

# Description of current and future JEFF Fission Yield Evaluations

Dr Robert W. Mills,  
NNL Research Fellow for Nuclear Data,  
UK National Nuclear Laboratory.

- Timescale

JEF-2.2 1993 , JEFF-3.1.1 2007,  
JEFF-3.2 2014, JEFF-3.3 2016/17, JEFF-4 2020?

- JEFF-3.2 fission yields

- Updated Data Analysis – new measurements
- GEF model
- Proposed method using GEF and testing
- Same systems as JEF-2.2/JEFF-3.1.1

- JEFF-3.3

- Extend to include full GEFY systems and energies.
- Uncertainties and covariance

- Conclusions

## What is nuclear data “evaluation”

- Can be described as the processing of giving value to a quantity or assessing quality

.... But

- Has to be consistent with measurements and constraints of physical laws within currently accepted knowledge.
- Has to be consistent with best models.
- Has to be reported/distributed in a form that all can use easily (e.g. ENDF format).
- Has to be tested against appropriate experiments.

## History of UK evaluations

1960-1981 Crouch

Atomic and Nuclear Data Tables (1977)

1981-1987

James and Banai UKFY1 / JEF1 (1986)

1988-1995

Mills, James and Weaver UKFY2 / JEF-2.2 (1993)

1995-present

Mills UKFY3.x series - JEFF-3.1.1 (UKFY3.6A)

(UKFY4 photon, neutron and charged particle induced energy dependent or spontaneous fission using Wahl code).

## Definitions

The independent yield  $y(A,Z,I)$  is the number of atoms of  $(A,Z,I)$  produced directly from one fission, but after the emission of prompt neutrons (but before any radioactive decay and hence the emission of delayed neutrons). It can be written as the product of 3 factors:

$$y(A, Z, I) = Y(A) \times f(A, Z) \times R(A, Z, I)$$

where the **sum yield** or **mass yield**  $Y(A)$  is the total of the independent yields (before delayed neutron emission) of all fission products of mass number  $A$ ;  $f(A,Z)$  is the **fractional independent yield** of all isomers of  $(A,Z)$ ; and  $R(A,Z,I)$ , the **isomeric yield ratio**, is the fraction of  $(A,Z)$  produced directly as isomer  $I$ .

## Definitions

The **cumulative yield**  $c(A,Z,I)$  of nuclide  $(A,Z,I)$  is the total number of atoms of that nuclide produced over all time after one fission. If the nuclide is stable the cumulative yield is the total number of atoms of that nuclide remaining per fission after all precursor decays (ignoring the effects of other nuclear reactions e.g. neutron capture). However, for a radioactive nuclide for which this is not the case, some atoms will have decayed before all have been produced.

An equivalent definition that is more useful is the following: immediately at the end of an “infinite” irradiation at the rate of 1 fission per second,  $c(A,Z,I)$  is the rate of decay of  $(A,Z,I)$  if that nuclide is radioactive, or its rate of production if it is stable.

The **chain yield**  $Ch(A)$  is equal to the sum of all stable or long-lived cumulative yields for a given mass chain. It should be noted that the chain yield,  $Ch(A)$ , and the sum or mass yield,  $Y(A)$ , for a mass chain  $A$  may differ by a few per cent because the former applies after, and the latter before, delayed neutron emission.

