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Title: MCNP Monte Carlo Progress - Nuclear Criticality Safety

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DOE Nuclear Criticality Safety Program
Technical Seminar at ORNL, 1-2 March 2011

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MCNP Monte Carlo Progress
-
Nuclear Criticality Safety

Forrest Brown & Brian Kiedrowski

Monte Carlo Codes, XCP-3
Los Alamos National Laboratory

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NNSA Nuclear Criticality Safety Program

Abstract

MCNP Monte Carlo Progress – Nuclear Criticality Safety

Forrest Brown & Brian Kiedrowski, XCP-3, LANL

This presentation covers recent progress in development and support of the MCNP Monte Carlo code during FY 2010 and early FY 2011. Activities and accomplishments are summarized in five major areas:

- MCNP5-1.60 development, V&V, documentation, and release
- Verification / Validation
- Work in progress
- User support & training
- Future release plans

MCNP Progress

- **MCNP5-1.60 release**
  - Features & bug-fixes
  - Verification / validation
- **Verification / validation**
  - Expanded criticality suite
  - Additional V&V suites
- **User support & training**
  - Criticality classes
  - Communications / collaborations
  - Reference collection
- **Work in progress**
  - Adjoint-weighted perturbations & sensitivity/uncertainty
  - Diagnostics for population size & coverage
- **Future release plans**
  - MCNP6 – merged MCNP5 + MCNPX
  - Release plans

MCNP5-1.60
Release

MCNP5-1.60 Release

- **Chronology**
  - Development: Fall 2009 – Spring 2010
  - Extensive testing & V&V: Summer 2010
  - Sent to RSICC: September 2010
  - RSICC release: October 2010

- **Focus**
  - **Stability + reliability for criticality calculations**
  - **Support for latest computers – multicore, Windows/Mac/Linux, 32/64 bit**
  - **Rigorous, extensive code V&V**
  - **A few new features, many minor bug-fixes**

- **Notable**
  - **Most rigorous & extensive MCNP testing ever**
  - **Over 5,000 hr computer time for V&V, mostly on criticality problems**
  - **First production release of adjoint-weighted tallies (kinetics parameters)**

New Features in MCNP5-1.60 (1)

Monte Carlo Codes
XCP-3, LANL

- **Adjoint-weighted Tallies for Point Kinetics Parameters**
  - First correct calculation of β_{eff}, Λ_{eff}, Rossi-alpha using continuous-energy Monte Carlo and adjoint weighting
  - First production application of iterated fission probability to compute adjoint-weighted tallies
  - Thorough V&V against analytic, Sn, experiment

- **Mesh Tallies for Isotopic Reaction Rates**
  - Previously, could only do flux, dose, material reaction rates
  - Important extension to specific isotopes
  - Possible use in activation analysis or burnup

- **Increased Limits for Geometry, Tally, and Source Specifications**
  - Allow up to 100M for cell, surface, material specs. Previous 100K limit
  - Complex cell spec up to 9999 items, previous 999 limit
  - Needed to support complicated problems, CAD conversion, …..

New Features in MCNP5-1.60 (2)

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- **Web-based documentation**
  - 280 MB of reference material – theory, coding, V&V, user manual
  - Installation instructions & scripts

- **Utility programs**
  - Improved **`merge_mctal`** for merging results from multiple runs
  - Improved **`merge_meshtal`** for merging results from multiple runs

- **Additional V&V suites – see part 3 of this presentation**

- **General**
  - Support for threading on multicore computers
  - Parallel processing efficiency for MPI criticality calculations
  - Arbitrary number of threads for restart (continue) runs
  - 12 other minor enhancements to code
  - 30 minor bug-fixes (none affect results for criticality calculations)

Verification / Validation for MCNP5-1.60 (1)

- **Testing + V&V Suites**

```
VALIDATION_CRITICALITY          VERIFICATION_KEFF
VALIDATION_SHIELDING            KOBAYASHI
POINT_KINETICS                  REGRESSION
```

- **Computers**
  - Mac / Linux / Windows, 32 / 64 bit
  - Sequential, threads, MPI, threads+MPI
  - Over 5,000 hr computer time
  - 2 students full-time + 2.5 staff part-time for 3 months

- **Criticality calculations**
  - Tested with ENDF/B-VI & ENDF/B-VII.0
  - All results should match previous versions of MCNP5

Verification / Validation for MCNP5-1.60 (2)

Monte Carlo Codes
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MCNP Criticality Validation Suite, Results on Mac OS X for ENDF/B-VII.0

