Incorporation of Uncertainty Templates into EXFOR

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Uncertainty analysis is a complex process, and often only the final result is presented

- It is generally recognized that the total uncertainty on a cross section should always be given for an experiment, but often more information is needed.
- To do a proper covariance analysis, the individual uncertainty components are needed

Table from Fotiades et. al. PRC 69, 024601 (2004)

	1998 Data (%)	1999 Data (%)
E_γ (keV)	$\delta\epsilon_\gamma$ [a]	$\delta\epsilon_\gamma$ [a]
100–400 (Planars)	5	5
600–750 (Coaxials)	10	11
751–900 (Coaxials)	9	10
901–1200 (Coaxials)	8	9
>1200 (Coaxials)	7	8
E_n (MeV)	$\delta\Phi(E_n)$	$\delta\Phi(E_n)$
1–4	1.0	0.8
4–8	1.5	1.0
9–19	2.0	1.4
20–50	1.5	1.2
51–100	1.2	1.1
δt	0.3	0.3
δ Dead T_γ	0.1	0.1
δ Dead T_Φ	0.2	0.15
Additional fluence uncertainty[b]	5	5

[a]Includes uncertainties in the γ-ray absorption in the sample, finite beam size effects, as well as detector efficiency uncertainties.
[b]Includes uncertainties in the fission foil thickness, fission cross section, and ionization chamber efficiency.

Proper covariance calculations require that all uncertainty sources are split out

- The first-order linear approximation of the covariance matrix:

x, y are variables with uncertainty (such as sample mass, or detector efficiency)

i, j are neutron energy data points

$$\mathrm{cov}_{x,y}(\sigma_i, \sigma_j) = \left.\frac{\partial \sigma}{\partial x}\right|_{x_i} \delta x_i \; \mathrm{cor}(x_i, y_j) \; \delta y_j \left.\frac{\partial \sigma}{\partial y}\right|_{y_j}$$

Covariance between the cross section at two energy points, E_i and E_j, due to the two uncertainty sources *x* and *y*

To standardize uncertainty analysis in evaluations, Denise Neudecker started by creating a template of experimental uncertainties for fission cross section measurements

Unc. source	Typical range	Cor(Exp$_i$, Exp$_i$)	Cor(Exp$_i$, Exp$_j$) $i \neq j$
Sample mass	>1%	Full	$\neq 0$ if same sample used
Counting statistics	Sample and measurement time-dependent	Diagonal	0
Attenuation	0.02%–2%	Gaussian	Likely
Detector efficiency	0–0.3%, 1%–2%	Full < 10 MeV	Likely, 0.5–1
FF angular distribution	≈0.1%	Gaussian	Likely, 0.75–1.0
Background	0.2–>10%	Gaussian	Possible
Energy unc.	1%, 1–3 ns	From conversion	Technique-dependent
Neutron flux	0%, >1%	0.5–Full	Technique-dependent
Multiple scattering	0.2%–1%	Gaussian	0.5–0.75
Impurities in the sample	Sample-dependent	0.9–1	0.5–0.75
Dead time	>0.1%	Full	0

Table from Neudecker, D., Hejnal, B., Tovesson, F., White, M. C., Smith, D. L., & Vaughan, D. (2018). Template for estimating uncertainties of measured neutron-induced fission cross-sections. *European Physical Journal N*, *4*(21).

