Study on mass distribution with semi-empirical model for n+^{233}U fission

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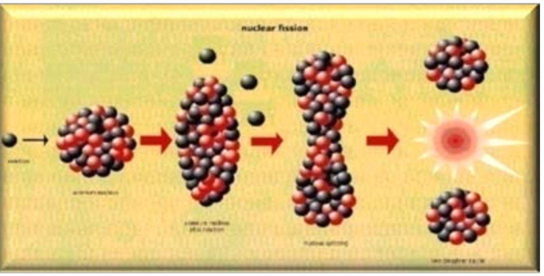
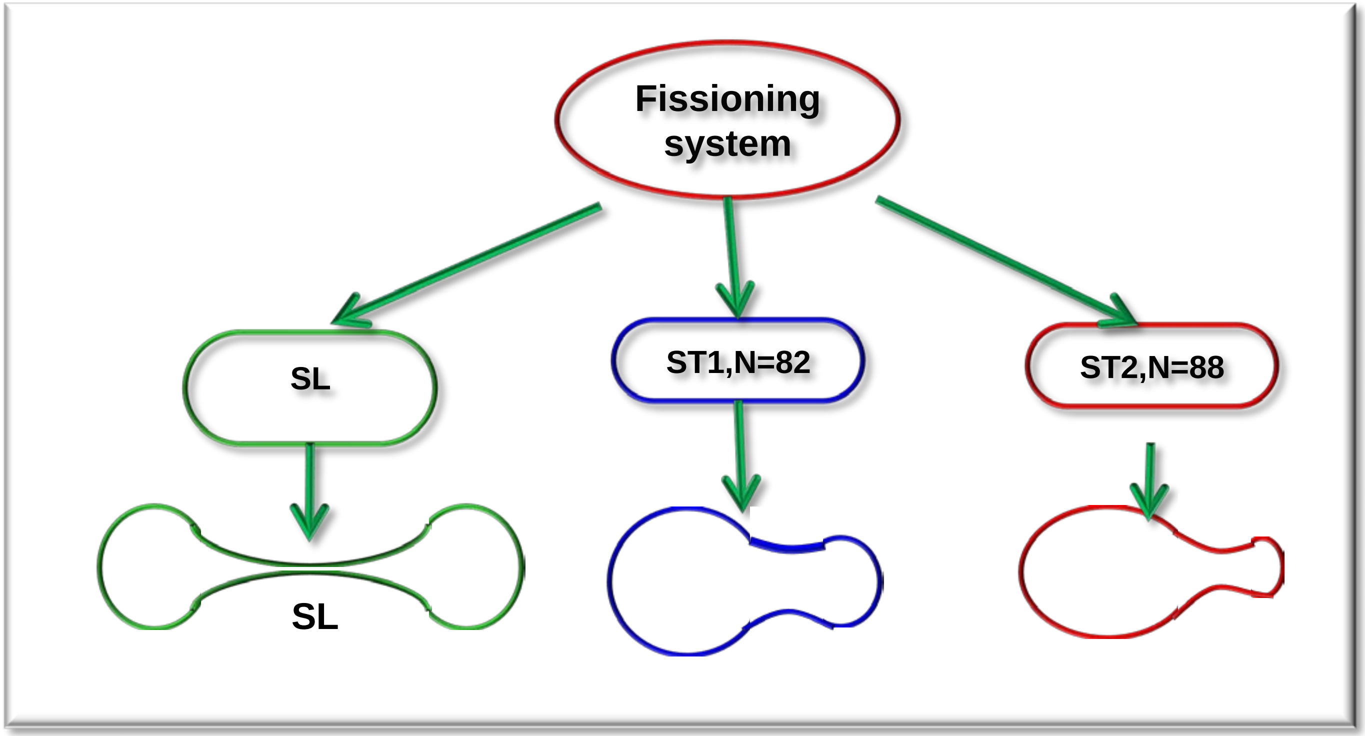
1.Introduction

- ***CYF and TALYS programs are widely used for yield study:***
  - CYF with used systematics method (Wahl 2002)
  - TALYS was based on theoretical model.
- ***The motivation of this work is to develop a code named SEEP(SEmi-EmPirical):***
  - it is a mixture of theoretical model and systematics.
  - it has advantages of the two method, and avoid the complex of the theoretical model and the lack of physics of the pure systematic method.
  - could compute: mass distribution at <20 MeV

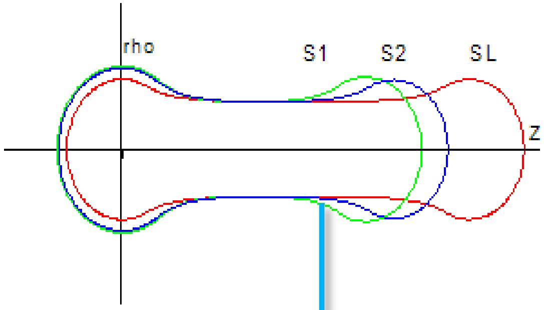
2. Semi-empirical model description



According to multi-mode random neck rupture model (Brosa model): A fission system has 3 deformation routines, corresponding to 3 fission modes: Superlong, Standard I and Standar II.



For each fission mode, the fragment has a Gaussian mass distribution around the scission point:



$$E^* = E_0^* - U$$

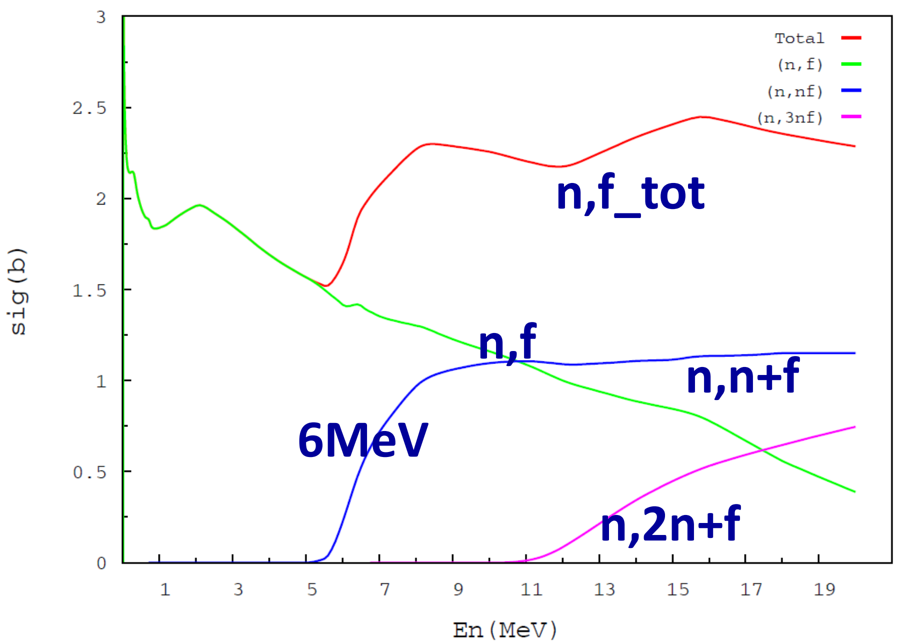
At sission:

$$Y_i = C_i \exp\left(2\sqrt{aE^*}\right)$$

$$Y(E_0^*, N) = C_0 \sum_{i=1}^{5} Y_i \times \exp\left[-(N_i - N)^2 / \sigma_i^2\right]$$

Multi-mode

random Neck rupture)

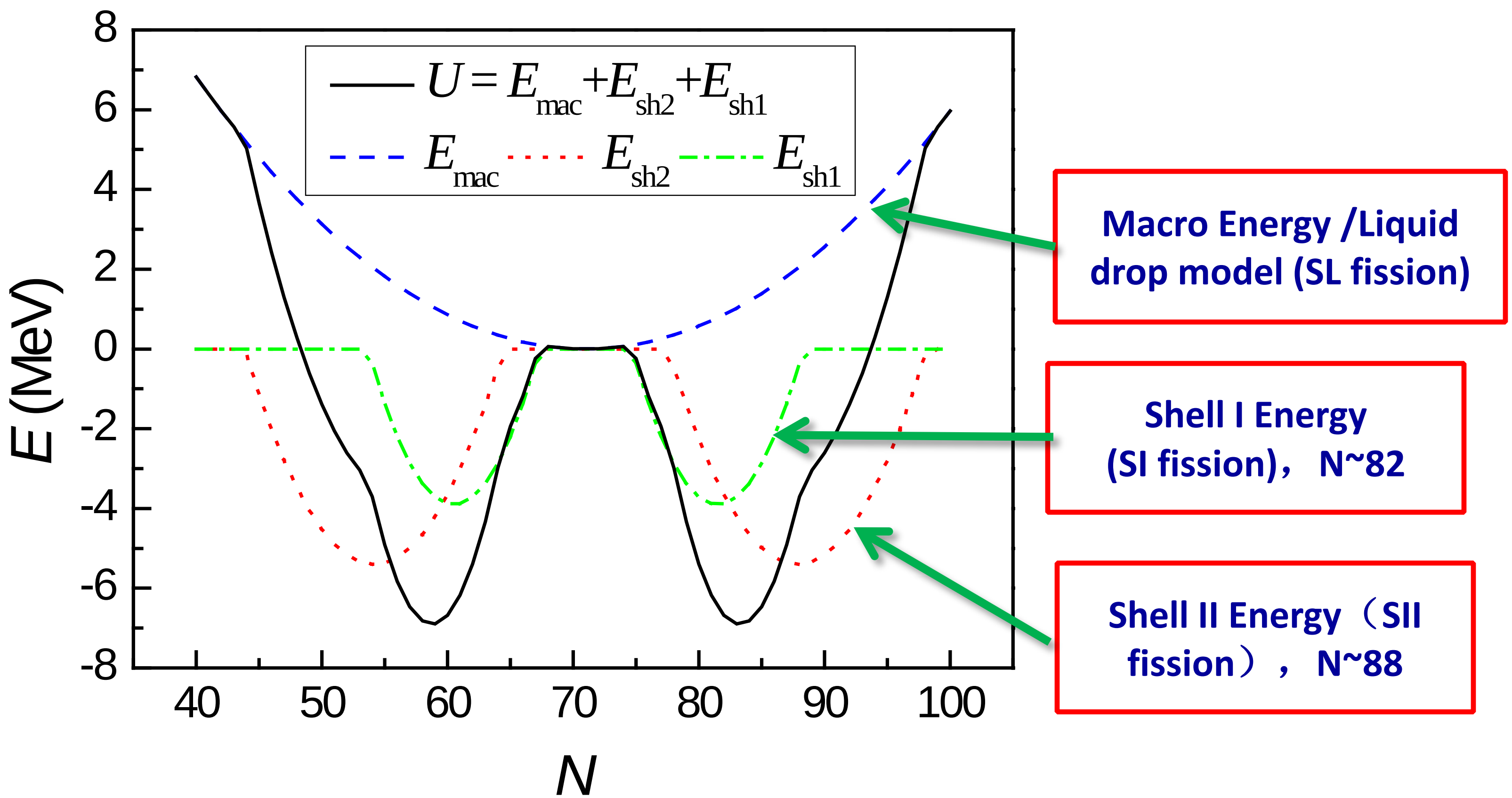


When En>6 MeV or up to 12MeV , (n,nf) and (n,2nf) will be open, their contributions must be taken account.

M-channel Reaction

Potential Energy :

So the system energy, as well as the potential energy at scission is important, which should be calculated theoretically , but it is too complex. In this work it is simplified and parameterized with parabola expressions approximately. It includes the macro energy, two shell effects around N~82 and 88. The macro energy could be described with liquid drop model。



Model parameters

The model have 11 parameters to be determined :

- **Shell effects energy depth and coefficients：** dU_4, dU_5, C_4, C_5

$$Esh_2 = Esh_4 = (dU_4 + C_4(N - N_4)^2)\exp(-\gamma\varepsilon),$$
$$Esh_1 = Esh_5 = \ldots$$

- **Shell effects decrease with temperature with decreasing factor :** γ
- **Gaussian Distribution widths factor for *SI,SII:***

$$\sigma_4 = \sigma_{4\_0} f(E,N), \quad \sigma_5 = \sigma_{5\_0} f(E,N)$$

- **Positions for SI,SII：** N_4, N_5
- **Normalization constant：** C_0
- **Factor in level density expression：** $a = A_c / 10 + C_a (a_F - A_F / 10)$

Other parameters definition taken from J.Benlliure, A.Grewe, M.de Jong et al. "Calculated nuclide production yield in relativitic collisions of fissile nuclidei", Nucl.Physics, A628, 458(1998).

Content

3 Experimental data base of ^{233}U+n

There are 632 data of chain (or cum.) yields in 40 of experiments were collected from EXFORE lib., covering 73 chains.

- 38 sets were measured with radiochemistry method:
  - The incident neutron energy were at thermal, fission spectrum （0.4, 0.7, 1.0MeV） and higher energy（14.7, 14.8MeV）;
- 2 sets were measured with double kinetic energy method：
  - energies are at thermal, 0.45, 1.04, 1.45, 1.94, 2.54, 3.15, 3.97, 4.58, 5.42MeV;
- All the data were checked and evaluated, and then used to determine the model parameters.

