Influence of fission fragment distributions on prompt emission results of the Point-by-Point model

The exercise is done for:
the fissioning systems: $^{235}U(n_{th},f)$, $^{239}Pu(n_{th},f)$ and $^{252}Cf(SF)$
using the FF distributions: of IRMM and provided by the GEF code and P.Talou (only for $^{252}Cf(SF)$)

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PbP calculations:

- at each A (covering the A range of FF distributions) three Z are taken as the nearest integer values above and below the most probable charge Zp
- Zp is considered as Zucd corrected with the charge polarization ΔZ. ΔZ(A) and RMS(A) are taken from A.C.Wahl (see Appendix 1)
- compound nucleus cross section of the inverse process of neutron evaporation from fully accelerated FF $\sigma_c(\varepsilon)$ from optical model calculations (SCAT2 code) with the Becchetti-Greenlees potential.
- level density parameters: super-fluid model with shell corrections from the database of Moller and Nix with parameterizations of the dumping and asymptotic level dens. parameter proposed by Ignatiuk
- TXE partition from modeling at scission (as described in [1, 2])

FF distributions:

- experimental data for $^{235}U(n_{th},f)$, $^{239}Pu(n_{th},f)$, $^{252}Cf(SF)$ (as provided files CRP)
- Y(A,Z,TKE) of Talou for $^{252}Cf(SF)$ (file CRP)
- Y(A,Z,TKE) of the GEF code for $^{235}U(n_{th},f)$, $^{239}Pu(n_{th},f)$, $^{252}Cf(SF)$ (files CRP)

Colors in figures:

- PbP results: red and magenta (using experimental FF distributions), blue (GEF distributions) and green (Talou distribution for $^{252}Cf(SF)$ – full symbols.
- Experimental data: black and gray (open and full symbols)

PbP results of prompt emission using different Y(A,Z,TKE) are referring to the following prompt emission quantities:

- **average quantities as a function of A: prompt neutron multiplicity ν(A), $\nu_{pair}(A_H)$, prompt γ-ray energy Eγ(A), $E\gamma_{pair}(A_H)$ and prompt γ-ray multiplicity Nγ(A)**
- **average quantities as a function of TKE: prompt neutron multiplicity <ν>(TKE), prompt γ-ray energy <Eγ>(TKE)**
- **prompt neutron multiplicity distribution P(ν)**
- **total average PFNS**

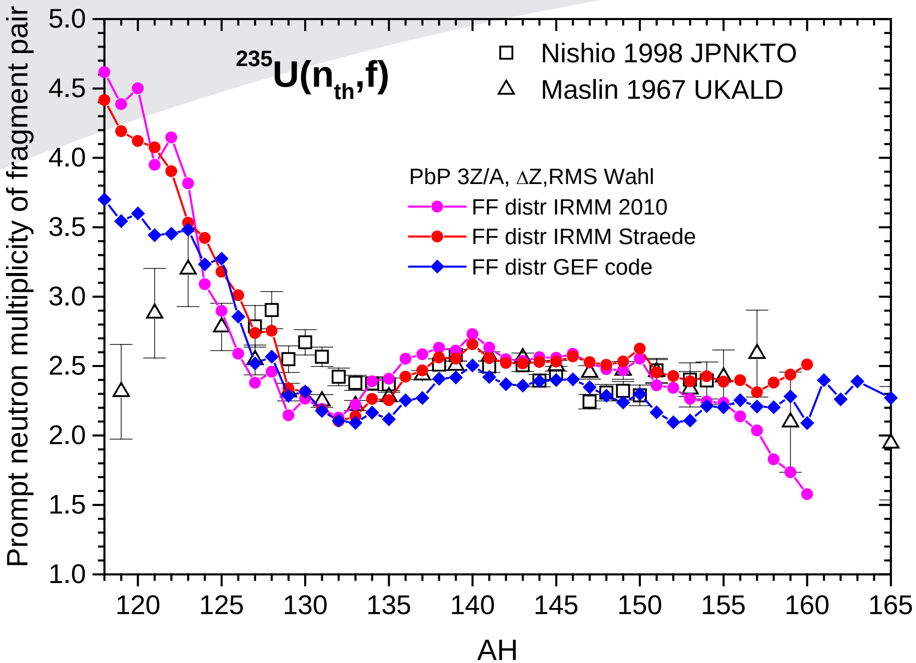
Appendices:

- plots of ΔZ and RMS (Wahl) used in calculations

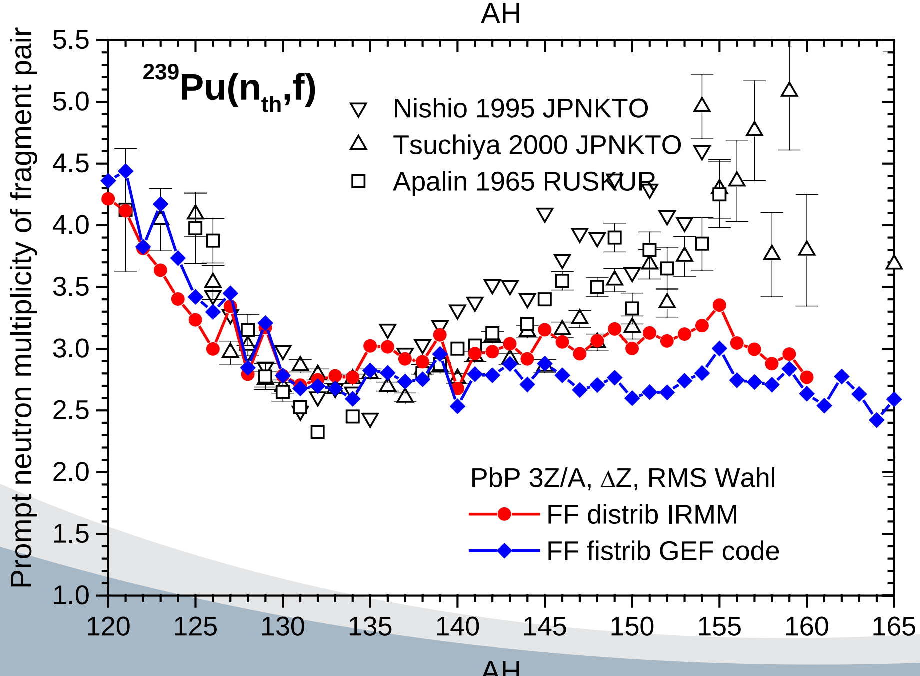
- plots of single FF distributions (projections) and even-odd effect

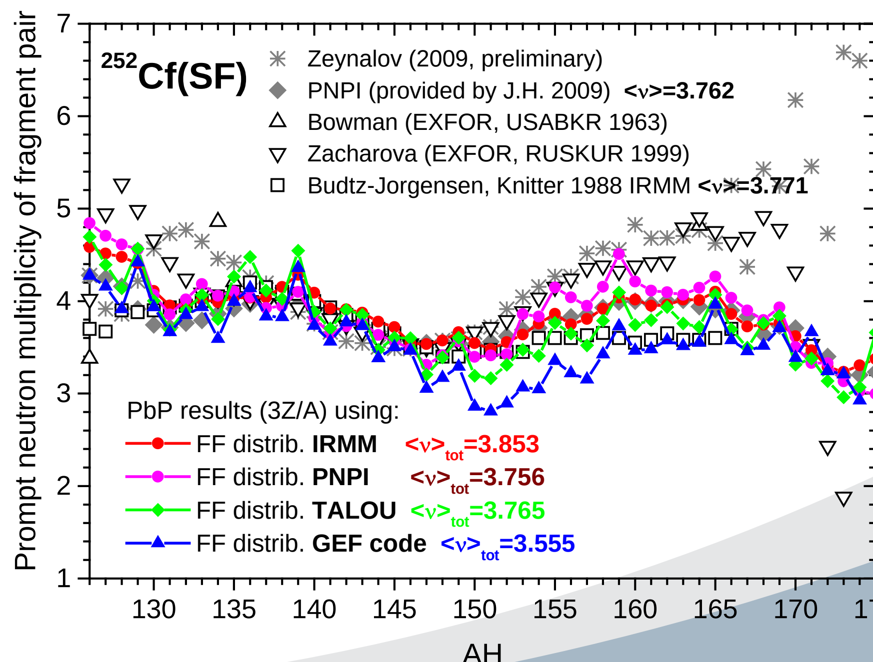
Great part of PbP results for ^{252}Cf(SF), ^{239}Pu(n_{th},f) and ^{235}U(n_{th},f) obtained with the experimental FF distributions were reported, see for instance: ν(A) in [1, 3] and references therein, Eγ(A) and Nγ(A) in Refs.[4 - 6], <ν>(TKE) in Ref.[2], <Eγ>(TKE) in Ref.[6], P(ν) in Ref.[7], PFNS during the CRP meetings.

$\nu_{pair}(A_H)$



PbP results with the FF distributions of GEF underestimate the experimental data and the results obtained with the experimental FF distributions and those of Talou.
This fact is due mainly to TKE(A) of GEF that are higher than the experimental data, especially in the case of ^{252}Cf(SF) (see figs. with FF single distributions in Appendix 2).





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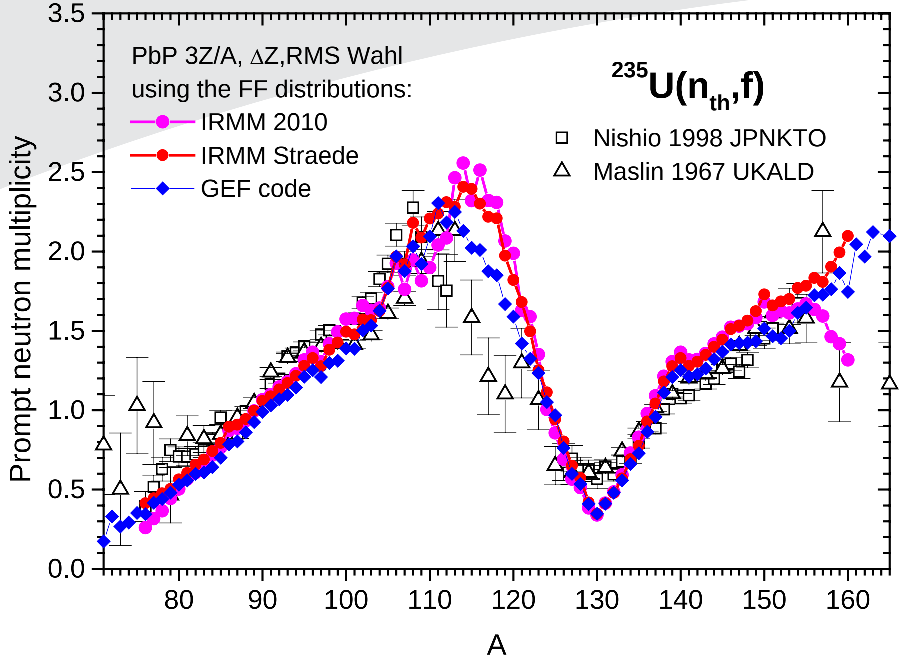
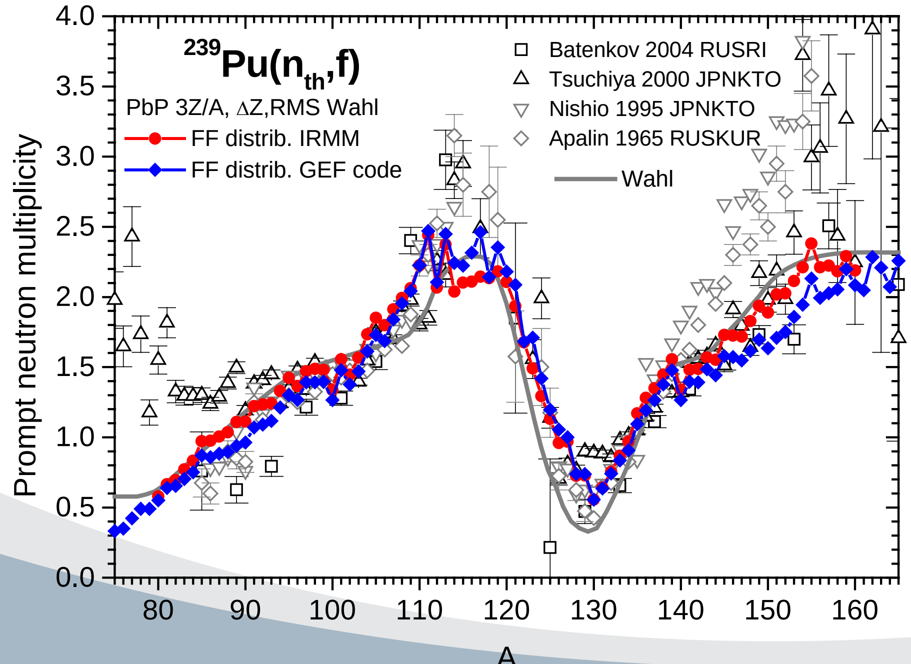
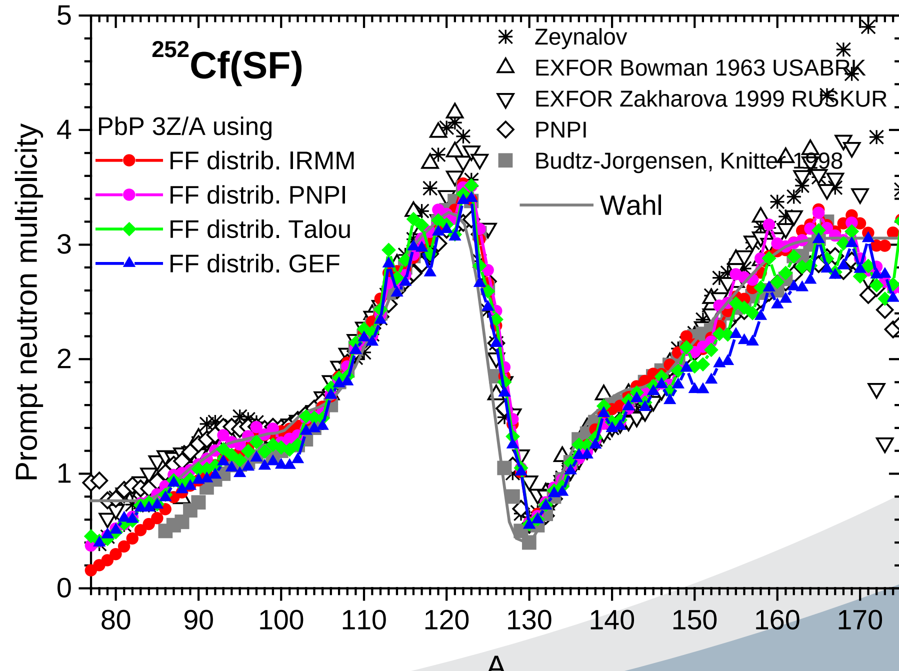
ν (A)

