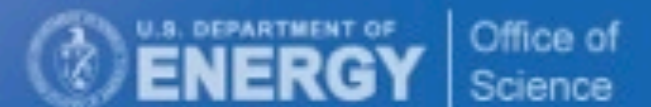


# ENDF Project Report

*M. Herman for CSEWG*



# Post ENDF/B-VII.1 activities

- ENDF/B-VII.1 validation
- Numerous but minor fixes to VII.1
- Upgrading infrastructure
  - Evaluation methodology (reaction codes, PFNS, inelastic scattering, assimilation)
  - Continuous verification and validation
  - New XML format
  - CIELO

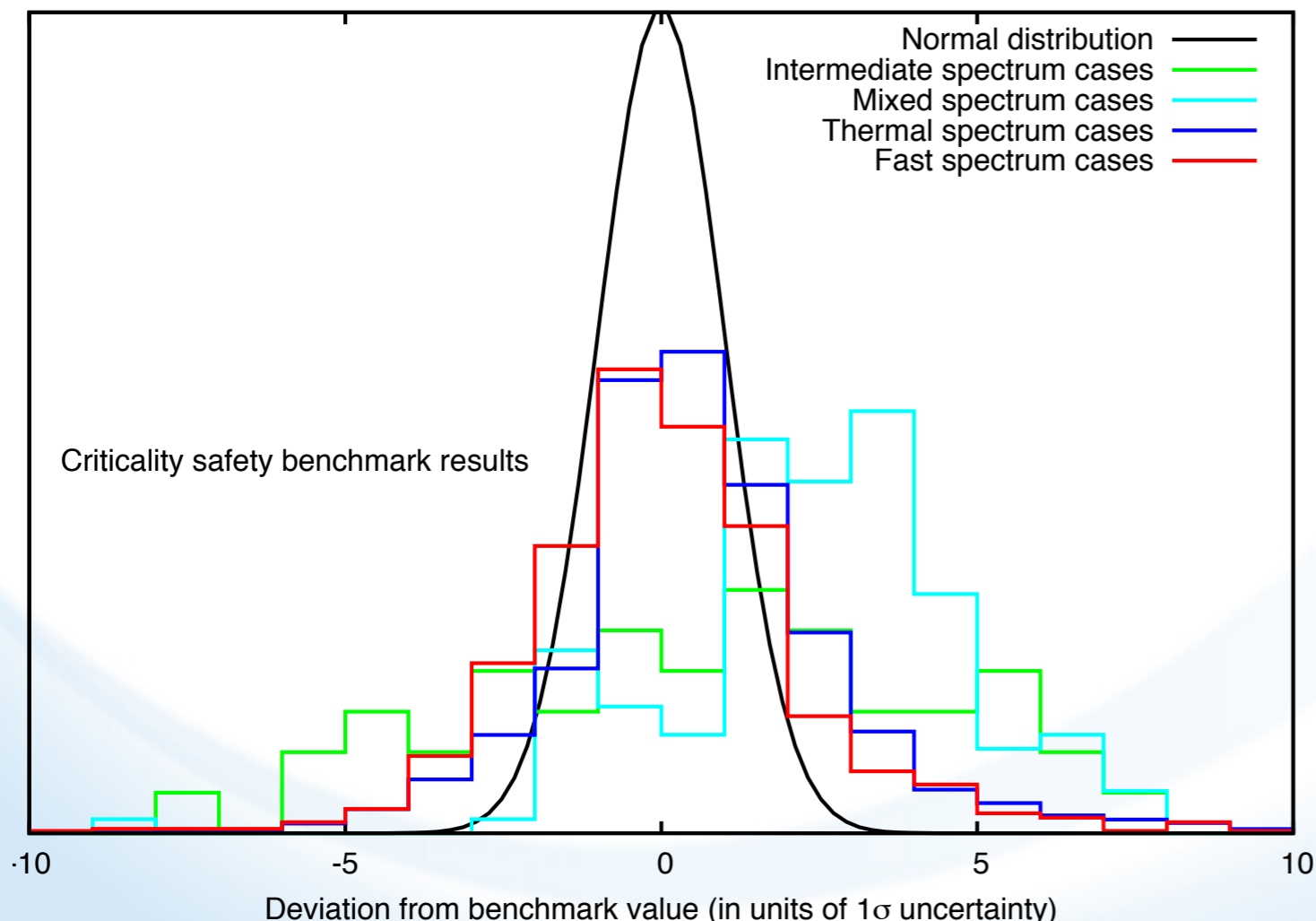
# ENDF/B-VII.1 validation

# Extensive validation by van der Marck

- Over 2000 CS benchmarks (ICSBEP)
- Shielding benchmarks (Oktavian, FNS, Pulsed & Water Spheres)
- Delayed Neutron Data



**Benchmarking ENDF/B-VII.1, JENDL-4.0 and JEFF-3.1.1 with MCNP6**  
Steven C. van der Marck



- Good overall performance of three libraries
- Improvements needed for major actinides, C, Cd, Fe, Zr, Gd
- Intermediate (and mixed) spectrum experiments reproduced poorly by all libraries.

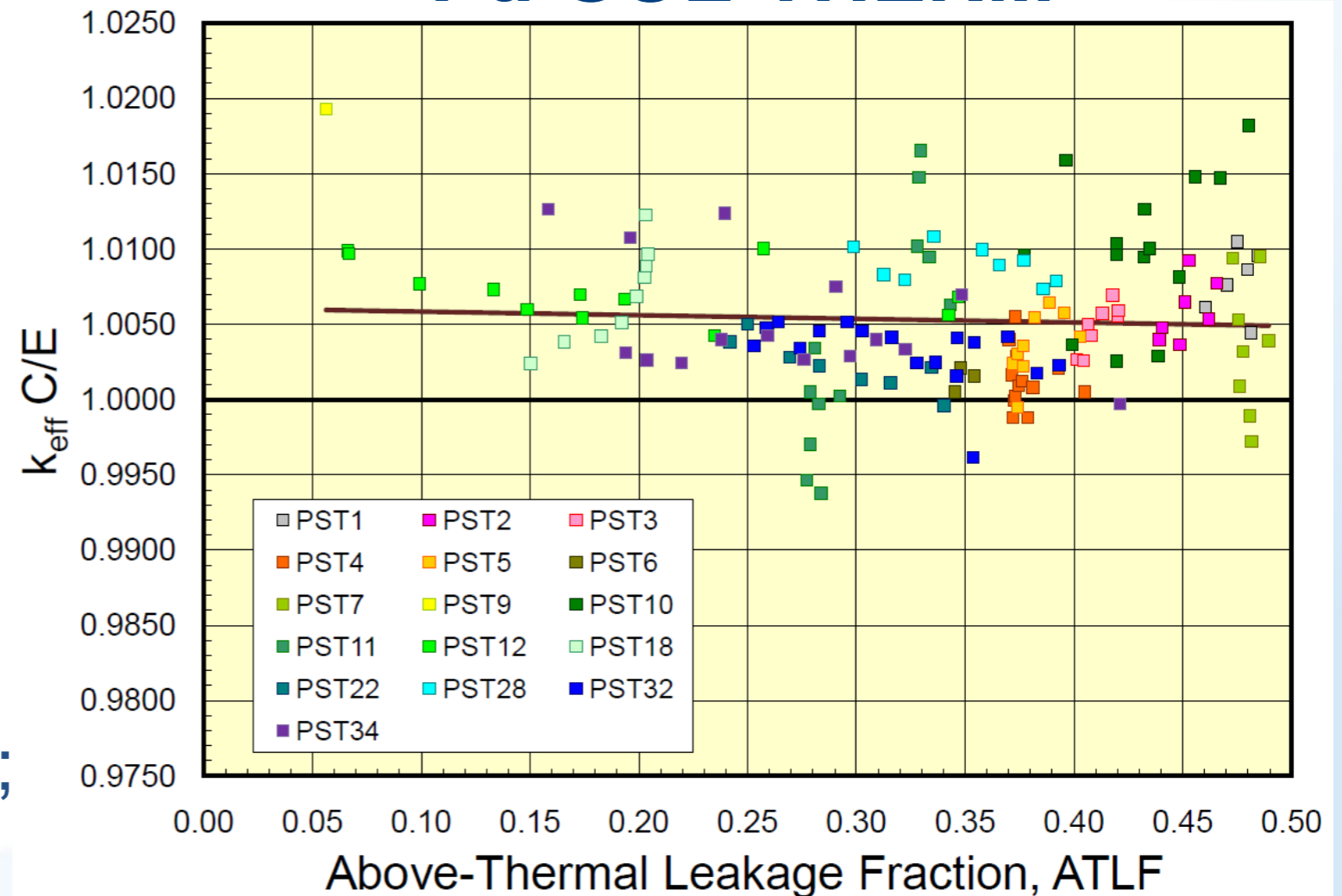
# ENDF/B-VII.1 neutron sublibrary (areas to improve)

**ENDF**  
B-VII.1

*Skip Kahler*  
LANL

- Pu-SOL-THERM;
- Pu-MET-FAST versus Energy;
- HEU-MET-FAST or LEU-COMP-THERM with Pb reflector;
- HEU-MET-FAST with V reflector;
- HEU-MET-FAST with Ni reflector;
- Fast Be reflected systems;
- <sup>233</sup>U Intermediate and Thermal systems;