4 Results: (1)parameters

No	dU_5	dU_4	C_5	C_4	σ_5	σ_4
1	-5.385	-3.904	0.053	0.085	1.253	0.849
2	-5.696	-4.073	0.038	0.163	1.034	2.419
3	-5.466	-3.670	0.039	0.051	1.275	0.424

No	N_5	N_4	C_0	C_a	γ	χ^2
1	87.83	81.55	1.232	1.237e-3	0.057	12.81
2	87.83	81.61	1.215	-0.011	0.039	1.68
3	88.32	81.19	1.223	-8.83e-3	0.047	9.0

Notes：

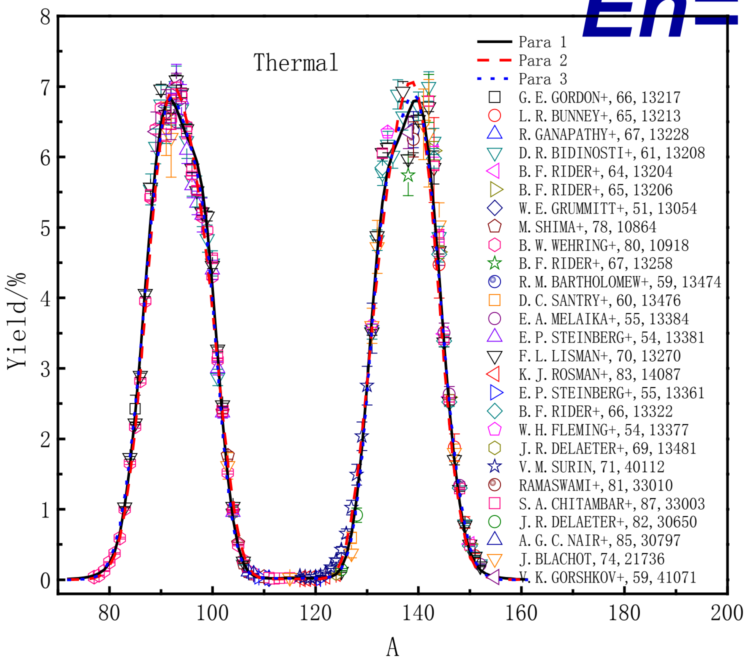
Para. Sets1： obtained by fitting to RC measured data.

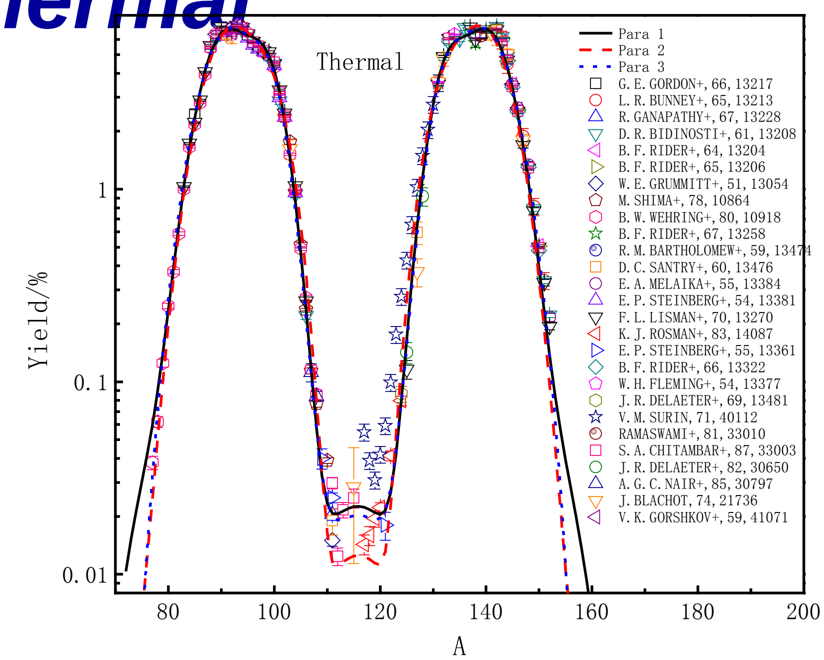
Para. Sets2： obtained by fitting to KE measured data.

Para. Sets3： obtained by fitting to ALL measured data

4. Result of n+^{233}U, (2)mass distributions

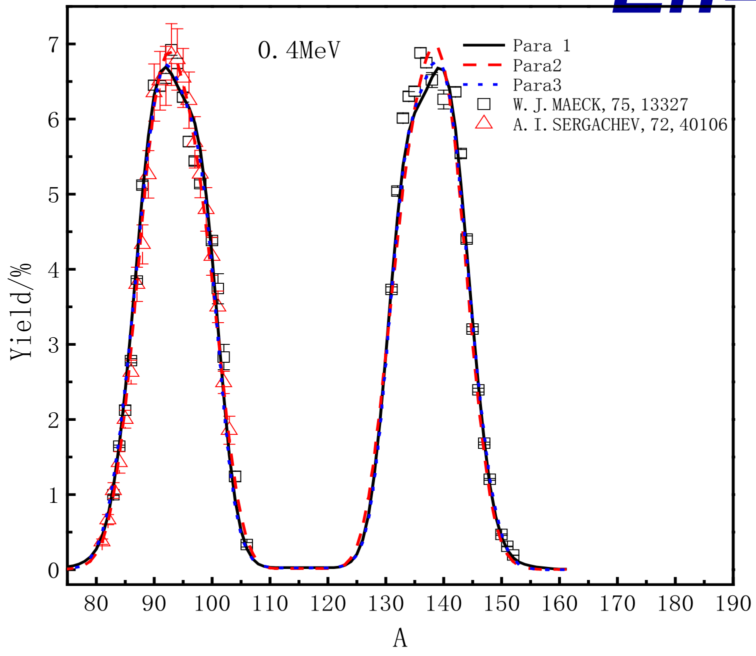
En=Thermal



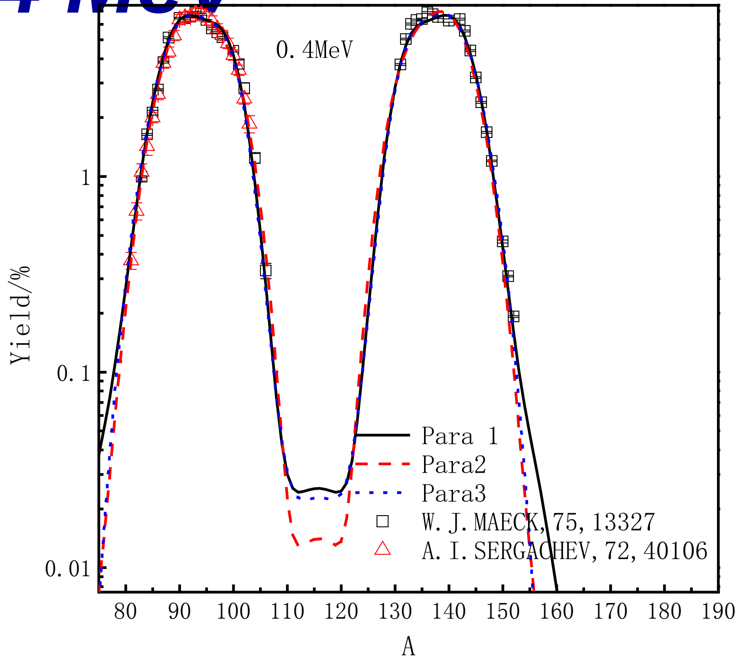


For energy thermal to 14.8 MeV, the calculated distributions show good agreement with measured data.

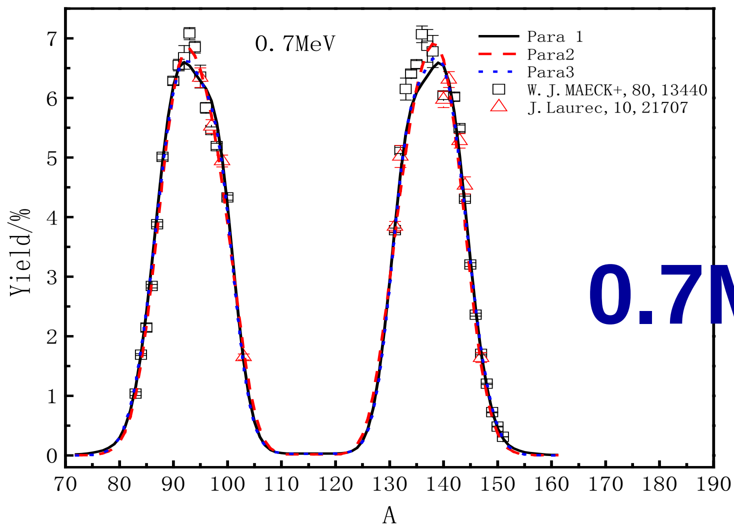
En=0.4 MeV

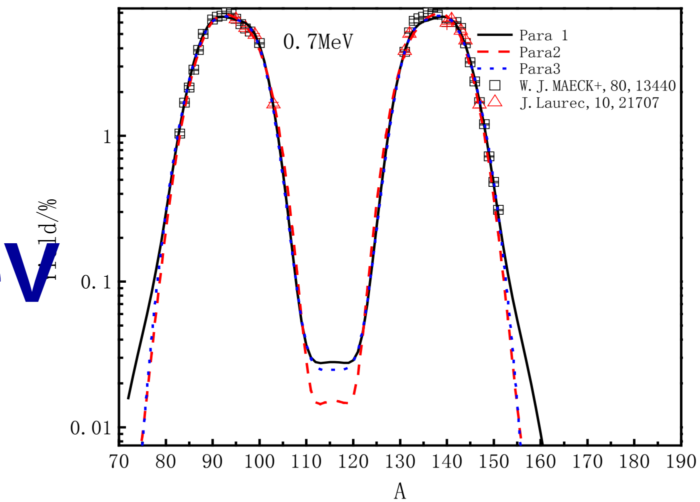


0. 4MeV
Para 1
Para2
Para3
W. J. MAECK, 75, 13327
A. I. SERGACHEV, 72, 40106
Yield/%
A

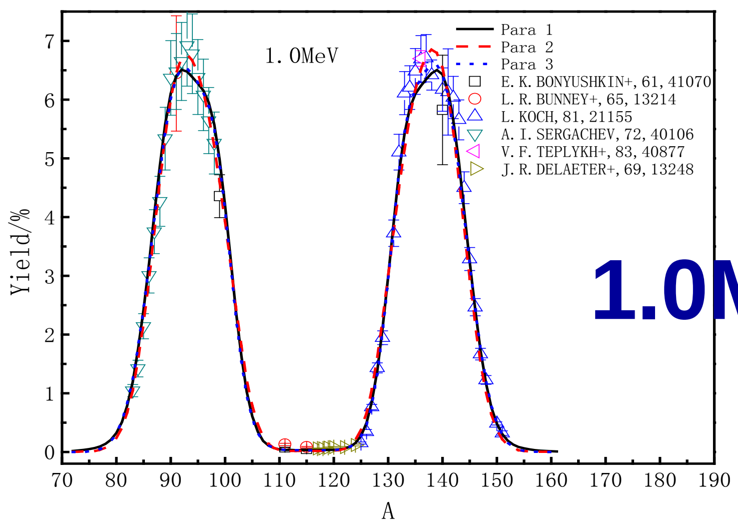


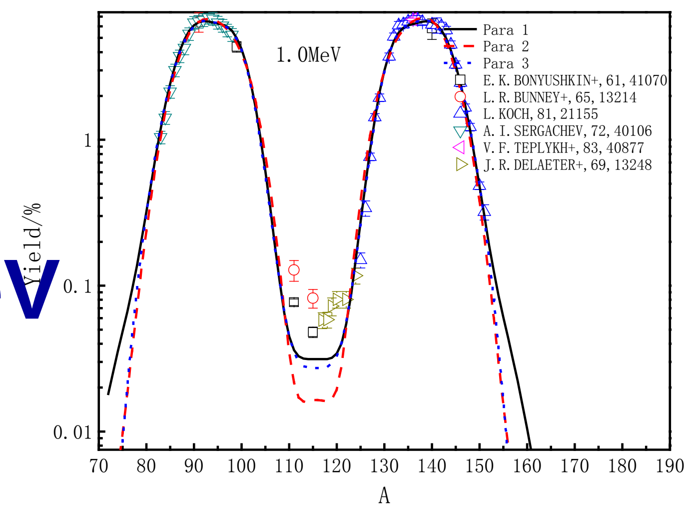
0. 4MeV
Para 1
Para2
Para3
W. J. MAECK, 75, 13327
A. I. SERGACHEV, 72, 40106
Yield/%
A


0. 7MeV
Para 1
Para2
Para3
W. J. MAECK+, 80, 13440
J. Laurec, 10, 21707
Yield/%
A

