Determining the nuclear data uncertainty on MONK10 and WIMS10 criticality calculations

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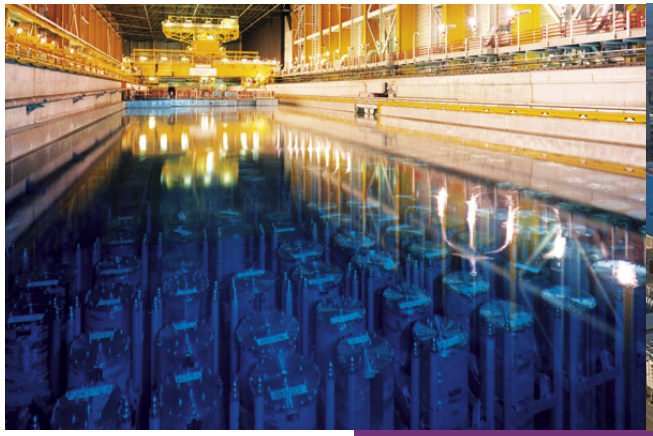
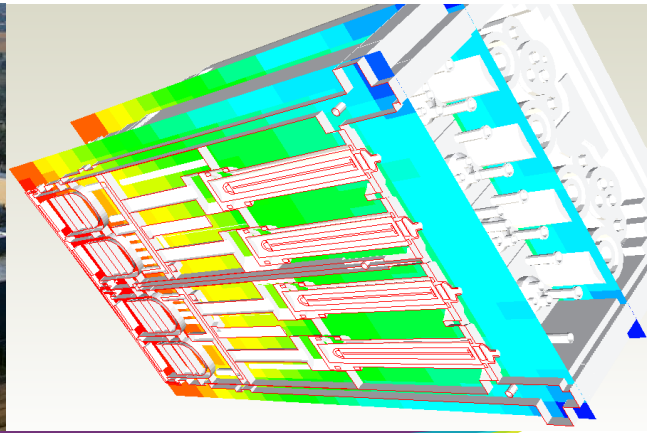




Outline

- ANSWERS physics codes and nuclear data libraries
- Sampling the nuclear data libraries
- Benchmark testing

ANSWERS Software Service

- The ANSWERS Software Service supplies high quality software and consultancy services for customers world-wide in the areas of reactor physics, radiation shielding, dosimetry, nuclear criticality and nuclear data

www.answerssoftwareservice.com

- MONK® - Monte Carlo code for criticality safety and reactor physics
  - Estimates neutron multiplication factor, k-effective
  - Detailed 3D geometry modelling package
  - Data library provided in continuous energy BINGO format
    - or WIMS library processed with the NOVICE routine
- WIMS – deterministic code for core physics calculations
  - Estimates reactivity, power and flux distributions
  - Several methods of solution using diffusion theory, discrete-ordinates, collision probability, characteristics or Monte Carlo methods
  - Data library provided in XMAS 172-group structure

BINGO and WIMS Data Libraries

- ~300 nuclides
- BINGO libraries include;
  - Continuous energy representation of cross sections
    - Doppler broadened to 293.6, 500, 1000, 1500, 2000, 3500 K + higher T
    - Runtime-Doppler-Broadening for intermediate temperatures
    - Sub-grouping of URR cross sections for some nuclides, e.g. U-238, Pu-239
  - Outgoing neutron data (scattering, nubar, fission spectra)
- WIMS libraries include;
  - XMAS 172 group representation of cross sections
    - Doppler broadened to 293.16, 573.16, 973.16, 1473.16, 2973.16 K
    - Interpolation for intermediate temperatures
    - Resonance pre-shielded URR cross sections for some nuclides, e.g. Fe, Ni, Cr
  - Outgoing neutron data (scattering, nubar, fission spectra) in 172 groups
  - Burnup data (half-lives, fission yields, branching ratios)

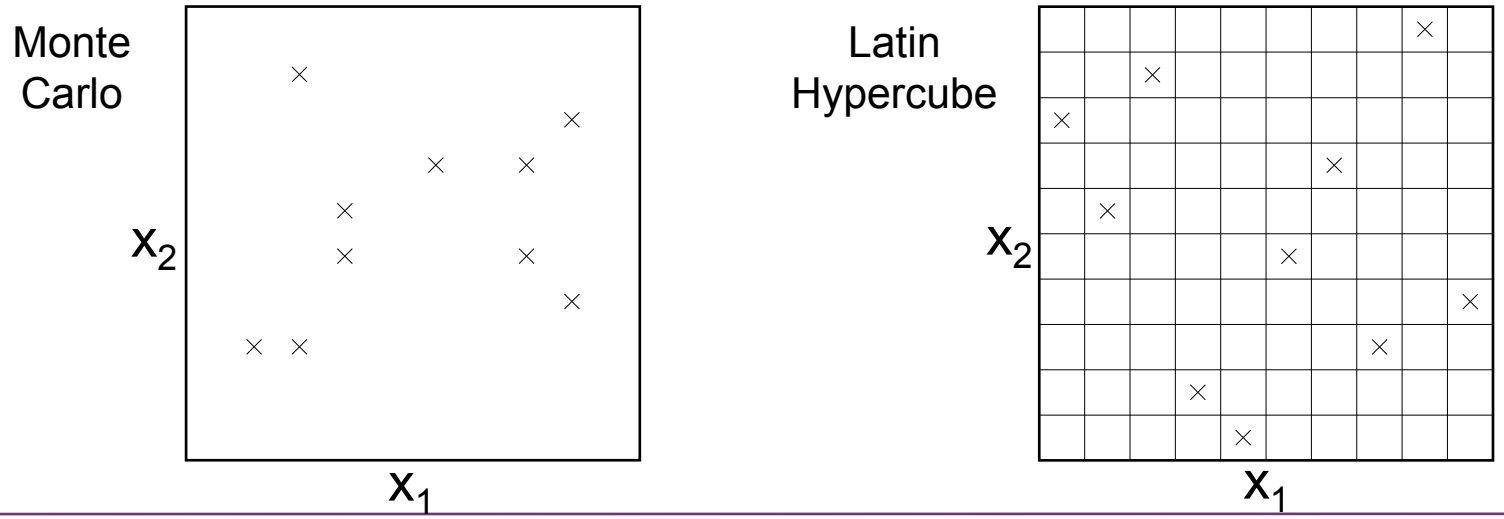
Calculating Uncertainty

- Uncertainties on reactor physics & criticality calculations;
  - Modeling assumptions
  - Manufacturing tolerances (geometry, material composition)
  - Stochastic uncertainty (in Monte Carlo sampling)
  - Nuclear Data
- ANSWERS have done further work on first three uncertainties

