Compilation of Fission Yields

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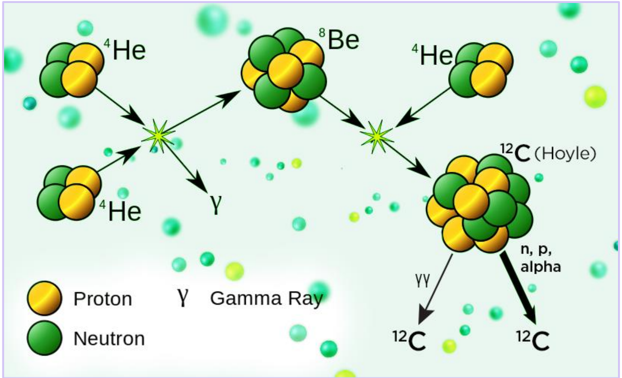
Compilation Databases

- There are three major compilation databases at NNDC: NSR, EXFOR and XUNDL.
- We will concentrate on NSR and EXFOR databases:
  - Nuclear Science References (NSR): all low- and intermediate-energy references for a broad use, not just nuclear structure and decay as before 90s.
  - Experimental Nuclear Reaction Data (EXFOR): all low- and intermediate-energy reaction data sets for neutron-, charged- and photo-induced reactions, not just neutron-induced as before 80s.
- The primary goal of both database efforts is a compilation of new data.
- The compilation scope and quality controls for NSR and EXFOR databases have evolved over the many years of operation. These facts plus lack of advanced computer tools in the past are responsible for missing references and data sets.

Value of Compilations

- Compilations create a basis for nuclear data evaluations and support research.
- Compilations are driven by
  - New results and discoveries in science
  - New rules and element names
  - Need for up-to-date databases
- NSR compilation of Notre Dame/MSU work on ``Enhancement of the Triple Alpha Rate in a Hot Dense Medium”.



ND/MSU, PRL 119, 112701 (2017)

2017BE18 Phys.Rev.Lett. 119, 1127501 (2017)

M.Beard, S.M.Austin, R.Cyburt

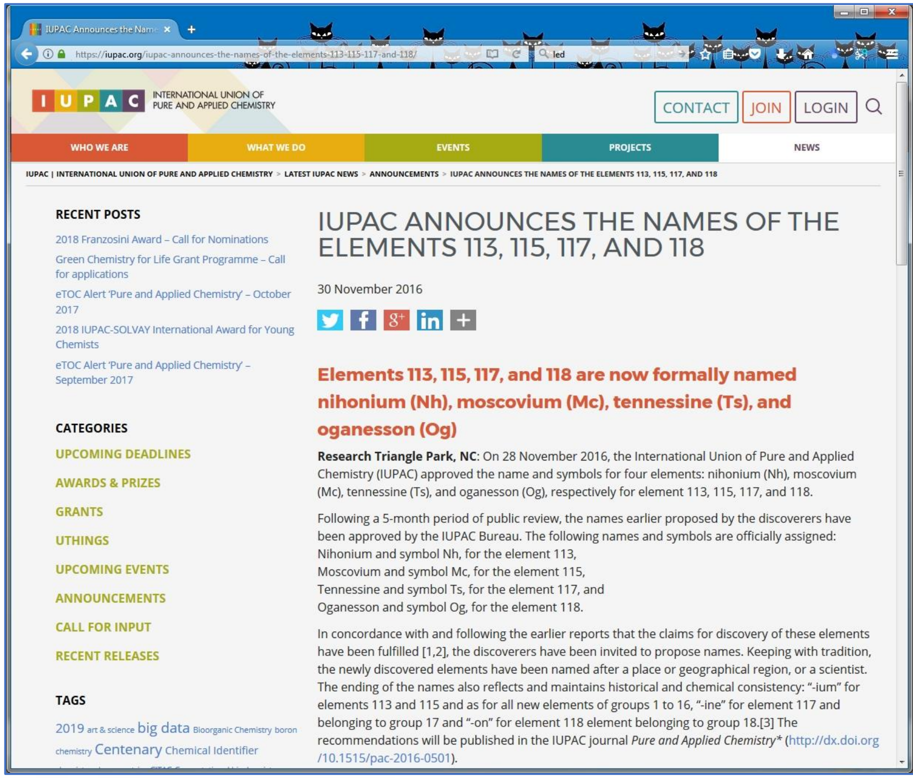
Enhancement of the Triple Alpha Rate in a Hot Dense Medium

NUCLEAR REACTIONS ^{4}He(α, X)^{8}Be, ^{8}Be(α, X)^{12}C, E<30 MeV; calculated 3α σ, reaction rates; deduced that in hot and dense astrophysical environment the rate of the triple-alpha reaction can increase greatly over the value appropriate for helium burning stars owing to hadronically induced deexcitation of the Hoyle state.

doi: 10.1103/PhysRevLett.119.112701

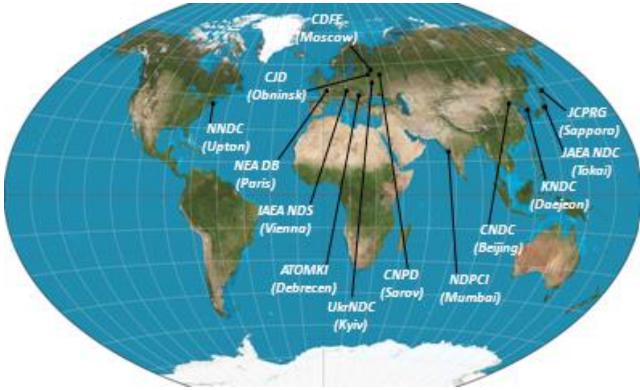
Speed of Compilations

- Compilations should be performed in a timely fashion.
- International Union of Pure and Applied Chemistry (IUPAC) assigned names to Z=113, 115, 117 and 118 as Nh, Mc, Ts and Og, respectively, on November 30, 2016.
- As of January 5, 2017 these changes were implemented in NSR.
- 594 entries/keywords were identified and modified to reflect the latest naming convention.
- N. Otuka wrote an EXFOR memo.



