RIKEN Cross Section Data Update

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Overview

- Current RIKEN ^{238}U cross section data requires updating for models to maintain accuracy.
- Provide updated data from the following approved papers containing experimental cross-section data from in-flight fission reactions at RIKEN:
  - N. Fukuda et. al, JPSJ 87 014202 (2018)
  - **Y. Shimizu et. al, JPSJ 87, 014203 (2018)**
  - Y. Shimizu et. al, PRC 109, 044313 (2024)
  - T. Sumikama et. al, PRC 95, 051601(R) (2017)
  - T. Sumikama et. al, PRC 103, 014614 (2021)
  - ***H. Suzuki et. al, NIMB 317, 752-756 (2013) – Does not contain ^{238}U projectile data***

- **Note:** Bolded and underlined sources contain statistical or systematic errors for some (or all for Y.Shimizu (2018)) cross section data at ~50% uncertainty in cross-section

Finding X4 Cross-Section Data

- Navigating through the NNDC's Nuclear Science References (NSR) page, search for the first author's name (as in paper) and identify the appropriate reference for the paper.
  - Filtering by *EXFOR Data Available* option simplifies the search for easy-to-access cross-section data
    - » See link for example search
- From the X4 data selection screen, simply customize and submit the data request and identify the desired file.
  - For cross-section data, choose EXFOR Original file for download
    - » This includes a summary of the paper's information and the data with readable formatting

Fig. 1: NSR UI for Y. Shimizu PRC 2024. *Highlighted left to right: EXFOR link, first author, and reference.*

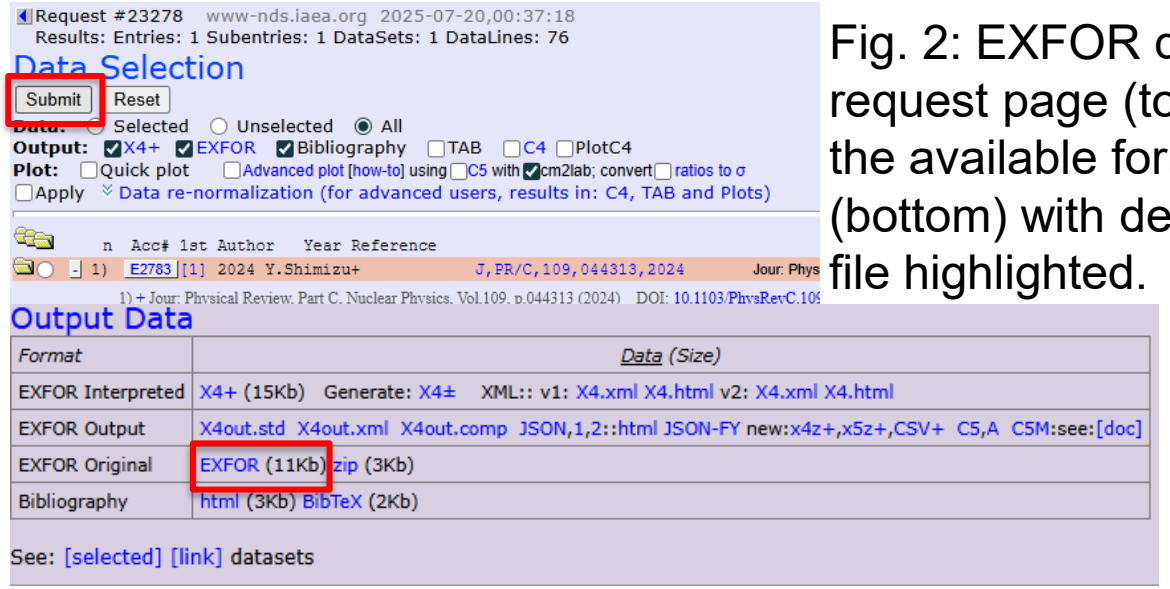

Fig. 2: EXFOR data request page (top) and the available formats (bottom) with desired file highlighted.

