Consultancy Meeting on the Preparation of a Major FENDL Release
May 13-15, 2025

IAEA

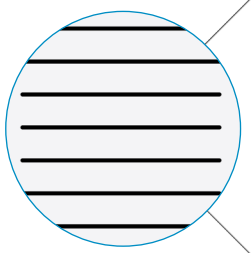
Modernizing Experimental Nuclear Data Access:
The IAEA Nuclear Reaction Data Explorer

Shin Okumura

1. **Nuclear Data Section**, Division of Physical and Chemical Sciences, Department of Nuclear Sciences and Applications, International Atomic Energy Agency

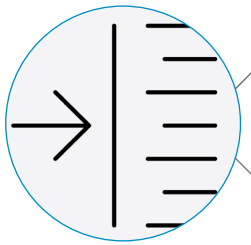
Background and Challenges

- Current nuclear data formats such as EXFOR, ENDF-6, XUNDL, and ENSDF inherited constraints from the Fortran era (Punch card legacy): making them difficult and often painful to first understand the format prior to use.



Challenges in data management and accessibility

due to ASCII text-based fixed-width formats, which complicate programmatic searching, version control, data retrieval, compatibility with plotting or visualization tools, and utilization of large-scale data to AI/ML application.



High entry barriers for newcomers

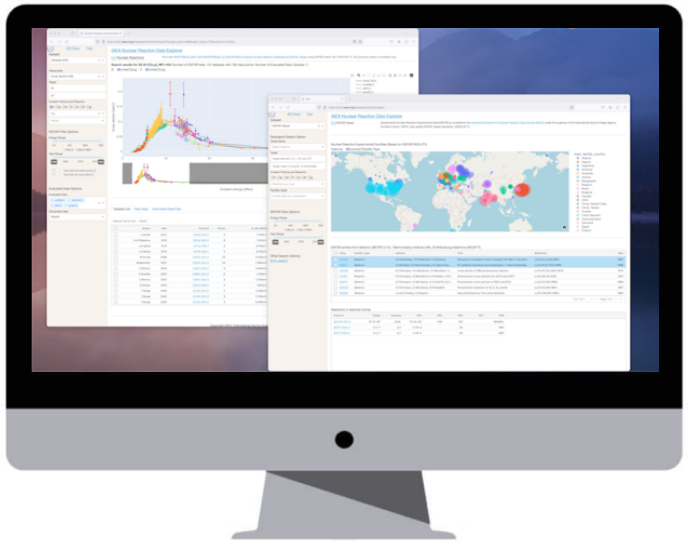
caused by the steep learning curve and the need for additional preprocessing or database support.

IAEA Nuclear Reaction Dataexplorer

- As only *experts* know how to work with ENDF-6 and EXFOR formatted data, it is necessary to decouple the presentation layer (UI) from the underlying data formats and access mechanisms for entry users.
- Solution:

https://nds.iaea.org/dataexplorer

Python 3 based, Open source project



Reaction based data plotter

- Input target and reaction to get evaluated and experimental datasets
  - Cross section
  - Thermal neutron cross section
  - Residual production cross section
  - Fission yield

EXFOR entry viewer

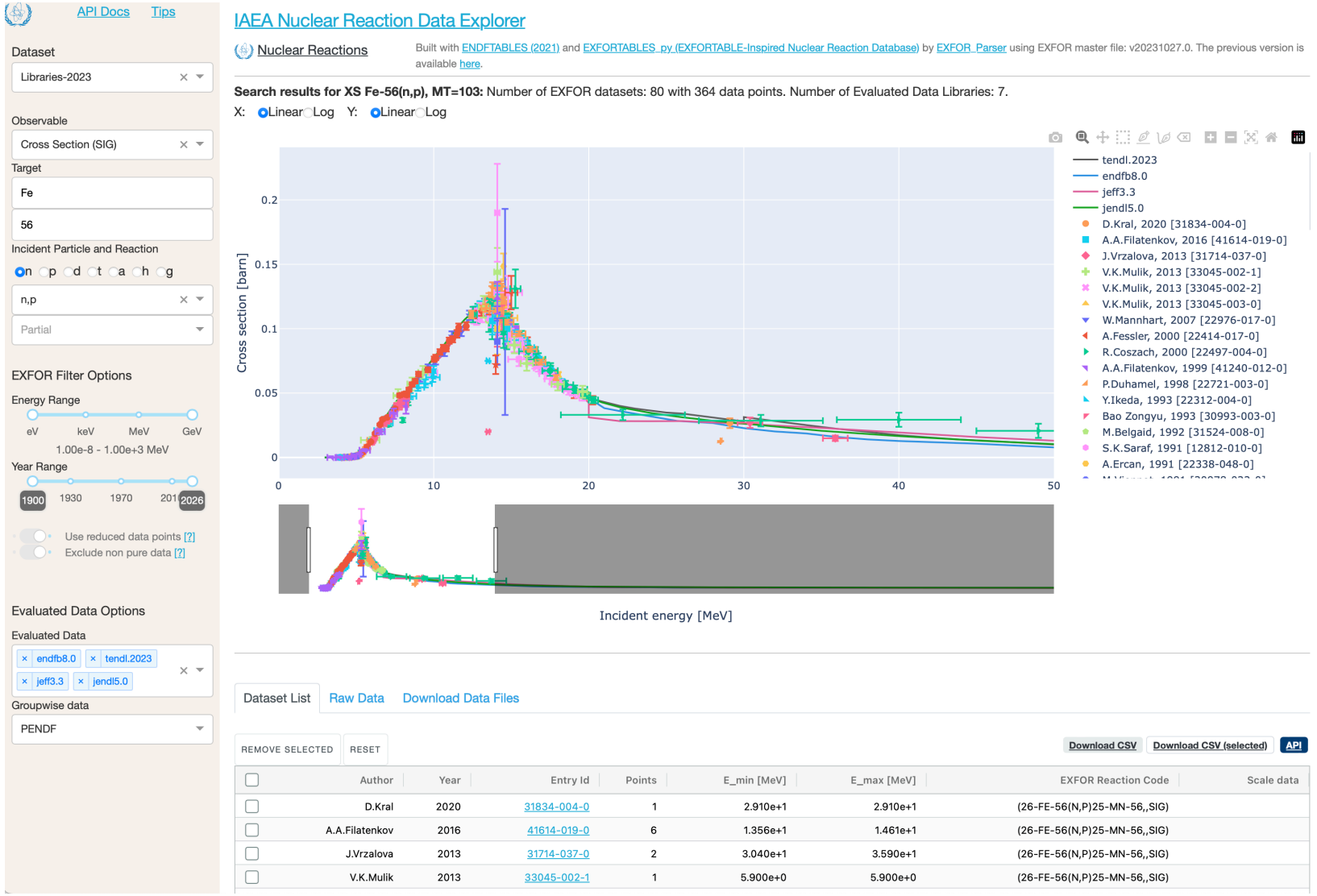
- Easy access without understanding of EXFOR format
  - Search by reactions
  - Entry viewer
  - Geographical analysis