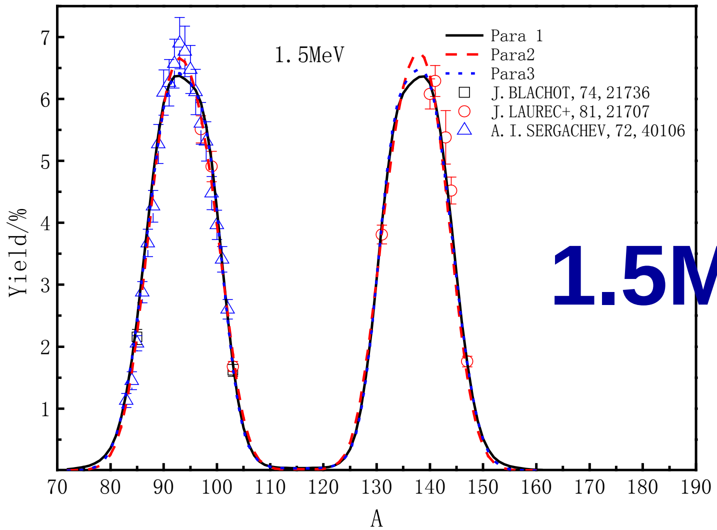

0. 7MeV
Para 1
Para2
Para3
W. J. MAECK+, 80, 13440
J. Laurec, 10, 21707
A

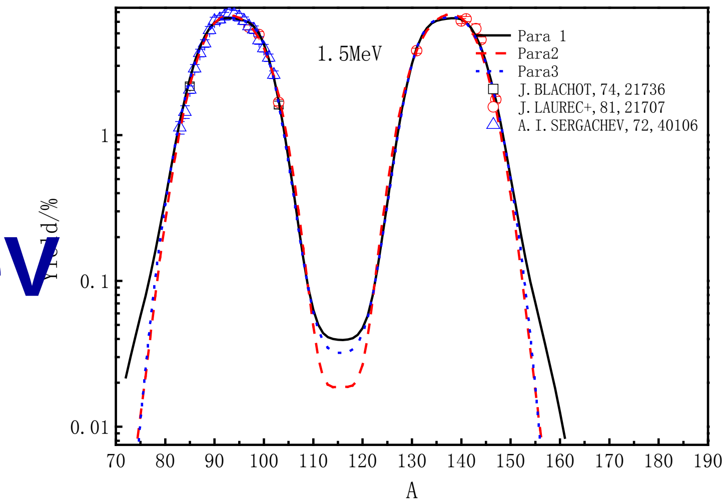
0.7MeV


1. 0MeV
Para 1
Para 2
Para 3
E. K. BONYUSHKIN+, 61, 41070
L. R. BUNNEY+, 65, 13214
L. KOCH, 81, 21155
A. I. SERGACHEV, 72, 40106
V. F. TEPLYKH+, 83, 40877
J. R. DELAETER+, 69, 13248
Yield/%
A

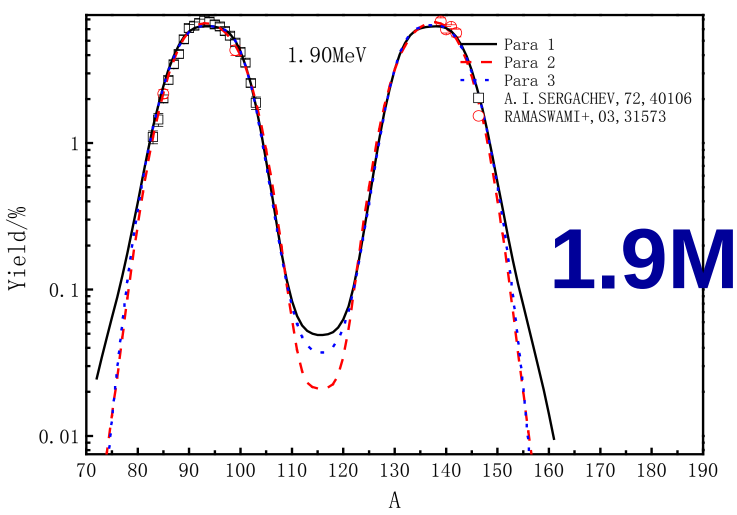

1. 0MeV
Para 1
Para 2
Para 3
E. K. BONYUSHKIN+, 61, 41070
L. R. BUNNEY+, 65, 13214
L. KOCH, 81, 21155
A. I. SERGACHEV, 72, 40106
V. F. TEPLYKH+, 83, 40877
J. R. DELAETER+, 69, 13248
Yield/%
A

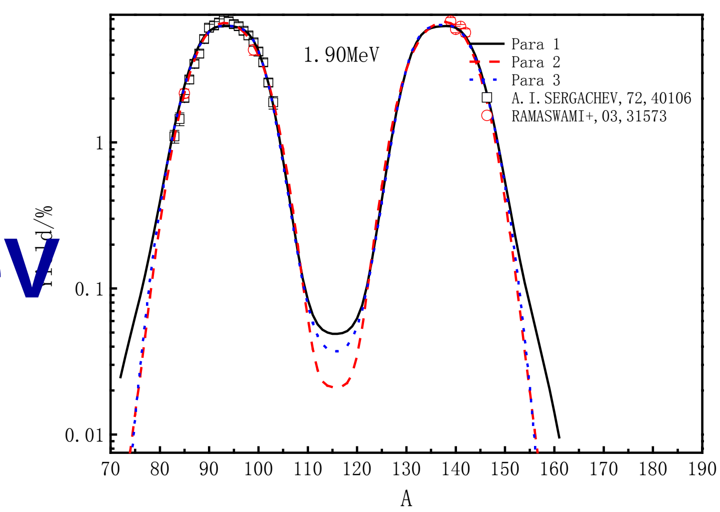
1.0MeV


1.5MeV
Para 1
Para2
Para3
J. BLACHOT, 74, 21736
J. LAUREC+, 81, 21707
A. I. SERGACHEV, 72, 40106
Yield/%
A

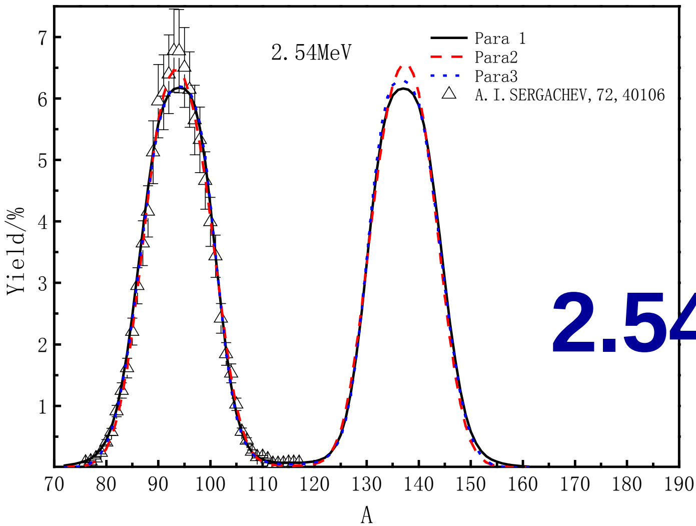

1.5MeV
Para 1
Para2
Para3
J. BLACHOT, 74, 21736
J. LAUREC+, 81, 21707
A. I. SERGACHEV, 72, 40106
A

1.5MeV

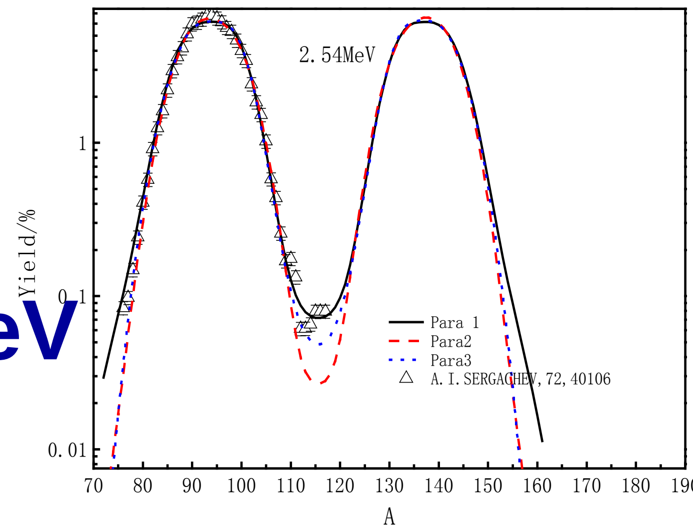

1.90MeV
Para 1
Para 2
Para 3
A. I. SERGACHEV, 72, 40106
RAMASWAMI+, 03, 31573
Yield/%
A

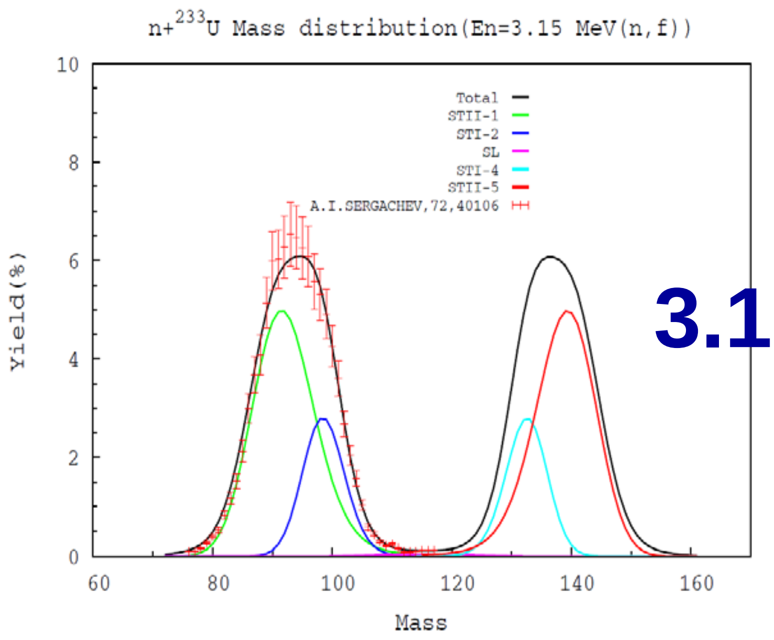

1.90MeV
Para 1
Para 2
Para 3
A. I. SERGACHEV, 72, 40106
RAMASWAMI+, 03, 31573
A

1.9MeV

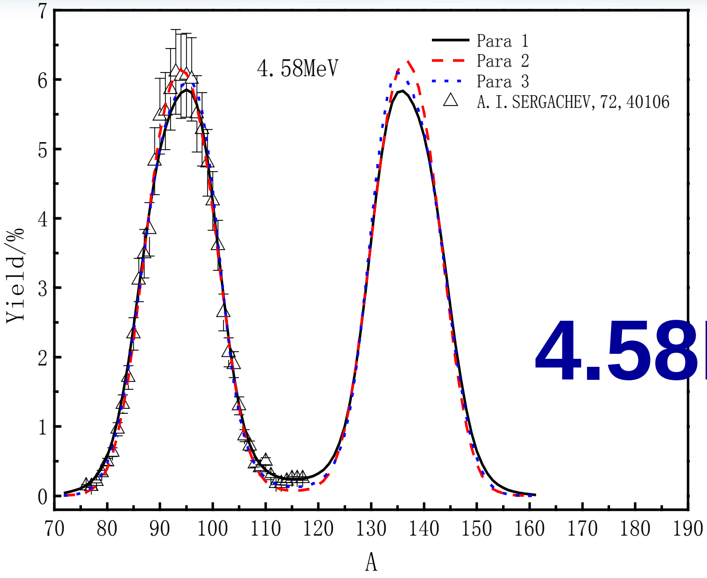


2.54MeV



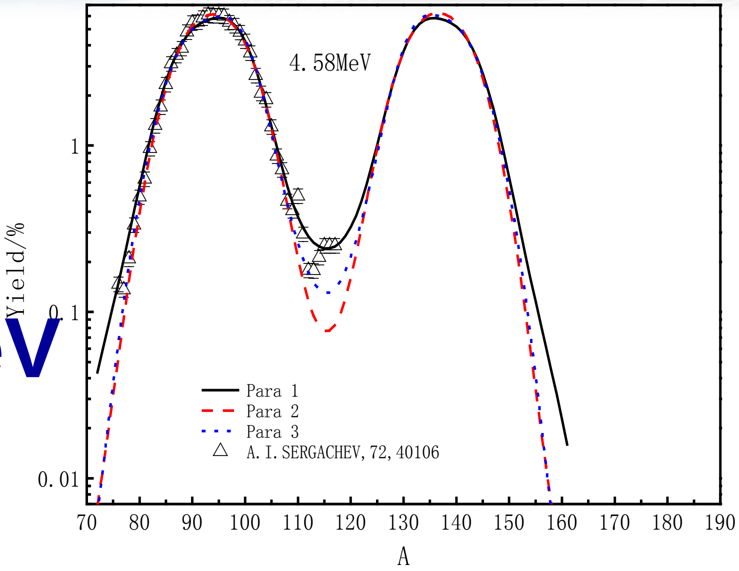


3.15MeV



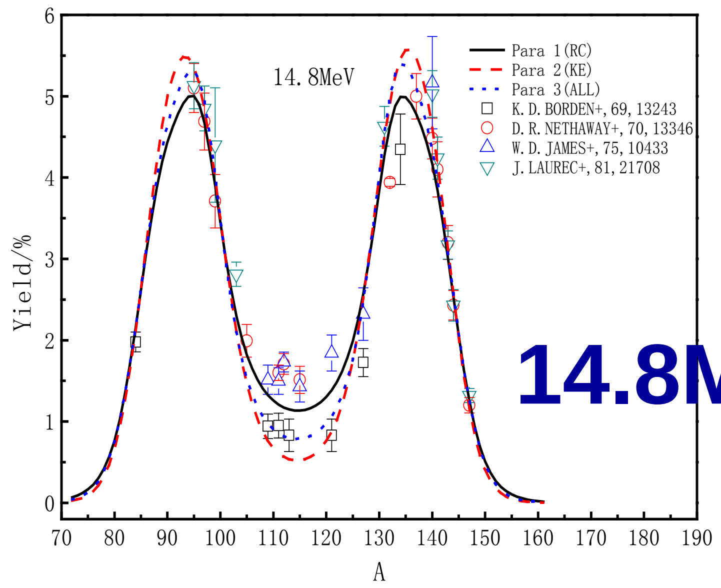
4.58MeV
Para 1
Para 2
Para 3
A. I. SERGACHEV, 72, 40106
Yield/%
A

