Fission Yields -
Template of Expected Uncertainties

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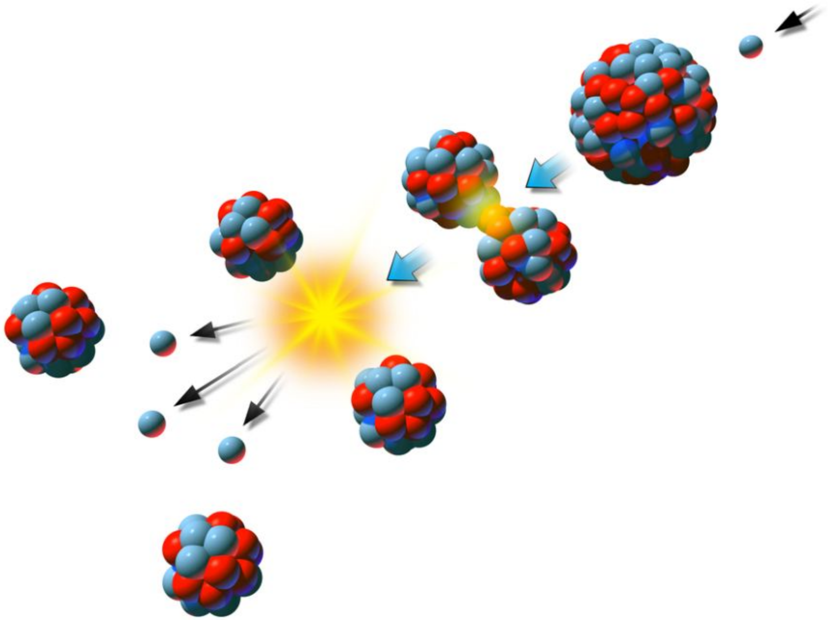

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image credit: Andrea Danti, shutterstock

What does this template cover?

- Neutron-induced fission yields only
  - These are most important to applications.

- Fission product yields only (post neutron emission)
  - Fragment yields cannot be measured directly.

- All fission yield types are considered: independent, cumulative, chain/mass, and charge.

Sources

- There are two major sources of information for this template:
  - **Expert Consultation**
    - ANL, LANL, and PNNL staff scientists (so far)
  - **Literature Review**
    - This includes a review of fission yields in EXFOR covering all entries for ^{235}U, ^{238}U, and ^{239}Pu from 1943–2019.
    - ~30 additional peer-reviewed publications.

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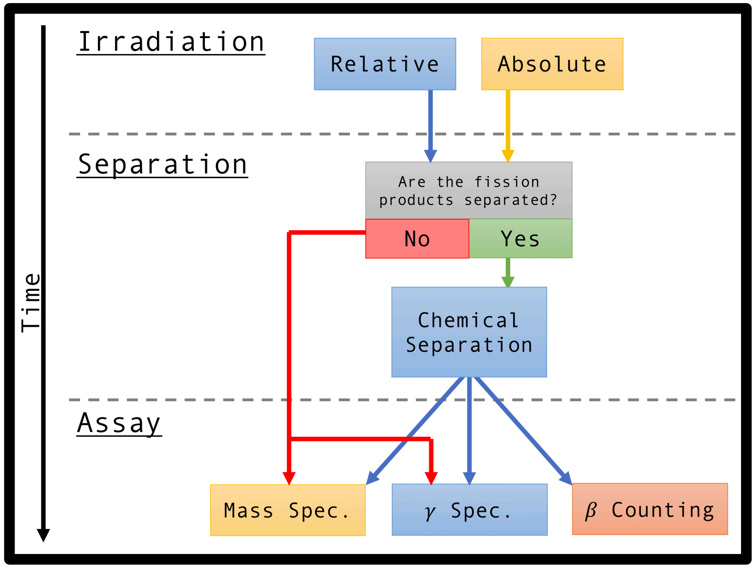
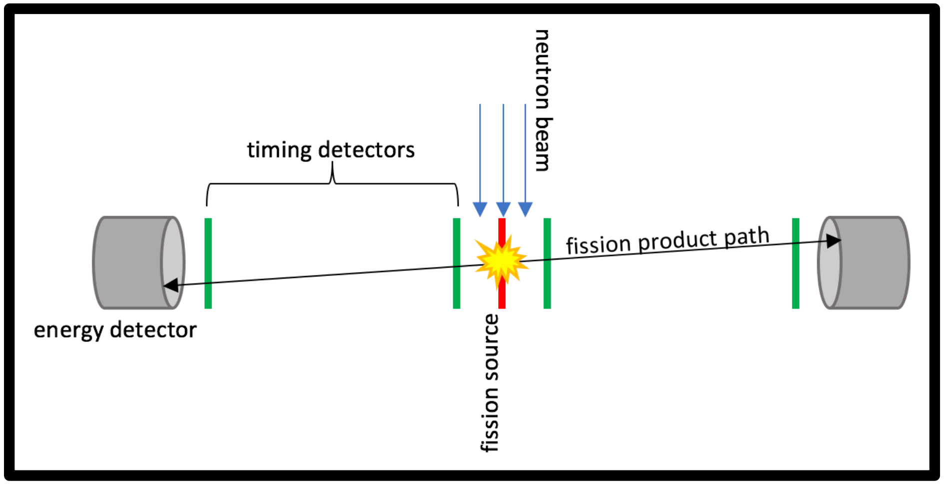
Measurement Techniques

