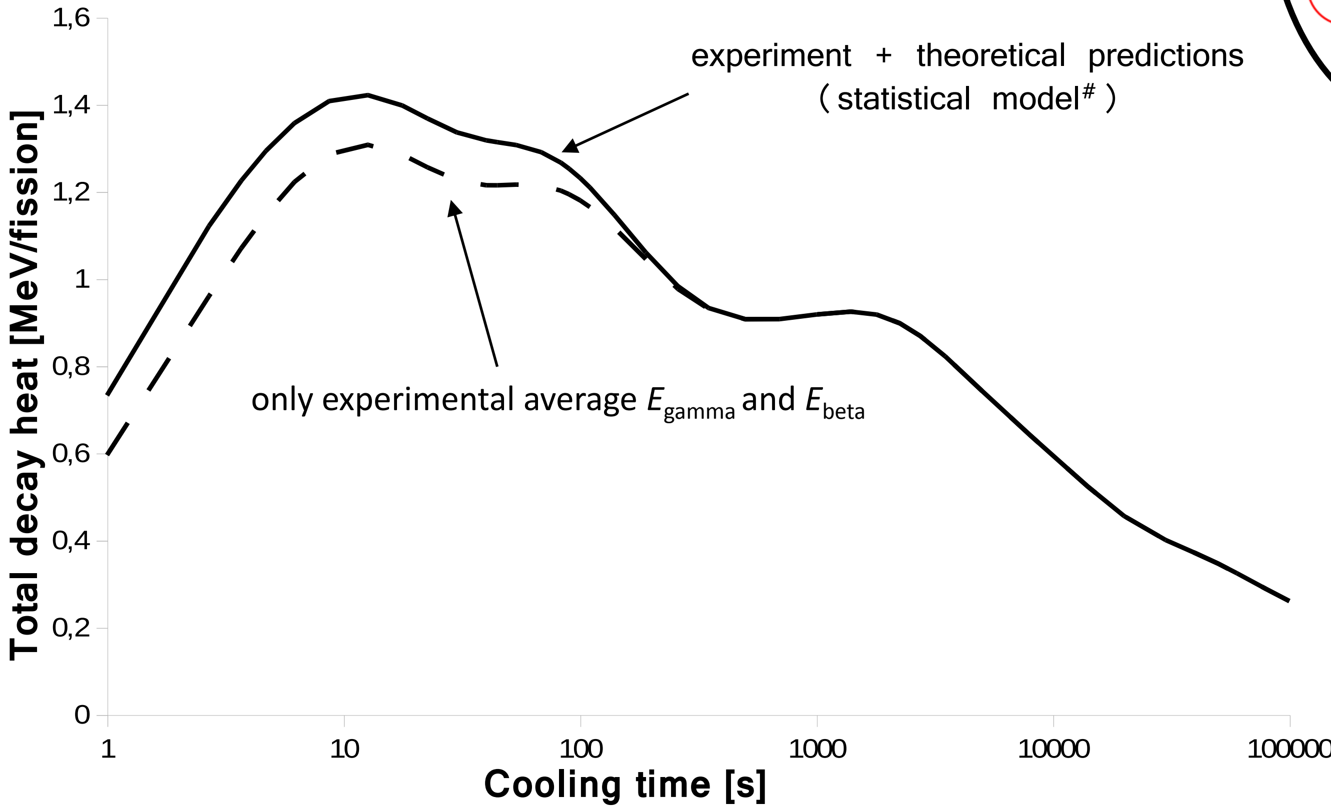




- Dickens J.K. *et al.*, ORNL/NUREG-14, 1977

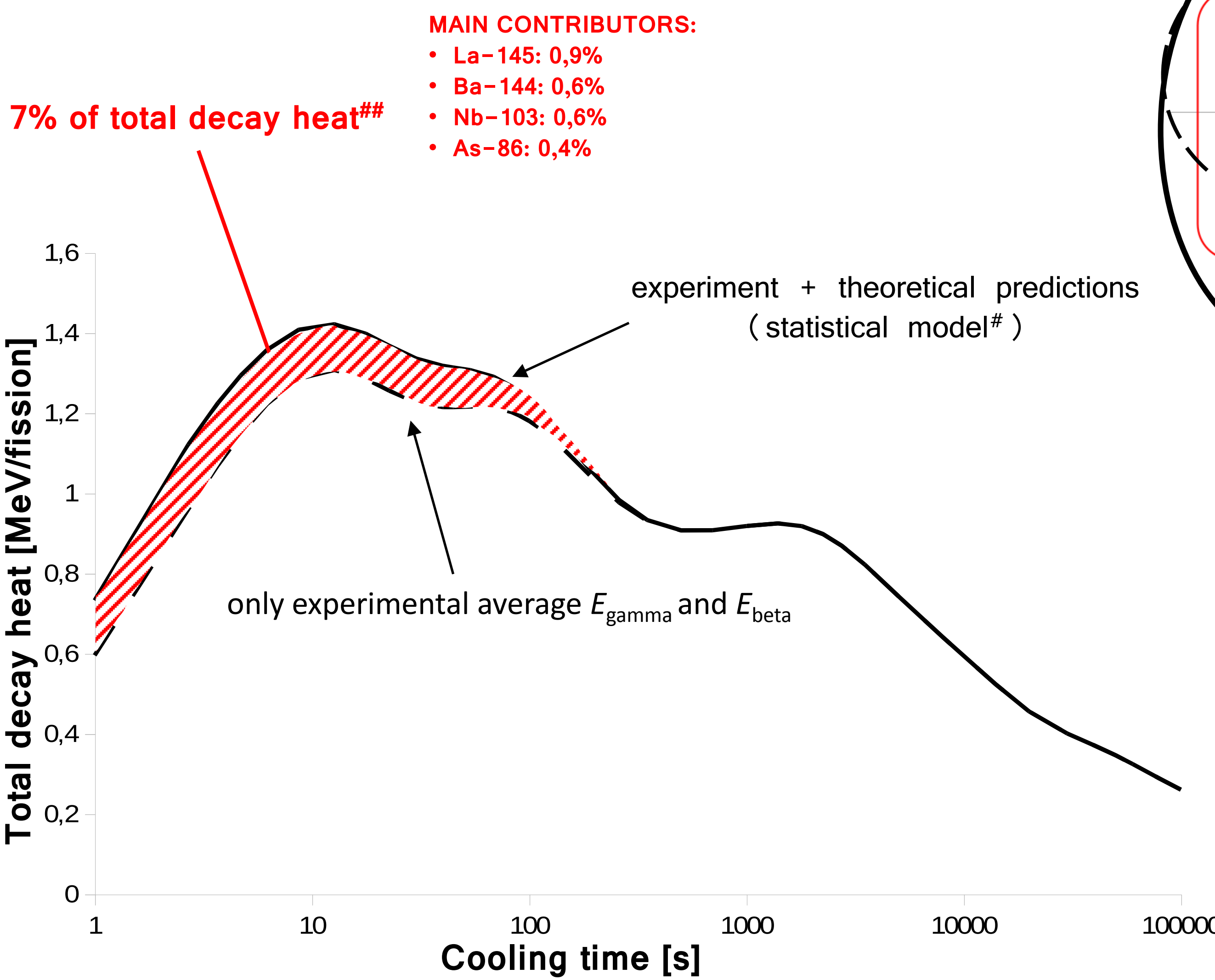
DECAY PROPERTIES DATABASES

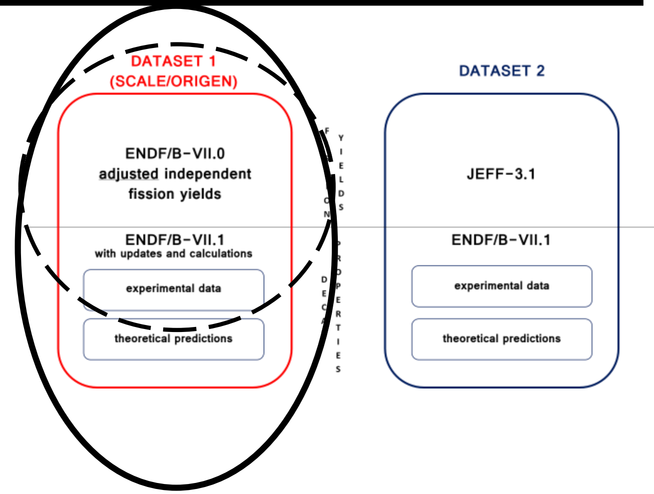




T. Kawano *et al.,* EPJ Web of Conferences 21, 04001 (2012)

DECAY PROPERTIES DATABASES

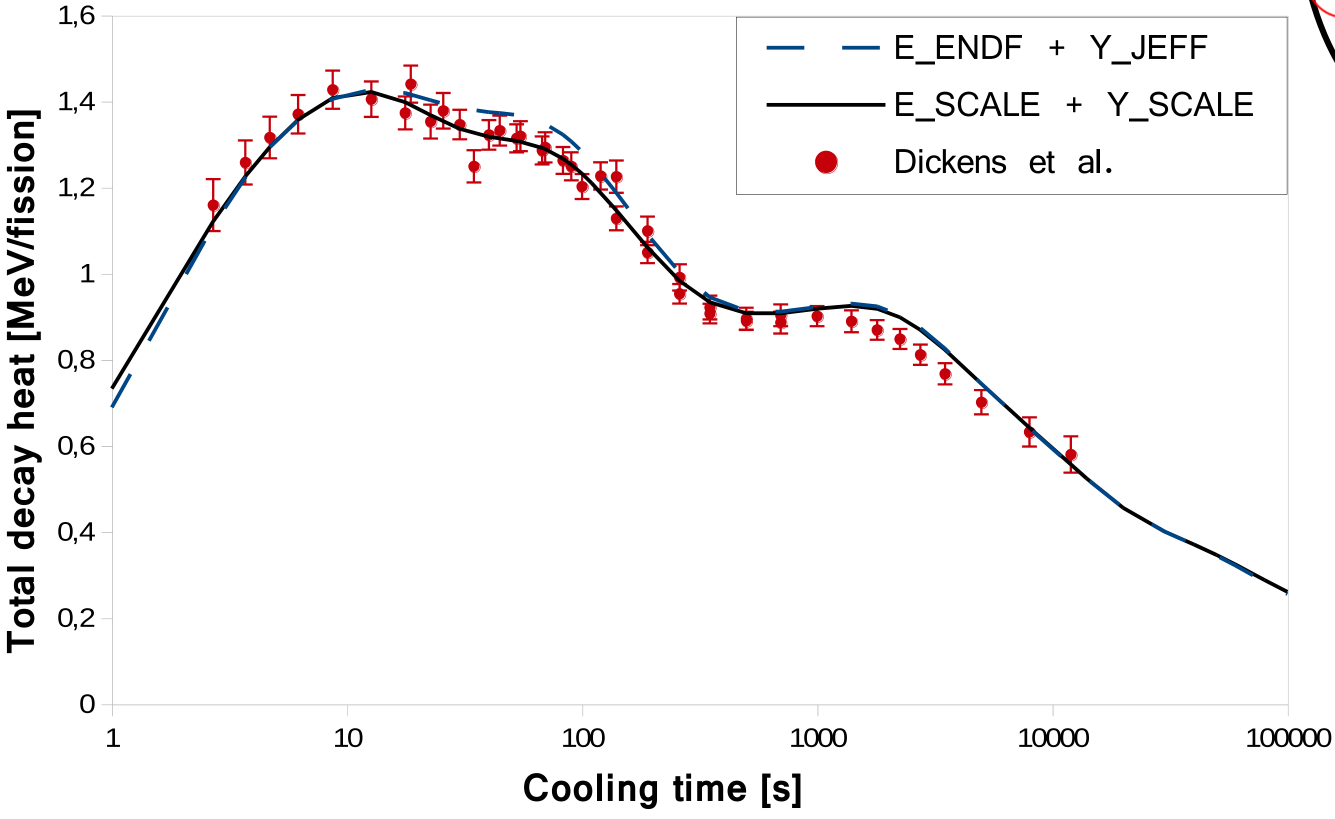


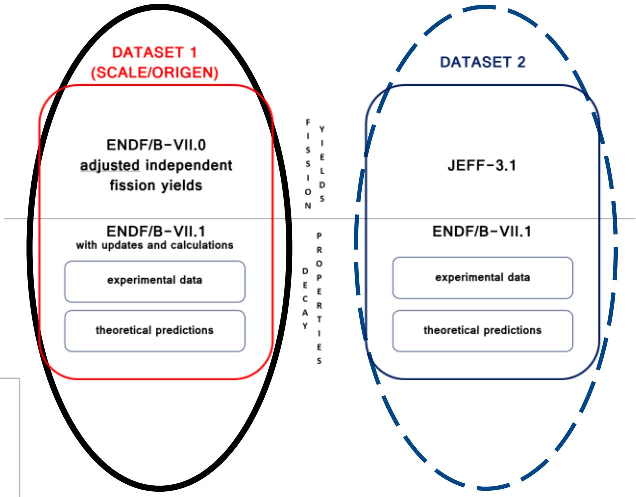


T. Kawano *et al.*, EPJ Web of Conferences 21, 04001 (2012)

More than 270 nuclides - few measured/published by Greenwood *et al.* in 90's

COMPARISON


