AREVA

NUDUNA:
“Nuclear Data Uncertainty Analysis”

Oliver Buss, Axel Hoefer, Jens-Christian Neuber
AREVA GmbH, PEPA-G (Offenbach, Germany)

Meeting on uncertainty propagations in the nuclear fuel cycle
Uppsala University, April 24-25, 2013

AREVA

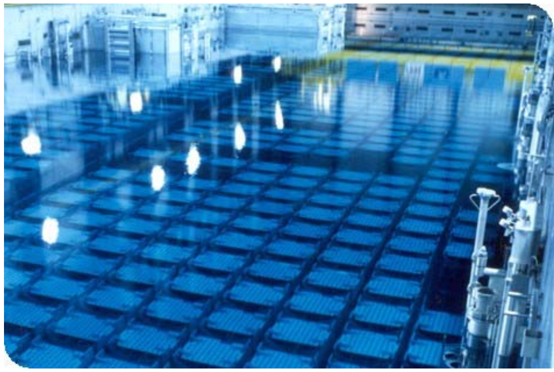
Content

- Motivation
  - Nuclear data uncertainty impact and criticality safety
- Methods for estimating the impact of Nuclear Data Uncertainty
- Monte-Carlo approach to the propagation of Nuclear Data uncertainty
- NUDUNA framework
  - Present issues with available uncertainty information
  - Results for k_{eff} and depletion
- Summary & Outlook

AREVA

Motivation

Motivation



- Criticality safety evaluations for (re-) processing, storage, transport and final disposal of nuclear fuel
  - Small Margins additional to the Regulatory Safety Margin
  - Regulatory Safety Margin: k_{eff}<0.95, 0.98 or even k_{eff}<1.00
- Analyses rely on transport codes
- Different types of analytical uncertainties:
  1. Geometrical and material data uncertainties ✓
  2. Burn-up uncertainties ✓
  3. Systematic uncertainties in the transport algorithms (Calc. Bias) ✓
  4. Nuclear data uncertainties ✗
- Status of nuclear data uncertainty estimation:
  - USA, France: Demand for estimates of nuclear data uncertainties
  - Otherwise nuclear data uncertainties considered to be covered by the safety margin (which includes errors not accounted for)
- We aim to provide a proper estimate for nuclear data uncertainties
  - Ensure bounding estimates in safety margins
  - Reduce conservatism in safety margins

AREVA

Methods for estimating Nuclear Data Uncertainty

Using Evaluations in Transport Codes

Experimental Data

↓ Modelling, Fitting, Expert Judgement

Data Eval

How to include nuclear data uncertainty ??

perature Effect)

summation

sonance Self-Shielding

Data compression / Discretization (Group-wise cross sections)

5. Formatting

↓

Transport Code Library

AREVA

Approaches to the estimation of Nuclear Data Uncertainty impact

1. Perturbation theory

Approximation, Fast!!

$$Cov(A) \approx \sum_{i,j} \frac{\partial A}{\partial \alpha_i} \frac{\partial A}{\partial \alpha_j} Cov(\alpha_i, \alpha_j)$$

Sensitivities

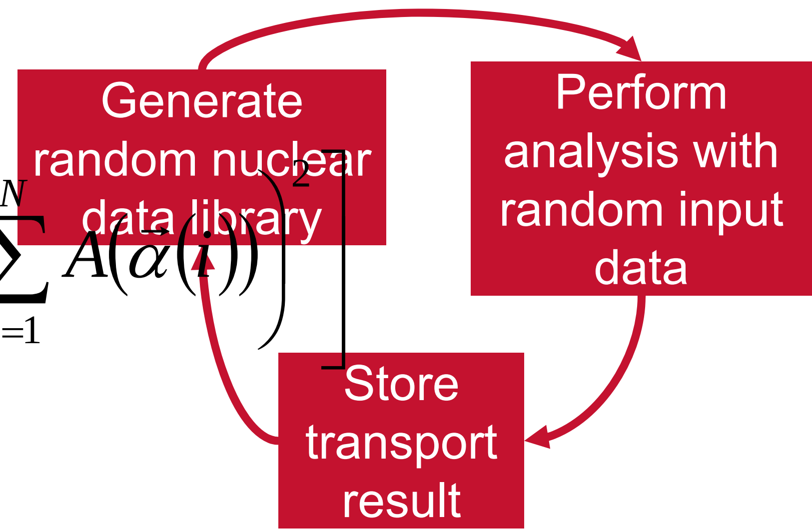
Nuclear Data Covariances

2. Monte Carlo

- Retrieve statistics for observable based on distribution of input parameters

$$Cov(A) \approx \frac{N}{N-1}\left[\frac{1}{N}\sum_{i=1}^{N} A(\vec{\alpha}(i))^2 - \left(\frac{1}{N}\sum_{i=1}^{N} A(\vec{\alpha}(i))\right)^2\right]$$

with $\vec{\alpha}(i)$ random draw



All orders included! Flexible Tool!