	Experiment	MCNP5-1.51	MCNP5-1.60
U233 Benchmarks			
JEZ233	1.0000 (10)	0.9989 (6)	0.9989 (6)
FLAT23	1.0000 (14)	0.9990 (7)	0.9990 (7)
UMF5C2	1.0000 (30)	0.9931 (6)	0.9931 (6)
FLSTF1	1.0000 (83)	0.9830 (11)	0.9830 (11)
SB25	1.0000 (24)	1.0053 (10)	1.0053 (10)
ORNL11	1.0006 (29)	1.0018 (4)	1.0018 (4)
HEU Benchmarks			
GODIVA	1.0000 (10)	0.9995 (6)	0.9995 (6)
TT2C11	1.0000 (38)	1.0018 (8)	1.0018 (8)
FLAT25	1.0000 (30)	1.0034 (7)	1.0034 (7)
GODIVR	0.9985 (11)	0.9990 (7)	0.9990 (7)
UH3C6	1.0000 (47)	0.9950 (8)	0.9950 (8)
ZEUS2	0.9997 (8)	0.9974 (7)	0.9974 (7)
SB5RN3	1.0015 (28)	0.9985 (13)	0.9985 (13)
ORNL10	1.0015 (26)	0.9993 (4)	0.9993 (4)

	Experiment	MCNP5-1.51	MCNP5-1.60
IEU Benchmarks			
IMF03	1.0000 (17)	1.0029 (6)	1.0029 (6)
BIGTEN	0.9948 (13)	0.9945 (5)	0.9945 (5)
IMF04	1.0000 (30)	1.0067 (6)	1.0067 (6)
ZEBR8H	1.0300 (25)	1.0195 (6)	1.0195 (6)
ICT2C3	1.0017 (44)	1.0037 (7)	1.0037 (7)
STACY36	0.9988 (13)	0.9994 (6)	0.9994 (6)
LEU Benchmarks			
BAWXI2	1.0007 (12)	1.0013 (7)	1.0013 (7)
LST2C2	1.0024 (37)	0.9940 (6)	0.9940 (6)
Pu Benchmarks			
JEZPU	1.0000 (20)	1.0002 (6)	1.0002 (6)
JEZ240	1.0000 (20)	1.0002 (6)	1.0002 (6)
PUBTNS	1.0000 (30)	0.9996 (6)	0.9996 (6)
FLATPU	1.0000 (30)	1.0005 (7)	1.0005 (7)
THOR	1.0000 (6)	0.9980 (7)	0.9980 (7)
PUSH2O	1.0000 (10)	1.0012 (7)	1.0012 (7)
HISHPG	1.0000 (110)	1 0122 (5)	1.0122 (5)
PNL2	1.0000 (65)	1.0046 (9)	1.0046 (9)
PNL33	1.0024 (21)	1.0065 (7)	1.0065 (7)

Verification / Validation for MCNP5-1.60 (3)

Monte Carlo Codes
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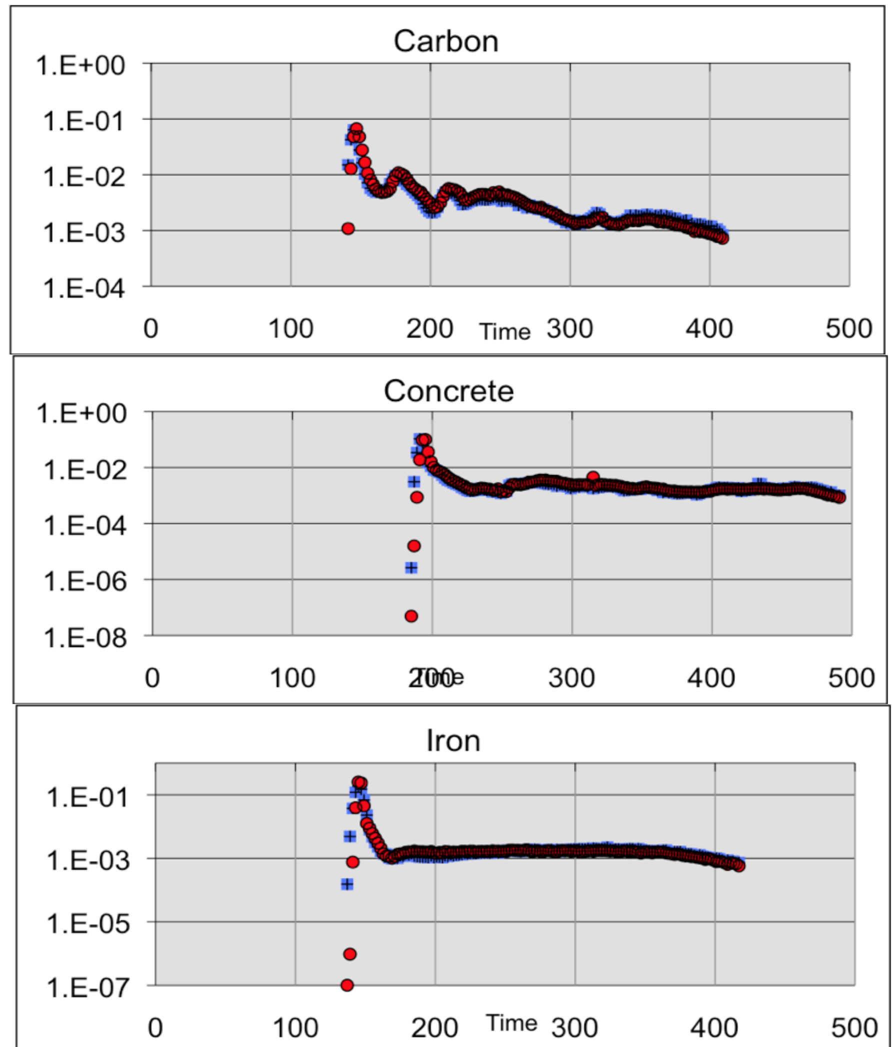
MCNP Kinetics Parameter Validation Suite Results on Linux