Web APIs

- Easy computational access
  - Reaction, EXFOR entry and definition of EXFOR keywords, RIPL-3 levels

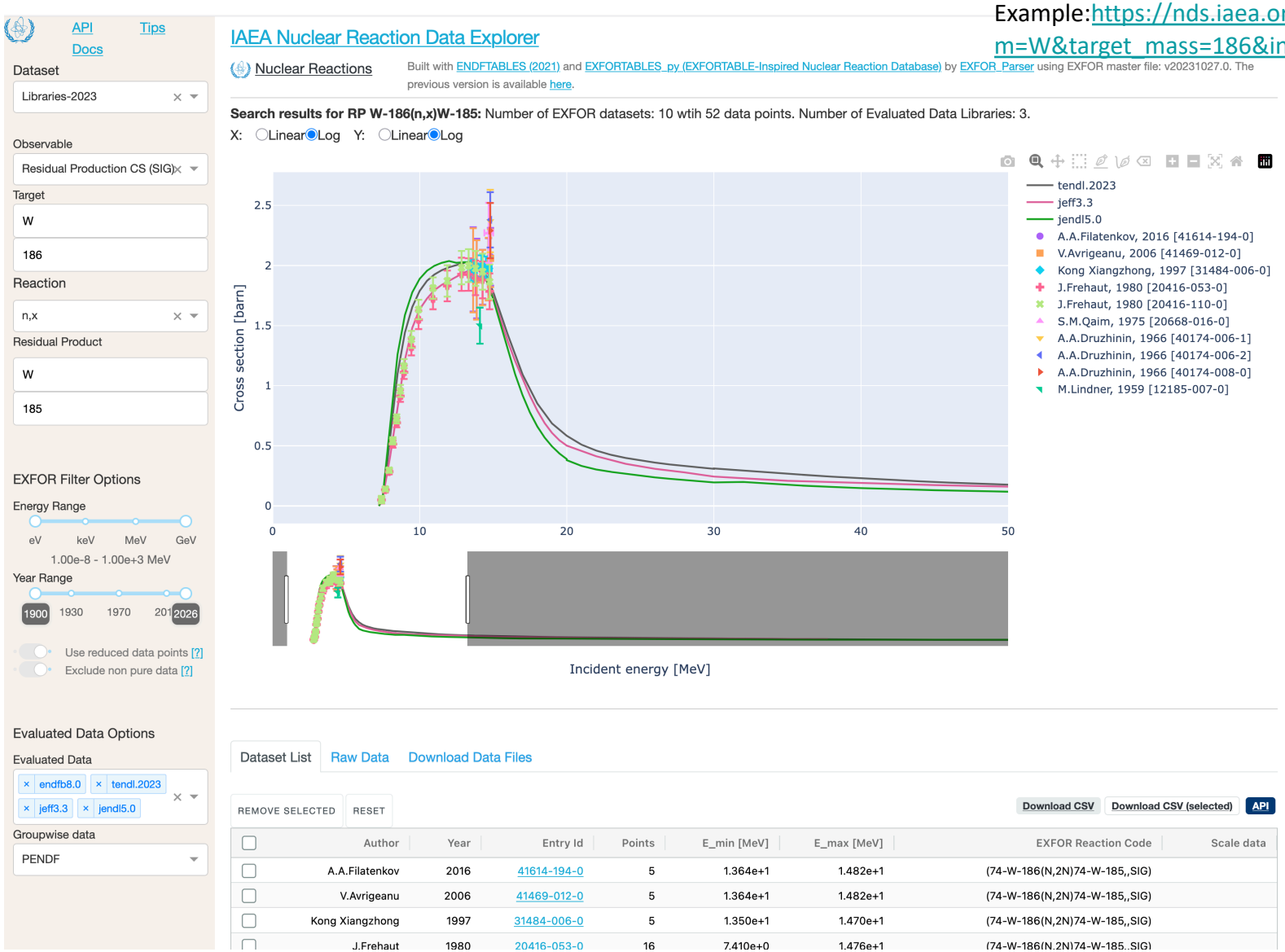
Fe56(n,p) Cross Section Plot

Example:https://nds.iaea.org/dataexplorer/reactions/xs?target_elem=Fe&target_mass=56&reaction=n%2Cp



$^{186}W(n,x)^{185}W$ Residual Production Cross Section Plot

Example:https://nds.iaea.org/dataexplorer/reactions/residual?&target_elem=W&target_mass=186&inc_pt=N&rp_elem=W&rp_mass=185