4.58MeV

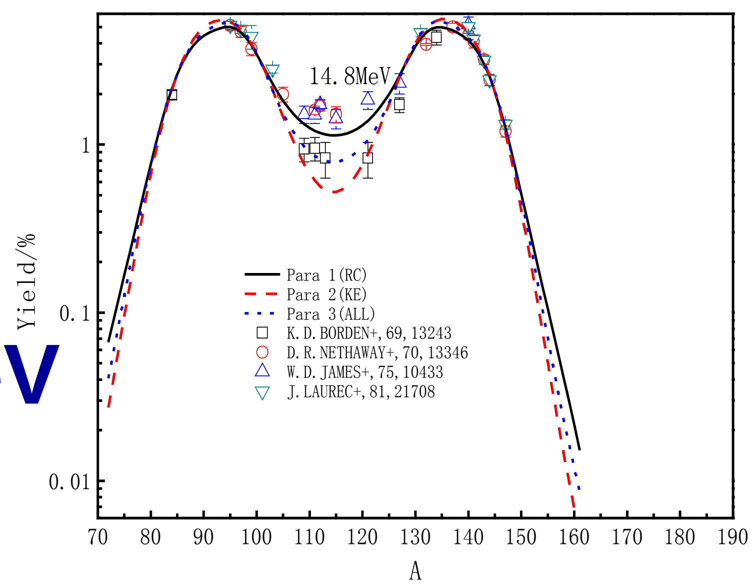


4.58MeV
Para 1
Para 2
Para 3
A. I. SERGACHEV, 72, 40106
Yield/%
A

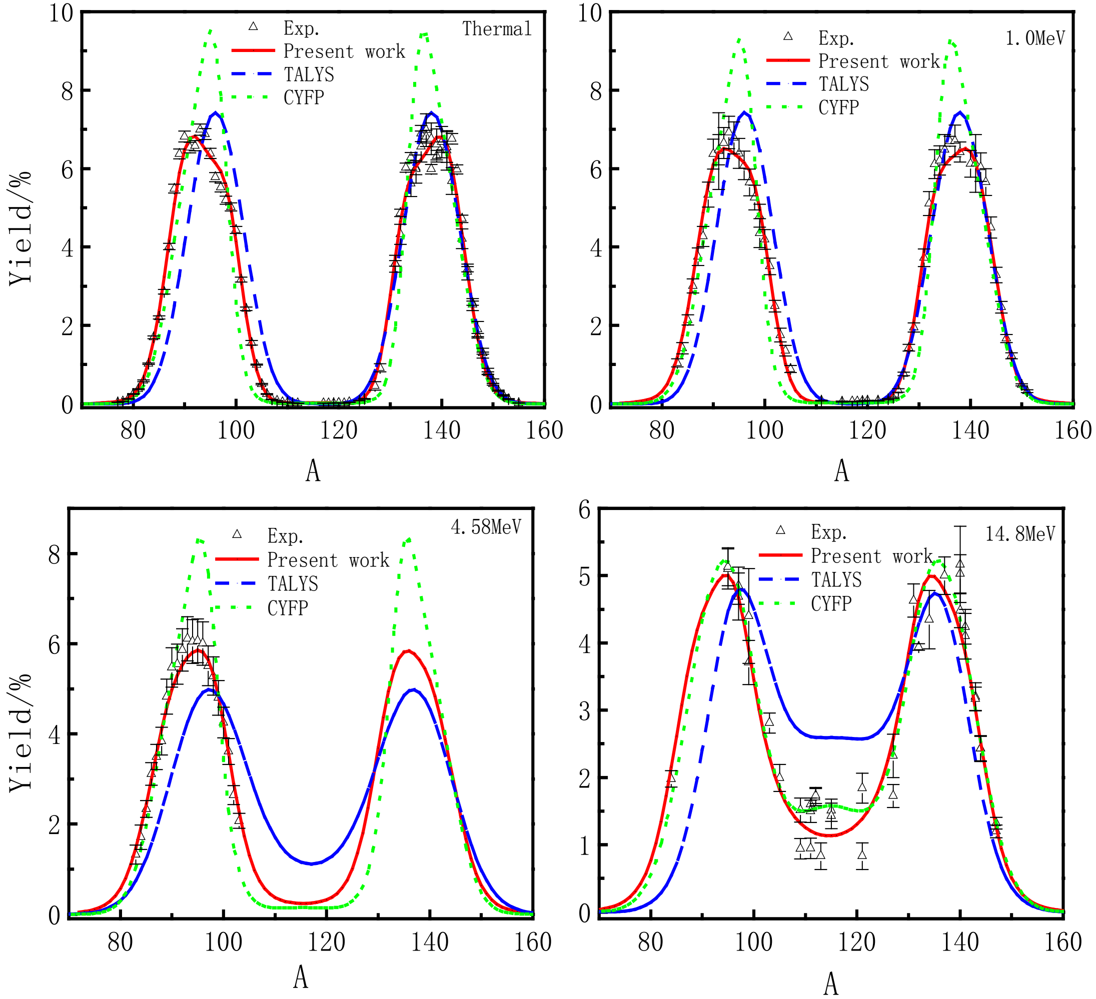
14MeV exists discrepancy between two sets of measured data, parameters set 3 is a compromising for the two data.



14.8MeV

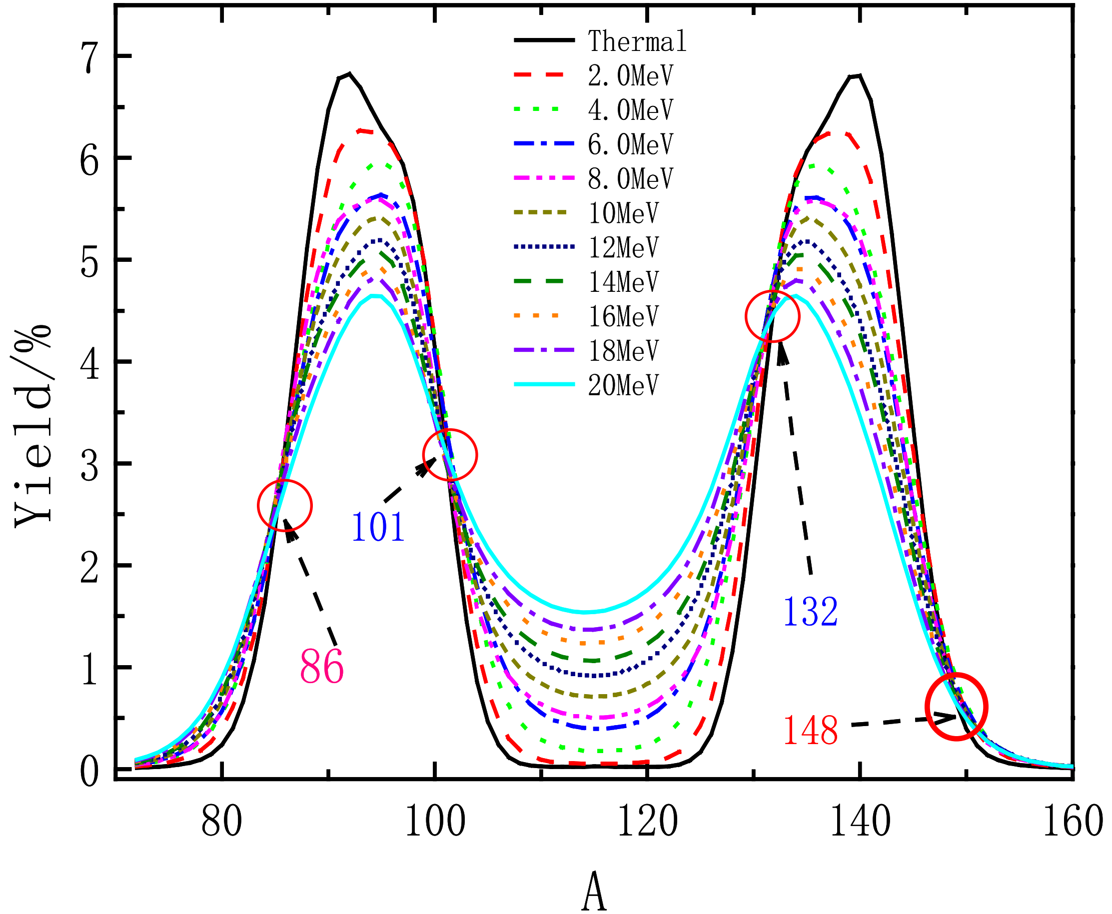


Compare to CYFP and TALYS



- *Comparisons to CYFP and TALYS were made, shows the present work has improvement.*

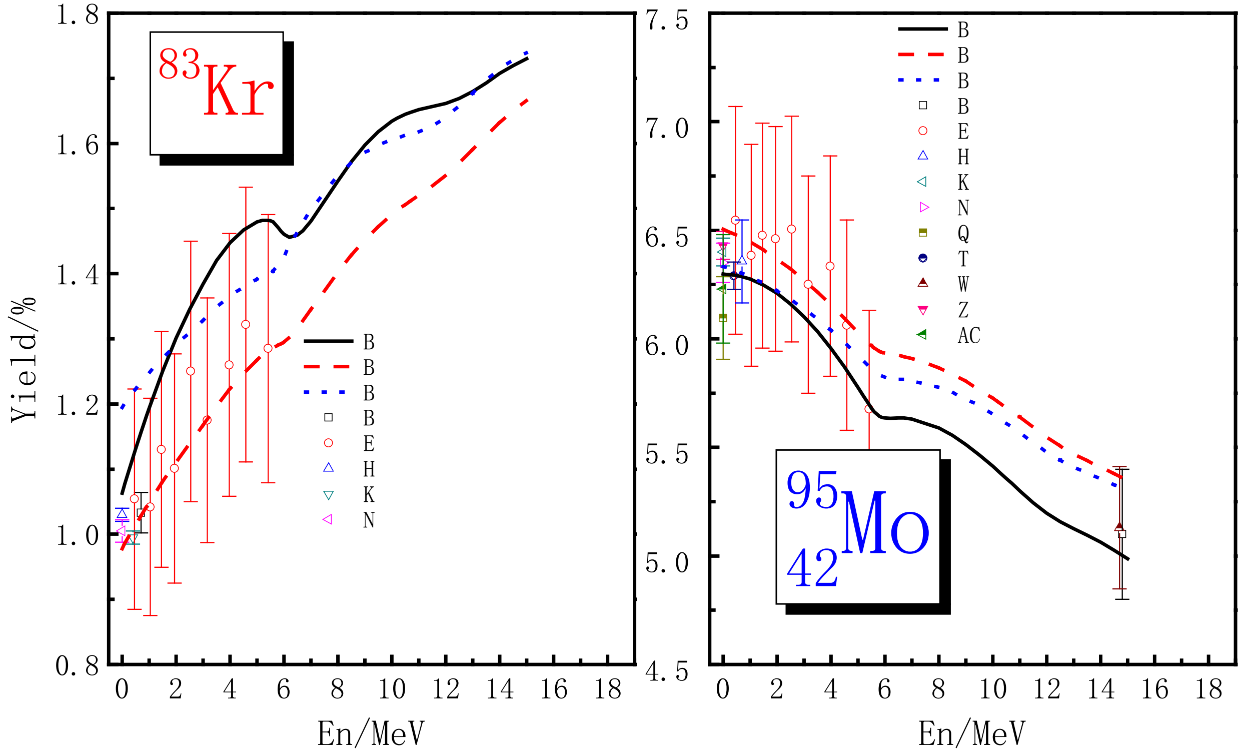
Trend turning point of yield energy relation