	Benchmark		MCNP5	
Rossi-Alpha vs Experiments				
GODIVA	-0.0011	2e-05	-0.001131	7e-6
JEZPU	-0.00064	1e-05	-0.000649	8e-6
BIGTEN	-0.000117	1e-06	-0.0001156	7e-7
FLAT23	-0.000267	5e-06	-0.0002931	3e-6
STACY29	-0.000122	4e-06	-0.0001222	9e-7
WINCO5	-0.001109	3e-06	-0.001124	1e-5
Generation Time vs Exact Analytic Solutions				
ONEINF	10		9.999	0.00085
TWOINF	14.17		14.16	0.00275
Generation Time vs PARTISN Solutions				
BARESLAB	9.793		9.792	0.00594
REFLSLAB	135.2		135.1	0.1068
THRESLAB	49.17		49.28	0.1018
INTRSLAB	112.1		112.7	0.4397
BARESPHR	1.721		1.722	0.00102
REFLSPHR	10.19		10.19	0.00737
SUBCSLAB	10.17		10.17	0.0073
SUPCSLAB	9.673		9.674	0.00526

Pulsed Sphere Problems (3 of 8)

■ Experiment, ● MCNP5-1.60



Verification

&

Validation

Verification / Validation Suites

- **MCNP V&V Suites**
  - Traditional:

– **VALIDATION_CRITICALITY**	31 experiment benchmarks
– **VERIFICATION_KEFF**	75 analytic benchmarks
– **VALIDATION_SHIELDING**	19 shielding/dose experiments
– **REGRESSION**	66 code test problems

  - New:

– **KOBAYASHI**	void & duct streaming, with point detectors
– **POINT_KINETICS**	reactor kinetics parameters
– **VALIDATION_CRIT_EXPANDED**	119 ICSBEP Handbook experiments

- **Focus**
  - Physics-based V&V, compare to experiment or exact analytic results
  - Part of MCNP permanent code repository & RSICC distribution
  - Automated, easy execution
  - Automated, easy collection of results & comparison to experiment

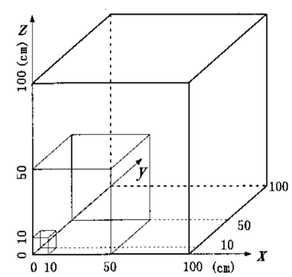
Kobayashi Benchmark Results (1 of 6 problems)