PbP results of ν(A) obtained with experimental FF distributions and with Y(A,Z,TKE) of Talou are in overall good agreement with exp.data.
The ν(A) results obtained with GEF distributions underestimate other results and the experimental data especially for heavy fragments.







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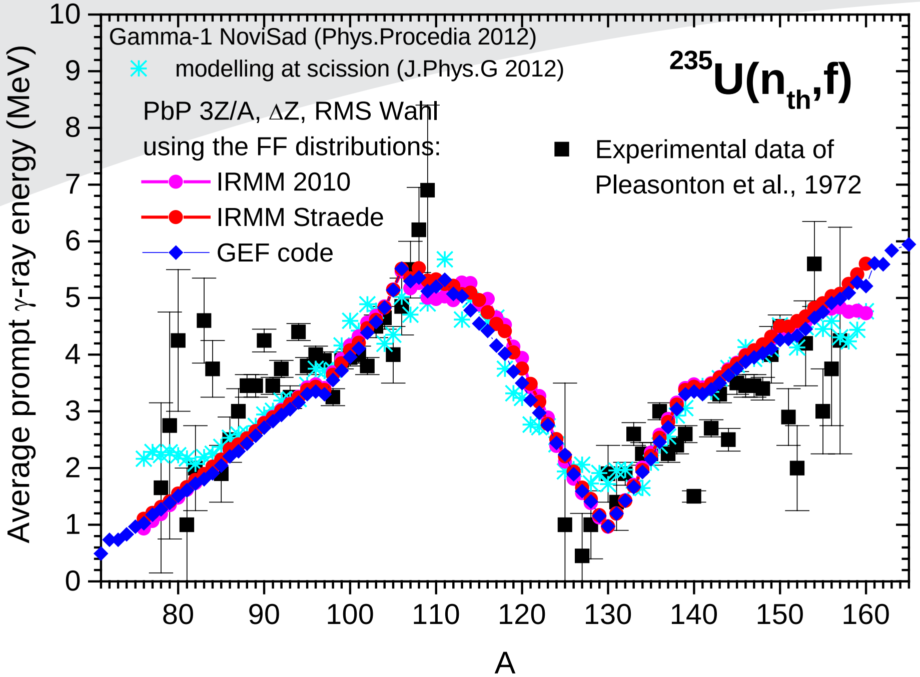
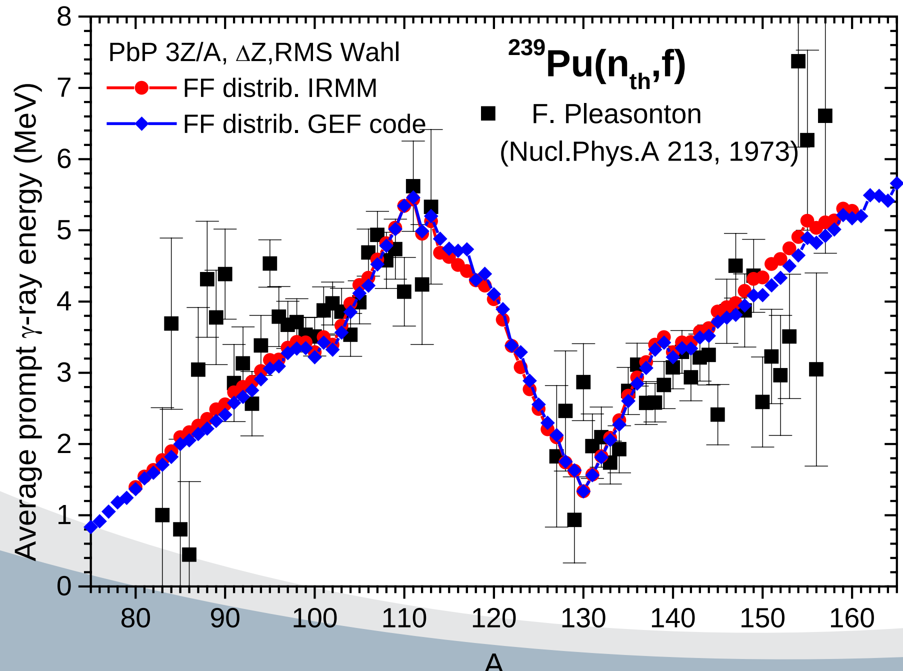
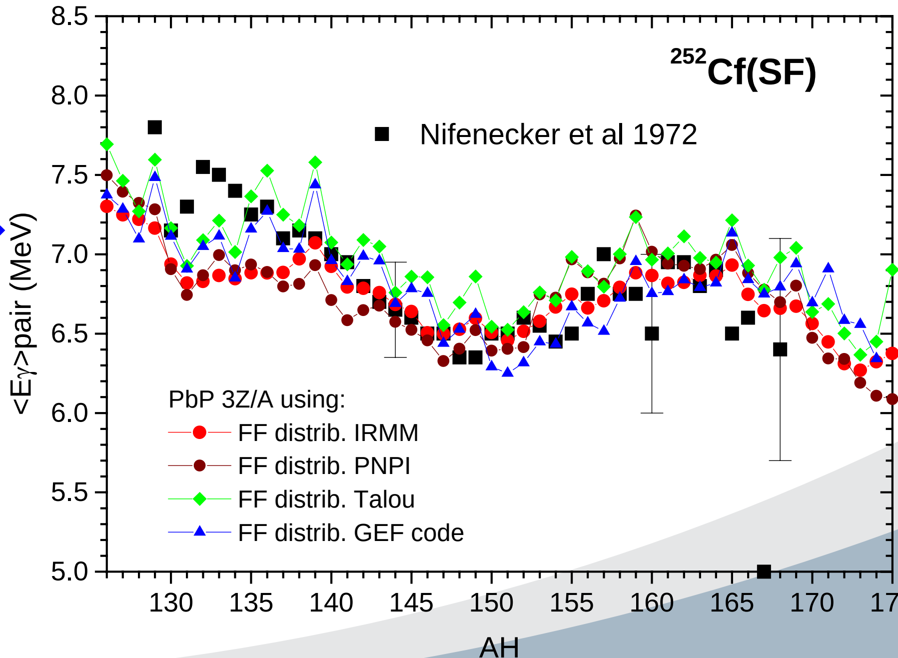
Eγ (A)



Eγ(A) results for ^{235}U(n$_{th}$,f) and ^{239}Pu(n$_{th}$,f) are close each other and describe well the experimental data of Pleasonton.

Differences between Eγ$_{pair}$(A) results obtained with experim. FF distrib. and those of Talou and GEF are visible in the case of ^{252}Cf(SF). All Eγ$_{pair}$ results are in overall agreement with the exp. data of Nifenecker.





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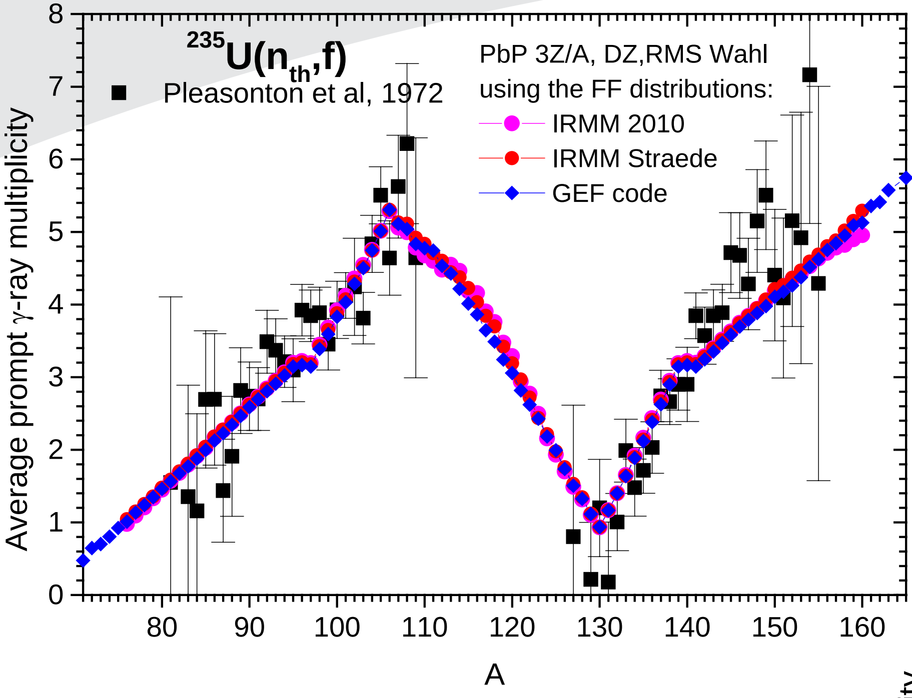
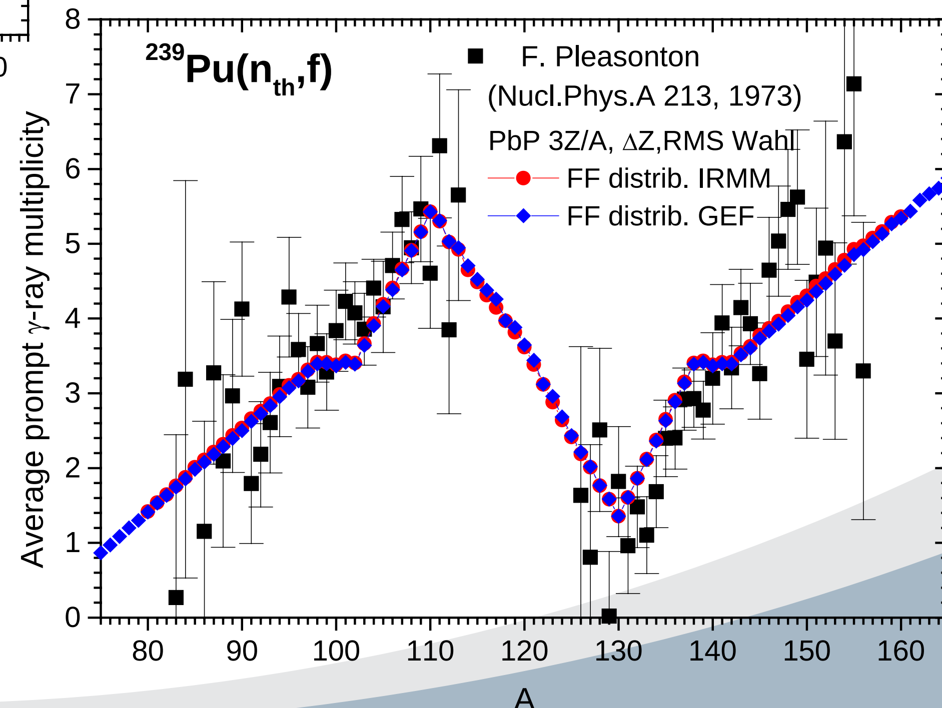
Average prompt γ-ray multiplicity Nγ (A)