The EXFOR Entry Viewer

Example: https://nds.iaea.org/dataexplorer/exfor/entry/40412

```
ENTRY            40412   20200318   20200515   20200514
SUBENT        40412001   20200318   20200515   20200514
BIB                 13         76
INSTITUTE  (4RUSFEI)
REFERENCE  (J,AE,38,82,1975) Issue 2.
           (J,SJA,38,105,1975) Engl.translation of AE,38,
           #doi:10.1007/BF01208866
           (R,FEI-274,1971)
           (R,INDC(CCP)-21,1972) Engl.translation of R,FE
           (C,71KIEV,1,293,1971)      Graphs of Alpha val
           (C,71KIEV,1,301,1971)      Exp.method.
           (R,FEI-290,1972)           Facility details.
           (J,AE,32,85,1972) Issue 1. Graphs of Alpha val
           (J,SJA,32,95,1972) Engl.translation of AE,32,8
           #doi:10.1007/BF01261042
           ((R,YK-15,12,1974)=
           (R,INDC(CCP)-57,12,1974))
           Even at NDS web-site in this INDC(CCP)-57 pdf
           are absent.
AUTHOR     (V.N.Kononov, E.D.Poletaev,B.D.Yurlov, Yu.S.Pr
           A.A.Metlev, Yu.Ya.Stavisskiy)
TITLE      Measurement of alpha and the 235U and 239Pu fi
           capture cross sections for 10-80 keV neutrons
FACILITY   (VDG,4RUSFEI)  FEI pulsed Van-de-Graaff accele
            Pulse duration 22ns, frequency 300.kHz.
INC-SOURCE (P-LI7)    Proton-Lithium-7
           Metal lithium targets were used
           (P-T)      Proton-tritium, standard tritium-ti
                      targets were used
SAMPLE     Four metal Pu-239 discs of 40 mm diameter, 2.9
            nuclei/b thickness.  Total weight 14.5 g.
            Pu-240 content in the sample - 0.2%.
           Triuranium octoxide U3O8 (90.3 percents of U-2
           Sample of 4.1E-3 U-235-nuclei/b thickness in a
           shell of 40 mm Diameter and 0.5mm wall thickne
           U3O8 weight - 24.4g.
            Background measurements equivalent scattering
            of carbon and lead were used
METHOD     (TOF)     Time-of-flight method with resolutio
           nsec/m for neutron energy range from 10 keV to
           And energy resolution from 10 keV to 30 keV
           For neutron energy range from 100 keV to 1 MeV
           at working on monoenergetic neutrons.
            Flight path 1.18 m.
DETECTOR   (STANK) Large (400. l) liquid scintillation de
                   loaded with cadmium
           (FISCH)   Fast ionization chamber with Cf-252.
           (NAICR)  NaI(Tl) Crystal of 150x80 mm size det
            Amplitude resolution about 13 % at E-gamma=47
            time resolution 8ns at E-gamma 420.-540. keV.
MONITOR    Measurement of the capture-to-fission cross-se
           ratios (ALFA) was absolute
           The fission cross-sections have been measured
           energy dependence of B-10(n,alpha-gamma) react
           given by Sowerby M.G. et al, 70HELSINKI,1,161
           Macklin P.L. et al, Phys.Rev., 165, 1147, 1968
           Normalization of fission cross-section was mad
           energy region 30-40 keV to evaluated data by S
           et al, Ann. Of Sci. and Eng., V1,No.718,1974.
CORRECTION Correction for isotopic impurities,correction
           neutron multiplication in the samples, correct
           energy dependence nu-bar, correction for multi
           neutron scattering and resonance self-shieldin
```

Docs Tips

Dataexplorer

Dataset

EXFOR

Entry search

40412-004-0

Reaction search

IAEA Nuclear Data Explorer

Experimental Nuclear Reaction Data (EXFOR) is compiled by the International Network of Nuclear Reaction Data Centres (NRDC) under the auspices of the International Atomic Energy Agency.

Number of entry: 2448, Number of dataset: 123456

Entry number: 40412: Last updated on 2020-05-15 (Rev. 7) Compilation history EXFOR Git JSON

Title: Measurement of alpha and the 235U and 239Pu fission and capture cross sections for 10-80 keV neutrons

← Simplified bibliographic info

Autors: V.N.Kononov, E.D.Poletaev, B.D.Yurlov, Yu.S.Prokopets, A.A.Metlev, Yu.Ya.Stavisskiy,

Institute: (4RUSFEI)

References: (J,AE,38,82,1975), (J,SJA,38,105,1975), (R,FEI-274,1971), (R,INDC(CCP)-21,1972), (C,71KIEV,1,293,1971), (C,71KIEV,1,301,1971), (R,FEI-290,1972), (J,AE,32,85,1972), ((R,YK-15,12,1974)=(R,INDC(CCP)-57,12,1974)), ((R,YK-15,12,1974)=(R,INDC(CCP)-57,12,1974)),

Reactions: 40412-004-0: (92-U-235(N,G)92-U-236,,SIG,,AV)

← Reactions in ENTRY

EXPERIMENTAL CONDITIONS

←Measurement info

CORRECTION		Correction for isotopic impurities,correction for neutron multiplication in the samples, correction for energy dependence nu-bar, correction for multiple neutron scattering and resonance self-shielding.
DETECTOR	(STANK)	Large (400. l) liquid scintillation detector loaded with cadmium
	(FISCH)	Fast ionization chamber with Cf-252.
	(NAICR)	NaI(Tl) Crystal of 150x80 mm size detector. Amplitude resolution about 13 % at E-gamma=478 keV, time resolution 8ns at E-gamma 420.-540. keV.
FACILITY	(VDG,4RUSFEI)	FEI pulsed Van-de-Graaff accelerator. Pulse duration 22ns, frequency 300.kHz.
INC-SOURCE	(P-LI7)	Proton-Lithium-7 Metal lithium targets were used
	(P-T)	Proton-tritium, standard tritium-titanium targets were used
METHOD	(TOF)	Time-of-flight method with resolution 18 nsec/m for neutron energy range from 10 keV to 80 keV And energy resolution from 10 keV to 30 keV For neutron energy range from 100 keV to 1 MeV at working on monoenergetic neutrons. Flight path 1.18 m.