## Pu-SOL-THERM



# Validation of the ENDF/B-VII Decay Data Sub-library

**ENDF**  
B-VII.1

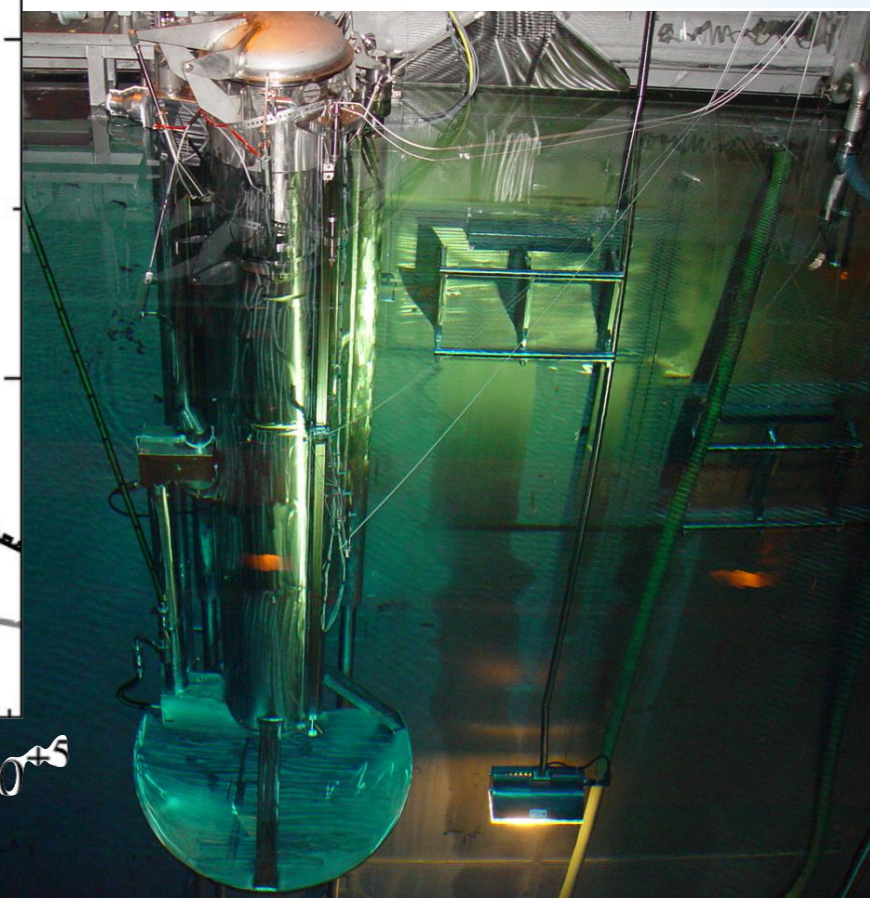
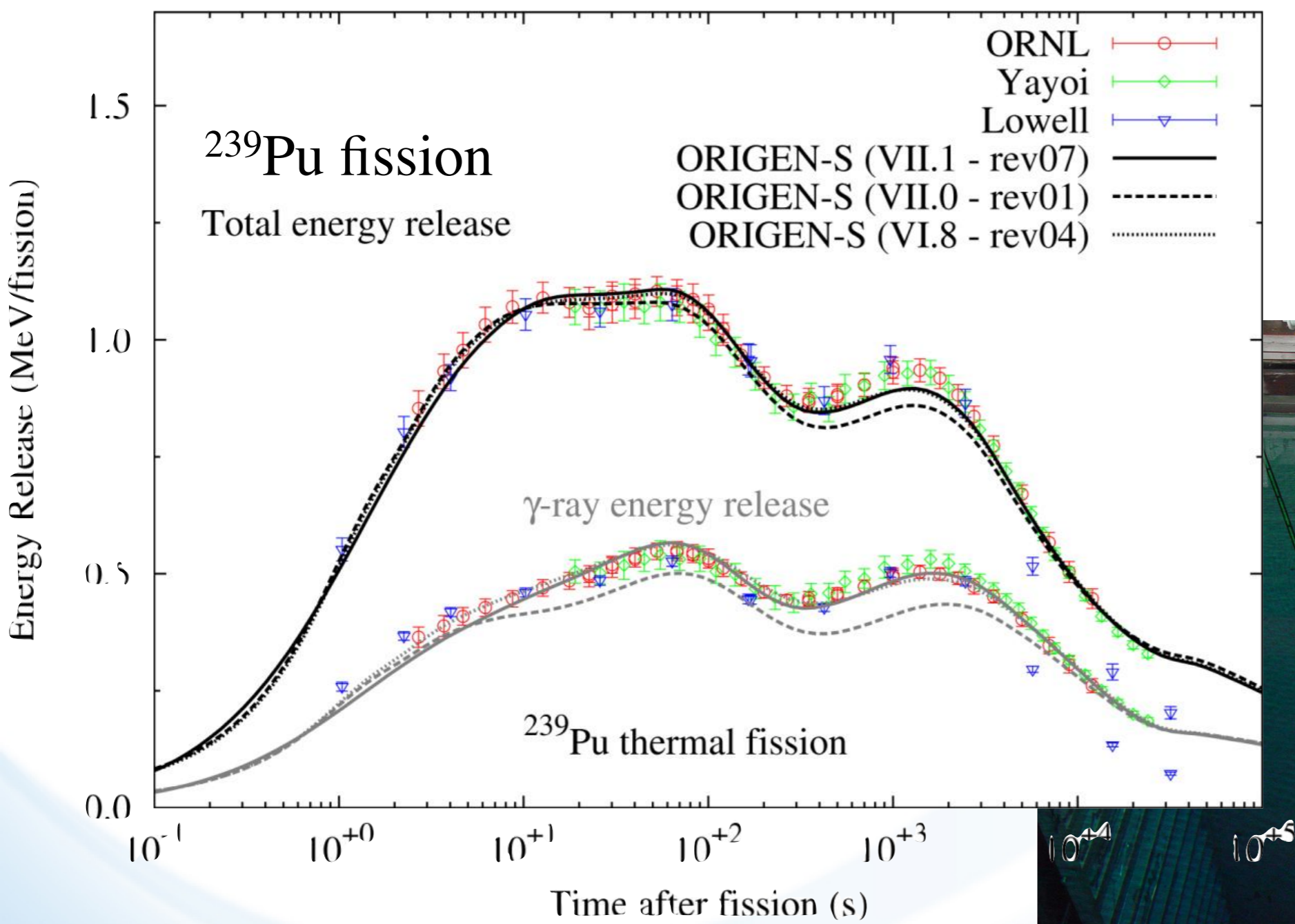
*Jan Gauld*  
ORNL

- Updated decay data in ENDF/B-VII.1
  - New decay modes
  - New gamma data
  - Removal of nuclides with  $T_{1/2} < 1$  ms
  - Additional metastable levels in new evaluations
- Most differences attributed to
  - Removal of errors in ENDF/B-VII.0
  - Missing decay modes in NuDat
  - Continuum evaluations in ENDF/B-VII.1 vs lines
  - Changes in evaluations and in half-lives

# Validation of the ENDF/B-VII Decay Data Sub-library

**ENDF**  
B-VII.1

*Jan Gauld*  
ORNL



# Validation of the ENDF/B-VII Decay Data Sub-library

**ENDF**  
B-VII.1

*Jan Gauld*  
ORNL

- ENDF/B-VII.1 has been fully integrated into ORIGEN
- Experience with ENDF/B-VII.1 decay sublibrary has been **very good** (contrary to VII.0 that should NOT be used)
- Systematic testing of ENDF/B using benchmarks should be extended to include the decay sublibrary – data are widely used and quality is important
- Benchmarks developed by ORNL represent a good starting point for decay sublibrary testing

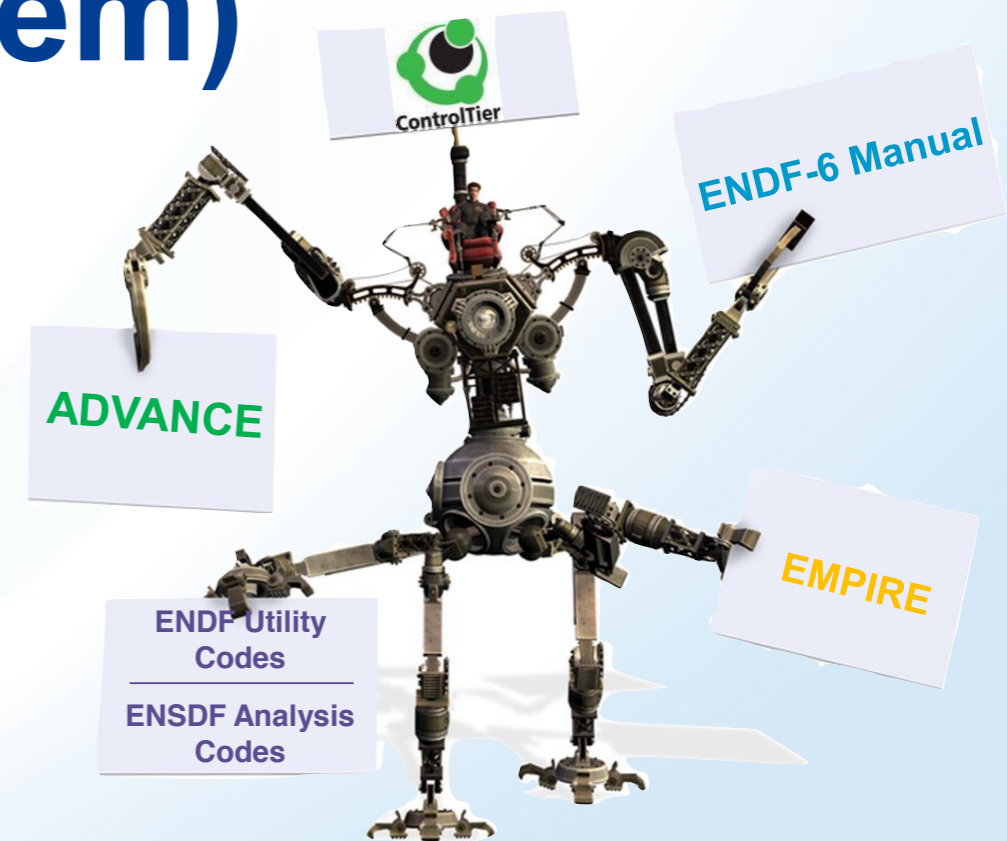
# Closing Observations

**ENDF**  
B-VII.1

*Skip Kahler*  
LANL

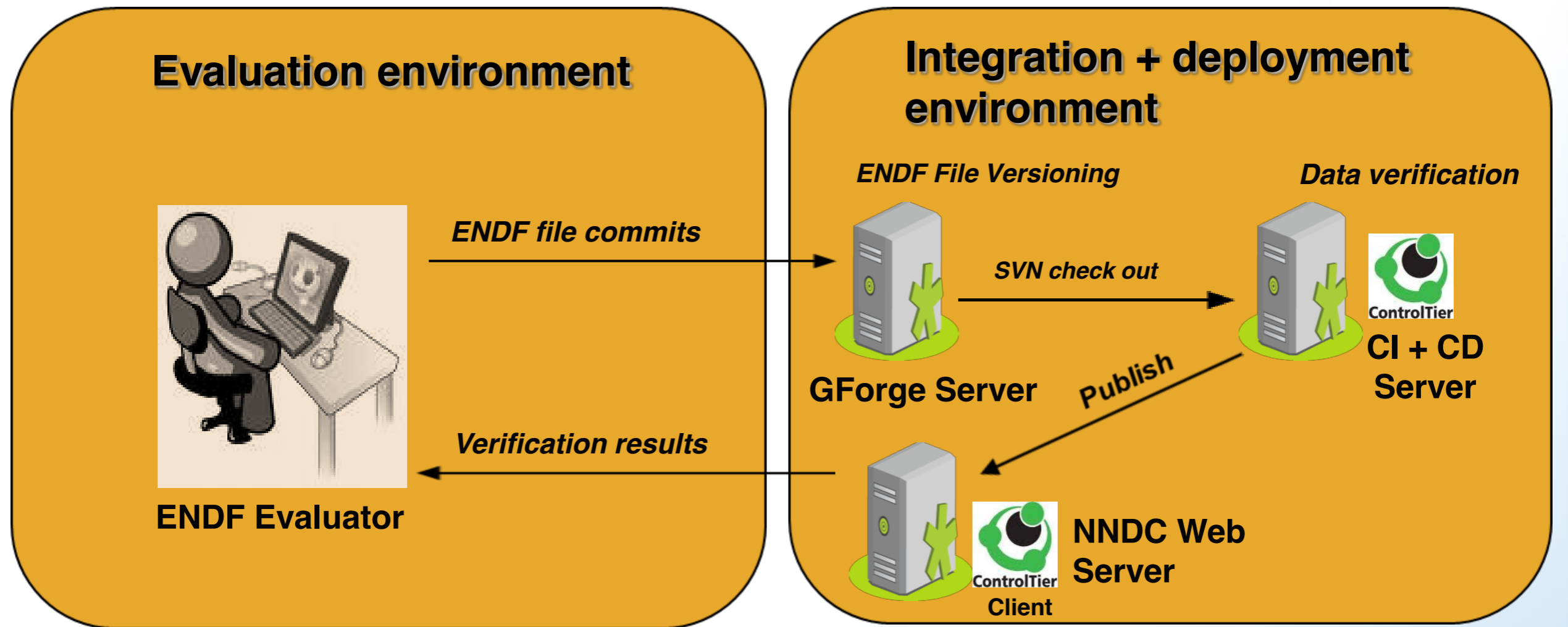
- There are many strengths and success stories associated with ENDF/B-VII.1.
- There are also a number of remaining deficiencies that should guide future efforts as we begin the next upgrade cycle for ENDF/B

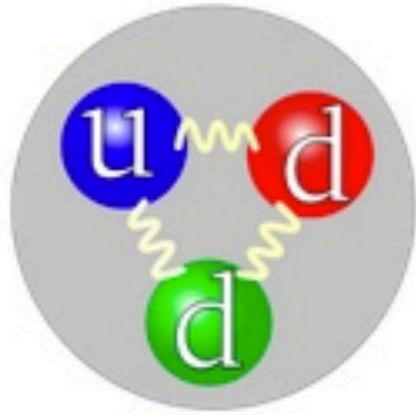
# Continuous verification & validation (ADVANCE system)



