Experimental FY compilation and decay data corrections

NNDC

Current status of compilation of experimental FYs

- collect, compile and correct experimental FY data for:
  ^{238}U(n,f), **^{241}Pu(n,f)**, **^{239}Pu(n,f)**, ^{235}U(n,f)
- collect, compile, correct and evaluate **Isomeric Yield Ratios** from all fissioning systems (sf, n-, g-, p-induced)
- start from NSR database (expected to be more complete than EXFOR compilation)
- Import FY into database and implement correction for decay data
- Use dependencies // FY(A|Z), FY(Z|A), FY(Z,A,E) // to identify outliers or issues with experimental data
- Document and report EXFOR compilation issues, outliers, changes to uncertainties / experimental values, possibly unreliable measurements

Retrieval of references and exp. data

- started with 150-200+ references for each system -- identify useful references with NSR selectors / studying the papers
- Identify those that have / do not have a corresponding EXFOR entry (too recent, being worked on, not properly linked in the db, etc.)
- We used the table of references as the starting point of the data compilation

NOTE	NSR - BibNr	NSR link	Exp I/O	X4 link (paste here)	X4 data (entrynr)	EXFOR ENTRY	Details	En / E*	N
	1958BIZZ	https://www.nnd	☐		12356	dataset12356.	(n, F)	E=thermal	
	1964FA12	https://www.nnd	☐		13070	dataset13070.	(n, F) 131Xe/132Xe/133Xe/134Xe/135Xe/136Xe/1	E=thermal	
	1965OK03	https://www.nnd	☐		13076	dataset13076.	(n, F) 135I/140Ba	E=thermal	
	1966OK03	https://www.nnd	☐		13287	dataset13287.	(n, F) 135Xe	E=thermal	
	1970SK08	https://www.nnd	☐		41078	dataset41078.	(n, F) 141La/143Ce/145Pr/149Nd/149Pm/151Pm/	E=thermal	
	1970LI29	https://www.nnd	☐				(n, F)	E=thermal	
	1970LI28	https://www.nnd	☐		13270	dataset13270.	(n, F)	E=thermal	
	1970KRZU	https://www.nnd	☐				(n, F)		
	1970JA03	https://www.nnd	☐		10125	dataset10125.	(n, F)	E=thermal	
	1971SO19	https://www.nnd	☐		41080	dataset41080.	(n, F)	E=slow	
	1971LI12	https://www.nnd	☐		13285	dataset13285	(n, F) 85Kr	E=thermal	
	1972JA17	https://							
	1973CHVZ	https://							
	1974WA20	https://							
	1975MAZV	https://							
	1977RA13	https://							
	1977BR11	https://							

NSR - BibNr	NSR link	Exp I/O	X4 data (entrynr)			pdf I/O	Details	En / E*	Note (from
2019RA07	https:/	1	n/a		0	1	1-n transfer reaction (CN: 238U)	7.4MeV Eex	
2019RA23	https:/	1	n/a		0	1	1-n transfer reaction (CN: 239U)	near barrier fission	
2019FO04	https:/	1	https://www.	https://www.nnd	14522	1		fast	
2017PE08	https:/	1	n/a		0	1		CoulEx	SOFIA/A
2017WI09	https:/	1	https://www.nr	https://www.nndc	23403	1	anomaly (see 2019FO04)		
2017NA17	https:/	1	https://www.nr	https://www.nndc	33106	1	charge distributions		
2017HI10	https:/	1	n/a		0	1	inv-kin | multinucleon transfer reaction | FFMD	E* > 10-20 MeV	
2017UL01	https:/	1	n/a		0	1	inv-kin | NO FY data		
2016GO02	https:/	1	n/a		0	1	FY mass distro | new data? Also see: LLNL	0.5-14.8 MeV	dual-fis
2016DU22	https:/	1	https://www.nr	https://www.nndc	14463	1	mass landscape / Fragment Y	1-30MeV	
2015NA13	https:/	1	https://www.	https://www.nnd	33093	1	FP offline: Y, peak/valley ratio	E=6.35, 8.53, 12.52 MeV	
2015BH09	https:/	1	https://www.	https://www.nnd	14423	1	92Sr 97Zr 99Mo 132Te 133I 140Ba 143Ce 14	8.9 MeV	TUNL
2015VO11	https:/	1	https://www.nr	https://www.nndc	0	1	inv-kin		
2014TO09	https:/	1	https://www.nr	https://www.nndc	14402	1	XS / Yields?	<200 MeV	
2014HA25	https:/	1	https://www.nr	https://www.nndc	23280	1	XS / Yields?	0.2-5 MeV	
2014GO06	https:/	1	https://www.nr	https://www.nndc	41598	1	FF yields		
2014BH11	https:/	1	n/a		0	1	FPY ratio	E=4.6, 9.0, 14.5 MeV	
2013NA18	https:/	1	https://www.	https://www.nnd	33052	1	FY mass distro	E=3.72, 5.42, 7.75, 10.09 MeV	
2013KH11	https:/	1	https://www.nr	https://www.nndc	41483	1	FFY's	E=5, 6.5 MeV	
2013GR14	https:/	1	https://www.nr	https://www.nndc	14377	1	deduced atomic X-ray yields per fission	0.7-400MeV	
2012FI07	https:/	1	https://www.nr	https://www.nndc	14441	1	FPs mass distro	0.00001 - 10 MeV	
2012RUZZ	https:/	1	n/a		0	1			
2011RY09	https://e of 2011RY04?				0				
2010SE15	https:/	1	n/a		0	1	99Mo/95Zr/137Cs/140Ba/141,143Ce/147Nd	E=0.4-1.9 MeV	LANL
2010AD13	https:/	1	https://www.nr	https://www.nndc	41529	1	inv-kin --> the X4 file doesn't contain all info?		