---

# Current JEFF FY systems

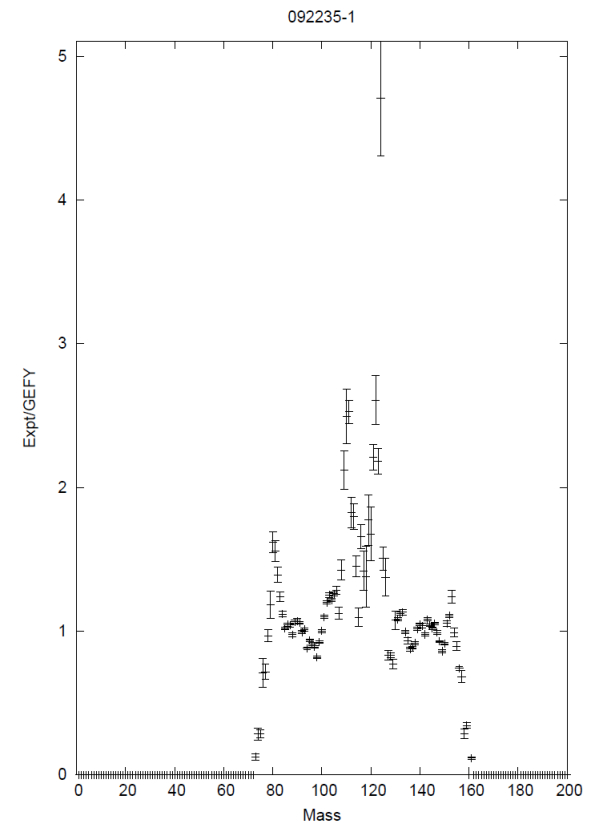
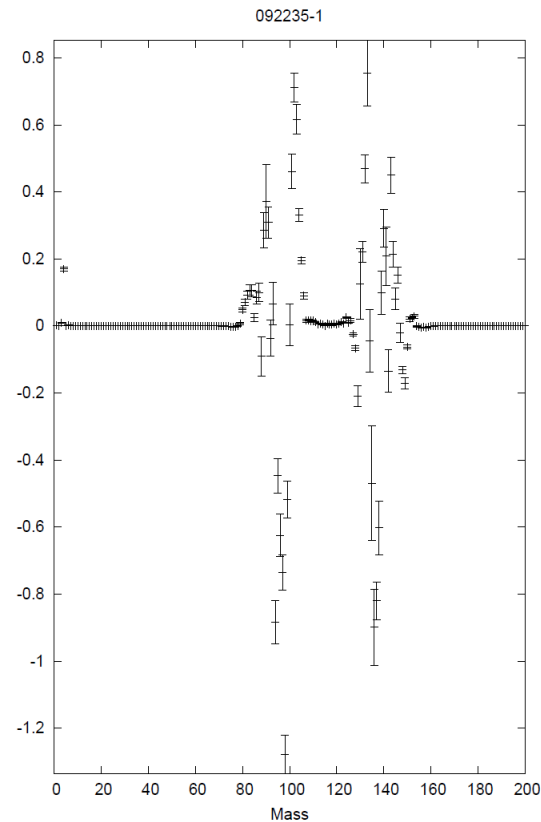
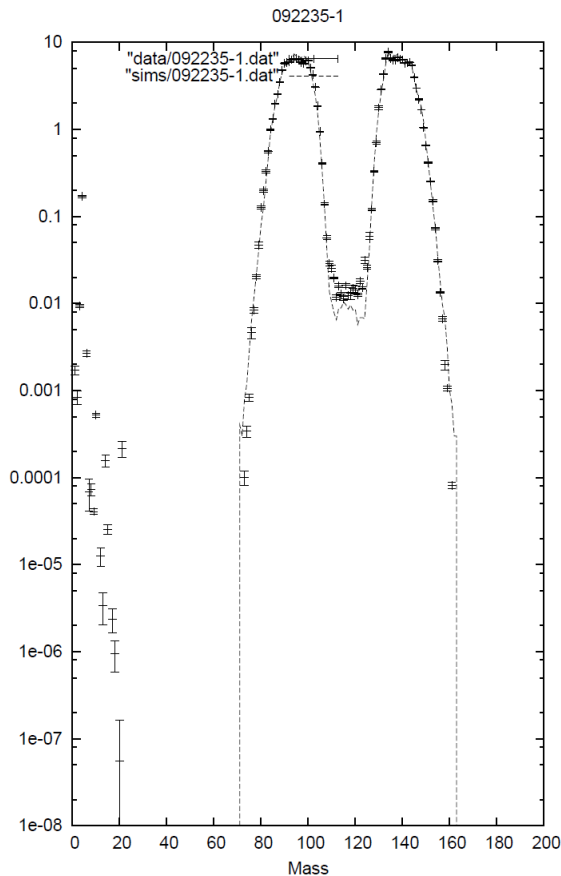
Maximum fraction of fission rate			Spontaneous fission
>10%	1-10%	0.1-1%	
Nuclides: <b>5</b>	<b>2</b>	<b>12</b>	<b>3</b>
$^{233}\text{U}^*$ TFH $^{235}\text{U}^*$ TFH $^{238}\text{U}^*$ FH $^{239}\text{Pu}^*$ TF $^{241}\text{Pu}^*$ TF	$^{240}\text{Pu}^*$ F $^{245}\text{Cm}$ TF	$^{232}\text{Th}^*$ FH $^{234}\text{U}$ F $^{236}\text{U}$ F $^{237}\text{Np}$ TF $^{238}\text{Np}$ TF $^{238}\text{Pu}$ TF $^{242}\text{Pu}$ F $^{241}\text{Am}$ TF $^{242\text{m}}\text{Am}$ TF $^{243}\text{Am}$ TF $^{243}\text{Cm}$ TF $^{244}\text{Cm}$ TF	$^{252}\text{Cf}$ Sp $^{242}\text{Cm}$ Sp $^{244}\text{Cm}$ Sp

