International Atomic Energy Agency

Advances in Nuclear Data

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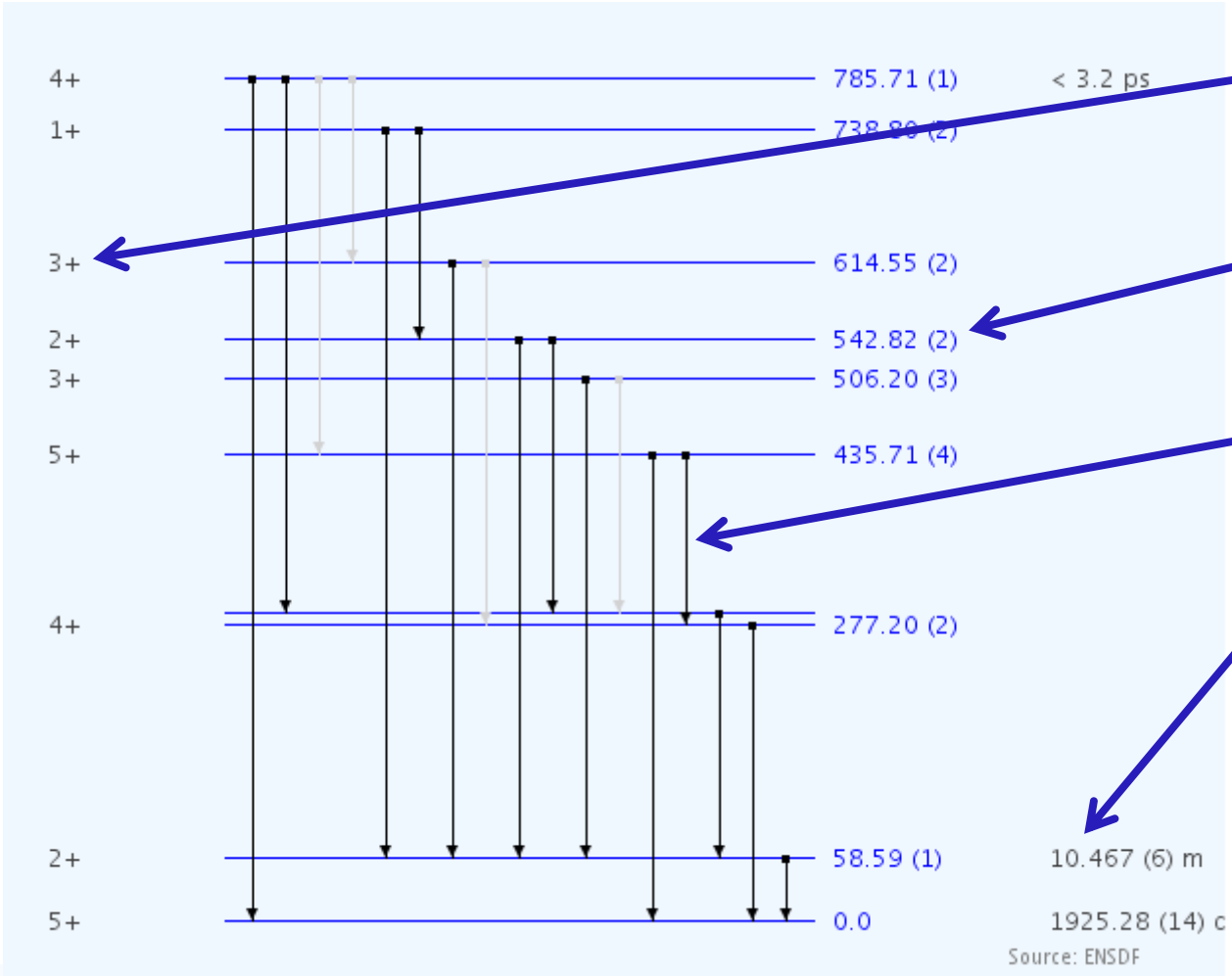
Introduction

- 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



Spin, parity

Energy

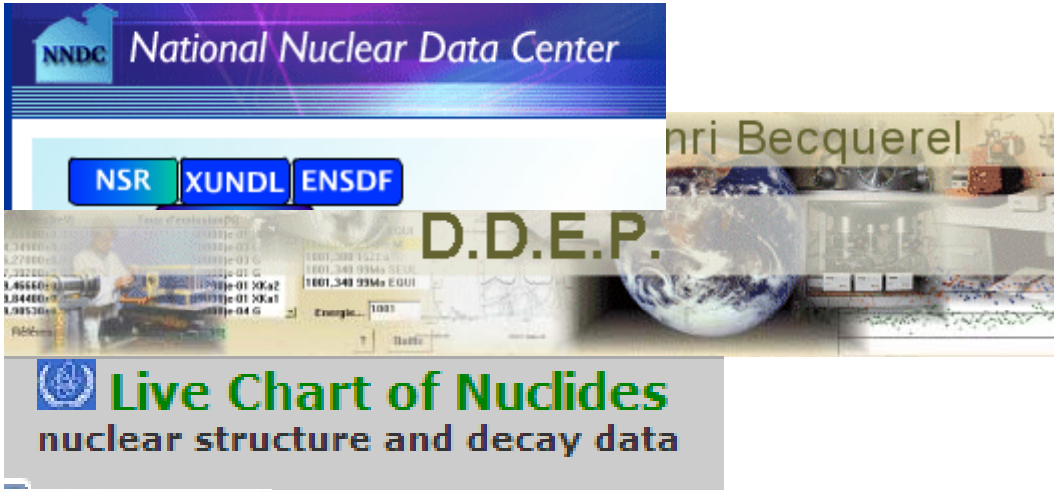
γ transition

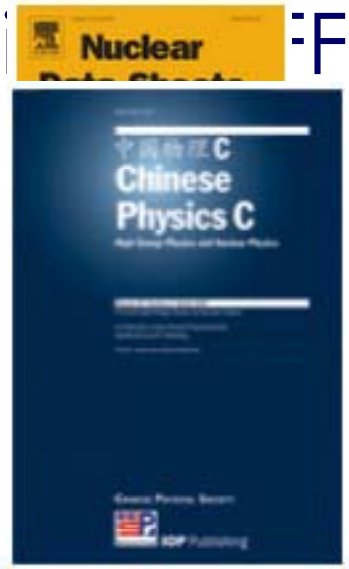
Half-life

Mass, decay mode

Static Nuclide Properties

- ENSDF
- DDEP
- LiveChart
- Nuclear Data
- Decay data f F, 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^{π} 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

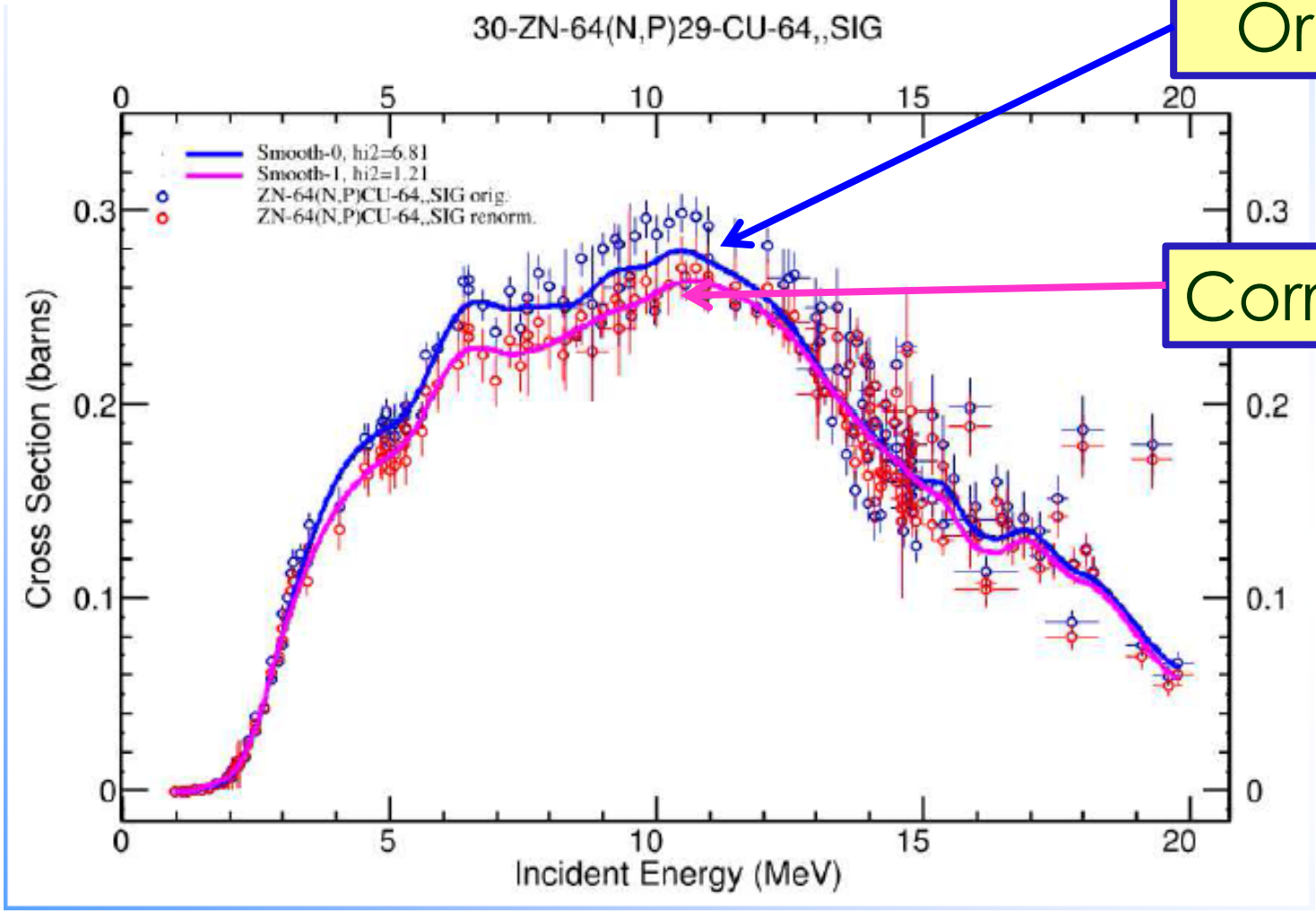
International Network of Nuclear Reaction Data Centres