# ADVANCE system

Immediate, automated, and digested feedback to evaluators (in future benchmarking)





# Neutrons Sublibrary

## ENDF/B Development Library

- ▶ General Information:
  - ▶ ENDF sublib designator: 10
- ▶ Revision Number: 611M
- ▶ Last Modified Revision: 532:611M
- ▶ Build Status:
  - ▶ Build status: **ERROR**
  - ▶ Build time: 2013-04-30 16:52:01.394282
  - ▶ Listfile: [neutrons.lst](#)
  - ▶ Release Notes: [neutrons-releaseNotes.pdf](#)
- ▶ GForge Links:
  - ▶ Browse [SVN](#)
  - ▶ Browse sublibrary [tracker](#)

### Latest Updates

sublib\_release\_notes: neutrons  
 Report sublib\_release\_notes on neutrons generated. The result was a SUCCESS  
 2013-04-30 16:57:39.661872

evaluation\_summary: n-098\_Cf\_251.endf  
 Code evaluation\_summary completed run on n-098\_Cf\_251.endf. The result was a SUCCESS  
 2013-04-30 16:52:41.503573

sublib\_html: neutrons  
 Report sublib\_html on neutrons generated. The result was a SUCCESS  
 2013-04-30 16:52:01.501892

### Periodic Table

### Material List

1 H								X									2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe

- ▶ Build status: **ERROR**
- ▶ Build time: 2013-04-30 16:52:01.394282
- ▶ Listfile: [neutrons.lst](#)
- ▶ Release Notes: [neutrons-releaseNotes.pdf](#)

Report sublib\_html on neutrons generated. The result was a SUCCESS  
2013-04-30 16:52:01.501892

▶ GForge Links:

- ▶ Browse [SVN](#)

Pu									
Status	Material	MAT #	Revision #	# Tests	# Failures	# Errors	Lab.	Date	Authors
<input type="checkbox"/>	<sup>236</sup> Pu	9428	603	756	0	44	JAEA+	FEB10	O.Iwamoto, T.Nakagawa, et al.
<input type="checkbox"/>	<sup>237</sup> Pu	9431	603	1398	0	136	JAEA+	FEB10	O.Iwamoto, T.Nakagawa, et al.
<input type="checkbox"/>	<sup>238</sup> Pu	9434	597	1004	0	180	LANL	SEP10	YOUNG, TALOU, KAWANO, KAHLER, CHADWIC
<input type="checkbox"/>	<sup>239</sup> Pu	9437	591	1508	0	68	LANL	SEP06	Young, Chadwick, MacFarlane, Derrien
<input type="checkbox"/>	<sup>240</sup> Pu	9440	532	1298	0	216	LANL	SEP09	YOUNG, TALOU, CHADWICK, KAHLER, KAWAN
<input type="checkbox"/>	<sup>241</sup> Pu	9443	532	924	0	10	ORNL	OCT03	L.Weston, R.Wright, H.Derrien , et al.
<input type="checkbox"/>	<sup>242</sup> Pu	9446	603	1268	0	108	BNL+JAEA	AUG11	S.F. MUGHABGHAB , et al. O.Iwamoto, etal
<input type="checkbox"/>	<sup>243</sup> Pu	9449	597	536	0	24	SRL,LLNL	JUL76	Benjamin, McCrosson, Howerton
<input type="checkbox"/>	<sup>244</sup> Pu	9452	603	846	0	60	JAEA+	FEB10	O.Iwamoto, T.Nakagawa, , et al.
<input type="checkbox"/>	<sup>246</sup> Pu	9458	603	850	0	60	JAEA+	FEB10	O.Iwamoto, T.Nakagawa, et al.

* <u>Lanthanides</u> (Lanthanoids)	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
** <u>Actinides</u> (Actinoids)	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

2 He
10 Ne
18 Ar
36 Kr
54 Xe
86 Rn
118 Uuo

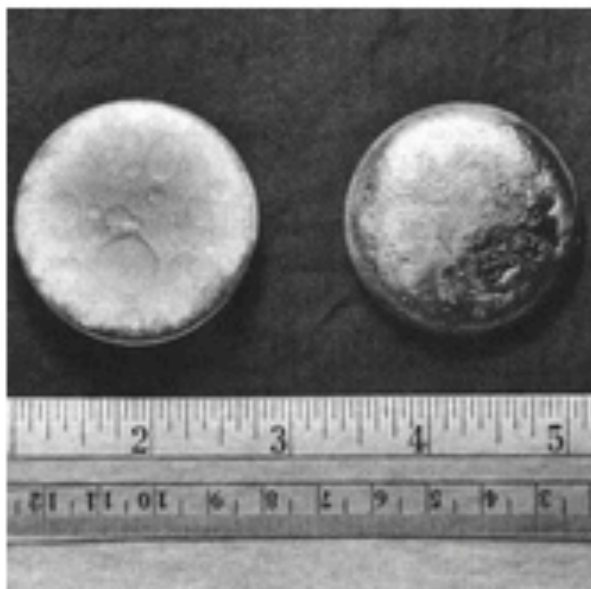


Image of plutonium from <http://images-of-elements.com/>

**239**  
**Pu**

## Neutrons Sublibrary

- ▶ General Information:
  - ▶ ENDF MAT designator: 9437
  - ▶ Evaluated by Young, Chadwick, MacFarlane, Derrien (LANL), SEP06
  - ▶ Natural abundance: 0.0 +/- 0.0 %
  - ▶ Check out Wikipedia's entry for [plutonium](#)
- ▶ Revision Number: 611M
- ▶ Last Modified Revision: 532:611M
- ▶ Build Status:
  - ▶ Build status: **ERROR** ([Submit tracker item](#))
  - ▶ Build time: 2013-04-30 06:17:38.108808
- ▶ GForge Links:
  - ▶ Browse [SVN](#)
  - ▶ View current [revision](#)
  - ▶ Download current [revision](#)

### Latest Updates

evaluation\_summary: n-094\_Pu\_239.endf  
Code evaluation\_summary completed run on n-094\_Pu\_239.endf. The result was a SUCCESS  
2013-04-30 06:17:39.392055

njoy2012: n-094\_Pu\_239.endf  
Code njoy2012 completed run on n-094\_Pu\_239.endf. The result was a ERROR  
2013-04-30 06:17:36.872836

inter: n-094\_Pu\_239.endf  
Code inter completed run on n-094\_Pu\_239.endf. The result was a SUCCESS  
2013-04-30 06:10:24.995505

**Code Results**

ENDF Overview

ACE Overview

Integral Quantities

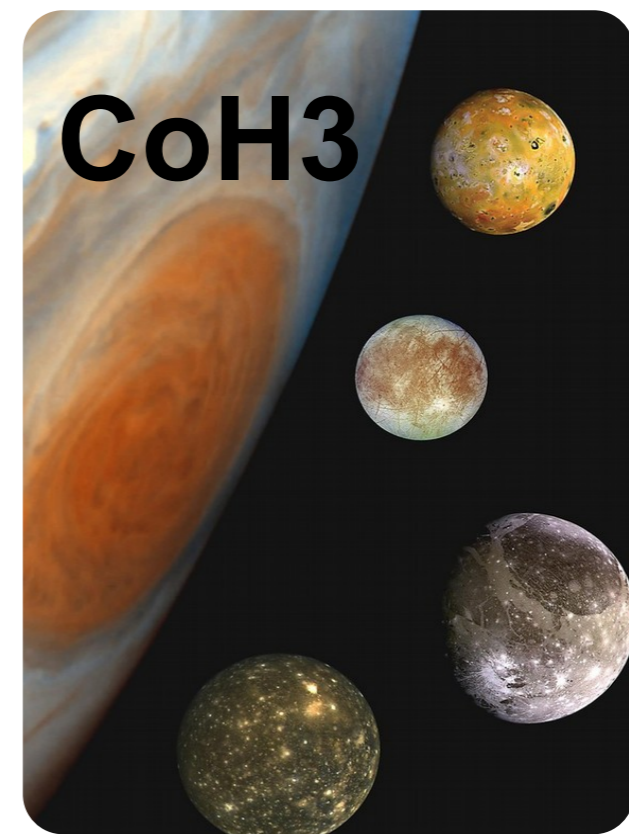
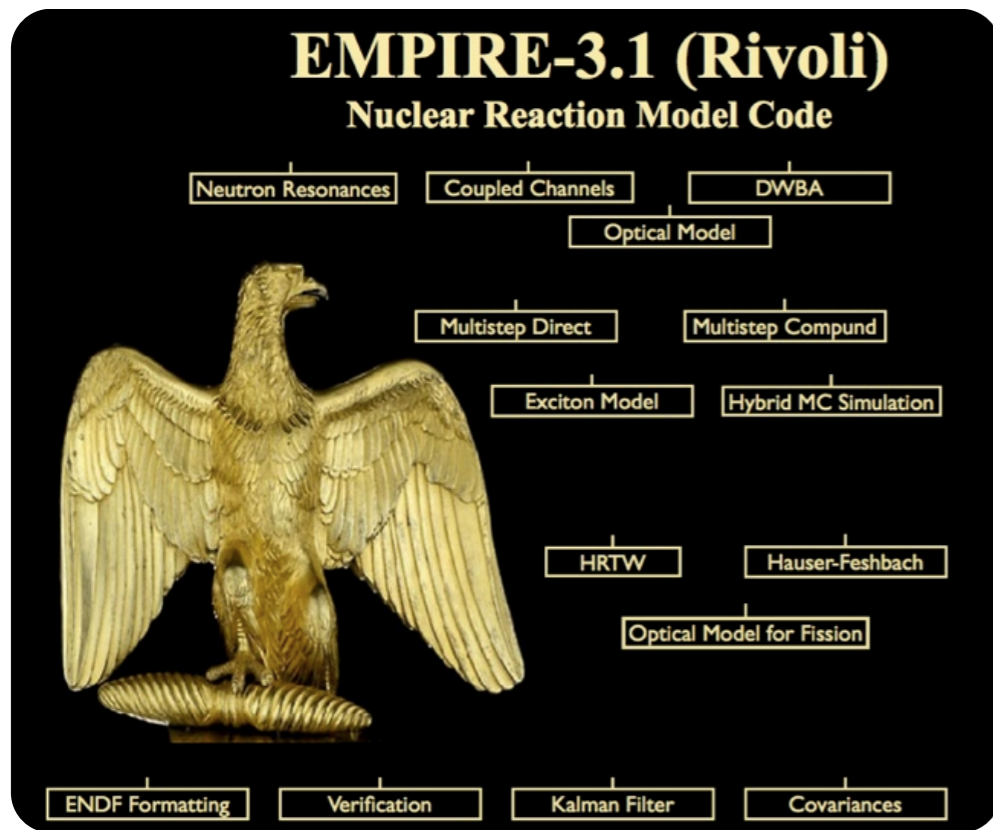
Cross Section Plots

## Summary of all tests on this evaluation.

Use checking code button to show/hide errors.

