



**International Atomic Energy Agency**

# Advances in Nuclear Data

RA Forrest

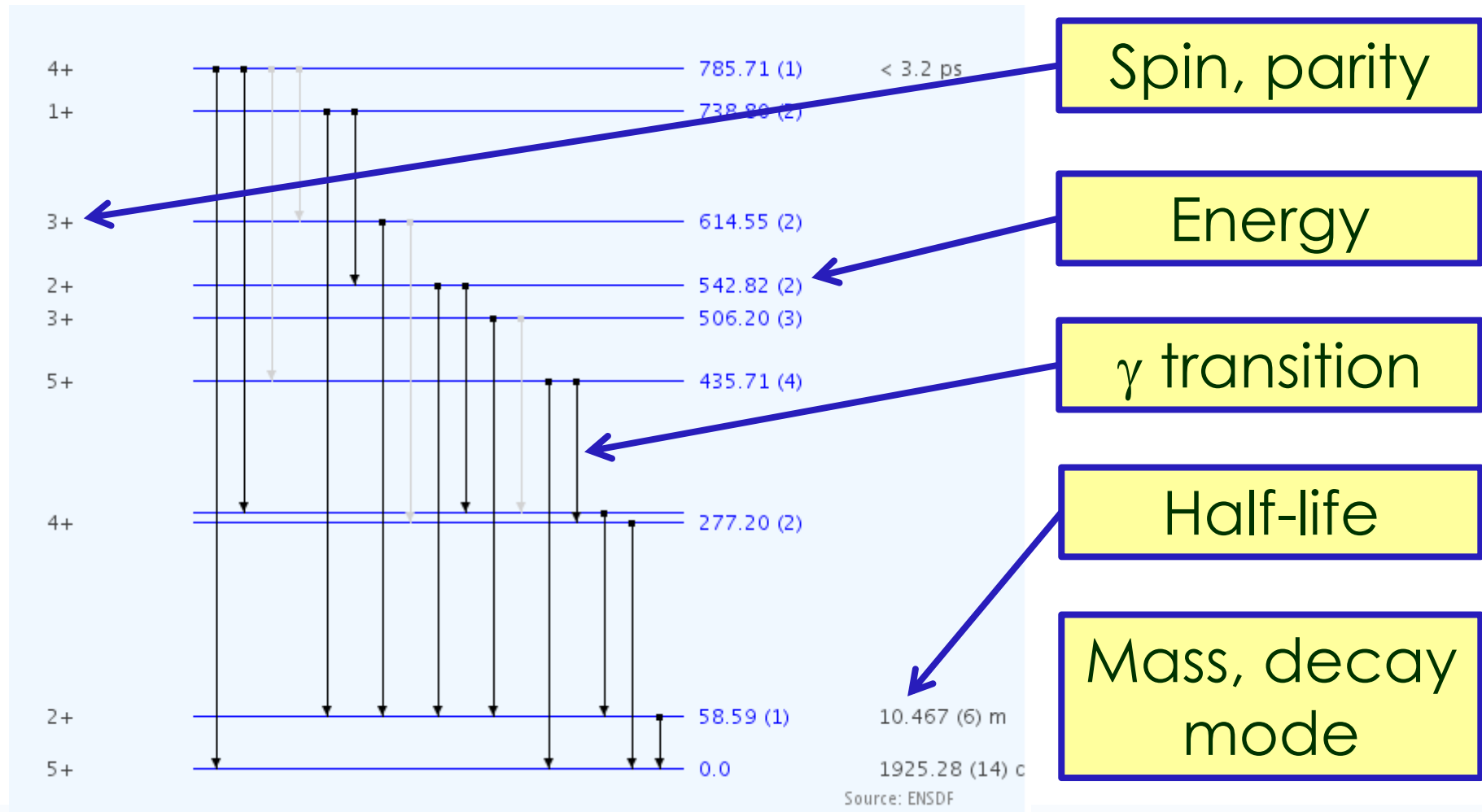
Nuclear Data Section  
Department of Nuclear Sciences and Applications

# Introduction

- Nuclear Data underpin all of Nuclear Science and Technology
- Nuclear Data include static and reaction properties of nuclides
- Compilation and Evaluation
- Stored in Data libraries and Databases
- Distribution by Data Centres
- Freely available, but not cost-free to produce

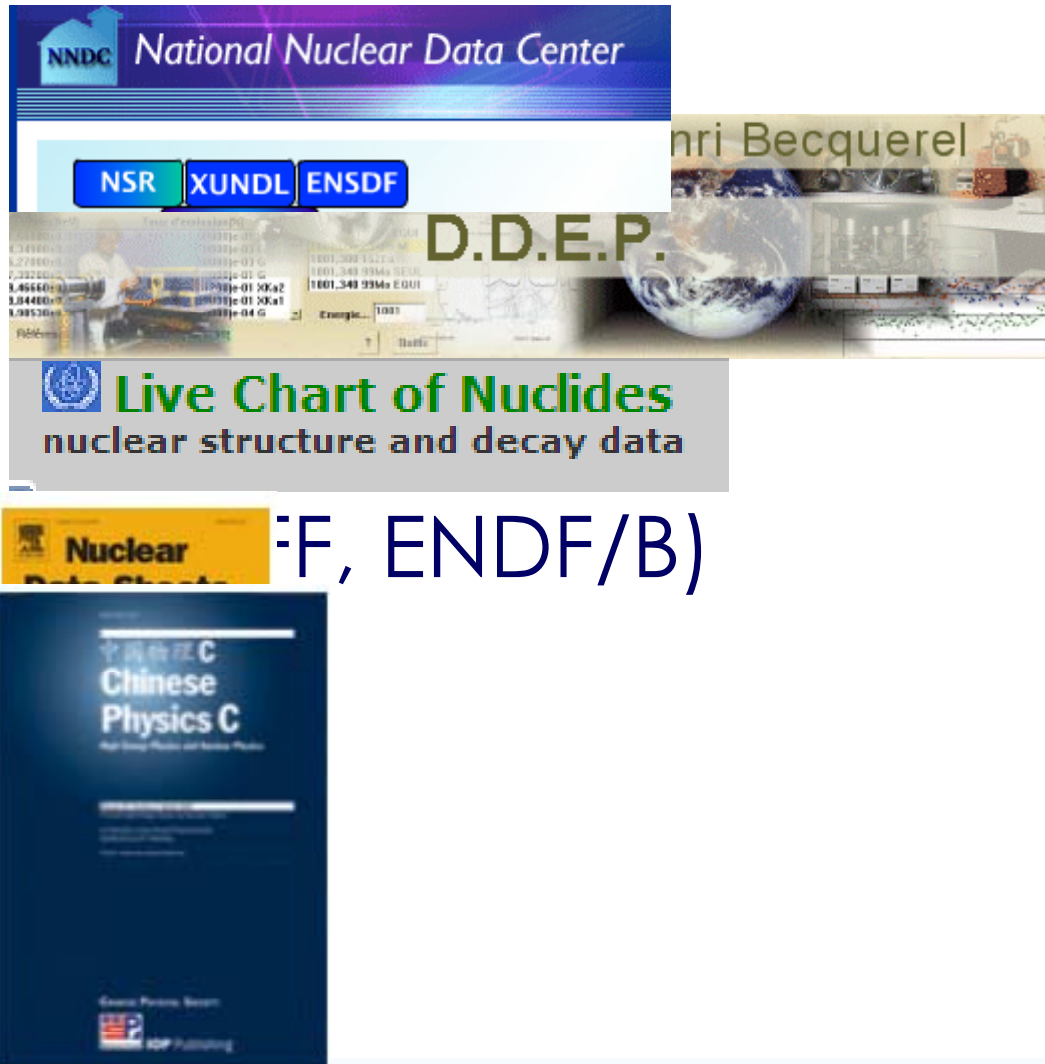


# Static Nuclide Properties



# Static Nuclide Properties

- ENSDF
- DDEP
- LiveChart
- Nuclear Data
- Decay data files (EXFOR, ENDF/B)
- AME
- NUBASE