EXFOR compilation control system

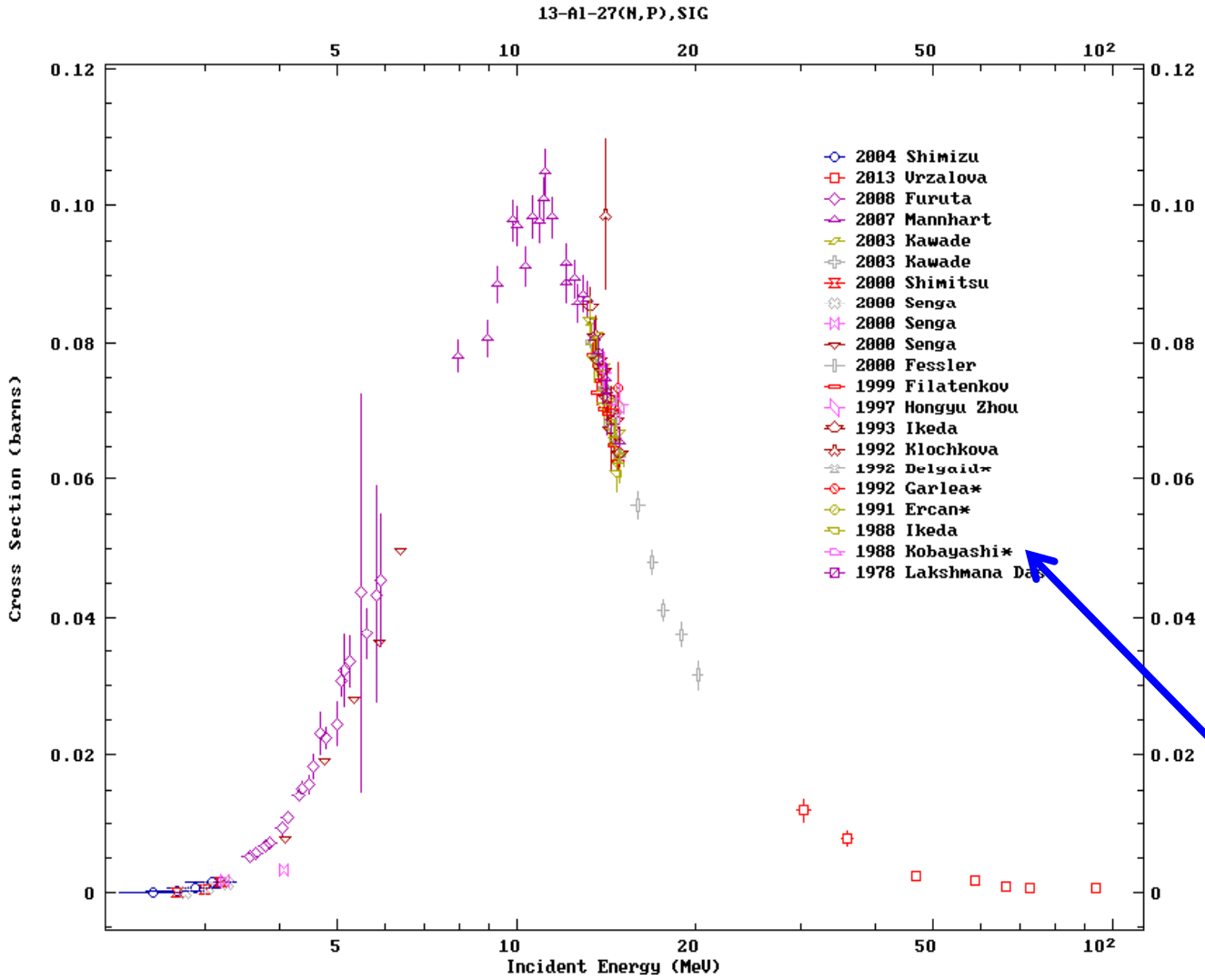
EXFOR

- 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}Al(n,p)

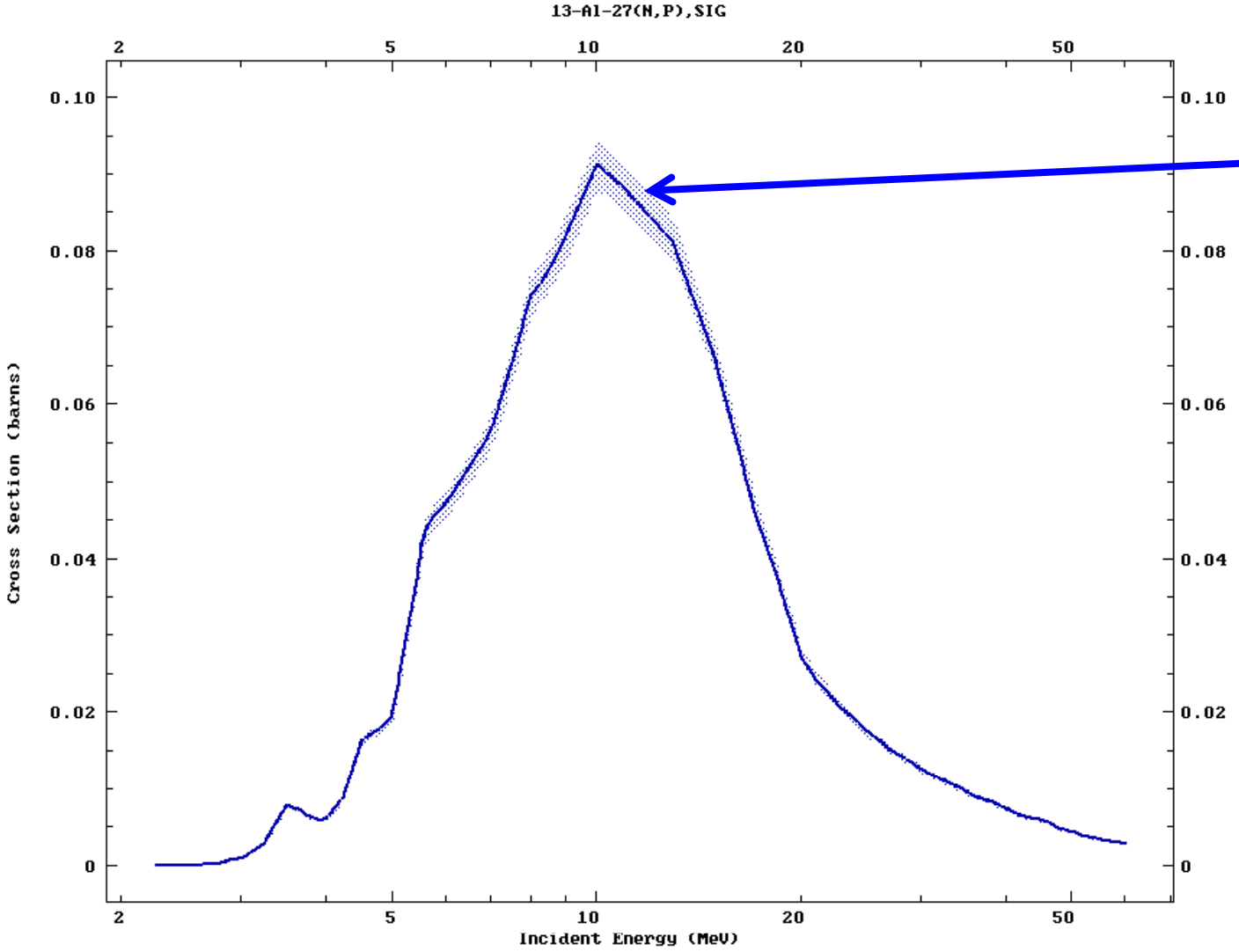


* = Corrected

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}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,α,γ}
- 2630 Targets, Energy 0-200 MeV
- Complete, including covariances
- Also includes 'random' libraries