Status	Code	# Tests	# Failures	# Errors	Run time (sec)	Files
<input checked="" type="checkbox"/>	STAN	0	0	0	31.533	<a href="#">STN File</a>
<input checked="" type="checkbox"/>	STANEF	0	0	0	29.316	

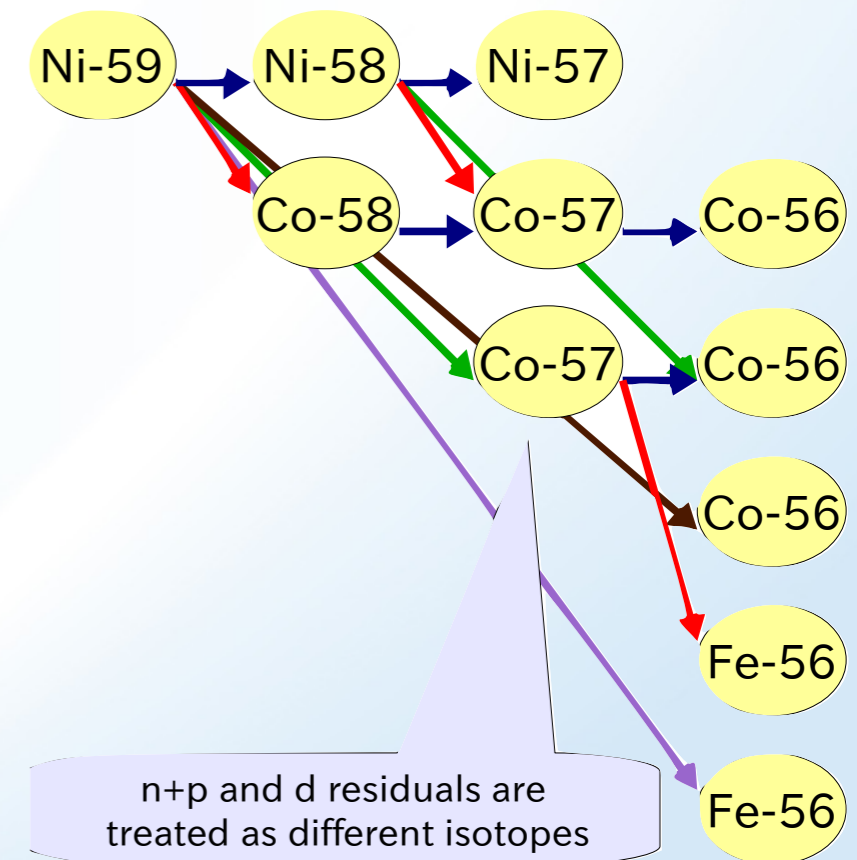
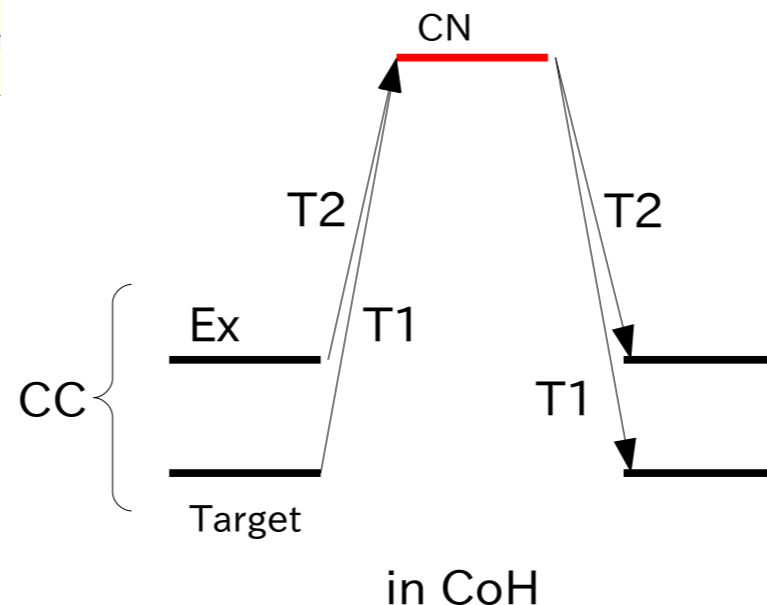
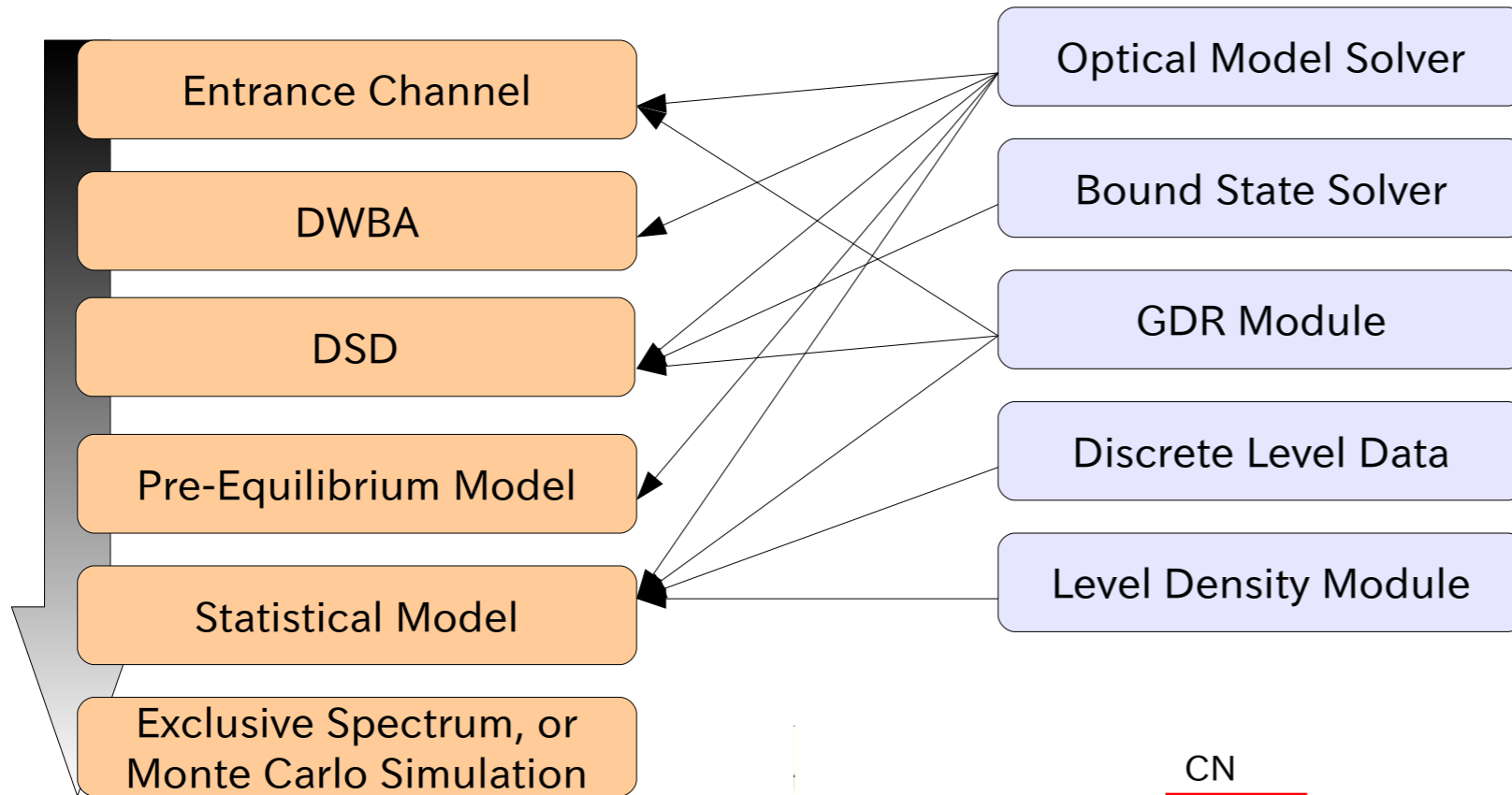