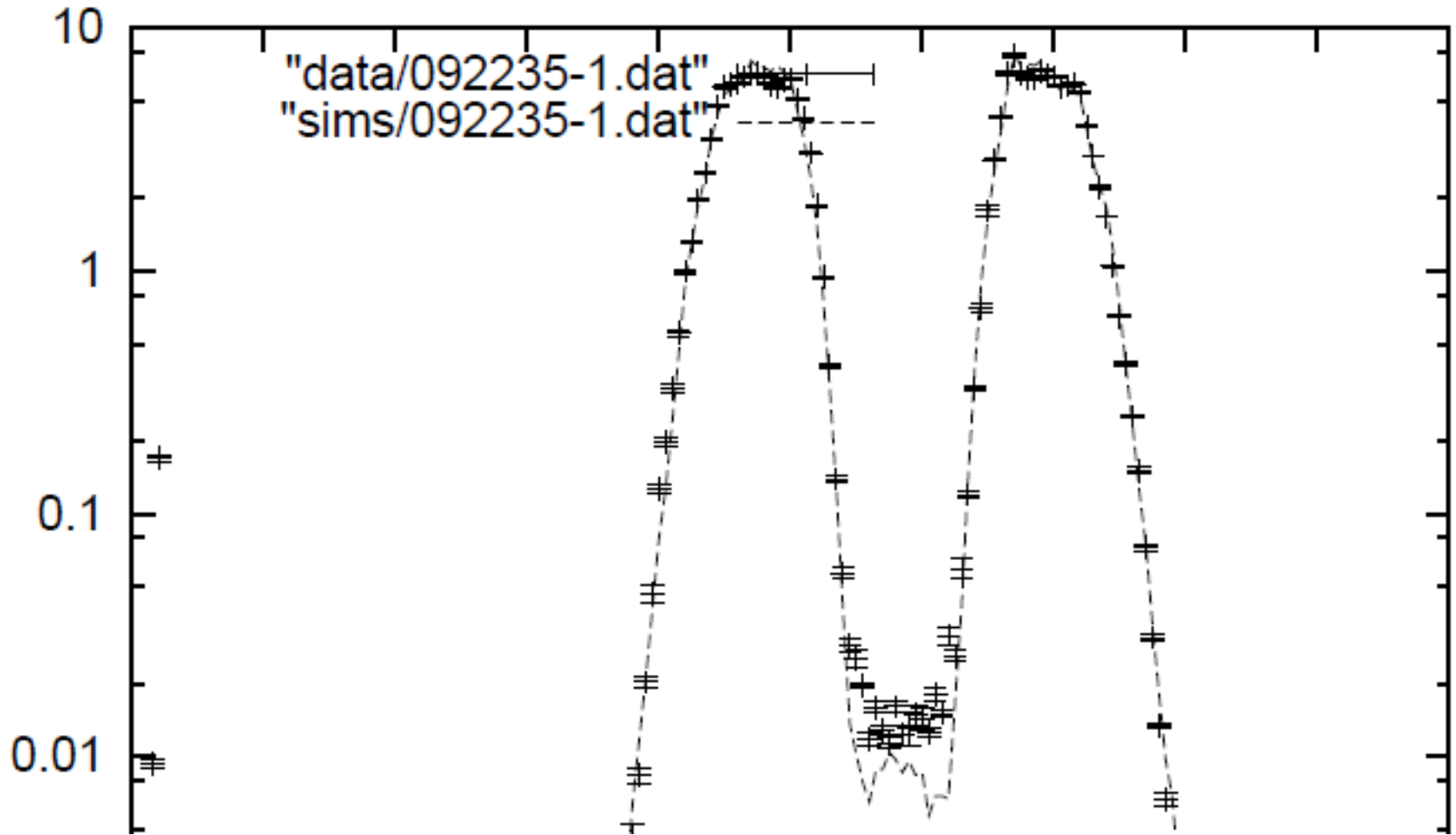
\* Nuclides in UKFY1 and previous UK libraries [5,7].  
 T Thermal fission.  
 F Fast fission.  
 H 14 MeV fission.  
 Sp Spontaneous fission.