- This presentation describes quantifying the nuclear data uncertainty
  - Sample the evaluated nuclear data, using covariances where they exist
  - Create sets of sampled libraries (BINGO and WIMS format)
  - Run criticality cases for each sampled library

Sampling Methods

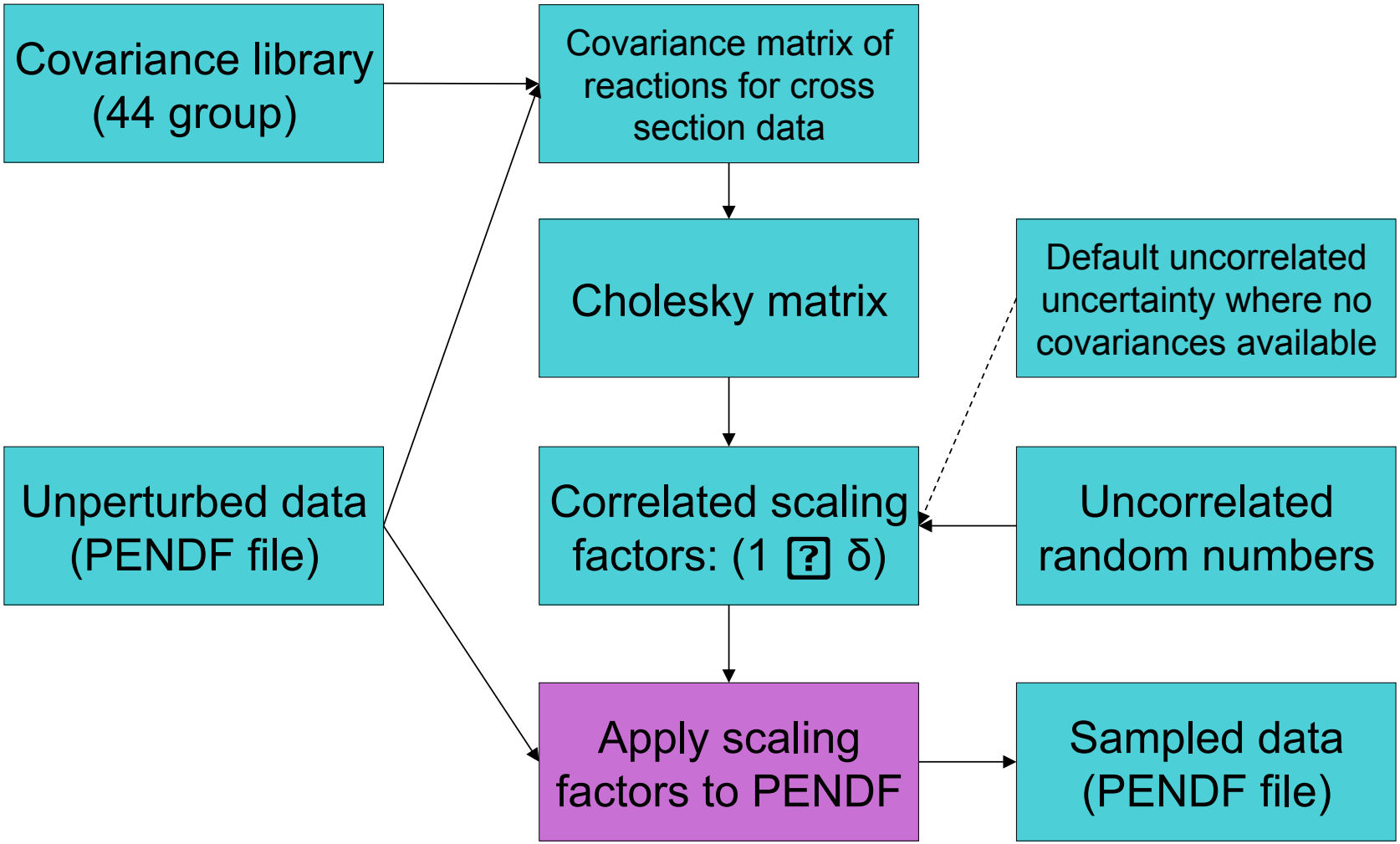
- Uncertain parameters are assumed uncorrelated and follow normal distribution
- Sampling methodologies include Monte Carlo and Latin Hypercube
- This work uses Latin Hypercube Sampling to ensure adequate coverage of the sample space (without excessive samples)
  - 22 samples – 90/90 confidence
  - 59 samples – 95/95 confidence



Covariance Library

- No evaluation contains full coverage of covariance data for all nuclides
- The ‘best’ evaluation was selected for each nuclide;
  - JEFF-3.2, ENDF/B-VII.1, JENDL-4.0, TENDL-2011, others
  - Key nuclides
    - H-1, B-10, C, Fe-56 JEFF-3.2
    - U-235, U-238, Pu-239, Zr ENDF/B-VII.1
- 177 nuclides with (some) covariance data
- Library constructed with SCALE 44-group scheme (with some group boundaries adjusted to be coincident with WIMS 172 group bounds)
- Used for sensitivity and perturbation methods in ANSWERS codes
- Used for sampling method described here