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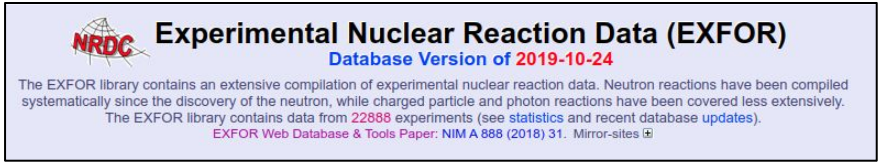
EXFOR → JSON-FY → FYdb



{JSON}
JavaScript Object Notation

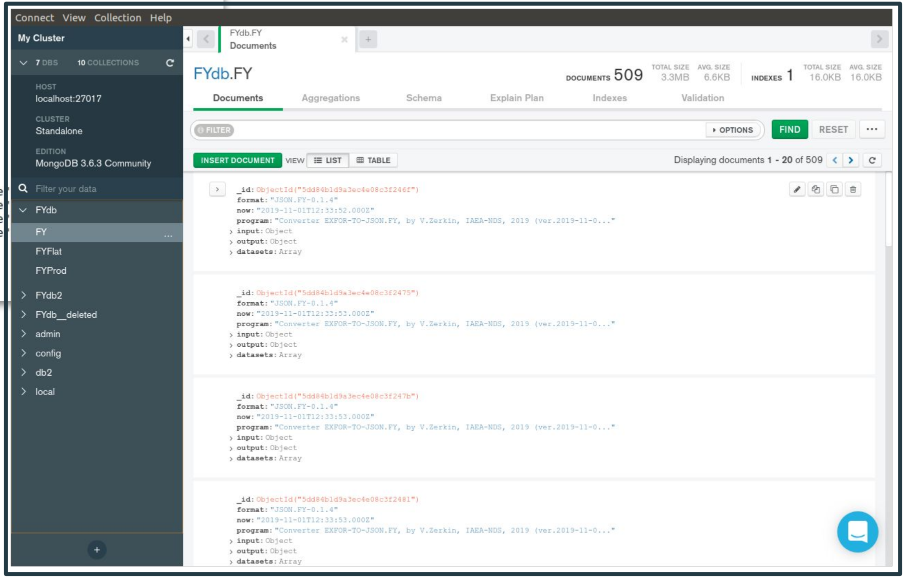
- Search EXFOR for selected entries linked from NSR (accession number or authors)
- Extract a list of datasets using an EXFOR search
- cross-reference and identify missing links / missing datasets

- Reformat JSON-FY from EXFOR to a more streamlined structure
- Store in data-structure for easy access (pandas+JSON) and in OO-database for storage and query
- Format allows for flags / annotation / comments and to include changes to the data

EXFOR → JSON-FY → FYdb


```
{
 "format":"JSON.FY-0.1.5"
,"now":"2022-08-28T14:28:03.000Z"
,"program":"Converter EXFOR-TO-JSON.FY, by V.Zerkin, IAEA-NDS, 2019-2022 (ver.2022-07-20)"
,"input": {  "files": [ {"name":"X4R1464_x4.txt", "format":"EXFOR", "created":"2022-08-28T14:20:11.000Z" } ] }
,"output": { "files": [ {"name":"X4R1464_x4.txt.x4jsonFy", "outBib":"0", "created":"2022-08-28T14:28:03.000Z" } ] }
,"datasets": [

{ "type":"FYdata", "id":"10517004"
 ,"subent":{"id":"10517004", "updated":"20040427" }
 ,"entry":{"id":"10517", "updated":"20040427" }
 ,"author1":"K.F.Flynn+"
 ,"year":1975
 ,"ref1":{"code":"J,JIN,37,869,197504"
         ,"exp":"Jour: Journal of Inorganic and Nuclear Chemistry, Vol.37, p.869 (1975)"
         }
 ,"reaction": {
    "code":"94-PU-239(N,F)ELEM/MASS,IND,FY"
   ,"Proj":"N"
   ,"Target":"94-PU-239"
   ,"ReactionType":"FY"     ,"MF":801   ,"ReacTypeExp":"Fission product yield"
   ,"DataType":"IND,FY"
   ,"Quantity":"Independent fission-product yield"
   ,"IndVarFamCode":"0 2     7"
 }
 ,"incEnergies": [
   {"incEnergy":2.53e-05,"incEnergyUnits":"KEV","Data":"IND_FY","DataUnits":"PART/FIS"
   ,"Products": [
     {"Z":37 ,"A":84       , "Nucl":"Rb-84"     ,"Data":3.9e-10   ,"dData":4.0e-11   ,"t12sec":2851200    ,"Radiations":[ {"Type
    ,{"Z":37 ,"A":86       , "Nucl":"Rb-86"     ,"Data":1.9e-06   ,"dData":2.0e-07   ,"t12sec":1615680    ,"Radiations":[ {"Type
    ,{"Z":55 ,"A":136      , "Nucl":"Cs-136"    ,"Data":0.001     ,"dData":0.0001    ,"t12sec":1140480    ,"Radiations":[ {"Type
                                                                                                                    ,{"Type
    ]
  }
 ]
}
```