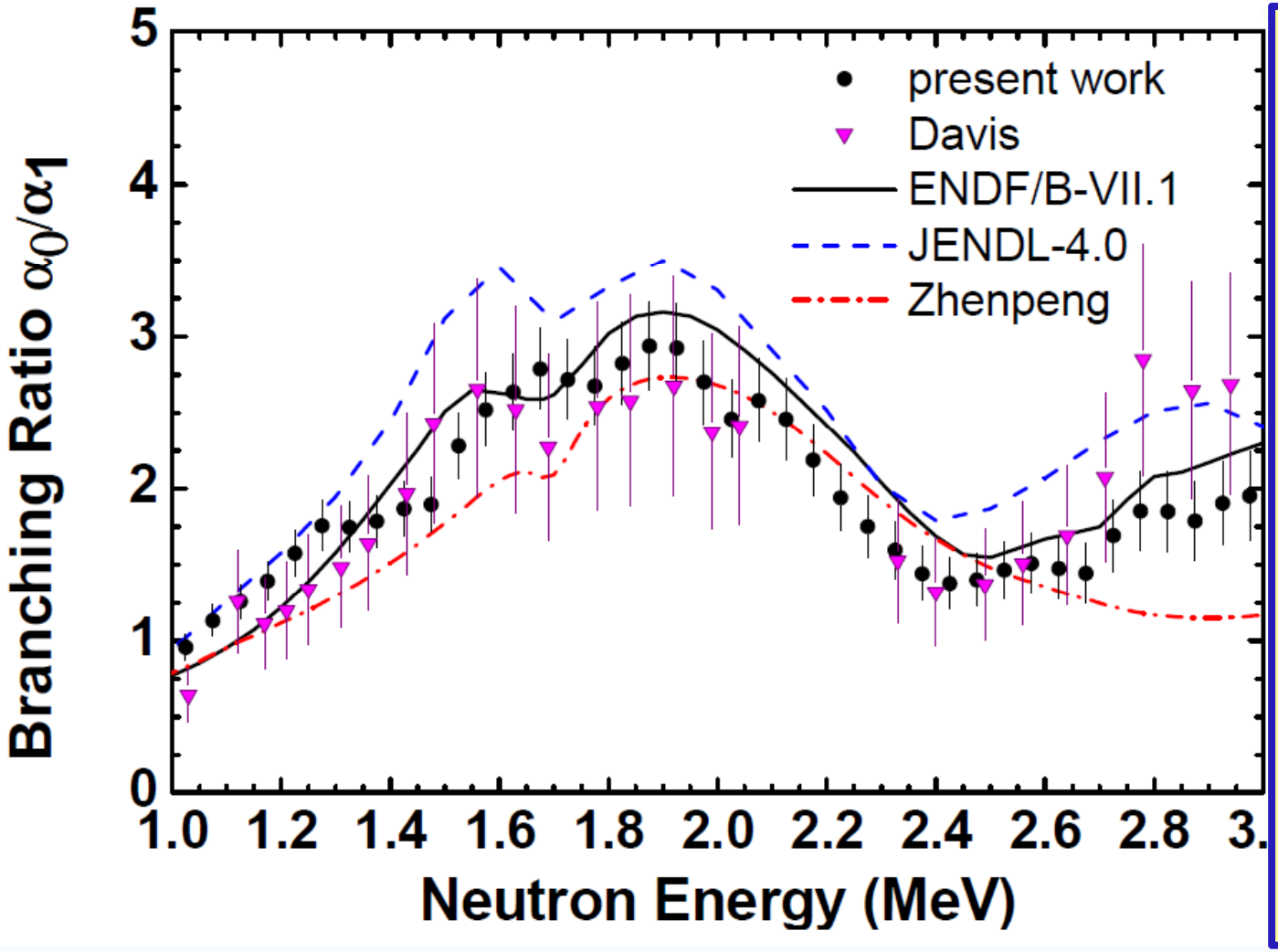
Multiple Libraries

- 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}H, ^{16}O, ^{56}Fe, $^{235,238}U$, ^{239}Pu
- If successful then need to consider more targets, perhaps as a Network (similar to NRDC) coordinated by IAEA

Standards

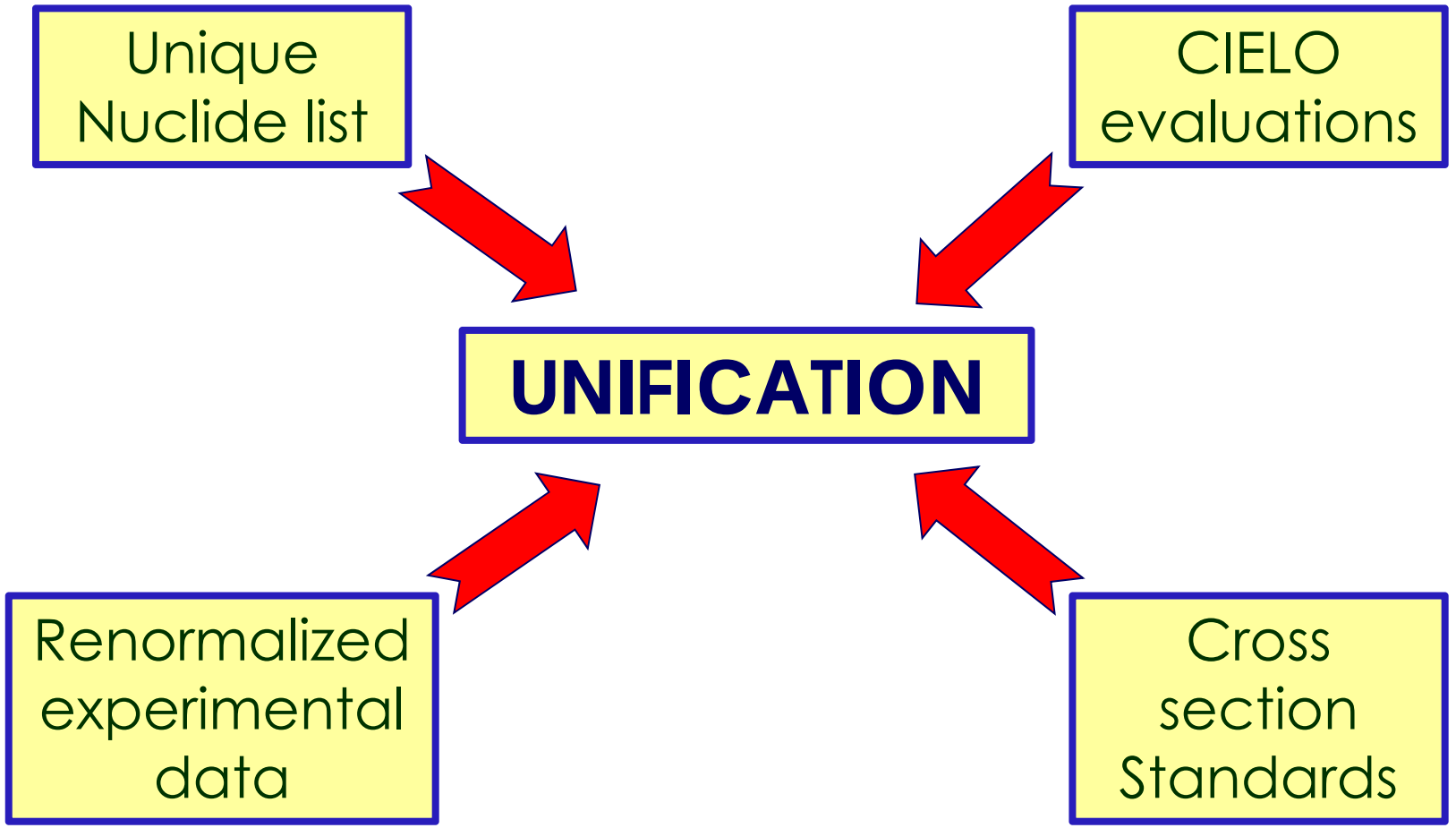
- The neutron cross section standards are a set of very precisely known cross sections that everything else is measured relative to
- Nine reactions [^{1}H(n,n), ^{3}He(n,p), ^{6}Li(n,t), ^{10}B(n,α)…] in particular energy ranges
- Currently IAEA coordinating an update by a series of meetings, expected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

Standards



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

Point 1


Unique Nuclide list
CIELO evaluations
UNIFICATION
Renormalized experimental data
Cross section Standards

