EXFOR project, and an update on the new SG50/SG54

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Brookhaven National Laboratory

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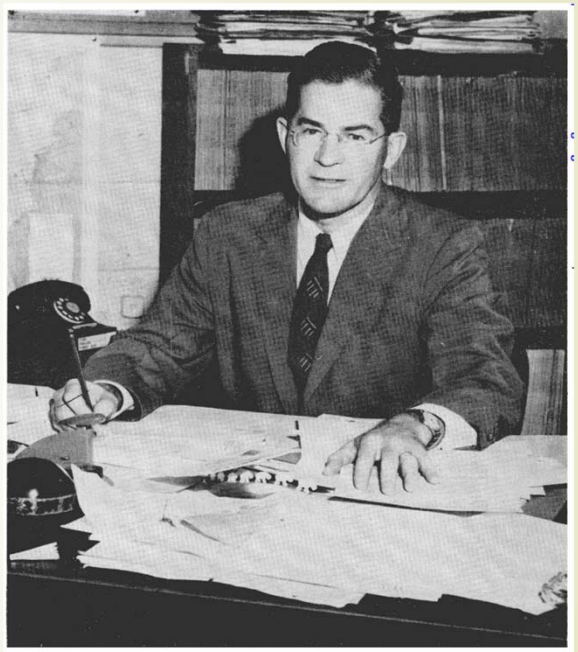
Nuclear Reaction Data Compilations

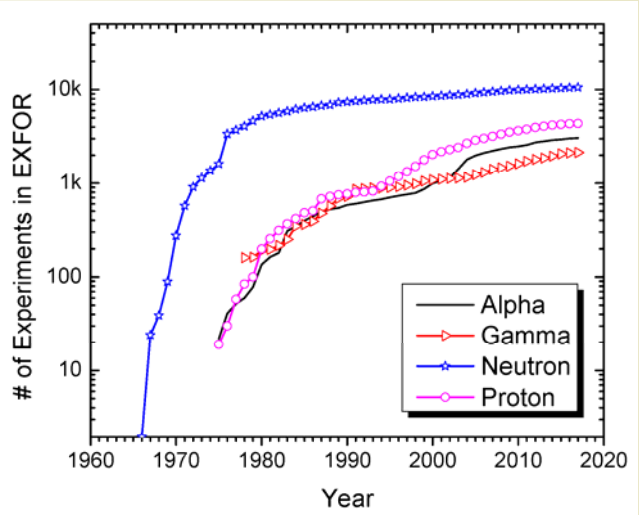
- Nuclear reaction data compilations were pioneered during the Manhattan Project.
- Manhattan Project alumni started reaction compilations at Brookhaven in the early 1950s in support of nuclear sciences and reactor activities.
- International cooperation was established in 1969 by the four neutron compilation centers: NNDC, NEA-Databank Paris, NDS IAEA, and IPPE (Former Soviet Union).
- Exchange Format (EXFOR) for data interchange between the four centers was adopted.
- Every second, third, and sixth data points in the library were contributed by the NNDC, NEA-Databank, and the rest of the world, respectively.

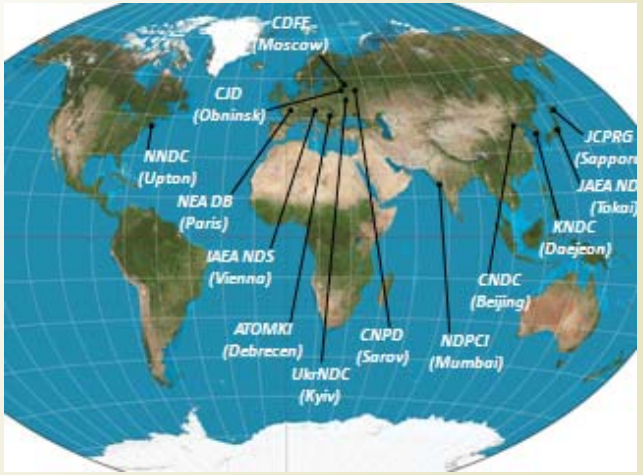


Donald J. Hughes, at his desk at Brookhaven National Laboratory.