- import simplified JSON-FY format into FYdb
- with ^{241}Pu compilation, development of a python code to streamline the conversion / upload process

Decay data correction

- about 20-30% of EXFOR entries contain some sort of information on decay data used in the experiment
- update decay data with latest values from ENSDF/NuDat
- initially hand-retrieved data, with compilation of ^{239}Pu implemented an automatic retrieval system using the new NuDat json format

X4

implement corrections in .json files -- use .csv file to flag outliers / compilations errors

Format (cleanup) .csv + create list of available radcorr files

Correction of .json files

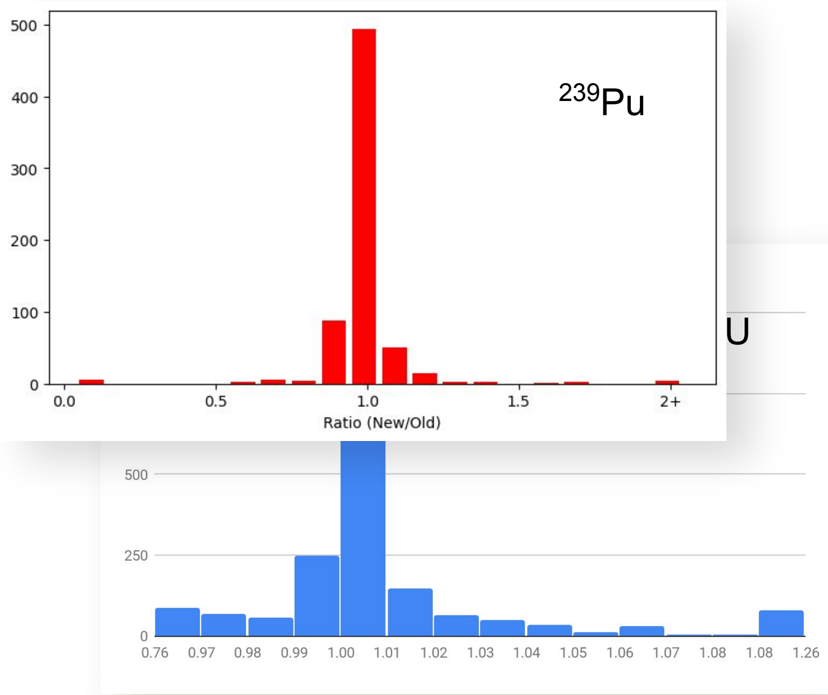
Update db + create FY .csv

EXFOR id	NSR	year	author1	incEnergy (keV)	Z	A	Nucl	Nudat www	t1/2 (sec)	new t12sec	ENSDF cutoff YEAR	Rad.Energy (keV)	Rad.Intensity	New Rad.Intensity	New Rad.IntensityUnc
31538002	2000IY01	2000	R.H.Iyer+	1900	35	83	Br-83	https://www	8604	8546	2014	529.5	0.013	0.013	0.004
30639003		1976	S.Daroczy+	14400	34	83	Se-83-G	https://www	1350	1335	2014	356.6	0.686	0.694	0.0085
33052003	2013NA18	2013	H.Naik+	3720		84	A84		1908	1906	2009	1616.2	0.062	0.0622	0.0077
33052003	2013NA18	2013	H.Naik+	5420		84	A84		1908	1906	2009	1616.2	0.062	0.0622	0.0077
33052003	2013NA18	2013	H.Naik+	7750		84	A84		1908	1906	2009	1616.2	0.062	0.0622	0.0077
33052003	2013NA18	2013	H.Naik+	10090		84	A84		1908	1906	2009	1616.2	0.062	0.0622	0.0077
14500003	2017PI01	2017	B.D.Pierson+	14300	33	84	As-84	https://www	4.2	4.2	2009	1454.55	0.89	0.89	0.082
10828003	1978CH05	1978	T.C.Chapman+	8100	35	84	Br-84	https://www	1908	1906	2009	881.5	0.42	0.42	0.03
10828003	1978CH05	1978	T.C.Chapman+	9100	35	84	Br-84	https://www	1908	1906	2009	881.5	0.42	0.42	0.03
10828003	1978CH05	1978	T.C.Chapman+	7100	35	84	Br-84	https://www	1908	1906	2009	881.5	0.42	0.42	0.03
33052002	2013NA18	2013	H.Naik+	3720	35	84	Br-84	https://www	1908	1906	2009	1616.2	0.062	0.0622	0.0077
33052002	2013NA18	2013	H.Naik+	5420	35	84	Br-84	https://www	1908	1906	2009	1616.2	0.062	0.0622	0.0077
33093002	2015NA13	2015	H.Naik+	6350	35	84	Br-84	https://www	1908	1906	2009	1616.2	0.062	0.0622	0.0077
33052002	2013NA18	2013	H.Naik+	7750	35	84	Br-84	https://www	1908	1906	2009	1616.2	0.062	0.0622	0.0077
33052002	2013NA18	2013	H.Naik+	10090	35	84	Br-84	https://www	1908	1906	2009	1616.2	0.062	0.0622	0.0077
33093002	2015NA13	2015	H.Naik+	6350	35	84	Br-84	https://www	1908	1906	2009	1616.2	0.062	0.0622	0.0077
33093002	2015NA13	2015	H.Naik+	8530	35	84	Br-84	https://www	1908	1906	2009	1616.2	0.062	0.0622	0.0077
33093002	2015NA13	2015	H.Naik+	9350	35	84	Br-84	https://www	1908	1906	2009	1616.2	0.062	0.0622	0.0077
33093002	2015NA13	2015	H.Naik+	12520	35	84	Br-84	https://www	1908	1906	2009	1616.2	0.062	0.0622	0.0077
33093002	2015NA13	2015	H.Naik+	8530	35	84	Br-84	https://www	1908	1906	2009	1616.2	0.062	0.0622	0.0077
33093002	2015NA13	2015	H.Naik+	9350	35	84	Br-84	https://www	1908	1906	2009	1616.2	0.062	0.0622	0.0077
33093002	2015NA13	2015	H.Naik+	12520	35	84	Br-84	https://www	1908	1906	2009	1616.2	0.062	0.0622	0.0077
10828003	1978CH05	1978	T.C.Chapman+	6000	35	84	Br-84-G	https://www	1908	1906	2009	881.5	0.42	0.42	0.03