Problem 1, Absorption + Scatter, 100M Histories

	x, y, z	Reference		MCNP-result		C/E
Detector Set A						
f1405	5, 5, 5	8.29e+0	0.0002	8.22e+0	0.0002	**0.99**
f1415	5,15, 5	1.87e+0	0.0001	1.86e+0	0.0002	**1.00**
f1425	5,25, 5	7.13e-1	0.0000	7.13e-1	0.0001	**1.00**
f1435	5,35, 5	3.84e-1	0.0000	3.84e-1	0.0001	**1.00**
F1445	5,45, 5	2.53e-1	0.0001	2.54e-1	0.0001	**1.00**
F1455	5,55, 5	1.37e-1	0.0007	1.37e-1	0.0005	**1.00**
F1465	5,65, 5	4.65e-2	0.0012	4.68e-2	0.0007	**1.01**
F1475	5,75, 5	1.58e-2	0.0020	1.59e-2	0.0008	**1.00**
F1485	5,85, 5	5.47e-3	0.0034	5.48e-3	0.0012	**1.00**
F1495	5,95, 5	1.85e-3	0.0062	1.83e-3	0.0019	**0.99**
Detector Set B						
F1505	5, 5, 5	8.29e+0	0.0002	8.22e+0	0.0002	**0.99**
F1515	15,15,15	6.63e-1	0.0000	6.63e-1	0.0001	**1.00**
F1525	25,25,25	2.68e-1	0.0000	2.69e-1	0.0001	**1.00**
F1535	35,35,35	1.56e-1	0.0001	1.57e-1	0.0001	**1.00**
F1545	45,45,45	1.04e-1	0.0001	1.04e-1	0.0002	**1.00**
F1555	55,55,55	3.02e-2	0.0006	3.01e-2	0.0009	**1.00**
F1565	65,65,65	4.06e-3	0.0007	4.08e-3	0.0015	**1.01**
F1575	75,75,75	5.86e-4	0.0012	5.89e-4	0.0034	**1.01**
F1585	85,85,85	8.66e-5	0.0020	8.73e-5	0.0087	**1.01**
F1595	95,95,95	1.12e-5	0.0038	1.16e-5	0.0236	**1.03**

	x, y, z	Reference		MCNP-result		C/E
Detector Set C						
F1605	5,55, 5	1.37e-1	0.0007	1.37e-1	0.0005	**1.00**
F1615	15,55, 5	1.27e-1	0.0008	1.28e-1	0.0005	**1.00**
F1625	25,55, 5	1.13e-1	0.0008	1.13e-1	0.0005	**1.00**
F1635	35,55, 5	9.59e-2	0.0009	9.65e-2	0.0006	**1.01**
F1645	45,55, 5	7.82e-2	0.0009	7.88e-2	0.0006	**1.01**
F1655	55,55, 5	5.67e-2	0.0011	5.65e-2	0.0007	**1.00**
F1665	65,55, 5	1.88e-2	0.0019	1.89e-2	0.0009	**1.01**
F1675	75,55, 5	6.46e-3	0.0031	6.50e-3	0.0012	**1.01**
F1685	85,55, 5	2.28e-3	0.0053	2.29e-3	0.0018	**1.01**
F1695	95,55, 5	7.93e-4	0.0089	8.00e-4	0.0029	**1.01**

 # 1



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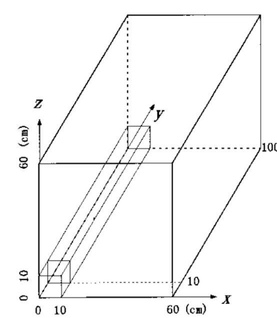

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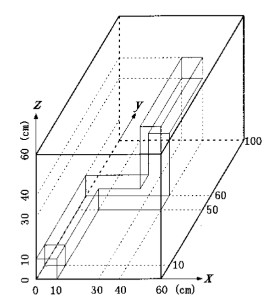


Rossi-alpha Validation Suite

- **MCNP5-1.60 can compute kinetics parameters**
  - Requires adjoint weighting techniques
  - Calculates of Rossi-alpha ($-\beta_{eff}/\Lambda$)
- **Twelve benchmarks identified by Mosteller**
  - 4 HEU, 3 IEU, 3 Pu, 2 U-233
  - 8 fast, 2 intermediate, 2 thermal

	Rossi-alpha (10^4 gens/second)		
Name	**Experiment**	**ENDF-VI**	**ENDF-VII.0**
Jezebel-233	-100 ± 1	-109 ± 1	-108 ± 1
Flattop-23	-26.7 ± 0.5	-30.9 ± 0.4	-30.2 ± 0.4
Godiva	-111 ± 2	-117 ± 2	-111 ± 2
Flattop-25	-38.2 ± 0.2	-40.9 ± 0.2	-39.7 ± 0.2
Zeus-1	-0.338 ± 0.008	-0.372 ± 0.002	-0.360 ± 0.002
Zeus-4	-2.61 ± 0.02	-3.27 ± 0.01	-3.21 ± 0.01
BIG TEN	-11.7 ± 0.1	-12.5 ± 0.1	-11.8 ± 0.2
STACY-30	-0.0127 ± 0.0003	-0.0133 ± 0.0003	-0.0133 ± 0.0003
STACY-46	-0.0106 ± 0.0004	-0.0110 ± 0.0002	-0.0104 ± 0.0002
Jezebel	-64 ± 1	-64 ± 1	-65 ± 1
Flattop-Pu	-21.4 ± 0.5	-21.6 ± 0.3	-21.0 ± 0.3
THOR	-20 ± 1	-20 ± 2	-21 ± 1