EXFOR - Experimental Nuclear Reaction Data

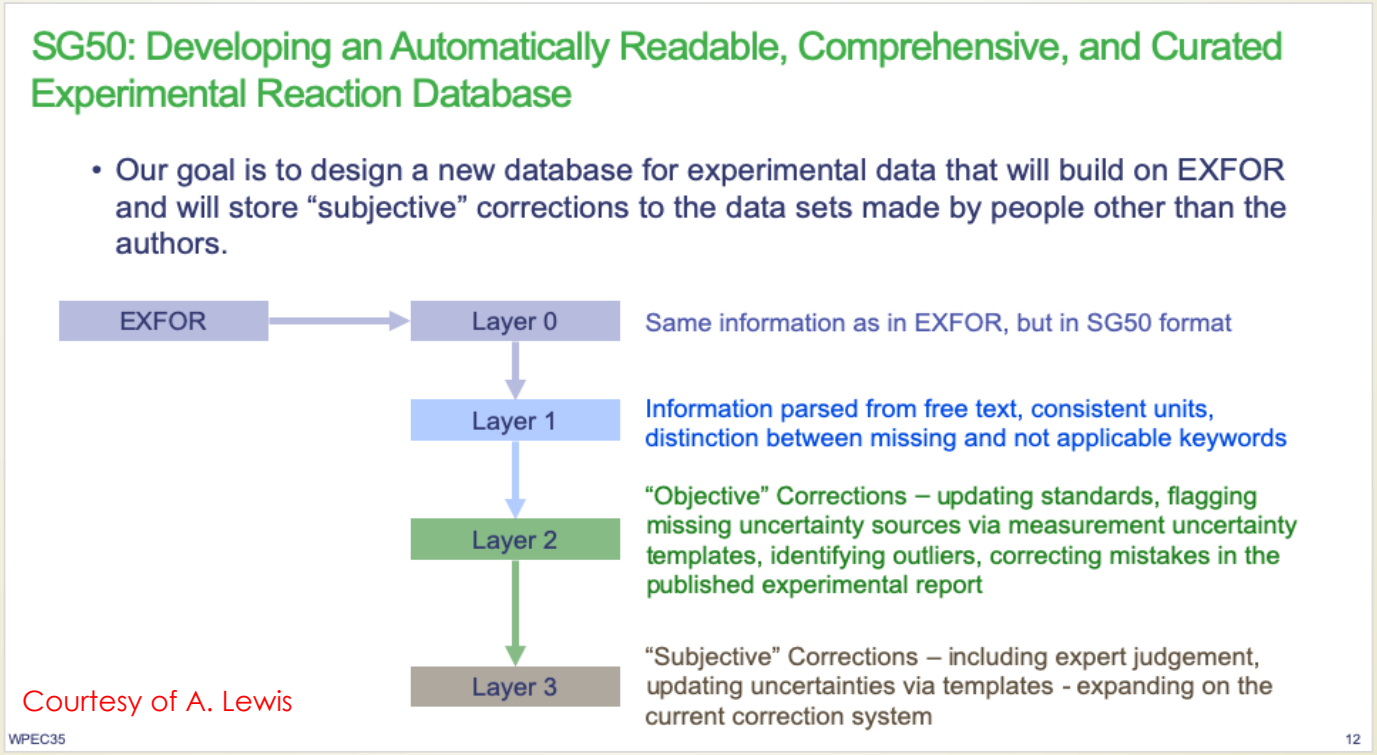
- The largest experimental nuclear reaction database: 25,366 (25K!!!) experiments (multiple publications are grouped into a single measurement), 169,596 subentries, and 186,220 data sets as of June 11, 2025.
- **EXFOR is a starting point for Evaluated Nuclear Data File (ENDF) libraries evaluations (many evaluated but a single experimental data library), it includes the uncertainties used by evaluators.**
- Run by the Nuclear Reaction Data Centres (NRDC) internationally.
- ***EXFOR's philosophy is to compile data as they were published (in consultation with authors) unless obvious errors are found.*** **Published nuclear reaction data contain outliers and discrepancies.**





WPEC SG50

The current evaluation process needs well-documented, fully traceable, machine readable, data corrections to make evaluations reproducible. We need to exclude or reduce repetitive work in data evaluations.



WPEC SG50

- SG50 (2021-2024): Developing an Automatically Readable, Comprehensive, and Curated Experimental Reaction Database (https://www.osti.gov/biblio/1990114)
- SG50 requirements (LA-UR-20-28933) and specification documents, May 2022.
- Amanda Lewis, Denise Neudecker, Arjan Koning, ``Status of WPEC SG50", May 17, 2023: Goals, documentation, examples of computer developments.
- MEDUSAL library collects data & corrections. In SG50 and in this project, data stored in NEA gitlab.