↓Tooltip from the EXFOR dictionary

Scintillator tank

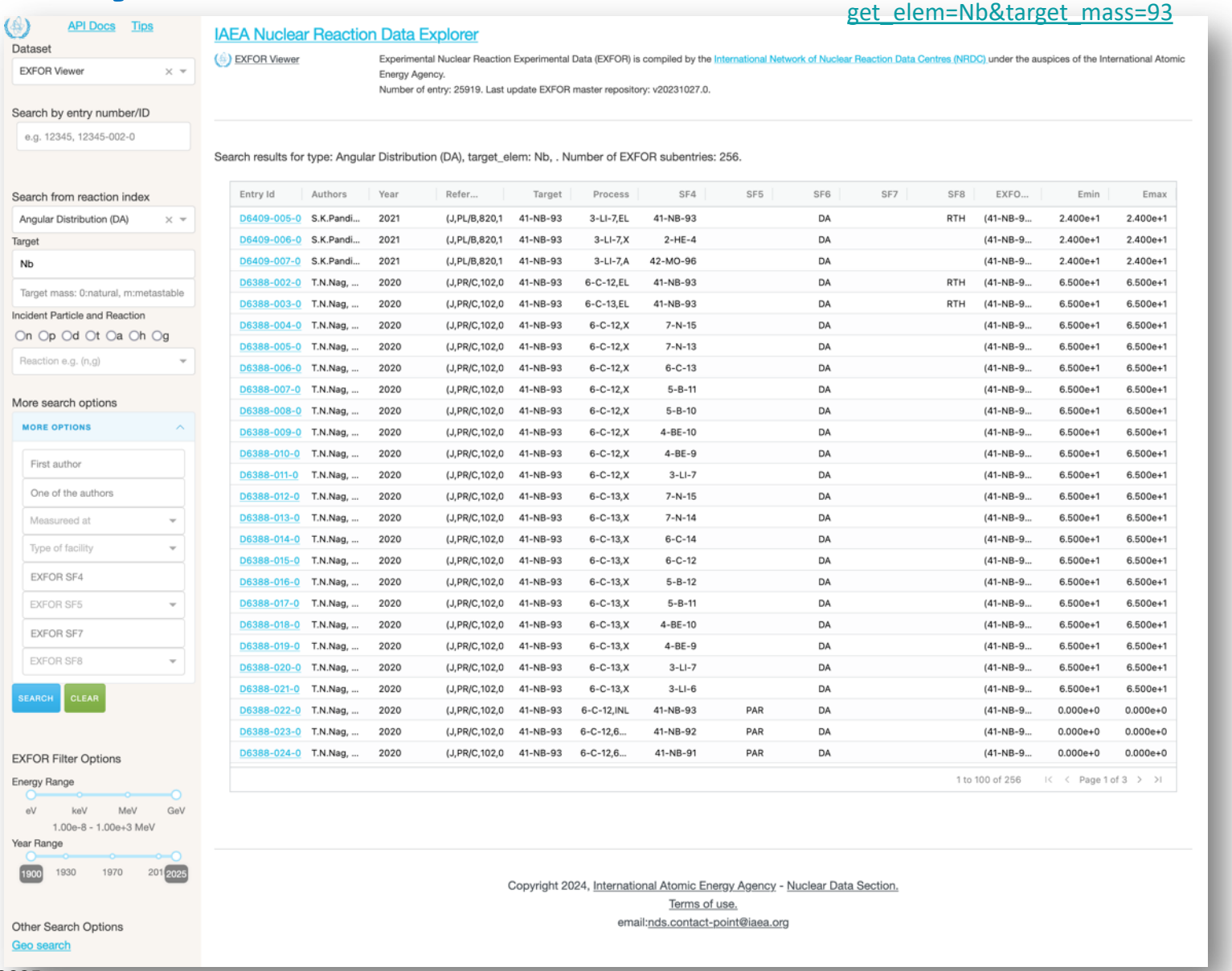
Separate code and free text→

20 40 60

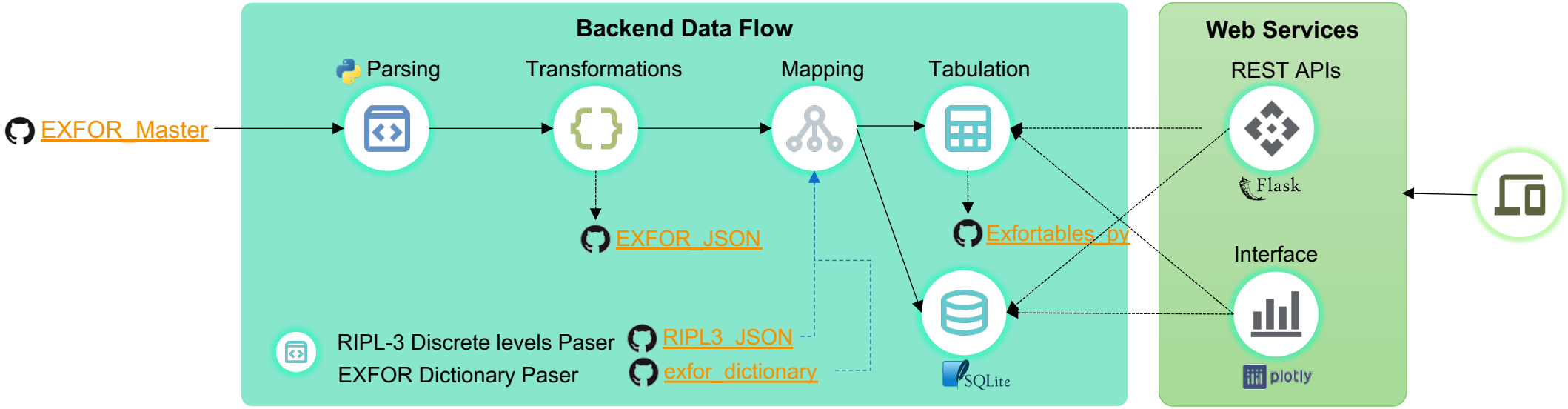
EN-MIN (KEV)