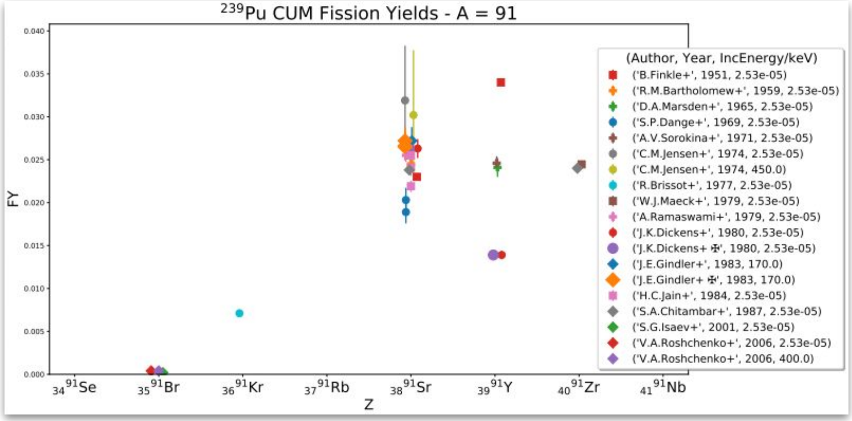
check decay → main source of corrections for EXFOR compiled yields (revisions for ~20 EXFOR entries for ^{239}Pu(n,f) were reported to Boris & Naohiko)