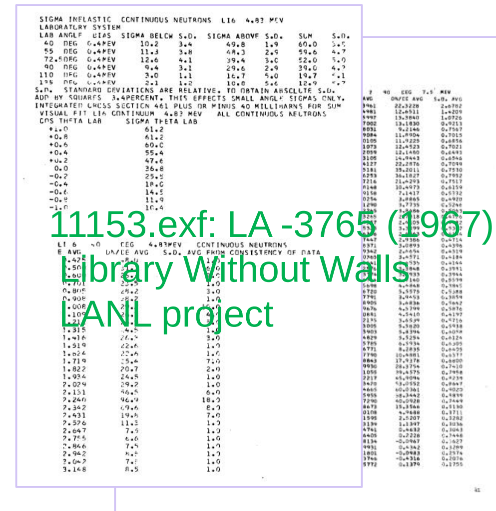
EXFOR Compilations Worldwide

- The EXFOR library was established in 1967 at a meeting of the four major nuclear data centers: Brookhaven National Laboratory, Upton, NY (Area # 1, USA, Canada); Nuclear Energy Agency (NEA) Databank, Paris, France (Area # 2, Western Europe and Japan); International Atomic Energy Agency, Vienna, Austria (Area # 3, Asia, Eastern Europe, Latin America, Africa, Australia and Oceania); and Institute of Physics and Power Engineering (IPPE), Obninsk, USSR (Area #4, Soviet Union => Russian Federation).
- The effort to translate all of the existing experimental nuclear reaction data sets, which were coded in the Sigma Center Information Storage Retrieval System (SCISRS) system format -1964, would be done later.

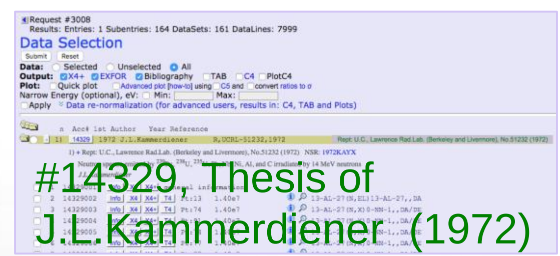


Missing Data

- EXFOR criticism by F. Kaeppeler (2006-2007) for nuclear astrophysics publications, and I started my work in EXFOR from KADoNiS references.
- Due to many historical and technical reasons not all nuclear physics papers and data sets were compiled, or data were not obtained by compilers for compiled entries.
- We address these issues at NNDC by adding missing references in NSR while in EXFOR we work on data recovery (e.g. nuclear archeology).
- Data recovery includes optical character recognition and data points digitization (Area #1: 11153, 14329). Both technologies work well with high quality images and become challenging otherwise.
- Finally, we work with scientists/evaluators on obtaining the missing publications and data sets, if available (i.e. ORNL *n,tot* and *n,γ* data).



11153.exf: LA -3765 (1967), Library Without Walls LANL project



#14329, Thesis of J.L.Kammerdiener (1972)

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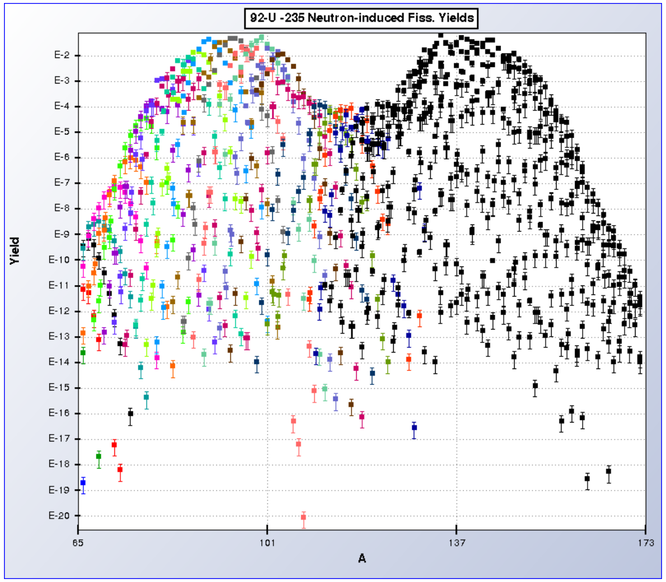
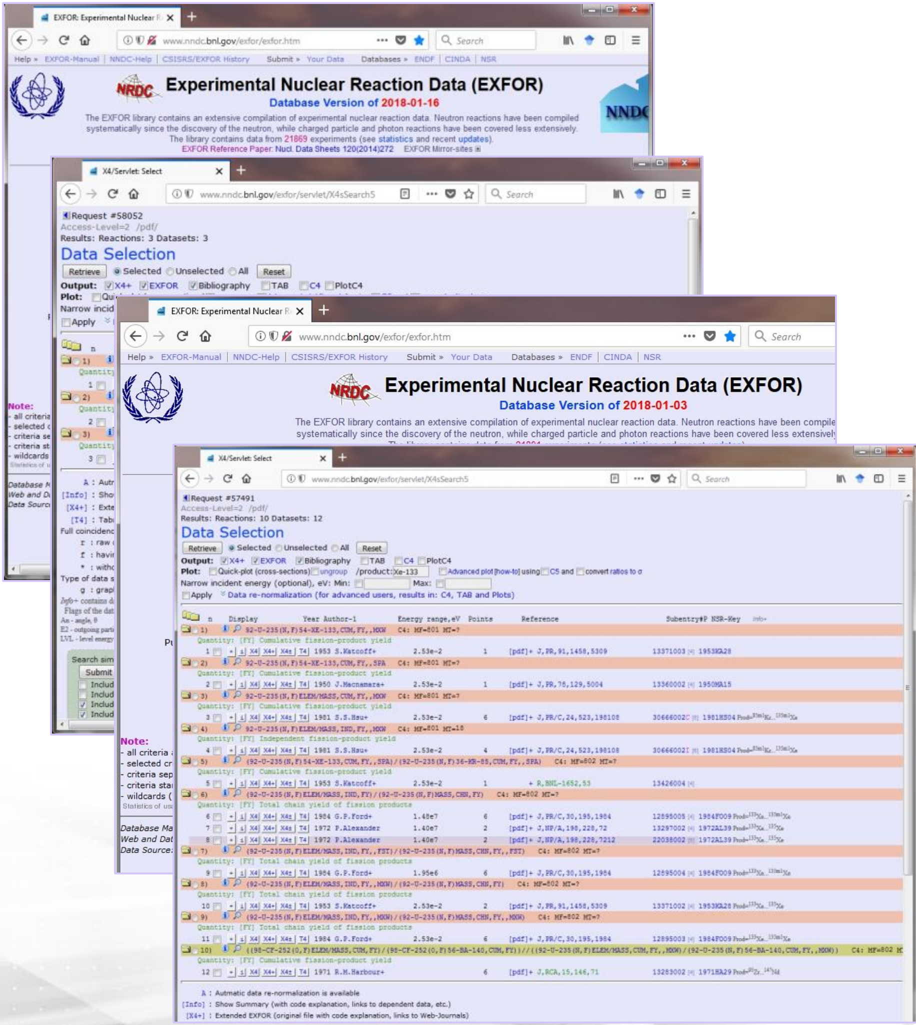
FY Compilation Completeness