- Two important measurement regimes were covered:

Activation-type Meas.



The 2E-2v Method



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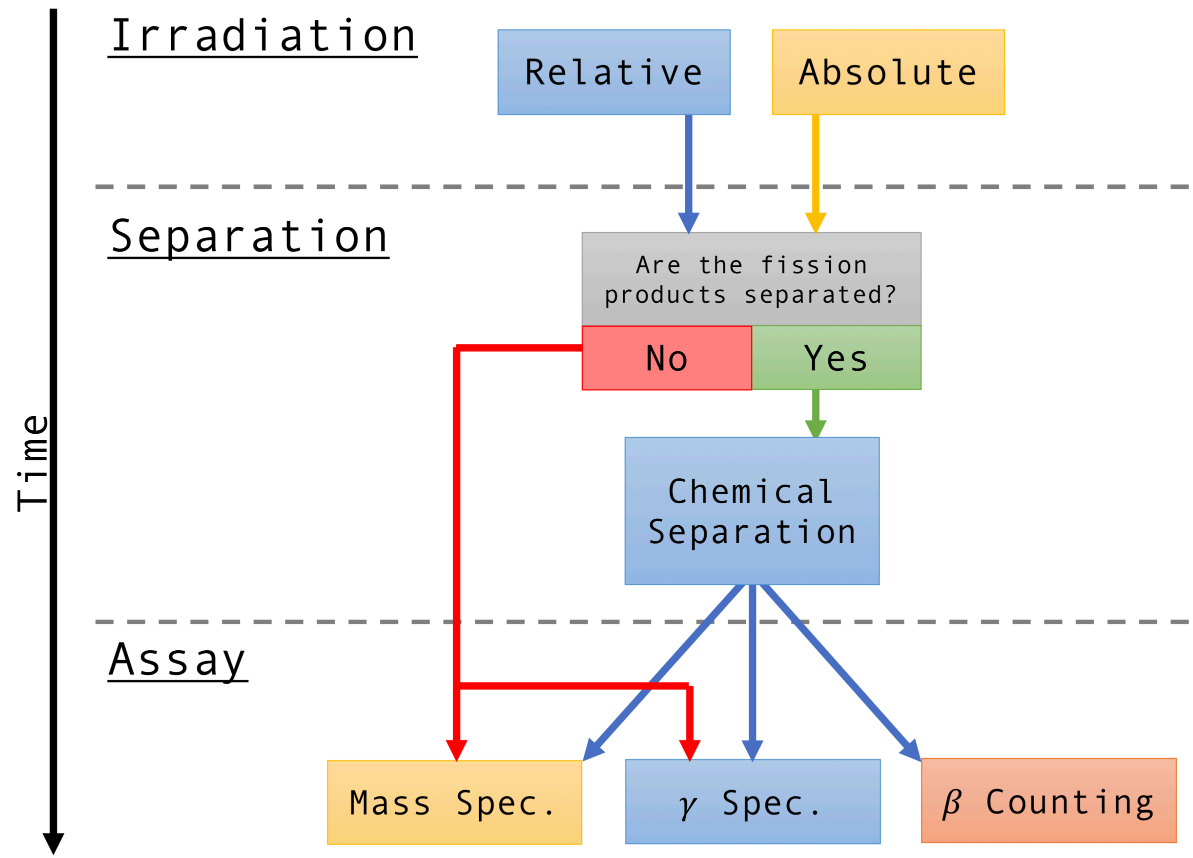
The Templates