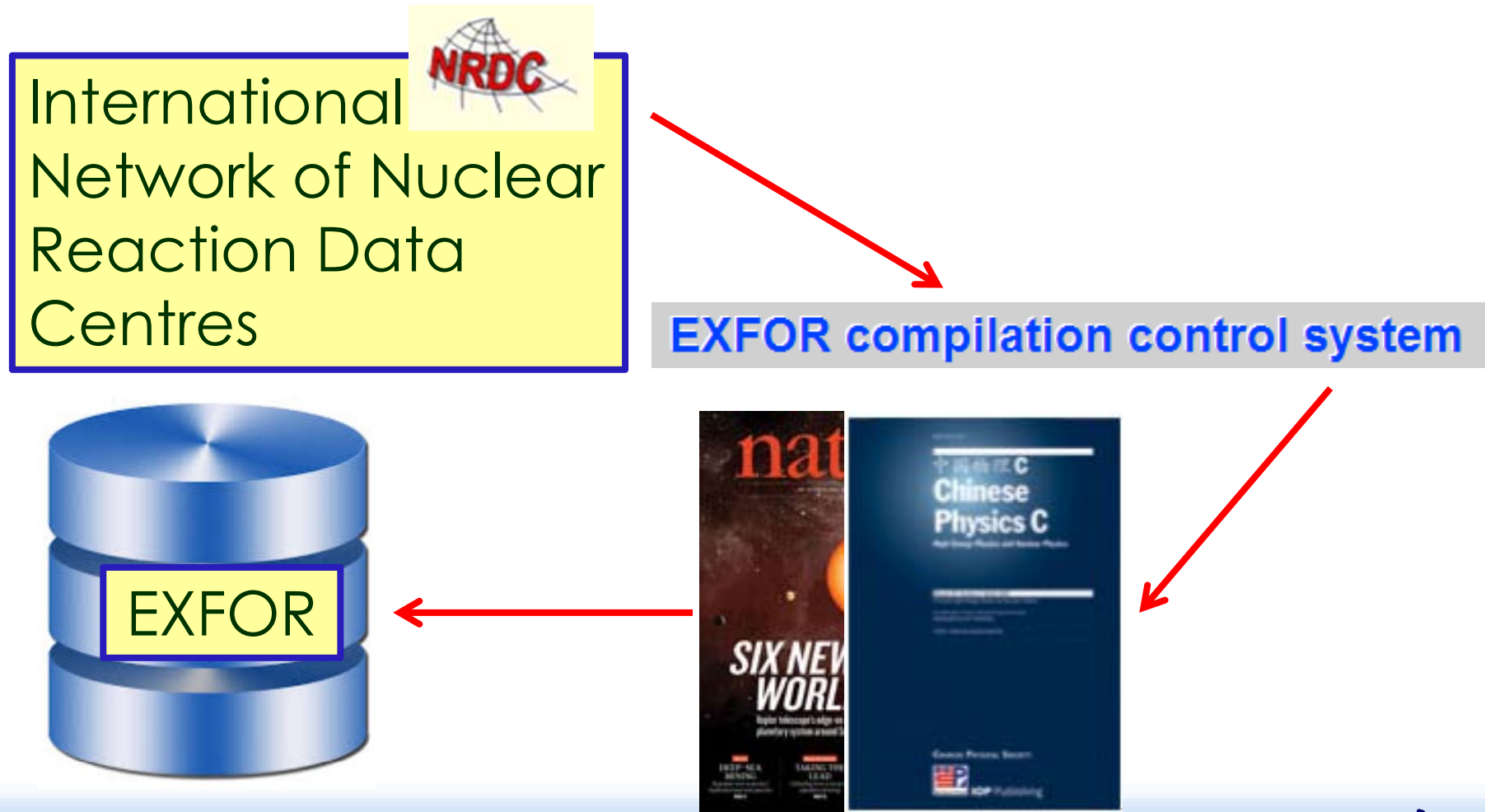
# How Many Nuclides?

- Stables (~254), Ground States, Measured, Between Drip-lines
- ~3500 nuclides reasonably well described
- BUT many cases where [g.s. ↔ isomer] or  $J^\pi$  or  $T_{1/2}$  differ in various sources
- A definitive list of nuclides not available
  - Produce as part of RIPL
  - Required for new XML format (GND)



# Experimental Reaction Data

- Compilation of journal papers → EXFOR

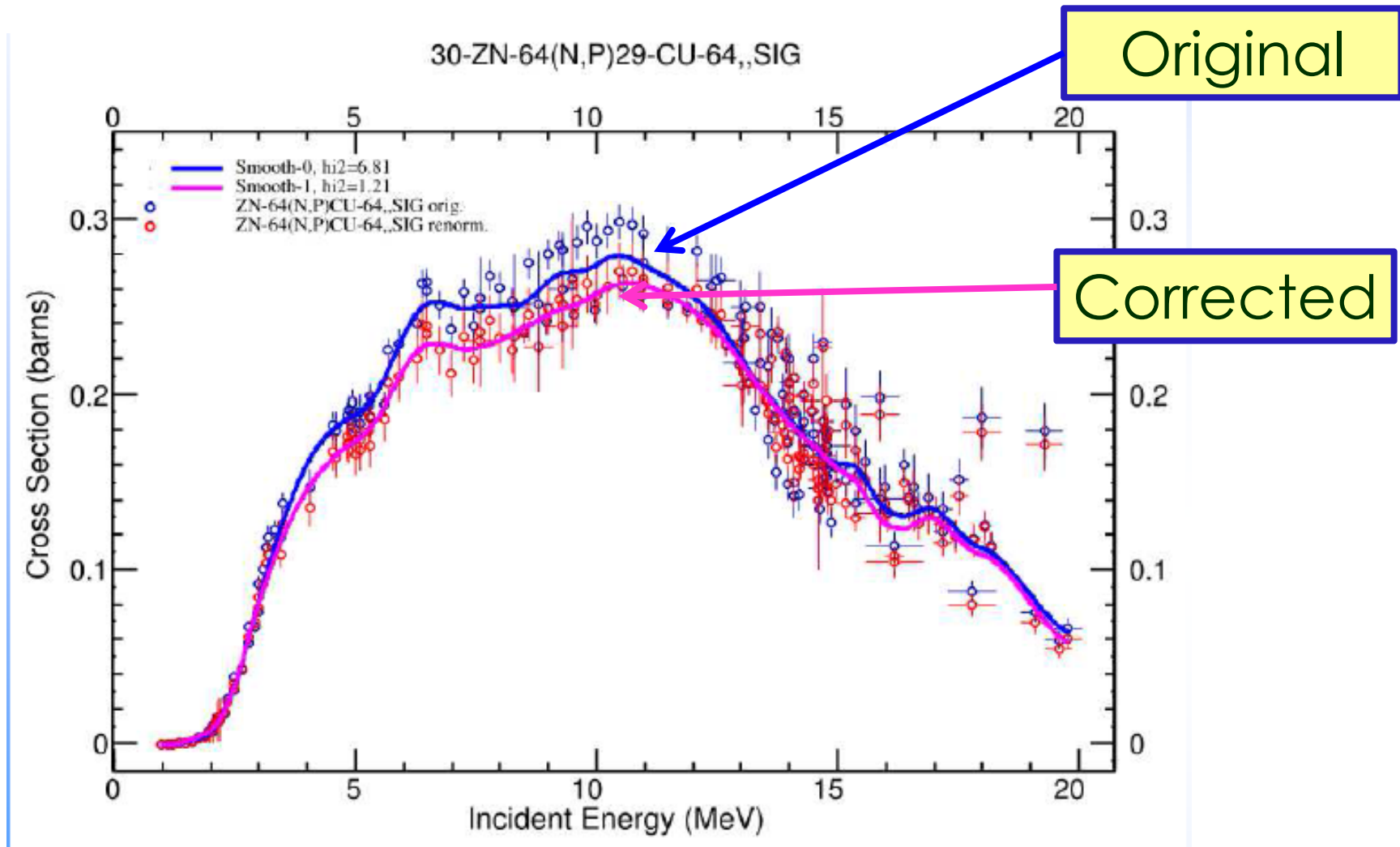


# EXFOR

- Details of 20,465 experiments (12,376,750 data points)
- Searching and visualisation
- Renormalisation
  - Monitor reactions changed
  - Automatic or manual
- Ensures that EXFOR data remains relevant for users