AREVA

Available Codes for Nuclear Data Uncertainty Estimation

Approximations →

Approximations ↓

	Monte Carlo Approach (All Orders)	1. Order Perturbation **FAST!!**
Measured Data	TMC (NRG)	
Evaluations	NUDUNA (AREVA NP) KIWI (LLNL) **Very Flexible, CPU intense**	
Grouped Data	XSUSA (GRS) **SCALE Cov based, FAST**	TSUNAMI (ORNL) TSURFER (ORNL) RIB (CEA) **Long History, Not flexible** **Very good Documentation**

Monte-Carlo approach to Nuclear Data Uncertainty Estimation

NUDUNA: Program Flow

Generation of random libraries

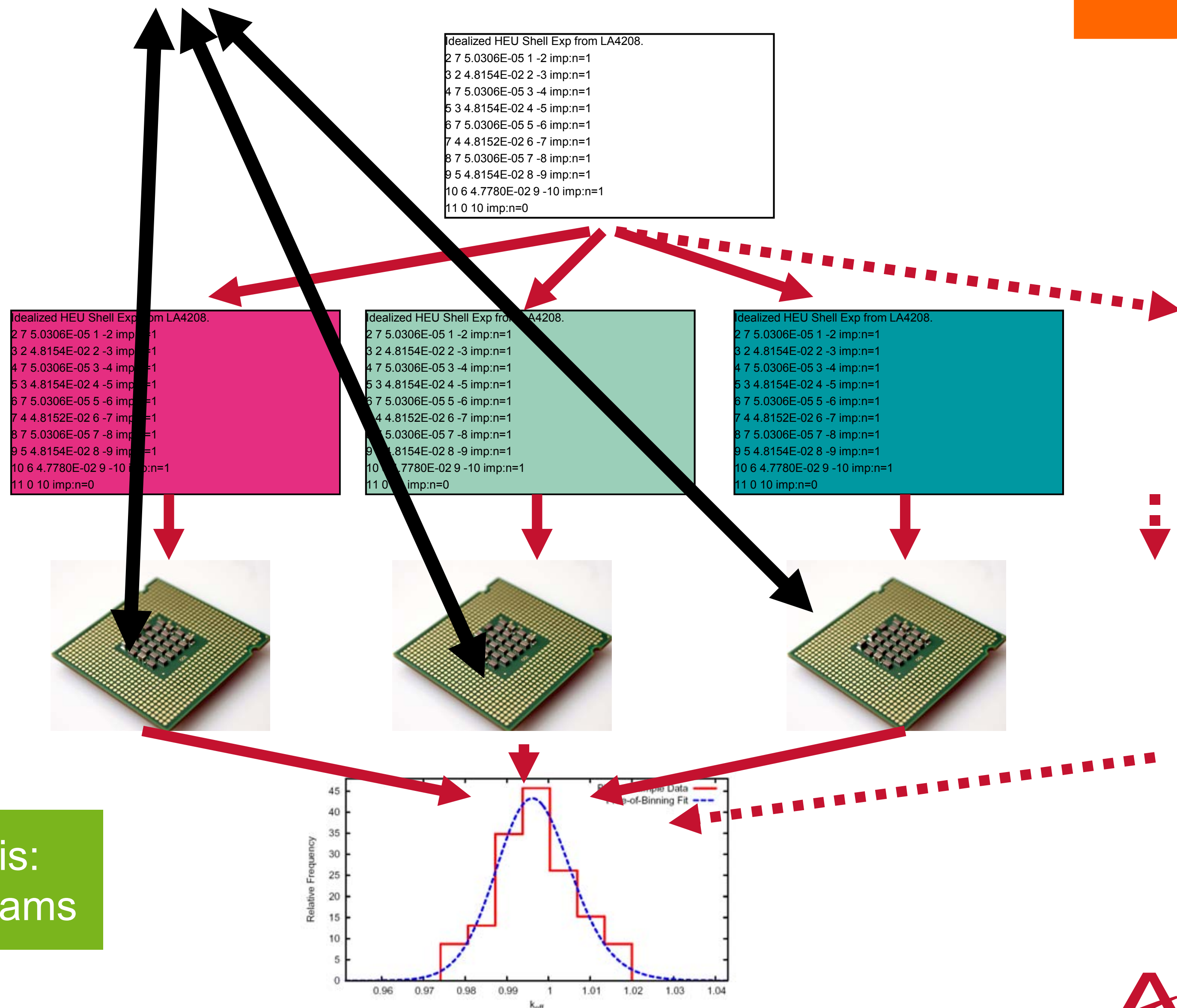
Random library data bench (XML based)