The results obtained with all FF distrib. are close each other and describe well the experimental data of Pleasonton for ^{235}U(n_{th},f) and ^{239}Pu(n_{th},f)



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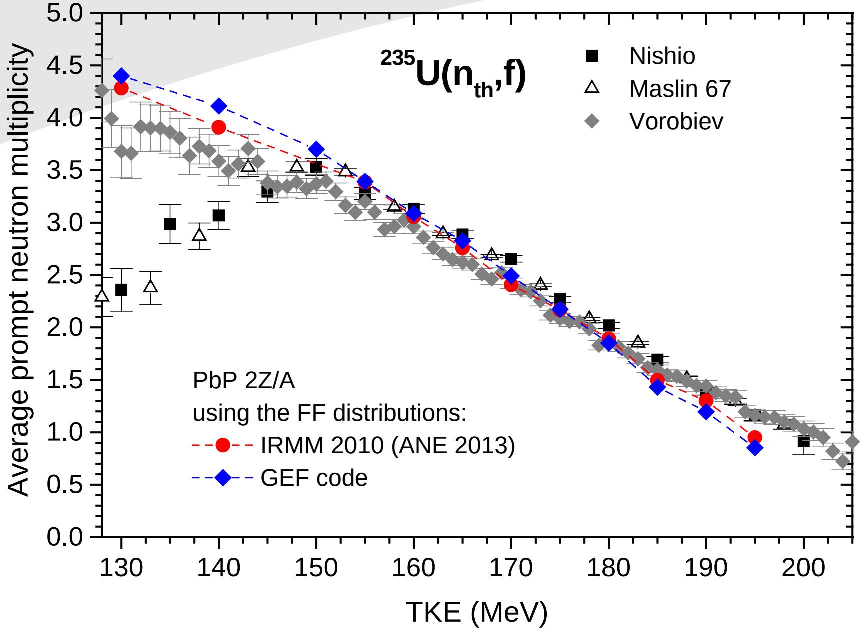
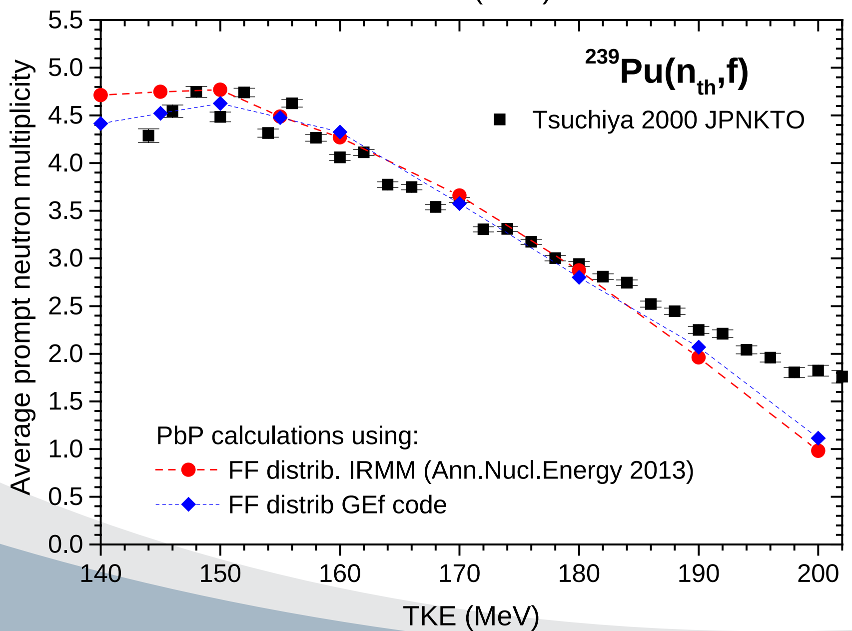
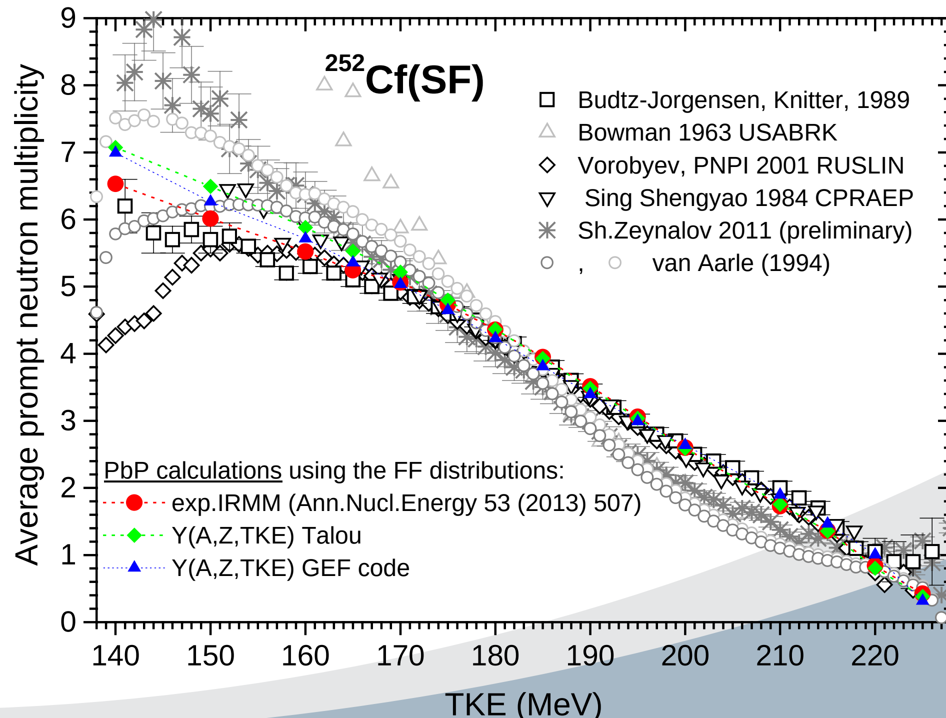
<ν> (TKE)

Very close <ν>(TKE) results are obtained with all FF distributions. Insignificant differences are visible only at low TKE.

<ν>(TKE) results of ^{252}Cf(SF) agree well with the exp. data of Budtz-Jorg., Vorobyev, Sing. The results for ^{235}U (n_{th},f) and ^{239}Pu(n_{th},f) underestimate the exp. data at high TKE values.







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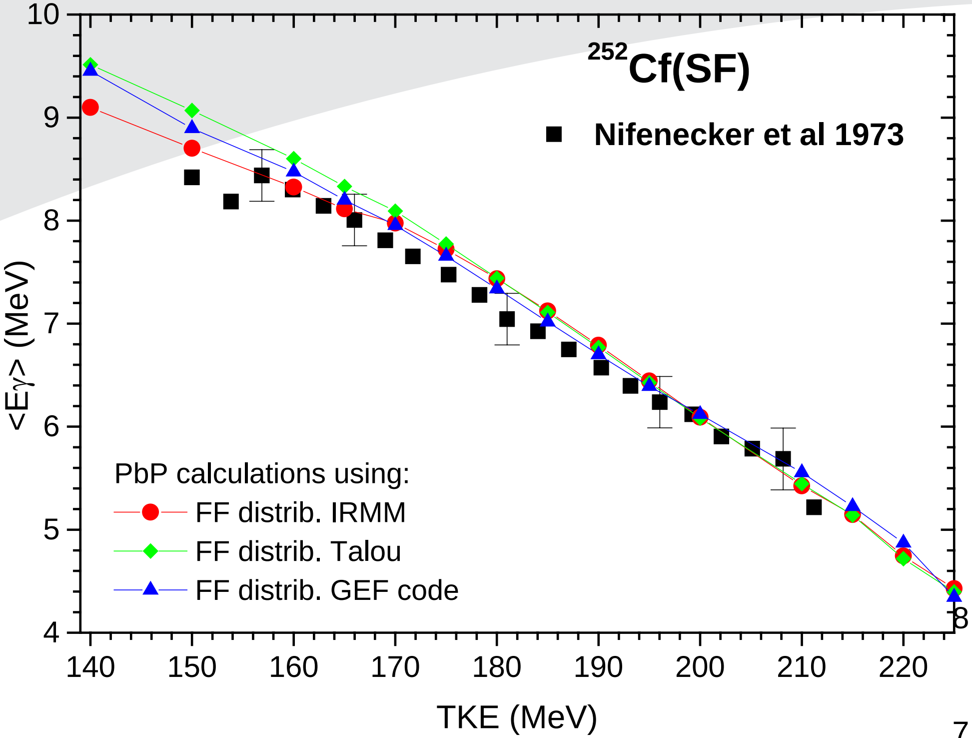
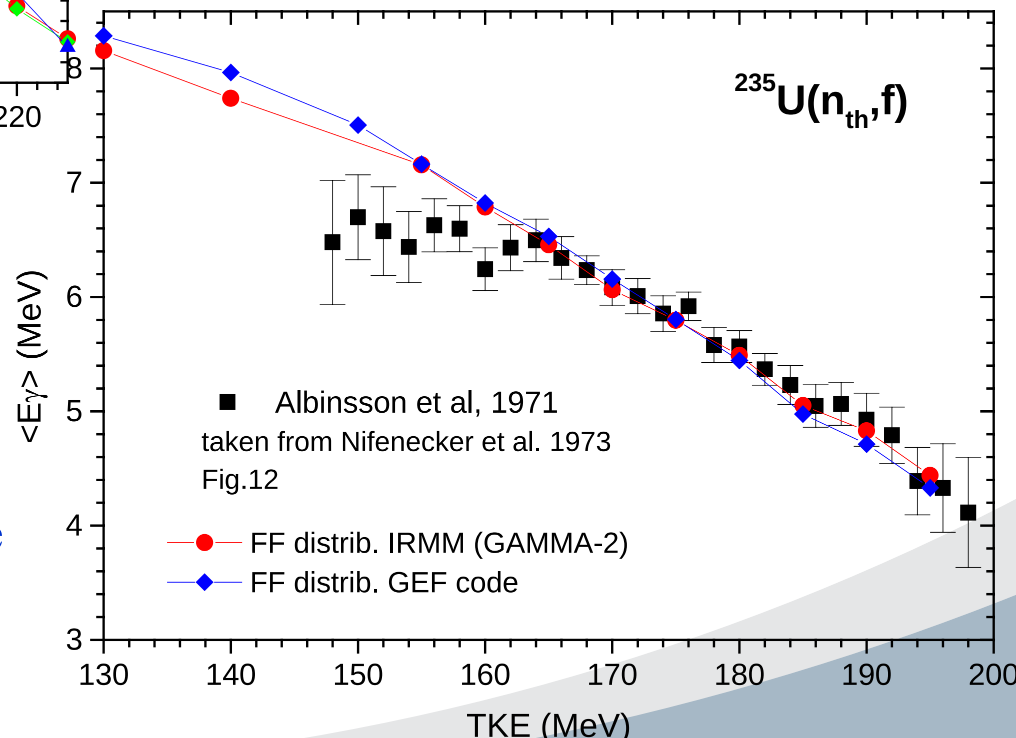
<Eγ> (TKE)