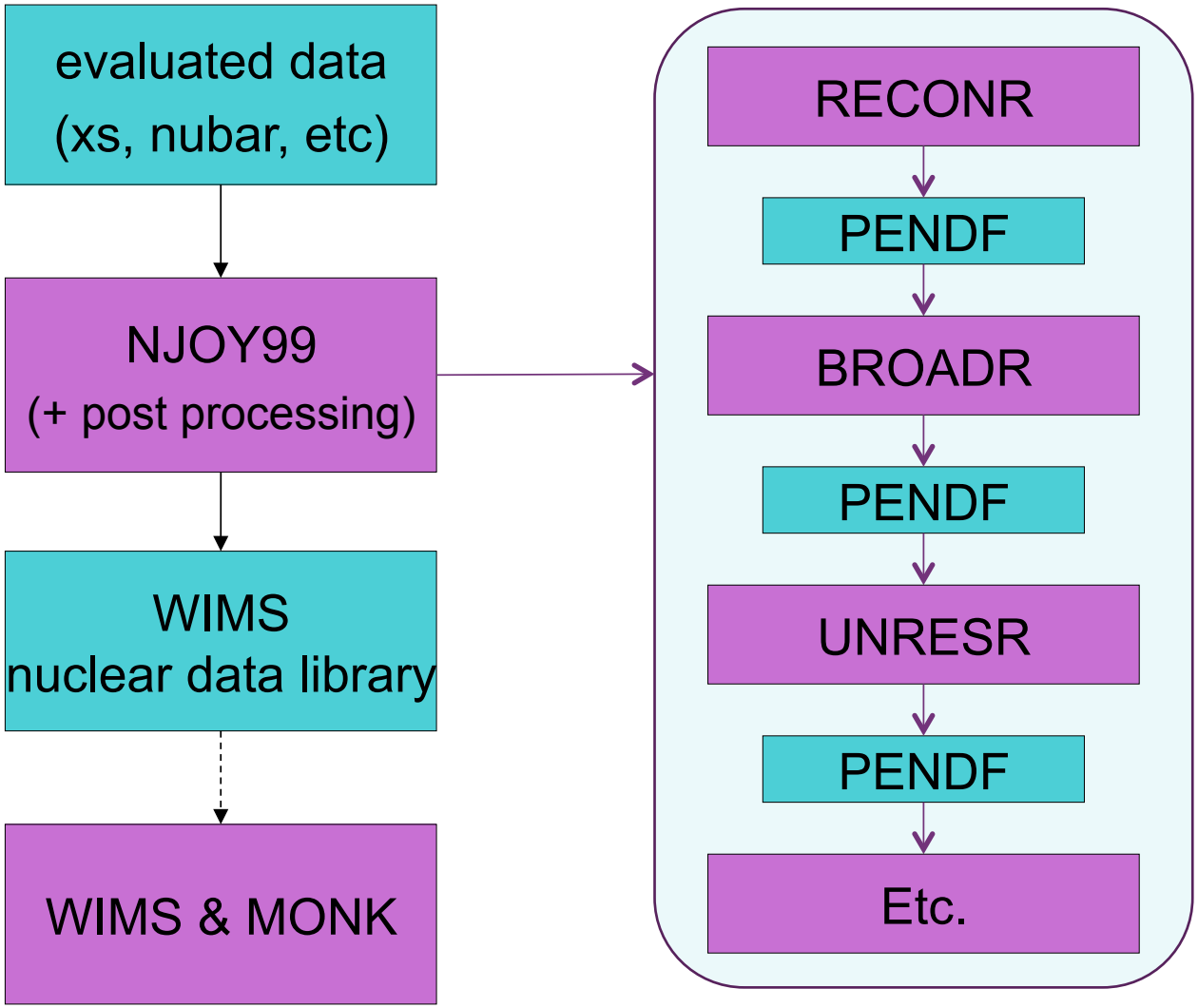
Nuclear data sampling tools



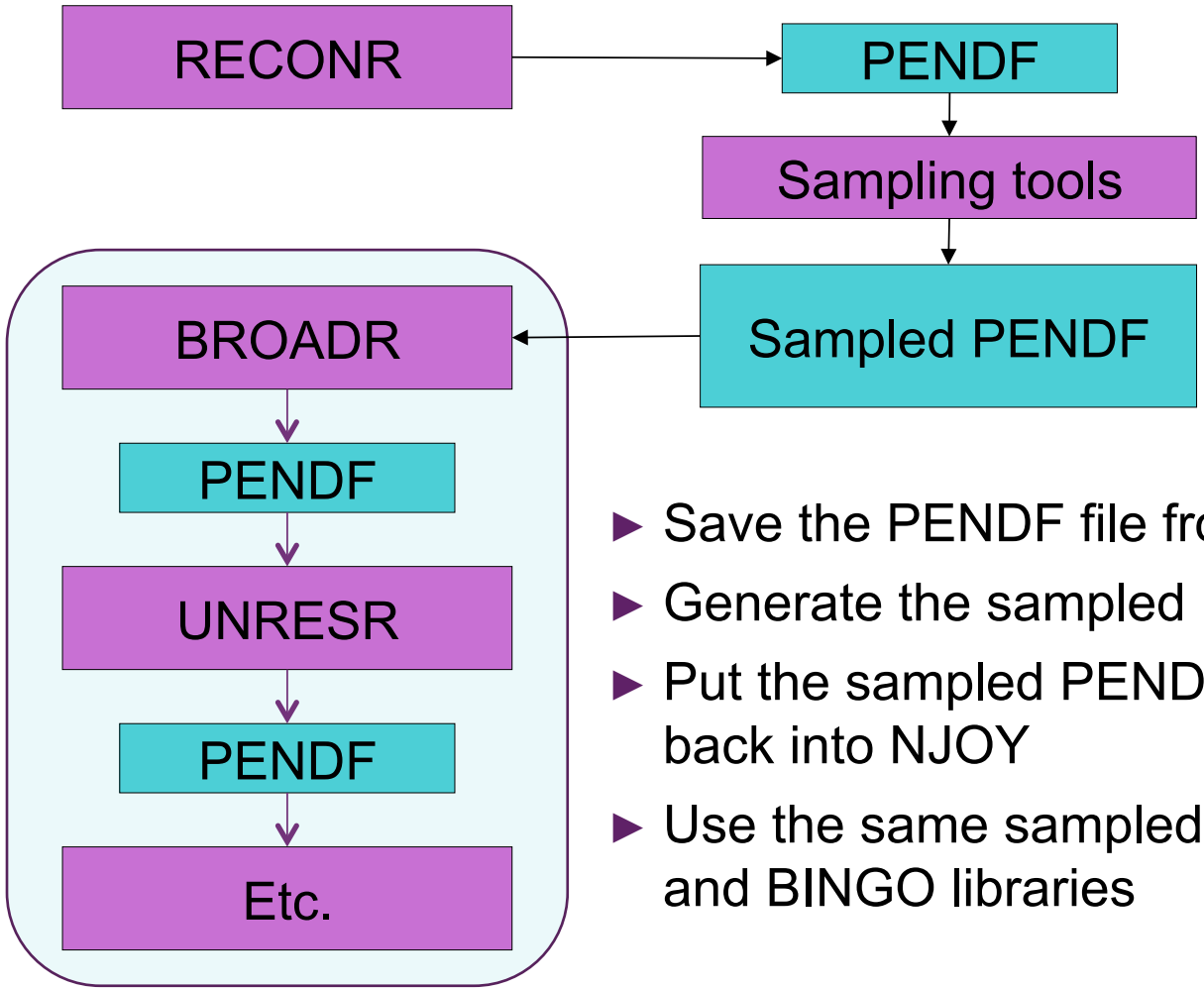
Uncertainties on nubar and fission spectra

- Covariances are available for most important actinides for;
  - Nubar (neutrons per fission) including prompt and delayed
  - Fission neutron energy spectrum
- Read directly from the ENDF-6 file
- Samples the tabulated data
  - Not yet able to sample functional data
- New sampled ENDF-6 files produced
- Combined with sampled PENDF files to generate sampled libraries