SG50 achieved a lot but this project is much bigger than one subgroup can handle

The work of SG50 must continue

- ***Note: EXFOR is very important. As with SG50, we would preserve EXFOR in the EXCHANGE format and the NRDC workflow.***
- Finalize the version of JSON (JavaScript Object Notation) format for EXFOR (Level 0).
- Begin correction/comment curation process (Levels 1-3)
  - Openly available correction collections
  - Newly completed experiments
- Develop framework for continuous updating of formats & tools for Levels 1-3. This should include a peer review process for curated database.

EXCHANGE: #13075

```
ENTRY            13075   20120711   20121203   20121127       1385
SUBENT        13075001   20120711   20121203   20121127       1385
BIB                  9         13
INSTITUTE  (1USAARK)
REFERENCE  (J,JIN,27,503,1965)
AUTHOR     (T.Mo,P.K.Kuroda)
TITLE      Yields of zirconium isotopes from spontaneous and
           14.7 MeV neutron-induced fission of uranium-238
DETECTOR   (PROPC) 2Pi end-window methane-flow proportional
            counter
METHOD     (RCHEM)
ERR-ANALYS No information
STATUS     (TABLE) Data from the text of JIN,27,503,1965
HISTORY    (19890512C) VM
           (20120711A) SD:Updated to new date formats,lower case.
                Corrected according to last EXFOR rules and Dict.
ENDBIB              13
NOCOMMON             0          0
ENDSUBENT           16
SUBENT        13075002   20120711   20121203   20121127       1385
BIB                  7         11
REACTION   1(92-U-238(N,F)42-MO-99,CUM,FY)
           2(92-U-238(N,F)42-MO-99,CUM,SIG)
            The results of triplicate measurements
FACILITY   (CCW,1USAARK)
INC-SOURCE (D-T)
SAMPLE      Depleted uranium trioxide. Isotopic composition:
           99.989% 238U, 0.011% 235U.
MONITOR    (13-AL-27(N,A)11-NA-24,,SIG)
           2(92-U-238(N,F),,SIG)
MONIT-REF  2(40424002,N.N.Flerov+,J,AE,5,657,1958)
HISTORY    (20120711A) SD: REACTION code 2 was added.
ENDBIB              11
COMMON               2          3
EN          EN-RSL
MEV         MEV
 14.7        0.4
ENDCOMMON           3
DATA                6          1
DATA       1DATA-ERR  1DATA      2DATA-ERR  2MONIT     2MONIT-ERR 2
PC/FIS      PC/FIS     B          B          B          B
 5.7         0.5          0.0642       0.005     1.13        0.05
ENDDATA             3
ENDSUBENT          23
ENDENTRY            2
```

JSON: #13075


```
{
 "format":"JSON.FY-0.1.3"
 ,"now":"2019-10-10T20:18:37.000Z"
 ,"program":"Converter EXFOR-TO-JSON.FY, by V.Zerkin, IAEA-NDS, 2019 (ver.2019-10-10)"
 ,"input": {  "files": [ {"name":"u238nfy_prod.x4", "format":"EXFOR",
"created":"2019-10-10T03:17:37.000Z" } ] }
 ,"output": { "files": [ {"name":"13075.json0.txt", "format":"JSON",
"created":"2019-10-10T20:18:37.000Z" } ] }
 ,"datasets": [
,
 { "type":"data", "id":"130750021" ,"pointer":"1"
  ,"subent":{"id":"13075002", "updated":"20120711" }
  ,"entry":{"id":"13075", "updated":"20120711" }
  ,"author1":"T.Mo+"
  ,"year":1965
  ,"ref1":{"code":"J,JIN,27,503,1965"
          ,"exp":"Jour: Journal of Inorganic and Nuclear Chemistry, Vol.27, p.503 (1965)"
          }
  ,"reaction": {
    "code":"92-U-238(N,F)42-MO-99,CUM,FY"
   ,"Proj":"N"
   ,"Target":"92-U-238"
   ,"ReactionType":"FY"
   ,"DataType":"CUM,FY"
   ,"Quantity":"Cumulative fission-product yield"
   ,"IndVarFamCode":"0 2    7"
  }
  ,"incEnergies": [
    {"incEnergy":14700, "incEnergyWidth":200, "incEnergyUnits":"KEV", "DataUnits":"PART/FIS"
    ,"Products": [
      {"Z":42 ,"A":99       , "Nucl":"Mo-99"     ,"CUM_FY":0.057     ,"dCUM_FY":0.005      }
     ]
    }
   ]
  }
]
}
```