Expanded Criticality Validation Suite (1)

- **New, well-documented criticality suite**

  R.D. Mosteller, "An Expanded Criticality Validation Suite for MCNP",
  LA-UR-10-06230 (227 pages including MCNP inputs)

- **119 ICBEP Handbook experiments:**

Fuel	Fast	Intermediate	Thermal	Total
U-233	10	1	7	18
HEU	29	5	6	40
IEU	10	1	6	17
LEU	-	-	8	8
Pu	21	1	14	36
Total	**70**	**8**	**41**	**119**

- **MCNP**
  - Automated execution & collection of results
  - Can run with ENDF/B-VI, T16+ENDF/B-VI, ENDF/B-VII.0 data
  - 7.75 hr on 8-core Mac Pro (714 M total neutron histories)

Expanded Criticality Validation Suite (2)

Monte Carlo Codes
XCP-3, LANL

HEU Benchmarks

Spectrum	Form	Shape	Reflector	Benchmark(s)
Fast	Metal	Sphere	Unreflected	heu-met-fast-001 heu-met-fast-008 heu-met-fast-018-case-2
			Normal uranium	heu-met-fast-003-case-1 heu-met-fast-003-case-2 heu-met-fast-003-case-3 heu-met-fast-003-case-4 heu-met-fast-003-case-5 heu-met-fast-003-case-6 heu-met-fast-003-case-7 heu-met-fast-028
			Depleted uranium	heu-met-fast-014
			Tungsten carbide	heu-met-fast-003-case-8 heu-met-fast-003-case-9 heu-met-fast-003-case-10 heu-met-fast-003-case-11
			Nickel	heu-met-fast-003-case-12
			Steel	heu-met-fast-013 heu-met-fast-021-case-2
			Duralumin	heu-met-fast-022-case-2
			Aluminum	heu-met-fast-012
			Graphite	heu-met-fast-019-case-2
			Beryllium oxide	heu-met-fast-009-case-2
			Beryllium	heu-met-fast-009-case-1
			Polyethylene	heu-met-fast-011 heu-met-fast-020-case-2
			Water	heu-met-fast-004-case-1
		Cylinder	Unreflected	heu-met-fast-015
		Lattice	Paraffin	heu-met-fast-026-case-c-11

HEU Benchmarks

Spectrum	Form	Shape	Reflector, Moderator and/or Buffer	Benchmark(s)
Intermediate	UH_3	Cylinders	Natural uranium	heu-comp-inter-003, case-6
	Metal	Cylinders	Graphite, copper	heu-met-inter-006-case-1 heu-met-inter-006-case-2 heu-met-inter-006-case-3 heu-met-inter-006-case-4
Thermal	$UO_2 + ZrO_2$	Lattice	Water, ThO_2	u233-comp-inter-001-case-6
	Solution	Sphere	Unreflected	heu-sol-therm-013-case-1 heu-sol-therm-013-case-2 heu-sol-therm-013-case-3 heu-sol-therm-013-case-4 heu-sol-therm-032

U-233 Benchmarks

Spectrum	Form	Shape	Moderator and /or Reflector	Benchmark(s)
Fast	Metal	Sphere	Unreflected	u233-met-fast-001
			HEU	u233-met-fast-002-case-1 u233-met-fast-002-case-2
			Normal uranium	u233-met-fast-003-case-1 u233-met-fast-003-case-2 u233-met-fast-006
			Tungsten	u233-met-fast-004-case-1 u233-met-fast-004-case-2
			Beryllium	u233-met-fast-005-case-1 u233-met-fast-005-case-2
Intermediate	Solution	Sphere	Beryllium	u233-sol-inter-001-case-1
Thermal	$UO_2 + ZrO_2$	Lattice	Water	u233-comp-therm-001-case-3
	Solution	Sphere	Unreflected	u233-sol-therm-001-case-1 u233-sol-therm-001-case-2 u233-sol-therm-001-case-3 u233-sol-therm-001-case-4 u233-sol-therm-001-case-5 u233-sol-therm-008

Expanded Criticality Validation Suite (3)