Resulting data

- From the EXFOR data, enter cross section values with Z and N numbers followed by cross section (in mb), lower error in cross section and the source in the fifth column.
  - Optionally include information in comments metadata regarding unclear decisions made on the data like systematic uncertainty (see note in slide 2)
- Data from the first 5 papers in Slide 2 provides the following N vs. Z counts of CS data:
  - There is an identifiable gap in data within the Z = ~42-55 range
  - Likely missing data from ^{124}Xe beam in the paper from H. Suzuki
    - » Data was manually entered for ^{124}Xe beam as it was not represented in the EXFOR data

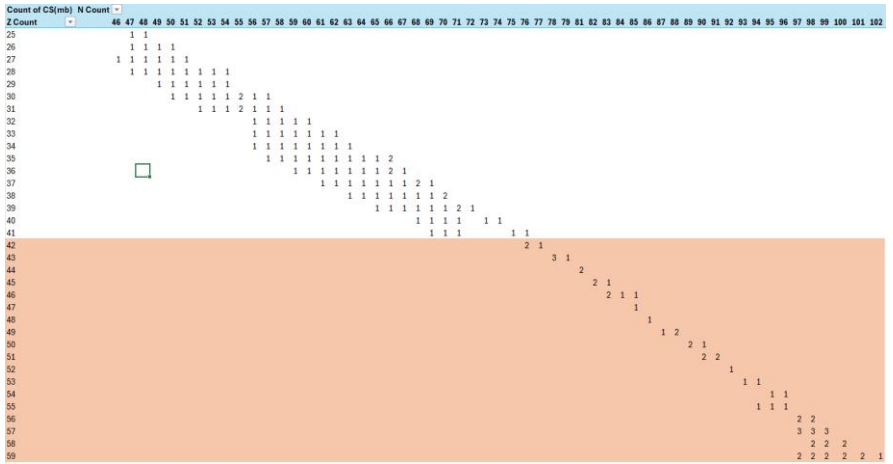

Fig. 3: Z vs. N table for counts of CS data from papers.

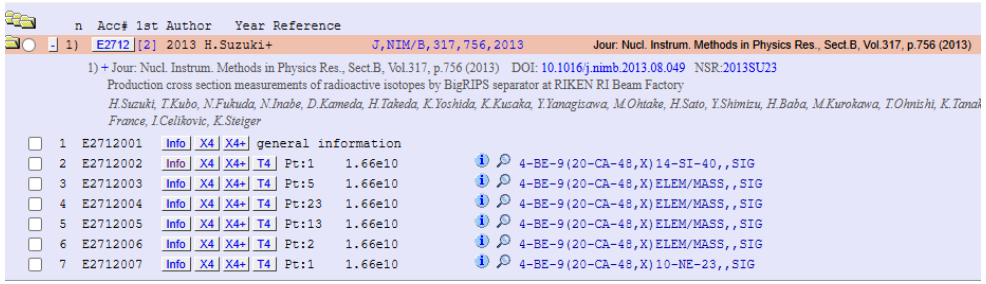

Fig. 4: EXFOR data included for H. Suzuki paper.

Gap Region Problem

- Problem area from roughly Z=42-55. Expanding with sources, we see Y. Shimizu (2018) is primary source of CS data in this region.
  - Investigate Y. Shimizu (2018) paper and identify why other similar papers are not providing supporting data within this region
- The table only accounts for in-flight fission data, H. Suzuki is not considered in this table as it covers fragmentation values.
- On the right we see the H. Suzuki data alone in a similar table.
  - This data is the manually copied data from the paper itself for ^{124}Xe beam

⊟42	2	1																		
Y.Shimizu et. al, JPSJ 87, 014203 (2018)	2	1																		
⊟43			3	1																
Y.Shimizu et. al, JPSJ 87, 014203 (2018)			3	1																
⊟44					2															
Y.Shimizu et. al, JPSJ 87, 014203 (2018)					2															
⊟45						2	1													
Y.Shimizu et. al, JPSJ 87, 014203 (2018)						2	1													
⊟46							2	1	1											
Y.Shimizu et. al, JPSJ 87, 014203 (2018)							2	1	1											
⊟47									1											
Y.Shimizu et. al, JPSJ 87, 014203 (2018)									1											
⊟48										1										
Y.Shimizu et. al, JPSJ 87, 014203 (2018)										1										
⊟49											1	2								
Y.Shimizu et. al, JPSJ 87, 014203 (2018)											1	2								
⊟50													2	1						
Y.Shimizu et. al, JPSJ 87, 014203 (2018)													2	1						
⊟51														2	2					
Y.Shimizu et. al, JPSJ 87, 014203 (2018)														2	2					
⊟52																1				
Y.Shimizu et. al, JPSJ 87, 014203 (2018)																1				
⊟53																	1	1		
Y.Shimizu et. al, JPSJ 87, 014203 (2018)																	1	1		
⊟54																			1	1
Y.Shimizu et. al, JPSJ 87, 014203 (2018)																			1	1
⊟55																		1	1	1
Y.Shimizu et. al, JPSJ 87, 014203 (2018)																		1	1	1

Fig. 5: Fission pivot table in interest region.