- UKFY3 based upon experimental data from >2000 papers, reports etc.
- Currently updating with 10 significant recent measurement reports (working with University of Manchester student Robert Frost).
- ~1100 new high resolution measurements

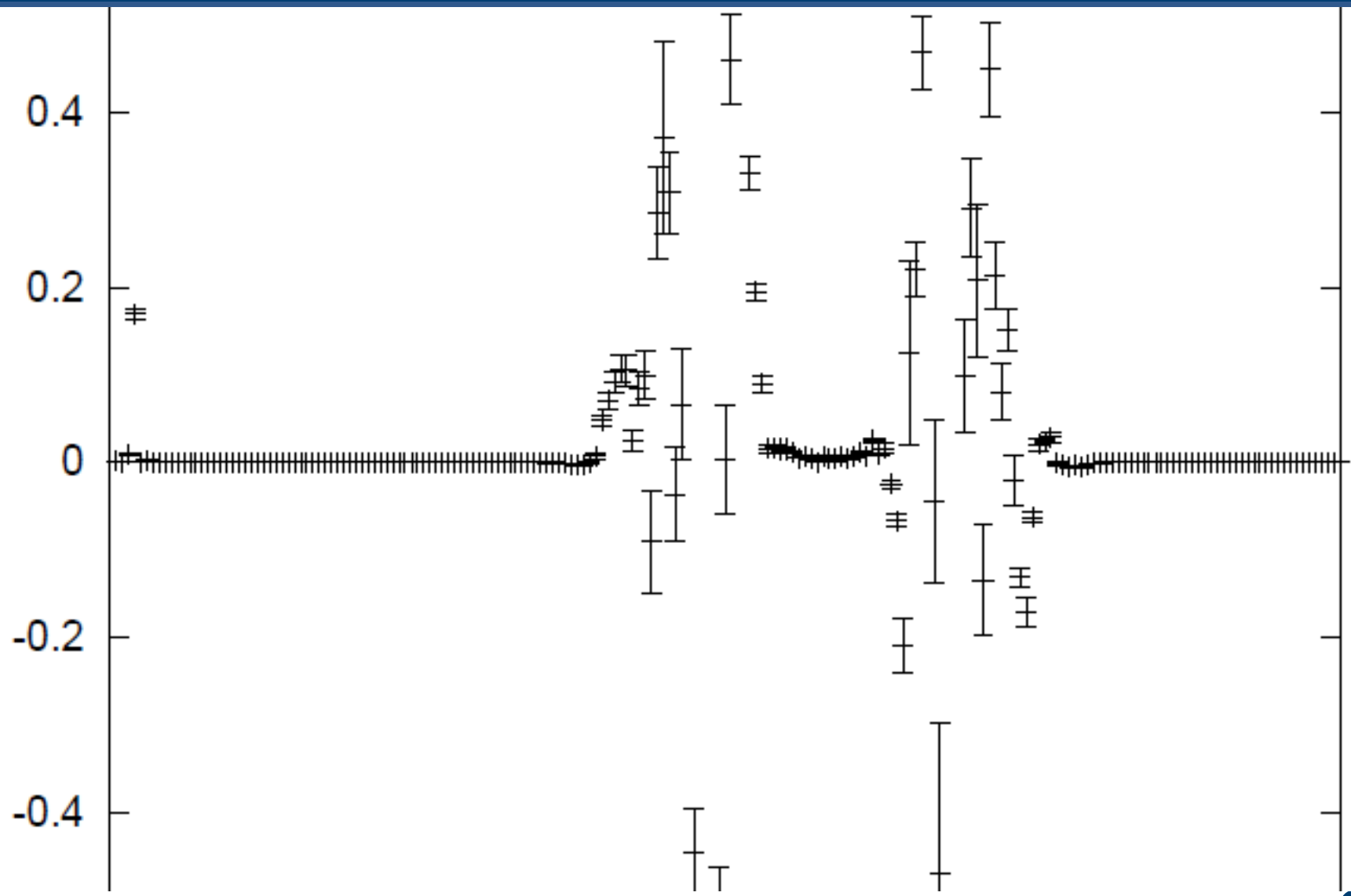
Dataset	Absolute	Ratio	Ratio of ratio	Total
UKFY3.6A	11887	1352	1471	14710
UKFY3.7 (Prelim)	12908	1441	1471	15820