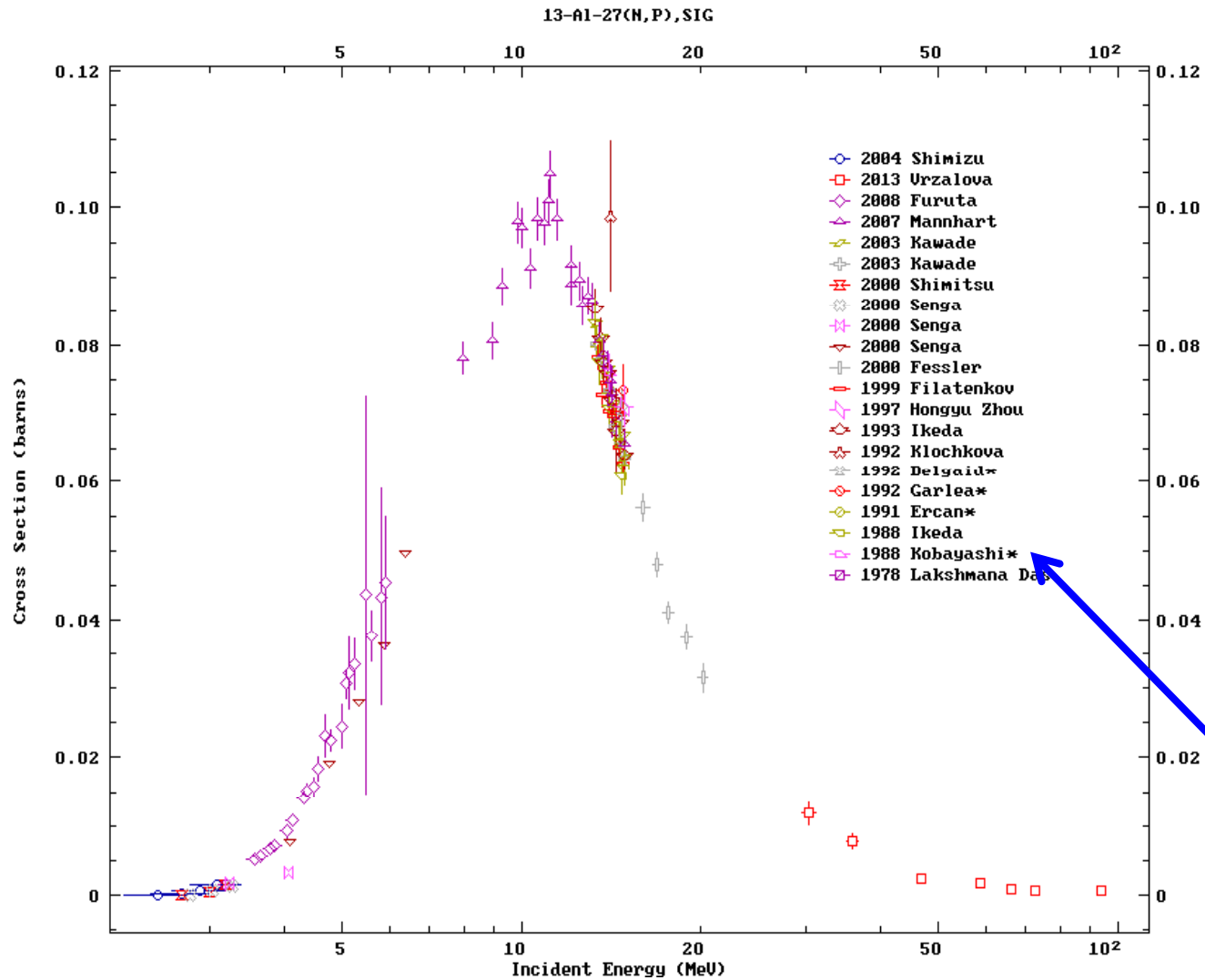


# Manual Renormalisation





# Data for $^{27}\text{Al}(n,p)$



\* =  
Corrected

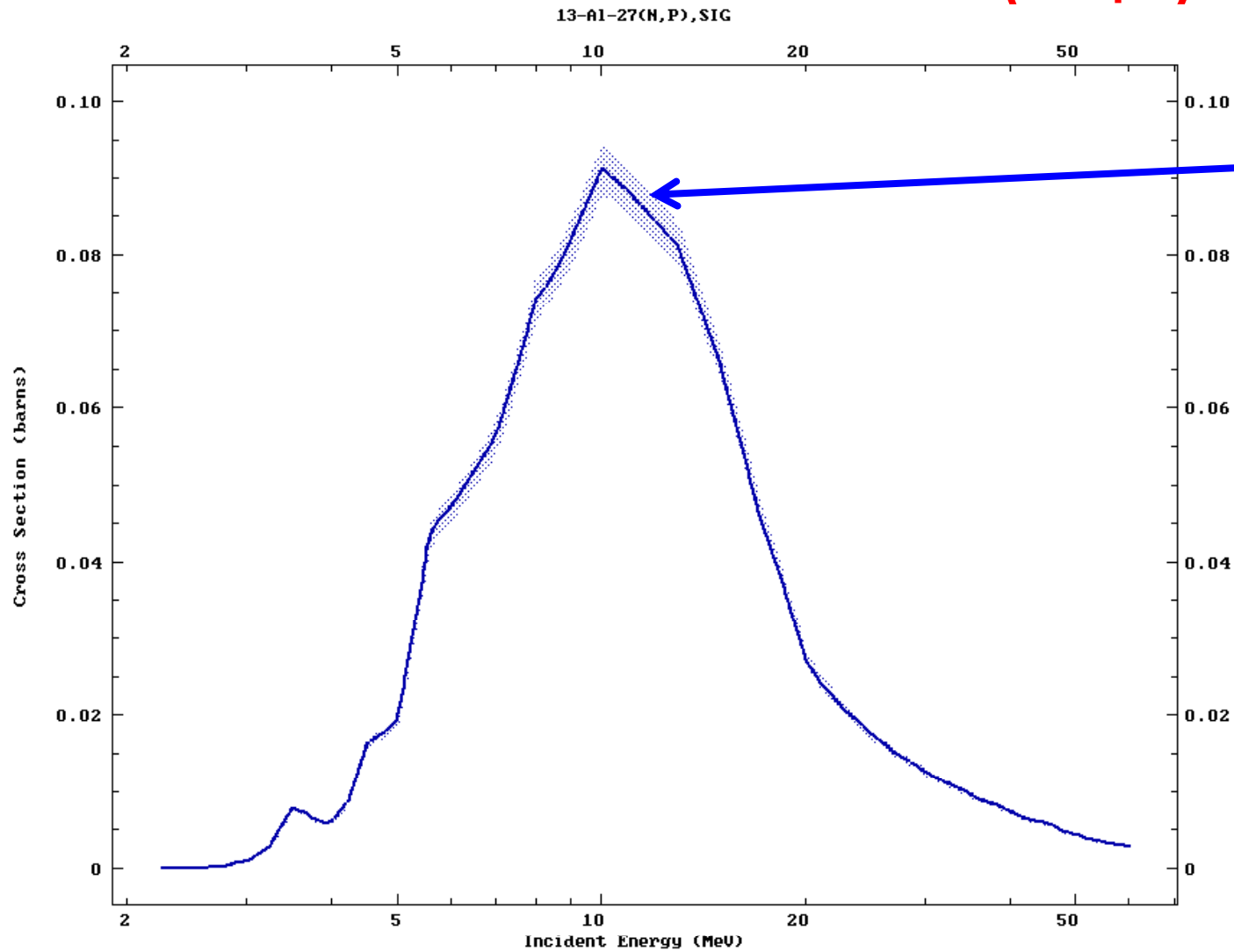


# Physical cross sections

- Cross section is a continuous curve, produced by a model code
- e.g. EMPIRE and TALYS
- Result determined by choice of parameters (RIPL)
- Evaluation = Code + Experimental data
- Complete = All reactions + Uncertainty
- Collections of evaluations = Library
- e.g. JEFF, JENDL, ENDF/B



# Data for $^{27}\text{Al}(n,p)$



Uncertainty estimate

# Data Libraries

- Traditional evaluated libraries are not complete
- ‘New’ approach (since 2008) are the TENDL libraries (TALYS + Expertise)
- For TENDL-2013
- Incident particles =  $\{n, p, d, t, h, \alpha, \gamma\}$
- 2630 Targets, Energy 0-200 MeV
- Complete, including covariances
- Also includes ‘random’ libraries



# Multiple Libraries

- The various evaluated libraries are 'different versions of the truth'
- Need to do better!
- WPEC Subgroup 40 (CIELO) uses international collaboration → best evaluation for  $^1\text{H}$ ,  $^{16}\text{O}$ ,  $^{56}\text{Fe}$ ,  $^{235,238}\text{U}$ ,  $^{239}\text{Pu}$
- If successful then need to consider more targets, perhaps as a Network (similar to NRDC) coordinated by IAEA

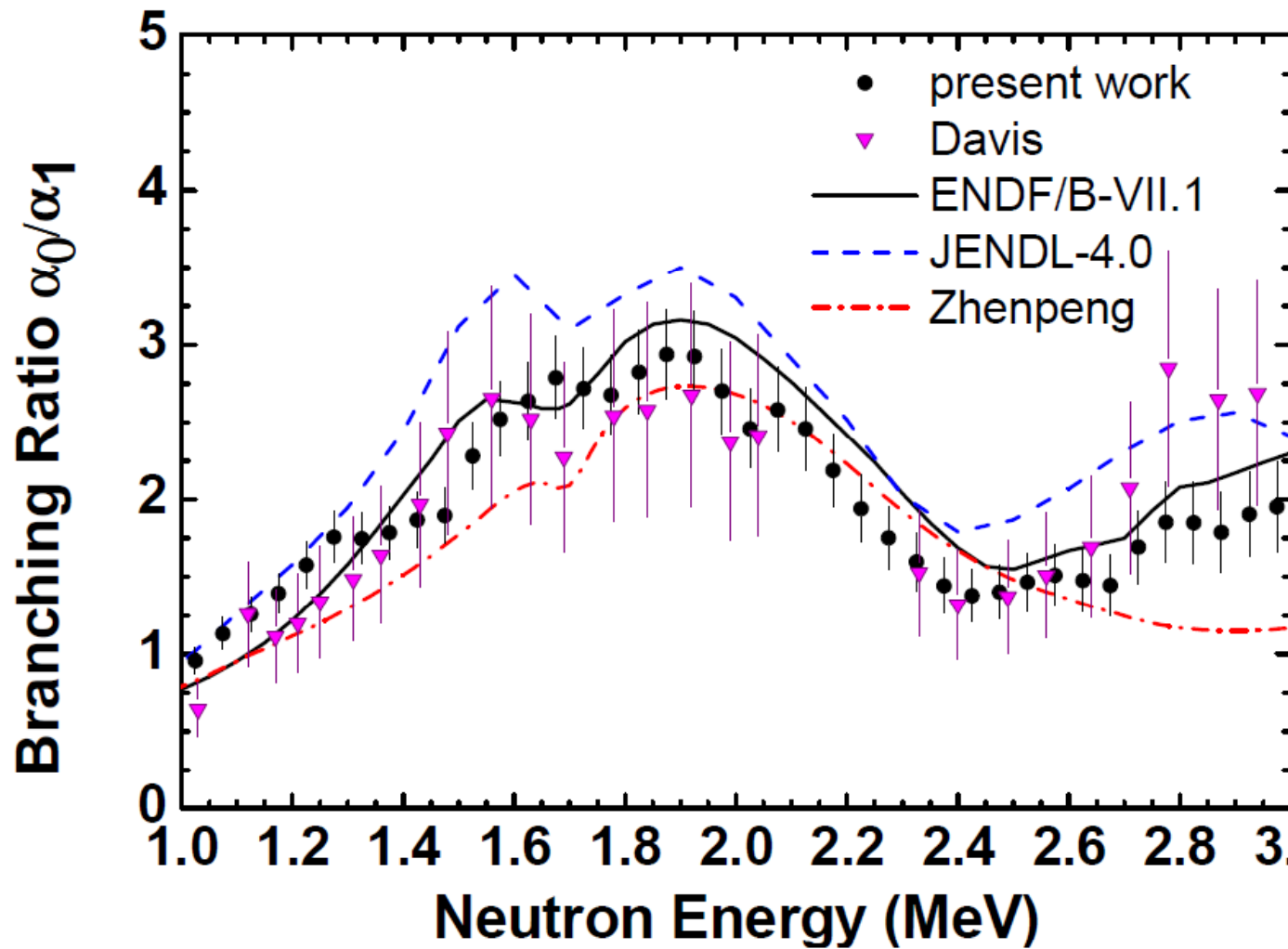


# Standards

- The neutron cross section standards are a set of very precisely known cross sections that everything else is measured relative to
- Nine reactions [ $^1\text{H}(n,n)$ ,  $^3\text{He}(n,p)$ ,  $^6\text{Li}(n,t)$ ,  $^{10}\text{B}(n,\alpha)\dots$ ] in particular energy ranges
- Currently IAEA coordinating an update by a series of meetings, expected to produce new version in 2016