PbP results of **<Eγ>(TKE)** for **^{252}Cf(SF)** using three FF distributions are very close each other and describe well the experimental data of Nifenecker et al. ←



PbP results of **<Eγ>(TKE)** for **^{235}U(n_{th},f)** using the FF distributions of IRMM and GEF are also close each other and describe well the experimental data of Albinsson (except the low TKE region). →

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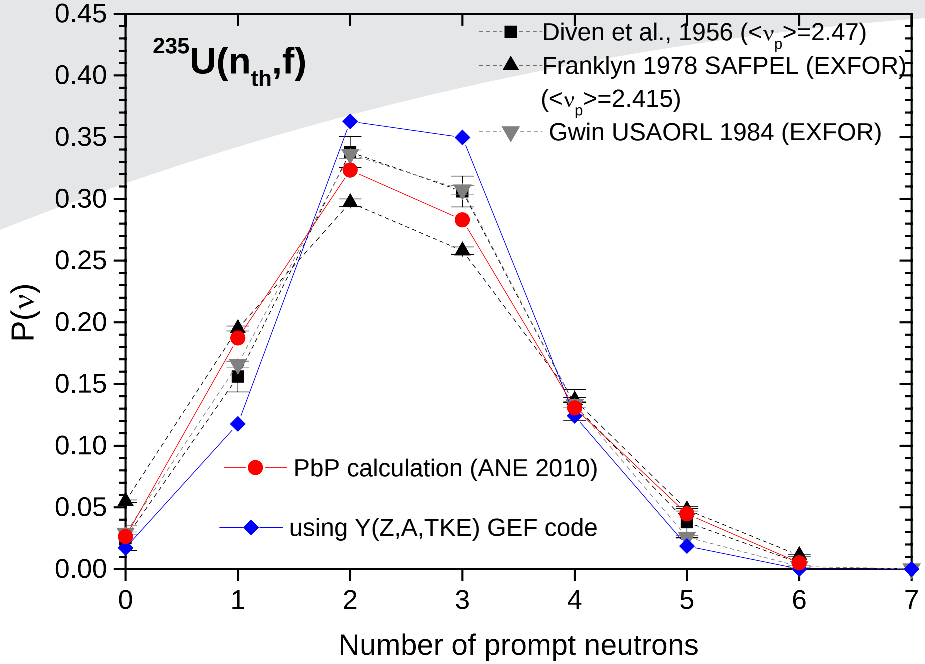
P(ν)

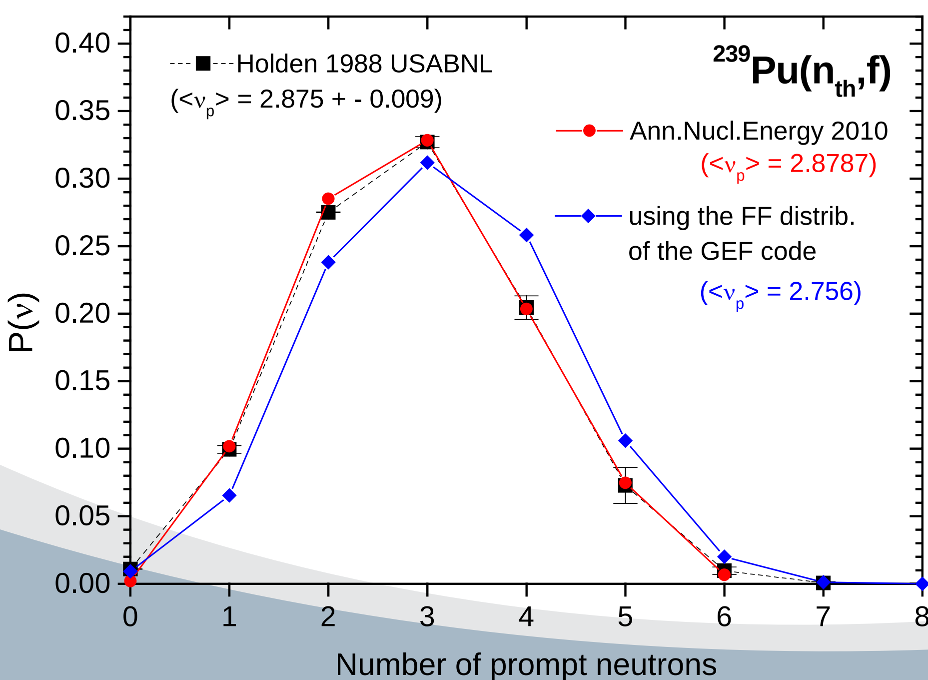
P(ν) is very sensible to Y(A,Z,TKE).

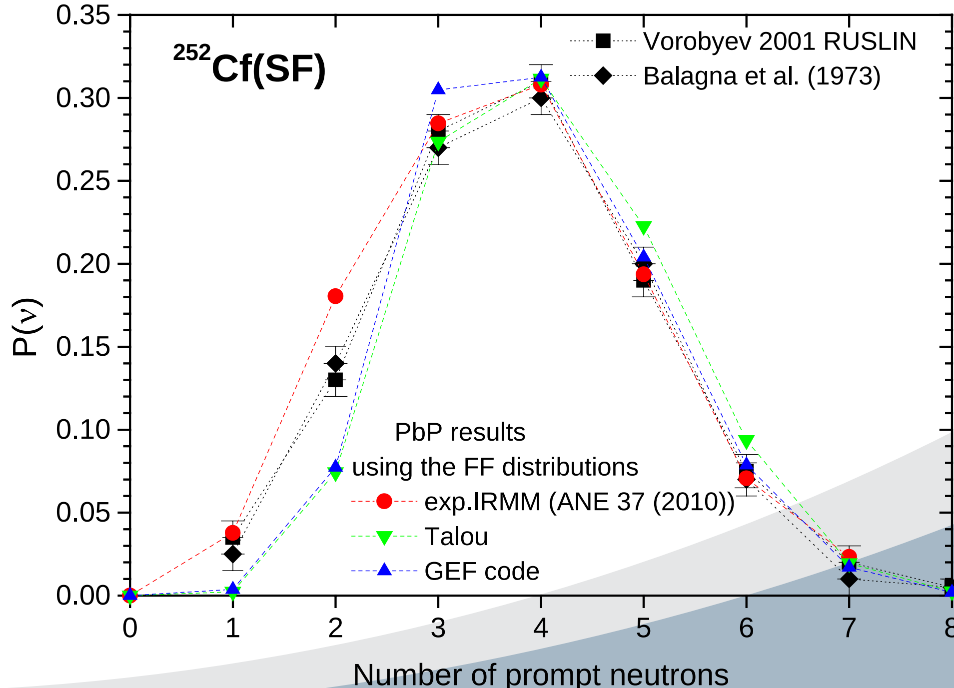
Large differences in P(ν) results are visible in the case of $^{235}U(n_{th},f)$ and $^{239}Pu(n_{th},f)$.

The differences are less pronounced in the case of $^{252}Cf(SF)$, the 3 results agree with exp. data excepting ν=2.

In the case of $^{239}Pu(n_{th},f)$ the P(ν) result obtained with the IRMM distrib. is in excellent agreement with the experimental data.







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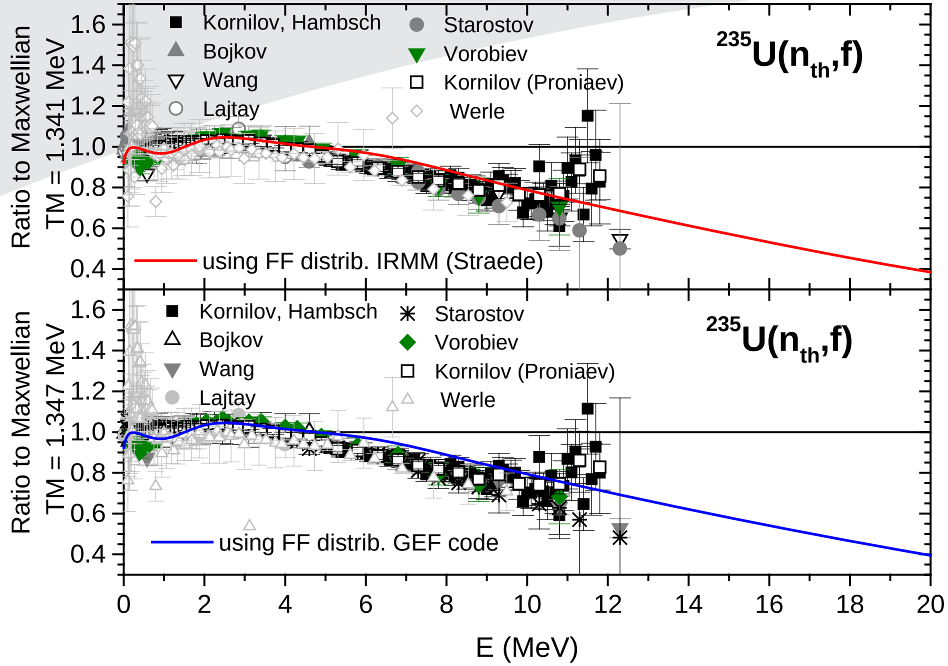
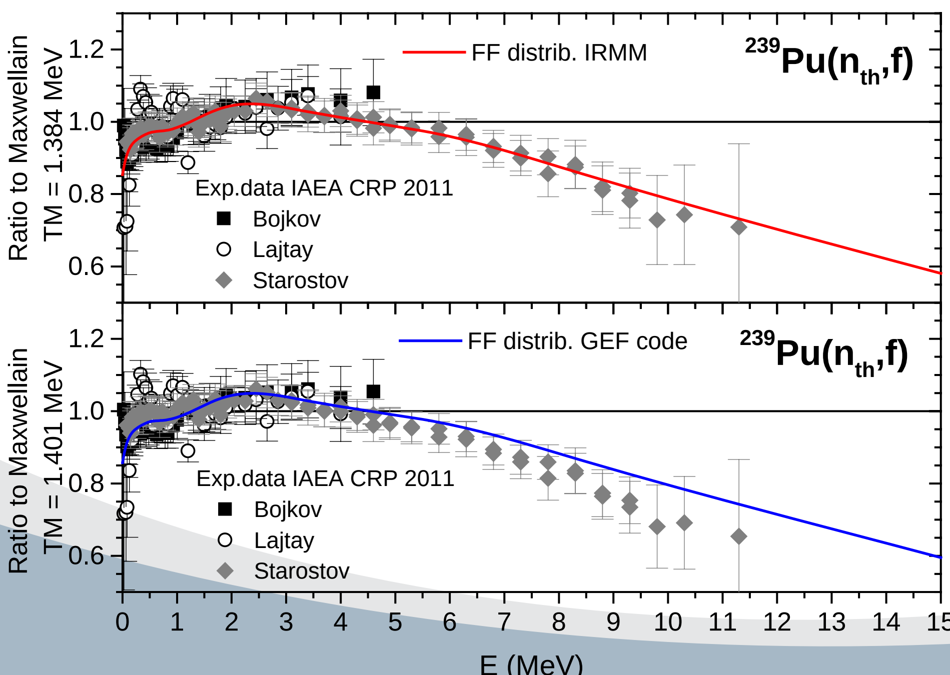
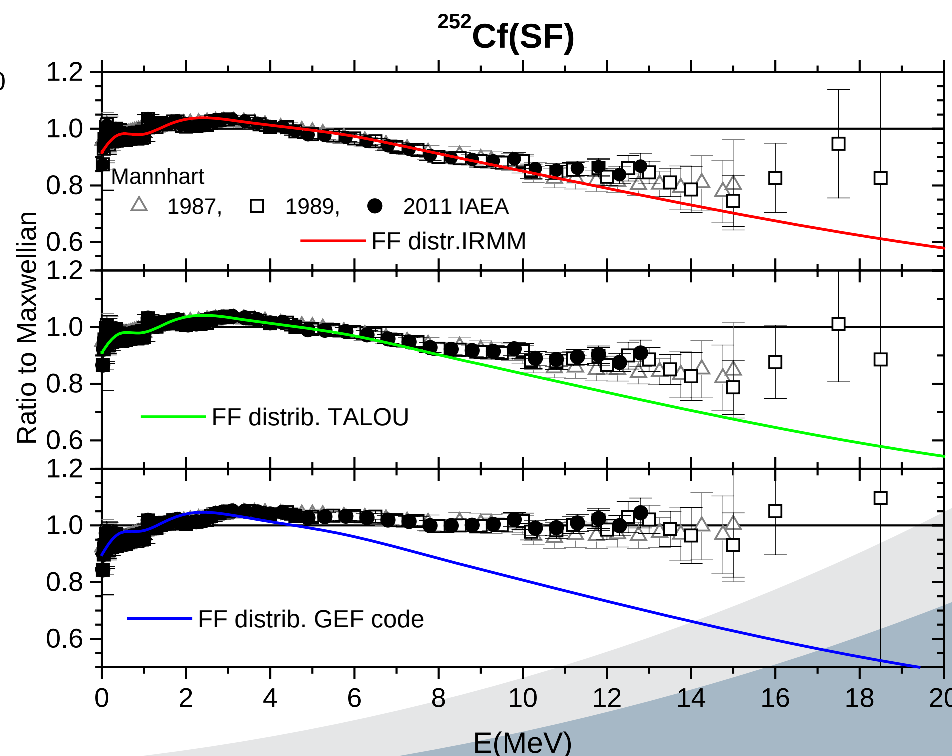
PFNS