Below turning points, Y(E) increases with E,

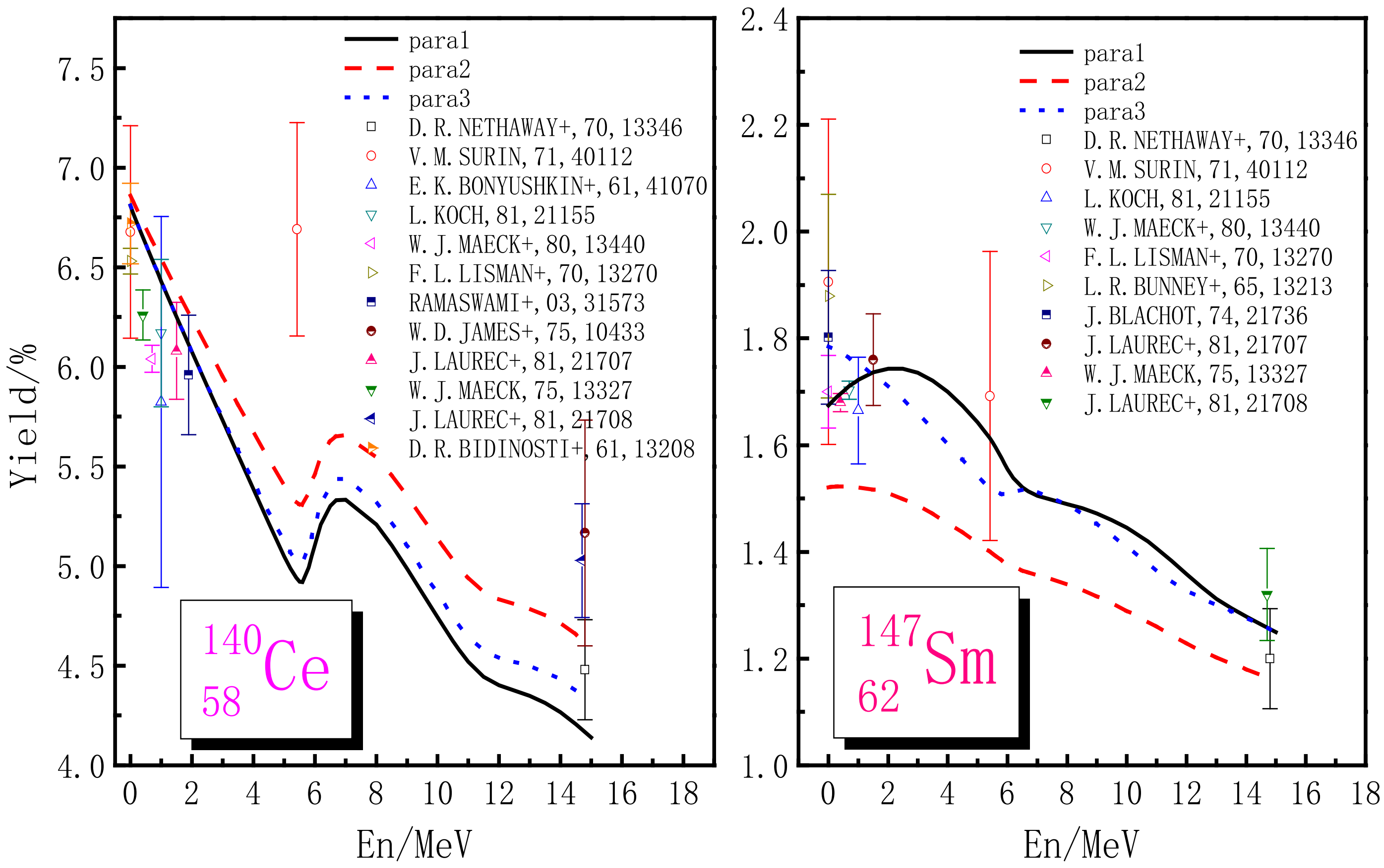
Above turning points, Y(E) decreases with E.

Yield Energy-dependence



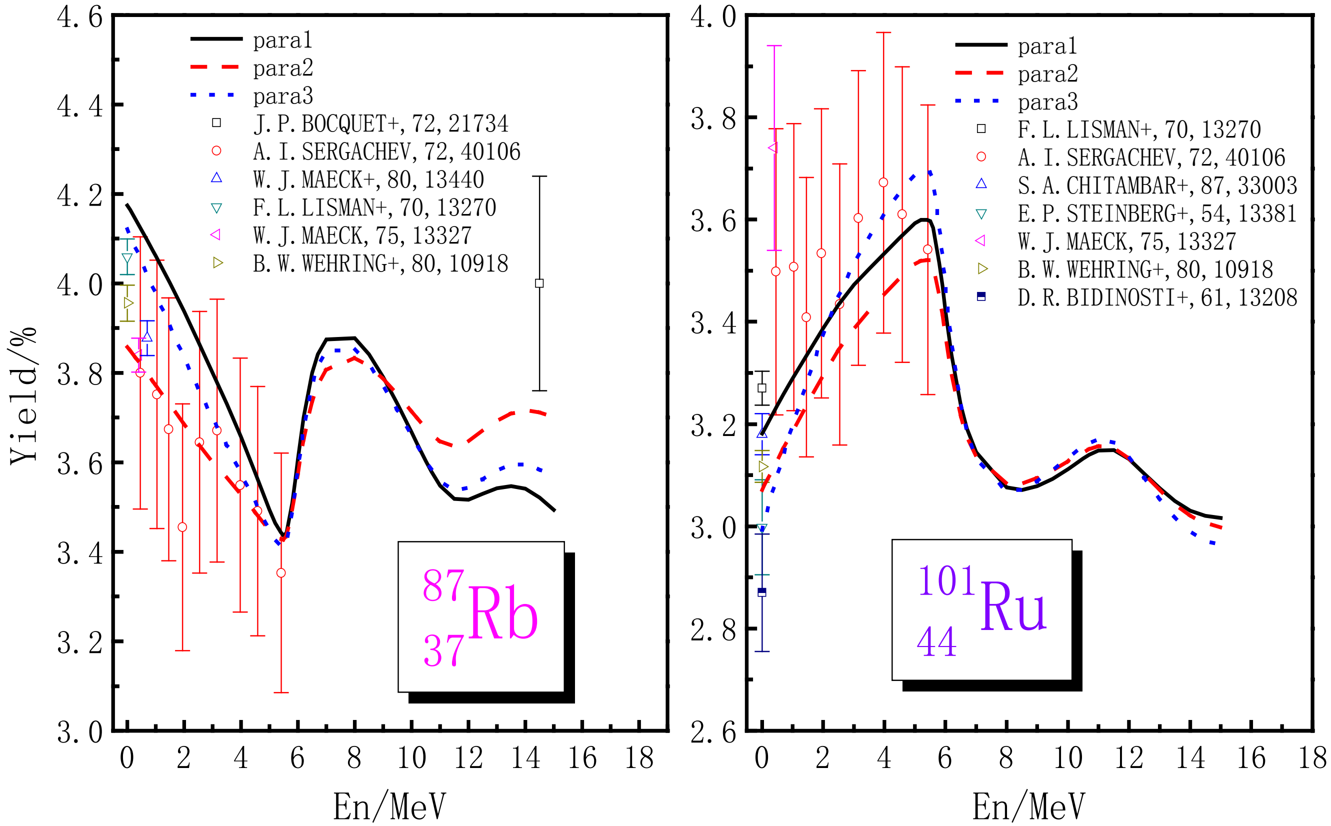
A=83 below turning points, increases with E,
A=95 above turning points, decreases with E.
There are pullback near 6 MeV, which is caused by the open of (n,nf) reaction.

Yield Energy-dependence



For A=140 and 147, above turning points, decreases with E.

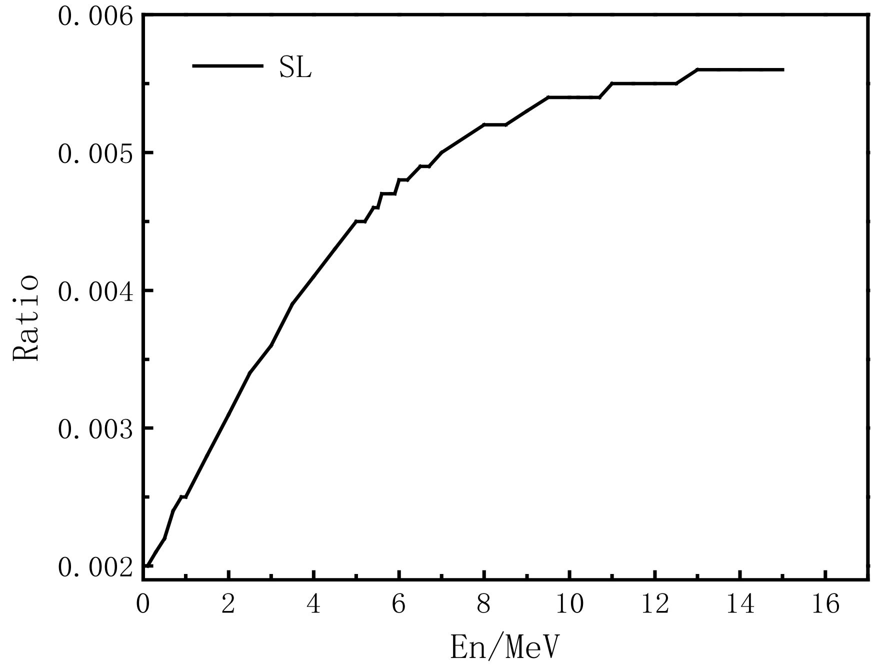
Yield Energy-dependence



For A=87 and 101, which are near turning points, the trend vibrated and the tends are not clear.

SL fission contribution

- Super long fission contributes 0.002 to 0.006 corresponding to En=T to 14 MeV.

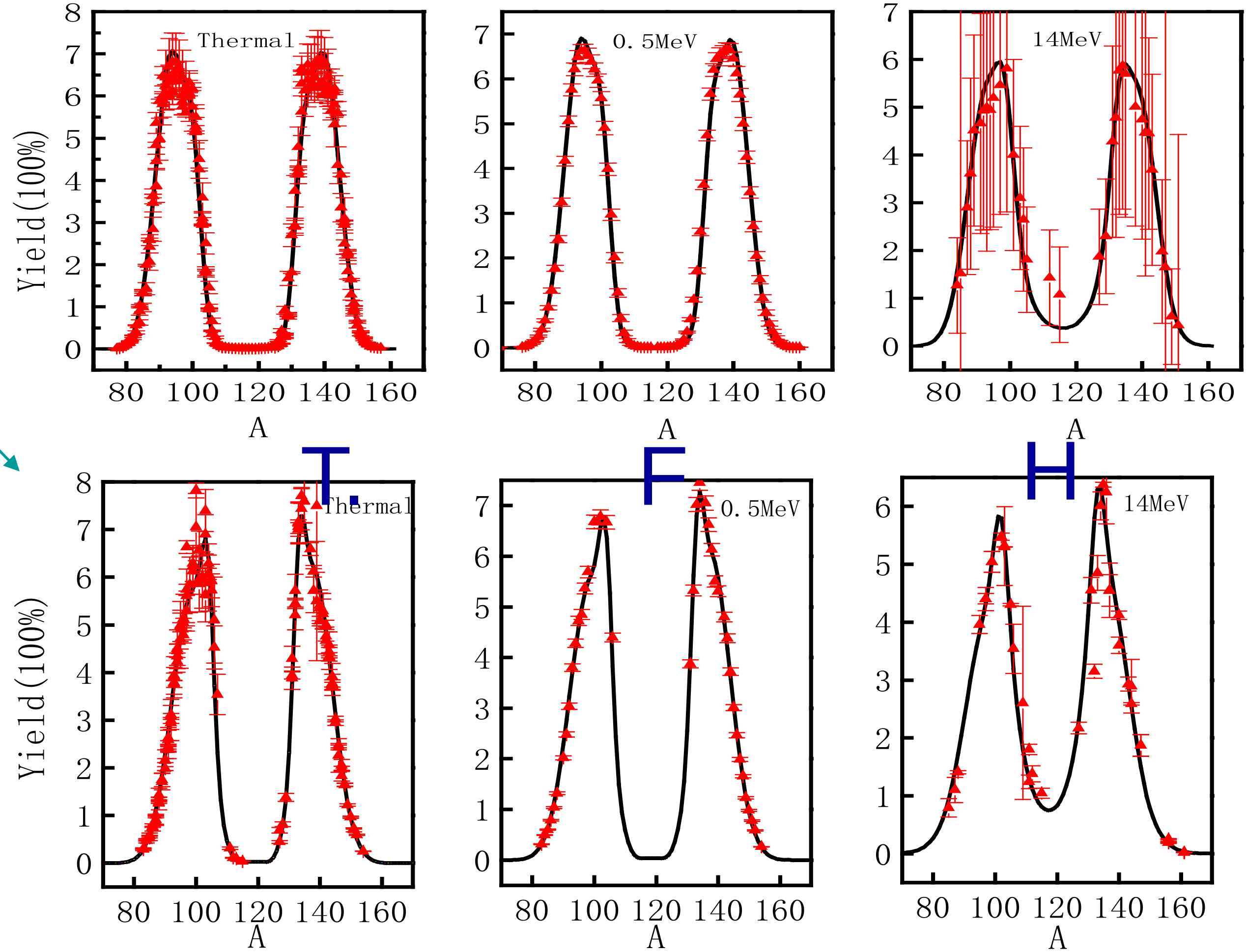


Content

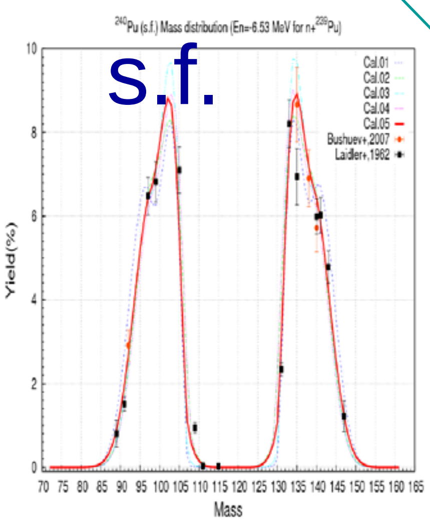
5. Results of n+^{235}U ,n+^{239}Pu fissions

