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Cross Section Measurements and Uncertainties of Cross Section Data

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Cross section measurements and uncertainties of cross section data

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http://www.jrc.ec.europa.eu/

Overview

General introduction

Some detailed measurement examples

Uncertainties in measurement

Some highlights of new possibilities

Measurement design

Quantity to measure (measurand)

cross section(s)
reaction parameter(s)

Measurement principle

activation, emitted particle detection, …

Expression of the quantity in terms of control and influence quantities

Identification of possible influence quantities (sources of error)

Method of measurement

Sequence of logical steps
how to fix control quantities
how to correct for other influence quantities

Measurement procedure

Detailed prescription
Physical operations
Data manipulations

Arriving at
Measurement value
Corrected
Uncertainties
Complete
Correlations

Evaluation of measurement uncertainty – Guide to the expression of uncertainty in measurement, JCGM 100:2008, www.bipm.org (2008)

Method of measurement

'Hardware'

Neutron source/collimation

Sample

Detection equipment fluence or normalization

Detection equipment process rate

Data acquisition

Peripheral control

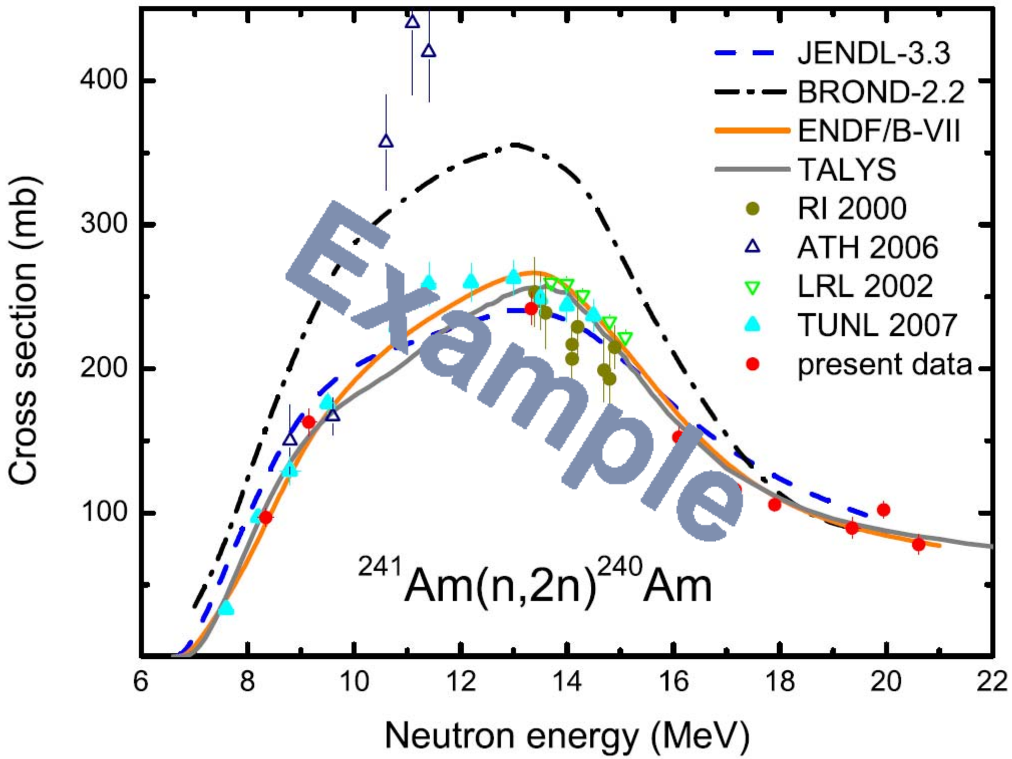
Ancillary measurements

'Software'

Measurement sequence
(foreground, background, iterate over samples, other experimental conditions, sample characterization, calibration)

Evaluation of data
Selection criteria
Data reduction
Determination of values, uncertainties and correlations

Uncertainties of measurements



Methodology

"Evaluation of measurement data - Guide to the expression of uncertainty in measurement"

Joint Committee for Guides in Metrology, *JCGM 100:2008, www.bipm.org (2008)*

General
Systematic
Standardized

Concepts and terminology
Summary of the procedure
Illustration

Developed by experts for measurements relied upon in application

Concepts

Quantity, measurand

True value

indeterminate, unknowable

Measured value, measurement result

corrected for systematic error
(qualify what you report!)