- The templates of expected uncertainties will be presented in the following slides.
- Due to the limited time we have today, there will not be time to get to cover or discuss all of this information in detail.
- Your input is very valuable to this effort and we want to hear from you! Please record your feedback and send to me via email to have it incorporated into the template.

Activation-Type Measurements

- Many fission yield measurements fall into the category of an activation measurement and differ only by irradiation, separation, and assay methods.

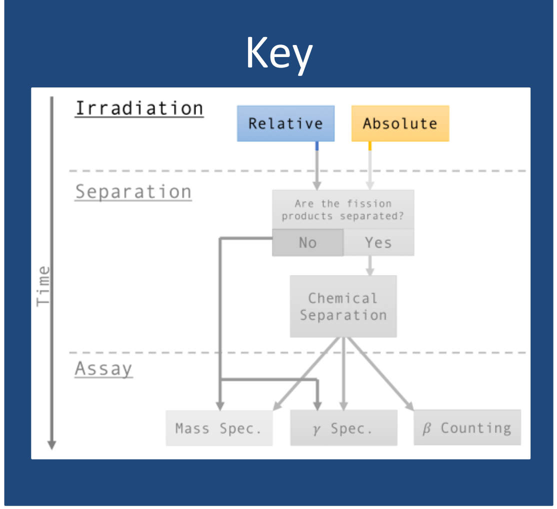
- The following flowchart was assembled to summarize this:



Activation - Irradiation

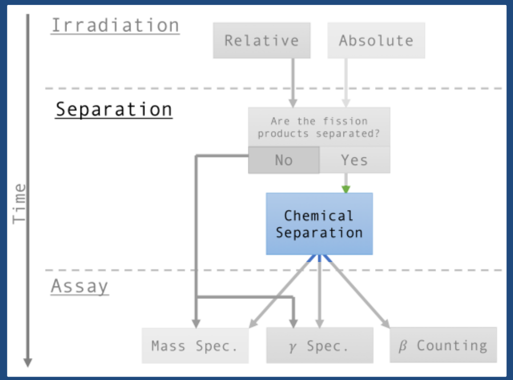
Symbol	Description
Relative and Absolute:	
$P(E_{inc})$	incident neutron energy spectrum
-L	TOF length
-Δt	time resolution
-ε	detector efficiency
-τ	dead time
-c	counting statistics
Absolute Only:	
N_f/R_f	number of fissions / fission rate
-ϕ	neutron flux
-σ_f	fission cross section*
-N	number of atoms/mass
- a	enrichment/abundance
- t_i	irradiation time
-B_u	reactor burnup
-c_T	fragment track counting
-F_C	fission chamber
$\oslash$	geometry
N	number of atoms/mass
- a	enrichment/abundance
Ω	solid angle
c	counting statistics
*indicates a nuclear data uncertainty (σ^{ND})	

Symbol	Minimum σ (%)
Relative and Absolute:	
$P(E_{inc})$	
-L	$\ll$0.1
-Δt	~0
-ε	2
-τ	~0
-c	Poisson dist.
Absolute Only:	
N_f/R_f	1
-ϕ	1
-σ_f	given by evaluation
-N	0.001
- a	abundance: See databases or given by enrichment
- t_i	~0
-B_u	1
-c_T	1.5
-F_C	1.5
$\oslash$	<0.1
N	0.001
- a	enrichment: given by manufacturer abundance: See databases
Ω	<0.1
c	Poisson distribution



Activation - Chemical Sep.