- Fission Yields (FY) are fundamental for many applications.
- FY evaluation for U or Pu may contain up to 800 fission product nuclides: ENDF/B-VII.1 ^{235}U(n,F) FY evaluation.
- Do we have a complete FY record in EXFOR?
- The EXFOR database contains 22,294 experiments (database entries). So, computer tools are needed to investigate it.
- The completeness of EXFOR was verified using the NSR database at NNDC (B. Pritychenko, O. Schwerer) + help of V. Zerkin (IAEA).



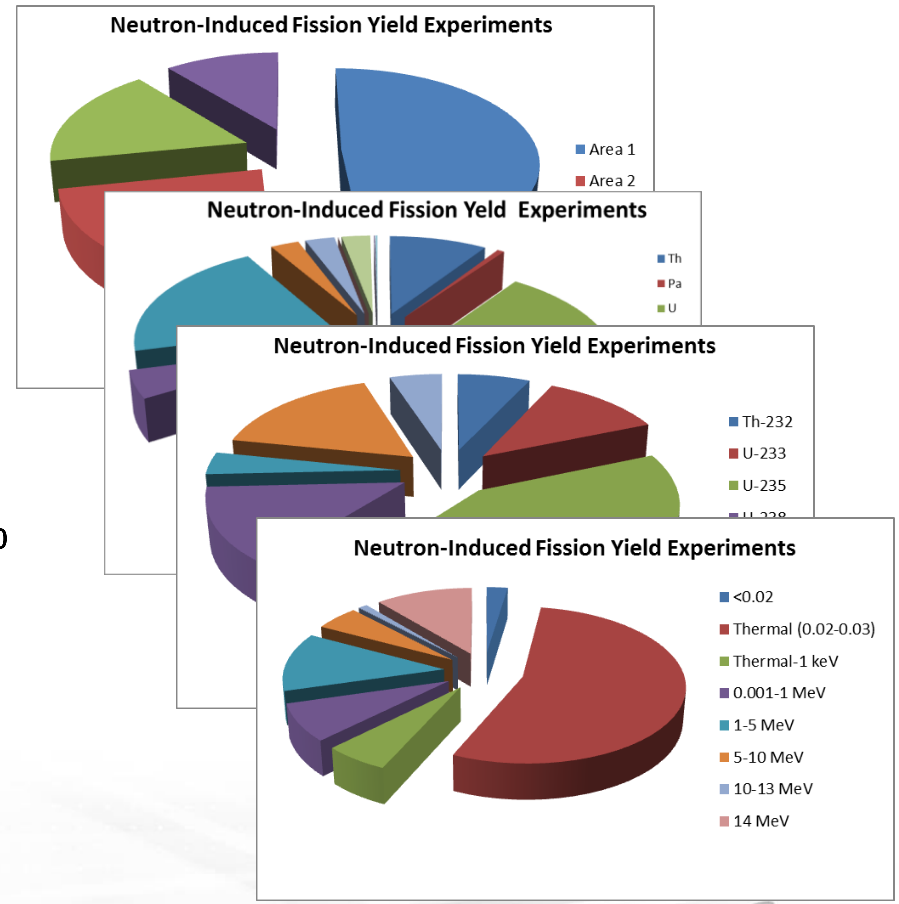
FY Compilations in EXFOR

- Two styles of data representation.
- Experimental data on neutron Fission Yields (FY) on U-235 for Xe-133.
- Products are encoded in EXFOR as Xe-133 or ELEM/MASS.
- Product & Enhanced search of products (Very useful but not trivial for many ``EXFOR experts”).
- Negative energies for ratios were discovered in Web Interface.