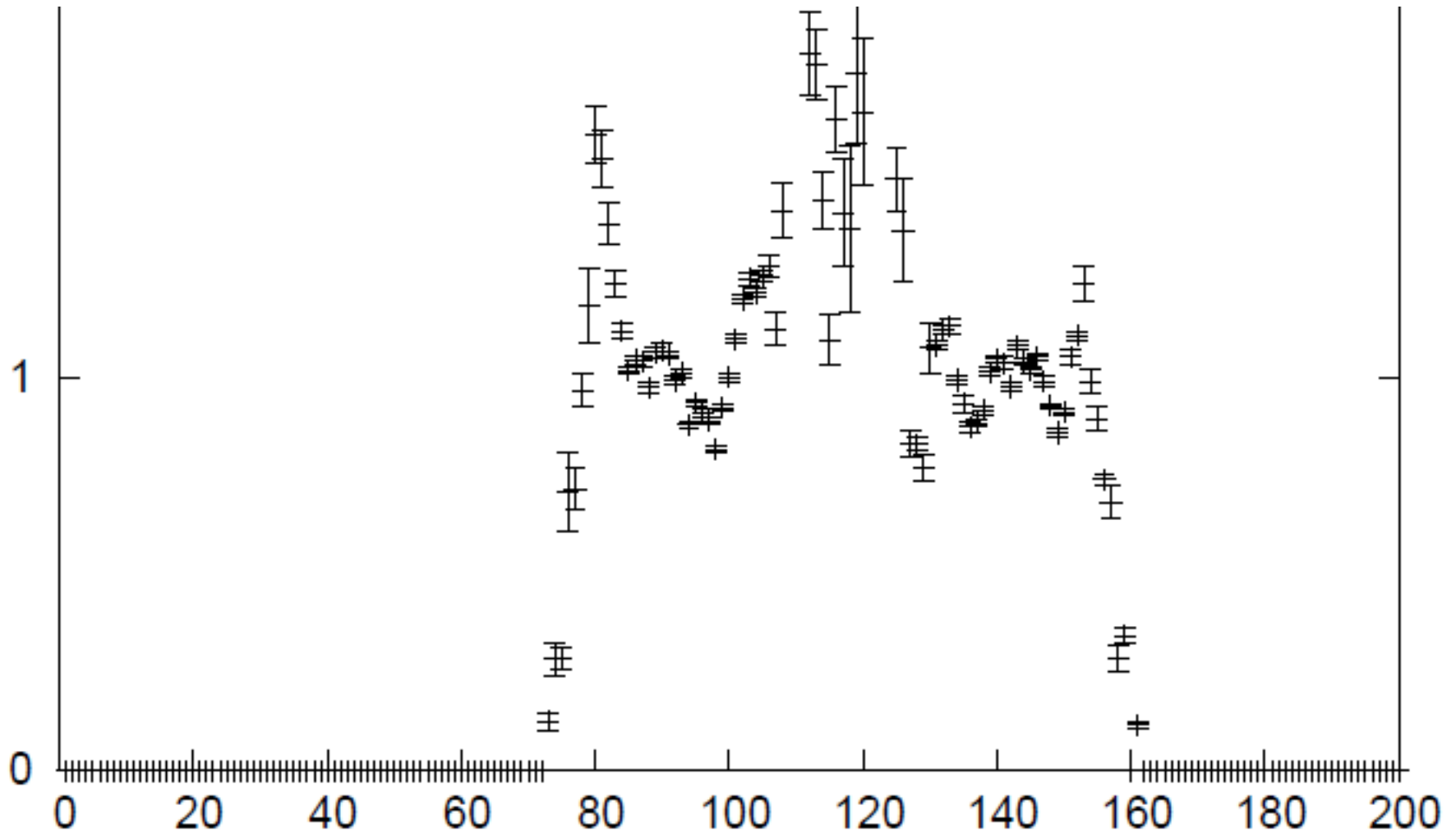
- Preliminary analysis based upon GEFY-4.1 (with Dr David Mountford)