n+^{235}U

n+^{239}Pu



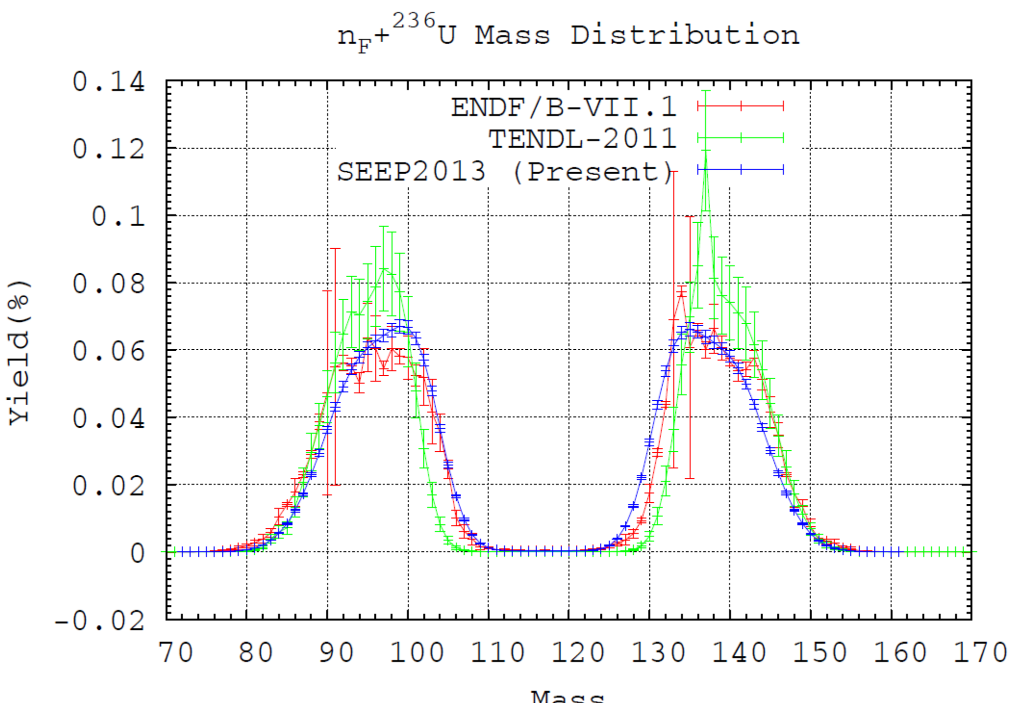
s.f.



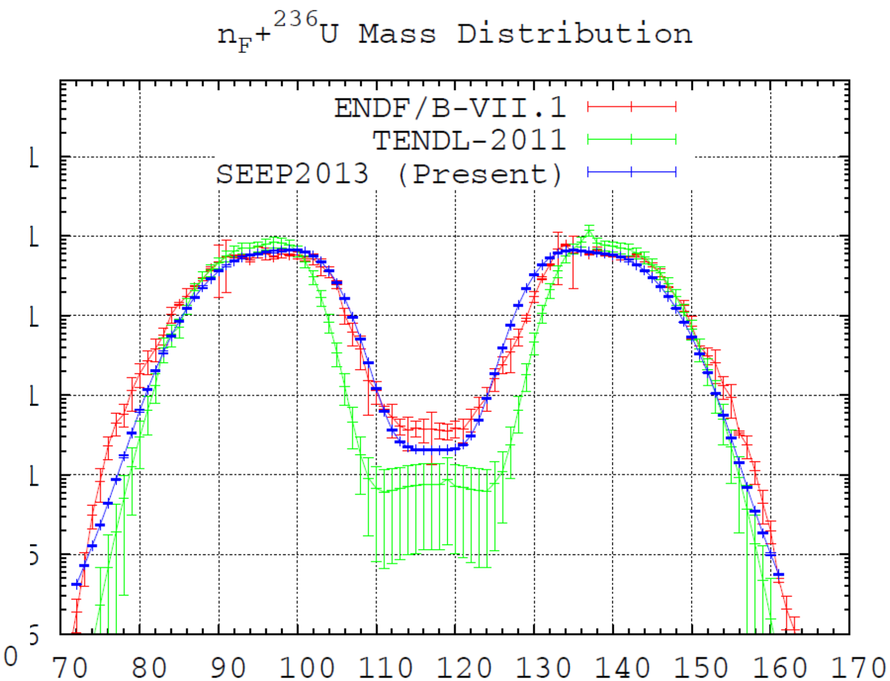
T. F. H.

6. Prediction for other fission systems

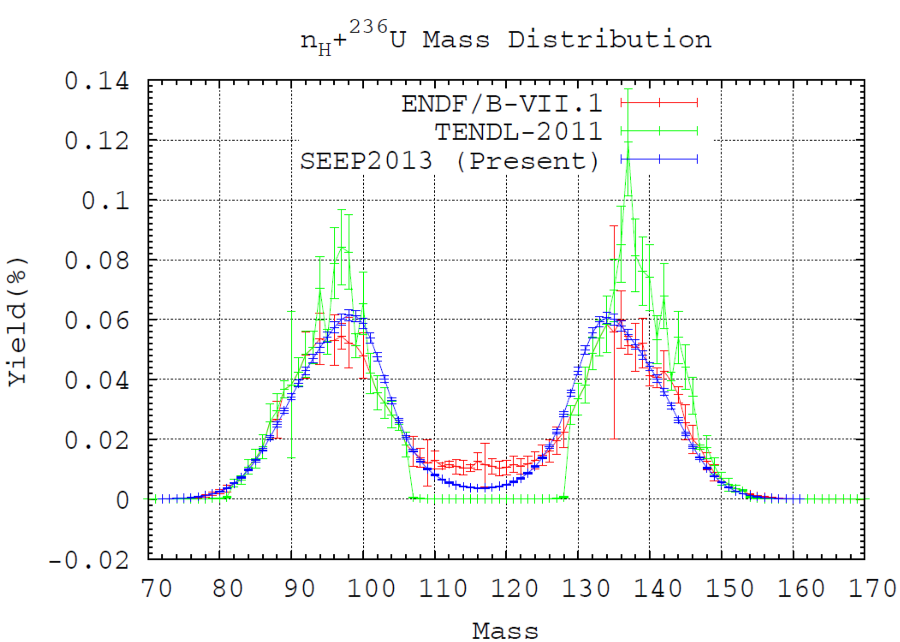
- ***Systematics parameters are estimated roughly assuming that model parameters are linear with fission compound nuclei mass Ac.***
- ***With estimated parameters, ^{236}U, ^{238}U and ^{238}Pu induced fissions were calculated, and were compared to ENDF/B-VII.1 and TENDL-2011.***



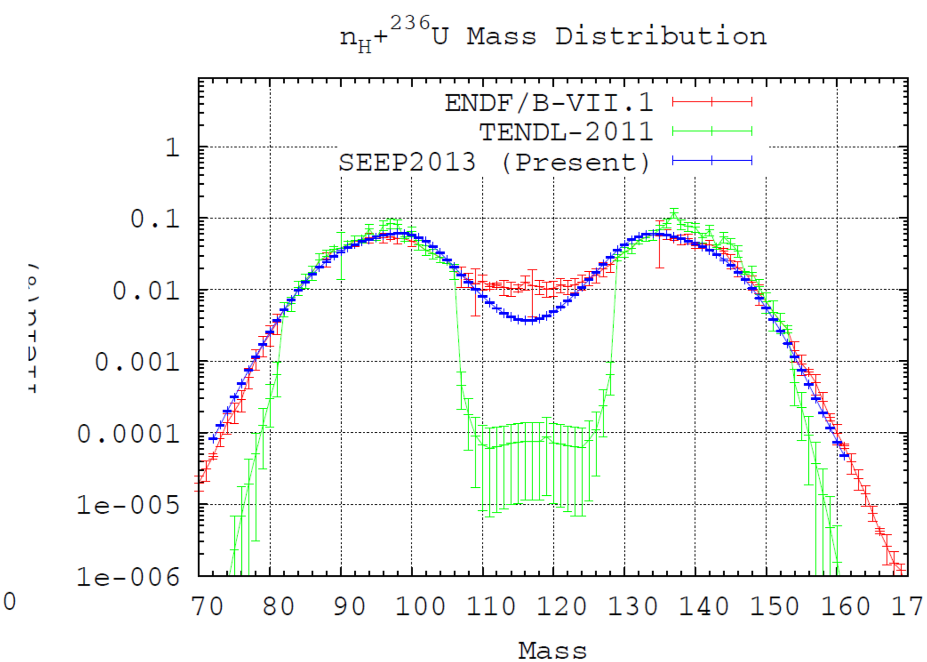
n_F+^{236}U Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
Yield(%)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
70 80 90 100 110 120 130 140 150 160 170
Mass



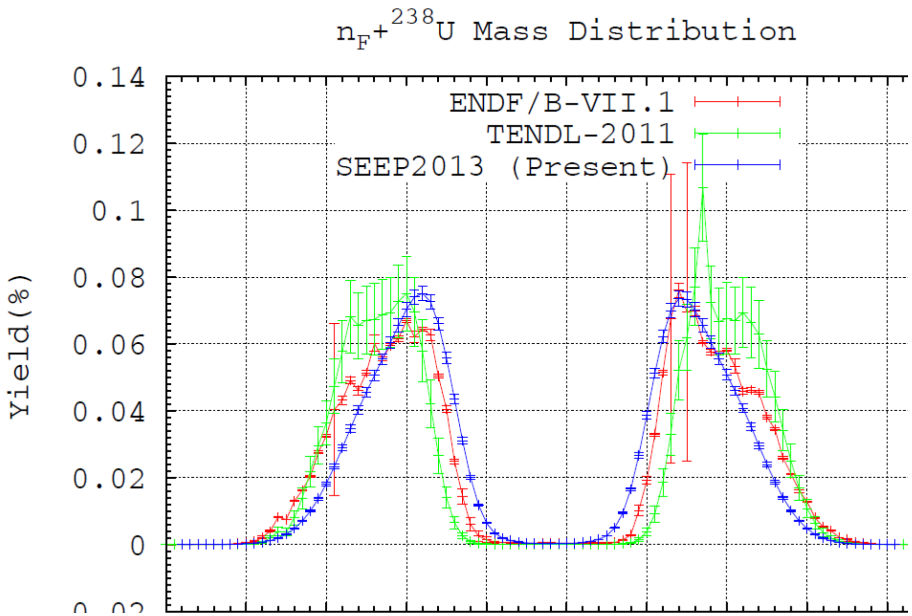
n_F+^{236}U Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
70 80 90 100 110 120 130 140 150 160 170