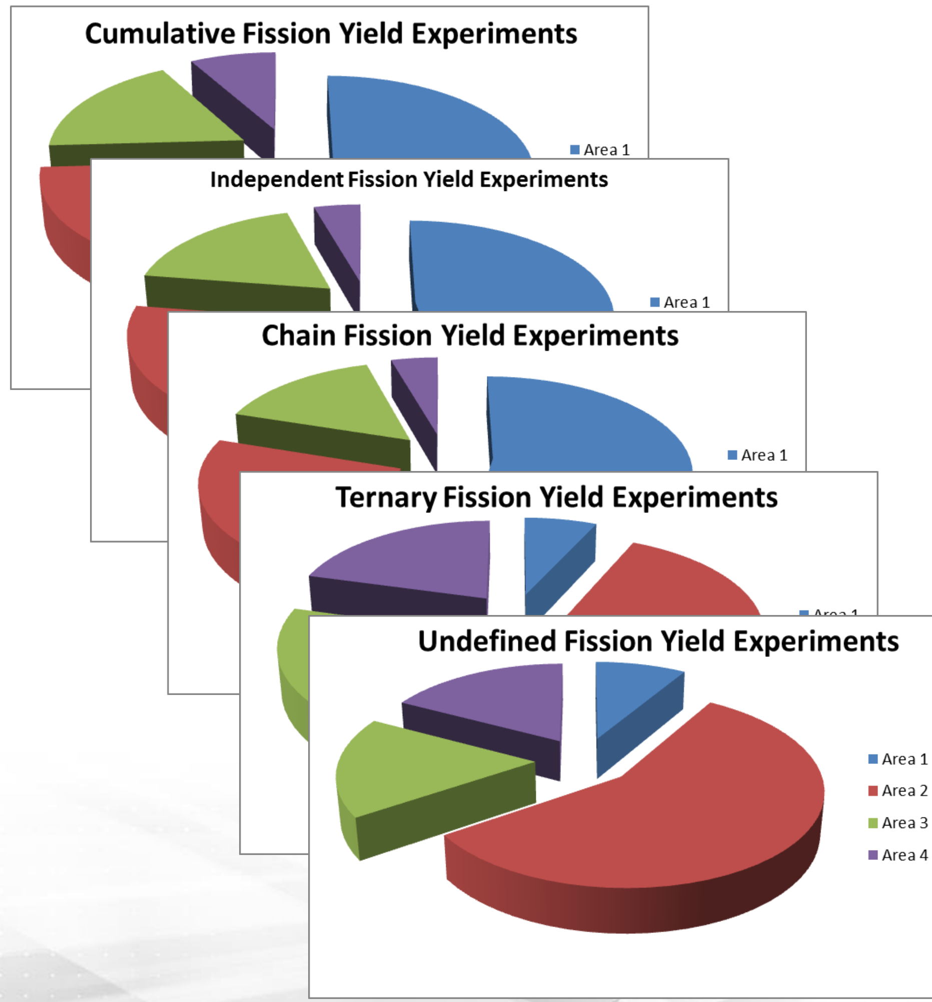
EXFOR Neutron FY Statistics

- FY by Numbers:
    - Articles: 817
    - Reactions: 1611
    - Data Sets: 2992
- FY by Area, Area #1: 48.8%
- FY by Element, U: 56.4%
- FY by Isotope, U-235: 41.9%
- FY by Energy, Thermal Neutrons: 54.4%
- All numbers in the current presentation represent the database state in April 2018.



More on EXFOR Neutron FY

- Cumulative FY
  - Articles: 502
  - Reactions: 585
  - Data Sets: 1197
- Independent FY
  - Articles: 226
  - Reactions: 436
  - Data Sets: 638
- Chains FY
  - Articles: 223
  - Reactions: 184
  - Data Sets: 427
- Ternary FY
  - Articles: 29
  - Reactions: 128
  - Data Sets: 154
- Undefined FY (discussed later)
  - Articles: 58
  - Reactions: 87
  - Data Sets: 110



Spontaneous FY (SFY)

- General SFY statistics
  - Articles: 189
  - Reactions: 345
  - Data Sets: 612
- SFY by Area, Area #1: 42.8%
- U(SF), Pu(SF), ^{252}Cf(SF)
- SFY by Element, dominated by ^{252}Cf(SF)