# GEF model

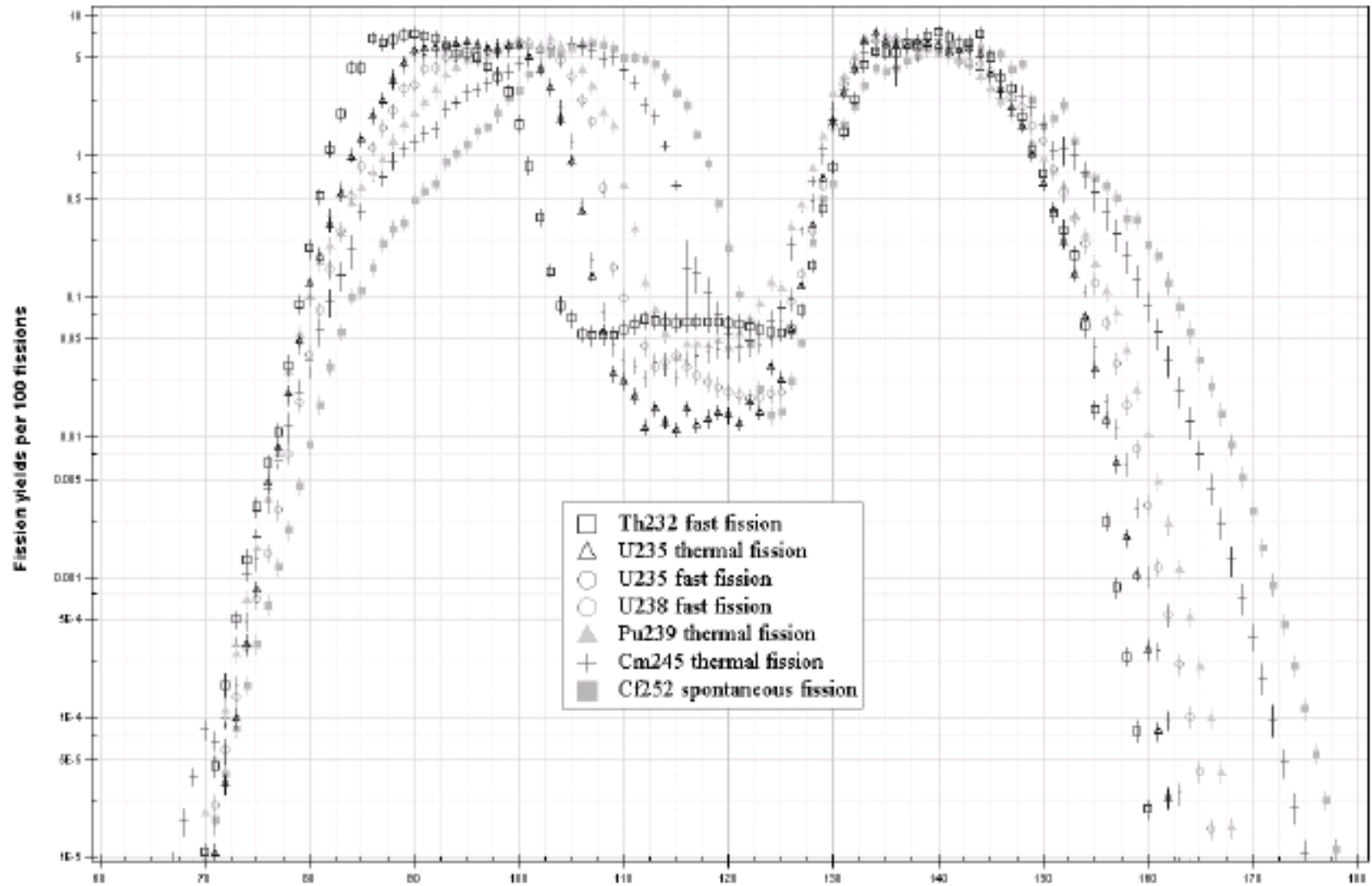




# Comparison of past and future JEFF FY models

Parameter	JEF-2.2 to JEFF-3.1.1	JEFF-3.2
Y(A)	5 Gaussian fits	GEF
F(A,Z)	Wahl Zp (1988)	GEF
R(A,Z,I)	Madland and England	GEF