IEU Benchmarks

Spectrum	Form	Shape	Reflector and/or Buffer	Benchmark(s)
Fast	Metal	Sphere	Unreflected	ieu-met-fast-003-case-2
			Steel	ieu-met-fast-005-case-2
			Duralumin	ieu-met-fast-006-case-2
			Graphite	ieu-met-fast-004-case-2
		Cylinders	Unreflected	ieu-met-fast-001-case-1 ieu-met-fast-001-case-2 ieu-met-fast-001-case-3 ieu-met-fast-001-case-4
			Normal uranium	ieu-met-fast-002
			Depleted uranium	ieu-met-fast-007-case-4
Intermediate	Plate	Lattice	Normal uranium, steel	mix-met-fast-008-case-7
Thermal	UO_2	Lattice	Water	ieu-comp-therm-002-case-3
	Solution	Cylinder	Unreflected	leu-sol-therm-027-case-14 leu-sol-therm-027-case-30 leu-sol-therm-027-case-32 leu-sol-therm-027-case-36 leu-sol-therm-027-case-49

LEU Benchmarks

Spectrum	Form	Shape	Buffer and/or Reflector	Benchmark(s)
Thermal	UO_2	Lattice	UO_2 Rods, Water	leu-comp-therm-008-case-1 leu-comp-therm-008-case-2 leu-comp-therm-008-case-5 leu-comp-therm-008-case-7 leu-comp-therm-008-case-8 leu-comp-therm-008-case-11
	Solution	Sphere	Water	leu-sol-therm-002-case-1
			Unreflected	leu-sol-therm-002-case-2

Pu Benchmarks

Spectrum	Form	Shape	Reflector and/or Buffer	Benchmark(s)
Fast	Metal	Sphere	Unreflected	pu-met-fast-001 pu-met-fast-002 pu-met-fast-022-case-2
			HEU	mix-met-fast-001 mix-met-fast-003
			Normal uranium	pu-met-fast-006 pu-met-fast-010
			Depleted uranium	pu-met-fast-020
			Thorium	pu-met-fast-008-case-2
			Tungsten	pu-met-fast-005
			Steel	pu-met-fast-025-case-2 pu-met-fast-026-case-2
			Aluminum	pu-met-fast-009
			Graphite	pu-met-fast-023-case-2
			Beryllium	pu-met-fast-018 pu-met-fast-019
			Polyethylene	pu-met-fast-024-case-2
			Water	pu-met-fast-011
		Cylinders	Beryllium oxide	pu-met-fast-021-case-2
			Beryllium	pu-met-fast-021-case-1
		Lattice	Unreflected	pu-met-fast-003-case-103

Spectrum	Form	Shape	Reflector and/or Moderator	Benchmark(s)
Intermediate	Mixture	Homogeneous	Hydrogen, graphite	pu-comp-inter-001
Thermal	MOX	Lattice	Water	mix-comp-therm-002-case-pnl-30 mix-comp-therm-002-case-pnl-31 mix-comp-therm-002-case-pnl-32 mix-comp-therm-002-case-pnl-33 mix-comp-therm-002-case-pnl-34 mix-comp-therm-002-case-pnl-35
	Solution	Sphere	Unreflected	pu-sol-therm-009-case-3a pu-sol-therm-011-case-16-5 pu-sol-therm-011-case-18-1 pu-sol-therm-011-case-18-6 pu-sol-therm-021-case-1 pu-sol-therm-021-case-3
		Cylinder	Water	pu-sol-therm-018-case-9 pu-sol-therm-034-case-1

User Support
&
Training

User Support & Training

- **Classes**
  - Theory & Practice of Criticality Calculations with MCNP5
    Hanford/PNNL, LANL, Y-12 (soon)
  - Introduction to MCNP5 – 3 classes at LANL
  - Advanced Variance Reduction – at LANL

- **Monte Carlo Workshop at PHYSOR-2010**

- **Conferences**

– SNA+MC-2010:	plenary talk + 3 papers	(crit, perturb, parallel)
– ANS Winter 2010:	1 paper	(V&V for perturb)
– M&C 2011:	1 paper	(statistical tests)
– ANS Summer 2011:	3 papers	(stats, V&V, crit suite)
– NS&E journal:	paper on adjoint-weighted tallies	

- **Participated in ANS 10.7 Standards committee**

User Support & Training

- **MCNP Forum**
  - User-group – beginners & experts, ~900 members
  - Feedback, bug reports, guidance

- **Reference collection**
  - 600+ MB of references on Monte Carlo & MCNP, ~300 items
  - Web browser based
  - All MCNP5 & previous MCNP code documentation
  - Criticality, V&V, adjoints, electrons, detectors, parallel, benchmarks, …..
  - Includes 8 half-day Monte Carlo workshops

- **University collaborations**
  - Michigan, New Mexico, Wisconsin, Oregon State, MIT, RPI
  - Summer students at LANL