EXFOR Entry Search

Example:https://nds.iaea.org/dataexplorer/exfor/search?type=DA&target_elem=Nb&target_mass=93



IAEA Nuclear Reaction Dataexplorer Data Flow



- EXFOR Parser*
  - Inspired by x4i by David Brown (NNDC, BNL)
  - Python program to convert all ASCII files in EXFOR_Master in EXFOR format into JSON and to produce tabulated (x, y, dx, dy) database
  - Python3.x (https://github.com/IAEA-NDS/exforparser)
- IAEA Nuclear Reaction Dataexplorer has been renewed in March 2024
  - EXFOR datasets are produced by EXFOR Parser (available in text and SQL)
  - Web interfaces
  - APIs: Easy computational access developed in Flask
  - ENDF-6 libraries is from ENDFTABLES**

* S. Okumura, G. Schnabel and A. Koning, *EPJ Web Conf.*, 292, 12003 (2024)
** A. Koning, https://nds.iaea.org/talys/

Available Web API Endpoints

- Users can access the following endpoints via HTTP requests:

  - **Reactions:** Datasets containing data tables used in the Data Explorer.

    GET https://nds.iaea.org/dataexplorer/api/reactions/

  - **EXFOR Entry:** Entries, subentries, bibliography, data, experimental conditions, and reactions.

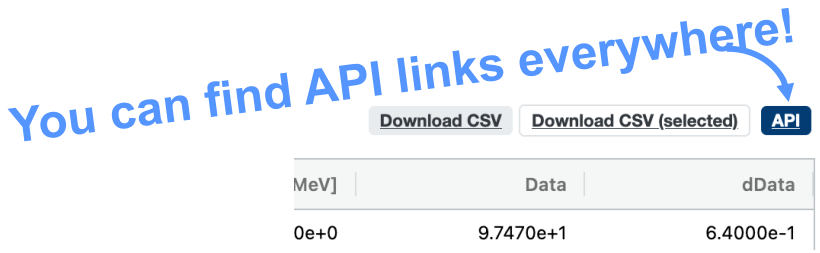
    GET https://nds.iaea.org/dataexplorer/api/exfor/entry/

  - **EXFOR Dictionary:** Provide information on facilities, institutes, methods, and detectors defined in the EXFOR dictionary.

    GET http://nds.iaea.org/dataexplorer/api/exfor/dict/

  - **RIPL-3 Discrete Level:** Includes levels and level records.

    GET http://nds.iaea.org/dataexplorer/api/ripl3/levels/



Reactions API

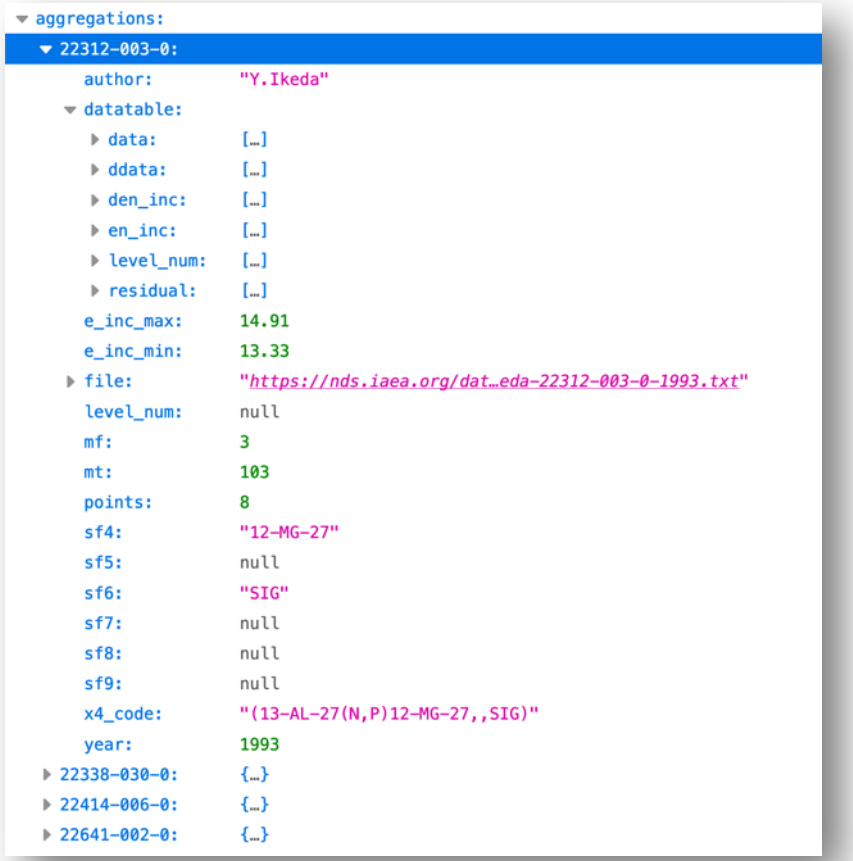
GET /dataexplorer/api/reactions/{type}

Name	Data Type	Required	Description
type	string		**xs**: Cross section **residual**: Residula production cross sections **thermal**: Thermal neutron cross sections **fy**: fission yields

- General search parameters

Name	Data Type	Required	Description
target_elem	string		e.g. Al
target_mass	number		e.g. 27
reaction	string		e.g. n,g
rp_elem	string	optional	Element name of the residual product
rp_mass	number	optional	Mass number of the residual product
fy_type	string	optional	Cumulative, Independent, Primary for FPY
table	boolen	optional	Default: False, True to include data table in the return
page	number		Default: 1, page number of pageing. 100 datasets in one page are returned.