^{235}U(n$_{th}$,f) and ^{239}Pu(n$_{th}$,f) PFNS ob. with the IRMM and GEF distributions are in good agreement with the exp.data of CRP.

^{252}Cf(SF) PFNS ob. with Talou and GEF distributions underestimate the Mannhart data at high E (spectrum queue).







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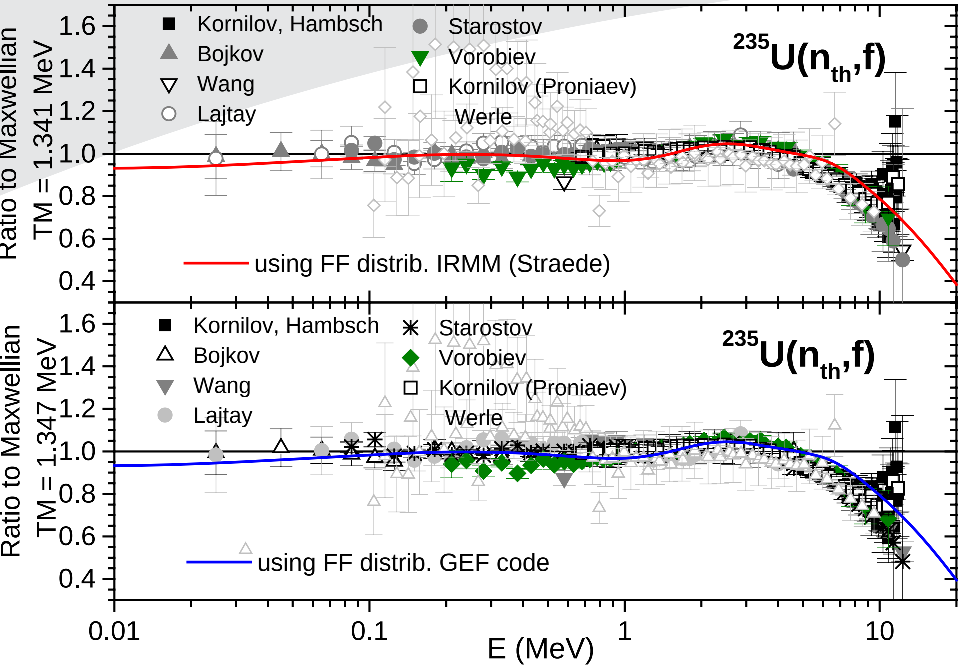
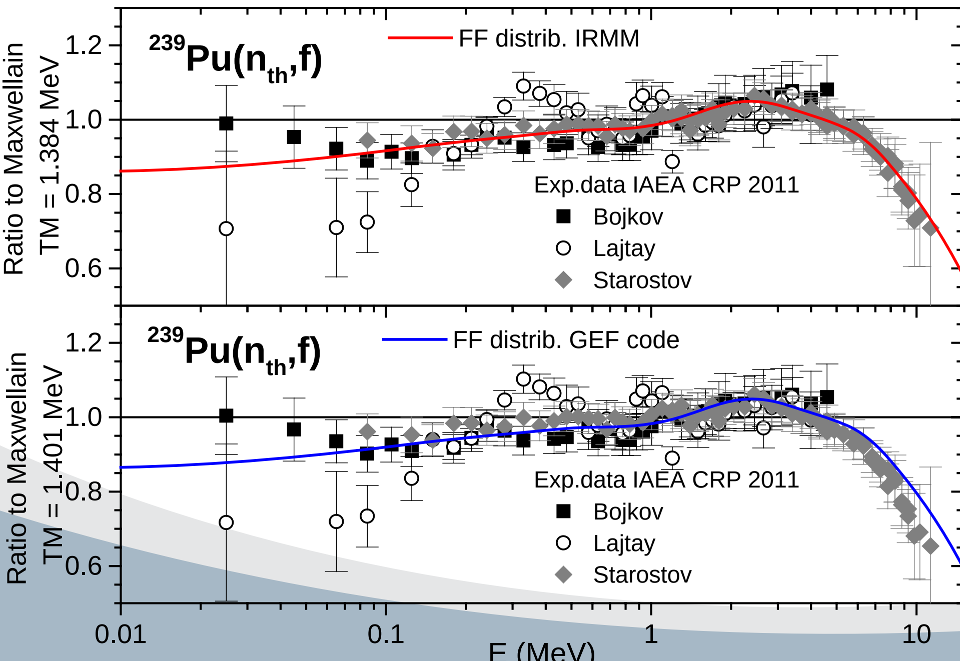
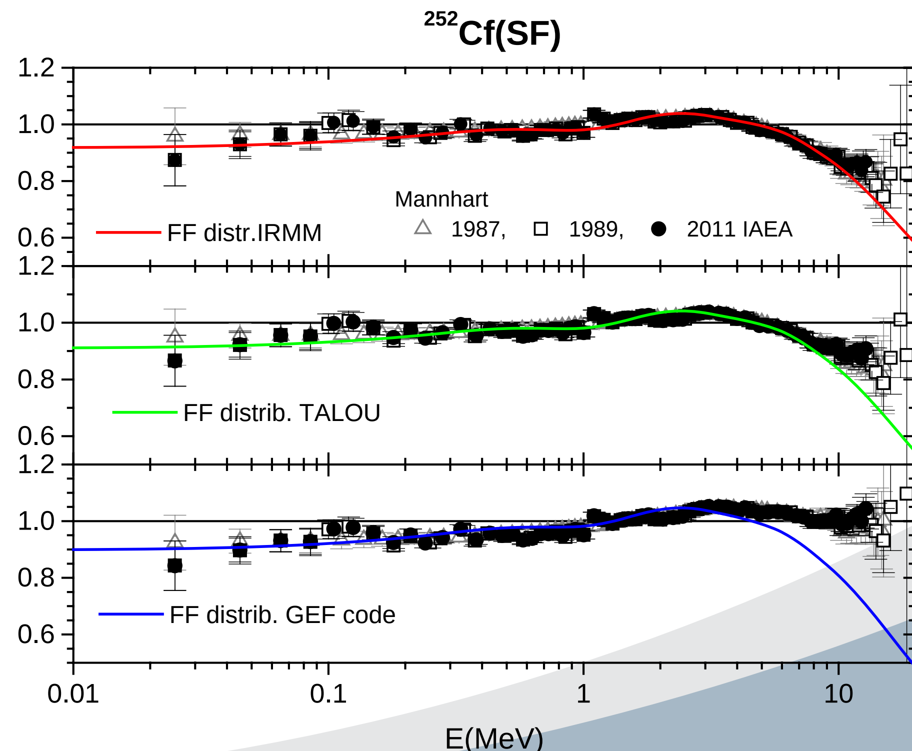
PFNS

PFNS of $^{235}U(n_{th},f)$ and $^{239}Pu(n_{th},f)$ obtained with the IRMM and GEF distrib. describe very well the experimental data of CRP in the low E region.





$^{252}Cf(SF)$: all PFNS results are in good agreement with the Mannhart data at low E.



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Short comments / conclusions:

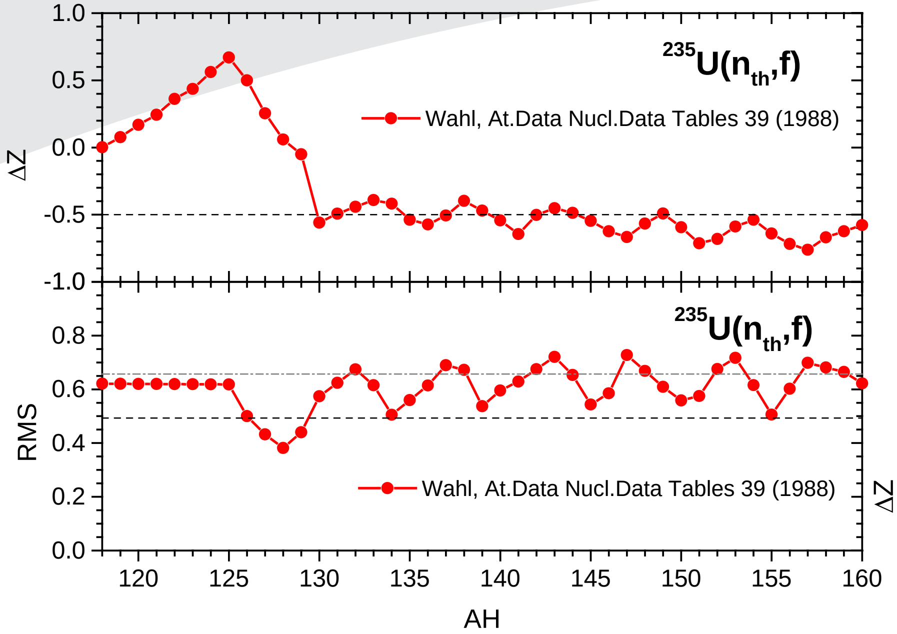
The pronounced differences between the TKE(A) distributions are reflected in:
- the large differences in PFNS at high E (queue) especially in the case of ^{252}Cf(SF) for which the TKE(A) distribution of GEF exhibits pronounced differences compared to experimental TKE(A) data. The TKE(A) data of Talou also differ from experimental data but the differences are less pronounced compared to GEF.
- the close $<\nu>$(TKE) results obtained with all distributions for the 3 studied systems and also the close $<E\gamma>$(TKE) results.

The differences appearing in ν_{pair}(A), ν(A), Eγ (A), $E\gamma_{pair}$(A) and Nγ(A) are due mainly to TKE(A) and less to Z distributions. The average prompt neutron multiplicity as a function of A is more sensitive to FF distributions than average prompt γ-ray quantities as a function of A.

P(ν) remains the most sensitive quantity to FF distributions.
P(ν) results obtained with the three FF distributions (experimental data, GEF and Talou) differ for all studied fissioning nuclei.