Job card creation

Automated job card multiplication

Parallel execution of jobs: Linux or Windows Cluster

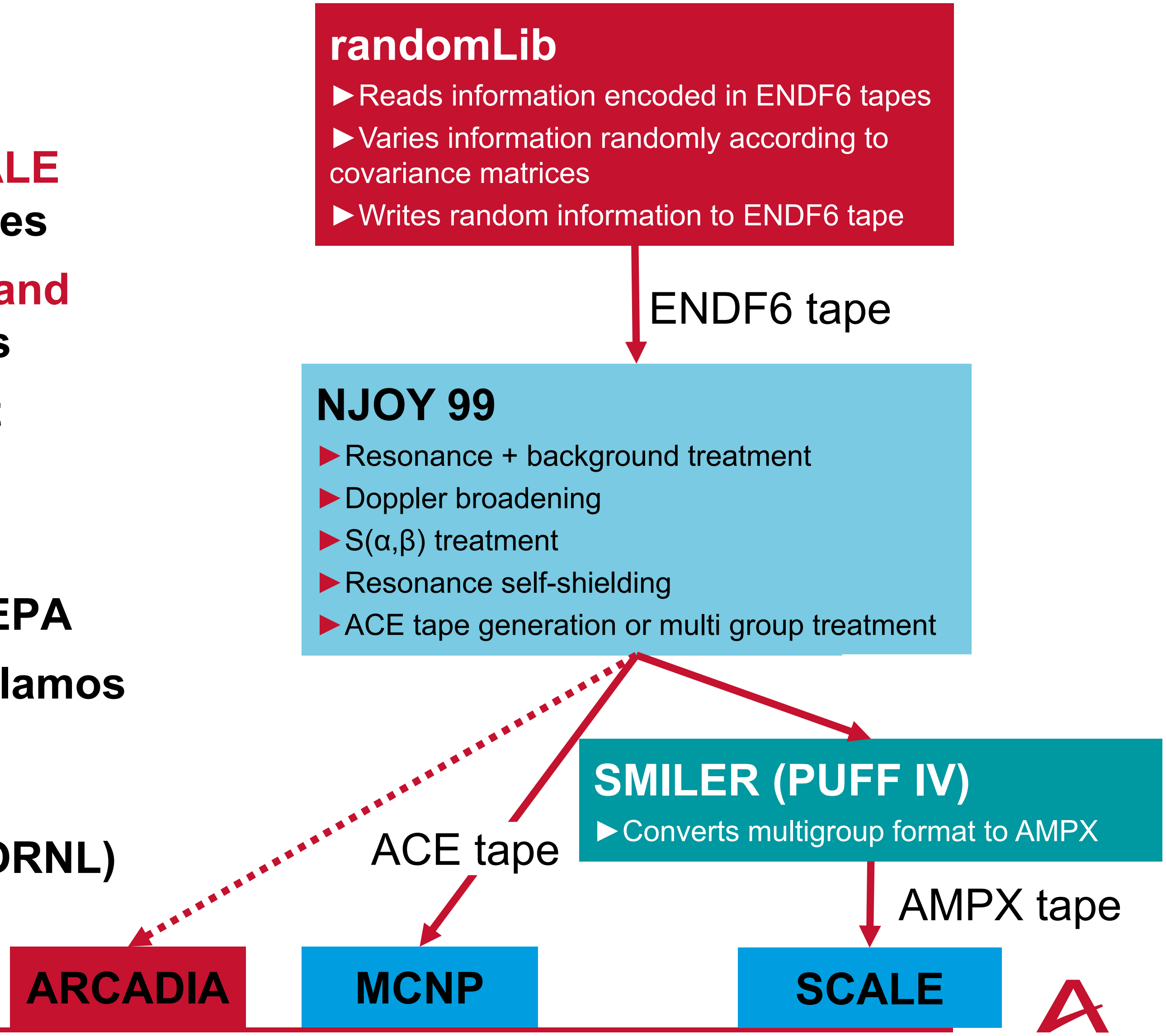
Automated Output Analysis: Upper/Lower 95/95, Histograms