# Mass distribution



- GEFY files have their lowest yields constrained by the Monte Carlo method. Previous JEFF to  $\sim 10^{-12}$  per fission.
  - GEF is believed to be the best current model and will thus will adopt (GEFY4.2?) for JEFF
- but ...
- Need to extend  $Y(A)$ ,  $f(A,Z)$  and  $R(A,Z,I)$ 
    - $Y(A)$  can be extrapolated by  $\ln(Y(A))$  against  $A$  fits
    - $F(A,Z)$  can be extrapolated by fitting  $Z_p$  model parameters
    - $R(A,Z,I)$  can used JEFF-3.1.1 Madland and England model
  - Add ternary fission yields - JEFF-3.1.1+ Serot et al (2004/14).
  - Need to adjust for trends in experimental data.
  - Will need to use latest JEFF decay data to calculate cumulative yields for consistency.
  - Need to adjust for physical constraints.

- $\sum_A Y(A) = 20$

- $\sum_{A > \frac{A_f}{2}} Y(A) = 1$

- From conservation of mass

$$\sum_A AY(A) = A_f - \bar{\nu}_p - A_{LCP}$$

- From conservation of charge

$$\sum_{ZA} Z f(A, Z) Y(A) = Z_f - Z_{LCP}$$

and as  $Z_1 + Z_2 = Z_f$

then

$$\sum_A f(A, Z) Y(A) = \sum_A f(A, Z_f - Z) Y(A)$$

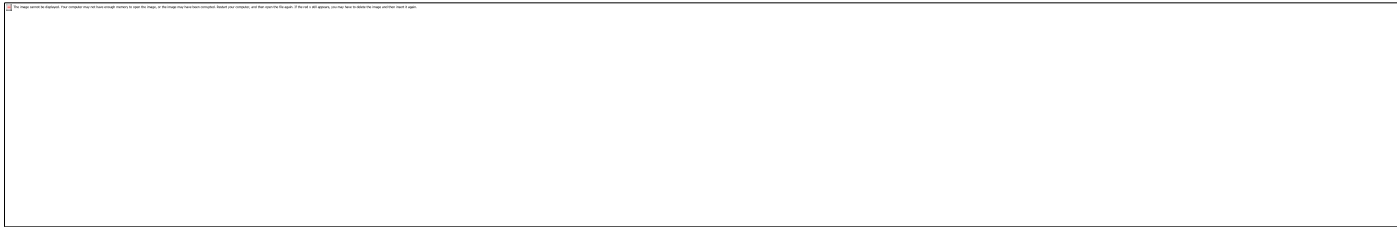
for all  $Z < \frac{Z_f}{2}$

Complementary yields should be equal

$$Z_1 + Z_2 = Z_f ; \quad \text{sum}(Y(A, Z_1, I)) = \text{sum}(Y(A, Z_2, I))$$

# Fission Product Yields- Q matrix method

- Given the individual decay branches for all nuclides in the decay paths from one nuclide to a distant daughter it is possible to calculate the fraction of  $j$  that decays to  $i$



- If  $Q_{i,i}$  is defined as 1 and  $Q_{k,i} = 0$  (where  $k$  does not decay to  $i$ ), Thus any cumulative yield can be calculated from the independent yield.

$$Y_i^c = \sum_j Y_j^i Q_{j,i}$$

Propose to do the following prior to release:

- Check of final consistency of files/conservations
- Decay neutron summation (quick)
- Decay heat pulses (several days)
- Decay heat assemblies (a selected few PWR)
- Chemical Analysis of fuel (a few samples)

2016/17

- For JEFF-3.3 want to include all GEFY systems (nuclides and energies)
- Investigate the MATCH code for adjustment and as a way of generating covariance matrices.
- Also need format for the covariance data and methods to use these within code systems.

- Route to JEFF-3.2 exists – pulling together the new pieces/models into an existing structure.
- Plan to have some files for testing in late summer/early autumn.
- WPEC subgroup 37 discussions and other work will feed into JEFF-3.3 over the next year.
- JEFF-4 beyond the current horizon...

I would like to thank the UK National Nuclear Laboratory (NNL), the UK Nuclear Decommissioning Authority (NDA) the UK Department of Environment and Climate Change (DECC), and the European Commission's ANDES and CHANDA projects for supporting this work.