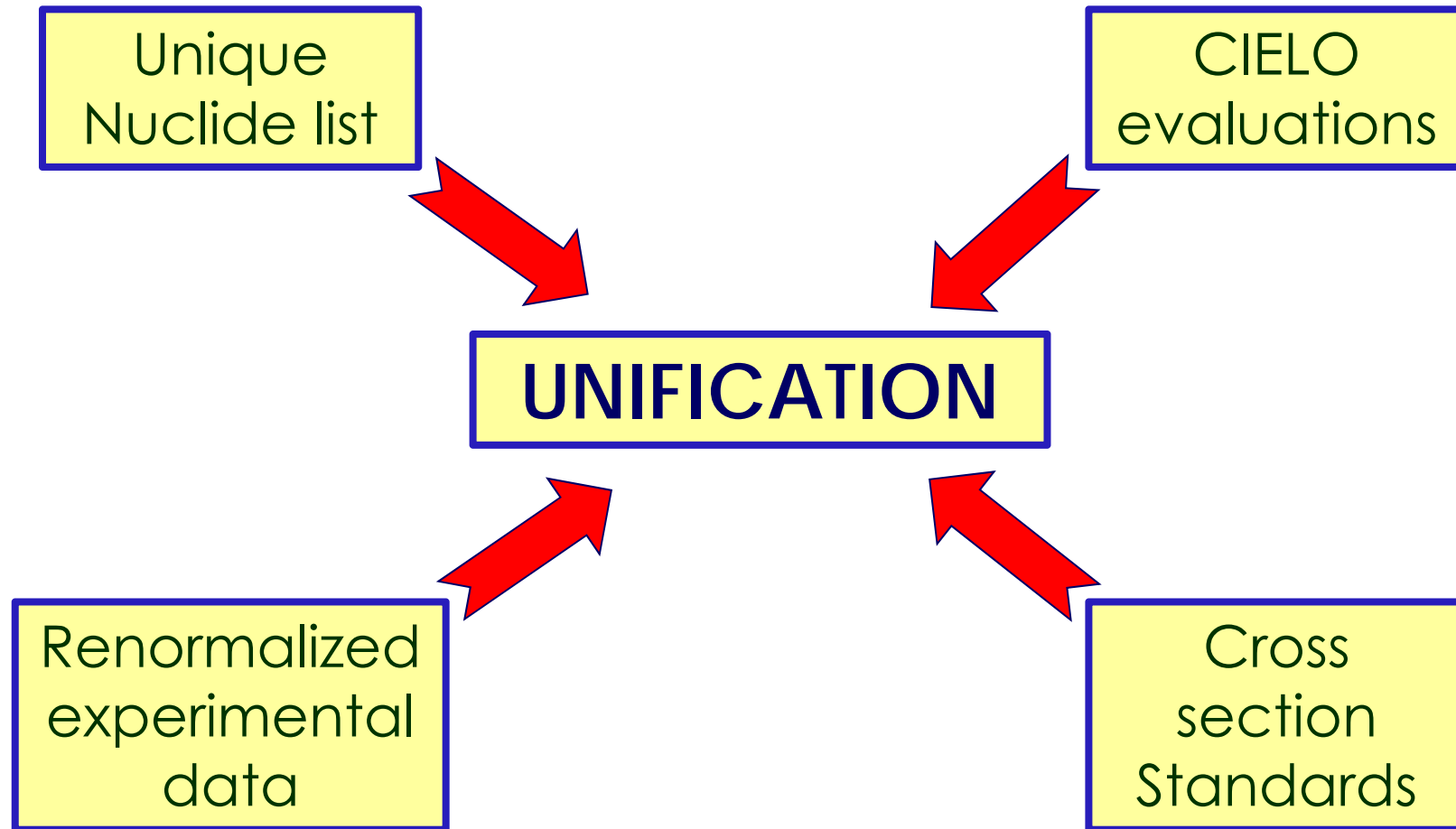
# Standards



$^{10}\text{B}(n,\alpha)$   
Branching  
ratio data  
from IRMM  
Geel  
presented at  
IAEA Meeting  
in July 2013  
See  
INDC(NDS)-  
0641  
Analysis in  
progress



# Point 1





# Structures and Formats

- To enable data to be efficiently used they must be stored in an agreed format
- The ENDF-6 format has been used for decades
- BUT nearing the end of its life and through WPEC Subgroup 38 a new structure is proposed, implemented in XML format (GND)
- Many advantages, but modernisation costs



# Structures and Formats

- ENDF-6 formats include details of the product nuclide – leads to inconsistency e.g. Q-values incorrect
- Use a separate product database with links
- ENSDF and EXFOR in XML (or outputs in XML) will allow better interconnection of data and better answers
- Practically will need to run ENDF-6 and XML in parallel for several years



# RIPL

- Model codes require many parameters (optical model, levels, fission barriers)
- Consistent set available in RIPL, developed over 20 years at IAEA
- New CRP to improve further
- Definitive list of nuclides

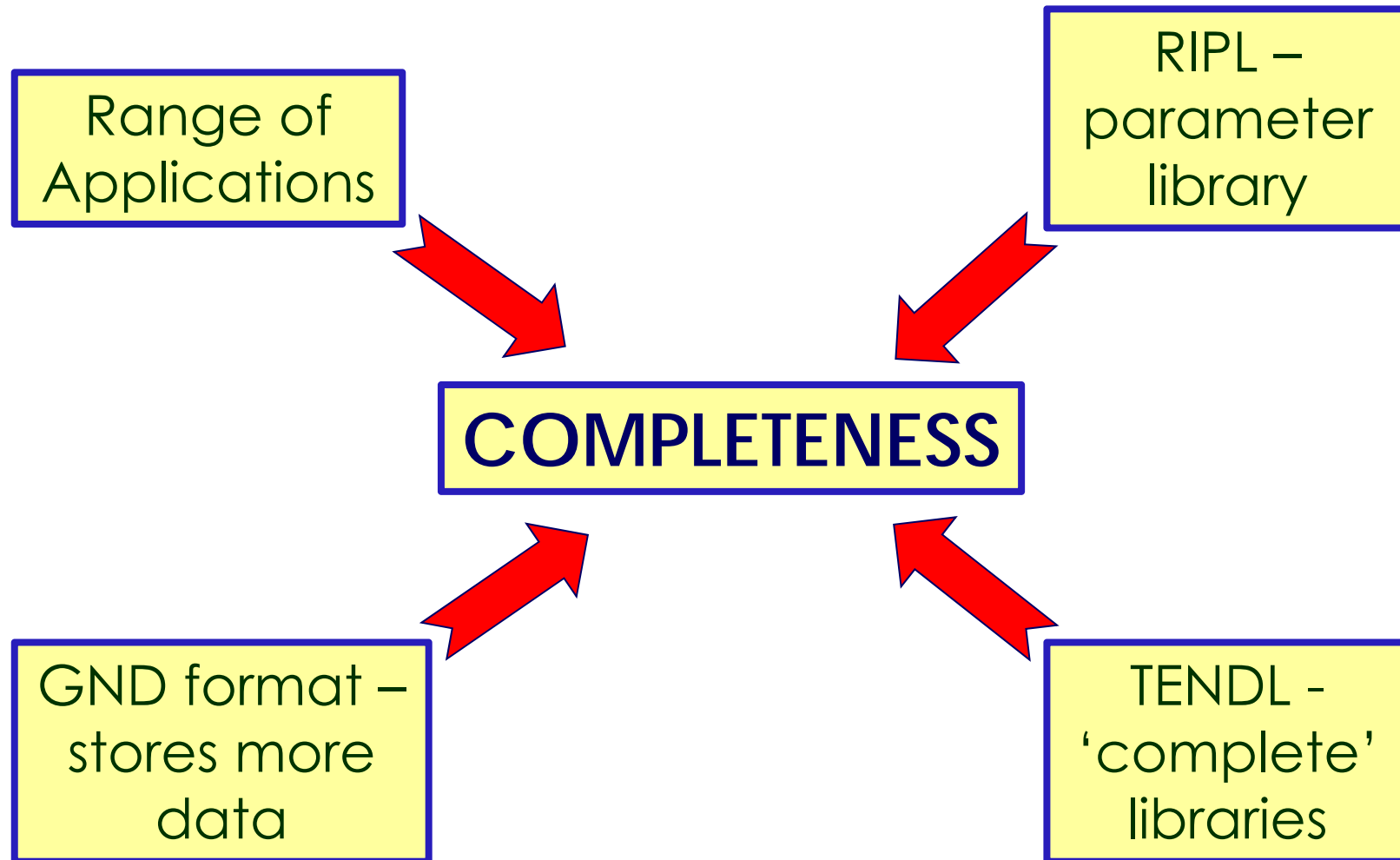
## ***Reference Input Parameter Library (RIPL-3)***

[Introduction](#) [MASSES](#) [LEVELS](#) [RESONANCES](#) [OPTICAL](#) [DENSITIES](#) [GAMMA](#) [FISSION](#) [CODES](#) [Contacts](#)