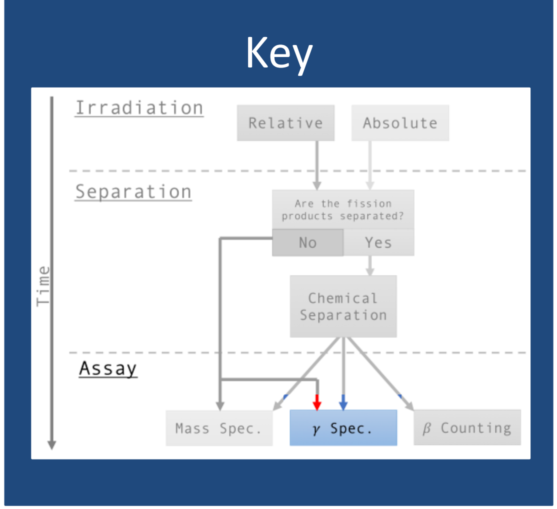
Key



Symbol	Description
N	sample mass(es)
- a	enrichment/abundance
- o	oxidation bias
y	chemical yield
x	isotopic exchange

Symbol	Min. σ (%)	Max. σ (%)
N	0.001	0.5
- a	abundance: See databases or given by enrichment	
- o	$\sim$0	stoichiometry ($\sim$17 for O_2)
y	0.3	3
x	$\sim$0	–

Activation - γ Spectroscopy

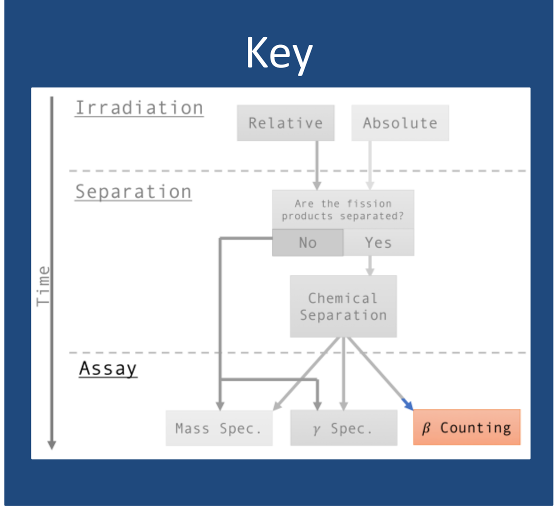


Symbol	Description
Resolved Only:	
ε	detector efficiency
$-I_\gamma$	gamma intensity*
$-T_{1/2}$	half-life*
$-A_0$	calibration source activity
$-g$	gamma spectroscopy fitting
$-c$	counting statistics
g	gamma spectroscopy fitting
Unresolved Only:	
ε	detector efficiency
Unresolved and Resolved:	
τ	dead time
η/Ω	counting geometry/solid angle
ξ	self attenuation
c	counting statistics

*indicates a nuclear data uncertainty (σ^{ND})

Symbol	Min. σ (%)	Max. σ (%)
Resolved Only:		
ε	0.5	20
$-I_\gamma$	given by evaluation	
$-T_{1/2}$	given by evaluation	
$-A_0$	calib. certificate	
$-g$	0.2	–
$-c$	Poisson dist.	–
g	0.2	–
Unresolved Only:		
ε	2	50
Unresolved and Resolved:		
τ	$\sim$0	–
η/Ω	<0.1	–
ξ	0.2	10
c	Poisson dist.	–

Activation - β Counting



Symbol	Description
ε	detector efficiency
τ	dead time
η/Ω	counting geometry/solid angle
ξ	self attenuation
c	counting statistics
*indicates a nuclear data uncertainty (σ^{ND})	

Symbol	Min. σ (%)
ε	0.1
τ	0.1
η/Ω	0.1
ξ	0.2
c	Poisson dist.