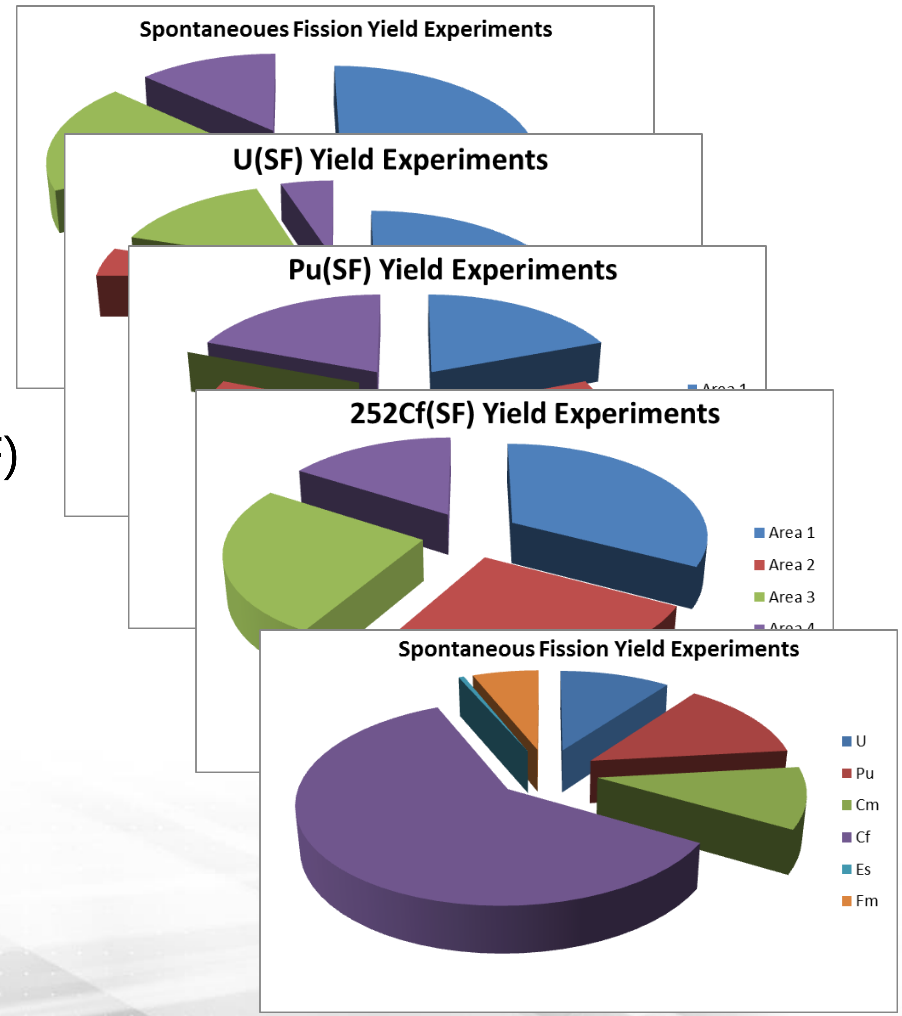
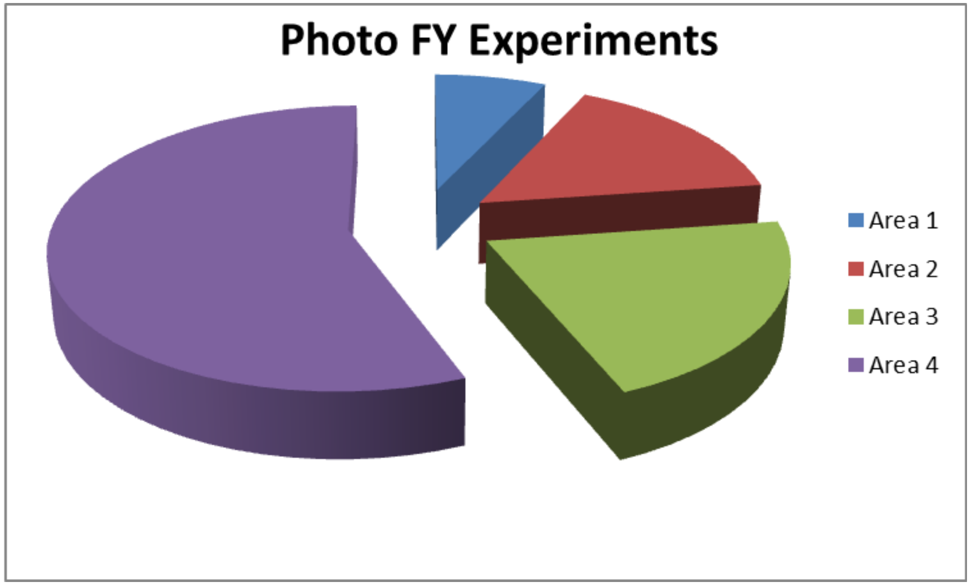