SG54: Continuation of Subgroup 50, Developing an Automatically Readable, Comprehensive, and Curated Experimental Reaction Database => Curated EXFOR: developing a machine-readable, comprehensive, and corrected by evaluators experimental nuclear reaction database

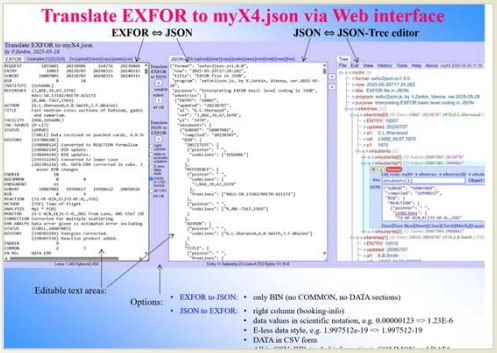
- The new WPEC subgroup was approved on August 1, 2024.
- The subgroup activity proposal was updated on March 27, 2025 and finalized on June 3, 2025 based on a PRG review.
- Title was updated on June 3, 2025.
- Scope was updated on March 27, 2025. This project's scope is limited to what is achievable with limited resources, but with the focus on populating the curated database and developing a framework for continuing the project as a future NEA Expert Group. Therefore, we seek to
  - Develop a system for continuous improvement of the specifications, infrastructure and database itself
  - Begin populating the curated database with community contributions and new data from recently finished experiments carried out by colleagues and collaborators.
- Lead organization (s) and co-ordination
  - Boris Pritychenko, BNL, USA (Chair), Georg Schnabel, IAEA, AUT (Monitor)
  - 23 participants (BNL, ORNL, IAEA, NIST, RPI, NNL, NEA/DB, LLNL, UTK, LANL)

Re-imagining SG54 Milestones

- 2025-2026:
  - Finalize EXFOR to JSON format conversion code.
  - Develop process for continuous improvement to level-1 and -2 MEDUSAL formats and content.
  - Start working on EXFOR corrections.
- 2026-2028:
  - Continue work on EXFOR corrections and collect existing corrected files from ENDF evaluators.
  - Develop process to a) submit corrections, annotations and other metadata for datasets in the curated EXFOR-derived database and b) ingest new experimental data into this database from EXFOR.
  - Framework for continuous improvement

JSON/Computer Developments

- Several implementations of EXFOR JSON provided by Naohiko (https://nds.iaea.org/nrdc/exfor-master/j4/), Viktor (https://github.com/vzerkin/EXFOR-X5json-years/tree/master/x5json), …
- V. Zerkin continued work on translation of EXFOR files to JASON format
  - Viktor produced the new system that successfully translates EXFOR to JSON and backward from JSON to EXFOR and CSV.
  - Viktor also produced a JSON editor that is essential for EXFOR curation.
- N. Otuka has releases the the EXFOR utility codes (ForEXy)
- G. Schnabel works on a data model-agnostic approach to collaborative version tracking
- J. Sprenger works on Meta Schema and API repository (Pydantic data validation library for Python)