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

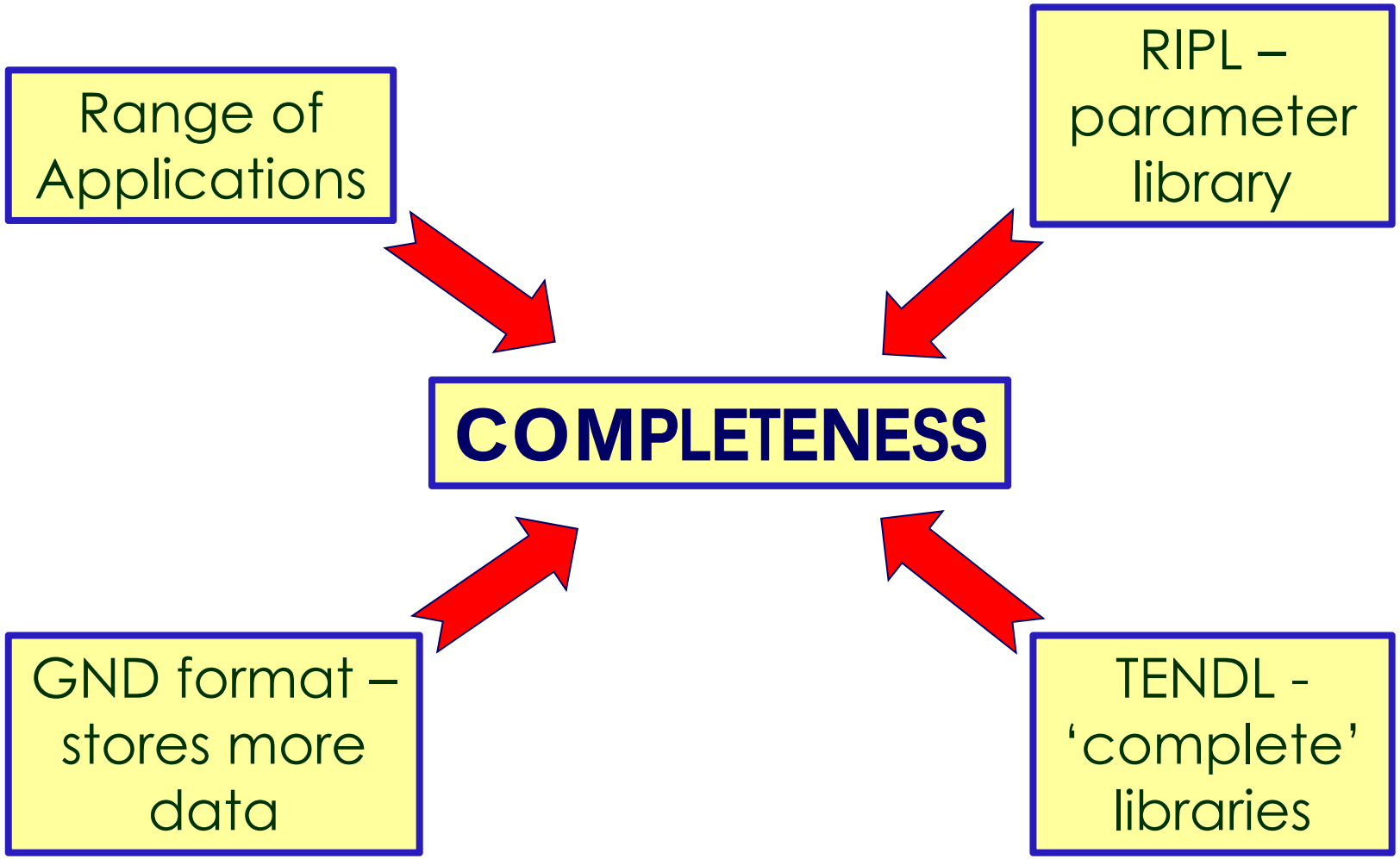
Structures and Formats

- 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

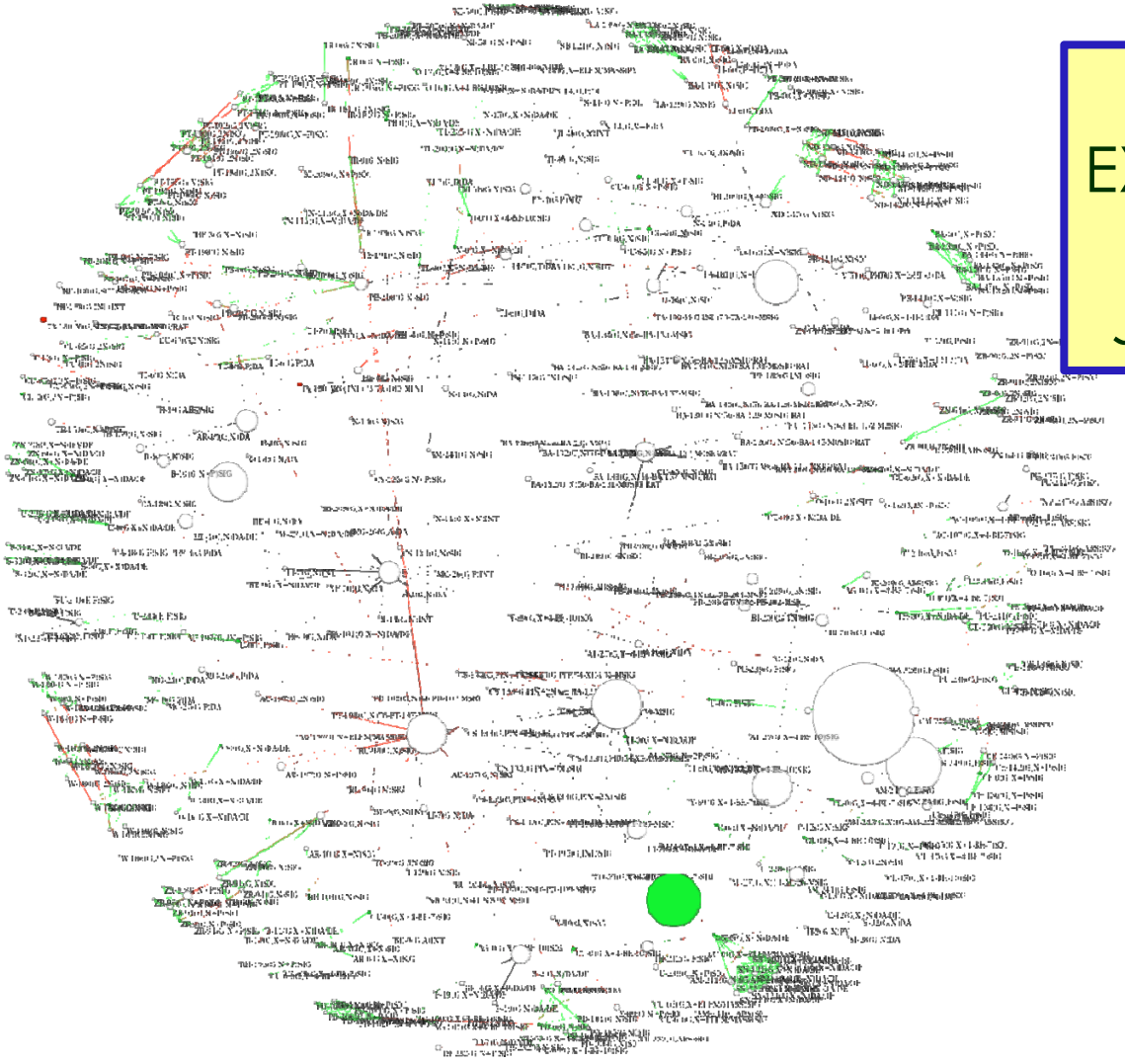
RIPL

- 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

Point 2


Range of Applications
RIPL – parameter library
COMPLETENESS
GND format – stores more data
TENDL - 'complete' libraries