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Attenuation
Detector efficiency
FF angular distribution
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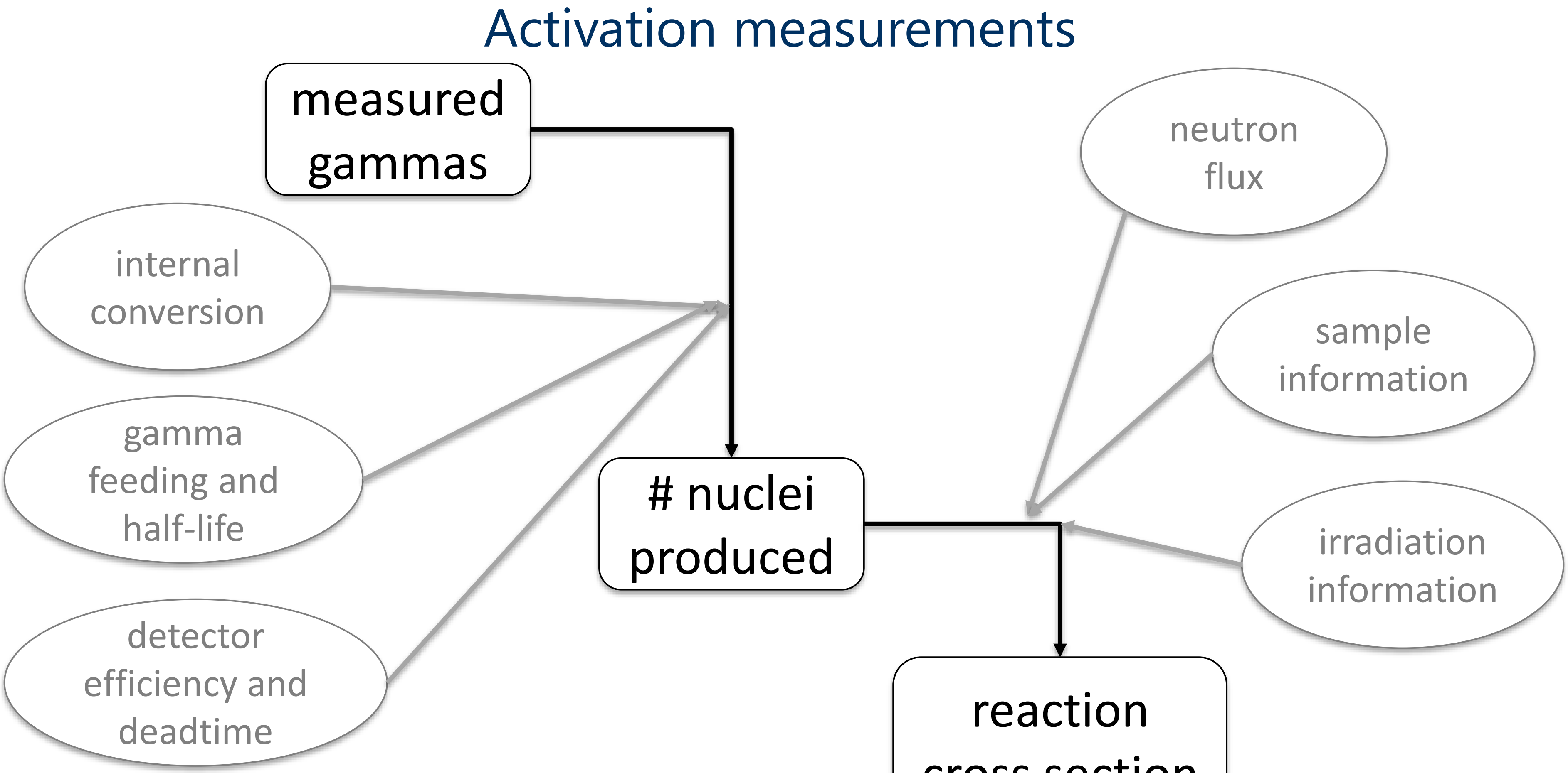
Energy unc.
Neutron flux
Multiple scattering
Impurities in the sample
Dead time

14015 – 1991 Carlson $^{235}U(n,f)$

```
ERR-ANALYS (ERR-S) Statistics
           (ERR-1) Fission fragment counting efficiency
           (ERR-2) Transmission and scattering
           (ERR-3) Background
           (ERR-T) Total uncertainty
```

Table from Neudecker, D., Hejnal, B., Tovesson, F., White, M. C., Smith, D. L., & Vaughan, D. (2018). Template for estimating uncertainties of measured neutron-induced fission cross-sections. *European Physical Journal N*, *4*(21).