Count of CS(mb)	Column Labels																													
Row Labels	11	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	39	40	41	42	48	49	50	51	52	53	54	55	56	Grand Total
5			1																												1
6		2	2		2																										6
7				1																											1
8			2		3																										5
10	1	1			1		1	2	2	1	1																				10
12		1		1		1			2	1	1	1	1	1	1																11
13										1							1														2
14														1	2	1	2														6
16													1		1		1														3
42																		1	1												2
44																				1	1	1									3
45																							1	1							2
46																						1	1	1							3
47																							1	1	1						3
48																								1	1	1					3
49																								1	1	1	1				4
50																								1	1	1	1	1	1	1	7
51																											1				1
52																											1	1			2
Grand Total	1	4	5	2	6	1	1	2	4	3	2	1	2	2	4	1	4	1	1	1	1	2	3	6	4	3	4	2	1	1	75

Fig. 6: Fragmentation Pivot Table

T. Ohnishi Paper Inclusion

- The paper from *Y. Shimizu (2018)* paper is the primary contributor to counts of cross section measurements in the Z=42-54 region.
- Within the paper, there are consistent references to *T. Ohnishi et. al, JPJ 79, 073201 (2010)* as an additional source of measurements of cross-sections with a Uranium beam.
  - Locating the X4 Data as done in Slide 4, the data is imported and added to the pivot table
- The new paper includes 26 new cross sections in the Z=40-56 range.
  - The boxed region indicates the primary region of contribution

Count of CS(mb)	Column Labels																														
Row Labels	68	69	70	71	73	74	75	76	77	78	79	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	Grand Total
40	1	1	1	1	1	1																								6
41		1	1	1			1	1																						5
42								2	1																					3
43										3	1																			4
44												2																		2
45													2	1																3
46														2	1	1														4
47																1														1
48																	1													1
49																		1	2											3
50																				2	1									3
51																					2	2								4
52																							1							1
53																								1	1					2
54																										1	1			2
55																									1	1	1			3
56																												2	2	4
Grand Total	1	2	2	2	1	1	1	3	1	3	1	2	2	3	1	2	1	1	2	2	3	2	1	1	2	2	2	2	2	51

Fig. 7: Pivot table without T. Ohnishi data.

Count of CS(mb)	Column Labels																														
Row Labels	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	Grand Total
40	1	1	1	2	1	1	1																									8
41		1	1	1		1	1	1	1																							7
42						1	1	1	2	1																						6
43									1	1	3	1																				6
44										1	1	1	1	2																		6
45											1	1	1	1	2	1																7
46															1	1	2	1	1													6
47																		1														1
48																		2	1													3
49																				1	2											3
50																					1	2	1									4
51																					1	2	2									5
52																							1	1								2
53																								1	1	1						3
54																										1	1	1				3
55																										1	1	1				3
56																													2	2	4
Grand Total	1	2	2	3	1	3	3	2	4	3	5	3	2	4	3	3	1	4	1	1	3	3	3	3	2	1	3	2	2	2	2	77

Fig. 8: Pivot table with T. Ohnishi data.

Inclusion of Feldman Statistical Uncertainty

- Certain sources include systematic or statistical uncertainty within the EXFOR dataset (ERR-S or ERR-SYS).
- For ERR-SYS only, the Feldman-Cousins confidence level is constructed based on counts for CS values from XUNDL datasets accessed through the NSR.
  - Depends on counts, acceptable for under 20 counts of a signal
  - Follows from *G. Feldman & R. Cousins, PRD 57, 3873 (1998)*
- The relative error from the Feldman-Cousins method is added in quadrature with the systematic relative uncertainty to create a new error bars for the data.