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

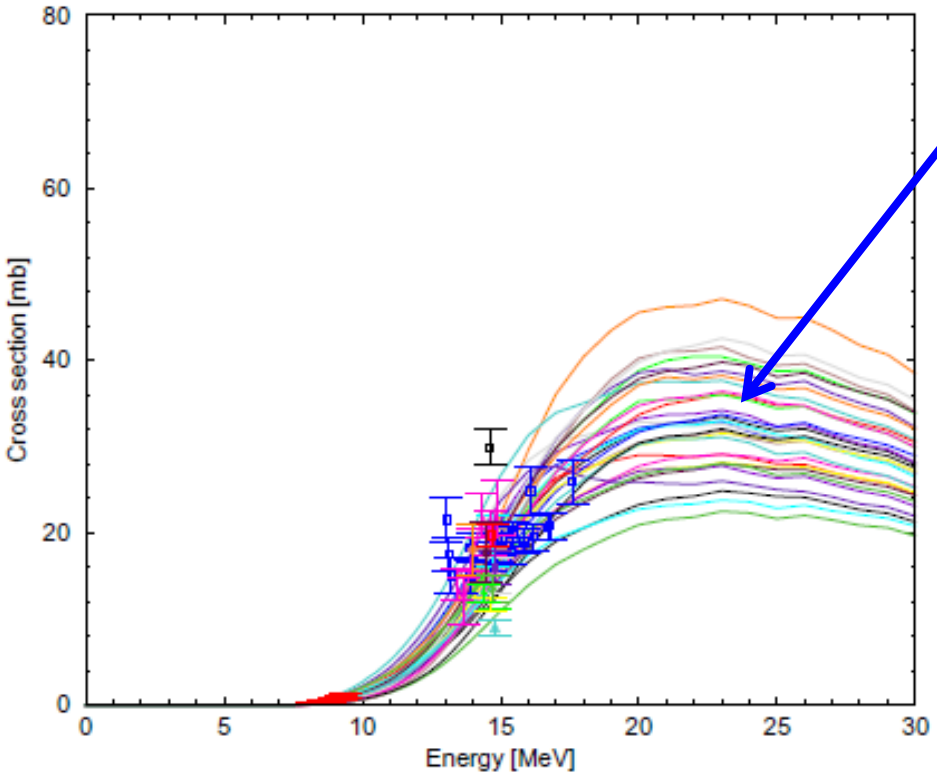
Covariance

- Connections ⇒ 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 ~n^2
- ENDF formatting only allows a subset of covariances to be represented

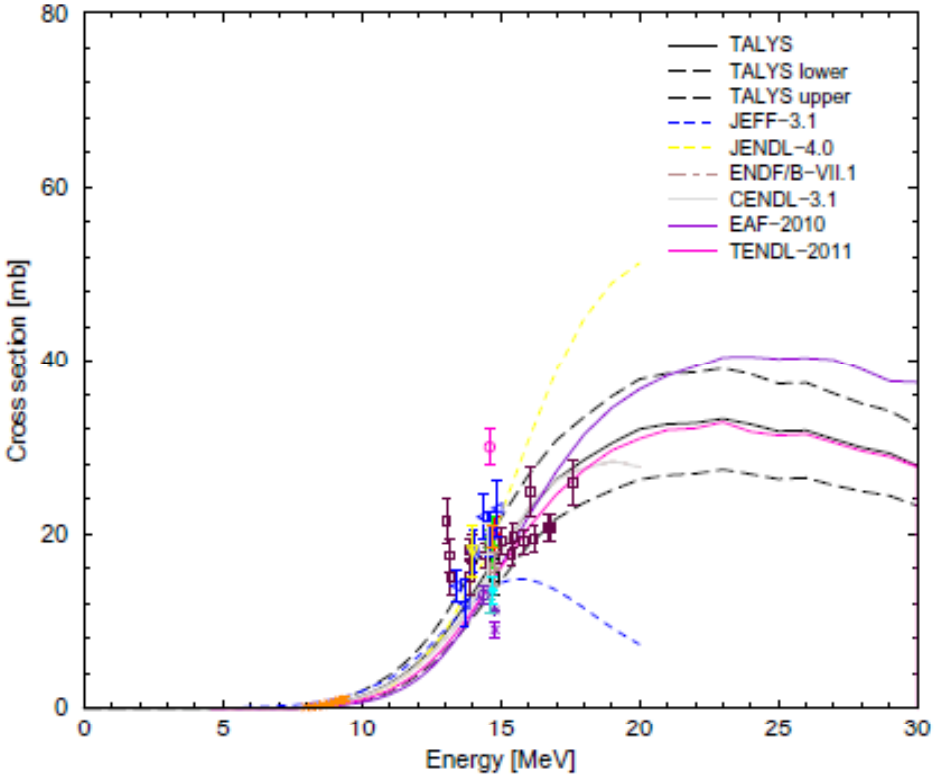
Covariance

- 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 ≠ Theoretical Covariance
- Useful covariance must be based on ALL available data

Uncertainty – $^{88}Sr(n,p)^{88}Rb$



Calculated with randomised parameters



Large variation in existing evaluations

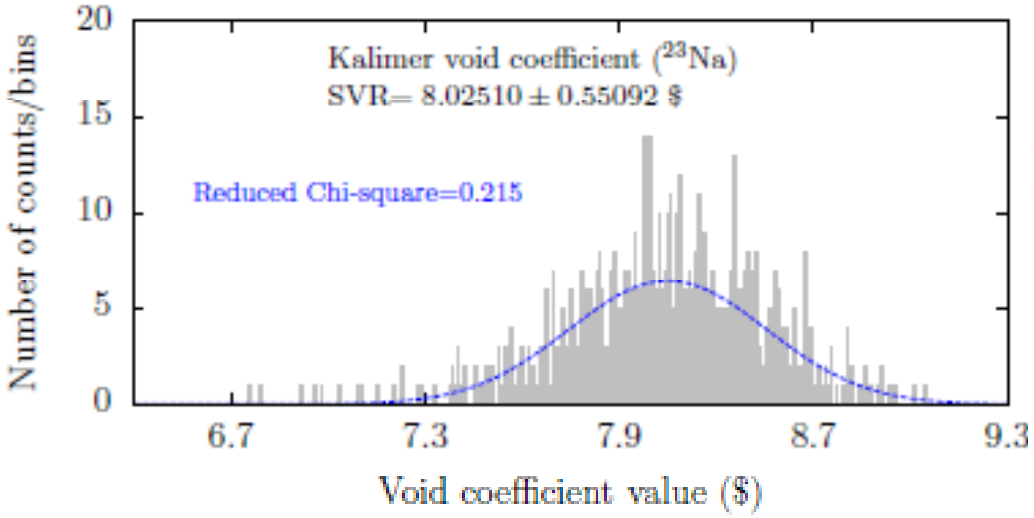
Total Monte Carlo (TMC)

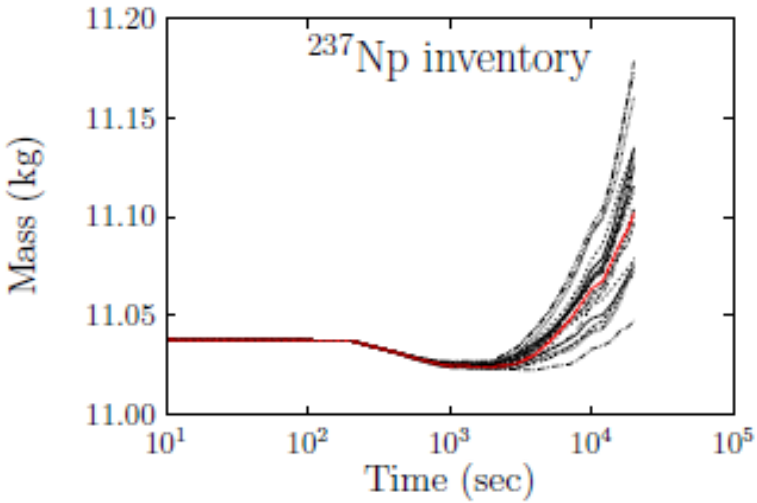
- TMC is a complementary approach to using covariance matrices
- Pioneered by Arjan Koning and Dimitri Rochman [Nuc. Data Sheets 113 (2012) 2841–2934]
- Sample model parameters → Random ENDF libraries → Application code → Multiple values of required quantity (q)→ $\langle q \rangle + \Delta q$

GEN-IV Fast Reactor

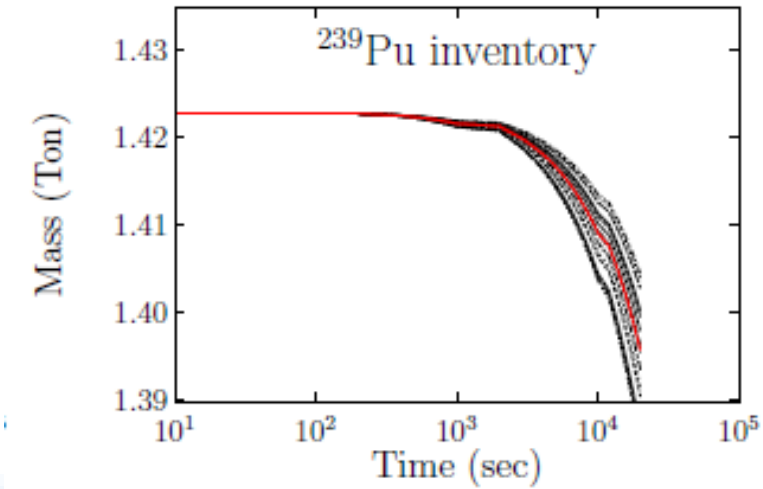
- Vary the ^{23}Na data and look at the variation of the Sodium Void Coefficient
- 800 MCNP runs
- Difficult because finding difference between 2 values (with and without Na)
- Vary ^{238}U data and look at variation of inventories of actinides
- 250 FISPACT runs