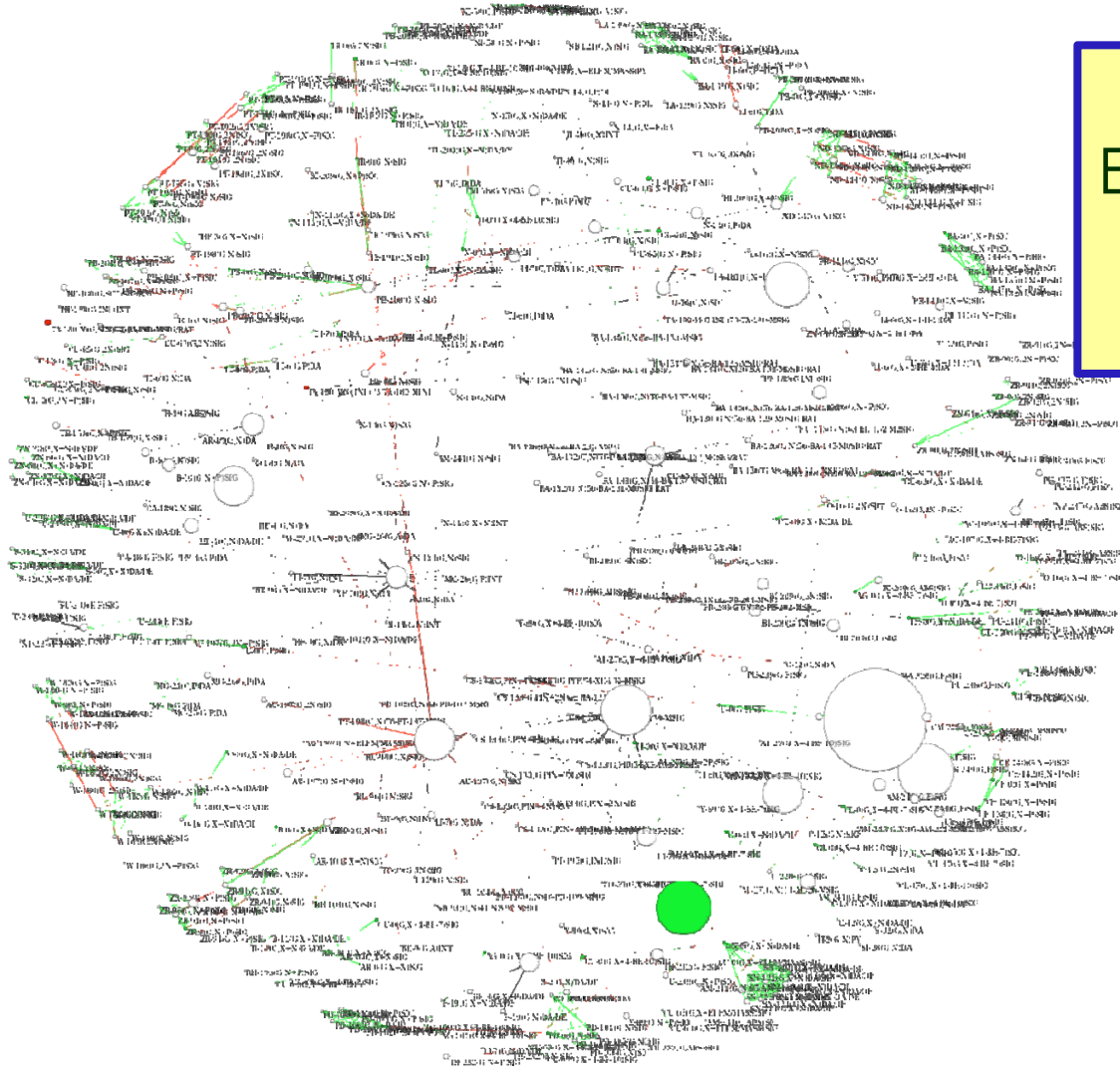
### ***Introduction***



## Point 2



# Reaction connections



Data mining the  
EXFOR database using  
network theory  
J.A. Hirdt, D.A. Brown

87,925 nodes  
276,852 edges  
Importance of  
standards

Photonuclear data



# Covariance

- Connections  $\Rightarrow$  Correlations
- Uncertainty as a 'sum of squares' is only true if quantities are uncorrelated
- Need covariance matrix to propagate uncertainty data correctly
- If quantities represented by  $n$  values then covariance data requires  $\sim n^2$
- ENDF formatting only allows a subset of covariances to be represented

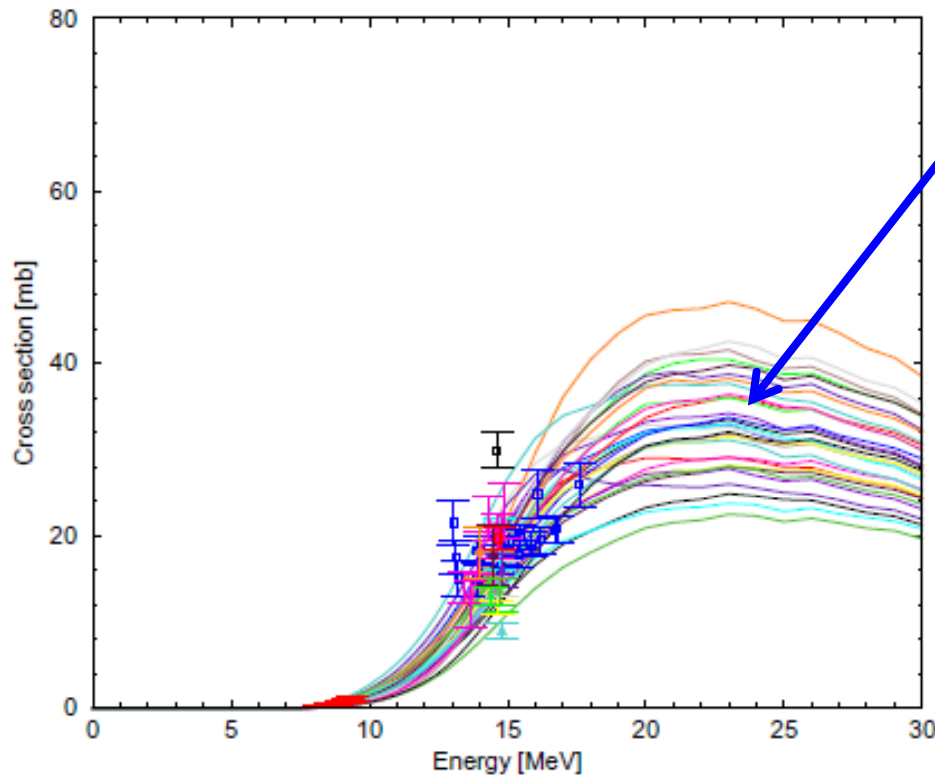


# Covariance

- The form of covariance depends on how it was produced, it is not measurable, so long as it is mathematically correct then many versions of a covariance matrix are possible
- Not [Right/Wrong] But [Useful/not Useful]
- Experimental  $\neq$  Theoretical Covariance
- Useful covariance must be based on ALL available data

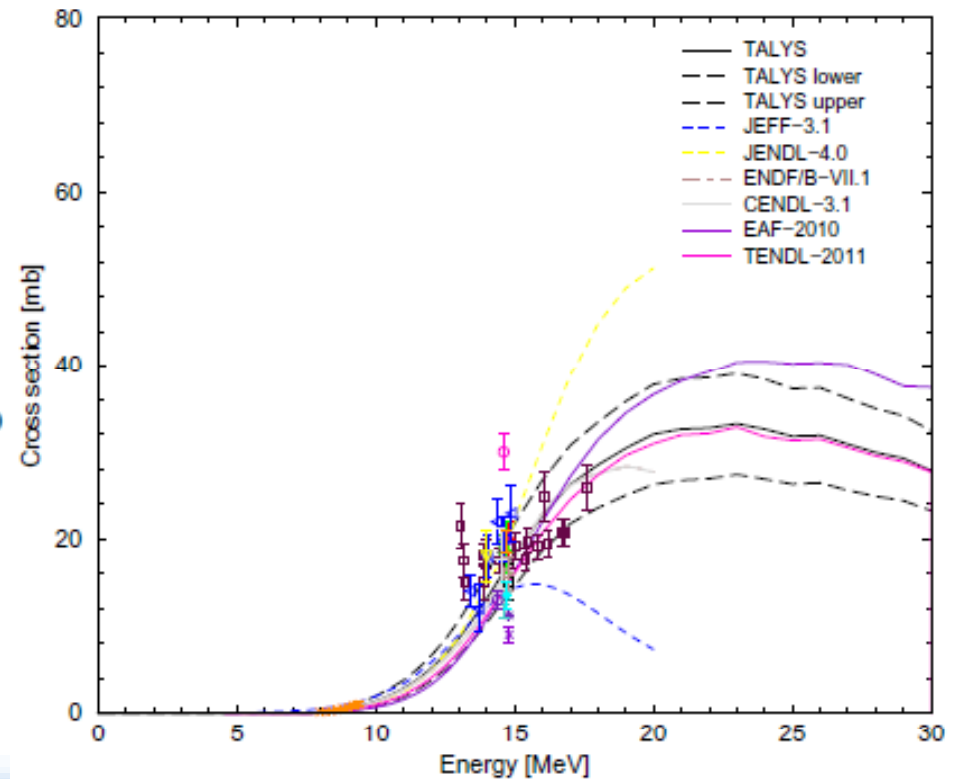


# Uncertainty – $^{88}\text{Sr}(n,p)^{88}\text{Rb}$



Calculated with  
randomised parameters

Large variation in existing  
evaluations





# Total Monte Carlo (TMC)

- TMC is a complementary approach to using covariance matrices
- Pioneered by Arjan Koning and Dimitri Rochman [Nuc. Data Sheets 113 (2012) 2841–2934]
- Sample model parameters → Random ENDF libraries → Application code → Multiple values of required quantity ( $q$ ) →  $\langle q \rangle + \Delta q$