Total decay heat [MeV/fission]
Cooling time [s]
E_ENDF + Y_JEFF
E_SCALE + Y_SCALE
Dickens et al.
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
1
10
100
1000
10000
100000


DATASET 1
(SCALE/ORIGEN)
ENDF/B-VII.0
adjusted independent
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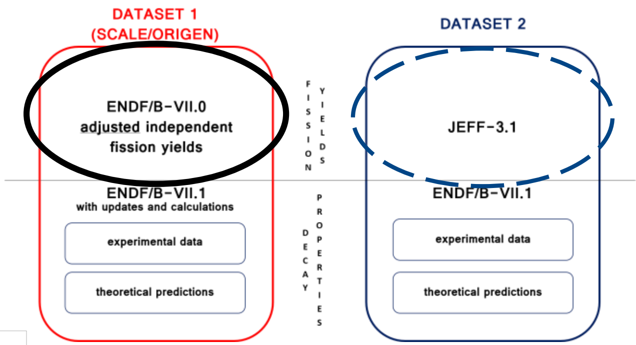
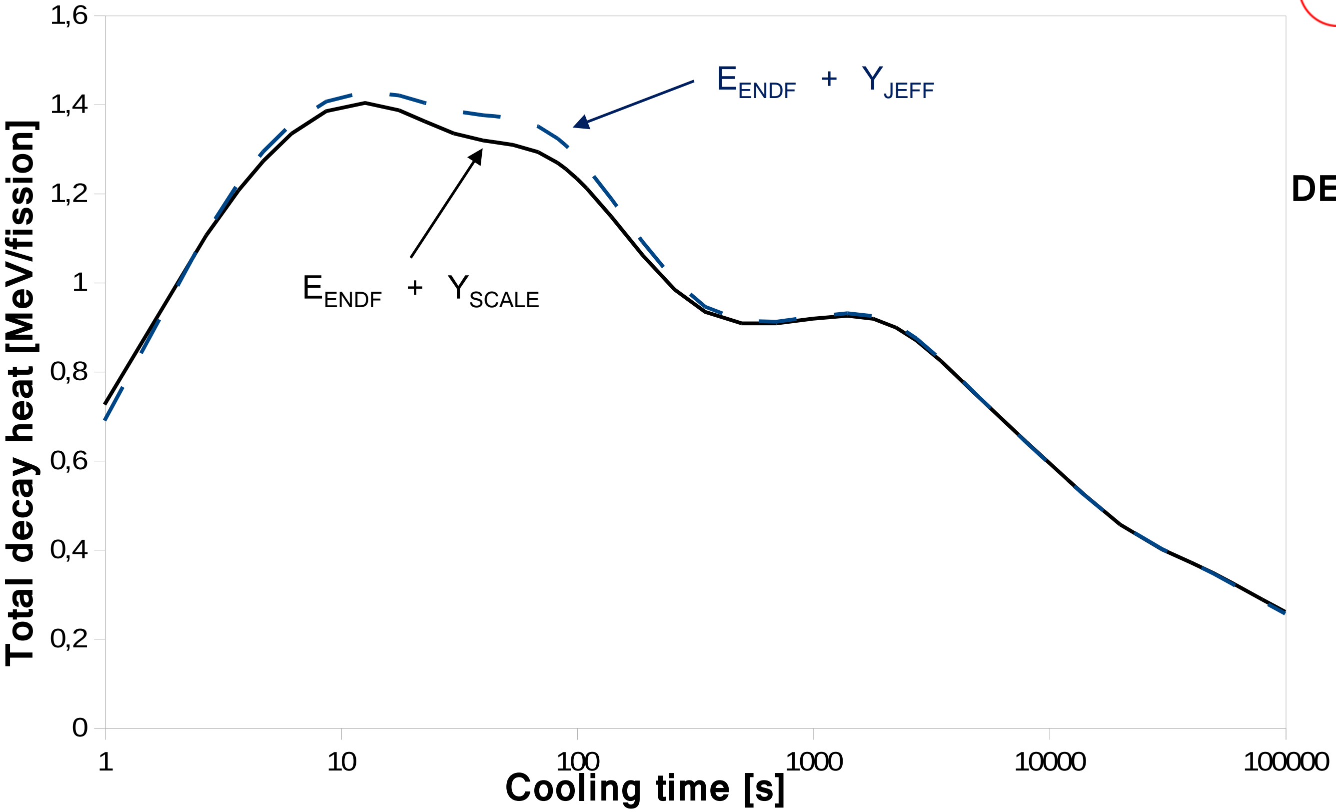
with updates and calculations
experimental data
theoretical predictions
FISSION
YIELDS
DECAY
PROPERTIES
DATASET 2
JEFF-3.1
ENDF/B-VII.1
experimental data
theoretical predictions