The template I have created focused on cross section measurements using discrete gammas



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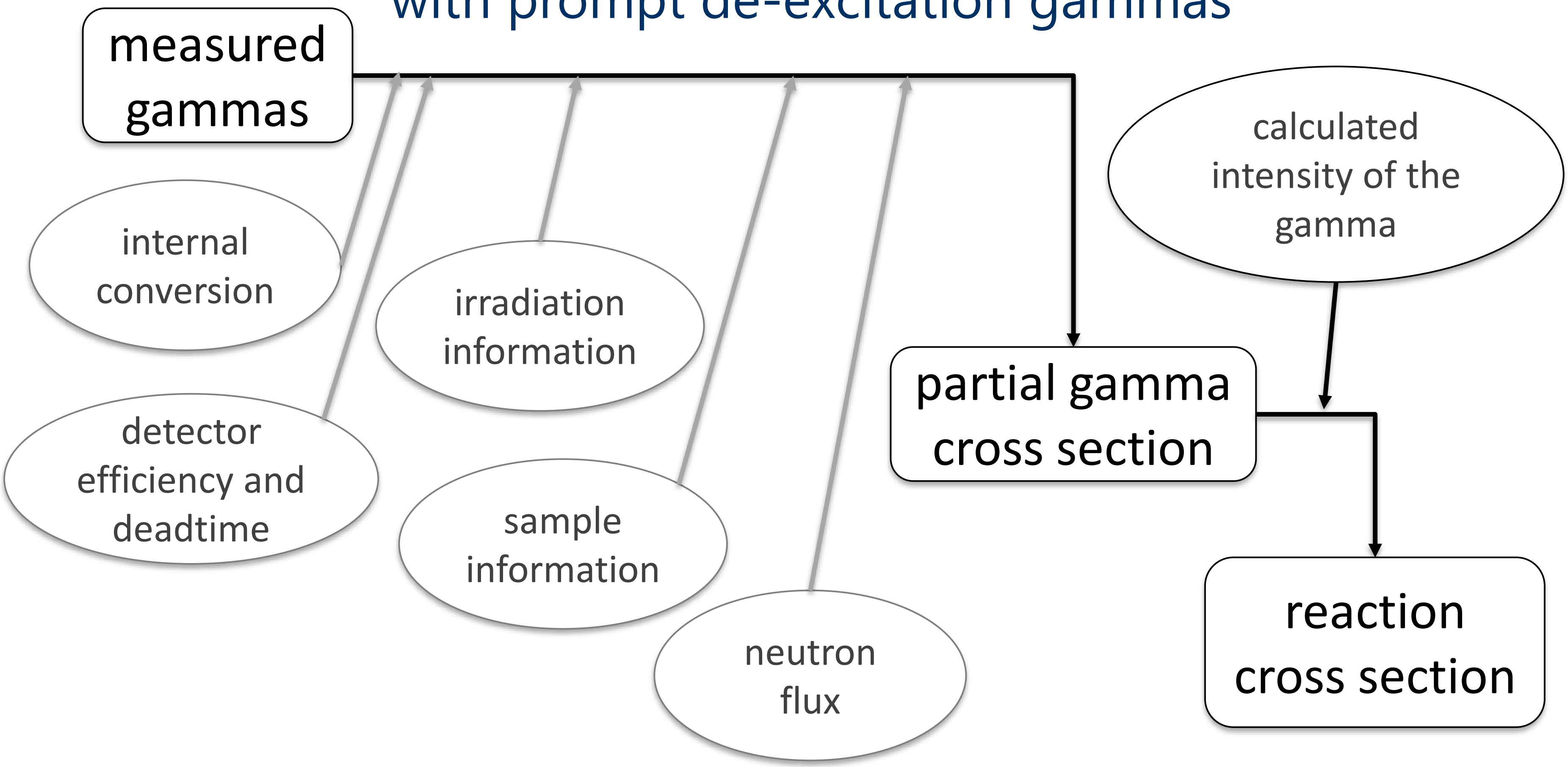
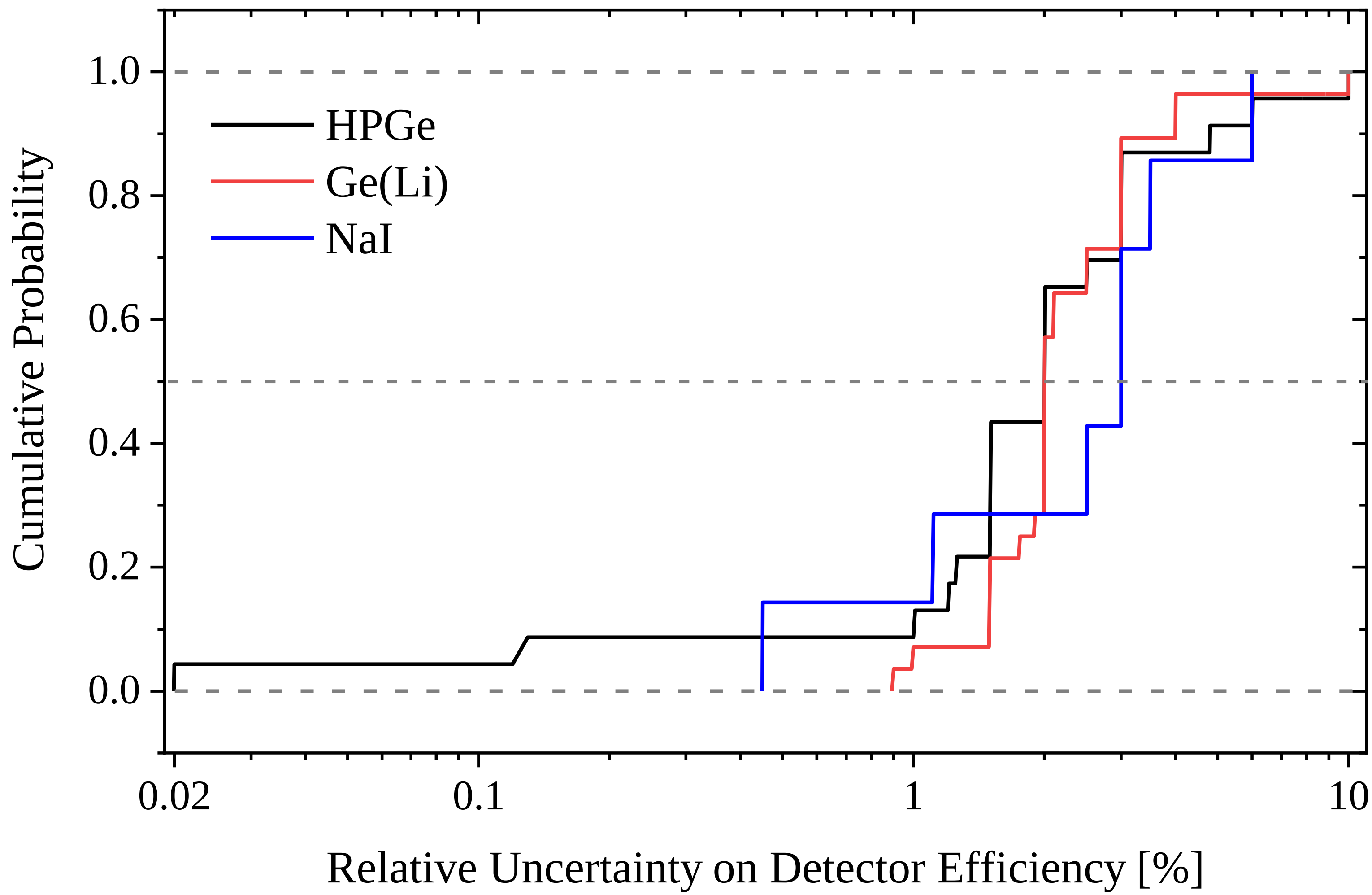
Partial cross section measurements with prompt de-excitation gammas