Conventional WIMS Library Generation

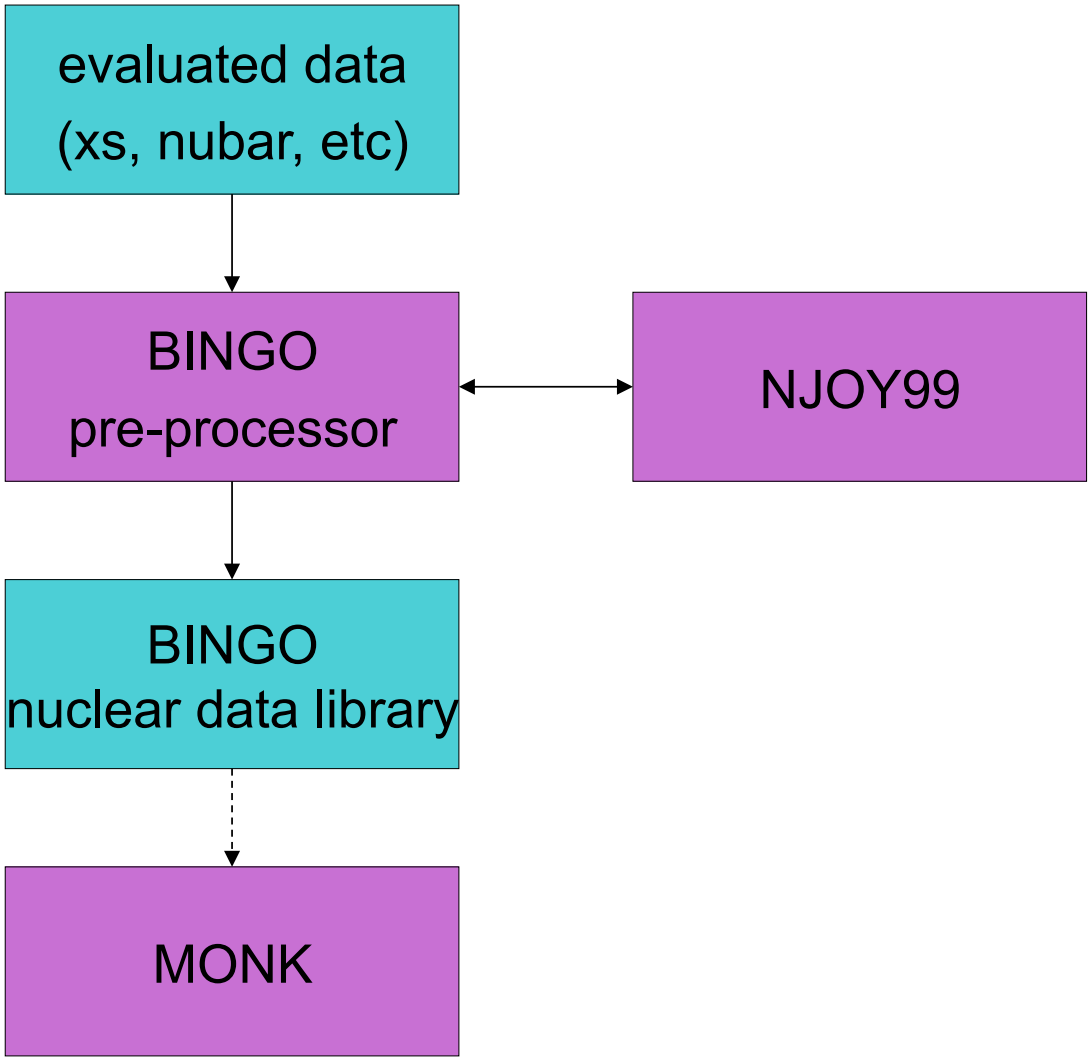


Sampled WIMS Library Generation

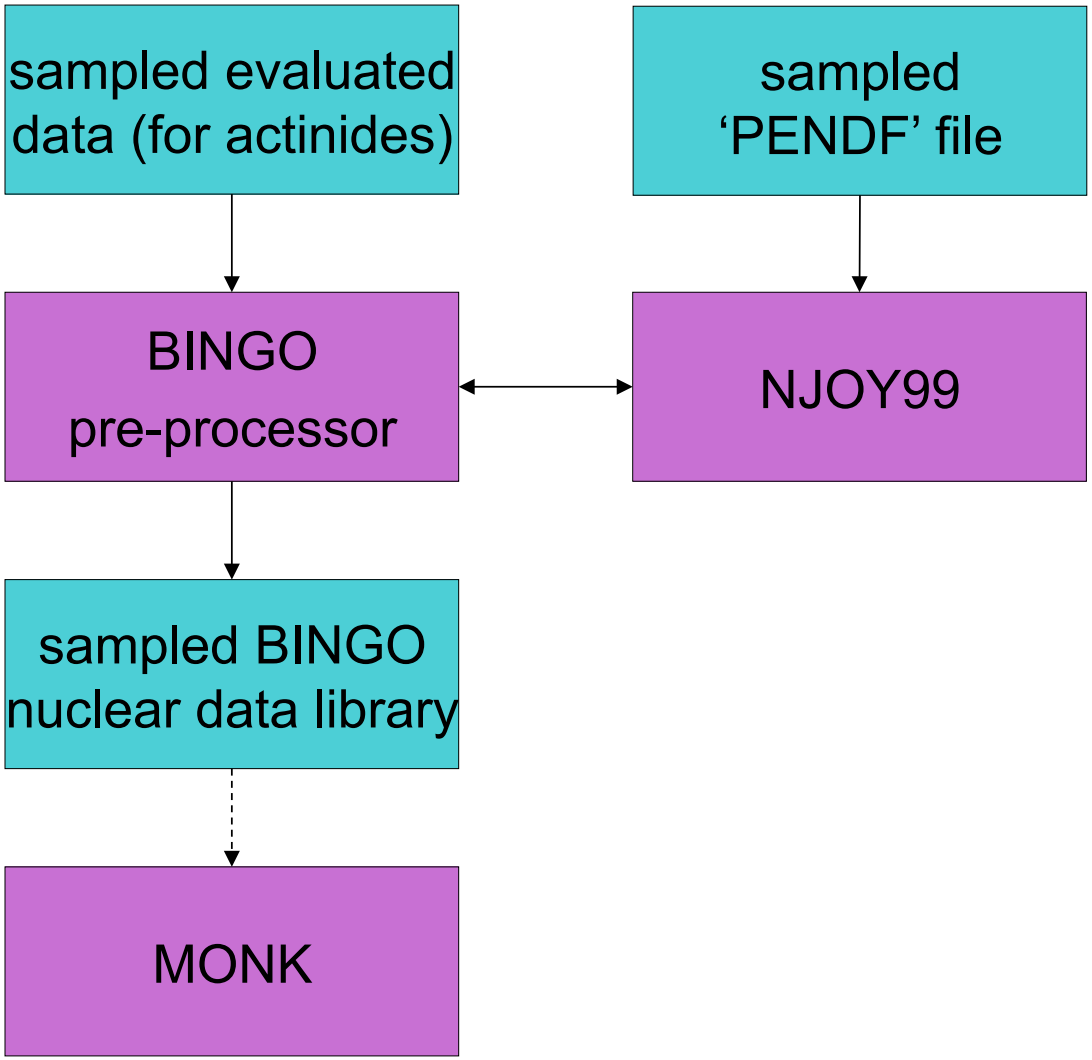


- Save the PENDF file from RECONR
- Generate the sampled PENDF files
- Put the sampled PENDF (and ENDF) files back into NJOY
- Use the same sampled PENDFs for WIMS and BINGO libraries

Conventional BINGO Library Generation



Sampled BINGO Library Generation



Uncertainties on thermal scattering data

- Bound nuclides - HinH2O, HinCH2, HinZrH, graphite …
- No covariances for bound thermal scattering (WPEC Subgroup 42)
- Use free gas elastic scattering cross section covariance data as approximation
- Current covariances for free gas elastic scattering are constant <4 eV
- Scaling factor (<4eV) used to perturb point-wise thermal scattering reconstructed from s(α,β) tabulations and incoherent scattering data
- For WIMS - modified NJOY THERMR applies the scaling factor to the reconstructed point-wise thermal scattering cross section
- For BINGO - apply scaling to final BINGO data files (post-processing)

Uncertainty of burnup data

- WIMS library burnup data consists of;
  - Decay constants (57 nuclides)
  - Fission product yields (19 actinides)
  - Capture branching ratios (8 nuclides)

- Decay constants sampled using half-life value and uncertainty
- Fission product yields sampled using the evaluated value and uncorrelated uncertainty
  - No established covariance data format yet (see WPEC subgroup 37)
- Capture branching ratios sampled using uncertainties on thermal capture cross section ratios

Summary of Sampled Nuclear Data Libraries

- Base nuclear data is JEFF-3.1.2
- Two sets of sampled libraries
  - LHS25
  - LHS60
- BINGO and WIMS libraries produced based on same data and uncertainties
- Sampled data
  - All cross sections for all ~300 nuclides (covariance data for 177 nuclides)
  - Includes thermal scattering cross sections for bound nuclides
  - Nubar and fission spectra for major actinides
  - Burnup data (half-lives, fission yields, branching ratios)