FISSION YIELDS DATABASE IMPACT





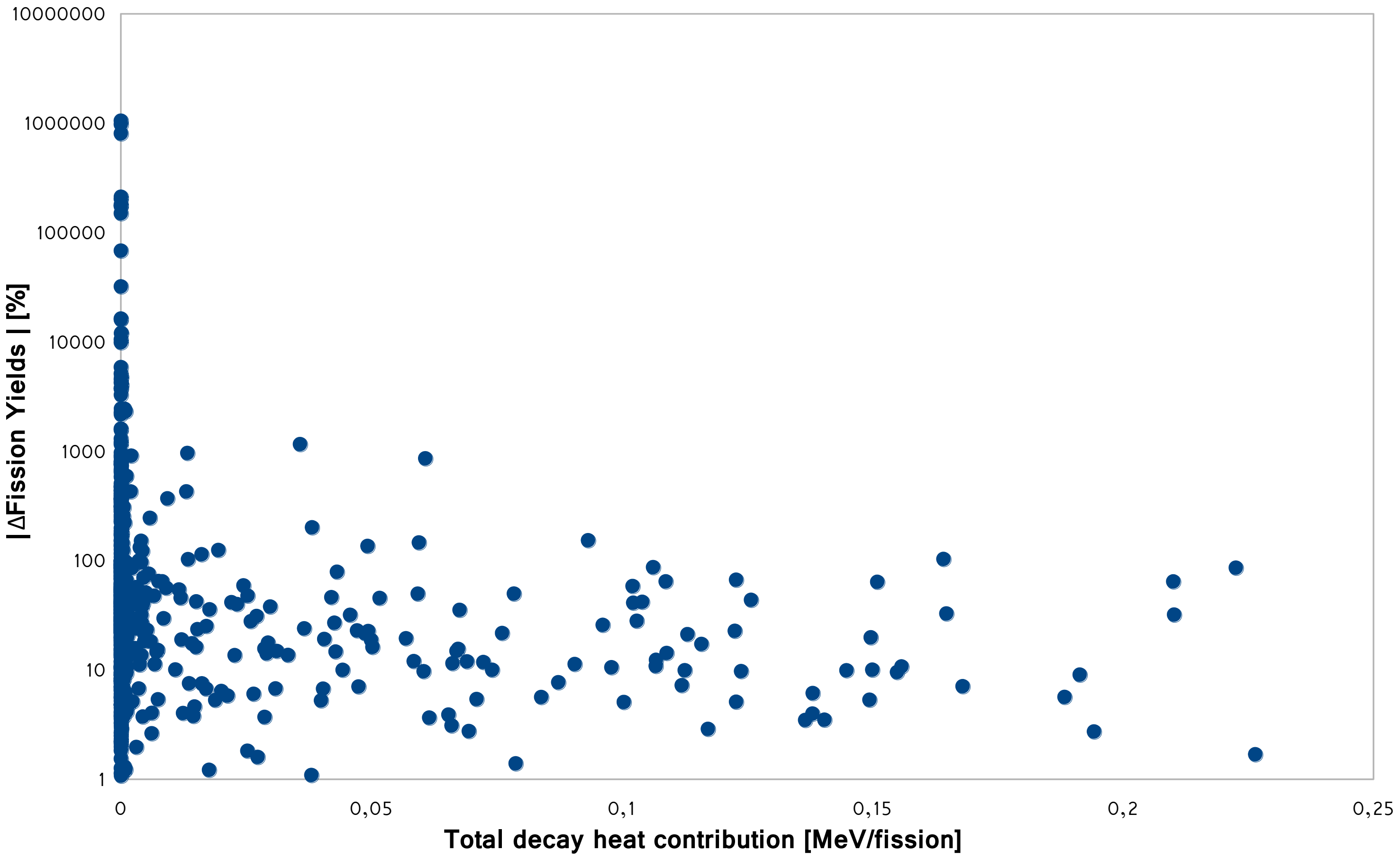
<u>**FIXED**</u>

DECAY PROPERTIES DATABASE

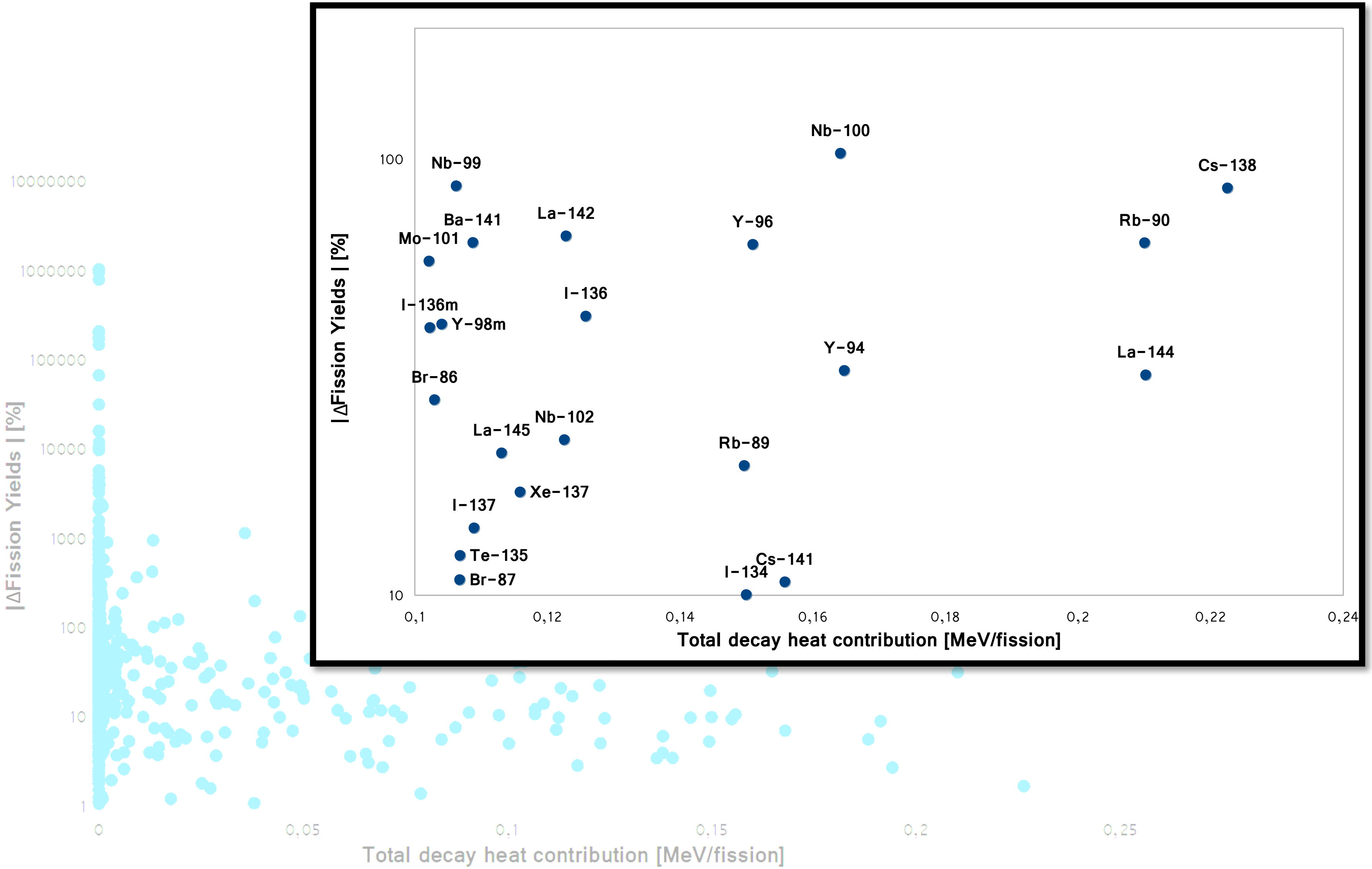
ENDF/B-VII.1

FOR BOTH CASES

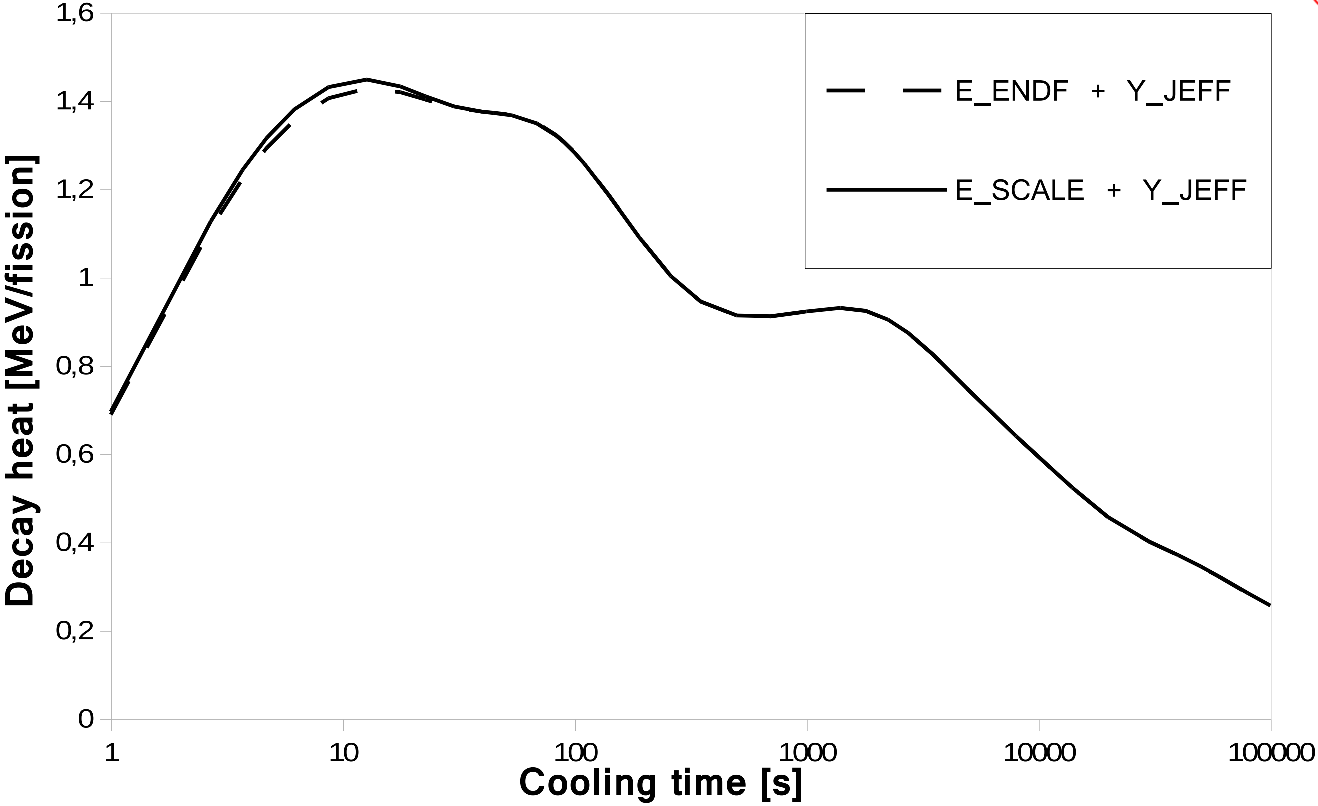
FISSION YIELDS DATABASE IMPACT

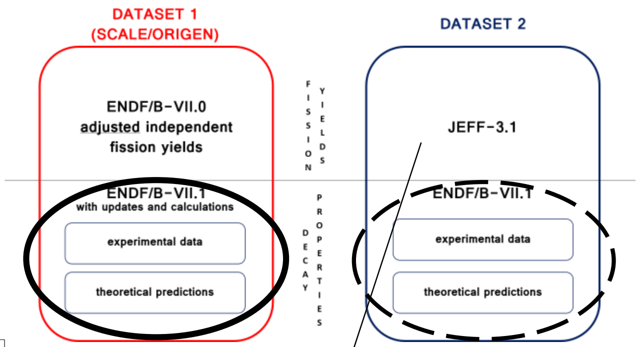


FISSION YIELDS DATABASE IMPACT



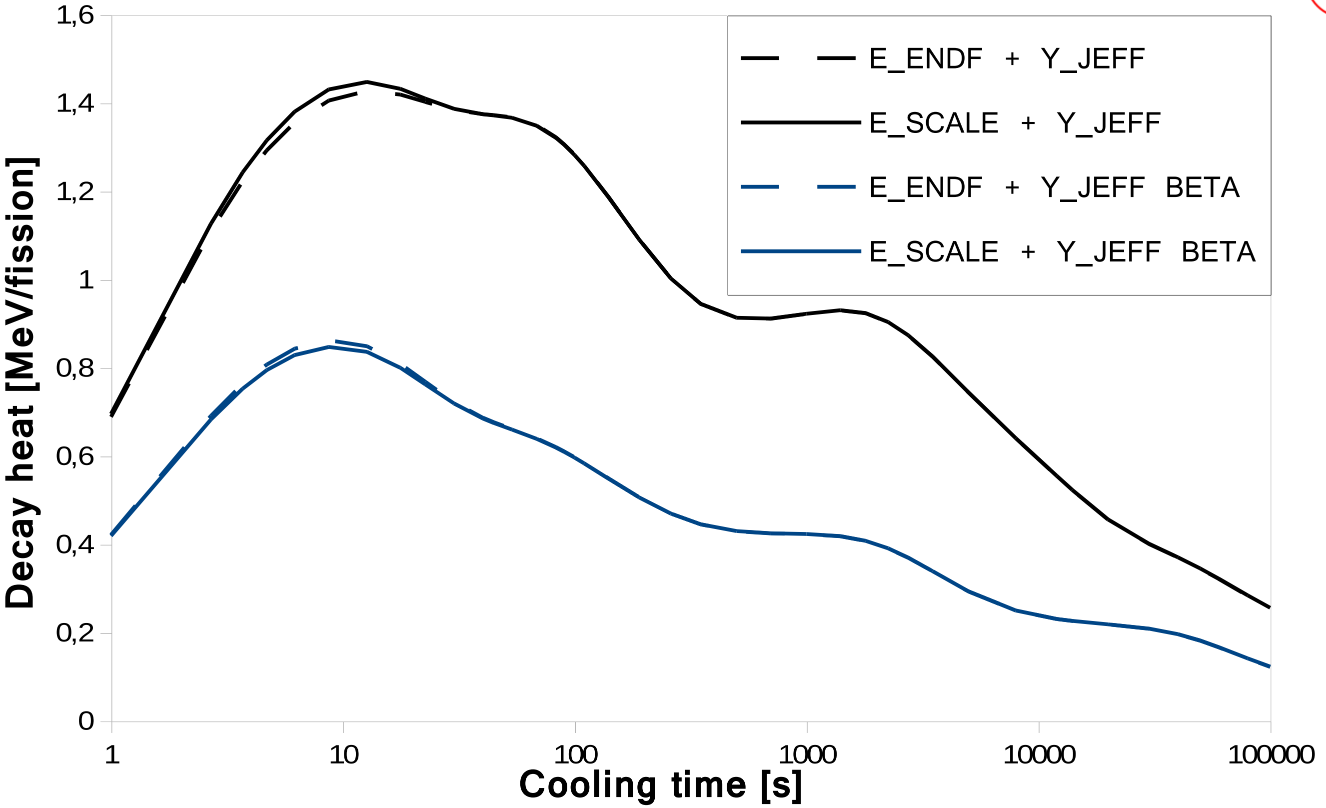