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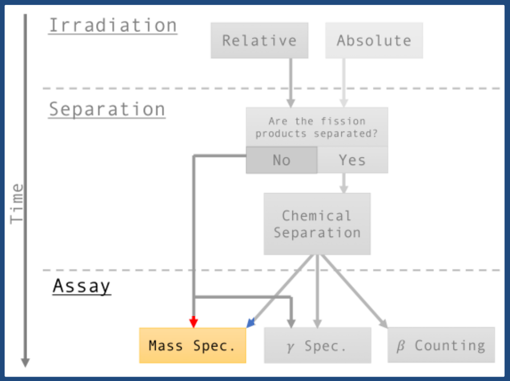
Activation - Mass Spectroscopy

Key



Symbol	Description
Forward Propagation (GUM):	
g	electronics gain
bl	electronics baseline
ε_{FC}	Faraday cup efficiency
n_S	Schottky noise
Y	yield calibrations
ℓ	linearity calibrations
f	filament geometry
s_{mass}	mass peak shaping
c	counting statistics
Integrated Quantification:	
σ_{MS}^{rep}	standard deviation of repeated trials

- Two methods of uncertainty estimation are possible with mass spectrometry.
- Due to a lack of literature information on these sources of uncertainty a template is not recommended.

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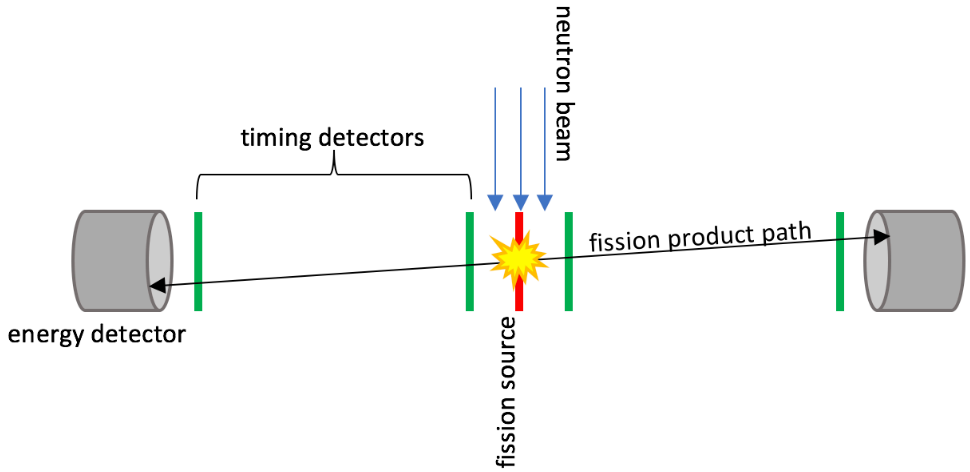
The 2E-2v Method

- This method measures mass yields by simultaneously detecting the energy and velocity of both fission products.



- This method is particularly useful to fission yield evaluations due to its simultaneous measurement of fission product mass yields and prompt-neutron multiplicities.

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The 2E-2v Method

Symbol	Description
E	fission product energy
t	fission product time-of-flight
L	fission product flight length
c	counting statistics

Symbol	Min. σ (%)
E	
Ion. Cham.	0.5
Si	1
t	0.5
L	0.1
c	Poisson dist.

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Conclusion

- Your input is very welcome!
  - Please email commentary to efmatthews@berkeley.edu
  - A full copy of the FY template can be requested via email.
  - You can find these slides on INDICO
    - https://indico.bnl.gov/event/7233/contributions/43613/

- Thank you to those that have contributed thus far!
  - Bruce Pierson (PNNL), Fredrik Tovesson (ANL), Dana Duke (LANL), Boris Pritychenko (BNL), Denise Neudecker (LANL), Amanda Lewis (NNL), Lee Bernstein (LBNL/UCB)