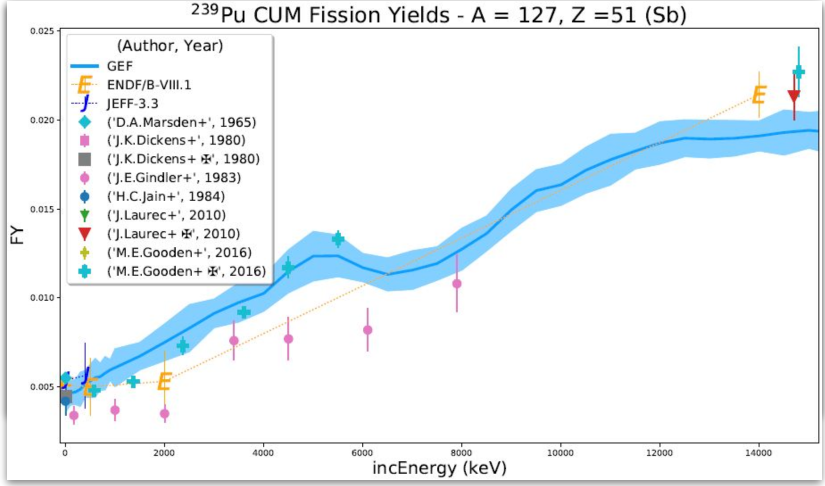
FY correction & update

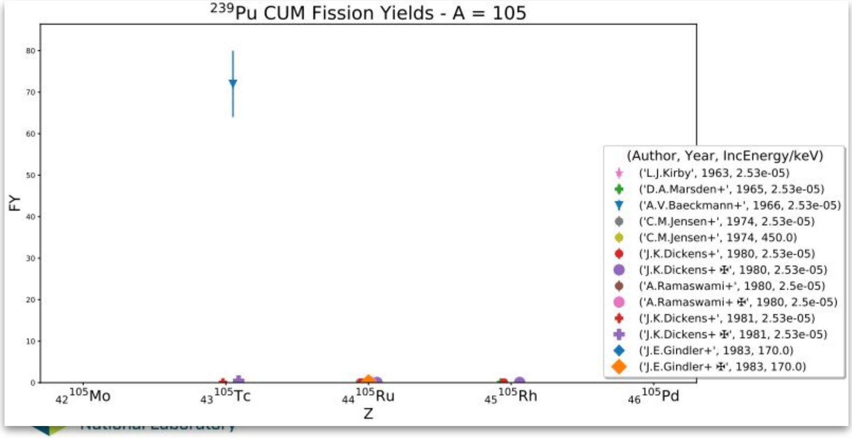
- For experiments that used γ-ray intensities to determine FYs, the correction can be implemented
- If the values used in the experiments were reported/referenced in the original paper we checked their currency and update the FY if necessary.
- The majority of the corrections are within uncertainties, but correction factors for older experiments can be significant



Flagging / Corrections / Nuclear Data Update

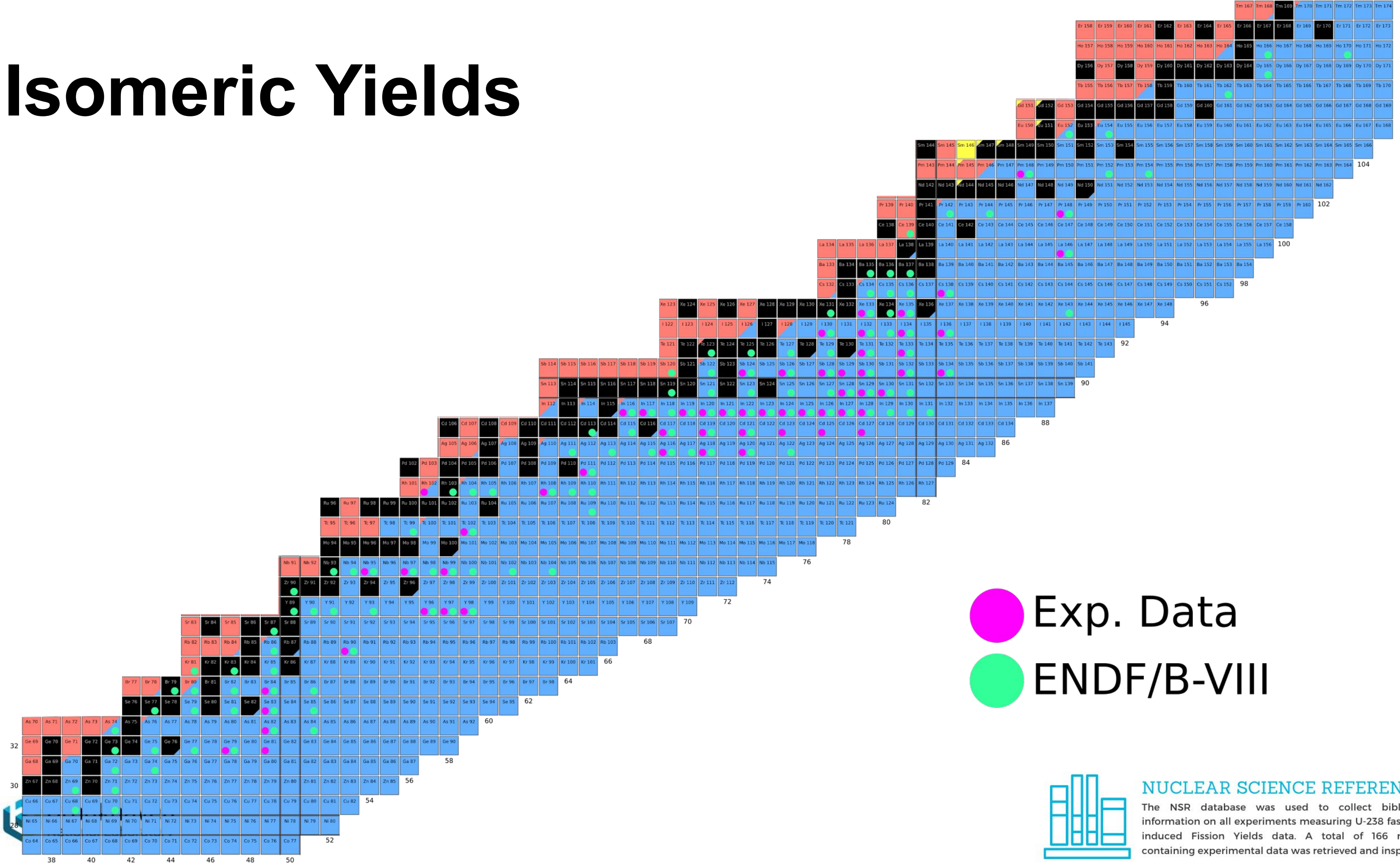






- use dependences to identify and flag outliers / compilation errors / conversion issues
- document changes in the database
- Open issue -- relative measurements: they are included in our database, but not corrected (yet). New value for the reference yield?