DECAY PROPERTIES DATABASE IMPACT

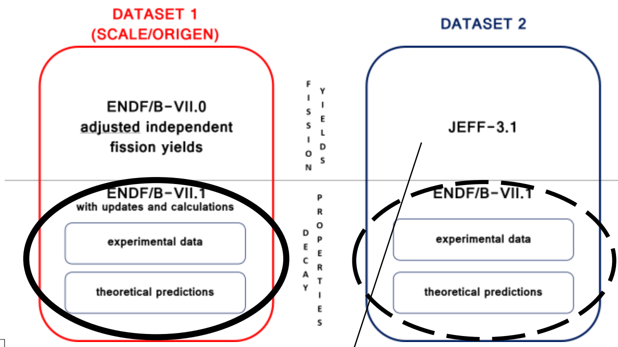




FIXED
FISSION YIELDS DATABASE
JEFF-3.1
FOR BOTH CASES

DECAY PROPERTIES DATABASE IMPACT





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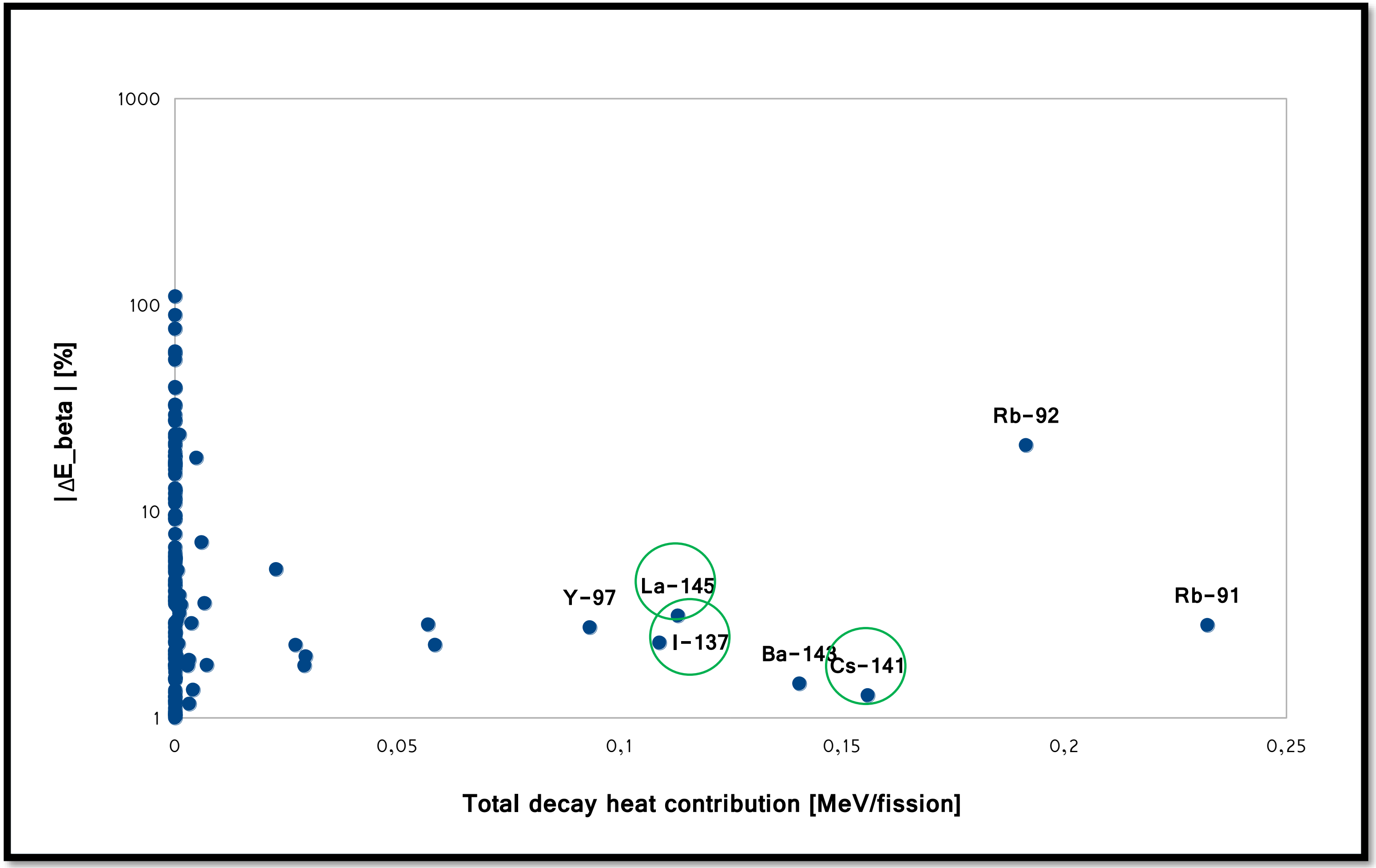
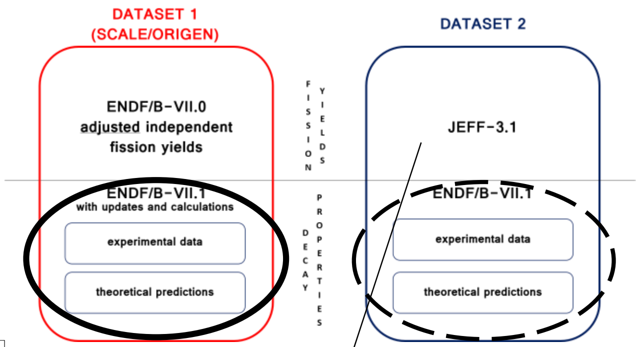
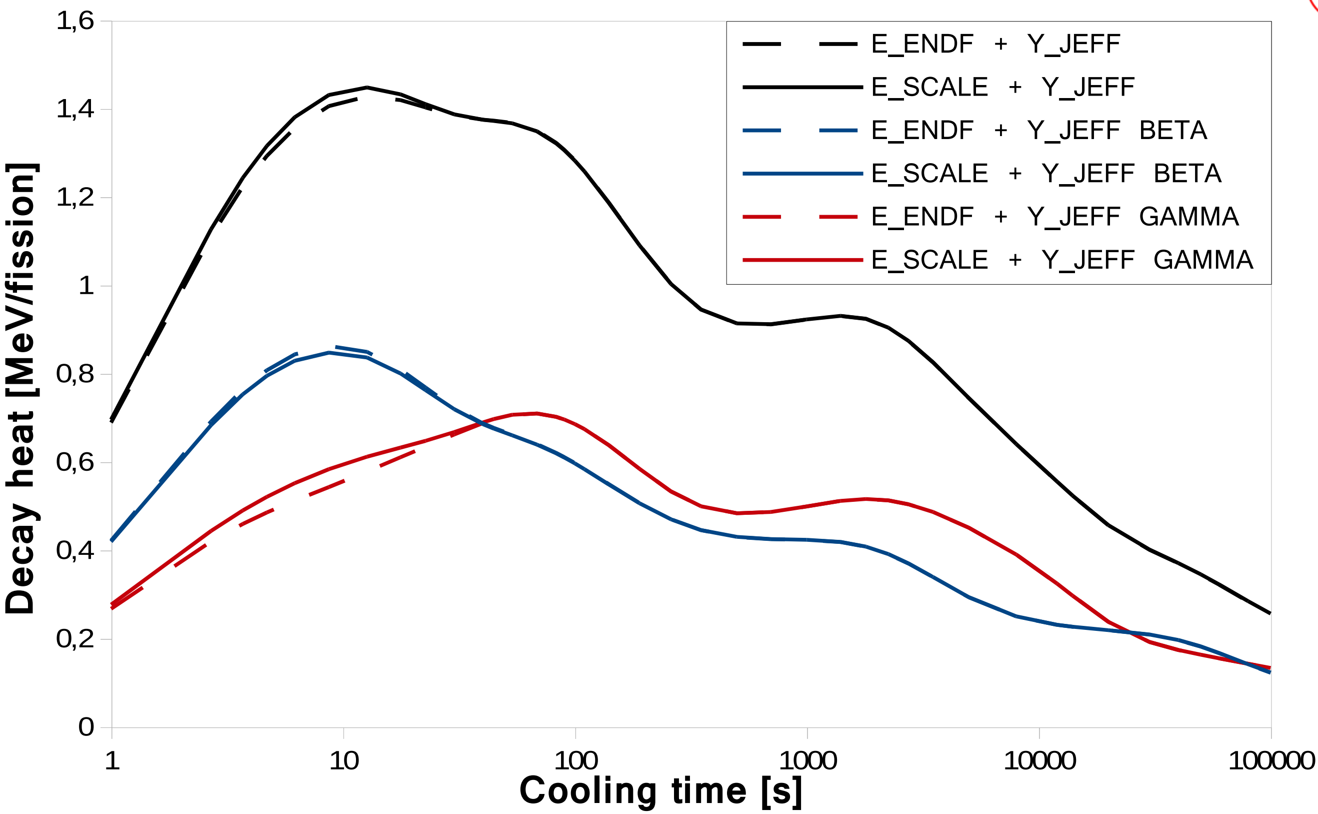
FISSION YIELDS DATABASE
JEFF-3.1
FOR BOTH CASES