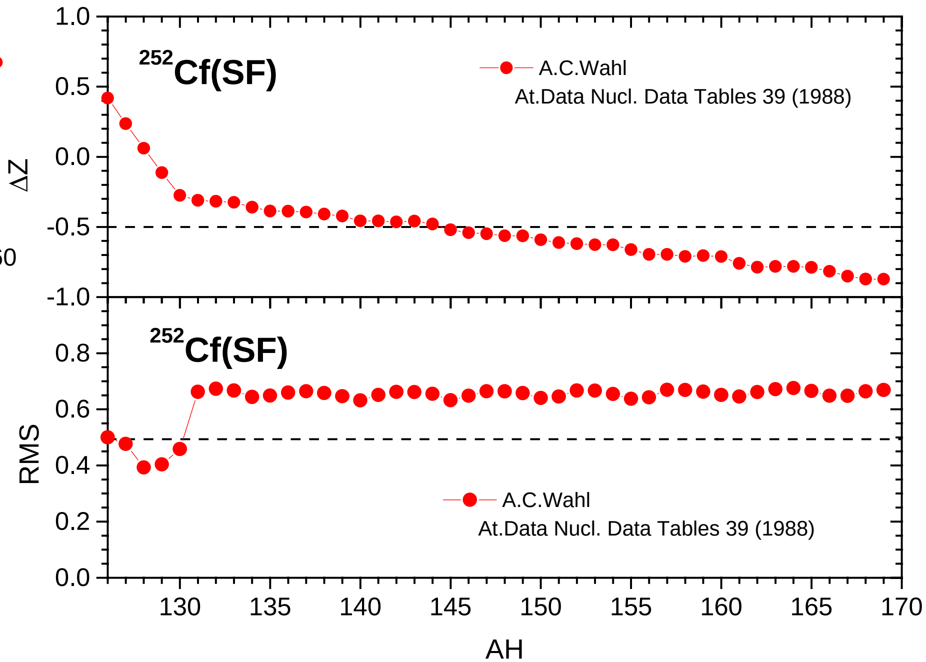
The agreement with experimental data of all studied prompt emission quantities is visibly better in the case of experimental FF distributions.

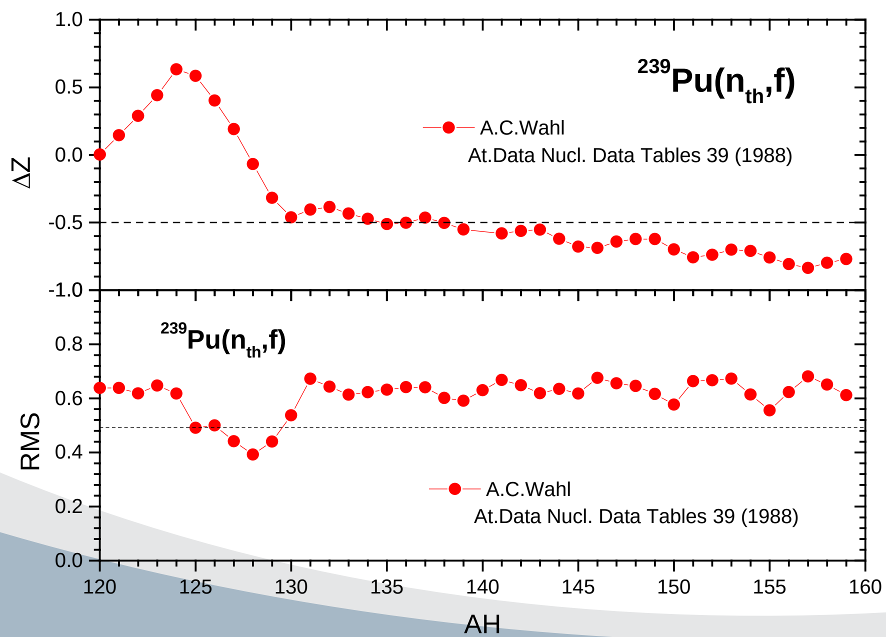
Appendix 1



A.C.Wahl, Atomic Data and Nuclear Data Tables 39 (1988) 1-156

From Fig.3 page 9 (digitized) given as a function of pre-neutron mass A’





Even-odd Z effect : periodicity of 5 mass units

The effect is pronounced in the case of ^{235}U(n$_{th}$,f) and almost vanished in the case of ^{252}Cf(SF). Confirming that the e-o effect is diminishing with the increase of the fissility parameter.

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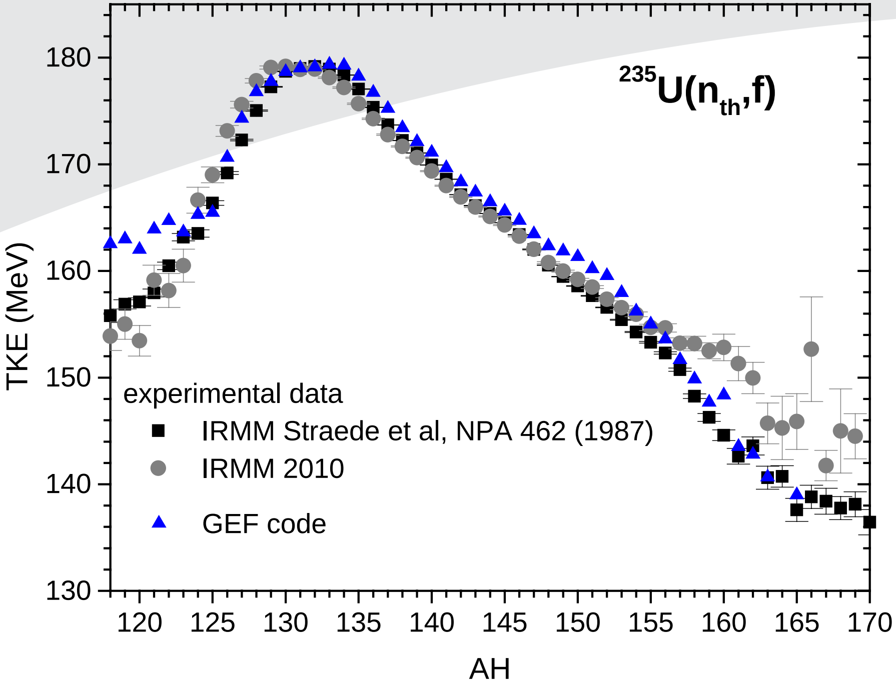
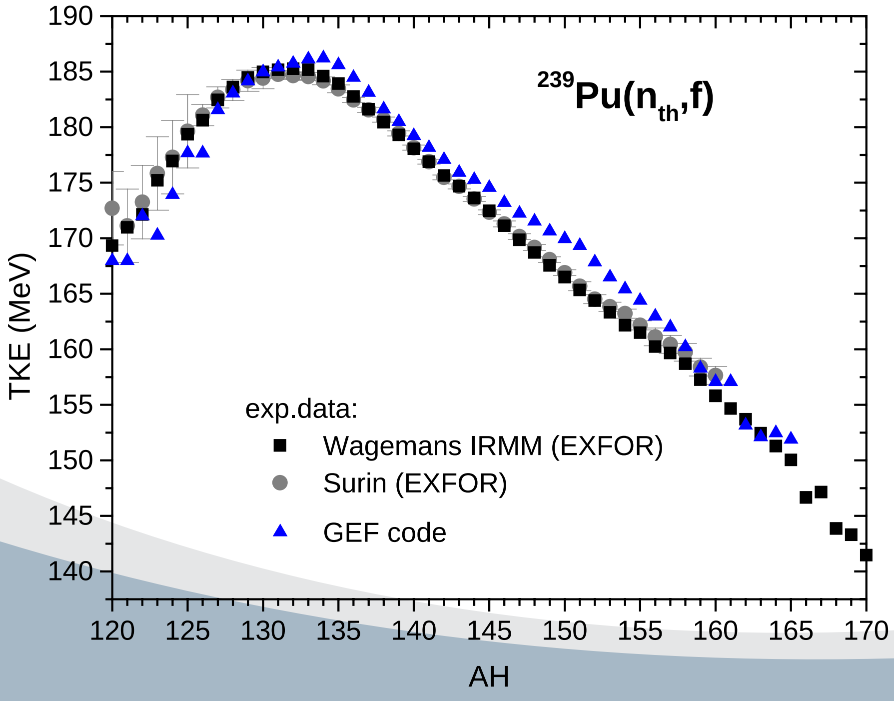
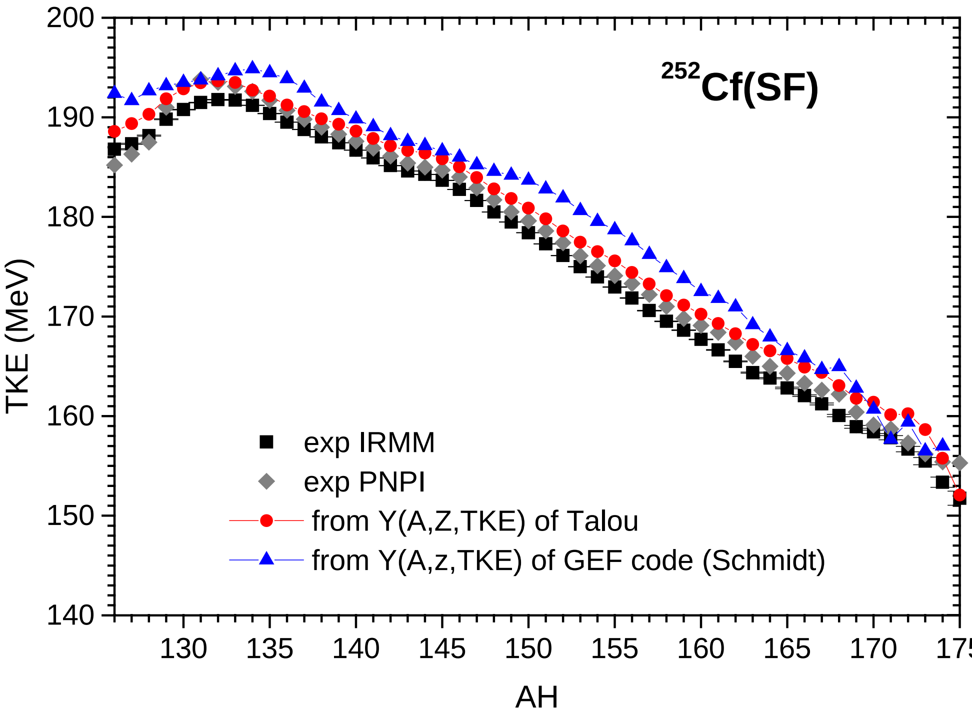
Appendix 2

TKE(A):

- exp.data (black, gray)
- GEF (blue)
- Talou (red)







In the case of ^{252}Cf(SF) large differences in TKE(A) of GEF compared to exp.data