The sources of uncertainty that are common to all experiments and must always be addressed

- Sample Uncertainties
  - Mass
  - Isotopic composition
  - Gamma attenuation
- Gamma Detector
  - Efficiency
  - Deadtime Correction
  - Counts
- Neutron Source Uncertainties
  - Flux
  - Energy, Resolution
  - Irradiation Geometry
- Nuclear Data
  - Half-lives, branching ratios, internal conversion, etc
- Calculated Gamma Intensity
  - when converting partial cross section to channel

Distributions of uncertainty values have been created using current EXFOR entries



The median values of the distributions are presented as reasonable values for the experimental uncertainties

Sample Uncertainties

Sample type	Mass (m)	Isotopic Abundance (w)	Self-Absorption (ξ)
Stable Metal	0.3 (21)	0.2 (10)	0.7 (17)

Median of 21 values found was 0.3%

Detector Uncertainties

Detector type	Efficiency (ε)
HPGe	2.0 (23)
Ge(Li)	2.0 (28)
NaI	3.0 (7)

Neutron Source Uncertainties

Source type	Flux (ϕ)	Energy (E_n)	Resolution
Associated Particle	1.0 (8)	1.3 (87)	0.7 (10)
Gas Target Generator	3.0 (9)	1.0 (9)	2.3 (6)
Solid Target Generator	2.6 (18)	0.7 (26)	1.7 (11)
Time-of-flight	2.0 (28)	2.9 (22)	5.7 (20)