AREVA

NUDUNA: Random input library creation

- **NUDUNA Scope:**
  - **Provide libraries for SCALE and MCNP transport suites**
  - **Need to generate AMPX and ACE formatted input files**
  - **Present Project: Support ARCADIA**
- **NUDUNA makes use of:**
  - **randomLib by AREVA PEPA**
  - **„NJOY 99“ tool by Los Alamos National Lab (LANL)**
  - **SMILER/PUFF IV tool by Oakridge National Lab (ORNL)**



AREVA

NUDUNA: Creating random ENDF6 tapes

File 1: Multiplicities

- Restoration of sum rules

$$m_{tot} = m_{prompt} + m_{delayed}$$

- Normal or log-normal model

File 2: Resonances

- Respect positivity bounds for widths
- Assume constant phases of amplitudes
- Dimension ≤ 10.000
- Normal or log-normal model

File 3: Cross sections

- Define common energy grid acc. to file 33 information
- Average data on grid
- Random draws for average data
  → scaling factors for energy ranges
- Rescale original data
- Restore ENDF6 sum rules

?

File 4: Angular Distributions

- Check for angular distribution > 0
- Normal or log-normal model

AREVA

Problems with current ENDF6 encodings of Data Uncertainties

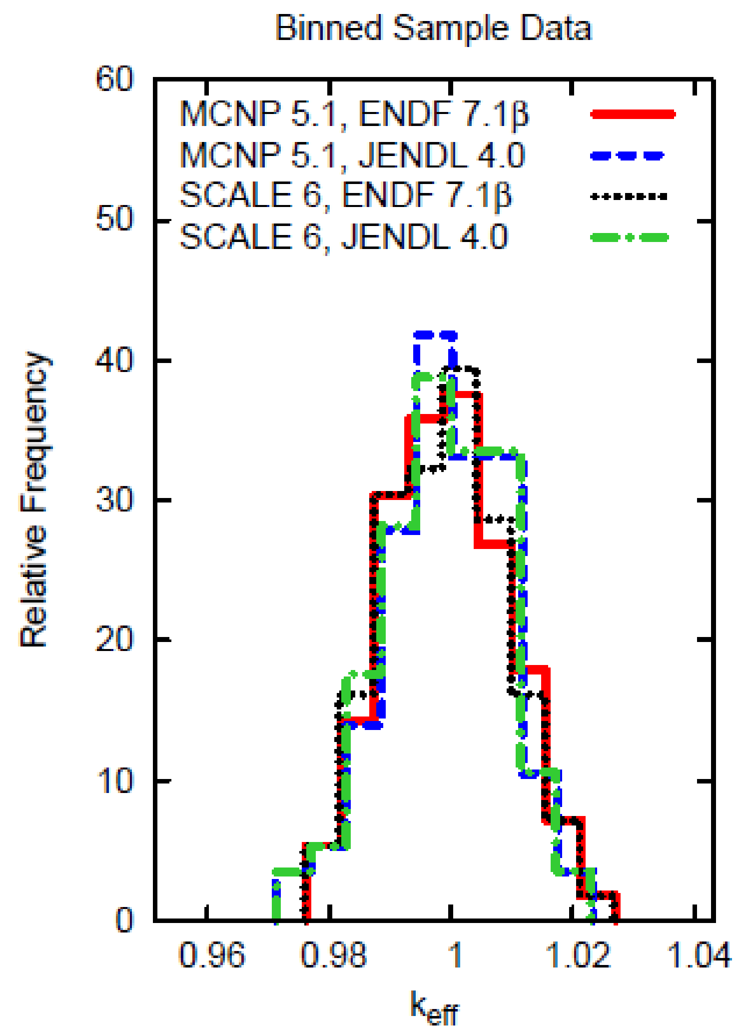
- **Missing LTY=0 Entries for Files 1&3**
  - Arbitraryness in restoring sum rules
- **File 1 phases**
- **Covariances of total and prompt neutron multiplicities must be consistent!**
- **Arbitraryness of Distribution Models**
  - Why not distribution model in ENDF6?
  - Especially problematic for forward-peaked angular distributions (File 4)
- **Incomplete Information in File 35**
  - Need for uncertainty of underlying parameters and not of the sum itself