Error

measured - true value
indeterminate, unknowable

Uncertainty

parameter associated with the measurement result characterizing the distribution in values that could reasonably be attributed to the measured quantity

… for a given quantity and measurement result there is an infinite number of values dispersed around it, consistent with the data and one's knowledge, that can be attributed to the measurand with varying degree of credibility.

Error

Every measurement is in error

All measurements are imperfect

imperfect realization of quantity
random variations
inadequate corrections
incomplete knowledge

number of nuclei
detection efficiency
fluence measurement
multiple scattering
standard cross section
calibration sources
statistics

Error *is unknowable, however sources of error may be recognized and should be corrected for:*
Measurement result = corrected result

Systematic error
Mean error that would result from infinitely many measurements under repeatability conditions

Correction (factor)
Value added (multiplied) to compensate for systematic error

Random error
Error minus systematic error

Uncertainty

Several ways to express

- *standard deviation*
- *a multiple thereof*
- *fwhm, half width…*

Many contributing components

- standardized approach
- estimate std.deviation
- uncertainty propagation

Methodology of evaluation

Assess distribution, mean and standard deviation.

Mean ⇨ measurement result

Std.dev. ⇨ measurement uncertainty

- Type A: repetition, mean,
  expt. standard deviation

-Type B: scientific judgment
  * previous measurements
  * experience/knowledge
  * specification manufacturer
  * (calibration) certificates
  * reference data (handbooks)

Procedure

1. Determine mathematical relation measured quantity and input quantities
2. Determine estimates for inputs
3. Determine standard uncertainties for inputs
4. Determine covariances of input uncertainties
5. Determine output estimate from input estimates
6. Determine the combined standard uncertainties and covariances from the input uncertainties and covariances
7. Report result with standard uncertainties and covariances

$$Y_k = f_k(X_1, X_2, \ldots X_N)$$

$$X_i \rightarrow x_i$$

$$\rightarrow u(x_i)$$

$$\rightarrow u(x_i, x_j) = C(x_i, x_j)u(x_i)u(x_j)$$

$$y_k = f_k(x_1, x_2, \ldots x_N)$$

$$u_c^2(y_k) = \sum_{i=1}^{N}\sum_{j=1}^{N} \frac{\partial f_k}{\partial x_i}\frac{\partial f_k}{\partial x_j} u(x_i, x_j)$$

$$u_c(y_k, y_l) = \sum_{i=1}^{N}\sum_{j=1}^{N} \frac{\partial f_k}{\partial x_i}\frac{\partial f_l}{\partial x_j} u(x_i, x_j)$$

$$u_c(y_k, y_l) = \sum_{i=1}^{N}\sum_{j=1}^{N} S_{ki} S_{lj} C(x_i, x_j) r(x_i) r(x_j)$$

Reporting

1. Be clear about definition of the uncertainty (combined standard uncertainty, state coverage factor if any, fwhm, …)

2. For nuclear data work the combined standard uncertainty is to be preferred. Harmonization

3. Notation
   - σ = 30.5 b with u_c = 0.3 b
   - σ = 30.5(3) b
   - σ = 30.5(0.3) b
   - σ = (30.5 ± 0.3) b

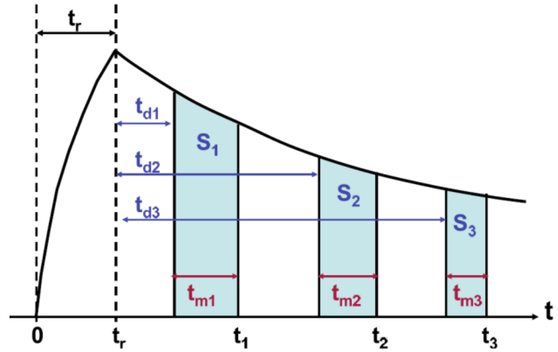
A. Measurement expression

B. Input quantities, values, uncertainties, correlations

C. Final results, combined standard uncertainties, correlations

Activation data evaluation

$$\sigma_{\mathrm{Am}} = \sigma_{\mathrm{Al}} \frac{S_{\mathrm{Am}}}{S_{\mathrm{Al}}} \frac{\left[I \epsilon f_{\Sigma} f_r n \Phi_0 \right]_{\mathrm{Al}}}{\left[I \epsilon f_{\Sigma} f_r n \Phi_0 \right]_{\mathrm{Am}}} \cdot \prod_k \frac{C_{\mathrm{k,Am}}}{C_{\mathrm{k,Al}}}$$