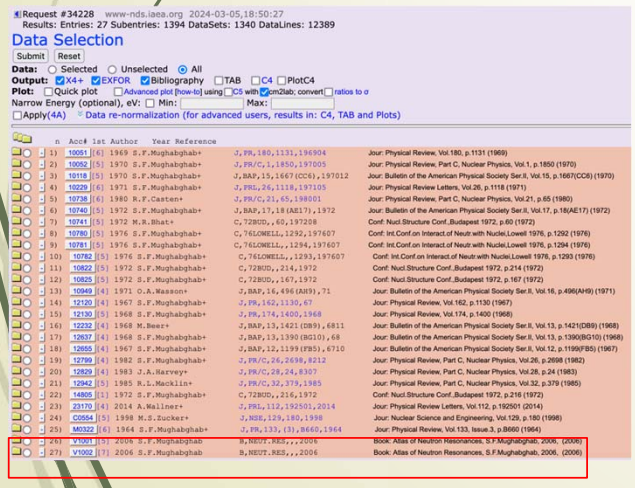


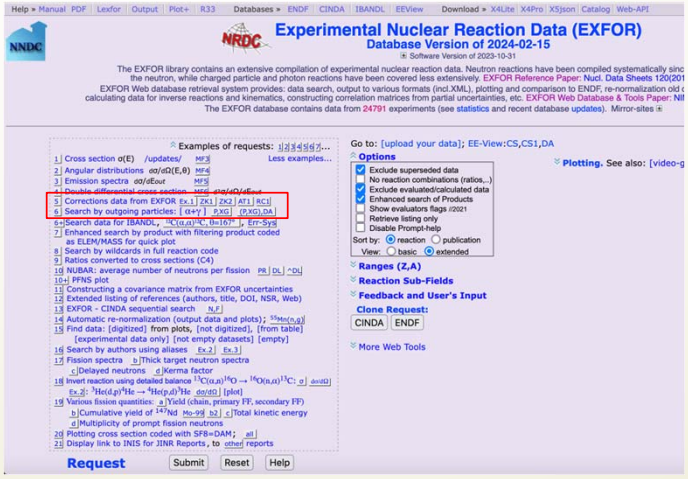
SG54 Discussion

- We agreed that we would use EXFOR format for original EXFOR files only, and JSON for curated and original EXFOR files.
- We would store in JSON data points, analytical functions and correction factors.
- Comments will be stored in either in "JSON patch" (or similar) or a separate file and reference that, rather than storing the comment directly in the data file.
- We will provide quality control, review and approval for corrected entries.
- We will use graphic and Web Interfaces for JSON files.
- Next WPEC SG54 meeting is September 16, 2025. We may have a development meeting during the summer of 2025.

Sources of Curated Data Sets (#1)

- Curated data are already exist in EXFOR: v-series compilations, i.e. Atlas of Neutron Resonances integral values: EXFOR entries V1001, V1002.
- Precursor curated database by V. Zerkin: Viktor has implemented Web (virtual space) corrections to some existing EXFOR data sets using the updated reaction monitor values, the latest decay gamma-ray intensities, and private communications from the late K.I. Zolotarev (IPPE, Obninsk).