TMC results

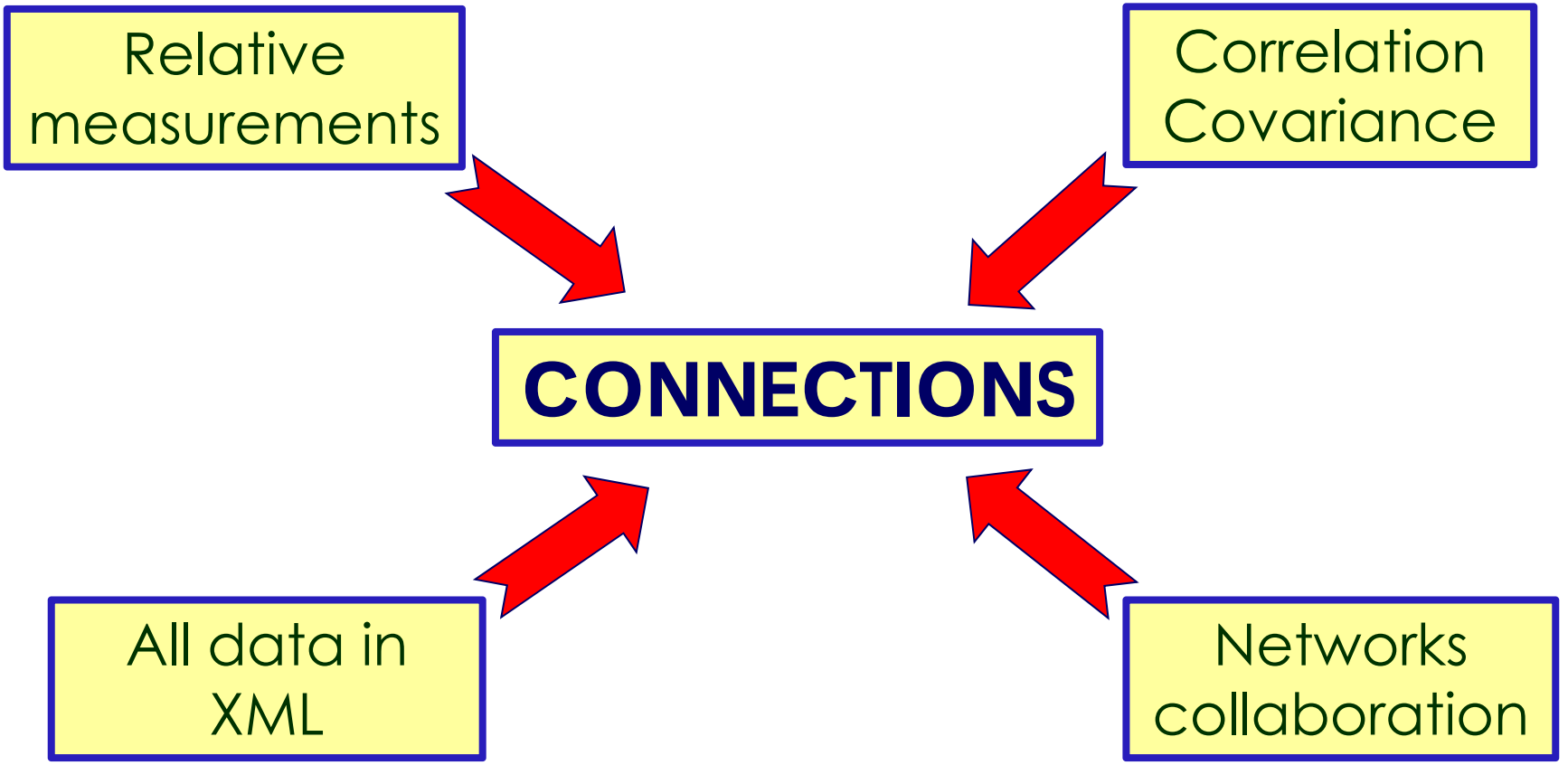




Variation in final quantities based on variation in nuclear data

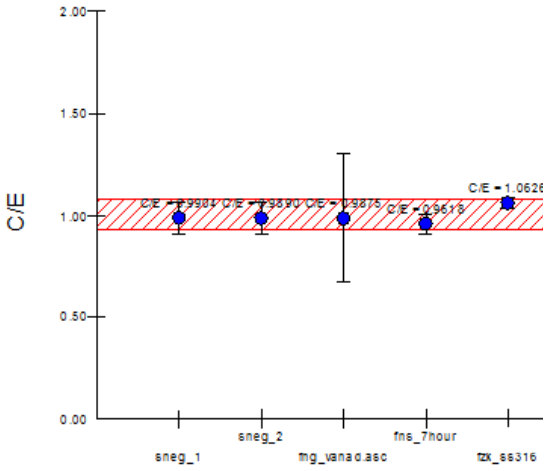


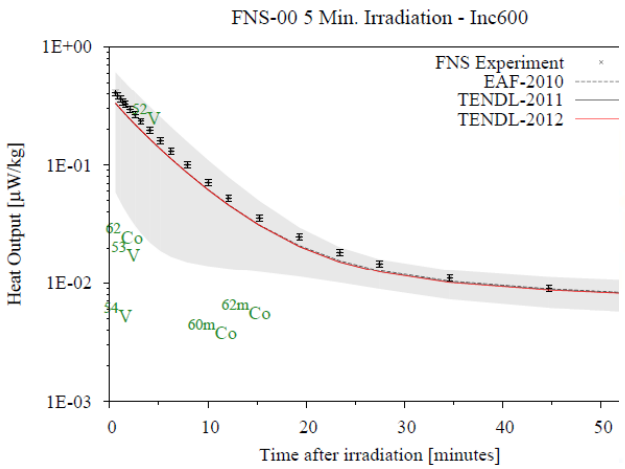
Point 3

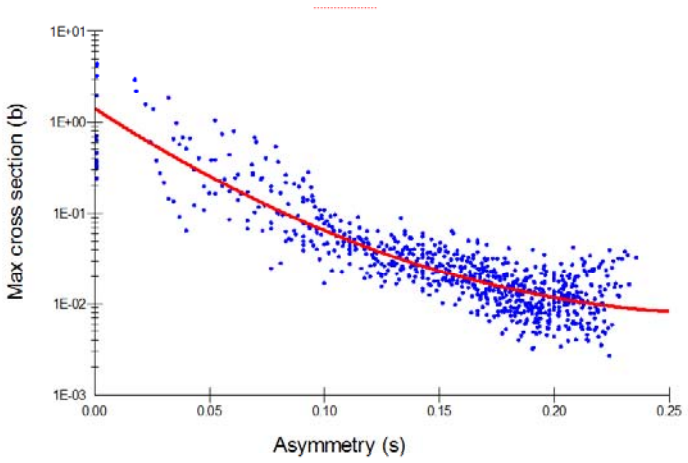

Relative measurements
Correlation Covariance
CONNECTIONS
All data in XML
Networks collaboration