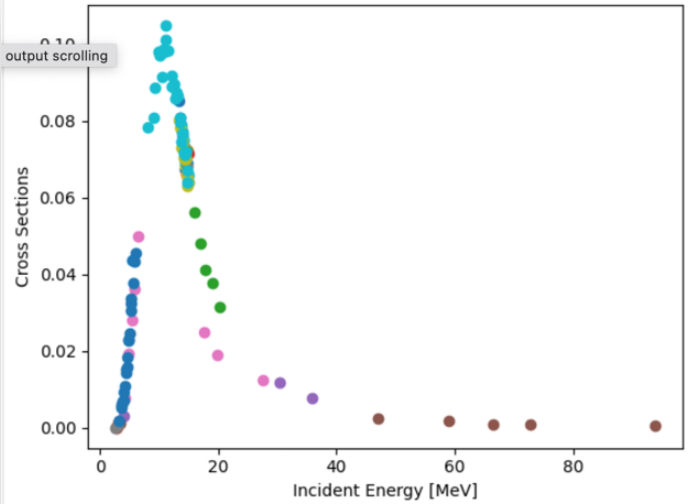
Example:https://nds.iaea.org/dataexplorer/api/reactions/**xs**?target_elem=Al&target_mass=27&reaction=n%2Cp&table=True&page=1

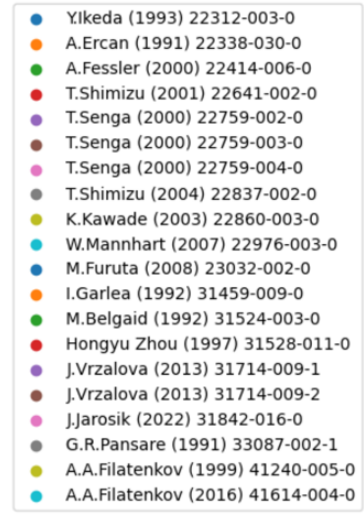


Simple Use Case of Reactions API

```python
import json
import pandas as pd
import requests
import matplotlib.pyplot as plt

# access to the reaction data via HTTPS
headers = {
    "Authorization": "Bearer xxxxxxxxxxx",
    "User-Agent": "Get all samples",
    "Content-Type": "application/json",
}
response = requests.get("https://nds.iaea.org/dataexplorer/api/reactions/xs?target_elem=Al&target_mass=27&reac
                        headers=headers)

# get response in JSON format
entries = response.json().get("aggregations")

# loop over the entries and make the plot and store the data into pandas dataframe
df = pd.DataFrame()
for entry in entries.keys():
    entry_df = pd.DataFrame.from_dict(entries[entry]["datatable"])
    author = entries[entry]["author"]
    year = entries[entry]["year"]
    plt.scatter(entry_df["en_inc"], entry_df["data"], label= f"{author} ({year}) {entry}")
    df = pd.concat([df, entry_df])

plt.ylabel('Cross Sections')
plt.xlabel('Incident Energy [MeV]')
plt.legend(bbox_to_anchor=(1.04, 1), loc="upper left")
plt.show()
print(df)
```

output scrolling





	data	ddata	den_inc	en_inc	level_num	residual
0	0.0641	0.0022	None	14.91	None	Mg-27
1	0.0688	0.0031	None	14.65	None	Mg-27
2	0.0675	0.0063	None	14.42	None	Mg-27
3	0.0721	0.0038	None	14.22	None	Mg-27
4	0.0760	0.003	None	13.98	None	Mg-27
..	...	...	...	...	...	...
3	0.0718	0.001501	None	14.04	None	Mg-27
4	0.0710	0.001377	None	14.26	None	Mg-27
5	0.0720	0.001368	None	14.44	None	Mg-27
6	0.0671	0.001389	None	14.63	None	Mg-27
7	0.0640	0.001242	None	14.81	None	Mg-27

[113 rows x 6 columns]

EXFOR Entry API

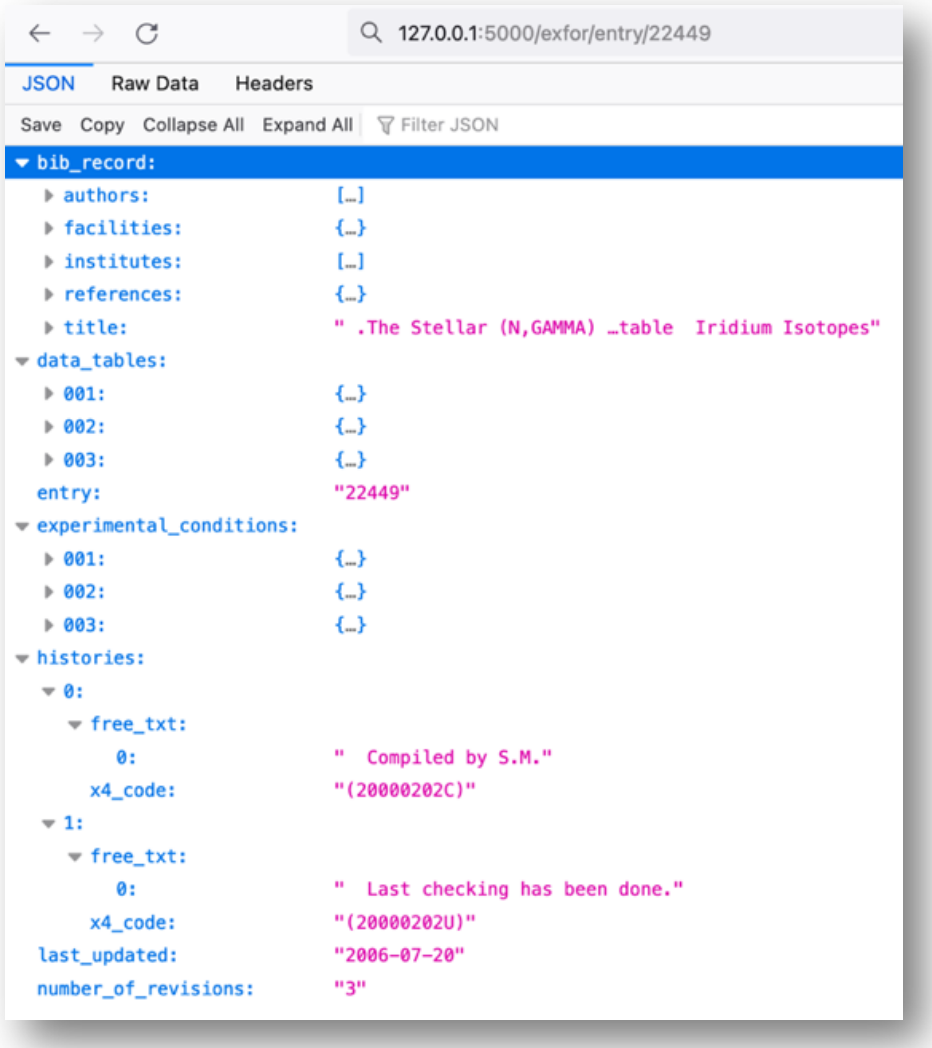
GET /dataexplorer/api/exfor/entry/{entry_id}/{subent_id}