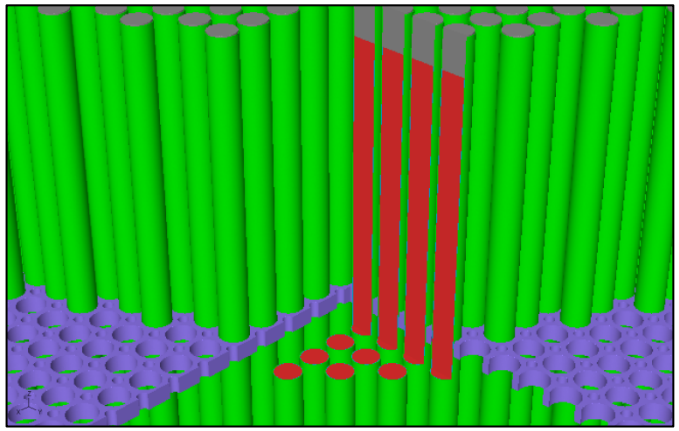
Basic Testing

- Initial testing performed using simple LWR test cases
- Included all nuclides and run at all temperatures
- Tests the methodology for producing sampled nuclear data libraries

- WIMS ran all WIMS libraries
- MONK ran all BINGO libraries
- MONK ran all WIMS libraries (using NOVICE routine)

DIMPLE Benchmark Test

- 5 experiments (SO1 core) performed at Winfrith UK (1983)
- ICSBEP exp LCT-0048
- k_{exp} = 1.0000 ? 0.0025
- 1441-1597 3^{w}% enr. UO2 pins in water (varying critical height)
- Modelled with detailed MONK and simpler WIMS geometry



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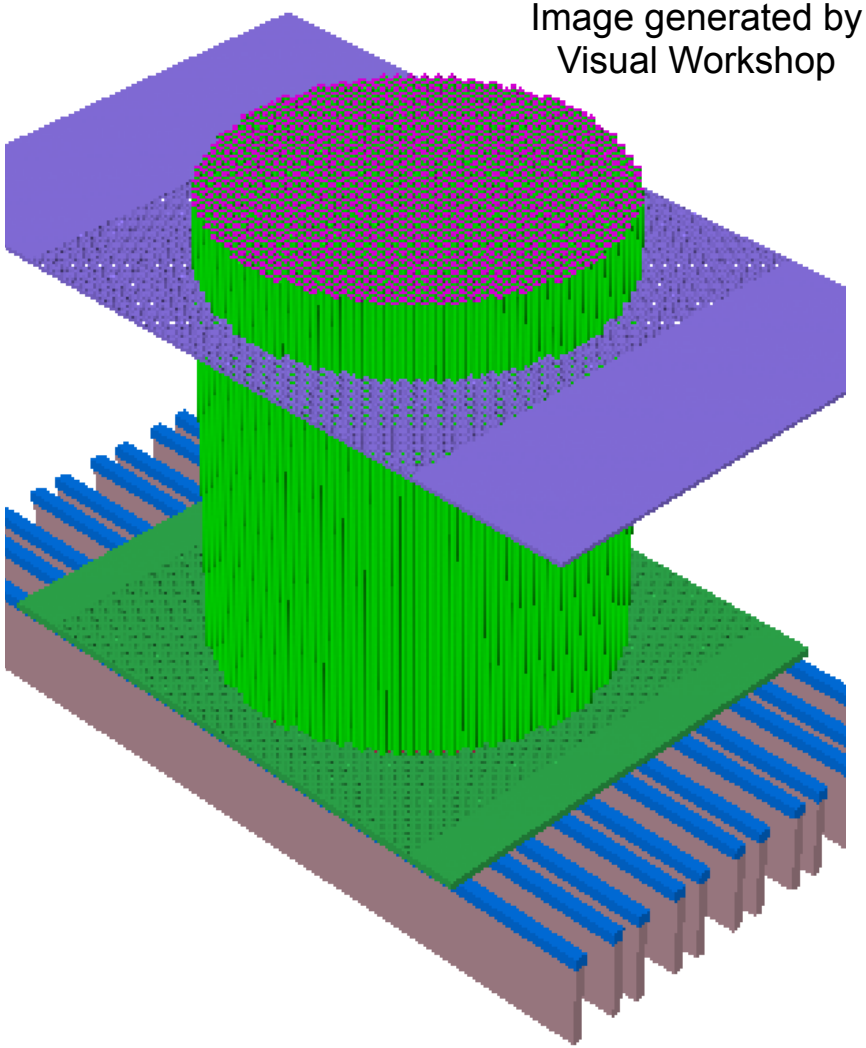
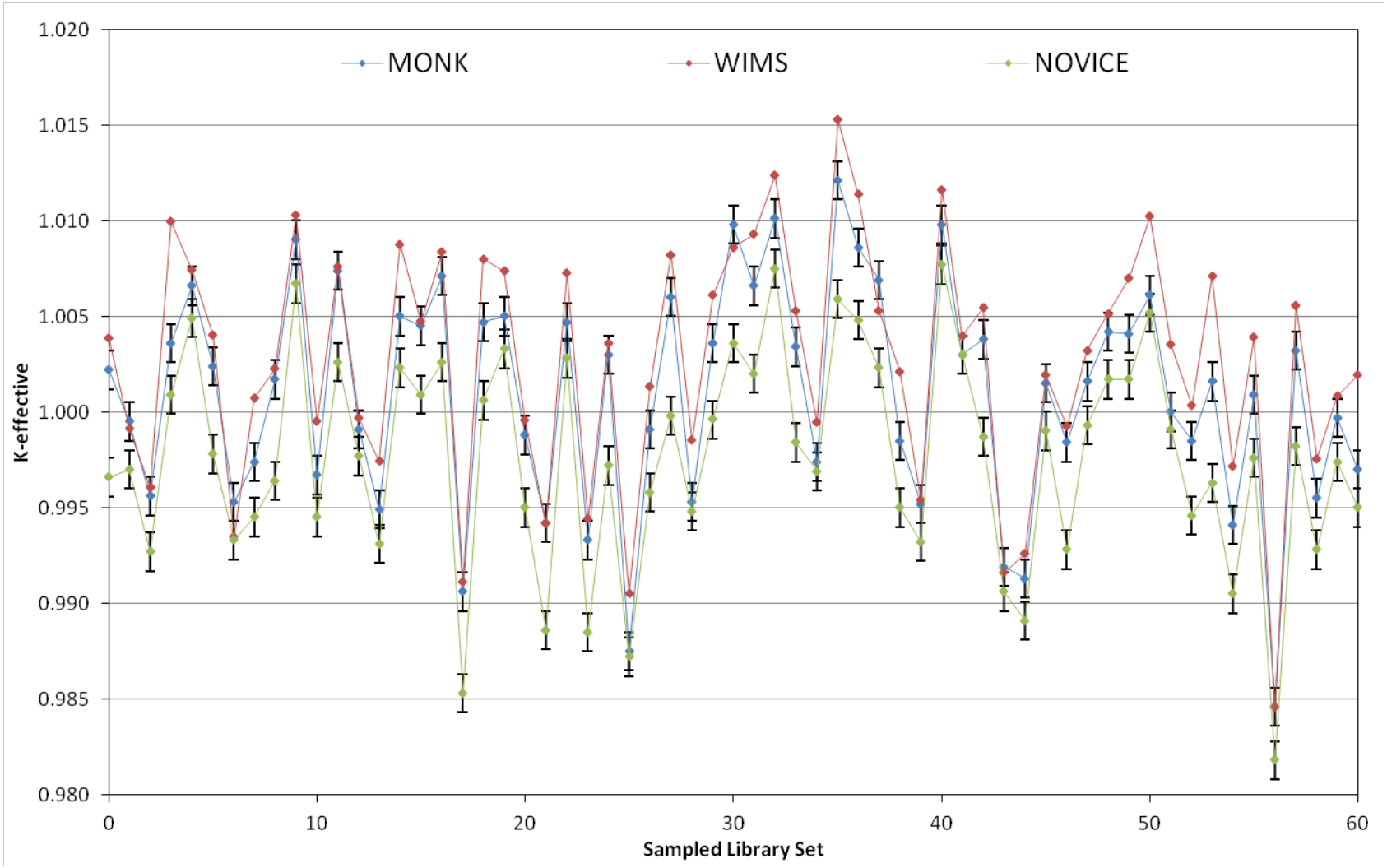