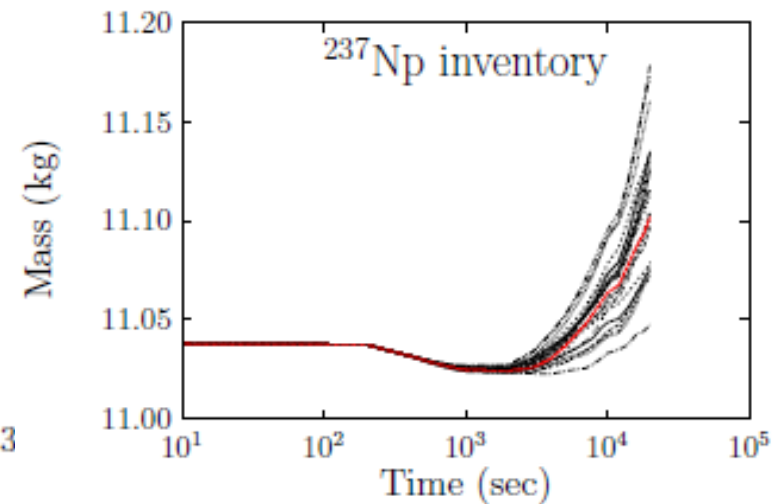
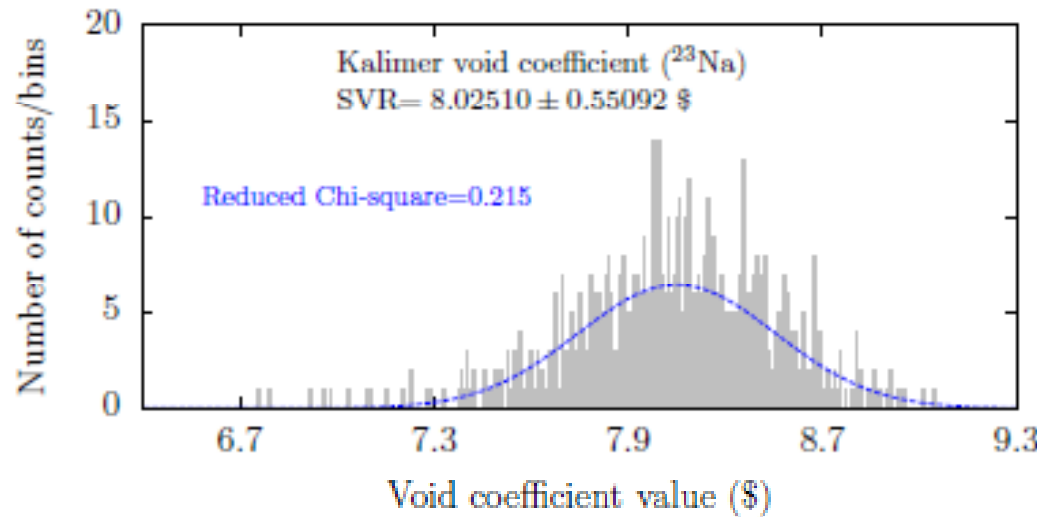


# GEN-IV Fast Reactor

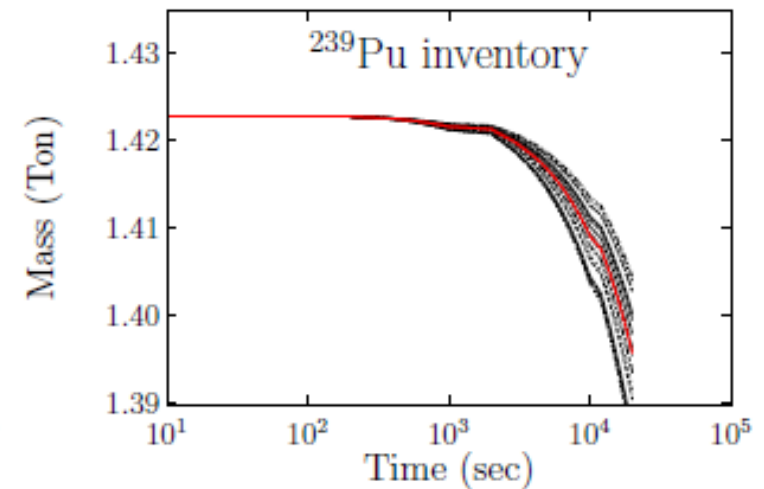
- Vary the  $^{23}\text{Na}$  data and look at the variation of the Sodium Void Coefficient
- 800 MCNP runs
- Difficult because finding difference between 2 values (with and without Na)
- Vary  $^{238}\text{U}$  data and look at variation of inventories of actinides
- 250 FISPACT runs