σ_{Al}	Reference cross section
S	Counts for gamma
I	gamma-ray intensity
ε	absolute detection efficiency
f_{Σ}	cooling time factor
f_r	irradiation time factor
n	number of nuclides
Φ_0	mean neutron flux
C_k	correction factors for * low energy neutrons * intensity fluctuations

$$f_{\Sigma} = \frac{1}{\lambda} \sum_i e^{-\lambda t_{d_i}} (1 - e^{-\lambda t_{m_i}})$$

$$f_r = 1 - e^{-\lambda t_r}$$

$$C_{\mathrm{flux}} = \frac{\bar{\Phi}(1 - e^{-\lambda t_r})}{\sum_{i=1}^{m} \Phi_i (1 - e^{-\lambda \Delta t}) e^{-\lambda (m-i) \Delta t}}$$

$$C_{\mathrm{low}} = 1 - \frac{\int_0^{E_c} \Phi(E) \sigma(E) dE}{\int_0^{\infty} \Phi(E) \sigma(E) dE}.$$

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Activation data reporting

	Neutron energy (MeV)								
	8.34	9.15	13.33	16.1	17.16	17.9	19.36	19.95	20.61
σ_{Al}	1.9	1.9	1.6	2	2	2.2	3.1	4.1	5.4
S_{Am}	5.0	4.0	2.5	2.1	1.5	1.3	6.3	1.4	5.7
S_{Al}	1.0	1.0	1.0	1.0	1.0	0.7	2.0	1.0	1.6
I_{Am}	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
n_{Al}	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
n_{Am}	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
$\epsilon_{\mathrm{Al}}/\epsilon_{\mathrm{Am}}$	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
$(f_{\Sigma} f_r)_{\mathrm{Am}}$	0.9	0.6	0.4	0.6	0.6	0.7	0.6	0.6	0.6
$\frac{C_{\mathrm{low,Am}}}{C_{\mathrm{low,Al}}}$			0.3	0.3	0.3	0.3	1.3	1.4	1.4

Energy (MeV)	C_{flux} Am	C_{flux} Al	C_{low} Am	C_{low} Al
8.34	0.9974	0.9925	1	1
9.15	1.0731	1.3117	1	1
13.33	0.9168	0.8288	1	1
16.10	1.0749	1.2335	1	1
17.16	0.9987	0.9878	0.998	0.997
17.90	0.969	0.933	0.998	0.997
19.36	1.0061	1.0157	0.941	0.926
19.95	0.9822	0.9433	0.922	0.891
20.61	0.9938	0.982	0.885	0.832

Activation reporting

Energy (MeV)	σ_{Am} (mb)	Unc. (%)	Correlation matrix (x100)								
8.34(15)	96.8	6.5	100								
9.15(15)	162.9	5.7	35	100							
13.33(15)	241.8	4.6	37	42	100						
16.10(15)	152.4	4.6	38	43	53	100					
17.16 (3)	116.1	4.4	40	45	57	58	100				
17.90(10)	105.7	4.4	41	45	57	59	84	100			
19.36(15)	89.5	8.2	21	24	30	31	39	39	100		
19.95 (7)	102.1	5.8	30	34	44	45	58	59	51	100	
20.61 (4)	77.9	8.8	20	22	29	30	40	42	39	65	100

Summary

There is an excellent guide on what to do

Its use should be promoted

Reporting should be as complete as possible

Correlations make this a challenge in data storage for large data sets, but there are solutions (AGS)

Cautions

A small uncertainty does not guarantee a small error: incomplete knowledge ⇨ incomplete corrections

Do not over- or underestimate uncertainties! Use all your current knowledge as best as possible.

1. overestimation leads to needless caution of users, attempts to remeasure, disregard for your hard work, difficulty identifying incomplete knowledge

2. underestimation leads to misplaced trust, undue weight of the result in evaluations, biased predictions