# Reaction Modeling Codes

# CoH3 - ver.3.2 Umbriel (released 10/2012)

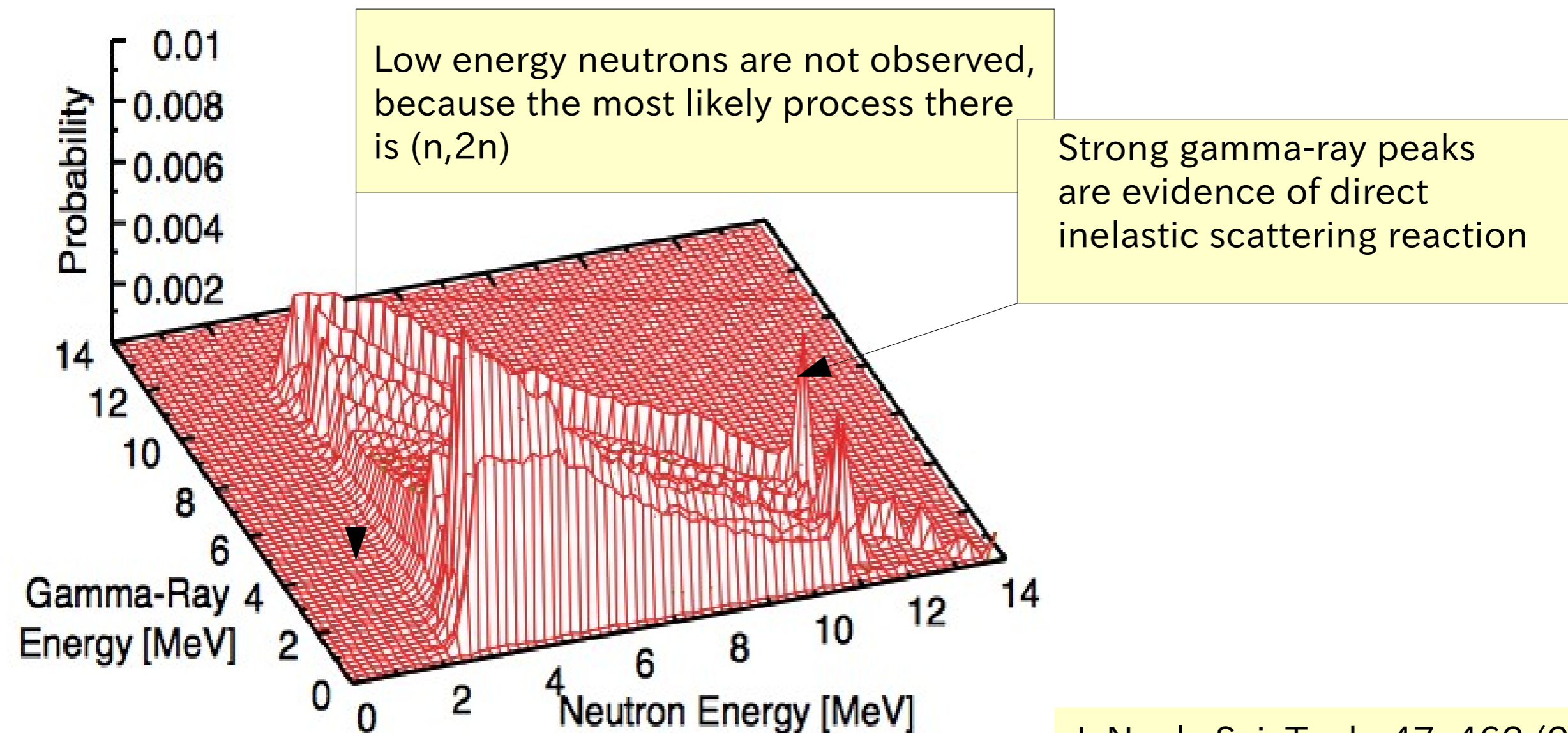
*Toshihiko Kawano*  
LANL



# Monte Carlo with CoH, N-G Correlation in (n,n') Reaction

*Toshihiko Kawano*  
LANL

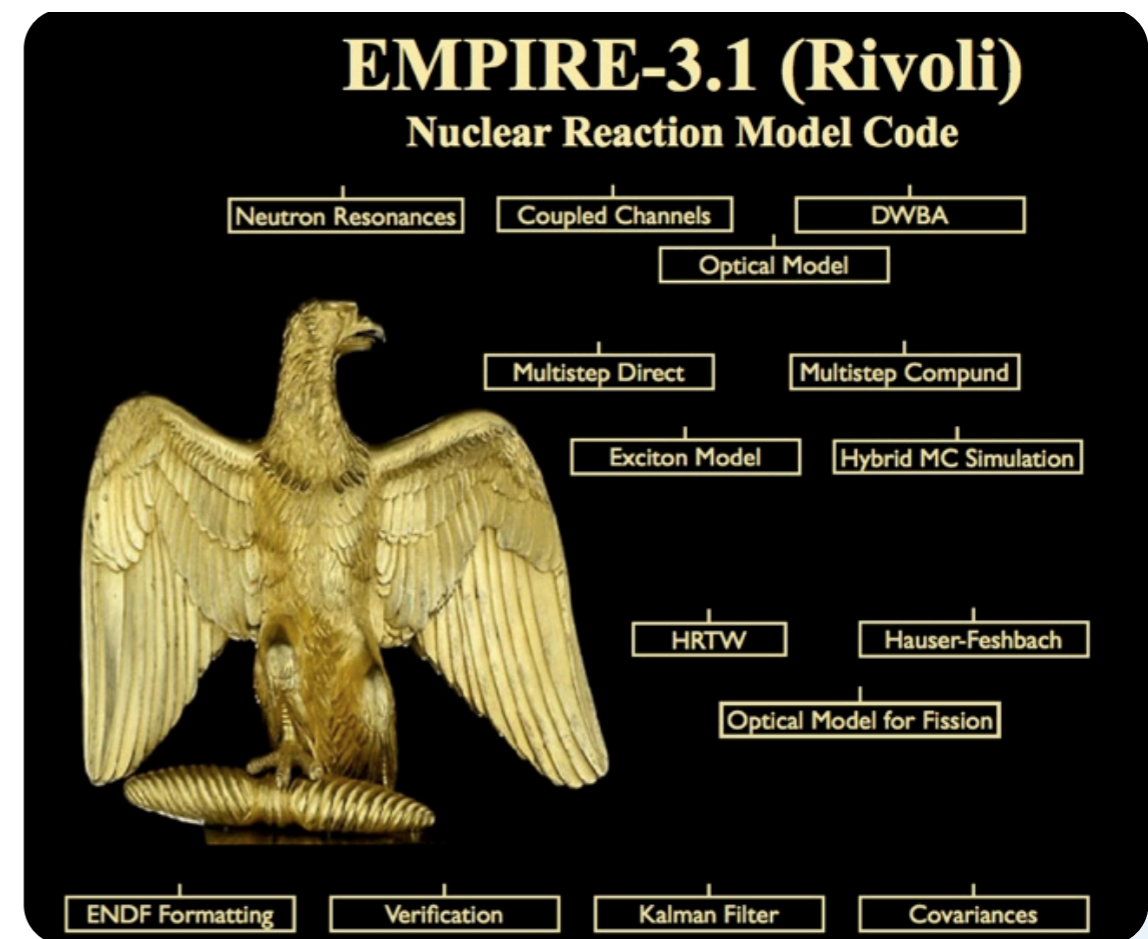
Joint probability of neutron and gamma energies for V-51 + n at 14 MeV (n,n') reaction



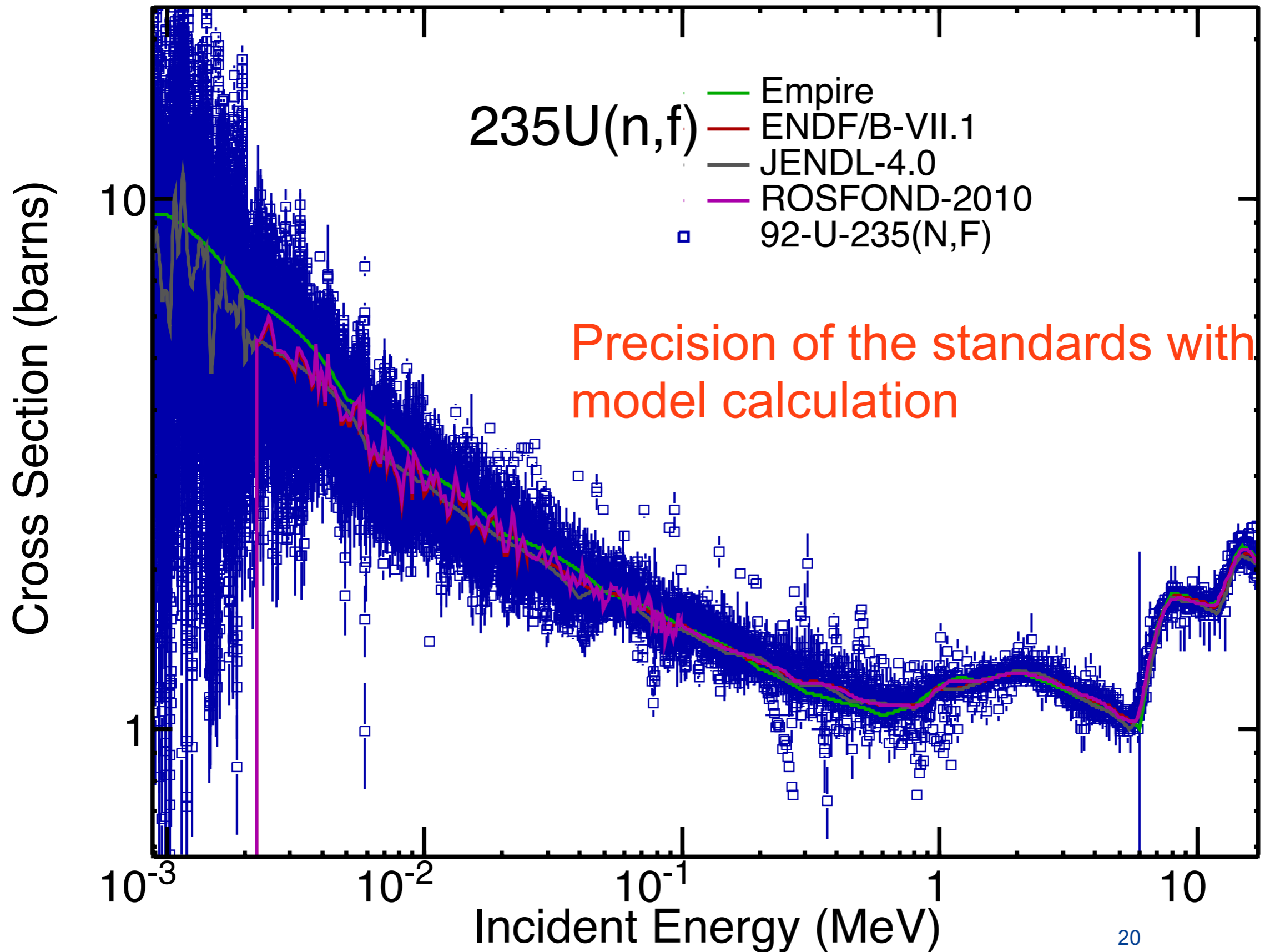
J. Nucl. Sci. Tech. 47, 462 (2010)

# EMPIRE-3; major post-Rivoli changes (on the way to Alexandria; ~1000 commits)

- PFNS implemented, Los Alamos and Kornilov (1<sup>st</sup> chance fission)
- Covariances for PFNS, mu-bars, and nu-bars
- Angular distributions for compound elastic and inelastics
- Engelbrecht-Weidenmueller transformation (scaling compound inelastic)
- Plotting of PFNS, mu-bars, and nu-bars
- ADVANCE - continuous built, benchmarking, and posting
- Improved makefiles
- New IO subroutines for ENDF-6



# Adjusted EMPIRE-3.1 calculations



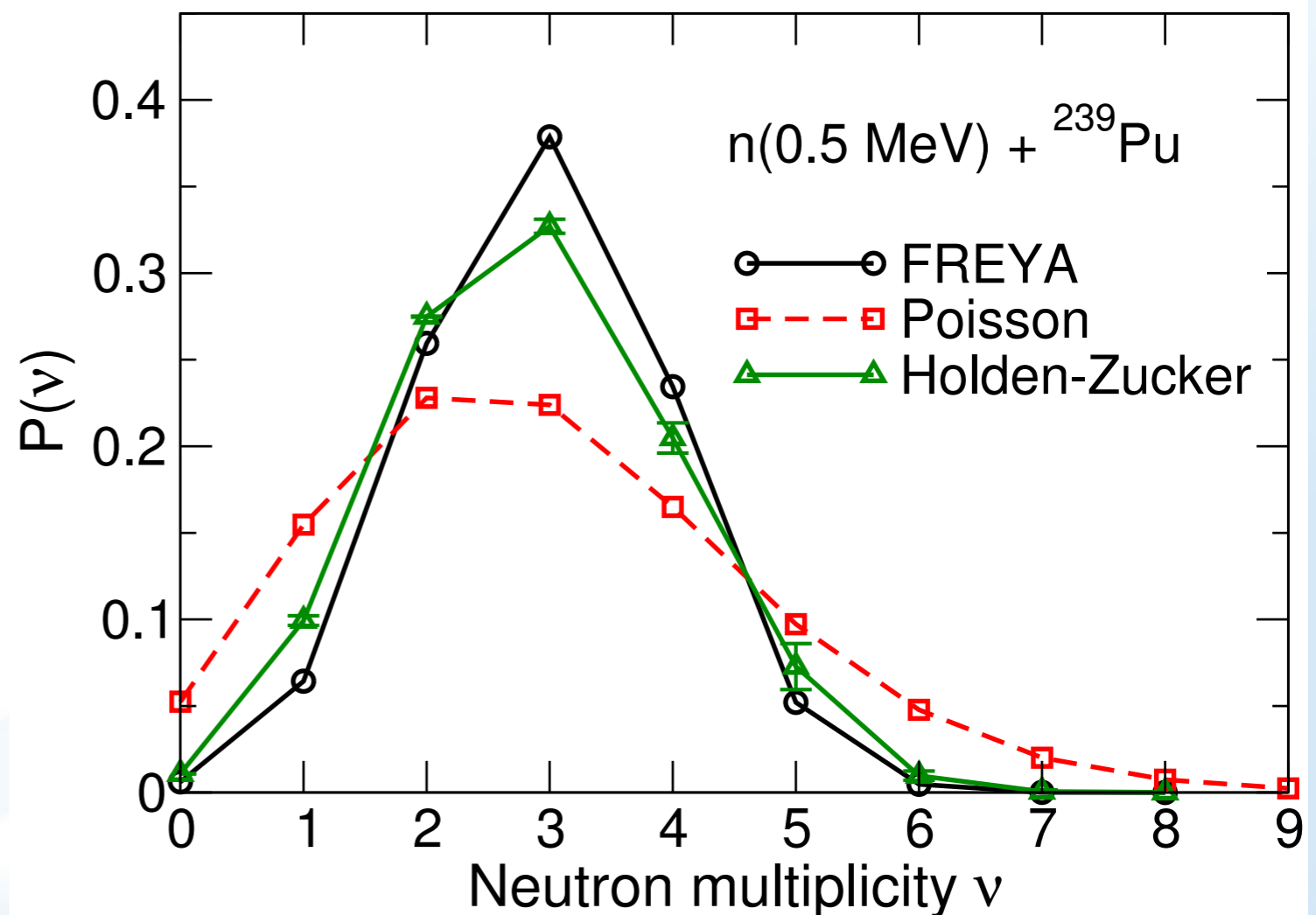
# Current version of EMPIRE is capable of treating actinides

- Improved level densities
- PFNS calculations with fitting experimental data and covariances
- Improved defaults - reproduce half of the 30 calculated fission cross sections within 20-30%
- Adjusted calculations can reproduce standards within  $\sim 2\%$  **without energy dependent tuning!**