	-	+
n0 / b	0	
0	0	1.29
1	0.37	2.75
2	0.74	4.25
3	1.1	5.3
4	2.34	6.78
5	2.75	7.81
6	3.82	9.28
7	4.25	10.3
8	5.3	11.32
9	6.33	12.79
10	6.78	13.81
11	7.81	14.82
12	8.83	16.29
13	9.28	17.3
14	10.3	18.32
15	11.32	19.32
16	12.33	20.8
17	12.79	21.81
18	13.81	22.82
19	14.82	23.82
20	15.83	25.3

	aboslute		relative	
	-dY	+dY	-dY	+dY
1	0.63	1.75	-63%	175%
2	1.26	2.25	-63%	113%
3	1.9	2.3	-63%	77%
4	1.66	2.78	-42%	70%
5	2.25	2.81	-45%	56%
6	2.18	3.28	-36%	55%
7	2.75	3.3	-39%	47%
8	2.7	3.32	-34%	42%
9	2.67	3.79	-30%	42%
10	3.22	3.81	-32%	38%
11	3.19	3.82	-29%	35%
12	3.17	4.29	-26%	36%
13	3.72	4.3	-29%	33%
14	3.7	4.32	-26%	31%
15	3.68	4.32	-25%	29%
16	3.67	4.8	-23%	30%
17	4.21	4.81	-25%	28%
18	4.19	4.82	-23%	27%
19	4.18	4.82	-22%	25%
20	4.17	5.3	-21%	27%

Fig. 9: Feldman statistics tables.

Summary

- Fission cross section data for ^{238}U beams at 345MeV/U on ^{9}Be is constructed from various papers detailing experiments done at RIKEN laboratory.
  - Intended to update the BigRIPS dataset used in cross section calculations in applications such as LISE^{++} for improved model predictions for isotope yields around Z = ~50
- Uncertainty statistics either sourced from papers or calculated with Feldman's statistical uncertainty to estimate errors in measurement.
  - Labeled as TOT1 (Feldman-Cousins) and TOT2 (quadrature) in tables

Z	N	CS(mb)	COUNT	SOURCE	TOT1-dCS[+]	TOT1-dCS[-]	TOT2-dCS[+]	TOT2-dCS[-]
57	97	2.58E-06	2080	N.Fukuda et. al, JPSJ 87, 014202 (2018)	#N/A	#N/A	6.48E-07	6.48E-07
57	98	1.20E-07	143	N.Fukuda et. al, JPSJ 87, 014202 (2018)	#N/A	#N/A	3.33E-08	3.33E-08
57	99	4.40E-09	5	N.Fukuda et. al, JPSJ 87, 014202 (2018)	3.310E-09	2.960E-09	5.30E-09	2.41E-09
58	98	4.84E-06	4920	N.Fukuda et. al, JPSJ 87, 014202 (2018)	#N/A	#N/A	1.21E-06	1.21E-06
58	99	2.00E-07	218	N.Fukuda et. al, JPSJ 87, 014202 (2018)	#N/A	#N/A	5.20E-08	5.20E-08
58	100	8.60E-09	11	N.Fukuda et. al, JPSJ 87, 014202 (2018)	5.235E-09	4.971E-09	7.53E-09	4.10E-09
59	97	1.04E-03	365000	N.Fukuda et. al, JPSJ 87, 014202 (2018)	#N/A	#N/A	2.60E-04	2.60E-04
59	98	1.34E-04	75700	N.Fukuda et. al, JPSJ 87, 014202 (2018)	#N/A	#N/A	3.35E-05	3.35E-05
59	99	7.38E-06	6100	N.Fukuda et. al, JPSJ 87, 014202 (2018)	#N/A	#N/A	1.85E-06	1.85E-06
59	100	6.80E-07	653	N.Fukuda et. al, JPSJ 87, 014202 (2018)	#N/A	#N/A	4.05E-07	4.05E-07
59	101	4.70E-08	38	N.Fukuda et. al, JPSJ 87, 014202 (2018)	#N/A	#N/A	2.58E-05	2.58E-05
59	102	6.70E-09	4	N.Fukuda et. al, JPSJ 87, 014202 (2018)	5.736E-09	4.354E-09	7.98E-09	3.72E-09
60	102	8.90E-08	68	N.Fukuda et. al, JPSJ 87, 014202 (2018)	#N/A	#N/A	2.55E-08	2.55E-08
60	103	3.50E-09	3	N.Fukuda et. al, JPSJ 87, 014202 (2018)	3.204E-09	2.824E-09	1.96E-08	3.28E-09

Fig. 10: Example fission cross section data drawn from the table.