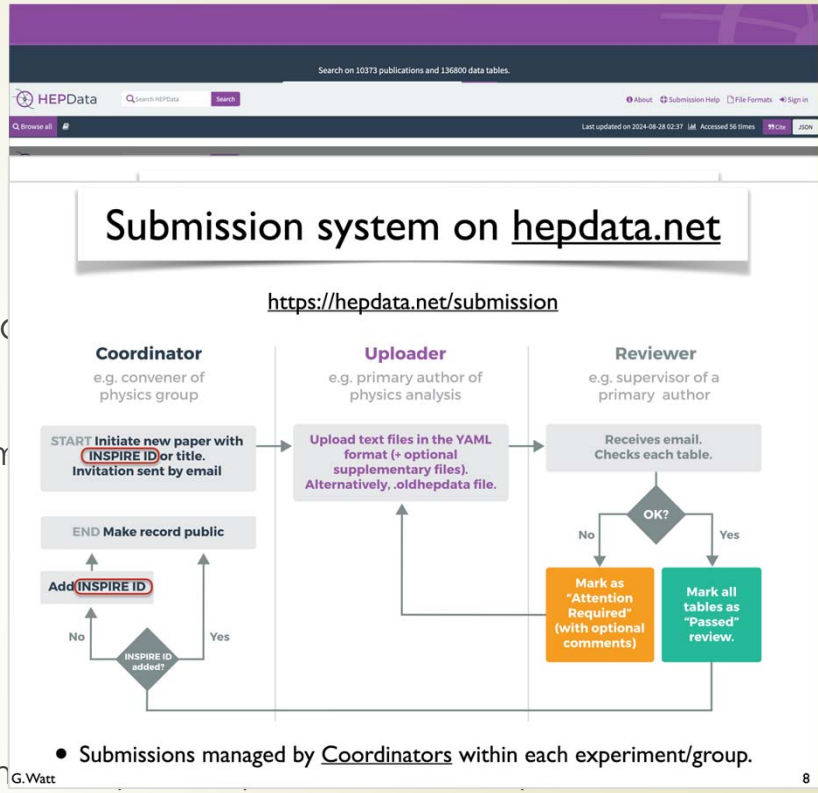


Sources (#2): Other projects

- AIACHNE Project (LANL/BNL): ^{252}Cf(SF) NS, D. Neudecker/B. Pritychenko
- PARADIGM Project (LANL): URR - focused data
- Zr Subgroup (WPEC): See G. Nobre's Zr SG proposal.
  They will find corrections, we will archive them!
- Prior LANL AI/ML & Evaluation Projects: Actinide data, D. Neudecker
- Fission Yields (BNL): A. Mattera, …
- Begging & pleading from "personal collections"
  - M. Paris, G. Hale (data used in R-matrix fits)
  - Charged Particles: K. Kravvaris (Solar Fusion), I. Thompson (LLNL)
  - Who else?

Sources (#3): More direct contacts with researchers

- HEPData is the HEP analog of EXFOR/NSR for HE data c
  - 10,373 publications, 136,800 data tables
  - HEPData provides a simple search, upload/download fram
  - It provides licenses for the publication of data and plots
  - HEPData is fully integrated with INSPIRE
  - Experiments submit their data
- We can improve the curated EXFOR
  - Shorten compilation time by integrating researchers into th the research (AICHNE project)
  - Extra data/corrections/information not present in the publication can be compiled (S.Harissopulos-targets, D.Neudecker-uncertainties, …); templates are guidance
  - Learn from HEP to make EXFOR data and plots publishable



Outlook

- We would continue SG50 as SG54.
- Finalize JSON format, explore free text to JSON conversion, and work on JSON conversion quality assurance (QA).
- We would look at the multiple sources of curated EXFOR data, analyze, document, and publish these corrections as a parallel to the EXFOR curated database.
- We should deliver the first version of the curated EXFOR.
- The curated EXFOR should not be considered as recommended. Users should make selections among the available curated data sets.

International Network of Nuclear Reaction Data Centres (NRDC)

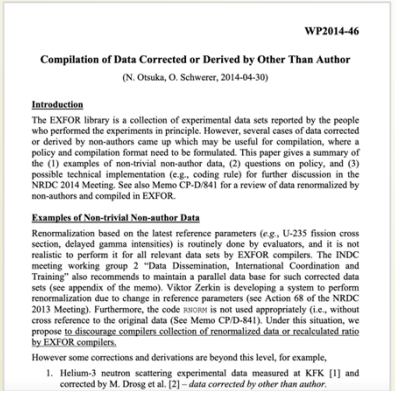
- The International Network of Nuclear Reaction Data Centres (NRDC) constitutes a worldwide cooperation of nuclear data centres under the auspices of the International Atomic Energy Agency. The Network was established to coordinate the world-wide collection, compilation and dissemination of nuclear reaction data.

Technical Meeting on International Network of Nuclear Reaction Data Centres
IAEA Headquarters, Vienna, Austria, 9 – 12 May 2023

Backup slides

NRDC Policies for Not Original or Corrected Data Sets

- EXFOR compiles author's data, any corrected data set must be accompanied by publication (WP2014-46): I was able to add T.Kawano correction for J.L.Kammerdiener thesis before 2014 NRDC meeting in Smolenice; EXFOR entry #14329.
- Recently, Baghdad Atlas data were added after they were published in NIM: A.M.Hurst, L.A.Bernstein, T.Kawano, A.M.Lewis, K.Song, *The Baghdad Atlas: A relational database of inelastic neutron-scattering (n, n'γ) data,* Nucl.Instrum.Methods Phys.Res. A995, 165095 (2021). LBNL report was not sufficient for Naohiko, EXFOR entry #14521.