Name	Data Type	Required	Description
entry_id	string		EXFOR entry number
subent_id	string	optional	Subentry number

GET /dataexplorer/api/exfor/entry/{entry_id}/{section}

Name	Data Type	Required	Description
section	string	optional	bib: return bibliographic data data: return datatable experiment: return experimental conditions histories: return entry history

Example:https://nds.iaea.org/dataexplorer/api/exfor/entry/31558



EXFOR Dictionary API

GET /dataexplorer/api/exfor/dict/{field}/{name}

Name	Data Type	Required	Description
field	string		institute: used in INSTITUTE field facility: used in FACILITY field method: used in METHOD field detector: used in DETECTOR field
name	string	optional	

http://nds.iaea.org/dataexplorer/api/exfor/**dict/institute/1CANALA**

```
active:        true
description:   "University of Alberta, Edmonton, Alberta"
```

https://nds.iaea.org/dataexplorer/api/exfor/**dict/facility/accel**

```
active:        true
description:   "Accelerator"
```

http://nds.iaea.org/dataexplorer/api/exfor/**dict/method/activ**

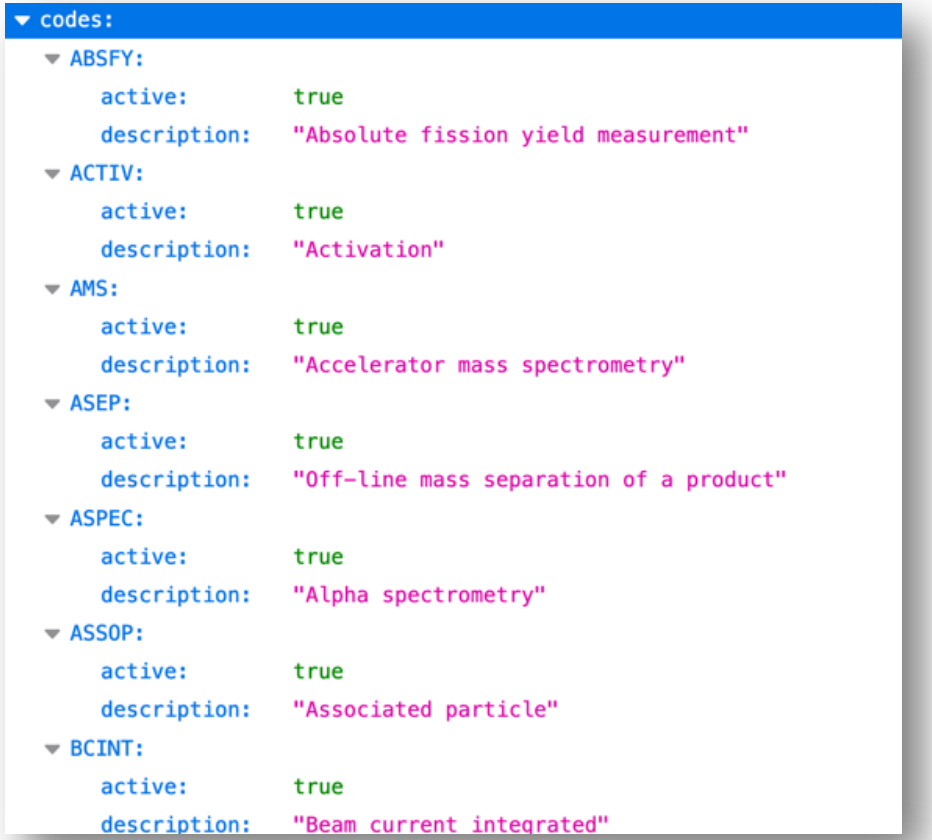
```
active:        true
description:   "Activation"
```