AREVA

Results

Results I
Godiva (HEU-MET-FAST-001)

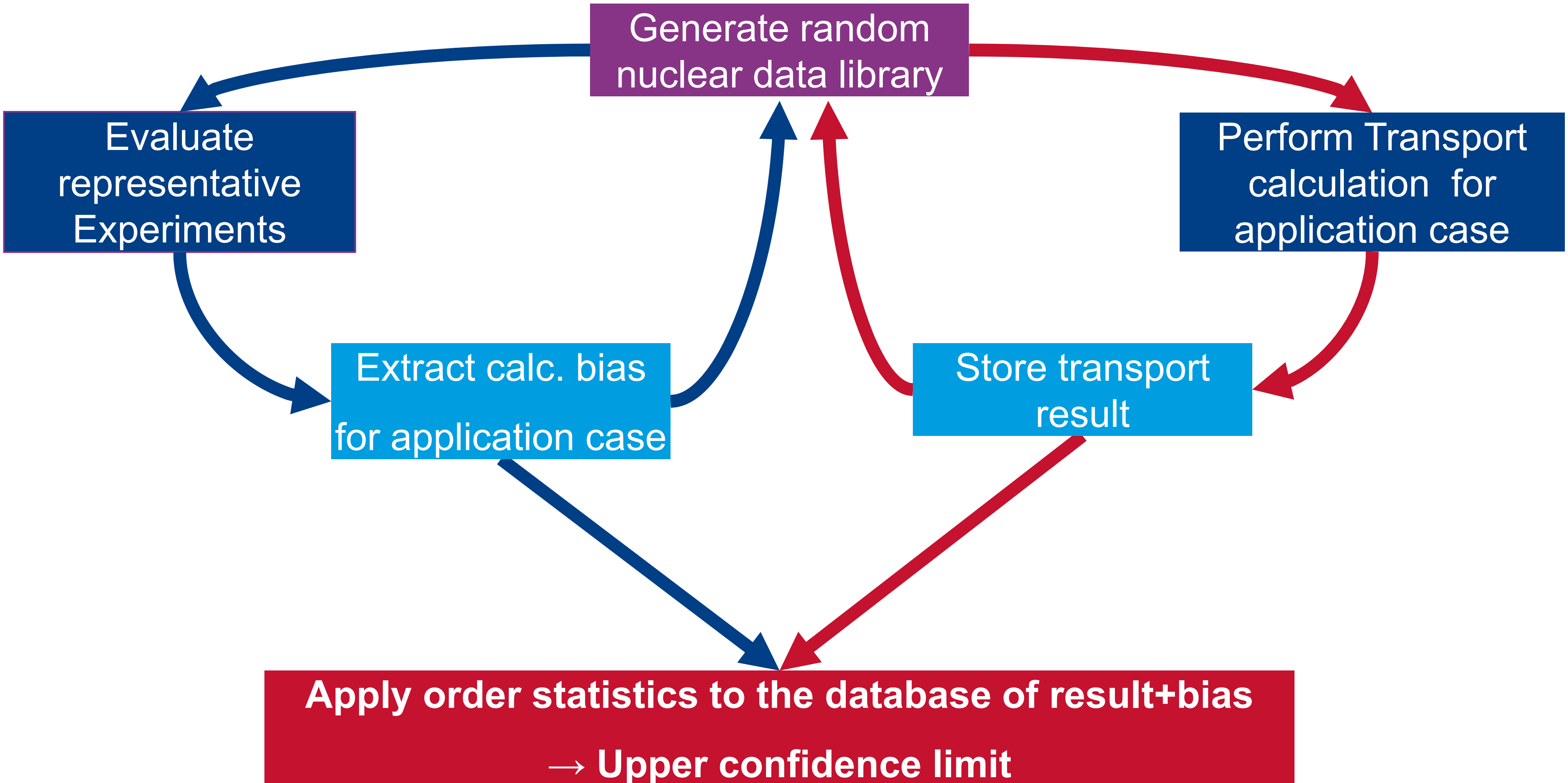
Evaluation	Transport Suite	Average k_{eff}	Standard Deviaton due to Nuclear Data Uncertainty [pcm]
JENDL 4.0	SCALE 6 238 Groups	0.99891	955
JENDL 4.0	MCNP 5	0.99937	953
ENDF 7.1β	SCALE 6 238 Groups	0.99900	1016
ENDF 7.1β	MCNP 5	0.99920	1018