WP2014-46

Compilation of Data Corrected or Derived by Other Than Author

(N. Otsuka, O. Schwerer, 2014-04-30)

Introduction

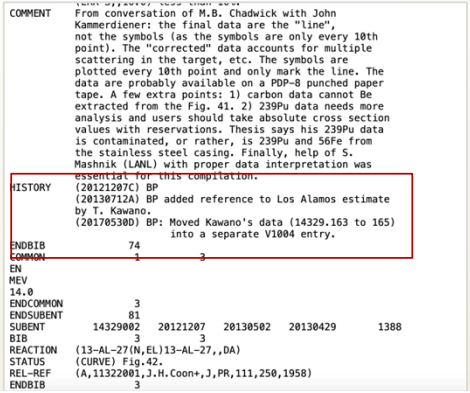
The EXFOR library is a collection of experimental data sets reported by the people who performed the experiments in principle. However, several cases of data corrected or derived by non-authors came up which may be useful for compilation, where a policy and compilation format need to be formulated. This paper gives a summary of the (1) examples of non-trivial non-author data, (2) questions on policy, and (3) possible technical implementation (e.g., coding rule) for further discussion in the NRDC 2014 Meeting. See also Memo CP-D/841 for a review of data renormalized by non-authors and compiled in EXFOR.

Examples of Non-trivial Non-author Data

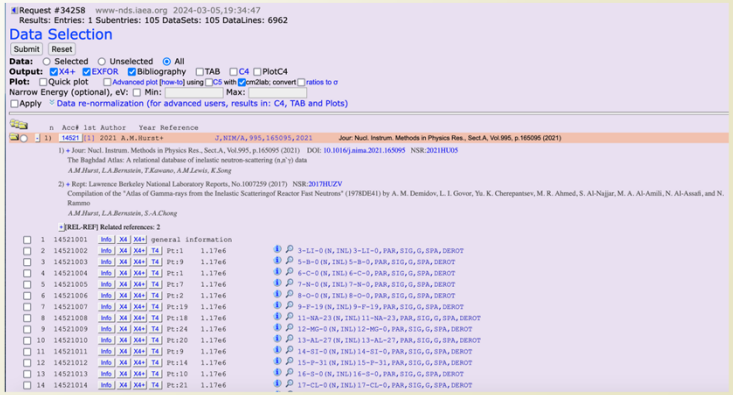
Renormalization based on the latest reference parameters (*e.g.*, U-235 fission cross section, delayed gamma intensities) is routinely done by evaluators, and it is not realistic to perform it for all relevant data sets by EXFOR compilers. The INDC meeting working group 2 "Data Dissemination, International Coordination and Training" also recommends to maintain a parallel data base for such corrected data sets (see appendix of the memo). Viktor Zerkin is developing a system to perform renormalization due to change in reference parameters (see Action 68 of the NRDC 2013 Meeting). Furthermore, the code RECORM is not used appropriately (i.e., without cross reference to the original data (See Memo CP/D-841). Under this situation, we propose to discourage compilers collection of renormalized data or recalculated ratio by EXFOR compilers.

However some corrections and derivations are beyond this level, for example,

1. Helium-3 neutron scattering experimental data measured at KFK [1] and corrected by M. Drosg et al. [2] – *data corrected by other than author.*



```
COMMENT     From conversation of M.B. Chadwick with John
            Kammerdiener: the final data are the "line",
            not the symbols (as the symbols are only every 10th
            point). The "corrected" data accounts for multiple
            scattering in the target, etc. The symbols are
            plotted every 10th point and only mark the line. The
            data are probably available on a PDP-8 punched paper
            tape. A few extra points: 1) carbon data cannot Be
            extracted from the Fig. 41. 2) 239Pu data needs more
            analysis and users should take absolute cross section
            values with reservations. Thesis says his 239Pu data
            is contaminated, or rather, is 239Pu and 56Fe from
            the stainless steel casing. Finally, help of S.
            Mashnik (LANL) with proper data interpretation was
            essential for this compilation.
HISTORY     (20121207C) BP
            (20130712A) BP added reference to Los Alamos estimate
            by T. Kawano.
            (20170530D) BP: Moved Kawano's data (14329.163 to 165)
                        into a separate V1004 entry.
ENDBIB             74
COMMON              1          3
EN
MEV
14.0
ENDCOMMON           3
ENDSUBENT          81
SUBENT      14329002   20121207   20130502   20130429       1388
BIB                 3          3
REACTION    (13-AL-27(N,EL)13-AL-27,,DA)
STATUS      (CURVE) Fig.42.
REL-REF     (A,11322001,J.H.Coon+,J,PR,111,250,1958)
ENDBIB              3
```



Request #34258 www-nds.iaea.org 2024-03-05,19:34:47
Results: Entries: 1 Subentries: 105 DataSets: 105 DataLines: 6962