Isomeric Yields



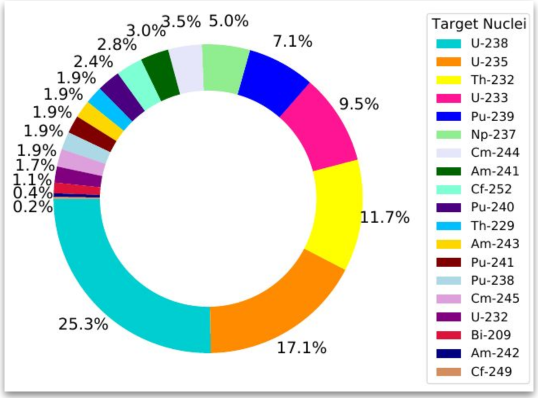
NUCLEAR SCIENCE REFERENCES

The NSR database was used to collect bibliographic information on all experiments measuring U-238 fast-neutron induced Fission Yields data. A total of 166 references containing experimental data was retrieved and inspected.

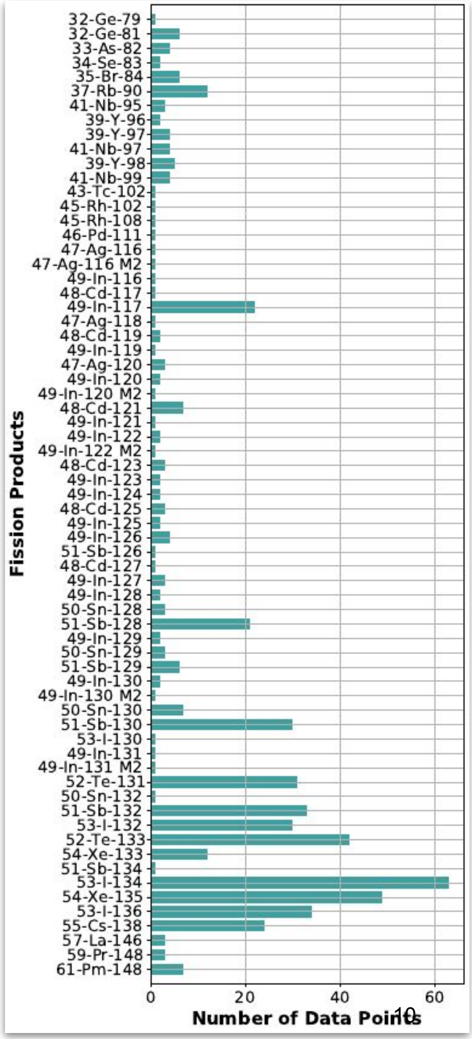
Evaluation of Isomeric Yield Ratios

We retrieved and compiled 538 independent isomeric yield ratios, from 39 compound nuclei, and 62 unique fission products.

5x the amount of data available to Madland & England when they developed the model



Wealth of new data can be used to benchmark new models for the prediction of IYRs



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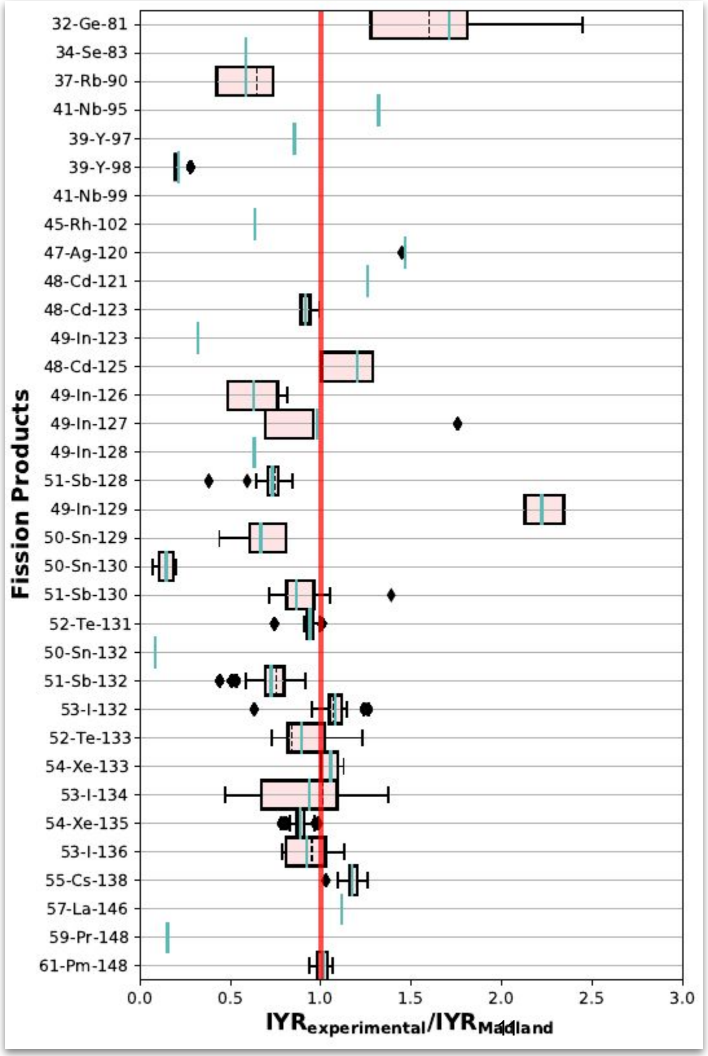
Evaluation of Isomeric Yield Ratios