► **Tsunami (SCALE 6): 930 pcm (ENDF/B VII)**

AREVA

Results II:
Adding the benchmark loop

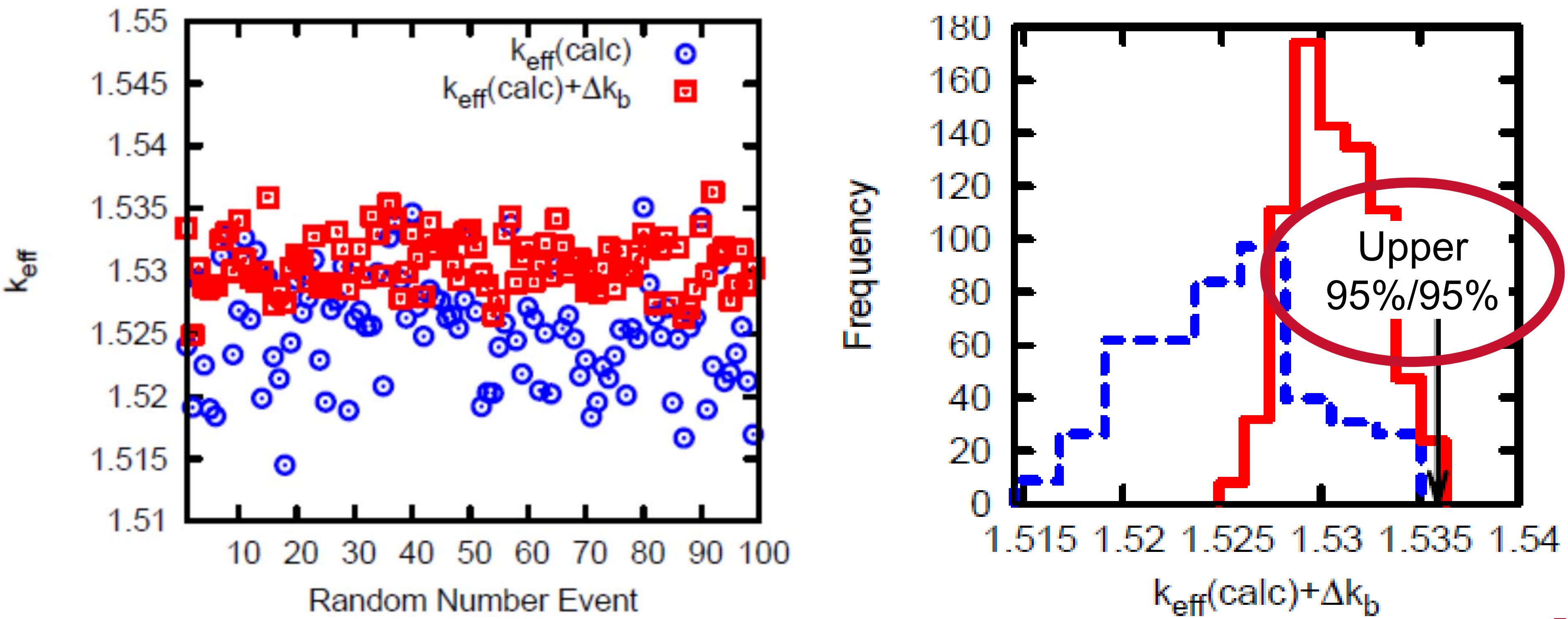


AREVA

Results II: Adding the benchmark loop

- Simple Pin-Cell Model: UO_2 with 5% enrichment water reflected
- Bias estimation based on LCT51 experiments
- $c_k \approx 0.9$ for all experiments

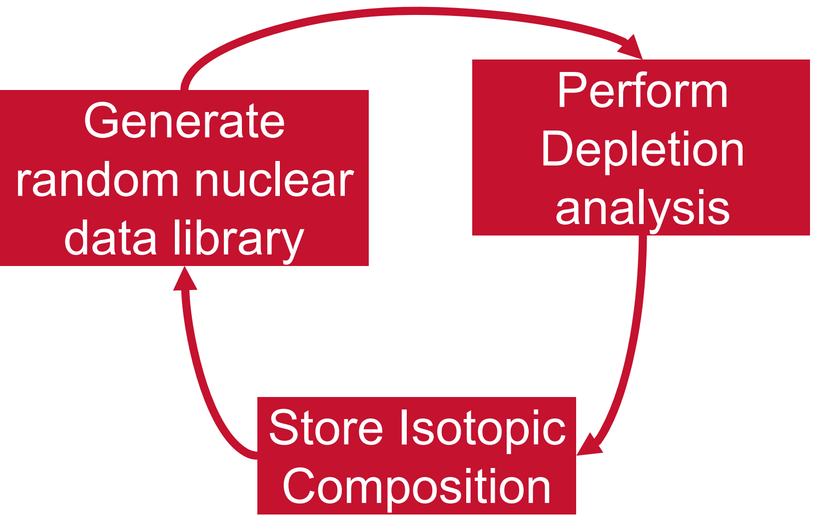
$$\Delta k_b = \frac{1}{18} \sum_{i=LCT51.2,\ldots,LCT51.19} k_{bench}(i) - k_{eff}^{calc}(i)$$