DECAY PROPERTIES DATABASE IMPACT



DECAY PROPERTIES DATABASE IMPACT





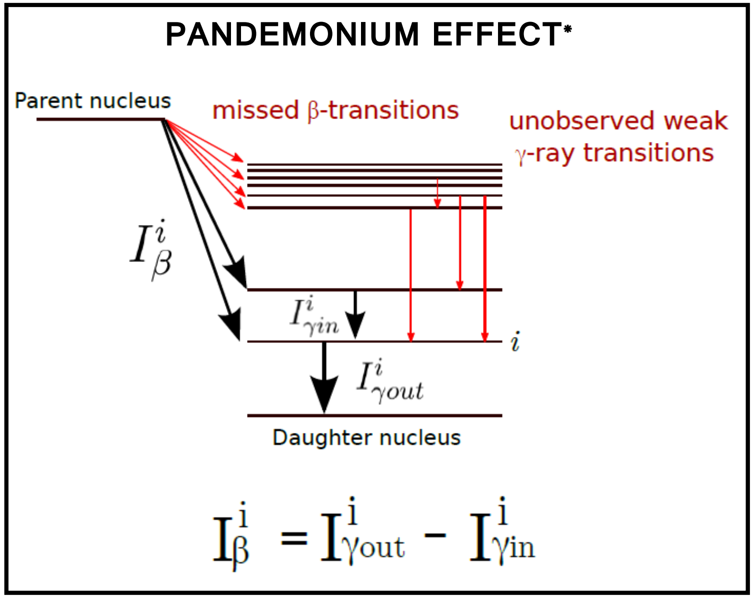
FIXED

FISSION YIELDS DATABASE

JEFF-3.1

FOR BOTH CASES

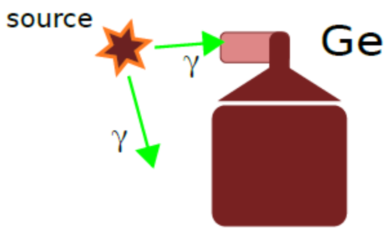
TOTAL ABSORPTION SPECTROMETER (TAS)

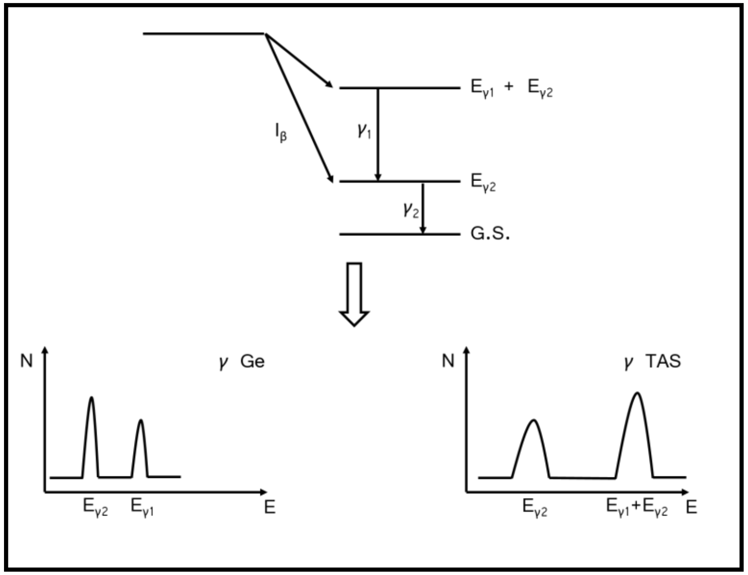


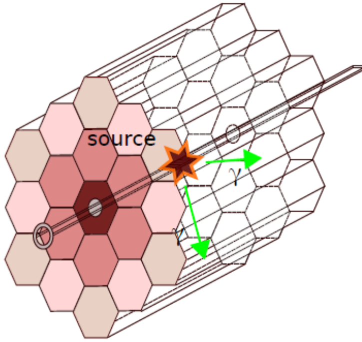
How to avoid the pandemonium effect?

<u>Total Absorption Spectroscopy</u> is an approach for increasing the efficiency of the detector.

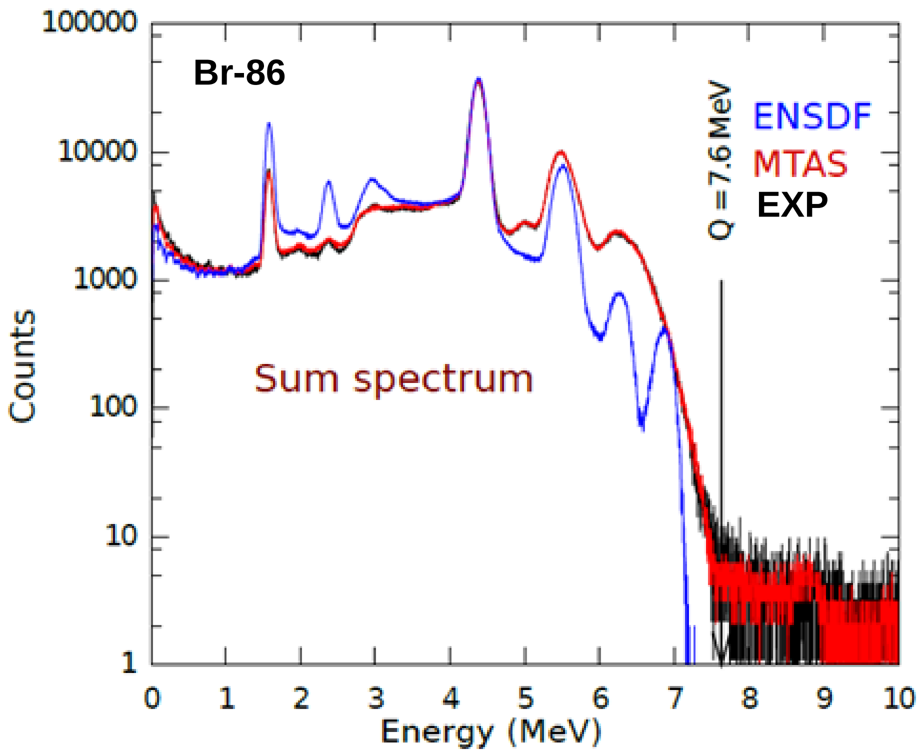
* Hardy J.C. *et al.*, Physics Letters B. 71. 307-310, (1977)







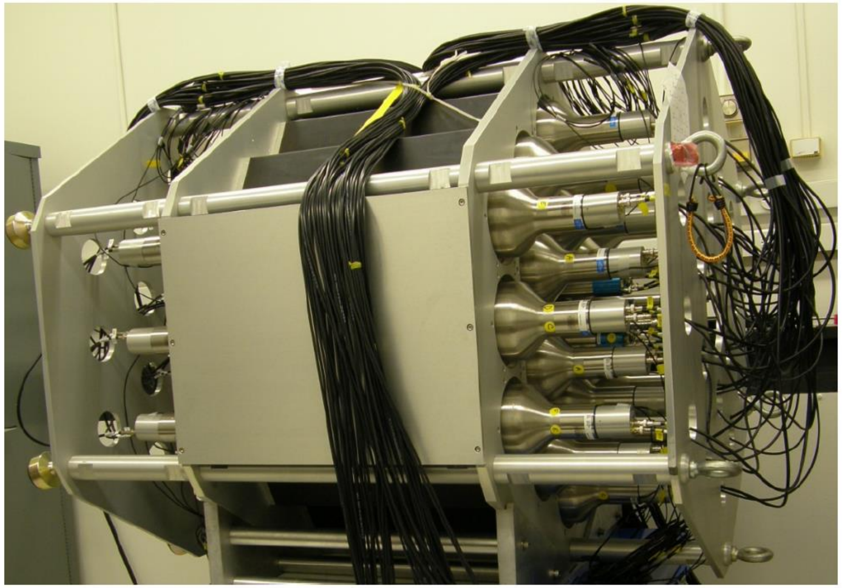
ORNL MTAS



Fijałkowska A. *et al.*, Phys. Rev. Lett. **119**, 052503, (2017)

$V_{NaI} = 0{,}27\ m^3 \approx 18 \times\ V_{NaI}^{Greenwood}$

SIZE MATTERS!