- compiled all the independent IYR we found in the literature (NSR + EXFOR) for all fissioning systems and energies
- identification of **outliers** (decay data, isomeric state assignments, trends vs IYR in other measured systems)
- **averaging** of IYR for low-energy n-induced fission (E_n < 2 MeV) -- assumption is that IYR does not change dramatically for these low energies
- new **recommended** experimental yields often incompatible with the Madland & England model



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Recommended Experimental Yields

Available online at www.sciencedirect.com
ScienceDirect
Nuclear Data Sheets 173 (2021) 118–143
ELSEVIER
Nuclear Data Sheets
www.elsevier.com/locate/nds

Compilation and Evaluation of Isomeric Fission Yield Ratios

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(Received February 18, 2021; accepted March 25, 2021)

Fission yields are essential data for reactor physics, forensics, and astrophysics. In some cases, the fission yield of a fragment is divided between the ground state and a long-lived excited state, and the relative population of the two states is referred to as the isomeric ratio. In this work, we present a comprehensive compilation of experimental isomeric fission yield ratios for all target and projectile combinations. When possible, these data are combined to provide recommended isomeric fission

- **Use the recommended experimental values** in evaluations for the available nuclides.
- 42 recommended values for low-energy n-induced fission can be used in the next FY evaluation
- The compiled experimental data can be used to extensively test current models

TABLE II: Recommended IYR values for all low-energy (thermal to 2 MeV) n-induced fission reactions on any fissionable target. The recommended yield ratios are expressed in the M/T form. The number of data points in brackets represents the number of values excluded from the average because considered statistical outliers.

Fission Product	Recomm. IYR (M/T)	Nr. of data points
32-Ge-81	0.32(4)	3
34-Se-83	0.11(7)	1
37-Rb-90	0.526(30)	3 *(1)*
41-Nb-95	0.248(29)	1
39-Y-97	0.695(14)†	1
39-Y-98	0.139(6)	2
41-Nb-99	0.83(17)	1 *(1)*
45-Rh-102	0.44(14)	1
47-Ag-120	0.86(4)	2 *(1)*
49-In-120	0.21(20)	1
49-In-120 M2	0.27(25)	1
48-Cd-121	0.89(11)	1
49-In-122	0.24(10)	1
49-In-122 M2	0.48(20)	1
48-Cd-123	0.65(6)	2
49-In-123	0.07(7)	1
48-Cd-125	0.85(5)	2
49-In-126	0.30(5)	3
49-In-127	0.185(31)	3
49-In-128	0.30(7)	1
51-Sb-128	0.463(16)†	14
49-In-129	0.42(6)	2
50-Sn-129	0.47(4)	3
49-In-130	0.25(5)	1
49-In-130 M2	0.41(7)	1
50-Sn-130	0.089(7)	4
51-Sb-130	0.499(17)†	18

†: uncertainty recalculated from statistical value to reflect possible systematic sources (see text for details).

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Documenting changes and updates

BNL-219899-2020-INRE

National Nuclear Data Center
BNL-219899-2020-INRE

Impact of current decay data on fast neutrons ^{238}U fission yields measured with the activation technique

A. Mattera[1 ♦], A.A. Sonzogni[1], E.A. McCutchan[1], V. Zerkin[2], B. Pritychenko[1], J. Totans[1], G. Fabricante[1]

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[2] Nuclear Data Section, IAEA, Vienna International Centre, P.O. Box 100, A-1400 Vienna, Austria

Abstract
Fission product yields are among the key observables of nuclear fission, important for nuclear applications and theory alike.
For the major actinides, experimental data represent the foundation of the fission yields evaluation process. As part of a larger effort aimed at updating the fission yields evaluation currently included in the ENDF/B nuclear data library, a new compilation of fission yields from fast-neutrons induced fission of ^{238}U has been carried out at the National Nuclear Data Center.
In the compilation process, the currency of nuclear data used to derive the measured fission yield was checked and, whenever possible, brought up to date using the latest values available from the ENSDF database. In this report we will describe the steps taken so far, and the future work to extend this correction procedure to additional fissioning systems.

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Contents

National Nuclear Data Center

A curated compilation of ^{239}Pu fission product yields and impact of updated decay data.

N. Joseph[1], A. Mattera[1 ♦], A.A. Sonzogni[1], E.A. McCutchan[1], V. Zerkin[2], B. Pritychenko[1], J. Totans[1]

[1] National Nuclear Data Center, Building 817, Brookhaven National Laboratory, Upton, NY 11973-5000, USA
[2] Nuclear Data Section, IAEA, Vienna International Centre, P.O. Box 100, A-1400 Vienna, Austria

Abstract
Fission product yields from neutron-induced fission of ^{239}Pu have been extracted from the EXFOR database, compiled and - wherever possible - corrected using the latest values of decay data intensities from the Evaluated Nuclear Structure Data Files (ENSDF) database.
This report will present the methodology and the improvements implemented to automate the time-consuming correction process, taking advantage of the improvements implemented during the ENSDF modernization process.