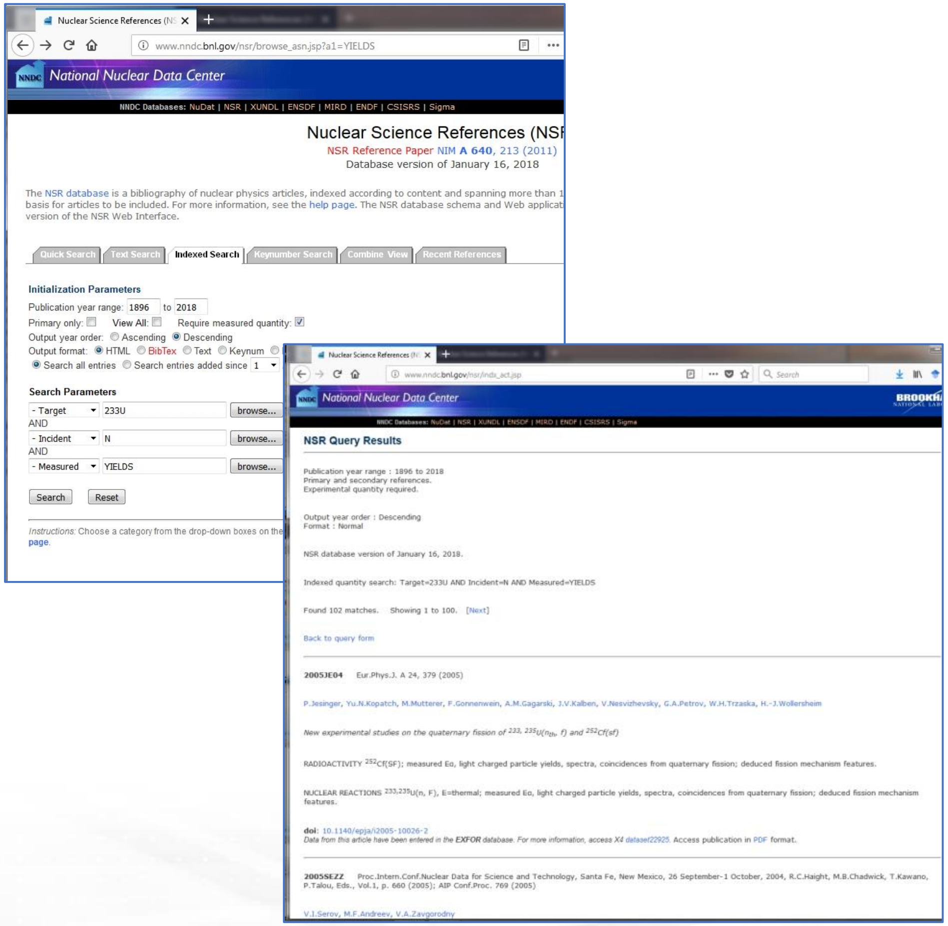
Photo FY

- General Photo FY statistics
  - Articles: 57
  - Reactions: 117
  - Data Sets: 189
- FY by Area, Area #1: 7.0 %
  - Clearly data are missing in the Area #1
- FY by Element, U: 49.1 %
- FY by Isotope: U-235: 12.3 %
- FY by Energy: Thermal: 0 % (Just a quality check)



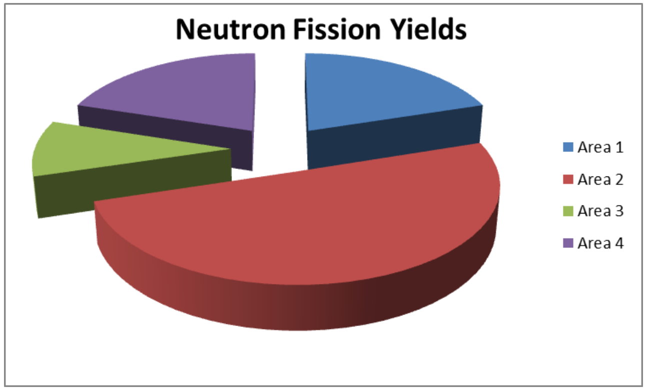
NSR FY Data

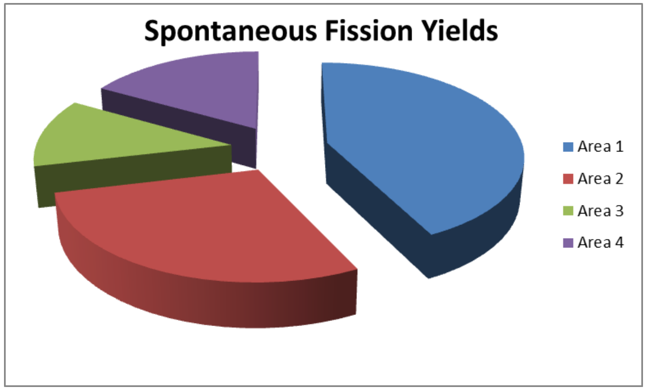
- Complementary check of FY using NSR database that contains 229,594 references (As of October 19, 2018).
- Simple NSR retrieval for ^{233}U(n,F) measured fission yields (exp. data only):
  - Total references: 102
  - Potentially missing in EXFOR: 40
- 40 cases should be reanalyzed and added to EXFOR if necessary.
- Data includes also other isotopes of U and Pu, ^{252}Cf(SF).

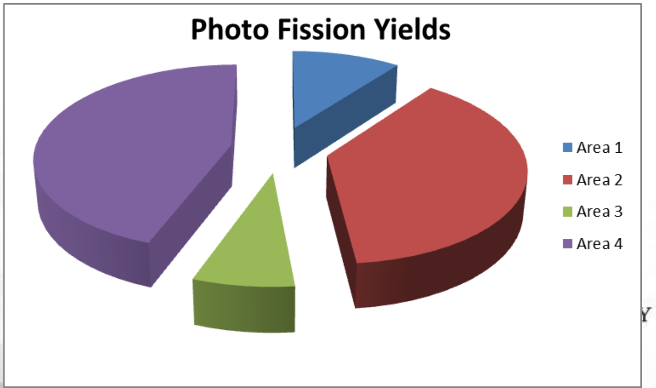


Work on FY References

- Finally, nuclear structure-like search for FY NSR references was conducted at NNDC:
  - Potentially Missing Neutron FY: 384
  - Potentially Missing Spontaneous FY: 142
  - Potentially Missing Photo FY: 126
  - Non-uniform findings in the areas: #3 small (IAEA), #2 large (NEA)
  - Ghent University results were ignored in the Area #2????
  - Yu.P. Gangrsky (Dubna) published a large number of preprints often on the same subject (rather background). Background noise in the Area #4.







NSR FY References

- New, updated, excluded (already existing) and difficult to find references for NF, SF and GF EXFOR entries.
- NSR impact
  - Project produced many modifications of NSR entries.
  - PDF collection assembly is in progress (540+), many thanks to J. Totans for rare reports.
- EXFOR impact
  - Area #1 papers will be compiled at NNDC, other references will be passed to the NRDC.