Validation

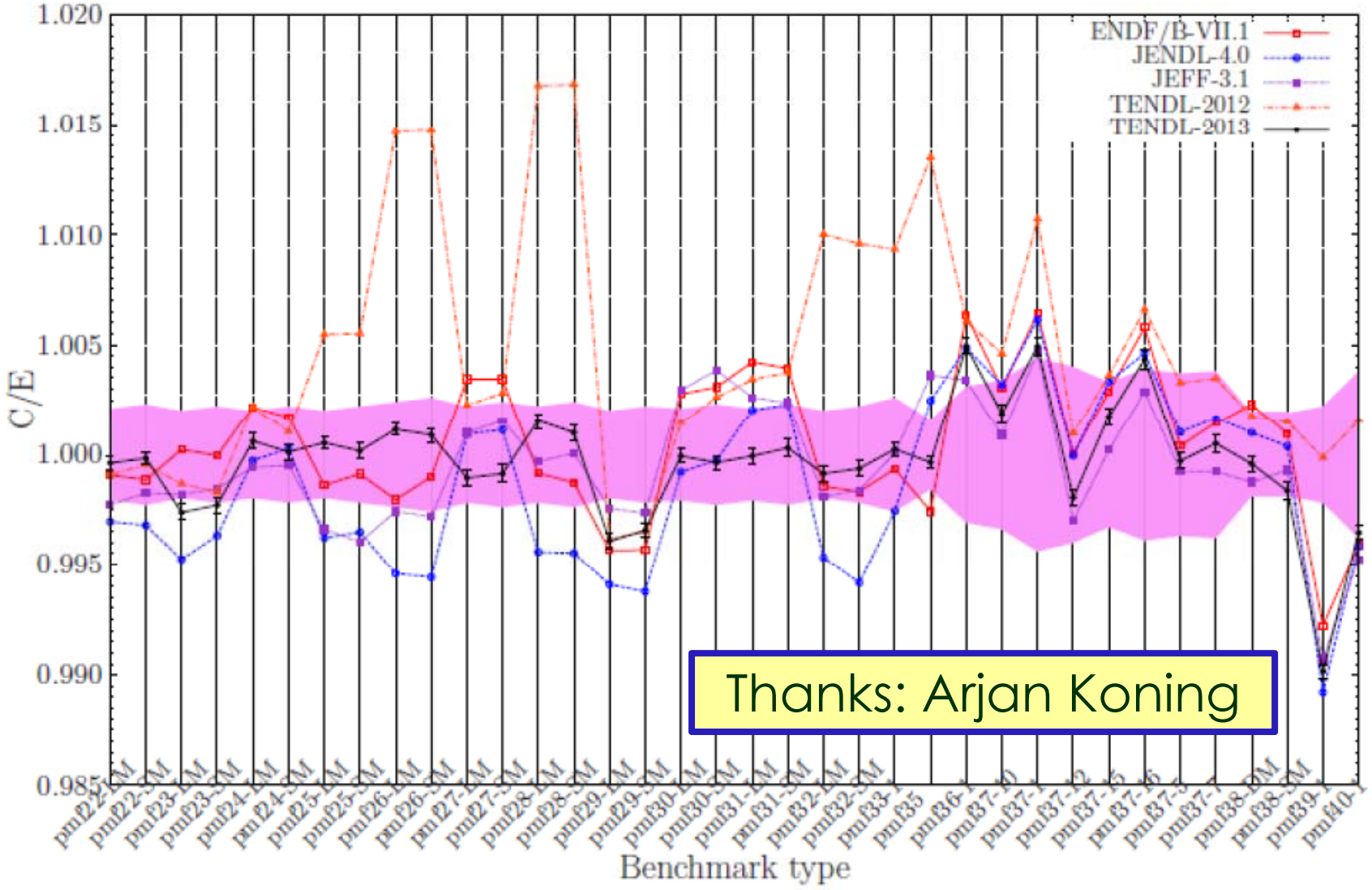
- Comparison of library data with experiment, typically for a well defined object – integral data
- Results in well defined neutron spectra
- What can be done when no experiments?