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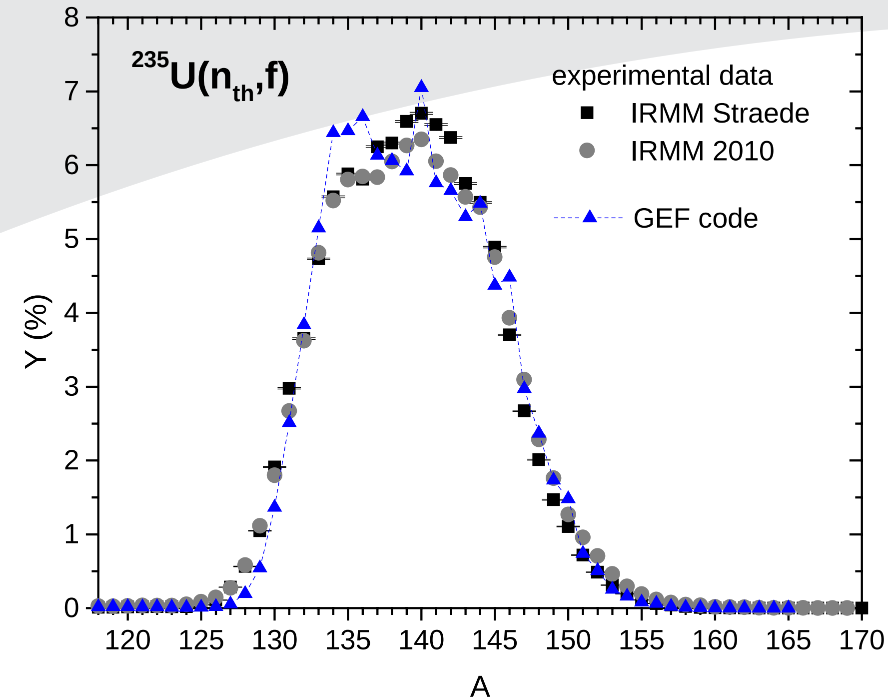
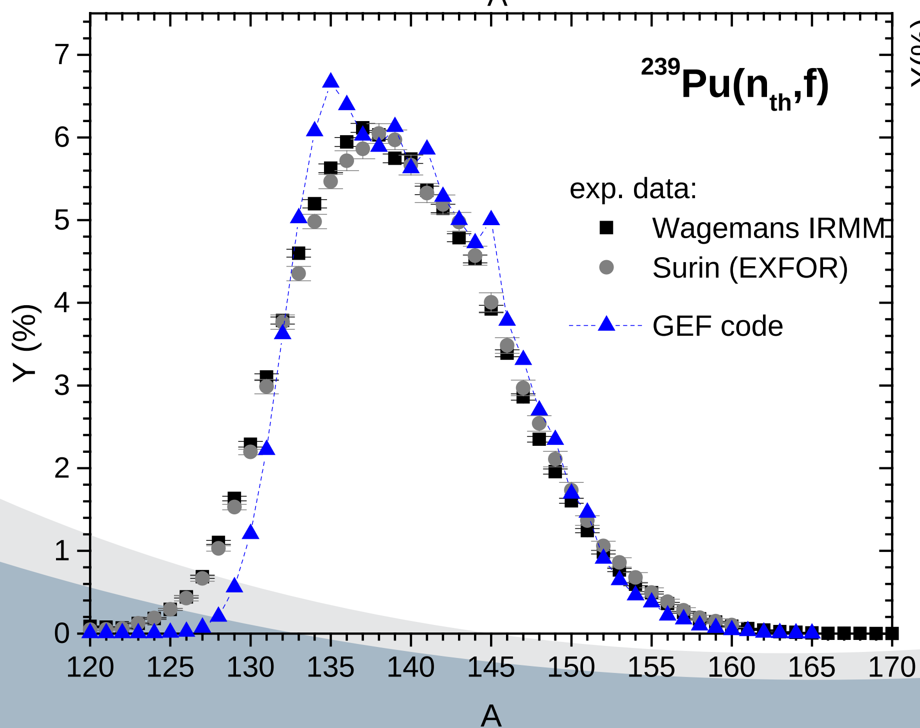
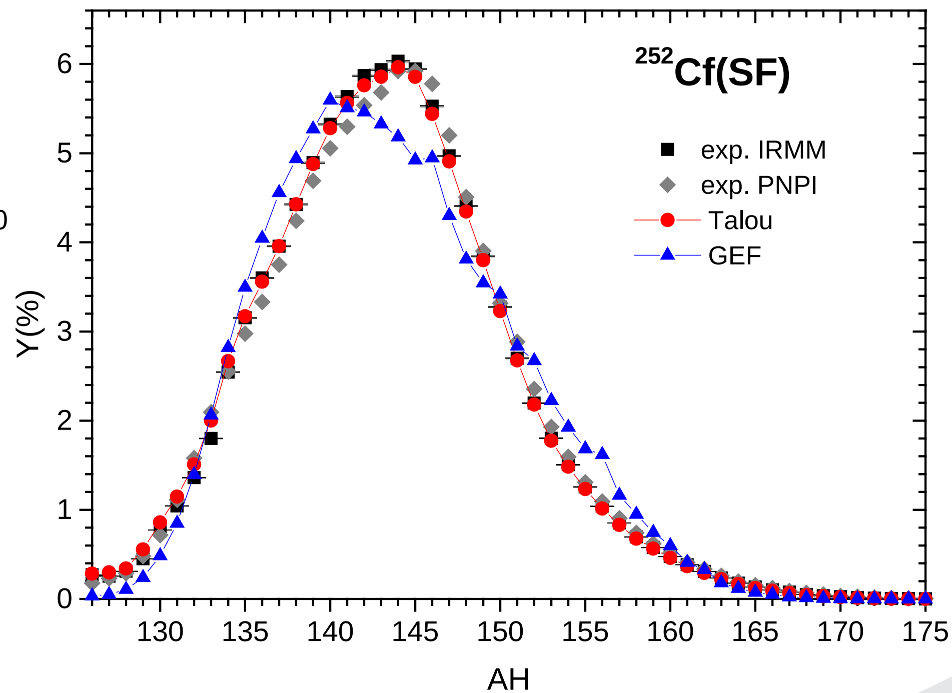
Appendix 2





Y(A):

- exp.data (black, gray)
- GEF (blue)
- Talou (red)



In the case of $^{252}Cf(SF)$ visible differences in Y(A) of GEF compared to exp.data and Talou distrib.

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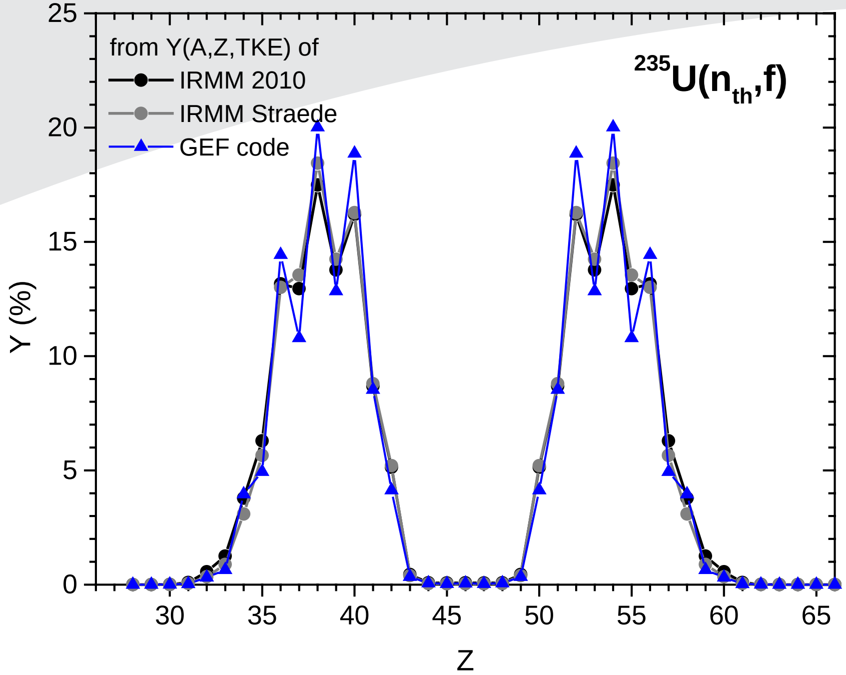
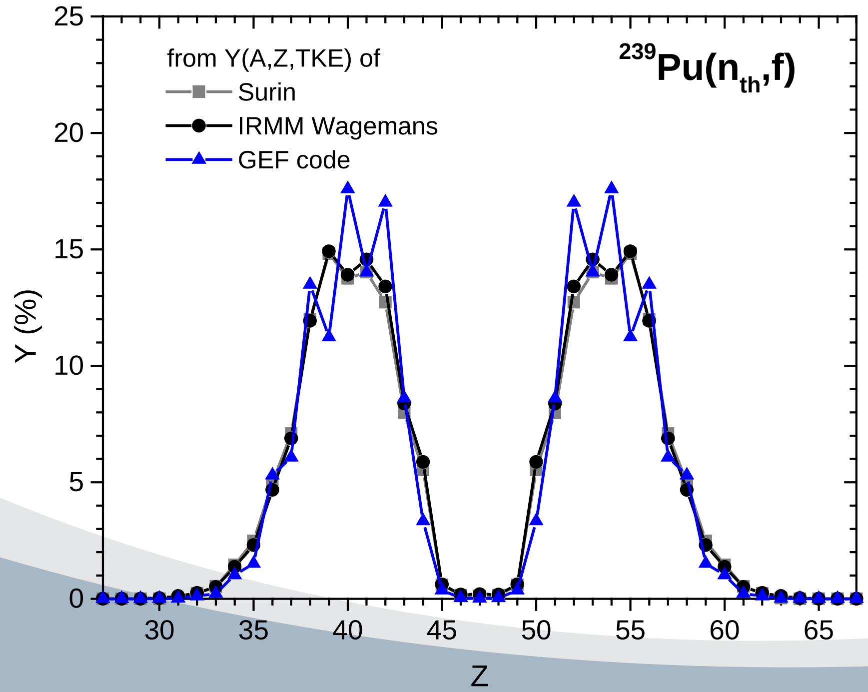
Appendix 2

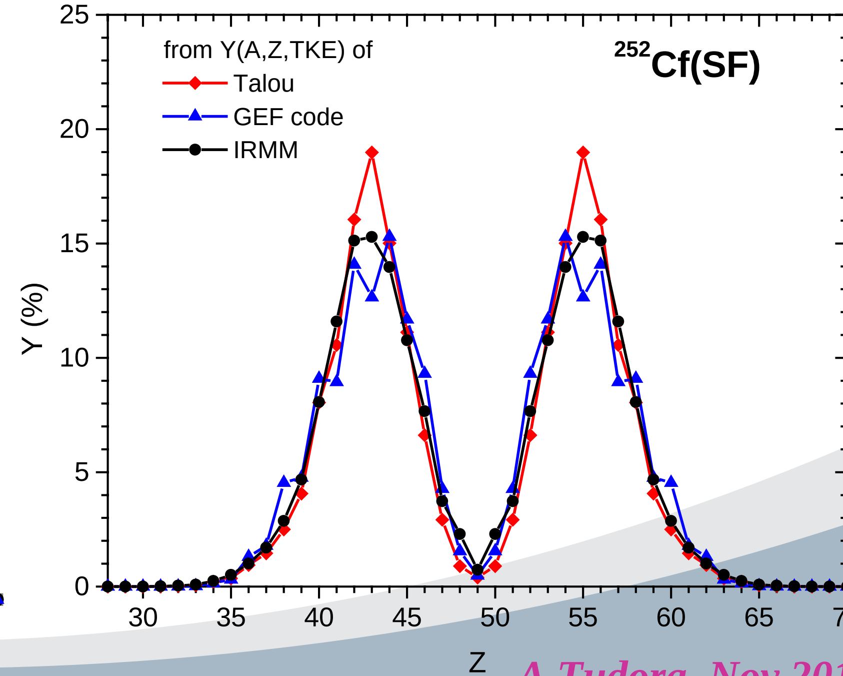


Y(Z):

exp.data (black, gray), GEF (blue), Talou (red)

The <u>even-odd effect</u> is diminished for heavy fissioning nuclei (high fissility parameter XF).
It is very visible in the exp.Y(Z) of $^{235}U(n_{th},f)$ and almost invisible in the exp.data of $^{252}Cf(SF)$.
Y(Z) of GEF exhibit large even-odd effects, in very good agreement only with the experimental Y(Z) of $^{235}U(n_{th},f)$, being more pronounced than exp.data in the case of $^{239}Pu(n_{th},f)$ and $^{252}Cf(SF)$.