NF/Area	#1	#2	#3	#4	Sum
New	28	103	19	47	197
Updates	39	68	14	20	141
Excluded	2	16	1	7	26
Not Found	9	4	3	3	19
Total	78	191	37	77	383

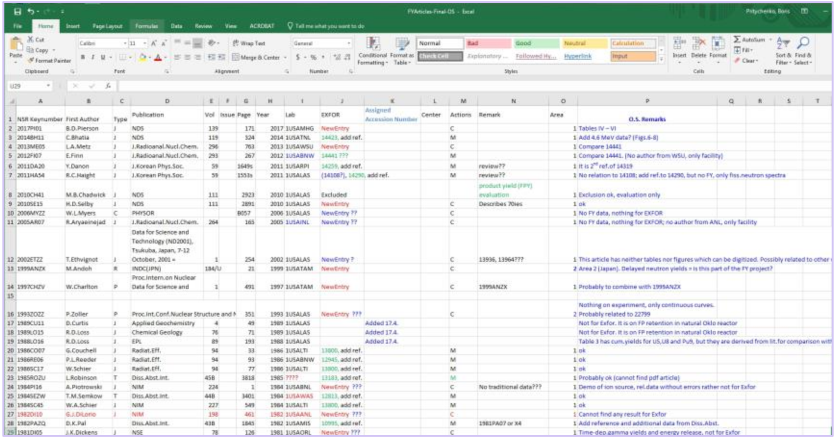
SF/Area	#1	#2	#3	#4	Sum
New	33	27	9	18	87
Updates	15	9	5	6	35
Excluded	1	3	0	0	4
Not Found	11	2	3	0	16
Tot					42

GF/					
Ne					69
Up					40
Exc					2
No					15
Tot					26

	Experiments	Data Sets	Missing References
Neutron-Induced (NFY)	817	2992	384
Photo-Induced (PFY)	57	189	126
Spontaneous (SFY)	189	612	142

Data Verification by O. Schwerer

- Data for Photo, Spontaneous and Neutron-Induced fission were verified by O. Schwerer
  - Spontaneous FY verification is in progress.
  - Overall numbers went down.
  - Many missing entries still remain.
  - Explanation: In the past, it was a policy not to list all FY references. These entries should be updated.



- Otto has managed EXFOR at the agency for many years; his analysis an explanation why experiments were missed are crucial for the project.

Pilot FY Compilation Project

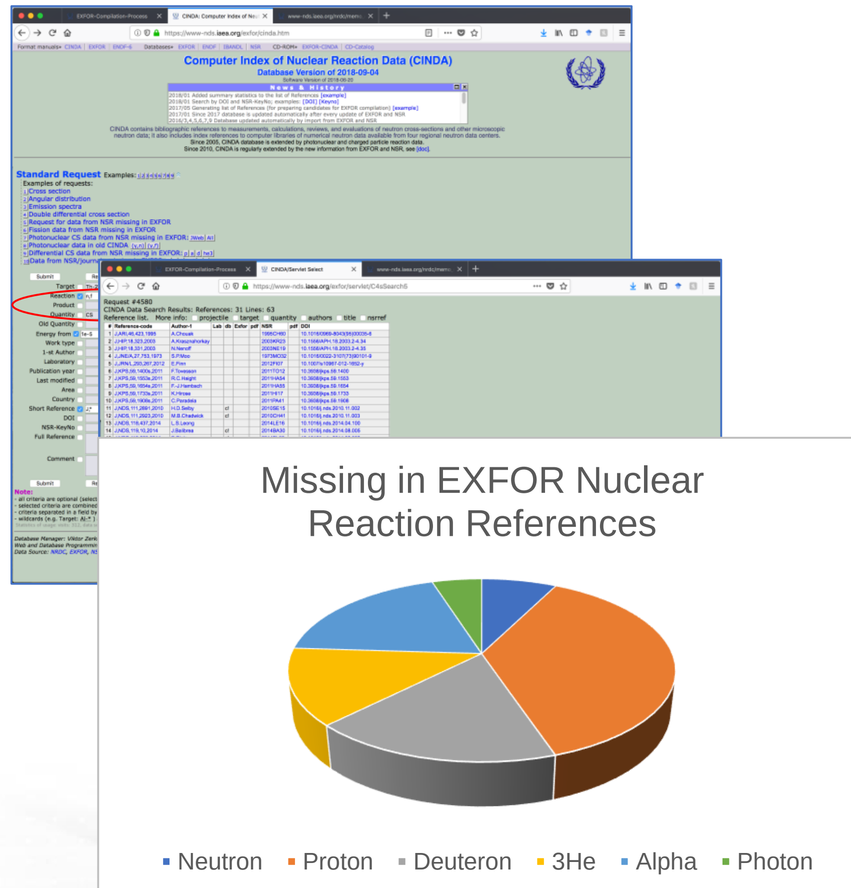
- Pilot project was launched at NNDC to estimate a time scale.
- Search for missing references at NNDC
  - Search for missing references (B. Pritychenko): ~160 h
  - Search for missing references (E. Betak): ~20 h
  - Verification (O. Schwerer): ~120 h
  - NNDC library work (J. Totans): ~120 h
  - Totals for searches and verification: 420 h
- Pilot Compilation Project
  - Compilation of 15 experiments (B. Pritychenko): ~120 h
  - Verification of 15 experiments (O. Schwerer): ~60 h
  - Corrections of 18 old entries (B. Pritychenko): ~60 h
  - Verification of 18 old entries (O. Schwerer): ~30 h
  - Totals for 15 new and 18 updated entries are 180 and 90 h, respectively.
- Please do not project the pilot project time scale to the whole effort!!! Rather consider the fact that NNDC already has invested 690 hours of work to FY compilations.