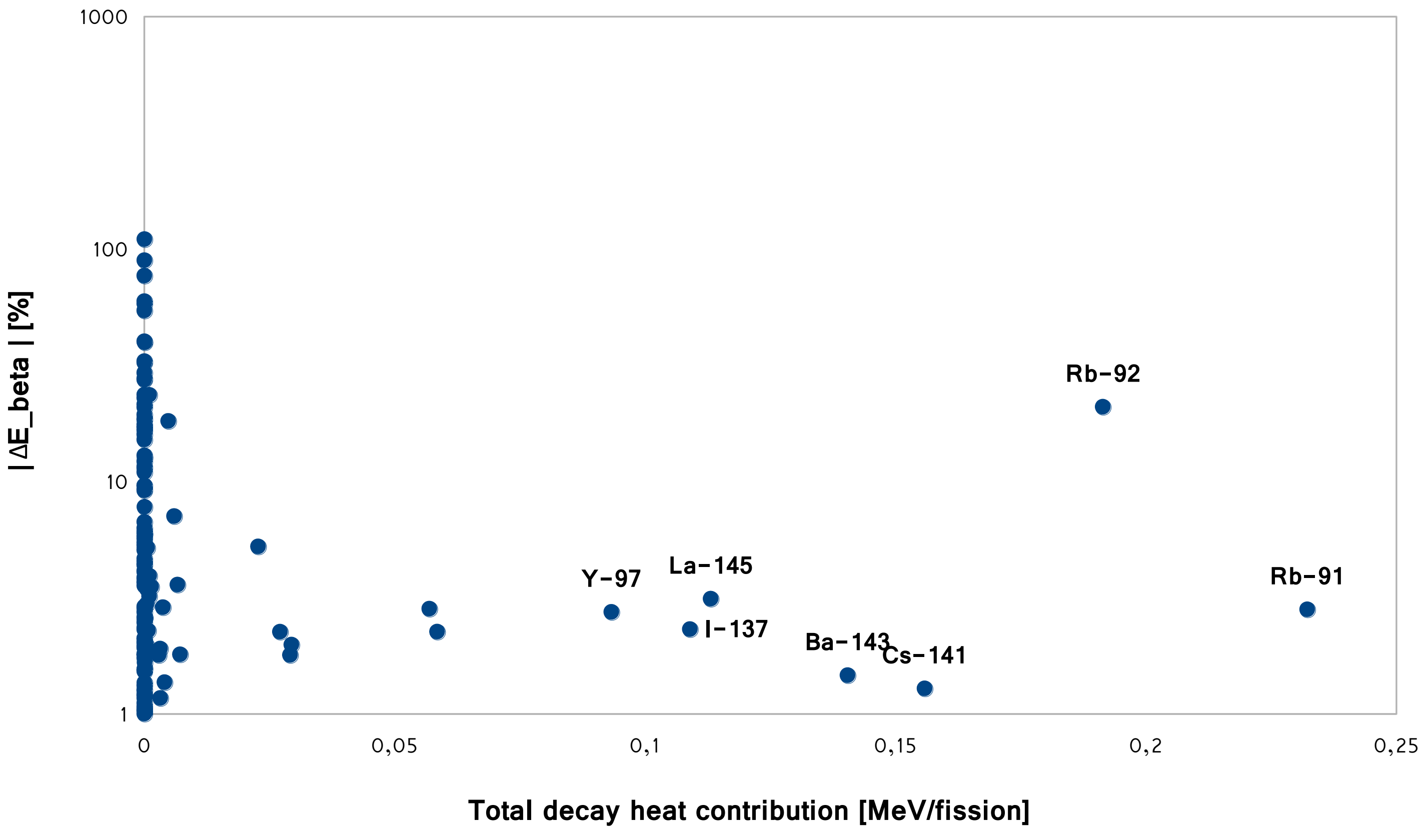


For 5 MeV Energy*:

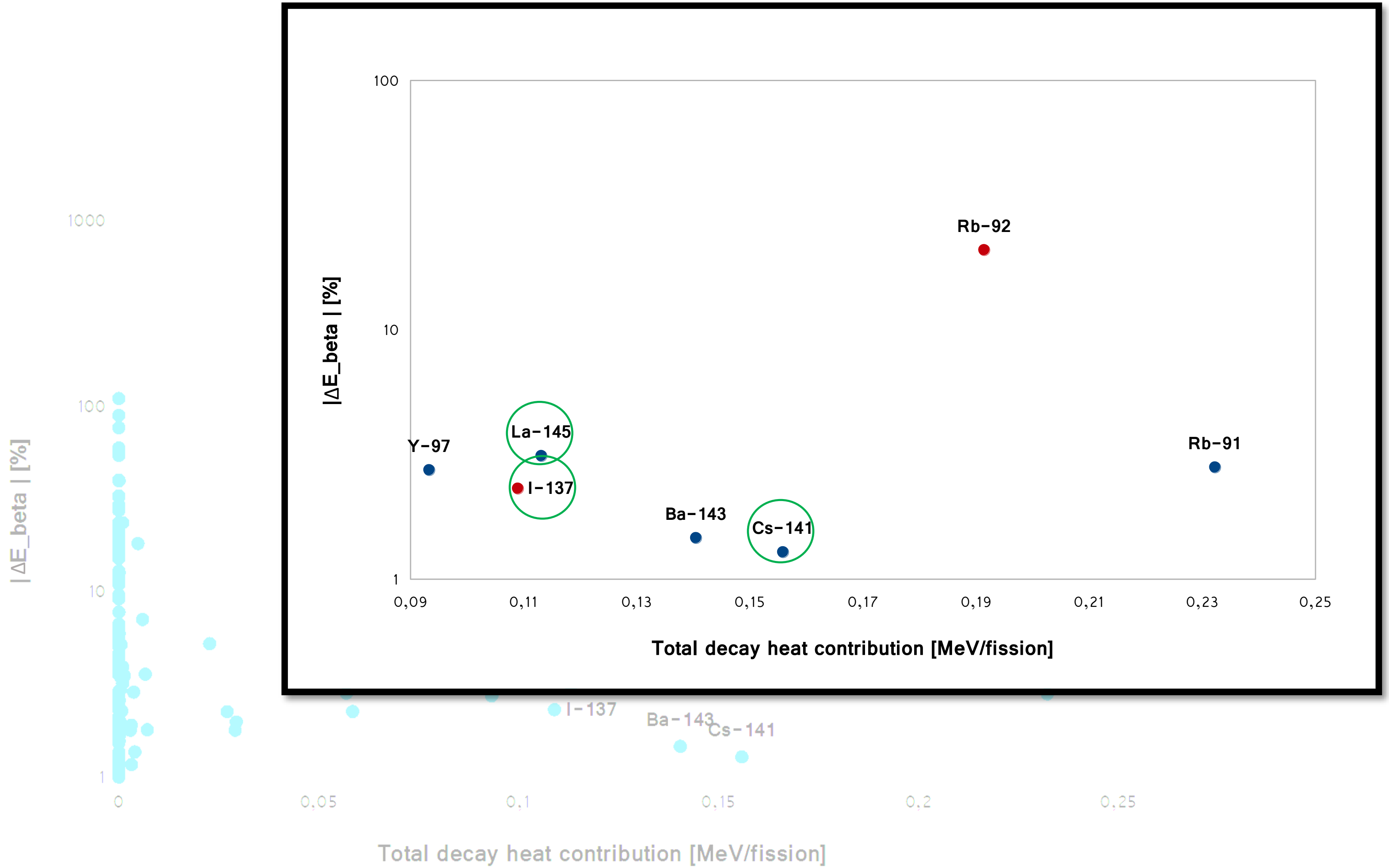
- Gammasphere Peak Efficiency ≈ 6%
- MTAS Peak Efficiency ≈ 73%

* Karny M. *et al.,* NIMA 836, 83-90 (2016)