All uncertainty values are relative, given in percent

Correlations between the neutron energy data points have been estimated for each source

- Many sources were **fully correlated**
  - Sample uncertainties
  - Detector uncertainties

- Neutron source uncertainties were **gaussian correlated**
  - Points closer in neutron energy are more highly correlated

- In the case of monitor experiments, there are correlations between the sample and monitor sources of uncertainty

The ERR-ANALYS section currently includes all sources specified in the paper, but not always all information

Example from EXFOR entry 13901 – 2004 Fotiades $^{238}U(n,n'g)$

```
ERR-ANALYS (ERR-S) Statistical uncertainty.
           (ERR-1,5.,11.) Uncertainties in the gamma-ray
           absorption in the sample, finite beam size effects, as
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           fission cross section, ionization chamber efficiency
           (ERR-3,1.,2.) The uncertainty in the neutron flux
           (ERR-4) Uncertainty in target thickness
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             the detection of gamma rays
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Ranges are given even when there is more specific information in the paper

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Fotiades et. al. PRC 69, 024601 (2004)

In addition, the sources of uncertainty and numbering are inconsistent between entries

ERR-1: several sources
ERR-2: fission chamber
ERR-3: flux
ERR-4: mass
ERR-5: dead time (Ge)
ERR-6: dead time (FC)

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14240 – 2009 Hutcheson $^{238}U(n,n'g)$

ERR-1: flux
ERR-2: internal conv
ERR-3: efficiency
ERR-4: mass

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ERR-ANALYS (ERR-S) Statistical uncertainty
           Total systematic unceratinty was calculated from
           systematic uncertainties in
           (ERR-1) neutron flux determination
           (ERR-2) internal conversion coeficient of measured
                   radiation
           (ERR-3) gamma ray detection efficiency
           (ERR-4,,1.0) 238U sample mass
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And even the wording used for each source can vary, making parsing difficult

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Incorporating the uncertainty template idea could allow for more consistent and complete reporting

- Want to make the error reporting more consistent between entries, and make it machine parsable
- Provide experimentalists with a list of uncertainty sources that should be considered, to reduce use of average or typical values
- Provide a framework for eventually ensuring that all new compilations provide all of template sources
- Allow for compilers, evaluators and users to easily see what the largest sources of uncertainty are
  - If machine parsable, this will be even easier

One idea for incorporation of uncertainty templates

- Take each required uncertainty source from the relevant template, and give a specific and constant number (informally)

  - Sample Uncertainties
    - Mass
    - Isotopic composition
    - Gamma attenuation

  - Gamma Detector
    - Efficiency
    - Deadtime Correction
    - Counts → ERR-S

One idea for incorporation of uncertainty templates

- Take each required uncertainty source from the relevant template, and give a specific and constant number (informally)

  - Sample Uncertainties
    - Mass → ERR-1
    - Isotopic composition → ERR-2
    - Gamma attenuation → ERR-3

  - Gamma Detector
    - Efficiency → ERR-6
    - Deadtime Correction → ERR-7
    - Counts → ERR-S

Specific sources can be given their own number, and groups could be given ranges

sample

- ERR-1 --- mass
- ERR-2 --- sample composition
- ERR-3 --- gamma self-attenuation
- ERR-4 --- open
- ERR-5 --- open

detector

- ERR-6 --- detector efficiency
- ERR-7 --- deadtime correction
- ERR-8 --- open
- ERR-9 --- open
- ERR-10 -- open

The sources that are included, and the number scheme, can be decided by the group creating the template

- The Mini-CSEWG meeting at LANL in April will focus on the creation of templates for many types of experiments
  - Cross section measurements:
    - Fission
    - Prompt gammas and activation
    - Transmission
    - Capture, scattering
    - Charged particle
  - Other
    - PFNS
    - Structure measurements
    - Fission yields
- The creation of this type of organized list can be part of the work

Feedback and comments

- This is just one idea – I would like suggestions, and to have a conversation about the best way to incorporate the templates

- I will be presenting at the mini-CSEWG on templates at LANL at the end of April, and will take with me the discussion here

Acknowledgements

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