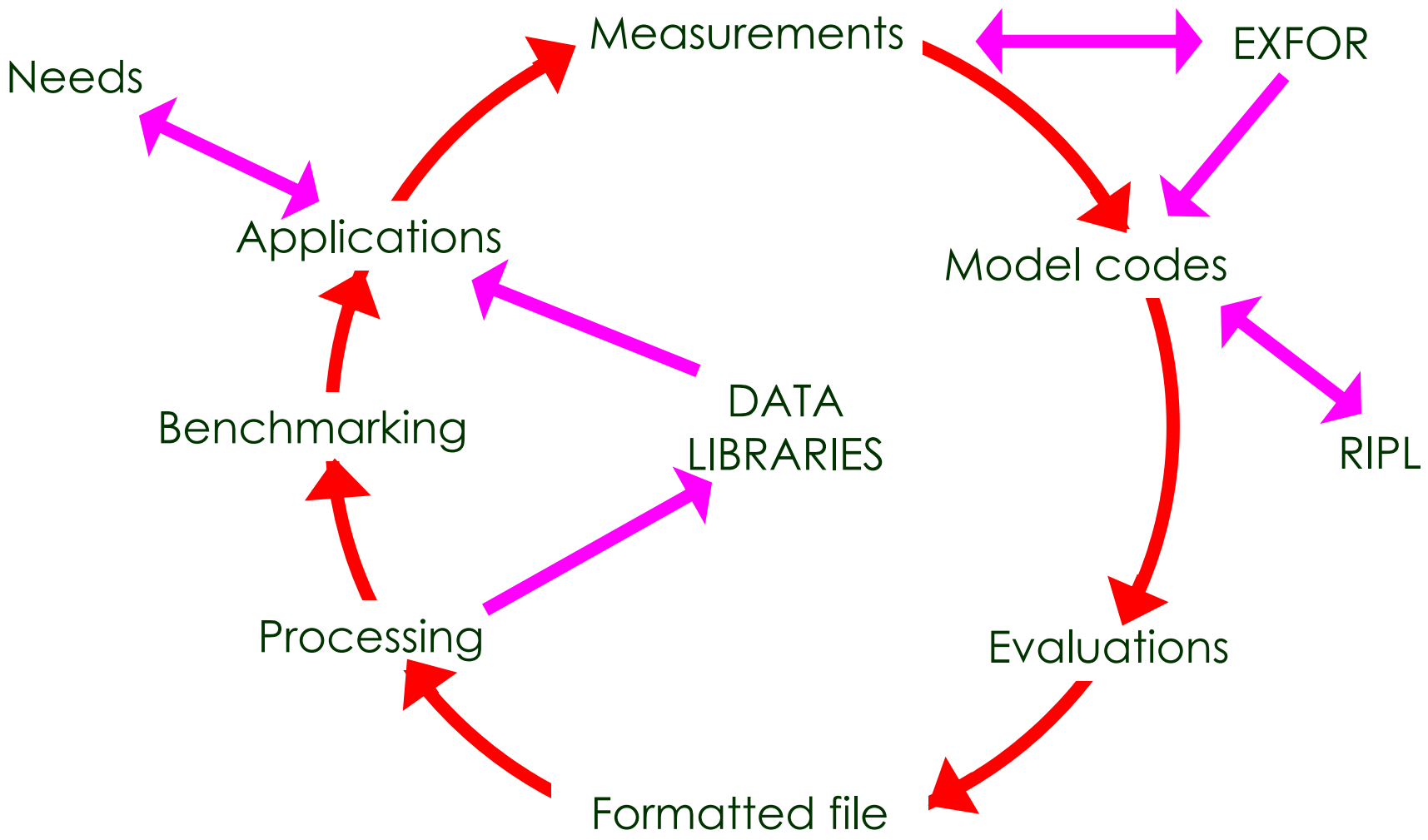


Automatic Validation

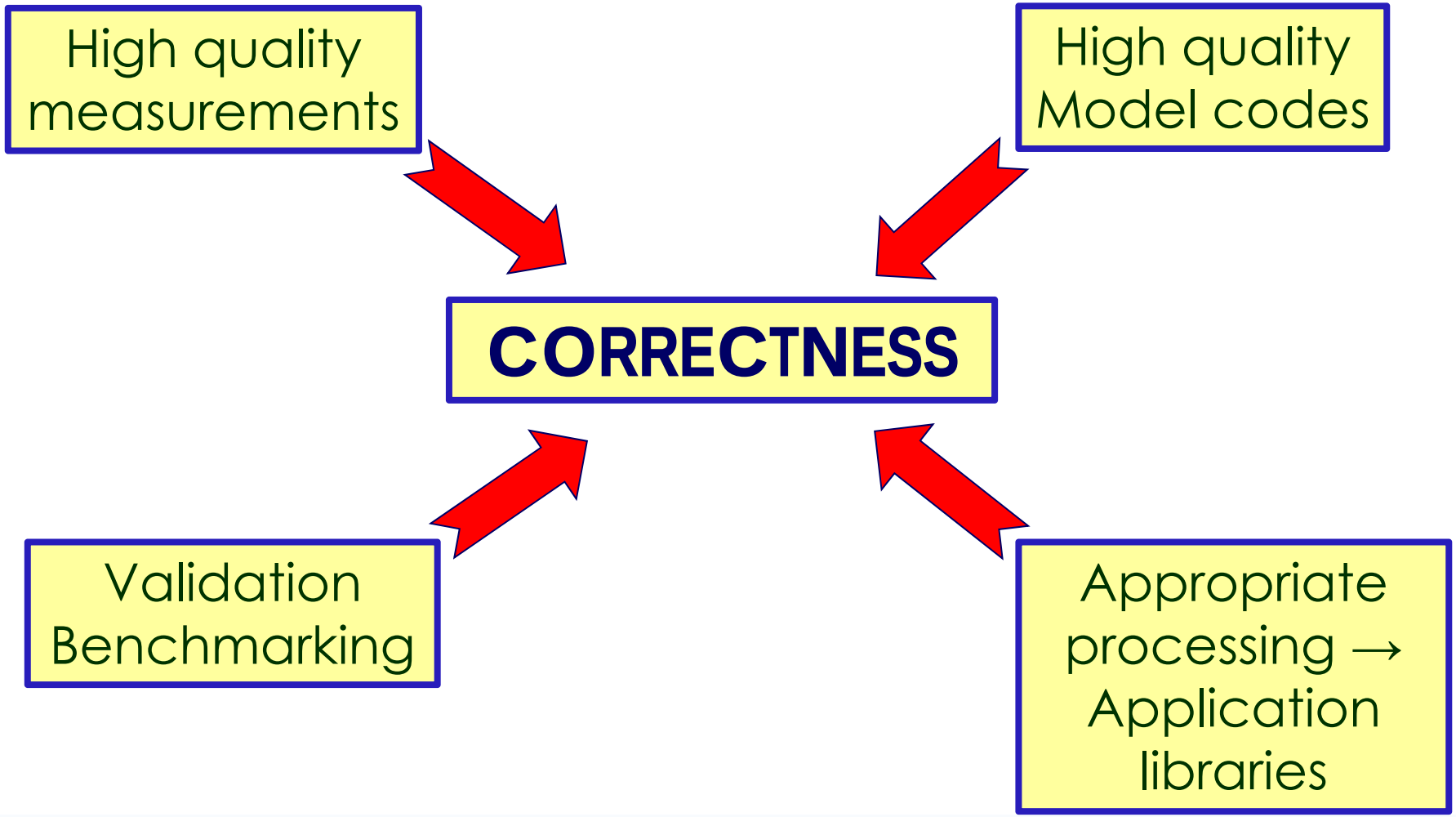


Thanks: Arjan Koning

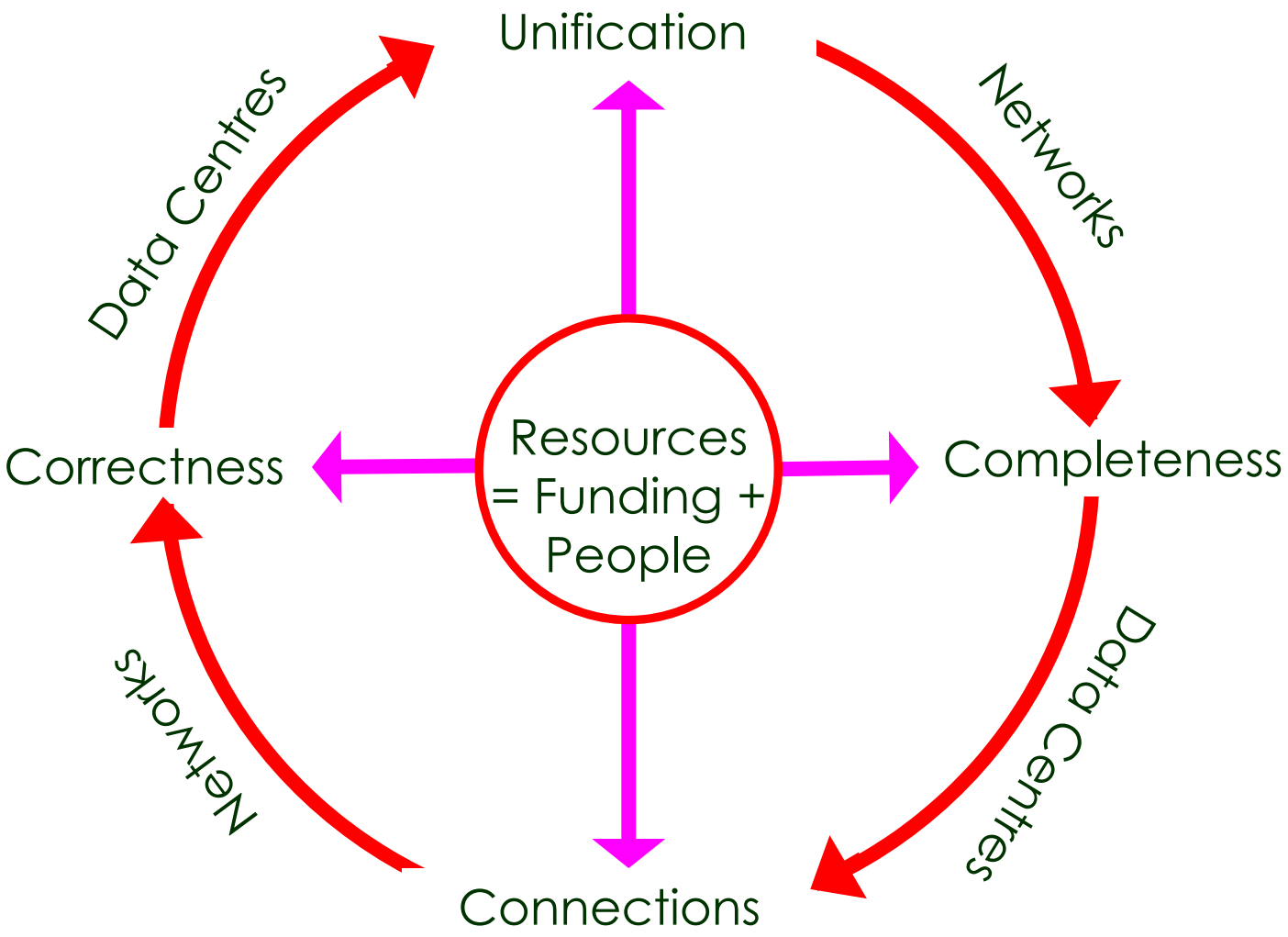
Nuclear data cycle



Point 4


High quality measurements
High quality Model codes
CORRECTNESS
Validation Benchmarking
Appropriate processing → Application libraries

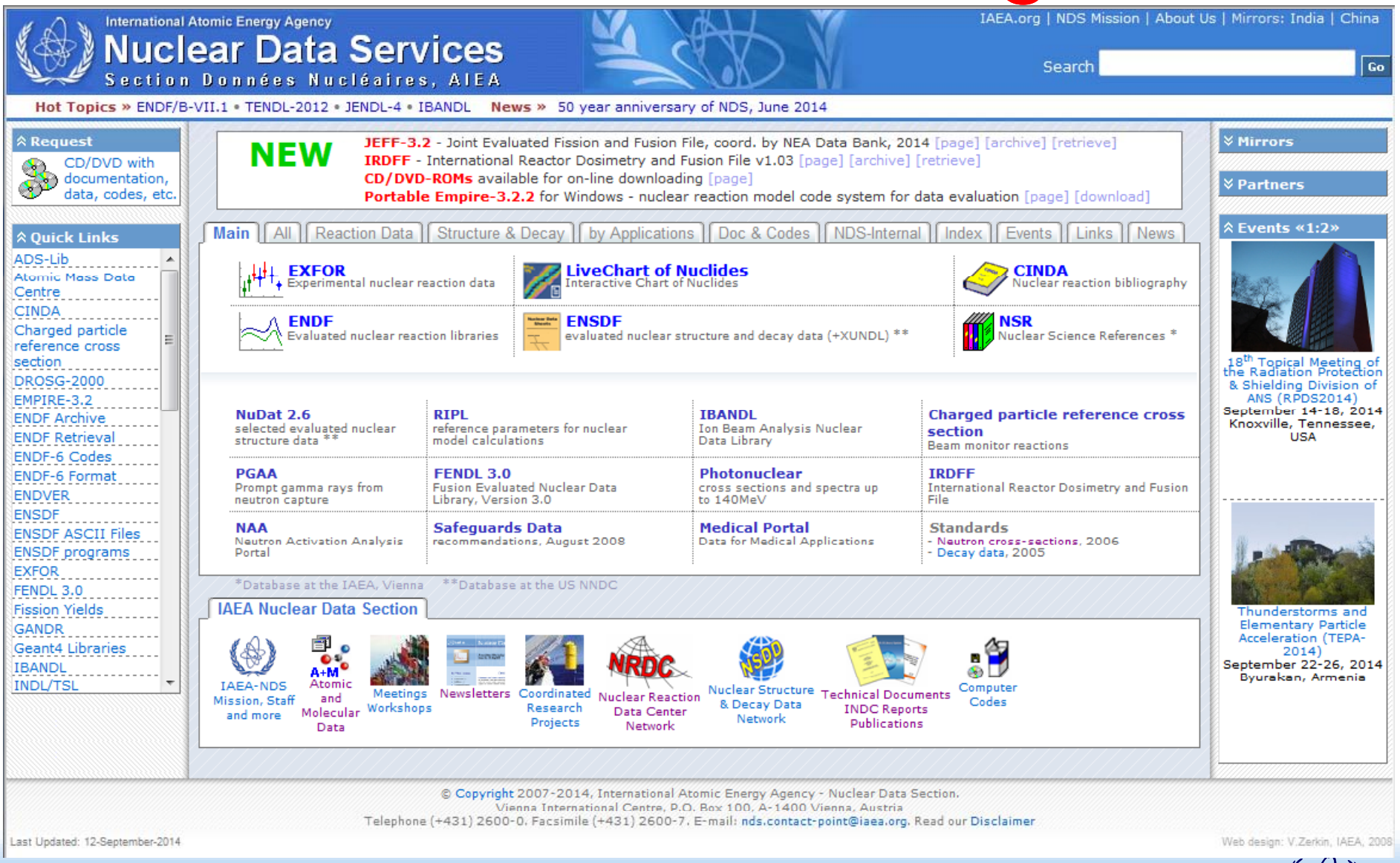
Nuclear data needs



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



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!