DIMPLE Results (SO1/A)



DIMPLE Results (SO1/A)

		MONK	WIMS	NOVICE
Unsampled		1.00180	1.00385	0.99750
LHS25	average	1.00099	1.00259	0.99755
	std. dev.	0.00541	0.00611	0.00566
	bias	-0.00081	-0.00126	+0.00005
LHS60	average	1.00085	1.00264	0.99750
	std. dev.	0.00586	0.00625	0.99764
	bias	-0.00095	-0.00121	+0.00563

BICEP Benchmark Test

- 26 experiments performed at Harwell & Winfrith UK (1963)
- U metal in graphite
  - 0.42-1.14 w% U-235,
  - varying rod diameters and pitches
- Extrapolation to derived critical buckling terms
- Modelled with MONK and WIMS as single fuel cell with reflective boundaries
  - Leakage is then applied using buckling terms

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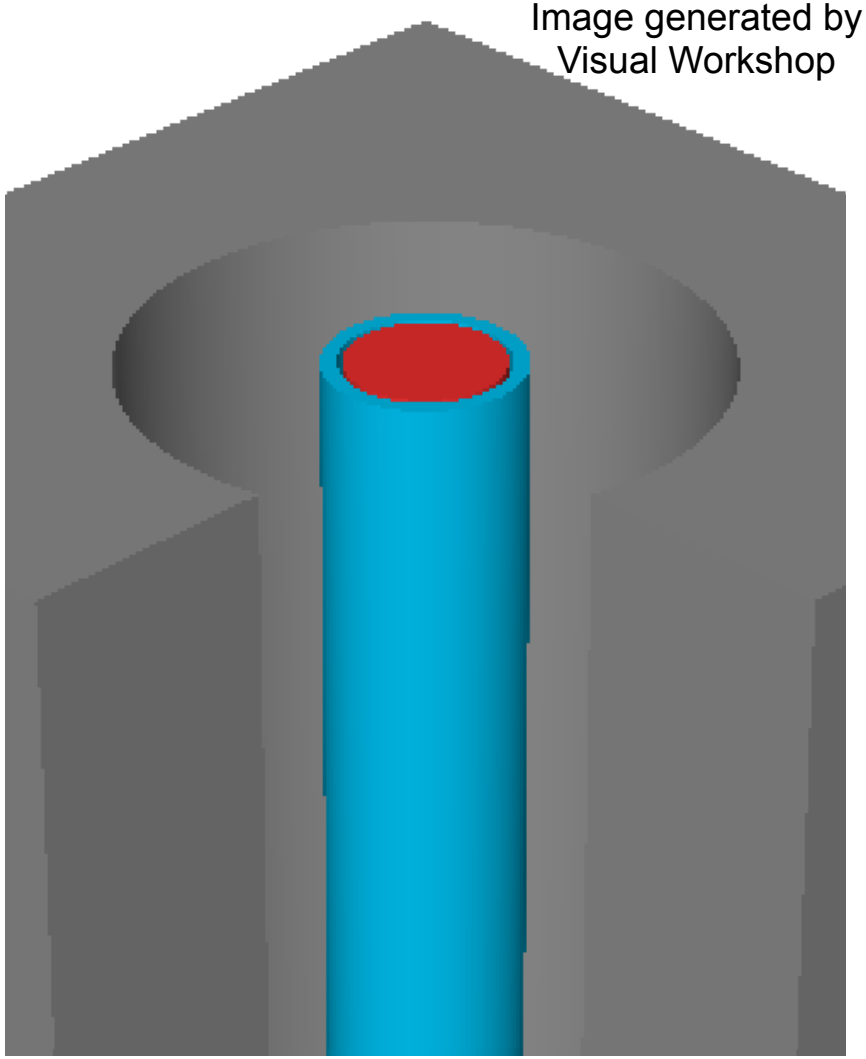
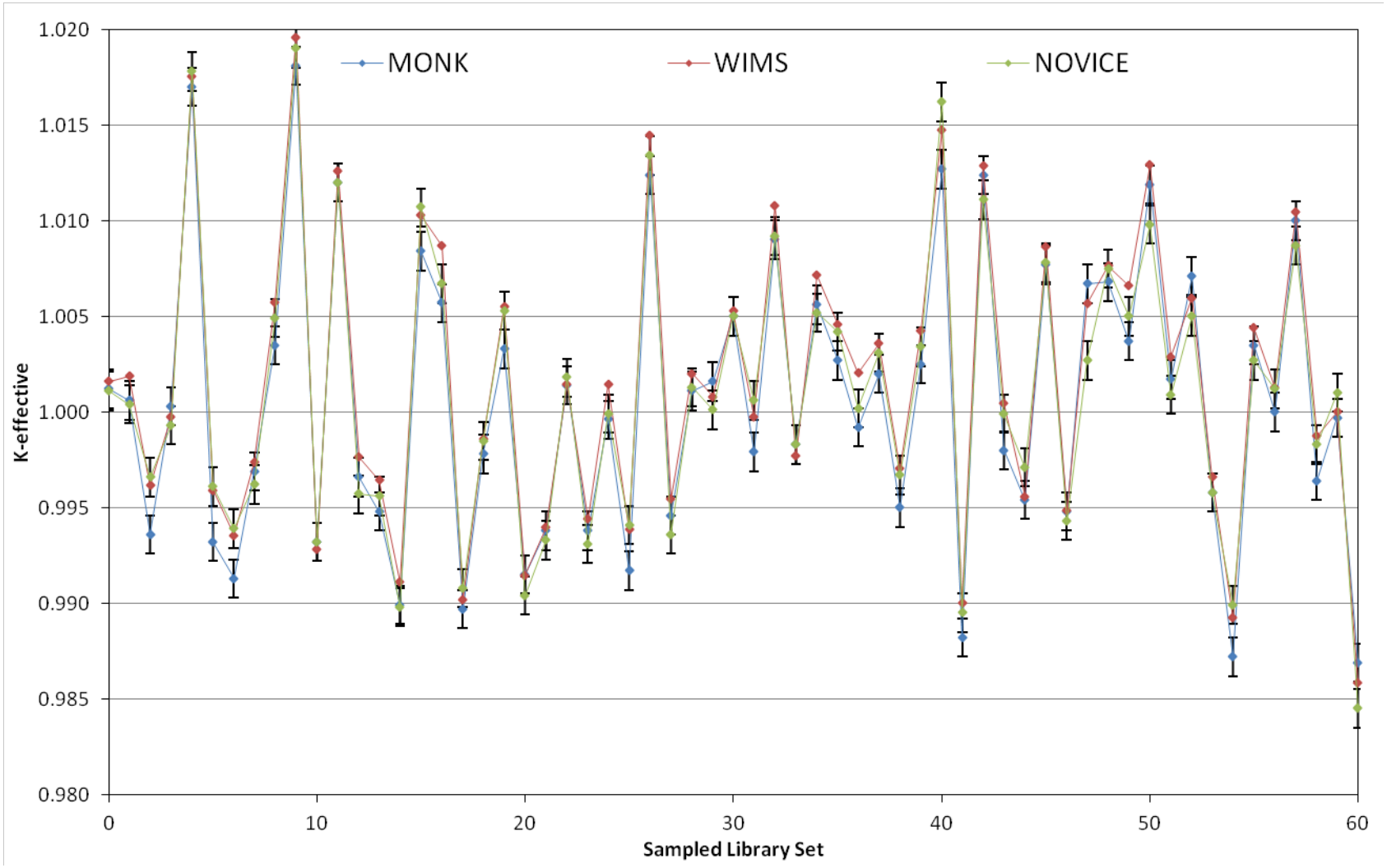


BICEP Results (Exp.97, U-nat fuel)



BICEP Results (Exp.97, U-nat fuel)

		MONK	WIMS	NOVICE
Unsampled		1.00120	1.00160	1.00110
LHS25	average	1.00020	1.00153	1.00116
	std. dev.	0.00691	0.00697	0.00687
	bias	-0.00100	-0.00007	+0.00006
LHS60	average	1.00052	1.00164	1.00097
	std. dev.	0.00746	0.00754	0.00739
	bias	-0.00068	+0.00004	-0.00013

Conclusions

- A method has been established to quantify the effects of nuclear data uncertainty through the production of sampled nuclear data libraries
- BINGO and WIMS versions of the libraries produce consistent results through MONK and WIMS respectively
- Testing against benchmarks
  - Satisfactory agreement between MONK and WIMS
  - Total nuclear data uncertainty 0.5-0.7% (indicative only)
- Future developments:
  - Refinement based on future releases of covariance data
  - Treatment of bound thermal scattering uncertainties (WPEC Subgroup 42)

- Thank you for your attention