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Contents

Hey!

Introduction

As part of the evaluation effort undertaken by the Cross Section Evaluation Working Group (CSEWG), exper-

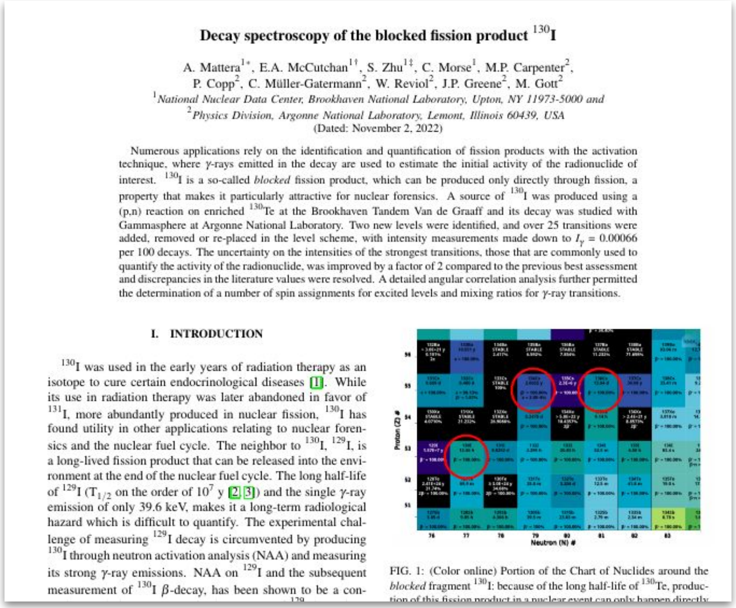
Improvements in the methodology for retrieval and correction of fission yields

- BNL tecrep for ^{239,241}Pu will be out before the end of the year
- Share data with Amy Lovell → feedback and correction with model comparison
- started extraction of ^{235}U data with a new SULI student (J. Henry)

NNDC Experimental activities

Improve decay data (BR) for selected fission products:

- ^{130}I - experiment performed in summer 2021. PRC under reviewed
- ^{140}La - experiment performed in summer 2021. Finalyzing analysis
- ^{135}I + ^{135}Xe - experiment at ANL (Oct. 2022)
- ^{143}Ce - experiment at UMass Lowell / BNL (Oct. 2022)



Decay spectroscopy of the blocked fission product ^{130}I

A. Mattera[1*], E.A. McCutchan[1†], S. Zhu[1‡], C. Morse[1], M.P. Carpenter[2],
P. Copp[2], C. Müller-Gatermann[2], W. Reviol[2], J.P. Greene[2], M. Gott[2]
[1] *National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY 11973-5000 and*
[2] *Physics Division, Argonne National Laboratory, Lemont, Illinois 60439, USA*
(Dated: November 2, 2022)

Numerous applications rely on the identification and quantification of fission products with the activation technique, where γ-rays emitted in the decay are used to estimate the initial activity of the radionuclide of interest. ^{130}I is a so-called *blocked* fission product, which can be produced only directly through fission, a property that makes it particularly attractive for nuclear forensics. A source of ^{130}I was produced using a (p,n) reaction on enriched ^{130}Te at the Brookhaven Tandem Van de Graaff and its decay was studied with Gammasphere at Argonne National Laboratory. Two new levels were identified, and over 25 transitions were added, removed or re-placed in the level scheme, with intensity measurements made down to $I_\gamma = 0.00066$ per 100 decays. The uncertainty on the intensities of the strongest transitions, those that are commonly used to quantify the activity of the radionuclide, was improved by a factor of 2 compared to the previous best assessment and discrepancies in the literature values were resolved. A detailed angular correlation analysis further permitted the determination of a number of spin assignments for excited levels and mixing ratios for γ-ray transitions.

I. INTRODUCTION

^{130}I was used in the early years of radiation therapy as an isotope to cure certain endocrinological diseases [1]. While its use in radiation therapy was later abandoned in favor of ^{131}I, more abundantly produced in nuclear fission, ^{130}I has found utility in other applications relating to nuclear forensics and the nuclear fuel cycle. The neighbor to ^{130}I, ^{129}I, is a long-lived fission product that can be released into the environment at the end of the nuclear fuel cycle. The long half-life of ^{129}I ($T_{1/2}$ on the order of 10^7 y [2, 3]) and the single γ-ray emission of only 39.6 keV, makes it a long-term radiological hazard which is difficult to quantify. The experimental challenge of measuring ^{129}I decay is circumvented by producing ^{130}I through neutron activation analysis (NAA) and measuring its strong γ-ray emissions. NAA on ^{129}I and the subsequent measurement of ^{130}I β-decay, has been shown to be a con-

FIG. 1: (Color online) Portion of the Chart of Nuclides around the *blocked* fragment ^{130}I: because of the long half-life of ^{130}Te, produc-