Work in Progress

Perturbation Theory

- **MCNP computes perturbations to k using two methods:**
  - **Differential operator/Taylor series** (1990's)
  - **Adjoint-based** (2010)
    - Only for k-effective (differential operator is more general)
    - Allows applications such as additions of impurities, cross-section library comparisons, and material substitutions that were not possible with differential operator

- **Verification and Validation efforts show:**
  - Good agreement when Δk's in same direction
  - When both are applicable, methods are complementary (neither one always better)
  - Often difficulties with scattering cross section perturbations observed

Continuous-Energy Sensitivity Coefficients

- **MCNP6 can produce sensitivity coefficients in continuous-energy**
  - Uses adjoint-weighted perturbation techniques
  - Verified against multigroup results
  - Good performance for capture and fission

- **Scattering needs some improvements**
  - In theory need double-differential scattering cross sections
  - Approximate extensions with scattering laws should be straightforward
  - Exact is theoretically possible, but costly

Boundary Sensitivity Coefficients

- **Boundary interface locations (e.g., radius of a sphere) is uncertain**
- **Favorite showed theory of computing sensitivity coefficients to interface locations**
- **Should be extendable to continuous-energy Monte Carlo**
  - Necessarily uses “exact” method for scattering sensitivities
  - Work in progress, results to be presented

Reliability of Large Collections of Tallies

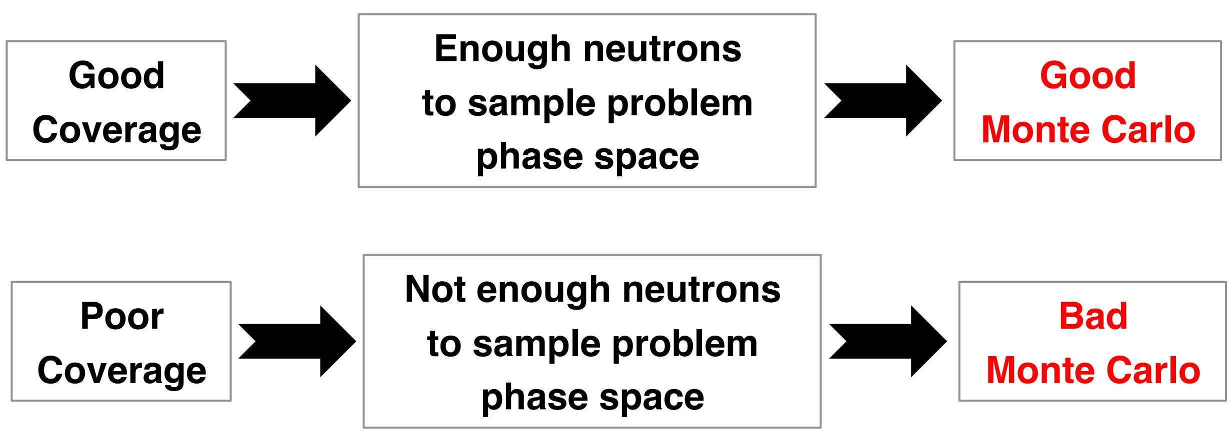
- **Criticality alarm design and accident assessment require global flux or dose fields**
  - High resolutions (often > 100K mesh elements)
  - Can results be trusted?

- **Some MCNP statistical checks extended**
  - Observe convergence of moments of relative variances
  - Minimal memory cost or computational time
  - Sensitive to large scores in few mesh elements
    - Suggests undersampling somewhere in problem

- **Applications in criticality safety, reactor physics, shielding, etc.**

Statistical Coverage

- **Recent focus on issues of criticality calculations**
  - Convergence (Shannon entropy, etc.)
  - Bias of k_{eff} (~1/N, use N > 5000)
  - Underestimation of uncertainties (Understood, work in progress to address)
- **Implicit assumption that all regions of problem are adequately covered**
  - Easy to satisfy for typical reactors
  - May be difficult for certain criticality safety problems
    - Multiple regions that are loosely coupled
    - Some region(s) more reactive than others
    - Asymmetric coupling between regions