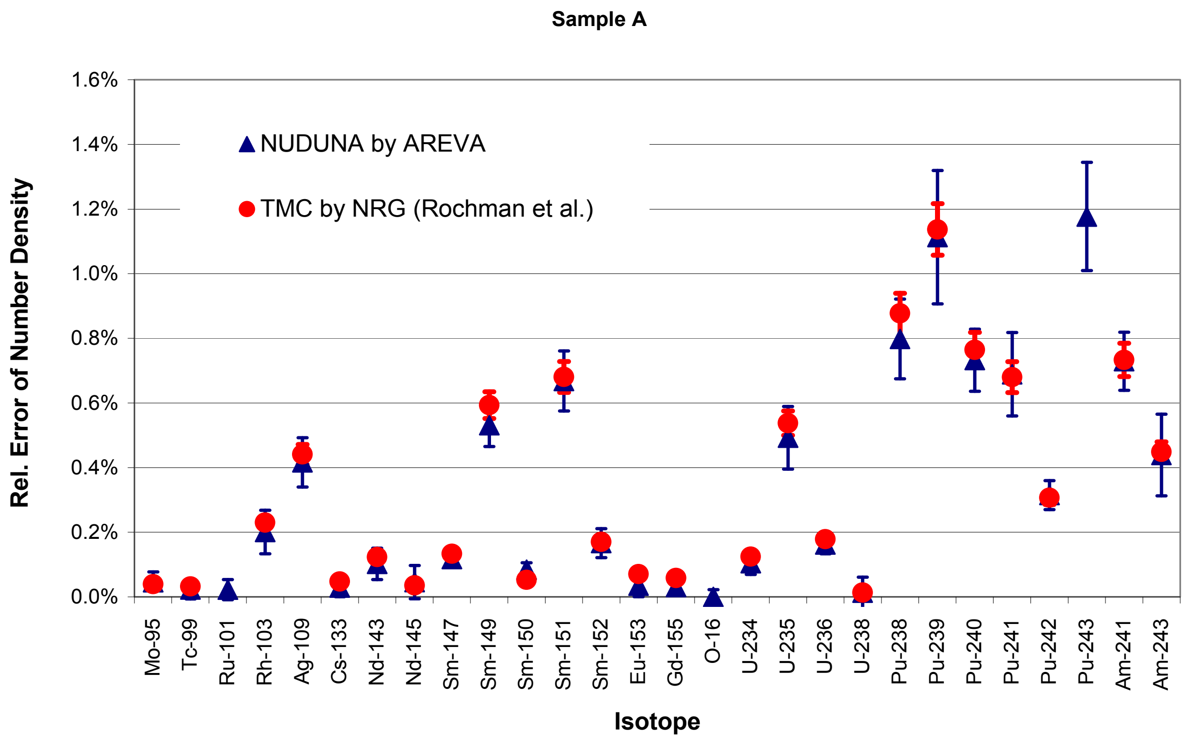


AREVA

Results III: Depletion calculations for BUC

- ▶ OECD Phase 1b Benchmark, Sample A (3.2 wt.-% enrichment, thermal pin-cell)
- ▶ Impact of U238 XS uncertainty based on TALYS
- ▶ TRITON / SCALE 6.0





Succesful Benchmarks with TMC (NRG)