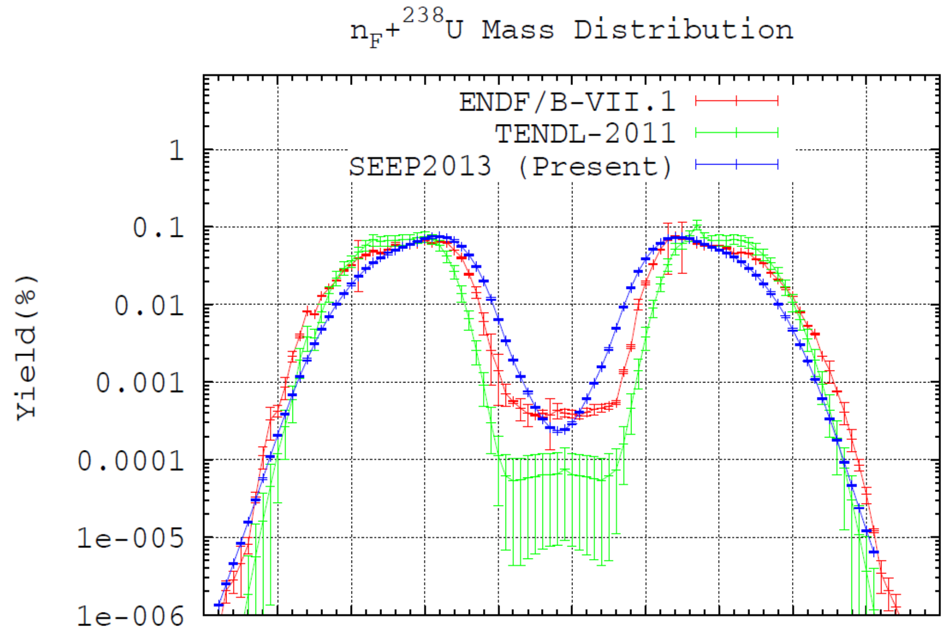


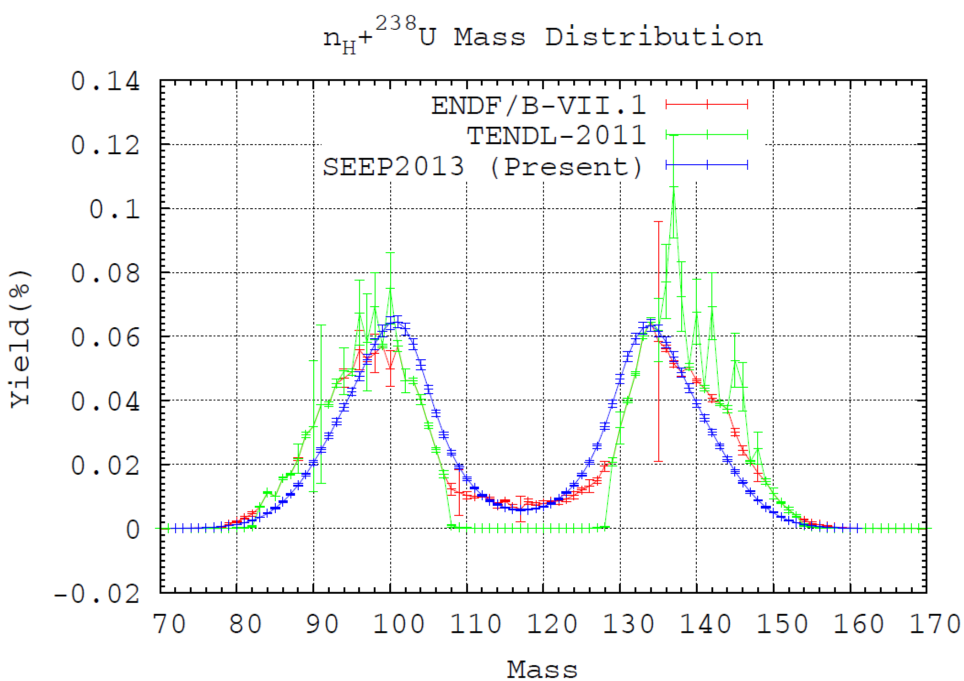
n_H+^{236}U Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
Yield(%)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
70 80 90 100 110 120 130 140 150 160 170
Mass

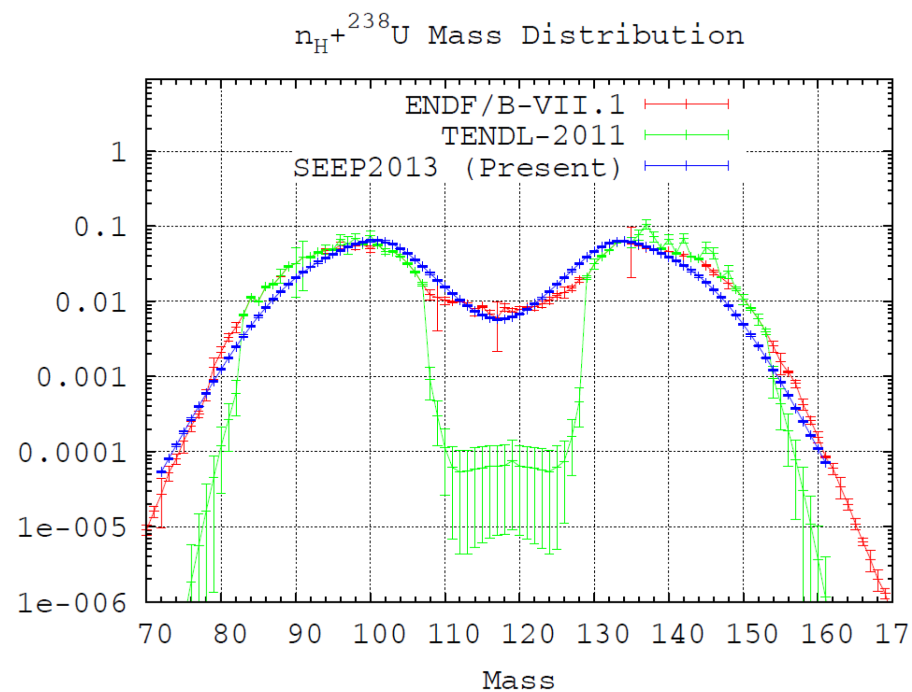


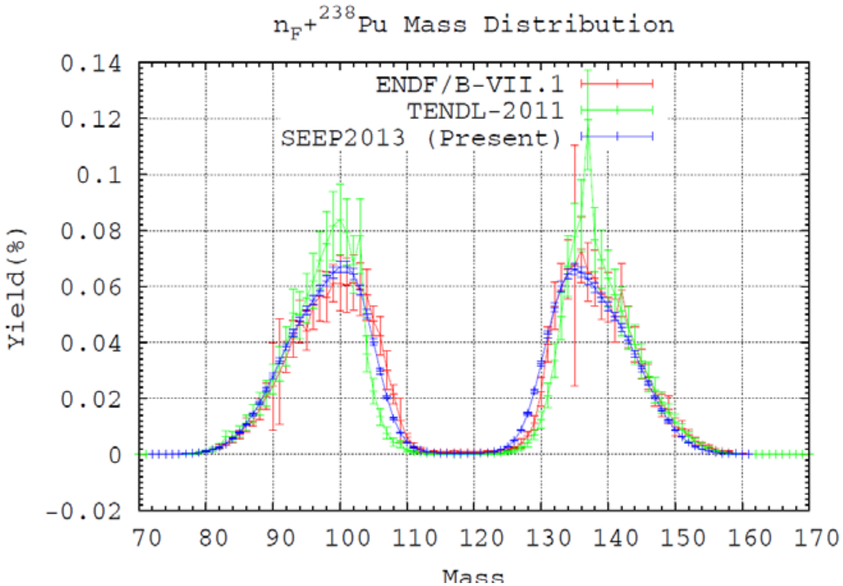
n_H+^{236}U Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
1
0.1
0.01
0.001
0.0001
1e-005
1e-006
70 80 90 100 110 120 130 140 150 160 170
Mass

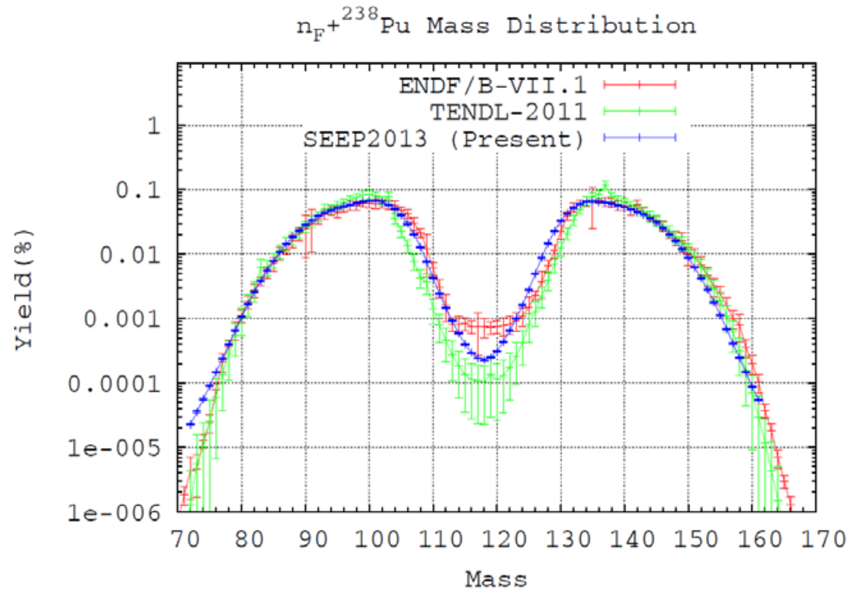

n_F+^{238}U Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
Yield(%)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02

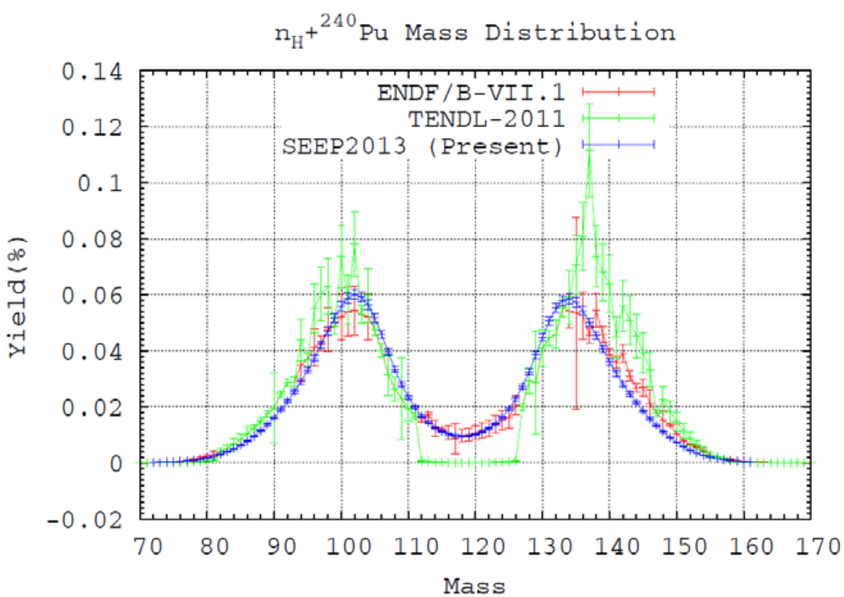

n_F+^{238}U Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
Yield(%)
1
0.1
0.01
0.001
0.0001
1e-005
1e-006

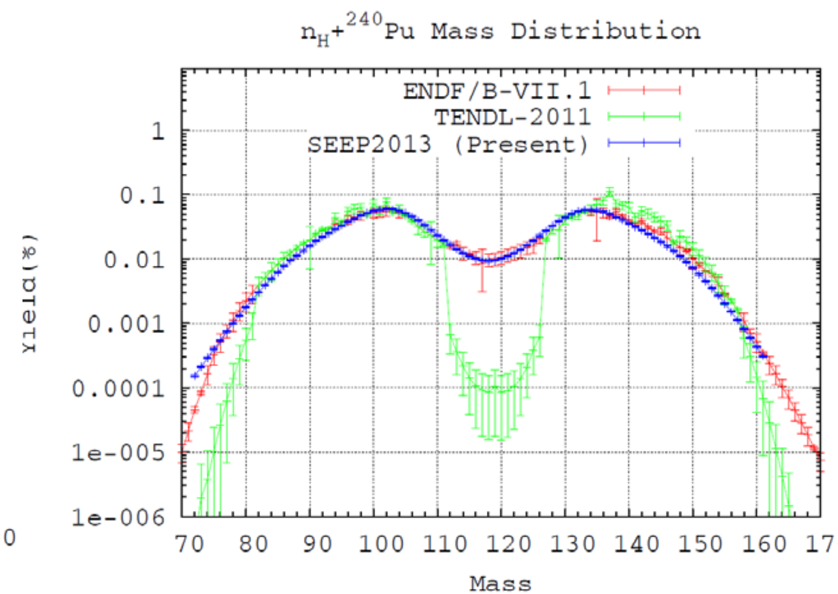

n_H+^{238}U Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
Yield(%)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
70 80 90 100 110 120 130 140 150 160 170
Mass

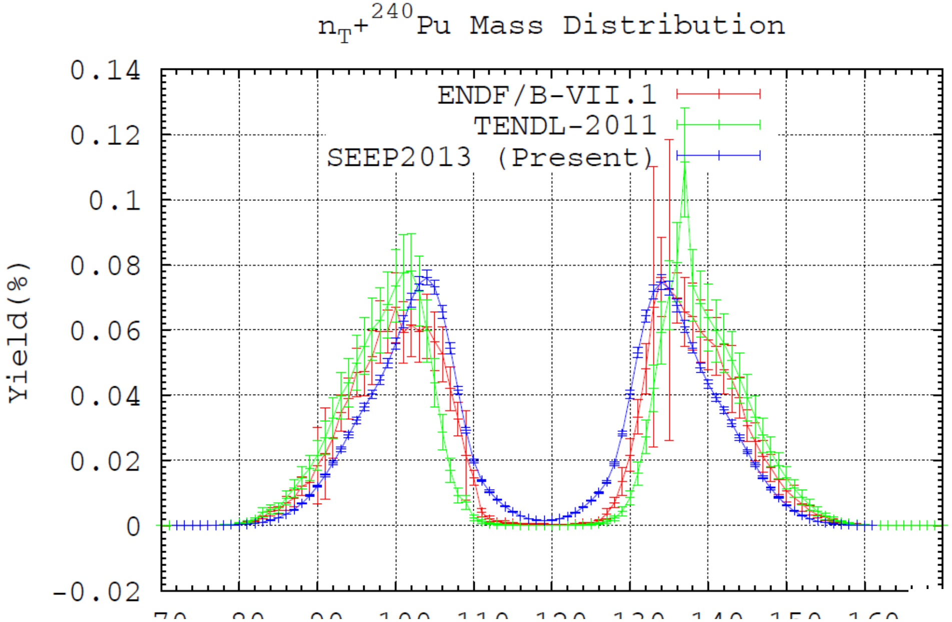

n_H+^{238}U Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
1
0.1
0.01
0.001
0.0001
1e-005
1e-006
70 80 90 100 110 120 130 140 150 160 170
Mass