Pilot Project Findings

- NSR and EXFOR databases FY contents were improved because of the pilot project.
- EXFOR compilation rules often contradict with a spirit of physics.
- Spallation vs. Fission
  - Both process produce lighter nuclei but distributions are different.
  - Physicists like G. Seaborg simply measure spallation or fission product cross sections or yields but it is not sufficient for EXFOR.
  - SF5=SPL only when spallation was explicitly measured, measuring spallation products is not sufficient in EXFOR.
  - Both spallation and fission timescales are small (direct/compound) to be detected in experiments, so reactions are separated using the product distributions. Therefore, it is difficult to understand the meaning of explicitly measured spallation. EXFOR rules are confusing.
- Fission yield cross section compilation rules
  - SF5=IND is redundant for beta shielded products, so SF5 is undefined or blank.
  - N/A for fission yields according to Otto but we saw undefined FY previously, more work is necessary here.
- These rules create problems for computer programs and Web interface retrievals, and I discussed these issues with O. Schwerer extensively.

NSR/CINDA Work of V. Zerkin

- The similar task has been solved by Viktor Zerkin using NSR/CINDA.
- CINDA search for all missing references in NSR: n-1202; p-5998; d-2831; ^{3}He-2170; a-3061; g-794: 16056 missing.
- NSR is really powerful, and NRDC users should explore NSR for missing references. Personally, I believe that could have as many proton reaction papers as neutron papers.
- Both approaches are complementary:
  - NSR/CINDA search is automatized.
  - Direct NSR search is more productive but requires more time, manual labor and specialized knowledge.
- For users with ENSDF background direct NSR search is preferable.
- Finally, CINDA/NSR computer search results validate the current work: 227 neutron fission references.



Conclusions

- Fission Yields is a big project that requires plenty of time, effort, specialized knowledge and a collaborative effort is necessary.
- NSR & EXFOR projects represent an excellent starting point for fission yields compilation and evaluation effort.
- We identified potential EXFOR database deficiencies using NSR database contents.
- These findings are verified by O. Schwerer and will be summarized in three NRDC memos.
- Pilot project has been conducted for further estimate and realistic analysis of the manpower FY effort. NNDC has invested 690 h into it.
- EXFOR compilation rules have to be revisited in order to avoid possible confusions and aligned with physics.
- Finally, no more missing data in present compilations, we need complete databases.

The IAEA Mission Statement

The International Atomic Energy Agency:

- is an independent intergovernmental, science and technology-based organization, in the United Nations family, that serves as the global focal point for nuclear cooperation;
- assists its Member States, in the context of social and economic goals, in planning for and using nuclear science and technology for various peaceful purposes, including the generation of electricity, and facilitates the transfer of such technology and knowledge in a sustainable manner to developing Member States;
- develops nuclear safety standards and, based on these standards, promotes the achievement and maintenance of high levels of safety in applications of nuclear energy, as well as the protection of human health and the environment against ionizing radiation;
- verifies through its inspection system that States comply with their commitments, under the Non-Proliferation Treaty and other non-proliferation agreements, to use nuclear material and facilities only for peaceful purposes.

NNDC Mission Statement

- The National Nuclear Data Center (NNDC) collects, evaluates, archives and disseminates nuclear physics data for basic nuclear research and for applied nuclear technologies.
  - The Center collects experimental information on nuclear structure and nuclear reactions, evaluates them employing nuclear physics theory and expertise in evaluating experimental techniques to provide recommended results, maintains nuclear databases and using modern information technology disseminates the results.
  - The data are kept in dedicated libraries, which are periodically updated.
  - The information is the product of the NNDC-coordinated US Nuclear Data Program that involves several National Laboratories and Universities, as well as, cooperating data centers and other interested groups worldwide.
  - There are two other major data banks operated by international organizations, one in Paris and another in Vienna.

Definitions of Fission Yields

- Independent fission yield (%): number of atoms of a specific nuclide produced directly (not via radioactive decay of precursors) in 100 fission reactions
- * Cumulative fission yield (%): total number of atoms of a specific nuclide produced (directly and via decay of precursors) in 100 fission reactions
- * Chain yield (Mass [number] yield) (%): It was used for the (sum of) cumulative yield(s) of the last (stable or long-lived) chain member(s) as well as for the isobaric sum of independent yields, and also for some yield types in between, e.g. the sum of cumulative yield of a product towards the end of an isobaric chain and the independent yield of its daughter. A complication arises due to b-delayed neutron emission: cumulative and — in consequence — chain yields are suffering increases by neutron emission from heavier mass chains and losses to lighter mass chains. In consequence, cumulative yields and chain yields are no more identical to the sum of the independent yields of their precursors. Two new clear definitions of this type of yields:
  - The (total) chain yield is defined as the (sum of) cumulative yield(s) of the last (stable or long-lived) chain member(s).
  - The mass (number) yields are defined as the sum of all independent yields of a particular mass chain and are this way distinguished from chain yields.
- Fractional independent/cumulative yields represent the independent or cumulative fission yield divided by the chain yield (or mass number yield) (%).
- Partial yields: Some methods of measurement provide yields for a specific condition (like a specific kinetic energy or a specific ionic charge state of the fission fragments). Such yields are called partial yields.
- Ternary yields.

Open Access Developments

- **Public access**
  - America COMPETES Reauthorization Act of 2010 addresses public access to research results, particularly in the forms of scholarly publications and digital data
  - Charge from DOE Office of Science: "Identify and assess current practices, policies and procedures to research results with report by 1-jul-2011."
- **Report of the NSAC Sub-Committee on Public Access to Research Results**
  - The nuclear physics community often submits research results to freely accessible databases such as the National Nuclear Data Center (NNDC, http://www.nndc.bnl.gov/) …
  - Programs like the U.S. Nuclear Data Program also provide an important service through critical independent evaluation efforts.
- **APS News (http://www.aps.org/publications/apsnews/201310/access.cfm)**
  - Open Access Mandate will Include Raw Data.