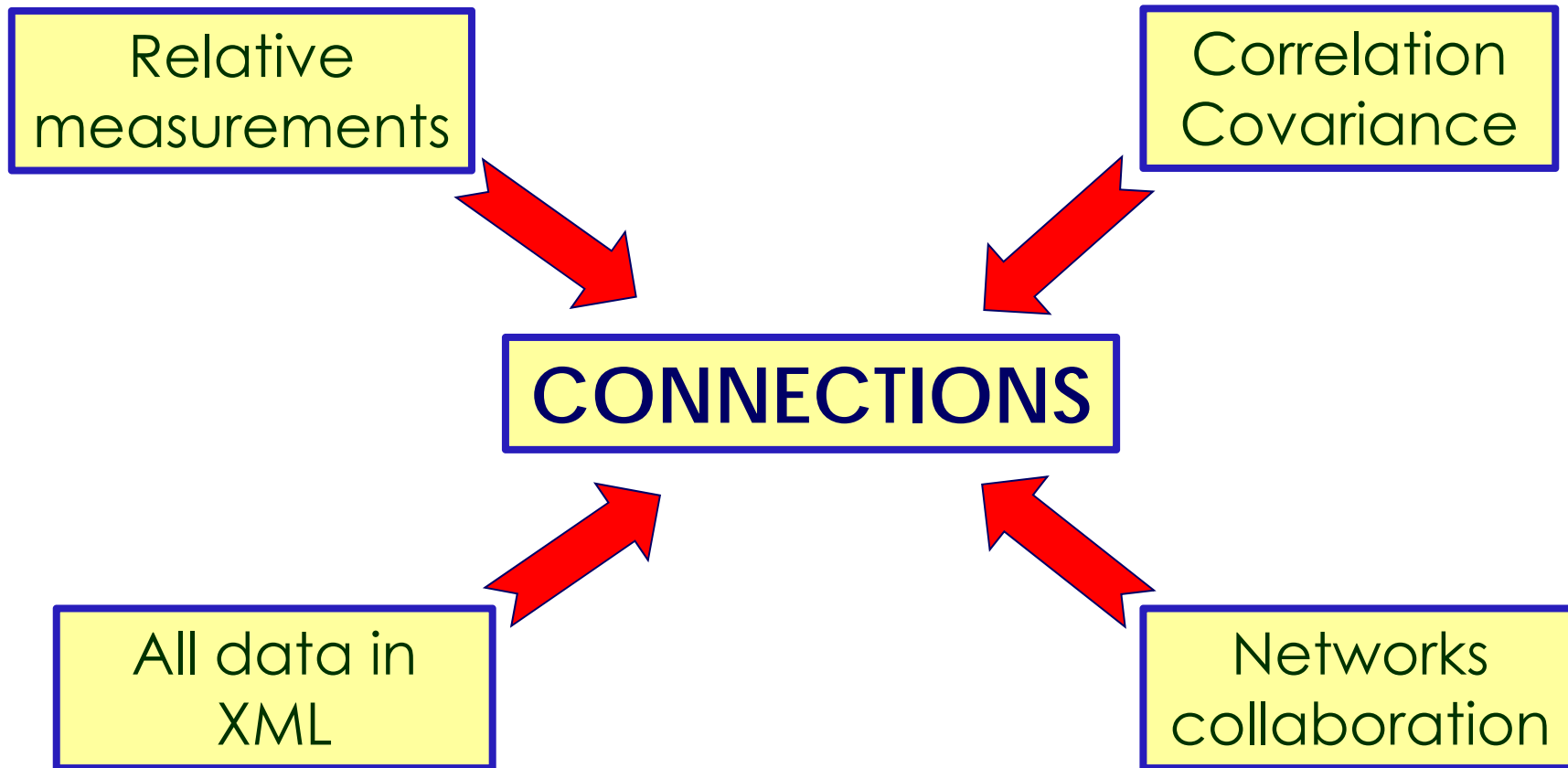
# TMC results



Variation in final quantities based on variation in nuclear data

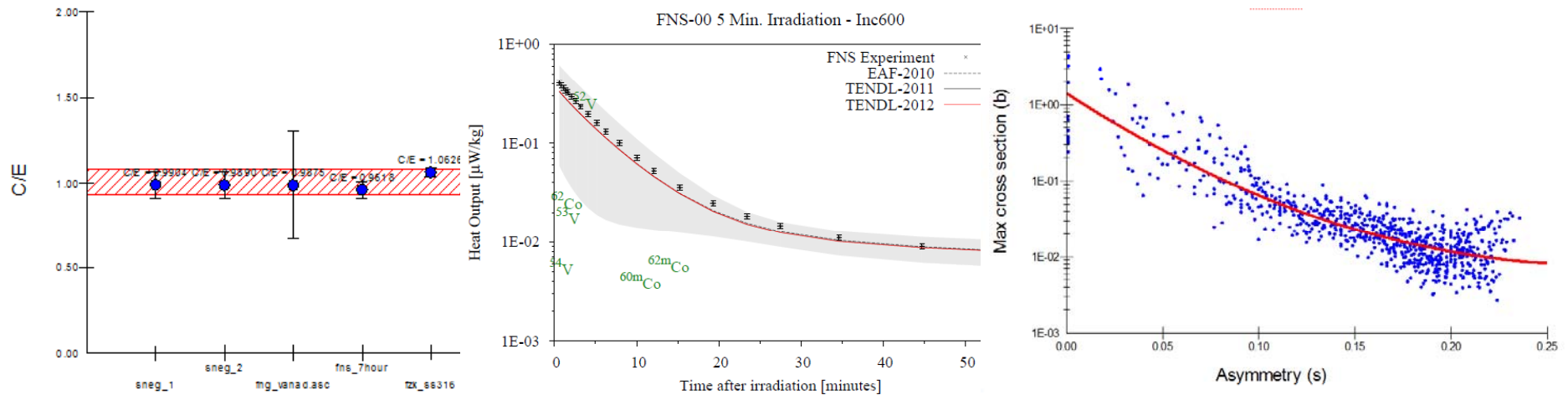


# Point 3

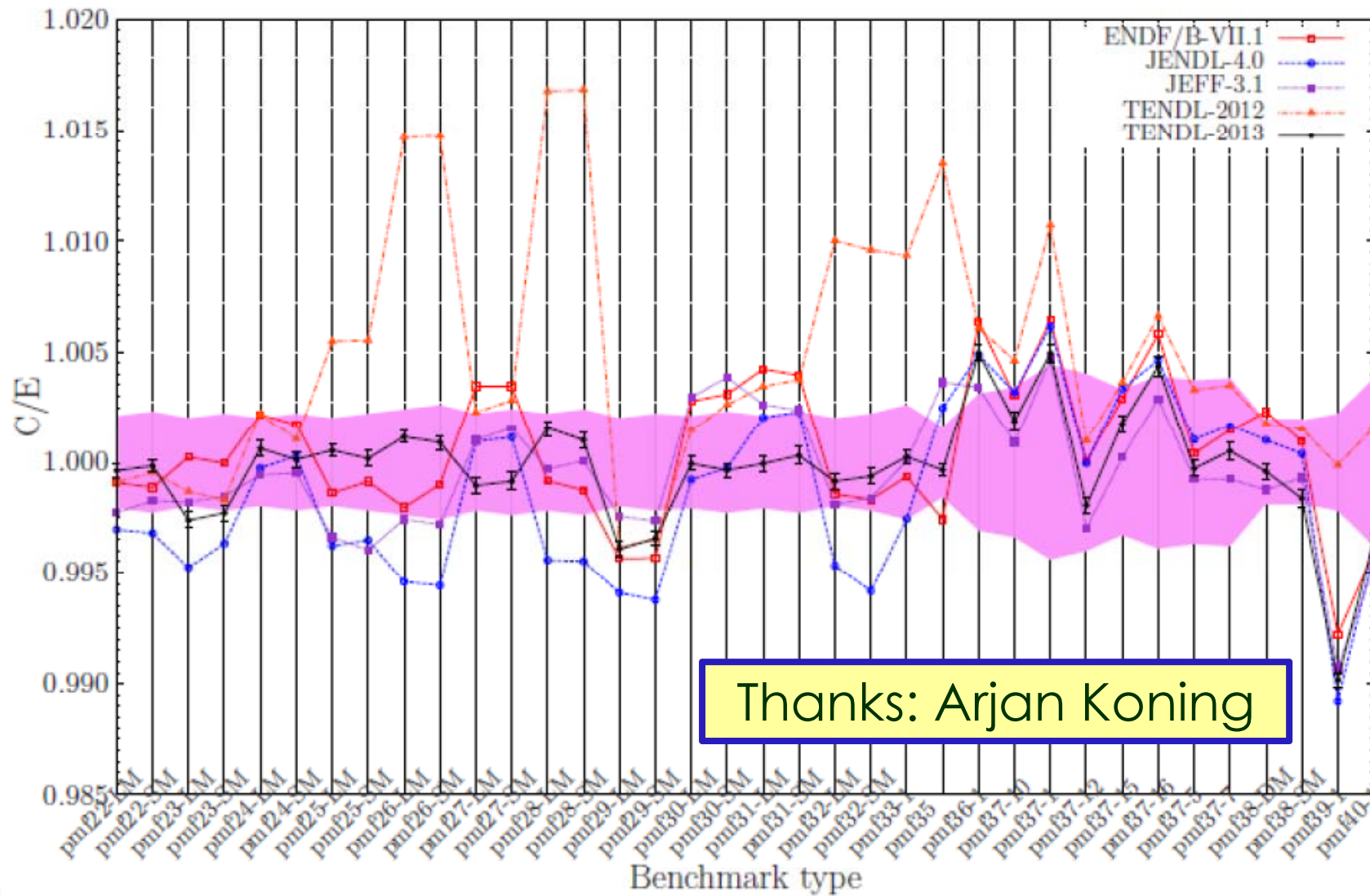


# Validation

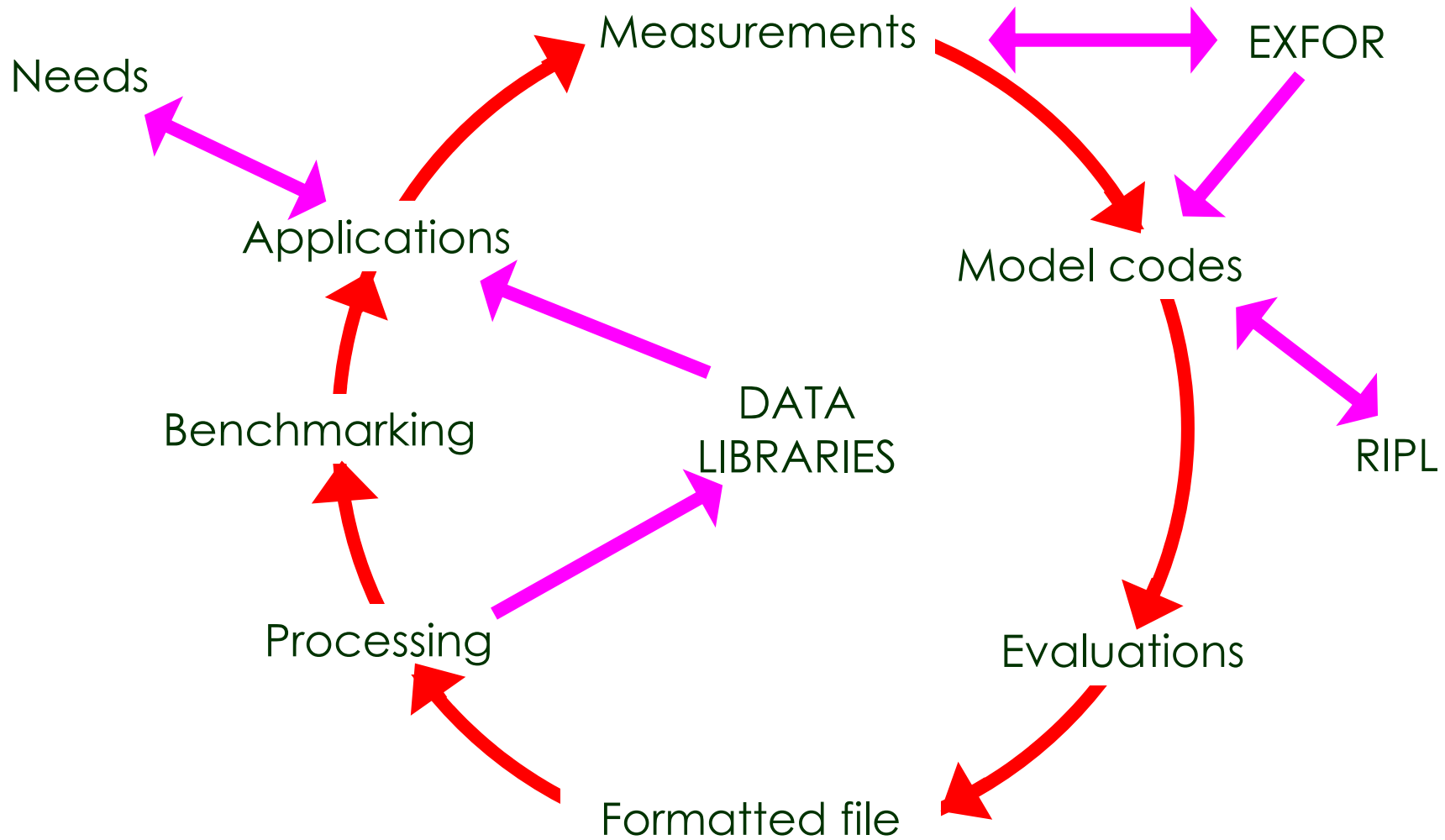
- Comparison of library data with experiment, typically for a well defined object – integral data
- Results in well defined neutron spectra
- What can be done when no experiments?