http://nds.iaea.org/dataexplorer/api/exfor/**dict/detector/hpge**

JSON

```
active:        true
description:   "Hyperpure Germanium detector"
```

Example: https://nds.iaea.org/dataexplorer/api/exfor/**dict/method**

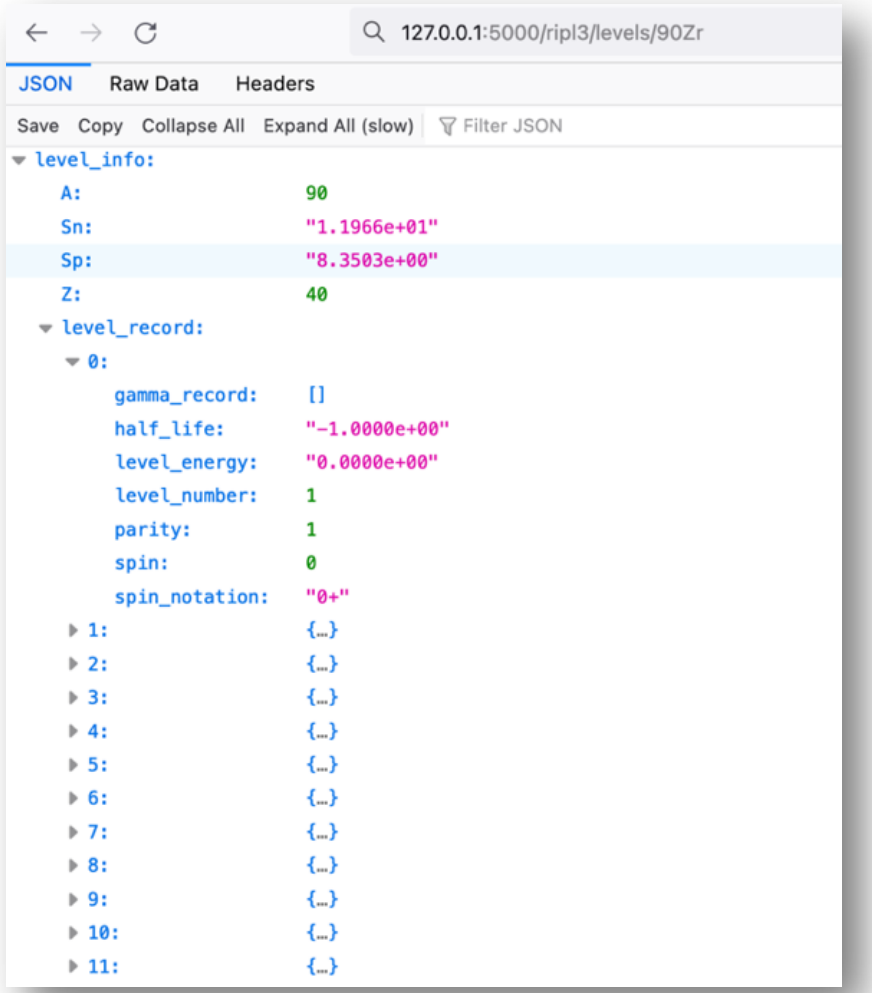


RIPL-3 discrete level API

GET /dataexplorer/api/exfor/ripl3/{field}/{nuclide}

Name	Data Type	Required	Description
field	string		levels: discrete level information
nuclide	string		Name of nuclide with '235U' format

Example: http://nds.iaea.org/dataexplorer/api/**ripl3/levels/90Zr**



Useful Resources around EXFOR

Area	Name	Purpose	GitHub Repository
EXFOR	EXFOR Master Files	Preservations of all historical changes on EXFOR entries, Created: September 2022	https://github.com/IAEA-NDS/exfor_master
	EXFOR in JSON	All EXFOR entries converted into JSON, Created: October 2022	https://github.com/IAEA-NDS/exfor_json
	EXFOR Dictionary in JSON	EXFOR dictionary converted into JSON, Created: October 2022	https://github.com/IAEA-NDS/exfor_dictionary
	EXFOR Parser	Program to Parse EXFOR and convert into JSON and create tabulated table, Created: May 2022	https://github.com/IAEA-NDS/exforparser
	EXFORTABLES_py	EXFOR data in tabulated format similar to EXFORTABLES, Created: April 2023	https://github.com/shinokumura/exfortables_py
	RIPL-3 Discrete Levels in JSON	All discrete levels converted into JSON, Created: November 2022	https://github.com/shinokumura/ripl3_json
	Thermal Cross Section	Extracted thermal cross section from EXFOR, Created: January 2021	https://github.com/shinokumura/thermaldata
	Resonance Parameters	Resonance spacing (D0, D1), resonance integrals (RI), MACS, Created: March 2025	https://github.com/shinokumura/resonance_data
	More DOIs for EXFOR	DOIs for REFERENCE, REL-REF and MONIT-REF for EXFOR entries, Created: Feb 2025	https://github.com/shinokumura/exfor_entry_doi

Forthcoming: ENDF-6 Viewer

- ENDF-6 content viewer powered by DeCE[1], C++ program to manipulate ENDF-6 formatted file.
  - showheaders (print parameters in header MF1 MT 451)
  - extract (print section in ENDF-6 format)
  - table (print section in tabulated table format)
  - reconstruct (cross section from resonance parameters)
- Allow users access to the historical ENDF-6 format libraries stored in IAEA-NDS.

[1] Developped by T. Kawano (LANL), https://github.com/toshihikokawano/DeCE

Ongoing and Upcoming Work

- Improve documentation across all repositories in the ecosystem to support long-term maintenance.
- Integrate latest ENDF-6 library data (will be provided by Alejandra Martinez, IAEA-NDS).
- Include additional physical observables from EXFOR, such as angular distributions and emission spectra.
- Unify the data model for EXFOR and ENDF-6 to ensure easy access and usability for end users.
- Expansion of features such as the renormalization of data by a new monitor reaction.

- New version should be online before summer (hopefully….)

Conclusion

- The IAEA Nuclear Reaction Data Explorer has been under development since 2021 and was renewed in March 2024 with the following updates:
  - Integration of EXFOR data using the EXFOR parser
  - Implementation of a new EXFOR entry interface
  - Update of ENDF-6 data from ENDFTABLES
  - Implementation of APIs for programmatic access

- Any comments and requests from FENDL community are appreciated.
  - Feedback: nds.contact-point@iaea.org or s.okumura@iaea.org

Thank you for your attention!

Feedback: nds.contact-point@iaea.org

s.okumura@iaea.org