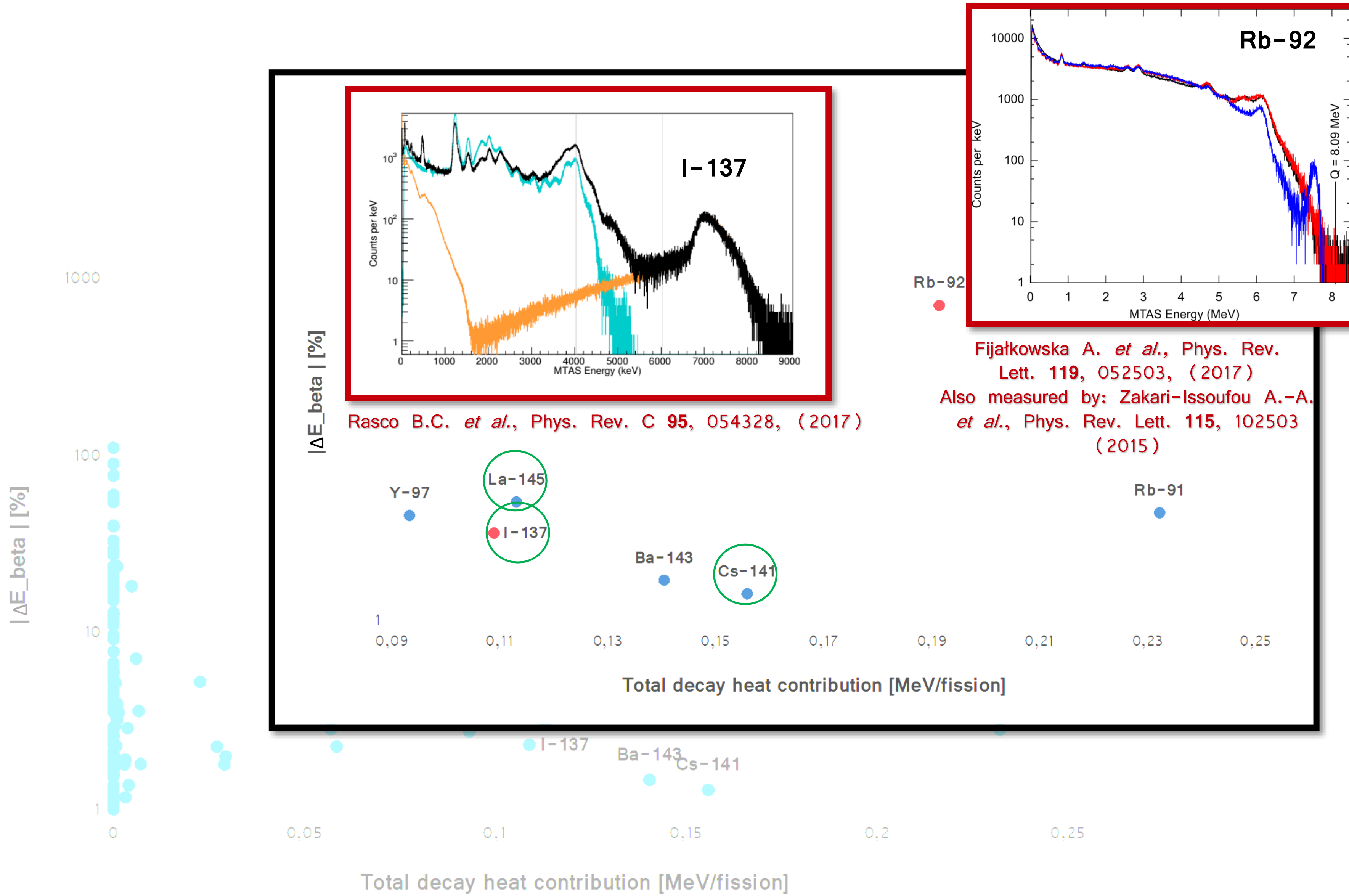
DECAY PROPERTIES DATABASE IMPACT



DECAY PROPERTIES DATABASE IMPACT



DECAY PROPERTIES DATABASE IMPACT



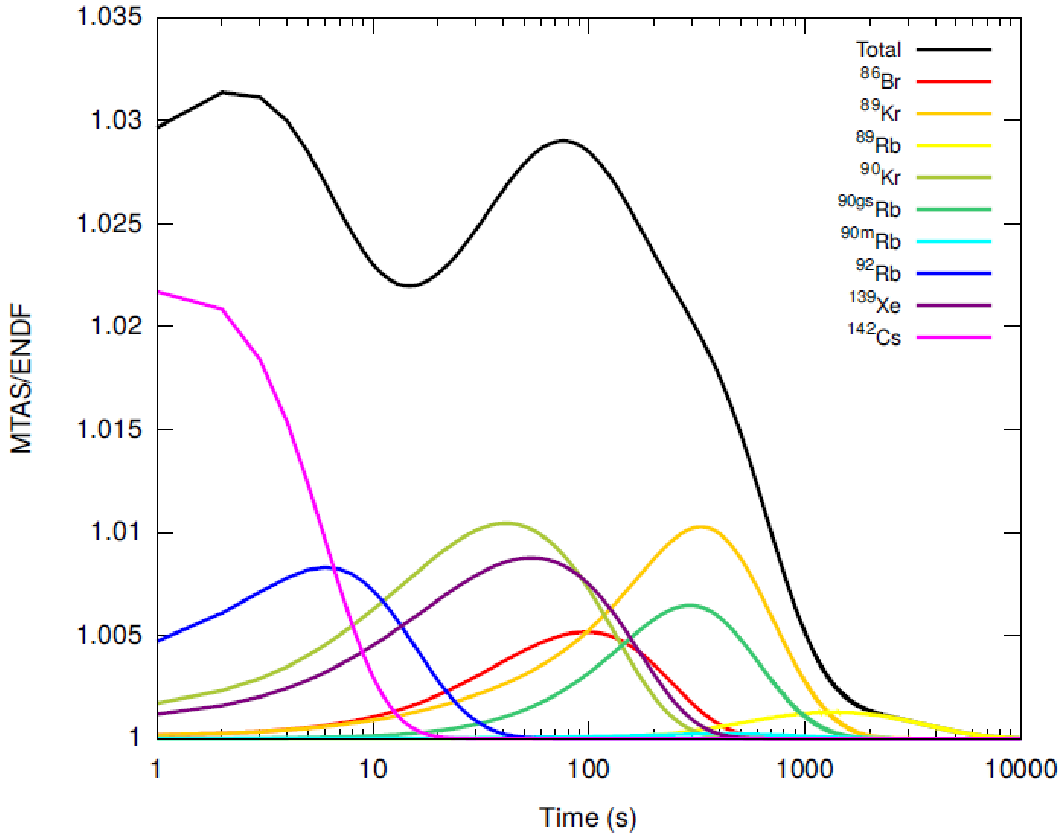
Rasco B.C. *et al.*, Phys. Rev. C **95**, 054328, (2017)

Fijałkowska A. *et al.*, Phys. Rev. Lett. **119**, 052503, (2017)
Also measured by: Zakari-Issoufou A.-A. *et al.*, Phys. Rev. Lett. **115**, 102503 (2015)

NEW DATA

ISOTOPE	Half-Life [s]	FISSION YIELD (JEFF-3.1)	OECD list (priority)
As-86	0,9	0,0004	-
Br-86	55,0	0,0062	+ (1)
Rb-89	909,0	0,0026	-
Rb-90	158,0	0,0008	-
Rb-91	58,4	0,0223	-
Rb-92	4,5	0,0287	+ (2)
Y-94	1122,0	0,0029	-
Y-96	5,3	0,0073	+ (2)
Nb-99	15,0	0,0023	+ (1)
Nb-100	1,5	0,0014	+ (1)
Nb-103	1,5	0,0178	-
Mo-101	876,6	0,0012	-
I-134	3150,0	0,0056	-
I-136	83,4	0,0091	+ (1)
I-137	24,5	0,0310	+ (1)
Cs-138	2004,6	0,0013	-
Cs-141	24,8	0,0327	-
Ba-141	1096,2	0,0101	-
Ba-143	14,5	0,0398	-
La-142	5466,0	0,0006	-
La-144	40,8	0,0081	-
La-145	24,8	0,0158	+ (2)

DECAY HEAT GAMMA COMPONENTS



Fijałkowska A. *et al.*, Phys. Rev. Lett. **119**, 052503, (2017)

CONCLUSION

- Decay heat calculations are senstitive to fission yields used – database chosen
- Measurements are needed to independently confirm Greenwood's experiments
- MTAS setup is suitable for measurements of properties which are essential to decay heat calculations

THANKS TO

MTAS Collaboration:

Karny M.[1,3], Fijałkowska A.[1,2,4], Rykaczewski K.P.[3], Rasco B.C.[2,3,5], Grzywacz R.[2,3], Gross C.J.[3], Wolińska-Cichocka M.[1,3], Goetz K.C.[2], Stracener D.W.[3], Goans R.[3], Hamilton J.H.[6], Johnson J.W.[3], Jost C.[2], Madurga M.[2], Miernik K.[1,3], Miller D.[2], Padgett S.W.[2], Paulauskas S.V.[2], Ramayya A.V.[6], Zganjar E.F.[5]

UNIVERSITAS VARSOVIENSIS
1

THE UNIVERSITY OF TENNESSEE KNOXVILLE
2

OAK RIDGE National Laboratory
3

RUTGERS
4

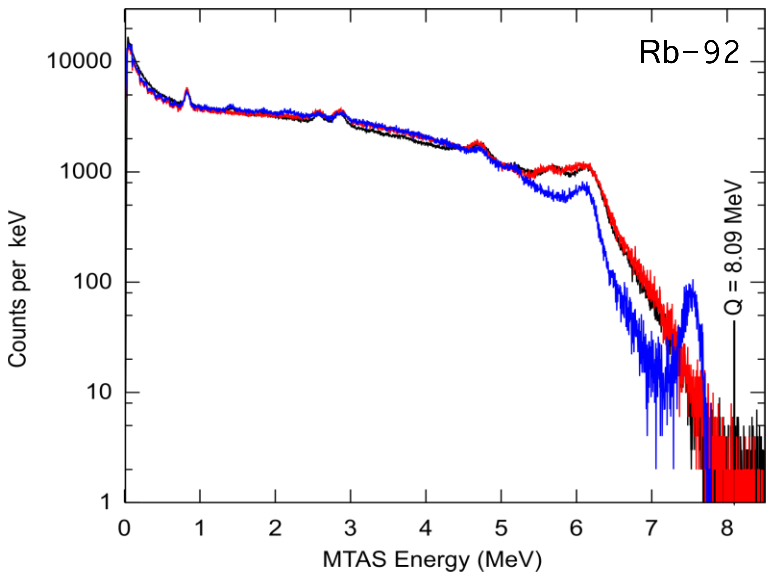
LSU LOUISIANA STATE UNIVERSITY
5

VANDERBILT UNIVERSITY
6

SCALE/ORIGEN support:

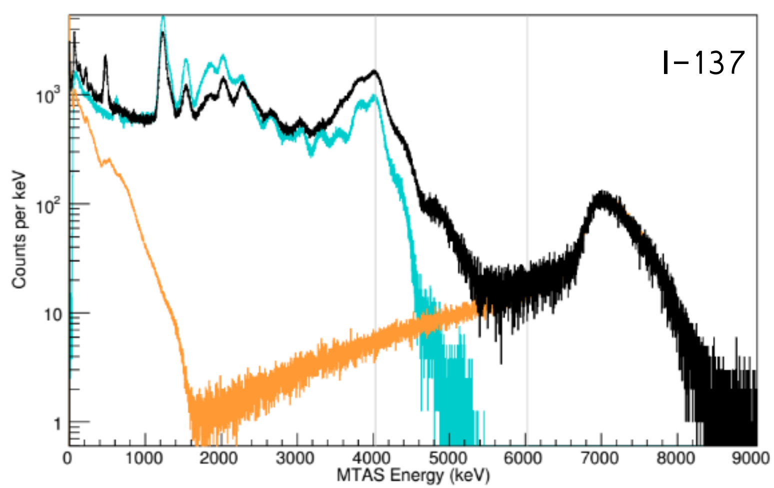
Gauld I.[3], Weiselquist W.[3]

ORNL MTAS MEASUREMENTS



$\tilde{E}_\beta^{ENDF}$ = 3628 keV
$\tilde{E}_\beta^{SCALE}$ = 2867 keV
$\tilde{E}_\beta^{MTAS}$ = 3570 keV

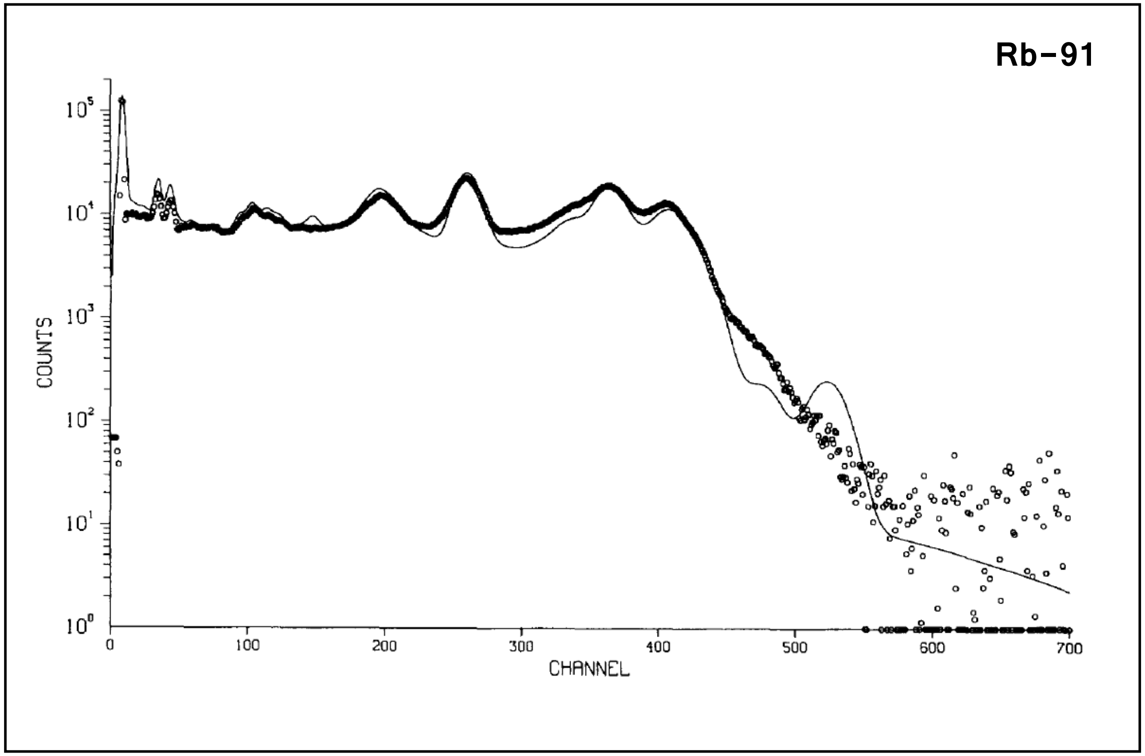
Fijałkowska A. *et al.*, Phys. Rev. Lett. **119**, 052503, (2017)
Also measured by: Zakari-Issoufou A.-A. *et al.*, Phys. Rev. Lett. **115**, 102503 (2015)



$\tilde{E}_\beta^{ENDF}$ = 1920 keV
$\tilde{E}_\beta^{SCALE}$ = 1964 keV
$\tilde{E}_\beta^{MTAS}$ = 1870 keV

Rasco B.C. *et al.*, Phys. Rev. C **95**, 054328, (2017)

GREENWOOD'S PAPERS



TOTAL NaI VOLUME:

V_{NaI} **= 0,015 m^3**

R.C.Greenwood *et al.*, Nucl.Instrum.Methods Phys.Res. A390, 95 (1997)
R.C.Greenwood *et al.*, Nucl.Instrum.Methods Phys.Res. A378, 312 (1996)
R.C.Greenwood *et al.*, Nucl.Instrum.Methods Phys.Res. A317, 175 (1992)

NEW INDEPENDENT MEASUREMENTS WITH BETTER (LARGER) EXPERIMENTAL SETUP NEEDED TO CONFIRM GREENWOOD'S RESULTS

M. Wolińska-Cichocka *et al.,* Nucl.Data Sheets 120, 22 (2014) – ^{142}Ba and ^{142}La

INVENTORY OF ISOTOPES

ISOTOPE	Half-Life [s]	FISSION YIELD (JEFF-3.1)	OECD list (priority)
As-86	0,9	0,0004	–
Br-86	55,0	0,0062	+ (1)
Rb-89	909,0	0,0026	–
Rb-90	158,0	0,0008	–
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Mo-101	876,6	0,0012	–
I-134	3150,0	0,0056	–
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I-137	24,5	0,0310	+ (1)
Cs-138	2004,6	0,0013	–
Cs-141	24,8	0,0327	–
Ba-141	1096,2	0,0101	–
Ba-143	14,5	0,0398	–
La-142	5466,0	0,0006	–
La-144	40,8	0,0081	–
La-145	24,8	0,0158	+ (2)

INVENTORY OF ISOTOPES

ISOTOPE	Half-Life [s]	Fission Yield (JEFF-3.1)	|ΔFission Yields| [%]	E_beta average exp (ENDF/B-VII.1) [keV]	|ΔE_beta average| [%]	TAS measurements
As-86	0,9	4,4E-04	57,2	—	—	—
Br-86	55,0	0,006	28,1	1944	1,76E-04	[6] , [8]
Rb-89	909,0	0,003	19,8	969	0,001	[6] , [9]**
Rb-90	158,0	8,1E-04	64,4	1905	0,002	[6] , [9]**
Rb-91	58,4	0,022	4,4E-02	1410	2,818	[8] , [9]**
Rb-92	4,5	0,029	9,0	3628	20,962	[6] , [7], [15]
Y-94	1122,0	0,003	32,8	1810	0,267	[9]** , [11]
Y-96	5,3	0,007	63,8	3210	0,131	[7]
Nb-99	15,0	0,002	87,0	1450	0,008	—
Nb-100	1,5	0,001	103,3	2550	0,088	—
Nb-103	1,5	0,018	21,7	—	—	—
Mo-101	876,6	0,001	58,5	548	0,002	[12]
I-134	3150,0	0,006	10,0	582	0,001	—
I-136	83,4	0,009	43,7	1950	0,098	—
I-137	24,5	0,031	14,3	1920	2,317	[13]
Cs-138	2004,6	0,001	86,0	1240	0,332	[9]**
Cs-141	24,8	0,033	10,7	1510	1,288	[9]**
Ba-141	1096,2	0,010	64,5	938	7,24E-05	[9]**
Ba-143	14,5	0,040	3,5	1200	1,468	[9]**
La-142	5466,0	5,7E-04	66,8	954	0,002	[9]** , [14]
La-144	40,8	0,008	32,0	1030	0,915	[9]**
La-145	24,8	0,016	21,2	854	3,132	[9]**

[6] Fijalkowska A. et al., Phys. Rev. Lett. 119, 052503, (August 2017)
[7] Rasco B.C. et al., Phys.Rev.Lett. 117, 092501 (2016)
[8] Rice S. et al., Phys.Rev. C 96, 014320 (2017)
[9] Greenwood R.C. et al., Nucl.Instrum.Methods Phys.Res. A390, 95 (1997)
[10] Zakari-Issoufou A.-A. et al., Int.Nuclear Physics Conf. 2013, (IUPAP), Firenze, Italy, June 2-7, 2013, S.Lunardi, P.G.Bizzeti et al., Eds.p.10019 (2014); EPJ web of Conf.v.66, (2014)
[11] Tain J.L. et al., Phys.Rev.Lett. 115, 062502 (2015)
[12] Algora A. et al., J.Korean Phys.Soc. 59, 1479s (2011)
[13] Rasco B.C. et al., Phys.Rev. C 95, 054328 (2017)
[14] Wolinska-Cichocka M. et al., Nucl.Data Sheets 120, 22 (2014)
[15] Zakari-Issoufou A.-A. et al., Phys. Rev. Lett. 115, 102503 (2015)