Data Selection

Submit Reset

Data: Selected Unselected All
Output: X4+ EXFOR Bibliography TAB C4 PlotC4
Plot: Quick plot Advanced plot [how-to] using ICS with Cori2lab: convert ratios to σ
Narrow Energy (optional), eV: Min: Max:
Apply Data re-normalization (for advanced users, results in: C4, TAB and Plots)

	n	Acc#	1st Author	Year	Reference			
1)	1	14521	[1]	2021	A.M.Hurst+	J,NIM/A,995,165095,2021	Jour: Nucl. Instrum. Methods in Physics Res., Sect.A, Vol.995, p.165095 (2021)	

1) + Jour: Nucl. Instrum. Methods in Physics Res., Sect.A, Vol.995, p.165095 (2021) DOI: 10.1016/j.nima.2021.165095 NSR:2021HU05
The Baghdad Atlas: A relational database of inelastic neutron-scattering (n,n'γ) data
A.M.Hurst, L.A.Bernstein, T.Kawano, A.M.Lewis, K.Song

2) + Rept: Lawrence Berkeley National Laboratory Reports, No.1007259 (2017) NSR:2017HUZV
Compilation of the "Atlas of Gamma-rays from the Inelastic Scatteringof Reactor Fast Neutrons" (1978DE41) by A. M. Demidov, L. I. Govor, Yu. K. Cherepantsev, M. R. Ahmed, S. Al-Najjar, M. A. Al-Amili, N. Al-Assafi, and N. Ramno
A.M.Hurst, L.A.Bernstein, S.-A.Chong

+[REL-REF] Related references: 2

1	14521001	Info	X4	X4+	general information			
2	14521002	Info	X4	X4+	T4	Pt:1	1.17e6	3-LI-0(N,INL)3-LI-0,PAR,SIG,G,SPA,DEROT
3	14521003	Info	X4	X4+	T4	Pt:9	1.17e6	5-B-0(N,INL)5-B-0,PAR,SIG,G,SPA,DEROT
4	14521004	Info	X4	X4+	T4	Pt:1	1.17e6	6-C-0(N,INL)6-C-0,PAR,SIG,G,SPA,DEROT
5	14521005	Info	X4	X4+	T4	Pt:7	1.17e6	7-N-0(N,INL)7-N-0,PAR,SIG,G,SPA,DEROT
6	14521006	Info	X4	X4+	T4	Pt:2	1.17e6	8-O-0(N,INL)8-O-0,PAR,SIG,G,SPA,DEROT
7	14521007	Info	X4	X4+	T4	Pt:19	1.17e6	9-F-19(N,INL)9-F-19,PAR,SIG,G,SPA,DEROT
8	14521008	Info	X4	X4+	T4	Pt:18	1.17e6	11-NA-23(N,INL)11-NA-23,PAR,SIG,G,SPA,DEROT
9	14521009	Info	X4	X4+	T4	Pt:24	1.17e6	12-MG-0(N,INL)12-MG-0,PAR,SIG,G,SPA,DEROT
10	14521010	Info	X4	X4+	T4	Pt:20	1.17e6	13-AL-27(N,INL)13-AL-27,PAR,SIG,G,SPA,DEROT
11	14521011	Info	X4	X4+	T4	Pt:9	1.17e6	14-SI-0(N,INL)14-SI-0,PAR,SIG,G,SPA,DEROT
12	14521012	Info	X4	X4+	T4	Pt:14	1.17e6	15-P-31(N,INL)15-P-31,PAR,SIG,G,SPA,DEROT
13	14521013	Info	X4	X4+	T4	Pt:10	1.17e6	16-S-0(N,INL)16-S-0,PAR,SIG,G,SPA,DEROT
14	14521014	Info	X4	X4+	T4	Pt:21	1.17e6	17-CL-0(N,INL)17-CL-0,PAR,SIG,G,SPA,DEROT

Sources (#1.5): Karlsruhe Corrections

- Present status of Karlsruhe cross sections (CP-C/472).
- 5-7% deviations in ^{197}Au(n,γ) cross sections produce 20-30% deviations in *r*-process abundances: B. Pritychenko, J. Phys. (London) **G48**, 08LT01 (2021).
- C30 The activation cross sections measured by the Karlsruhe renormalized with a new gold standard cross section are published as INDC(GER)-053 and the relevant EXFOR entries must be updated. See also CP-C/472=WP2021-27.
- EXFOR data sets were corrected by the NRDC.