# Prompt Fission Neutron Spectra (PFNS)

# Event-by-event fission modeling of prompt neutrons and photons with FREYA

- Efficient framework for incorporating fluctuations and correlations!
- Significant correlations between neutrons
- FREYA agrees rather well with most neutron observables
- Gammas included but need refinements

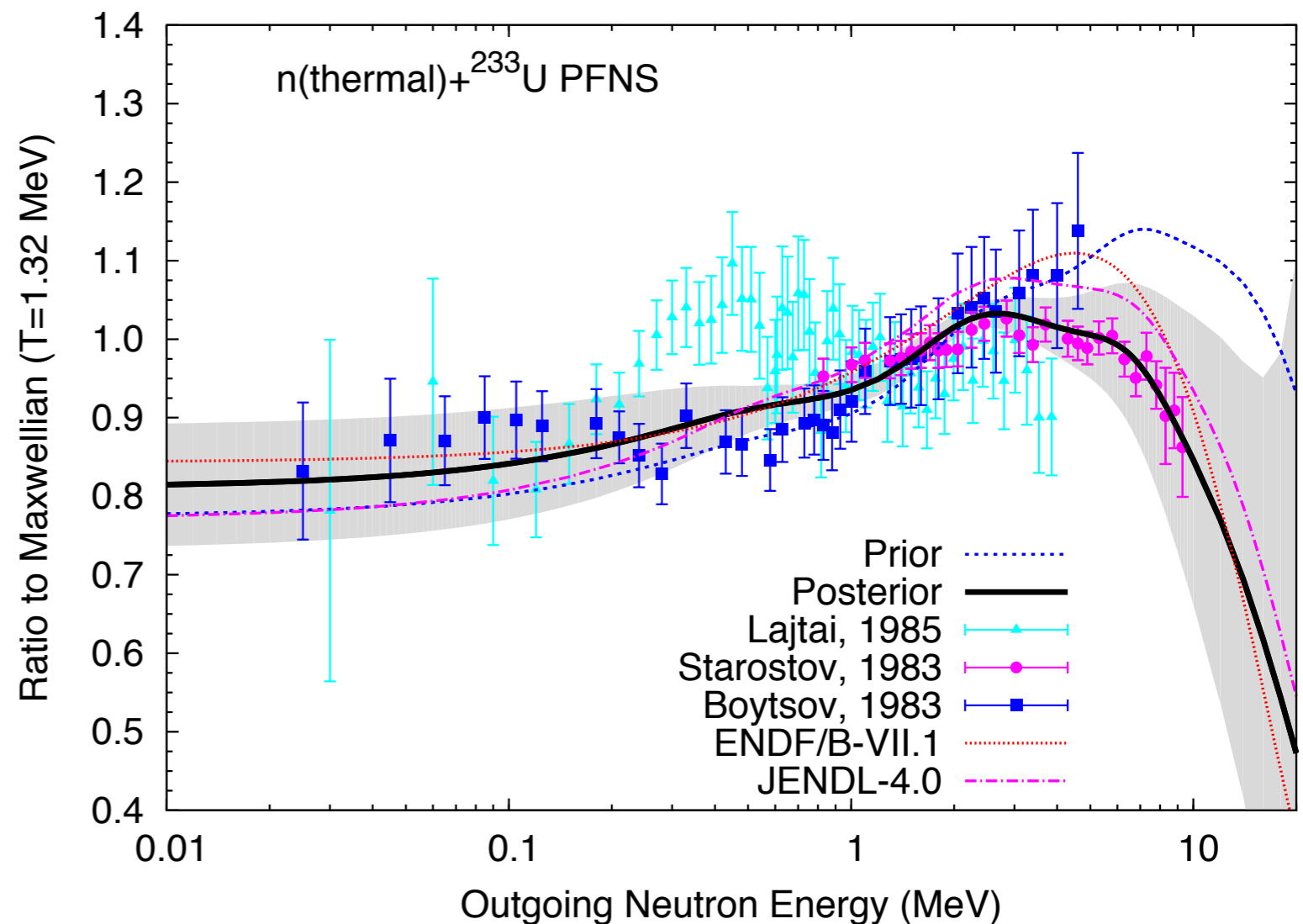


*Ramona Vogt*  
LLNL

# Extension of Los Alamos model (fragment asymmetry and covariances)

*Michael Rising*  
LANL

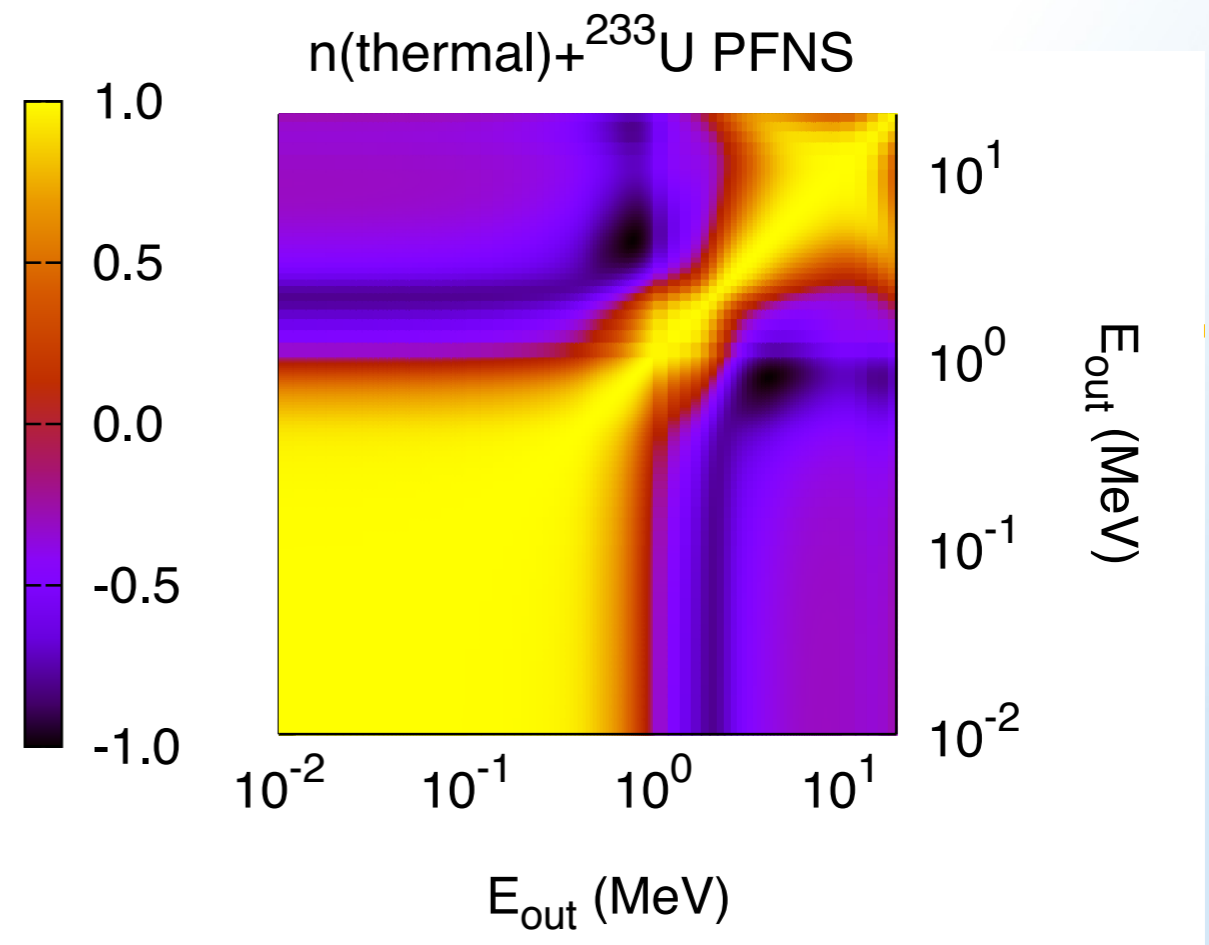
- PFNS for  $n+^{229-238}\text{U}$  and  $n+^{235-242}\text{Pu}$  systematically evaluated using differential experimental data and the Los Alamos model.
- Model extended to account for fragment mass asymmetry.



# Extension of Los Alamos model (fragment asymmetry and covariances)

*Michael Rising*  
LANL

- Model parameters constrained by experimental data using Kalman filter (or UMC).
- Covariances produced by propagating model parameters' covariances resulting from KALMAN fitting