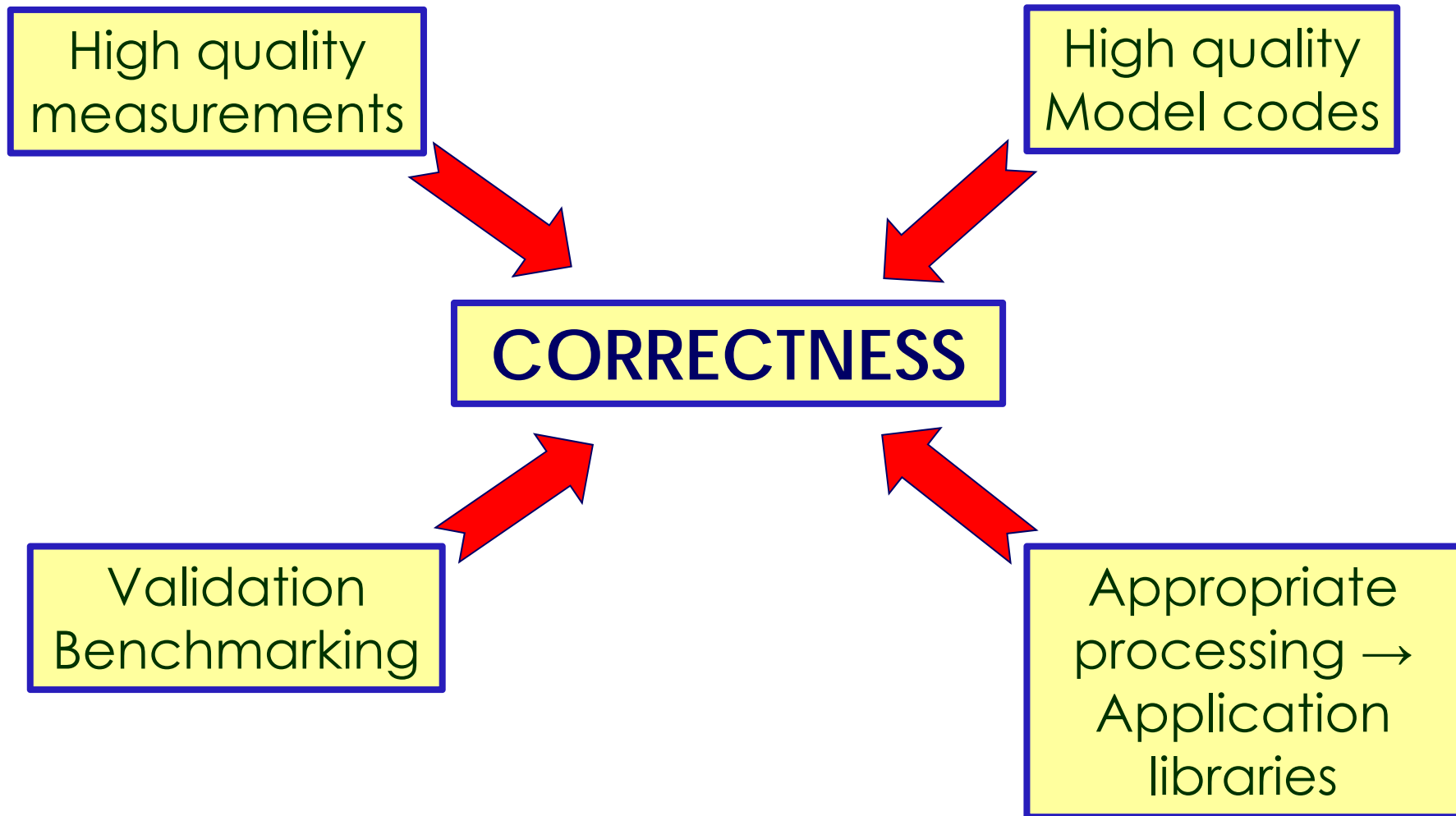
# Automatic Validation



# Nuclear data cycle

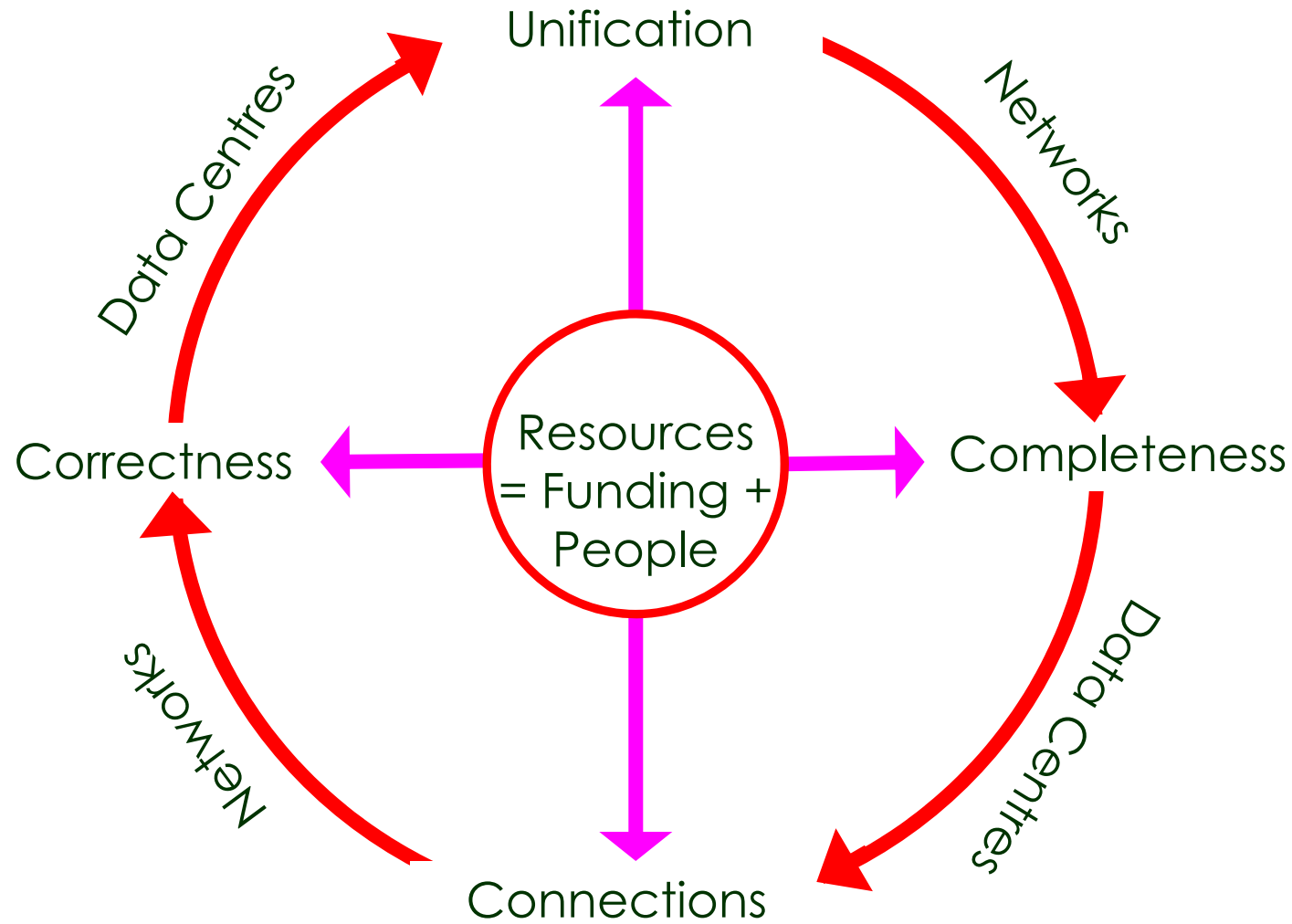


# Point 4





# Nuclear data needs



# Data Centres

- Collaboration is carried out in Networks such as NRDC and NSDD
- For NRDC the Core Centres are:
  - US National Nuclear Data Center
  - OECD NEA Data Bank
  - IAEA Nuclear Data Section
  - Russian Nuclear Data Center
- Work is much appreciated (Reviews), BUT continued funding essential



# www-nds.iaea.org

International Atomic Energy Agency  
**Nuclear Data Services**  
Section Données Nucléaires, AIEA

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**Hot Topics** » ENDF/B-VII.1 • TENDL-2012 • JENDL-4 • IBANDL **News** » 50 year anniversary of NDS, June 2014

**Request**  
CD/DVD with documentation, data, codes, etc.

**Quick Links**  
ADS-Lib  
Atomic Mass Data Centre  
CINDA  
Charged particle reference cross section  
DROSG-2000  
EMPIRE-3.2  
ENDF Archive  
ENDF Retrieval  
ENDF-6 Codes  
ENDF-6 Format  
ENDVER  
ENSDF  
ENSDF ASCII Files  
ENSDF programs  
EXFOR  
FENDL 3.0  
Fission Yields  
GANDR  
Geant4 Libraries  
IBANDL  
INDL/TSL

**NEW**  
**JEFF-3.2** - Joint Evaluated Fission and Fusion File, coord. by NEA Data Bank, 2014 [page] [archive] [retrieve]  
**IRDF** - International Reactor Dosimetry and Fusion File v1.03 [page] [archive] [retrieve]  
**CD/DVD-ROMs** available for on-line downloading [page]  
**Portable Empire-3.2.2** for Windows - nuclear reaction model code system for data evaluation [page] [download]

Main | All | Reaction Data | Structure & Decay | by Applications | Doc & Codes | NDS-Internal | Index | Events | Links | News

**EXFOR** Experimental nuclear reaction data  
**LiveChart of Nuclides** Interactive Chart of Nuclides  
**CINDA** Nuclear reaction bibliography  
**ENDF** Evaluated nuclear reaction libraries  
**ENSDF** evaluated nuclear structure and decay data (+XUNDL) \*\*  
**NSR** Nuclear Science References \*

<b>NuDat 2.6</b> selected evaluated nuclear structure data **	<b>RIPL</b> reference parameters for nuclear model calculations	<b>IBANDL</b> Ion Beam Analysis Nuclear Data Library	<b>Charged particle reference cross section</b> Beam monitor reactions
<b>PGAA</b> Prompt gamma rays from neutron capture	<b>FENDL 3.0</b> Fusion Evaluated Nuclear Data Library, Version 3.0	<b>Photonuclear</b> cross sections and spectra up to 140MeV	<b>IRDF</b> International Reactor Dosimetry and Fusion File
<b>NAA</b> Neutron Activation Analysis Portal	<b>Safeguards Data</b> recommendations, August 2008	<b>Medical Portal</b> Data for Medical Applications	<b>Standards</b> - Neutron cross-sections, 2006 - Decay data, 2005

\*Database at the IAEA, Vienna    \*\*Database at the US NNDC

**IAEA Nuclear Data Section**

IAEA-NDS Mission, Staff and more	A+M Atomic and Molecular Data	Meetings Workshops	Newsletters	Coordinated Research Projects	Nuclear Reaction Data Center Network	Nuclear Structure & Decay Data Network	Technical Documents INDC Reports Publications	Computer Codes
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**Mirrors**  
**Partners**  
**Events <1:2>**  
 18<sup>th</sup> Topical Meeting of the Radiation Protection & Shielding Division of ANS (RPDS2014)  
September 14-18, 2014  
Knoxville, Tennessee, USA  
 Thunderstorms and Elementary Particle Acceleration (TEPA-2014)  
September 22-26, 2014  
Byurekan, Armenia



# Conclusions

- Exciting time
  - CIELO evaluations
  - New standards and libraries
  - New XML formats
- Networks and Data Centres working well
- BUT changes to collaboration and formats must be adequately funded
- Users must appreciate importance of Nuclear Data – Support (Pay)



# Thank you!