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Appendix 2

To have a quantitative measure of the even-odd staggering of Y(Z) it is convenient to define δ according to ***C.Wagemans, "The Nuclear Fission Process" CRC Press 1991, Ch 8 (F.Gonnenwein) eq.(35) page 410:*** $\delta = (Y_e - Y_o)/(Y_e + Y_o)$

$^{235}U(n_{th},f)$	IRMM 2010	IRMM St.	GEF
δ	0.12891	0.12828	0.23658
Ye/Yo	1.297	1.294	1.619

$^{239}Pu(n_{th},f)$	IRMM	Surin	GEF
δ	0.03239	0.03299	0.15865
Ye/Yo	1.067	1.068	1.377

$^{252}Cf(SF)$	IRMM	Talou	GEF
δ	0.02564	0.05767	0.10644
Ye/Yo	1.053	1.012	1.238

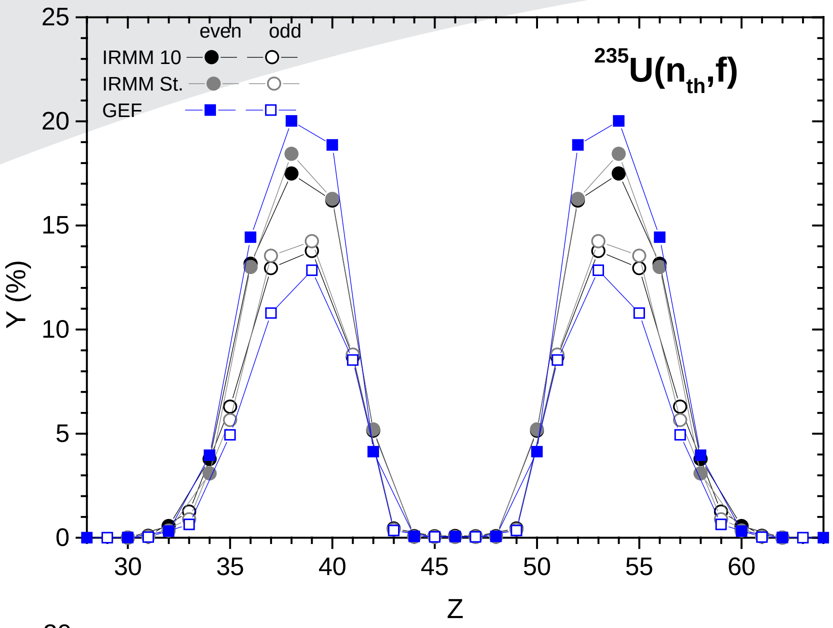
The even-odd effect is much more pronounced in the case of GEF distributions compared to the experimental data and the distrib. of Talou (for which the e-o effect is almost vanished)

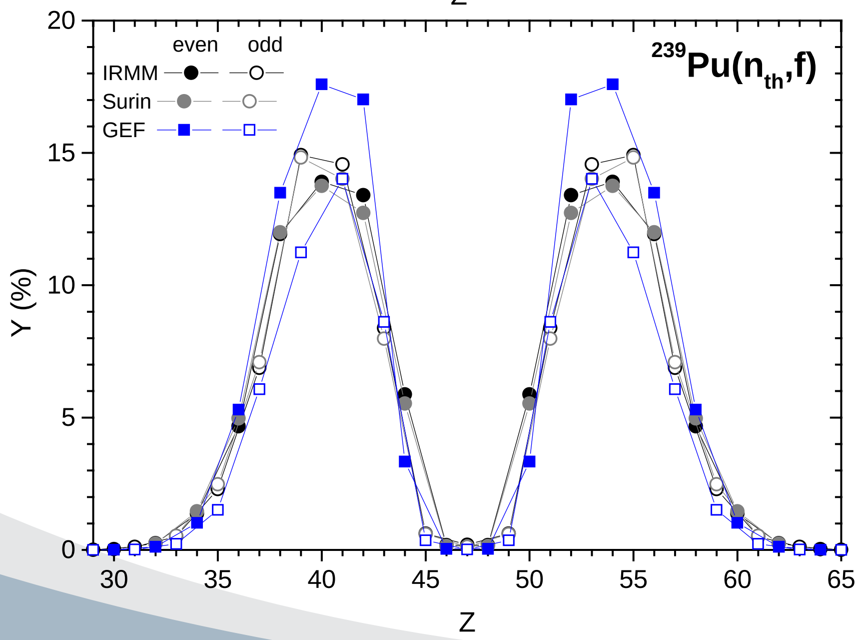
Appendix 2

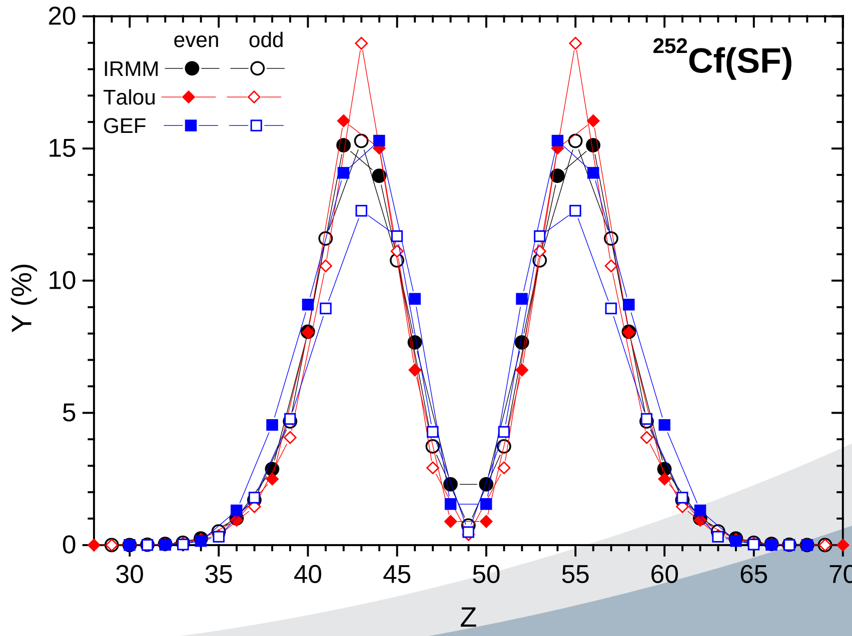
Y(Ze) full symbols

Y(Zo) open symbols

exp.data (black, gray), GEF (blue), Talou (red)







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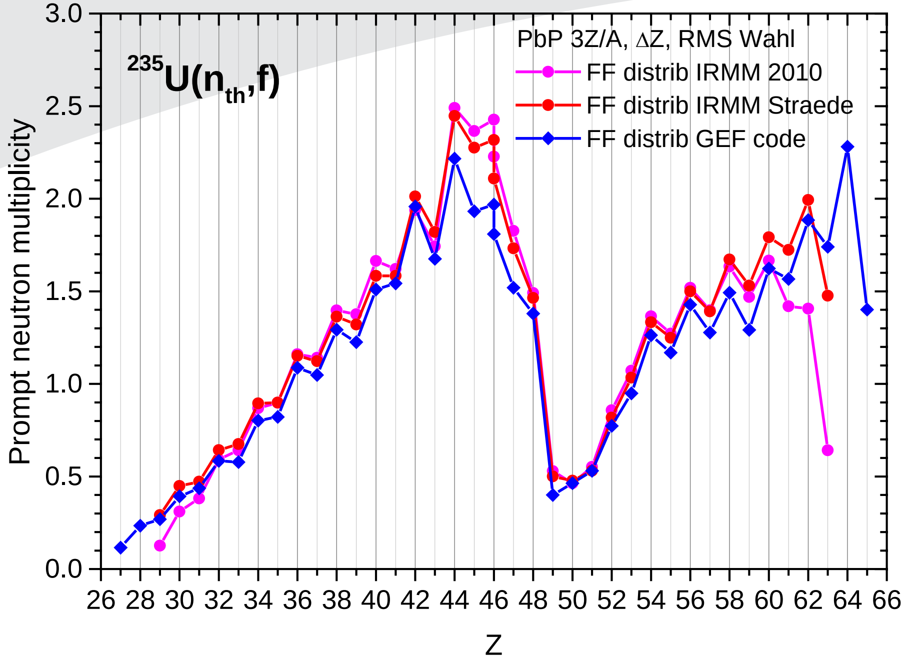
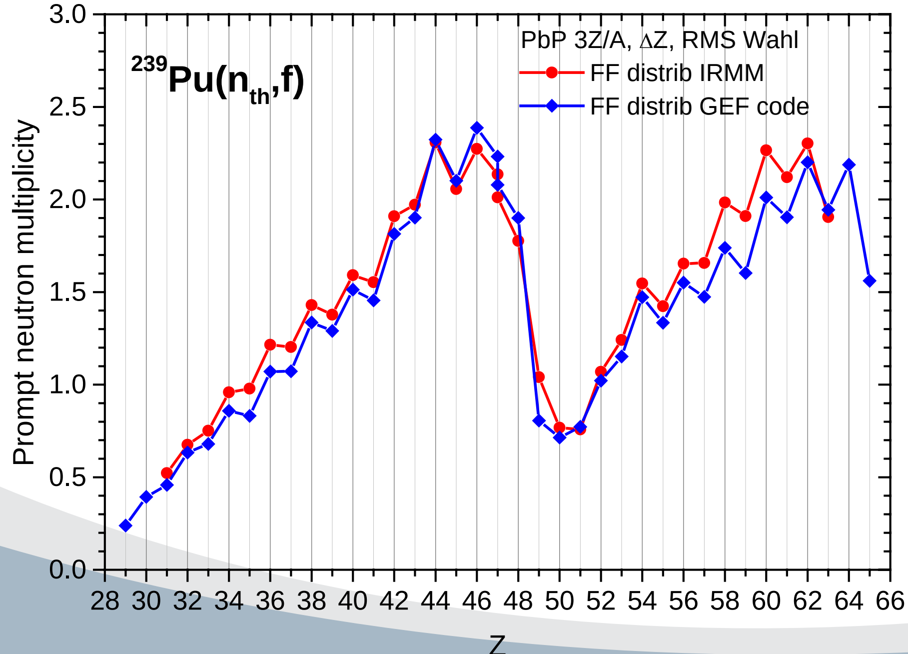
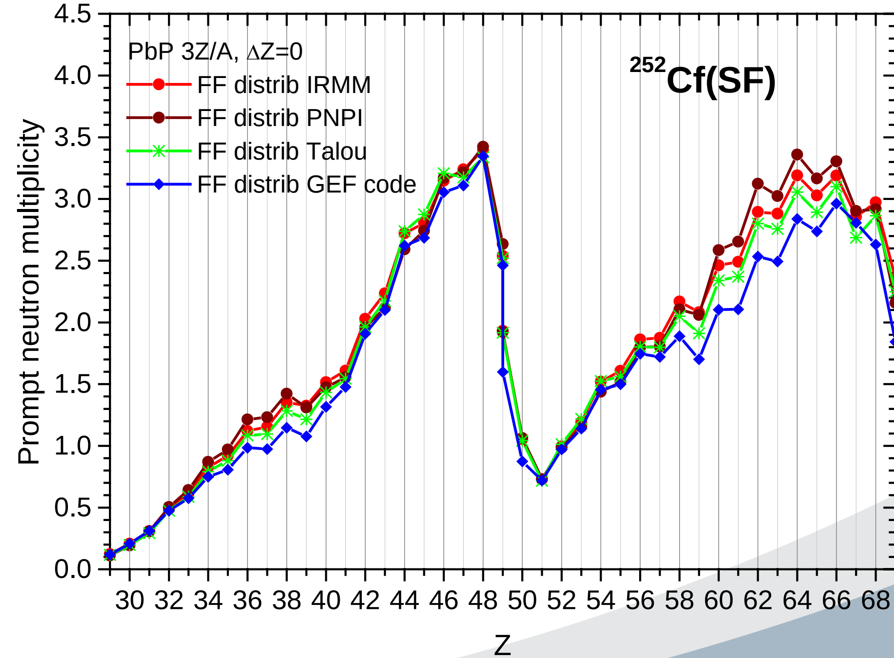
Appendix 2

Z-even-odd effect in prompt neutron multiplicity as a function of Z







A.Tudora, Nov.2013, CRP

References:

[1] C.Morariu, A.Tudora, F.-J.Hambsch, S.Oberstedt, C.Manailescu, *J.Phys.G, Nucl. Part.Phys. 39 (2012) 055103*

[2] A.Tudora, *Ann.Nucl.Energy 53 (2013) 507-518*

[3] C.Manailescu, A.Tudora, F.-J.Hambsch, C.Morariu, S.Oberstedt, *Nucl.Phys.A 867 (2011) 12-40*

[4] A.Tudora, *Ann.Nucl.Energy 35 (2008) 1-10*

[5] A.Tudora, C.Morariu, F.-J.Hambsch, S.Oberstedt, C.Manailescu, *Physics Procedia 31 (2013) 43-50*

[6] A.Tudora, F.-J.Hambsch, S.Oberstedt, *Gamma-2 workshop, Sr.Karlovci, Serbia (2013)*

[7] A.Tudora, F.-J.Hambsch, *Ann.Nucl.Energy 37 (2010) 771-777*