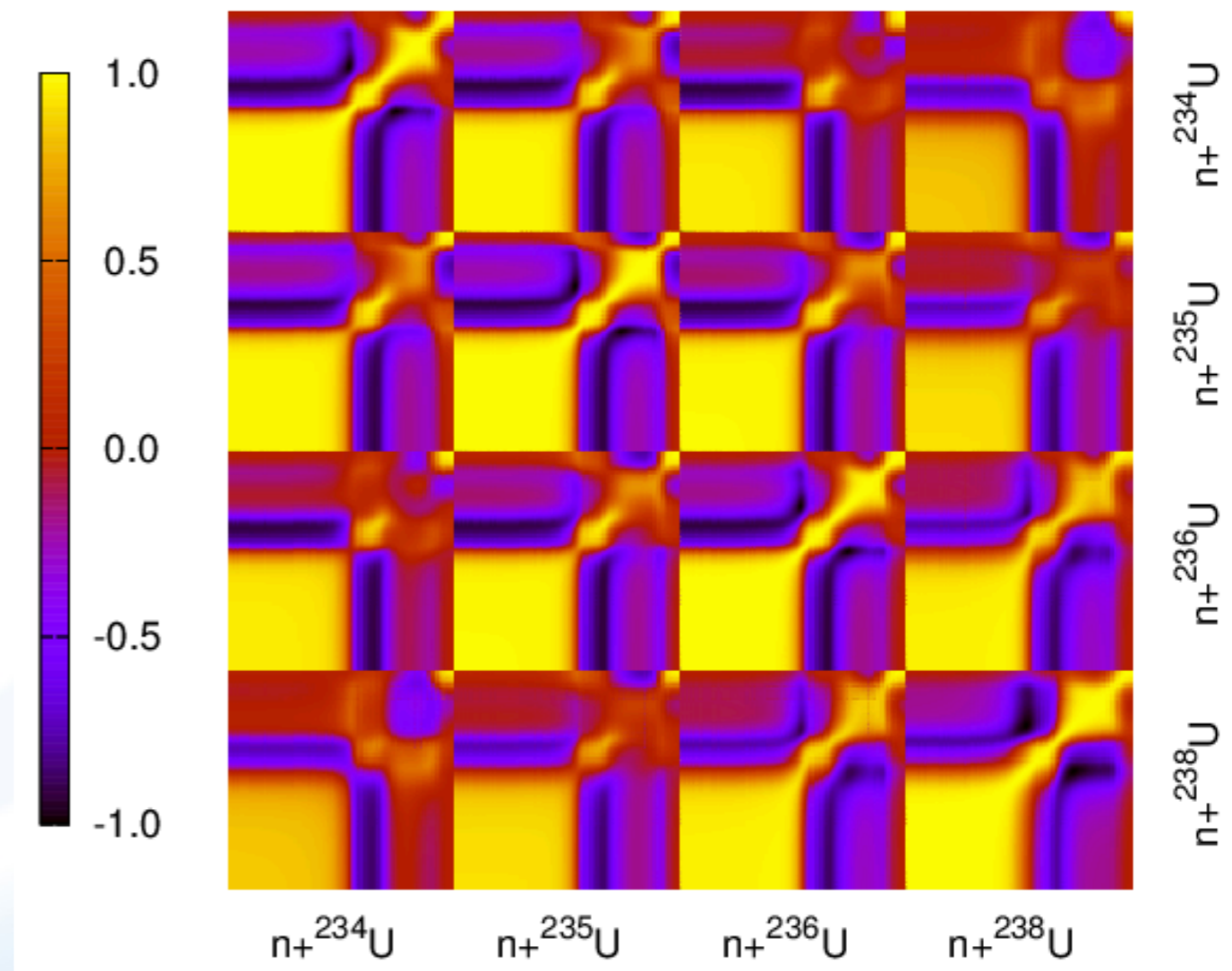


# Extension of Los Alamos model (fragment asymmetry and covariances)

*Michael Rising*  
LANL

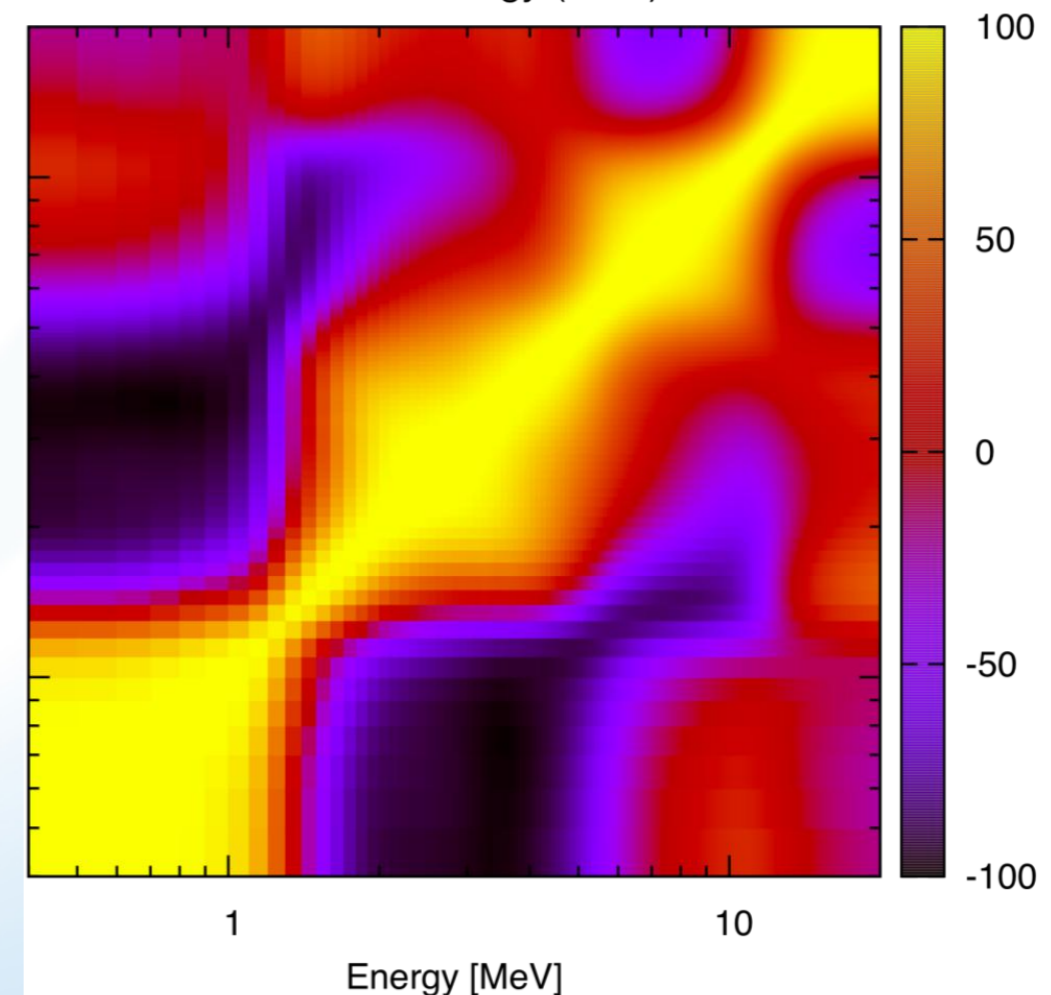
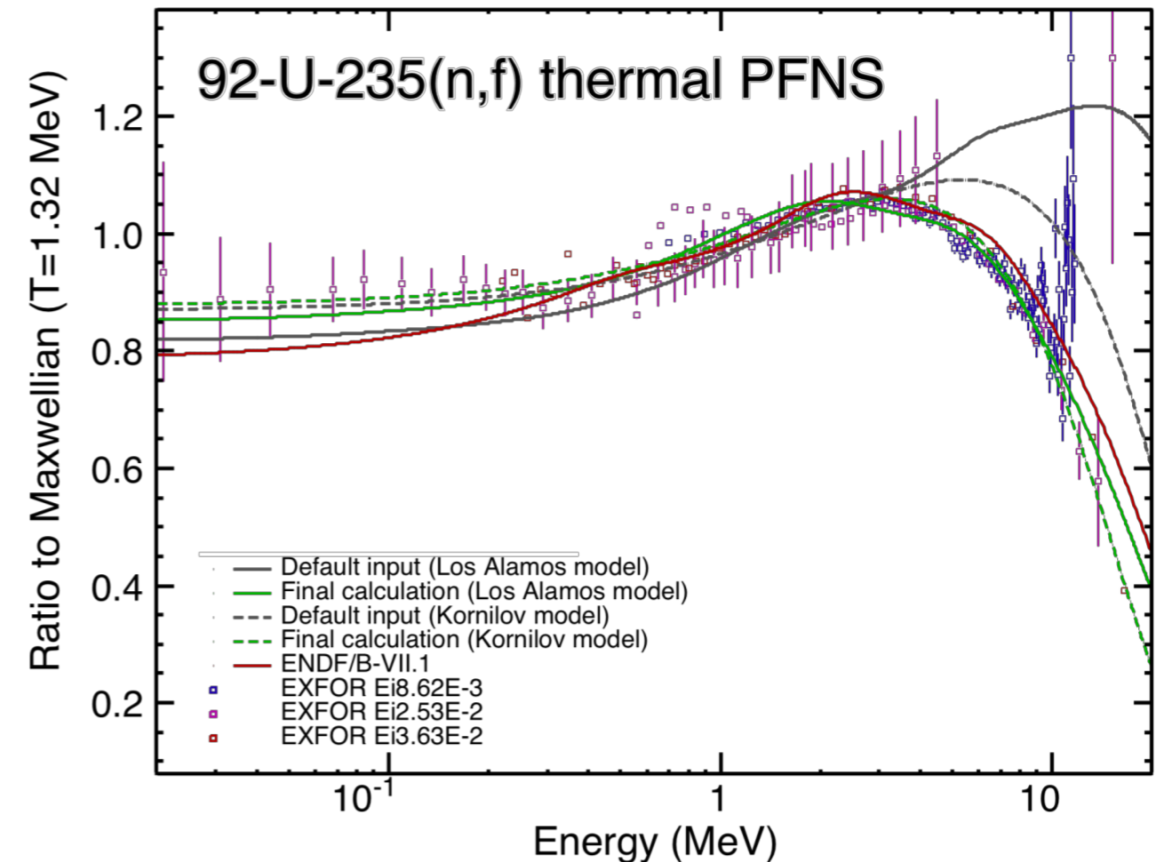
- Correlations between isotopes of each actinide result from the model parameter correlations.
- Results to be submitted to ENDF/B.

Correlated PFNS



# PFNS in EMPIRE

- Los Alamos and Kornilov models (1<sup>st</sup> chance fission)
- Both models adjustable with KALMAN filter
- PFNS covariances uncorrelated with cross section covariances
- PFNS covar. used in assimilation => correlation between PFNS and cross sections



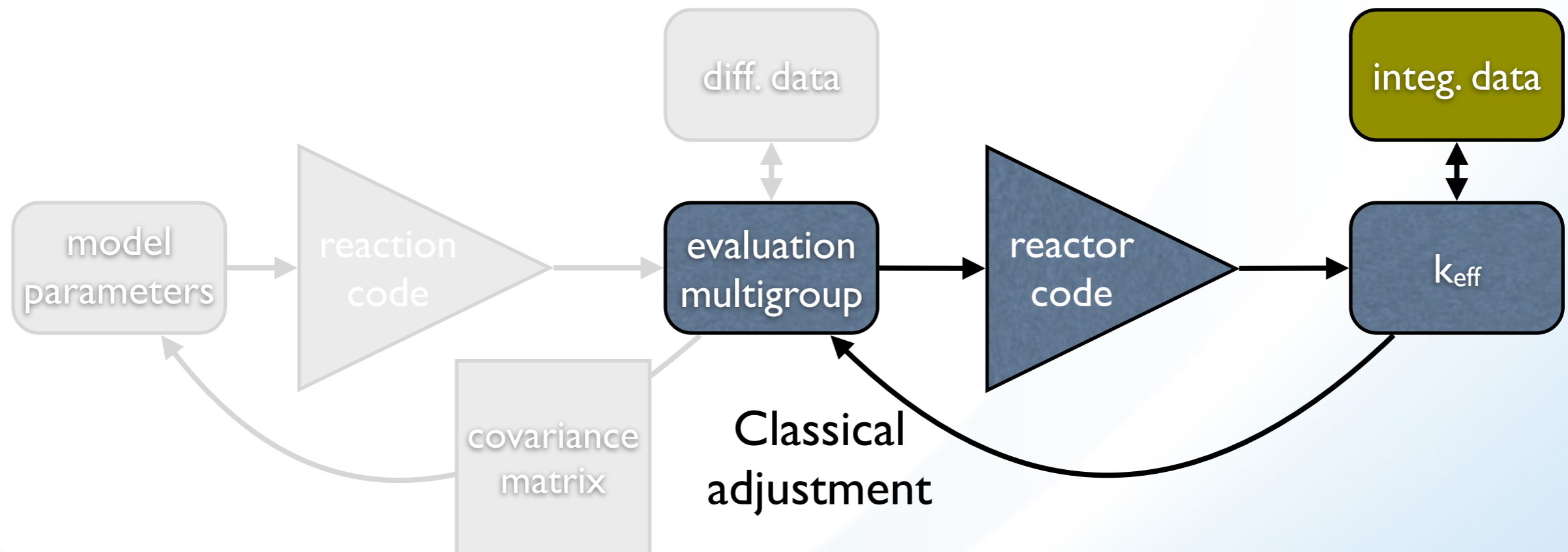
# Consistent adjustment (assimilation)