$n_F+^{238}Pu$ Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
Yield(%)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
70 80 90 100 110 120 130 140 150 160 170
Mass

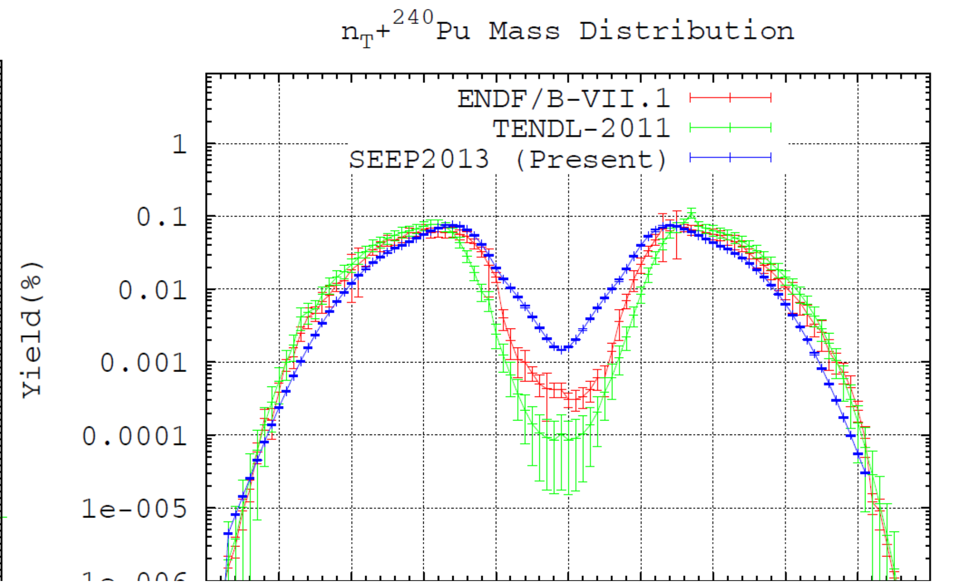

$n_F+^{238}Pu$ Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
Yield(%)
1
0.1
0.01
0.001
0.0001
1e-005
1e-006
70 80 90 100 110 120 130 140 150 160 170
Mass


$n_H+^{240}Pu$ Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
Yield(%)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
70 80 90 100 110 120 130 140 150 160 170
Mass

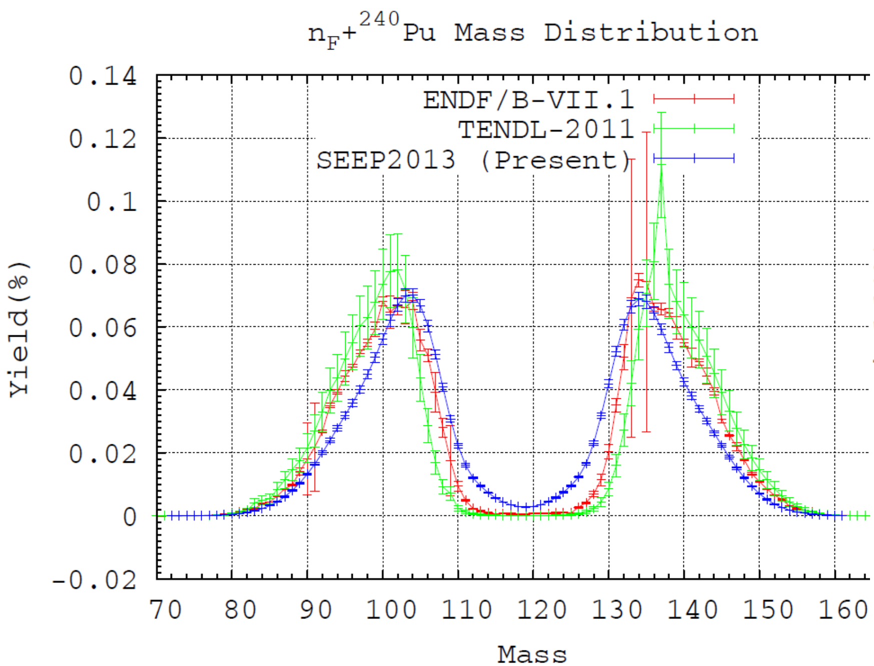

$n_H+^{240}Pu$ Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
Yield(%)
1
0.1
0.01
0.001
0.0001
1e-005
1e-006
70 80 90 100 110 120 130 140 150 160 170
Mass



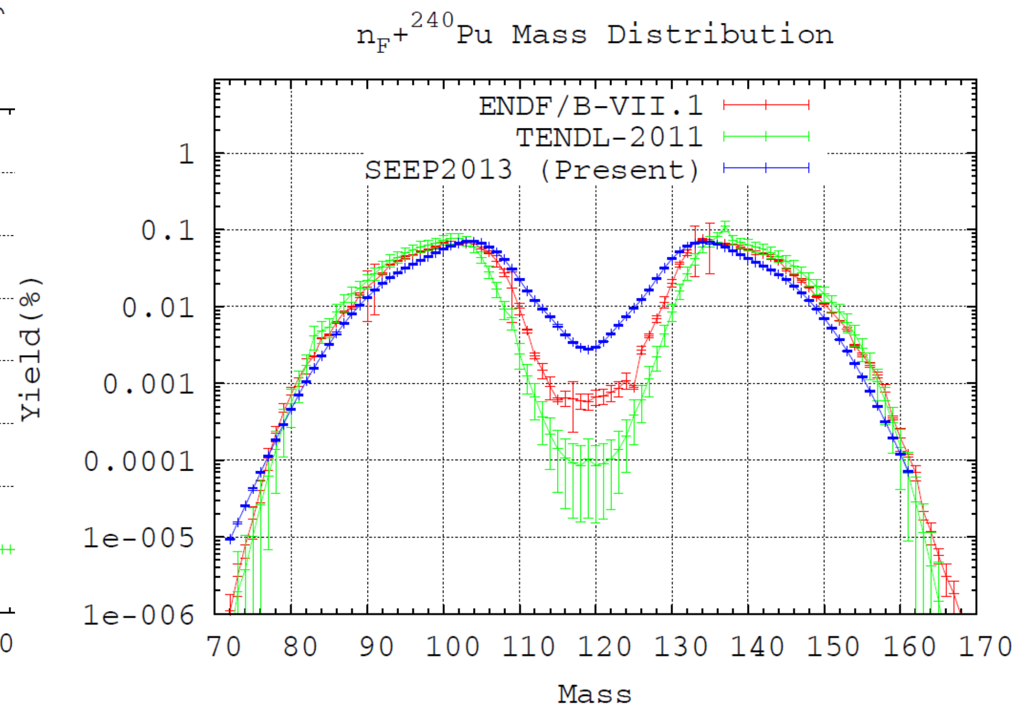
n_T+^{240}Pu Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
Yield(%)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02



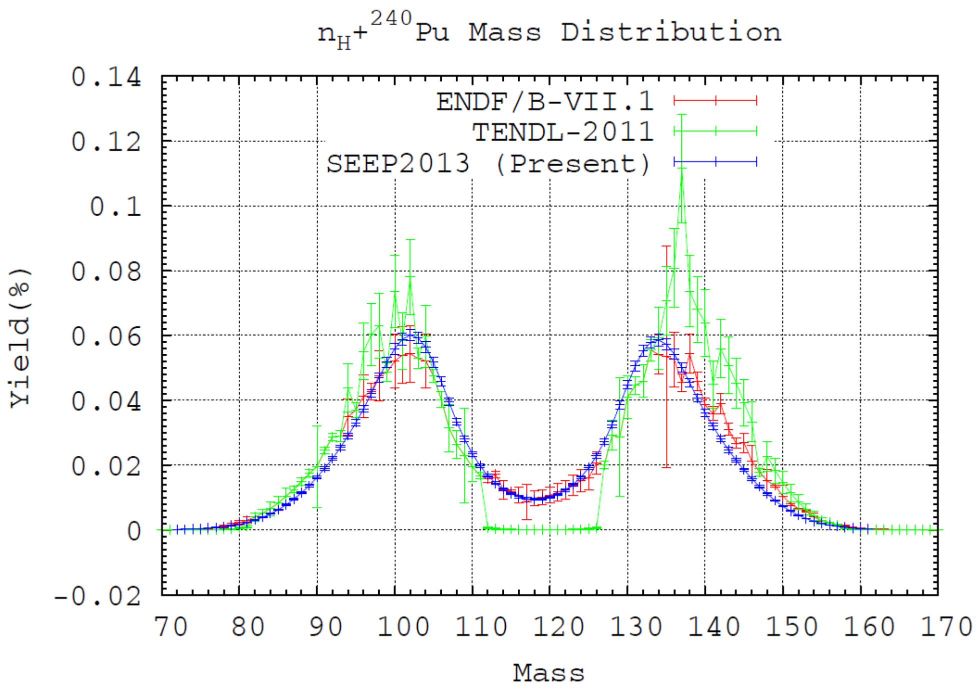
n_T+^{240}Pu Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
Yield(%)
1
0.1
0.01
0.001
0.0001
1e-005

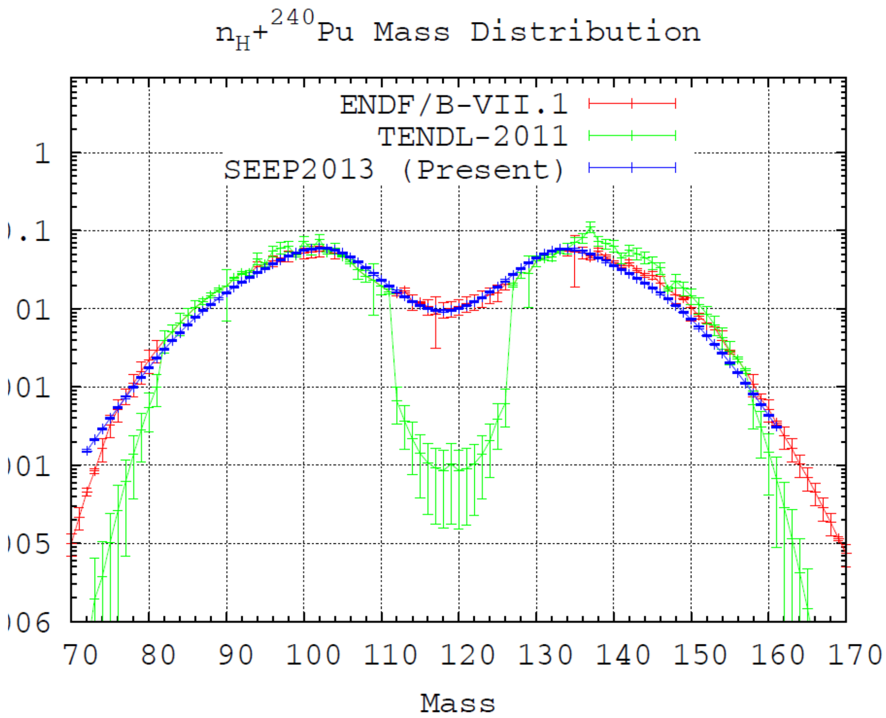


n_F+^{240}Pu Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
Yield(%)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
70
80
90
100
110
120
130
140
150
160
Mass



n_F+^{240}Pu Mass Distribution
ENDF/B-VII.1
TENDL-2011
SEEP2013 (Present)
Yield(%)
1
0.1
0.01
0.001
0.0001
1e-005
1e-006
70
80
90
100
110
120
130
140
150
160
170
Mass





These are very preliminary, but showed good future for this model.

5. Remarks

- ***A semi-empirical model codes (SEEP) was created to study the mass distribution over 0-20MeV. The model was based upon M ulti Mode Random Neck Rupture, with 11 simplified parameters, which were determined by fitting to measured data.***

- ***This empirical model could reproduce the mass distribution, o ver 0-20 MeV for ^{233}U, ^{235}U and ^{239}Pu neutron induced and fissio n successfully.***

- ***The model gives the turning points, to tell the yield increase or decrease.***

- ***Rough predictions were made for ^{236}U, ^{238}U and ^{238}Pu neutron in duced fissions, showed good promising to further study.***