AREVA

Burnup-Credit with Gd-Fuel

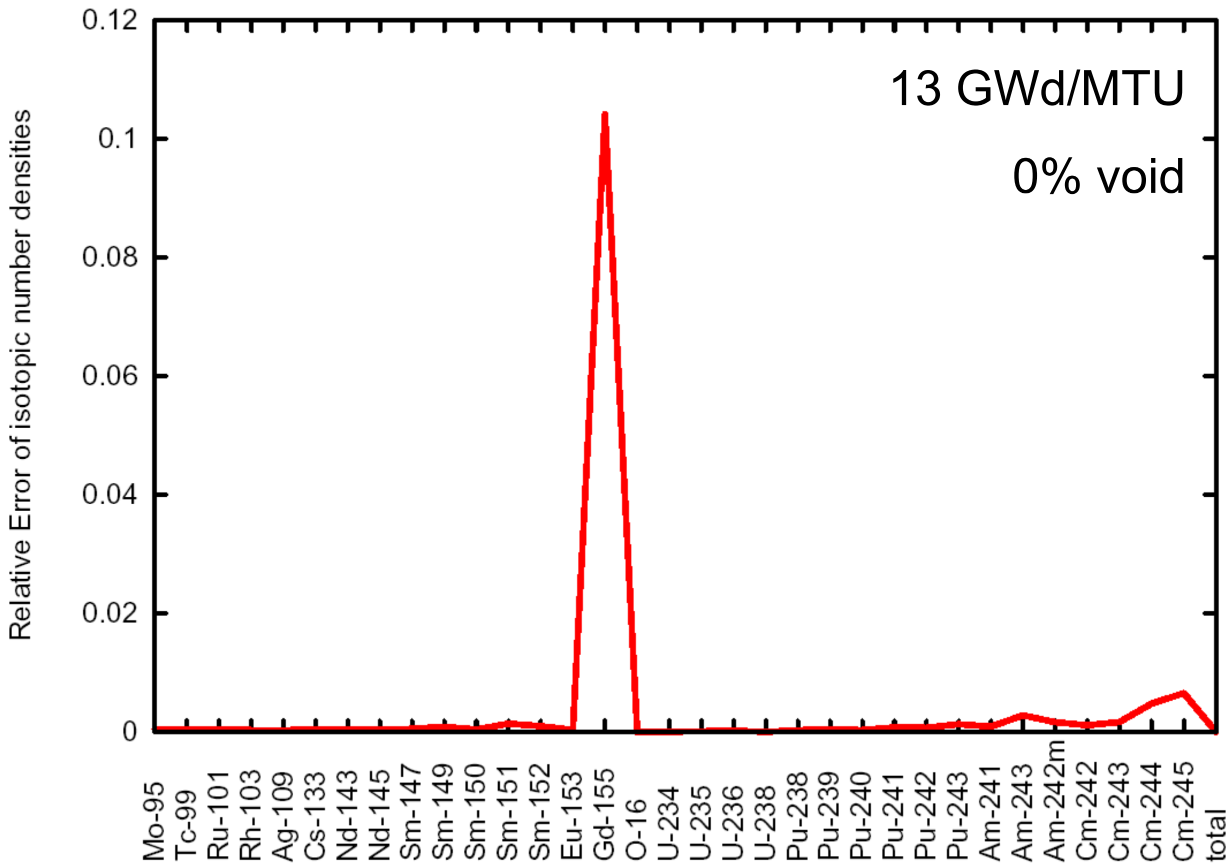
- **Problem: No experiments for validating Burn-Up of Gd fuel at low burn-up!!!**
- **How to estimate uncertainty of number densities? NUDUNA !!!**

Variation of ^{155}Gd cross sections according to ENDF 7.1β

<u>Assumption:</u> XS uncertainty dominates BU-Algorithm uncertainty

<u>Results:</u>

- ^{155}Gd XS uncertainties do not induce seizable relative errors on other number densities
- Expected relative uncertainty of ^{155}Gd number density : ca. 10%



AREVA

Summary

- NUDUNA provides nuclear data uncertainty impact estimates
- Support for continuous and group-wise XS libraries
- NUDUNA improves on the perturbation theory methodology
- Flexibility of MC ⇨ easy to embed in hierarchical schemes for uncertainty estimation
- Succesful benchmarks for k_{eff} and depletion
  - Consistent results for MCNP and SCALE
  - NUDUNA compatible to TSUNAMI (ORNL)
  - Succesful TMC (NRG) vs. NUDUNA benchmarks for OECD Phase-1b depletion problem

- Problems with ENDF6 standard and present evaluations
  - Strong support by Nuclear Data Community needed

AREVA

End of presentation NUDUNA – "Nuclear Data Uncertainty Analysis in Criticality Safety"

Oliver Buss, Axel Hoefer, Jens-Christian Neuber
AREVA NP GmbH, PEPA-G (Offenbach, Germany)

Workshop FDN & PEPA
08/03/2012

AREVA