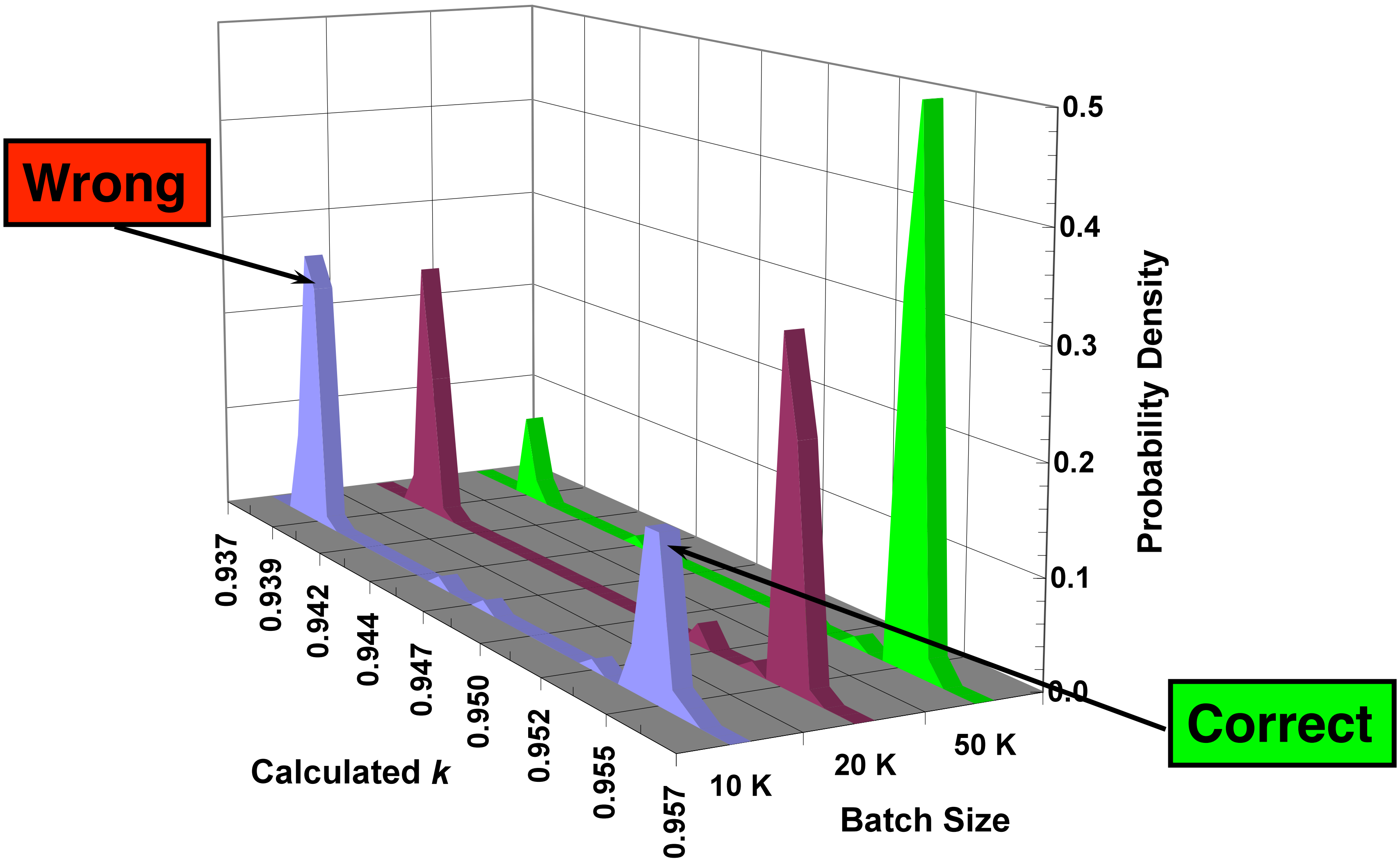


Statistical Coverage

- **"Revised k-eff of the World" problem**
  - 9x9x9 loosely-coupled array of Pu spheres in water
  - Central sphere larger than the rest and has a cadmium coating (asymmetric coupling)
- **Results of 100 independent trials:**
  - 10K particles per cycle, 1000 inactive, 500 active cycles
  - Starting guess: uniformly sample points in the center of each sphere
  - Convergence of k and Shannon entropy always observed

  - 60% chance of **getting wrong k**
  - 20% chance of **getting wrong k** **with no warning**

Statistical Coverage



Motivates need for population diagnostics

Future Release Plans

MCNP6

- **MCNP6 = MCNP5 + MCNPX merger**
  - Retains all capabilities in MCNP5 & MCNPX
    - High-energy physics (ie, GeV, TeV), 36 particle types, heavy ions, …..
    - Many new features for Homeland Security, detectors, …..
    - Depletion using CINDER-90, …..
- **Impact on Criticality Calculations → none**
  - **All KCODE criticality features same as for MCNP5**
  - **Matches results with MCNP5 for criticality suites**
- **Monte Carlo team will support MCNP6, not MCNP5/MCNPX/MCNP6**
- **MCNP6 is coming**
  - Beta-0 release: 1Q CY 2011 – very limited distribution
  - Beta-1 release: 4Q CY 2011 – general beta testing
  - Production release: ?

Later this year, we need to plan for MCNP5 → MCNP6 transition