# Consistent adjustment (assimilation)

linking reaction theory and integral experiments

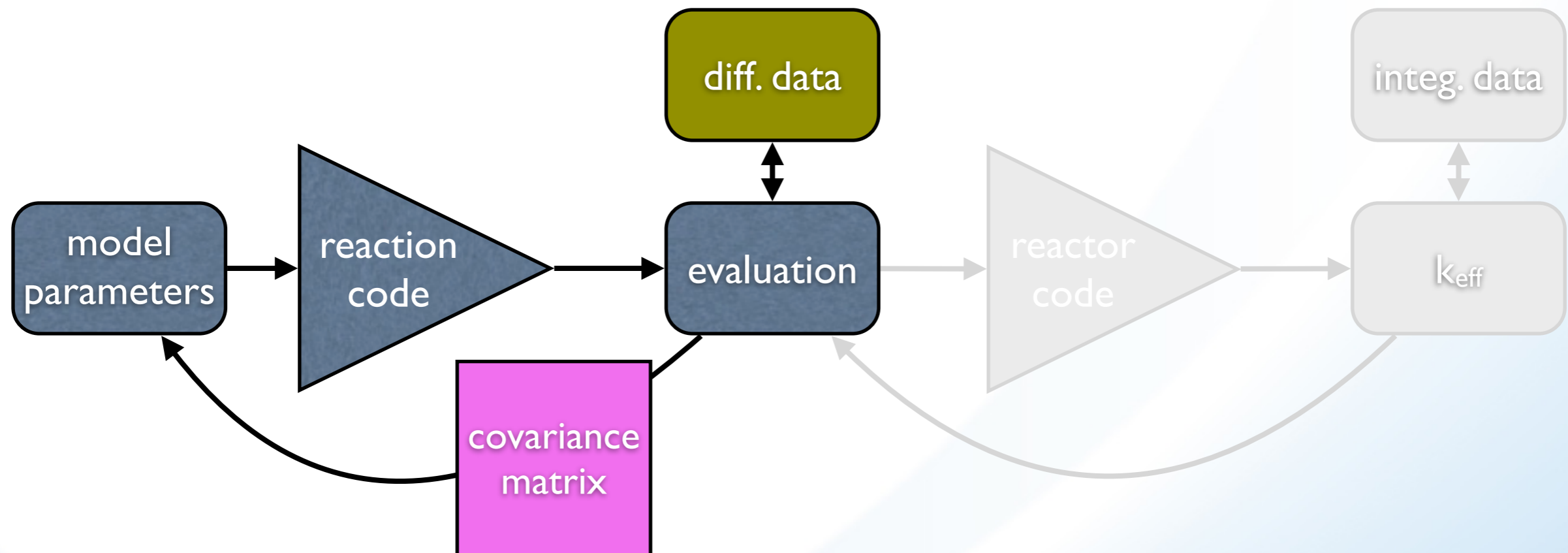
INL + BNL

- Users often tune multi-group evaluated files to a certain type of integral experiments
- Such adjusted file is only valid for a specific application



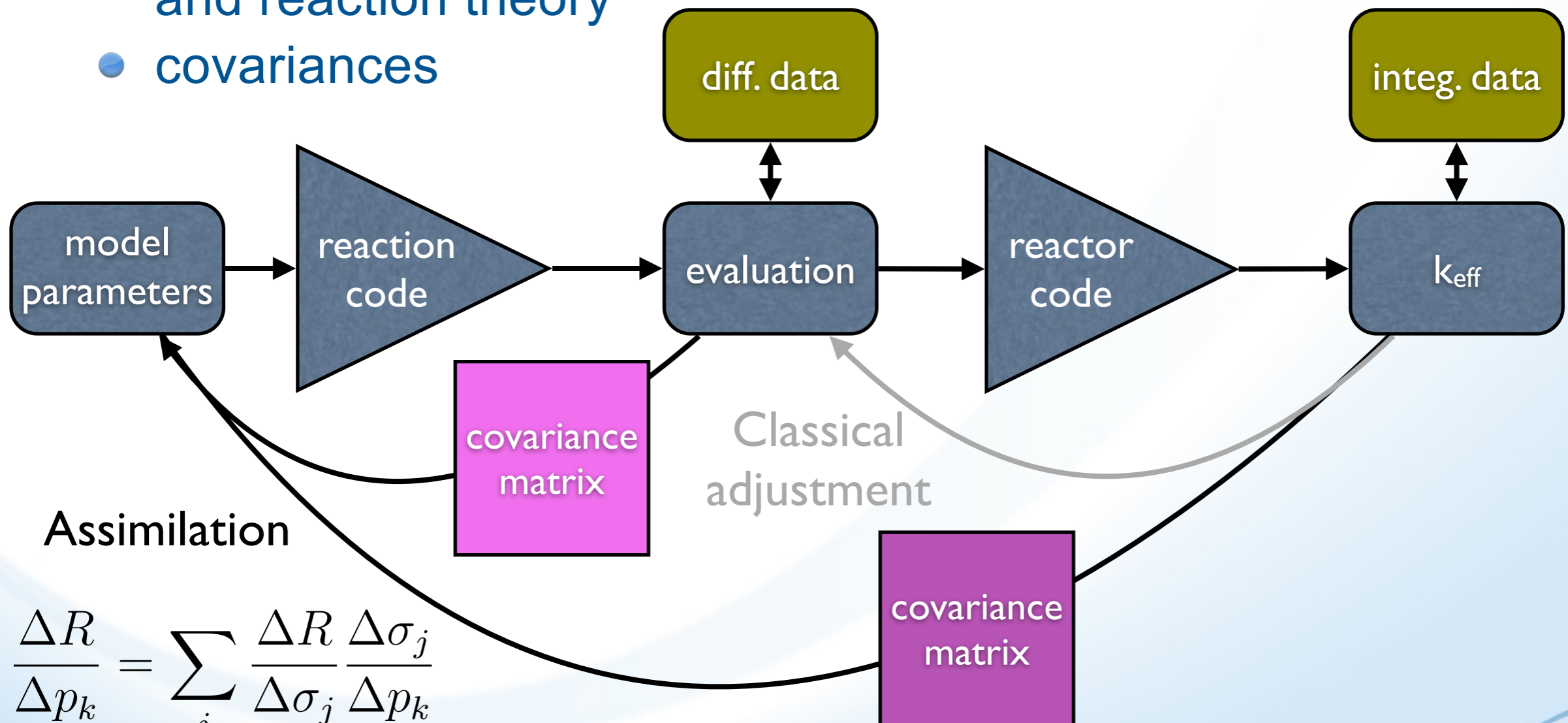
# Consistent adjustment (assimilation) linking reaction theory and integral experiments

- Modern practice is to use nuclear reaction code constrained by experimental data to produce evaluation and covariances



# Consistent adjustment (assimilation) linking reaction theory and integral experiments

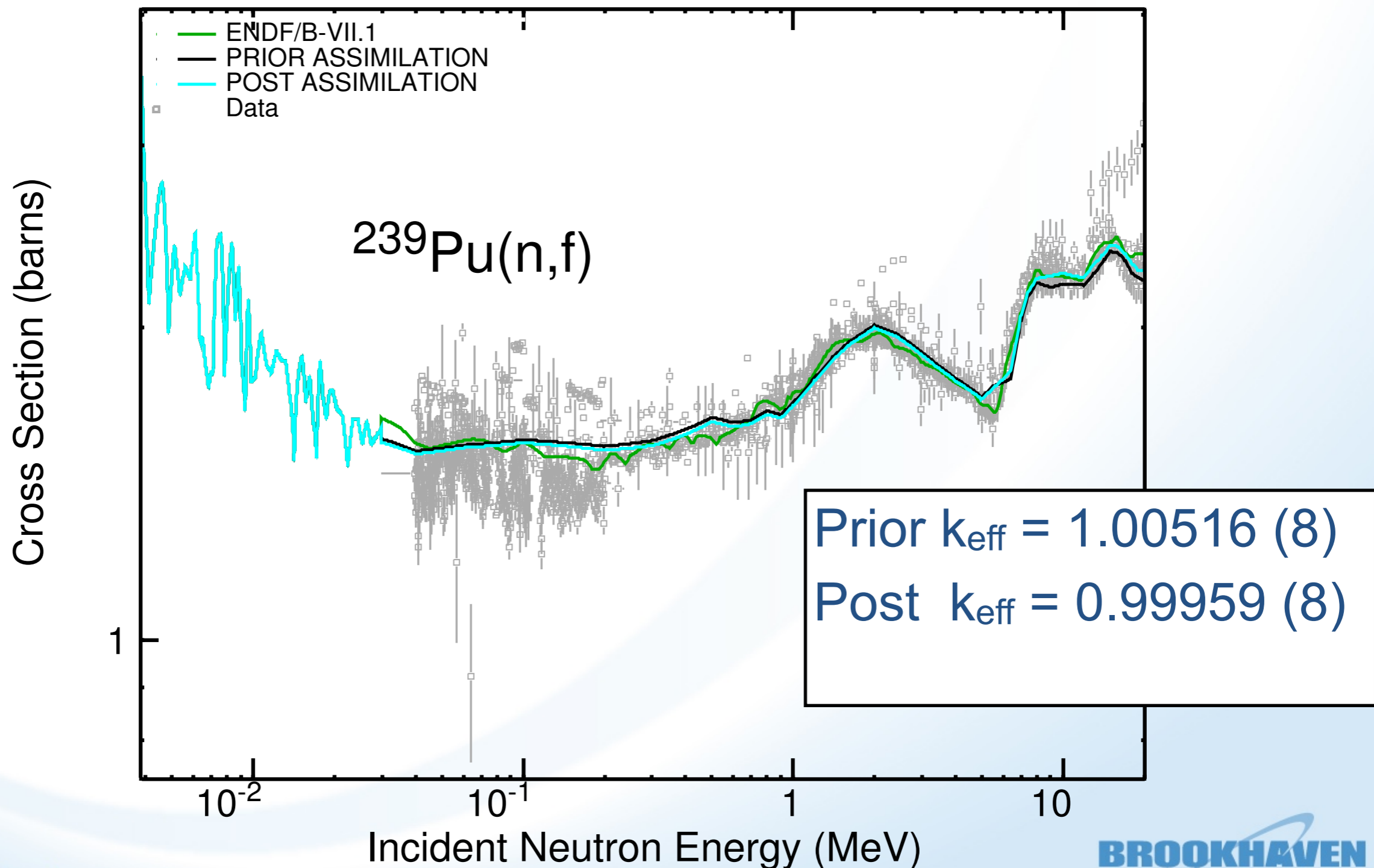
- Tuning is moved from multi-group file to reaction model parameters providing
  - evaluation constrained by differential and integral data and reaction theory
  - covariances



# Assimilation for $^{239}\text{Pu}$ (2<sup>nd</sup> round)

- EMPIRE-3.1 with improved fission parametrization (M. Sin)
- Overall very good prior
- EMPIRE calculated PFNS included in assimilation
- Direct assimilation on JEZEBEL's  $k_{\text{eff}}$  using MCNP.

# $^{239}\text{Pu}$ assimilated fission



# $^{239}\text{Pu}$ - assimilated parameters

Parameter Name	pre-assimilation	post-assimilation
ATILNO-000	1.083	1.0851
ATILNO-001	0.907	0.9034
ATILNO-020	0.938	0.9380
ATILNO-030	0.988	0.9880
TUNEFI-010	0.833	0.8327
TUNE-000	2.228	2.2230
FUSRED-000	0.970	0.9700
RESNOR-000	1.320	1.3200
FISVF1-000	1.000	0.9995
FISVF1-010	1.000	1.0005
FISVF2-000	1.000	1.0042
FISVE1-000	1.000	0.9985
FISVE2-000	1.000	0.9995
FISHO1-000	1.000	0.9992
FISHO2-000	1.000	0.9992
FISAT1-000	0.917	0.9157
FISAT2-000	0.971	0.9717
FISAT2-010	0.981	0.9810
FISDL1-000	1.000	0.9999
FISDL2-000	1.000	0.9999
LDSHIF-000	1.100	1.0990
LDSHIF-010	1.063	1.0647
LDSHIF-020	0.917	0.9170
PFNALP-000	0.963	0.9613
PFNRAT-000	0.928	0.9279
PFNERE-000	0.999	1.0002
PFNTKE-000	0.984	0.9853

- Changes required for assimilation are very small compared to experimental uncertainties.
- Changes in the parameters even smaller.
- Impossible to determine with such precision from differential data only!

# Beyond ENDF/B-VII.1

# Current changes to ENDF/B-VII

- 1 deuteron-incident evaluation,
- 5 decay evaluations
- 111 neutron-incident evaluations.
  - $^1\text{H}$  covariance replacement
  - new  $^{236\text{m}1}\text{Np}$
  - many minor bug fixes

# Priorities for the next ENDF/B

## Highest Priority

- 239-Pu
- 235-U
- 238-U
- 56-Fe
- 16-O
- Standards
- Update covariances

## Lower Priority

- CP reactions
- Be
- 12,natC
- 23-Na
- Ca
- V
- Ti?
- Cr
- Ni
- Cu
- Zr
- Mo?
- Ta
- Gd
- Dy