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Verification of MCNP5-1.60 & MCNP6.1 for Criticality Safety Applications

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Nuclear Criticality Safety Program

Abstract

Verification of MCNP5-1.60 and MCNP6.1 for Criticality Safety Applications

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To verify that both MCNP5-1.60 and MCNP6.1 are performing correctly for criticality safety applications, several suites of verification/validation benchmark problems were run in early 2013. Results from these benchmark suites were compared with results from previously verified versions of MCNP5. Testing results for 354 problems on Mac OS X, Linux, and Windows systems indicate that: (1) Both MCNP5-1.60 and MCNP6.1 perform correctly for criticality safety applications. (2) Using the latest compilers, small differences were noted for a few cases compared to using older compilers, but these are strictly due to computer roundoff and are not a concern for verification. (3) MCNP5-1.60 and MCNP6.1 yield the same results on different computer platforms – Mac OS X, Linux, and Windows – for criticality safety applications. (4) MCNP5-1.60 and MCNP6.1 yield the same results using OpenMP threading and/or MPI message-passing parallelism. Criticality safety analysts should consider testing MCNP6.1 on their particular problems and validation suites, to prepare for the migration from MCNP5 to MCNP6. It is expected that this migration should be accomplished within the next 1-3 years.

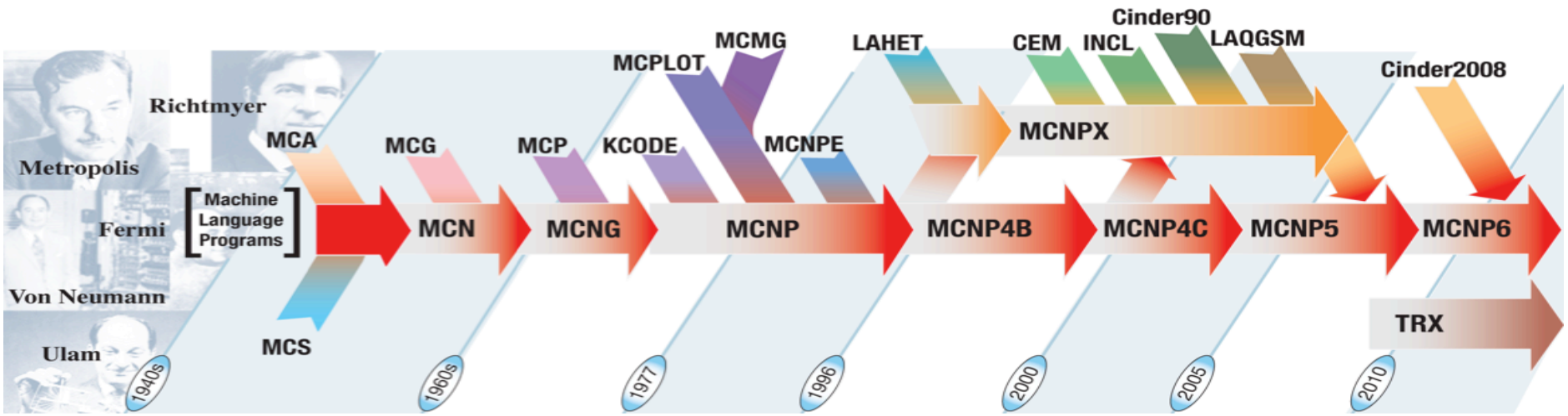
US DOE/NNSA Nuclear Criticality Safety Program –

What have we done for you lately ?

- MCNP6 Release, with ENDF/B-VII.1
- Verification / Validation
- User Support & Training
- New Criticality Methods

This talk: Verification & Validation

MCNP Progress



- **MCNP release by RSICC in July 2013**

  MCNP6.1 + MCNP5-1.60 + MCNPX-2.70

  Nuclear Data Libraries + MCNP Reference Collection

- **Over 1 year of beta-testing + verification-validation for MCNP6**

- **MCNP5 & MCNPX were frozen – future development only in MCNP6**

Support from DOE/NNSA, DOE, DoD, DTRA, DHS/DNDO, NASA, & others

MCNP5-1.60 vs MCNP6.1

mcnp5

neutrons, photons, electrons
cross-section library physics
criticality features
shielding, dose
"low energy" physics
V&V history
documentation

mcnp6

protons, proton radiography
high energy physics models
magnetic fields

Partisn mesh geometry
Abaqus unstructured mesh

mcnp6

mcnpx

33 other particle types
heavy ions
CINDER depletion/burnup
delayed particles

New Criticality Features
Sensitivity/Uncertainty Analysis
Fission Matrix
OTF Doppler Broadening

High energy physics models
CEM, LAQGSM, LAHET
MARS, HETC

Continuous Testing System
~10,000 test problems / day

mcnp5 – 100 K lines of code
mcnp6 – 500 K lines of code

Verification
&
Validation

MCNP V&V Work for Criticality Safety

We do a lot of verification/validation work, all the time:

MCNP Verification-Validation, 100+ reports on MCNP Website

•Brown, Kiedrowski, Bull, "**Verification of MCNP5-1.60 and MCNP6.1** for Criticality Safety Applications", LA-UR-13-22196 (**2013**).

•Brown, Kiedrowski, Bull, "**Verification of MCNP5-1.60 and MCNP6-Beta-2** for Criticality Safety Applications", LA-UR-12-21041 (**2012**).

•Brown, Kiedrowski, Bull, M.A. Gonzales, N.A. Gibson, "**MCNP5-1.60 Release & Verification**", Trans Am Nuc Soc 104, June 2011, LA-UR-11-00230 (**2011**).

•Kahler, et al., "**ENDF/B-VII.1 Neutron Cross Section Data Testing** with Critical Assembly Benchmarks and Reactor Experiments", Nuclear Data Sheets, Vol 112, No. 12, 2997-3036 [also LA-UR-11-11271] (**2011**).

•Mosteller, Brown, Kiedrowski, "An **Expanded Criticality Validation Suite for MCNP**", ICNC-2011, LA-UR-11-04170 (**2011**).

•Brown, Kiedrowski, Bull, Gonzales, Gibson, "**Verification of MCNP5-1.60**", LA-UR-10-05611 (**2010**).

Nuclear Data

•Conlin, et al., "**Listing of Available ACE Data Tables**", LA-UR-13-21822 (**2013**)

•Conlin, et al., "Continuous Energy **Neutron Cross Section Data ...ENDF/B-VII.1**", LA-UR-13-20137 (**2013**).

•Kahler, et al., "LANL **Data Testing Support for ENDF/B-VII.1**", LA-UR-12-20002 (**2012**).

•Chadwick, et al., "**ENDF/B-VII.1 Nuclear Data.....**", Nuclear Data Sheets, Vol 112, No. 12, 2887-2996 (**2011**).

•Chadwick, et al., "**ENDF/B-VII.0: ... Nuclear Data** ...", Nuclear Data Sheets, Vol. 107, Number 12 (**2006**)

•Trellue, et al., "New ACE-Formatted Neutron and Proton Libraries Based on **ENDF/B-VII.0**", LA-UR-08-1999 (**2008**).

•Trellue, R. Little, "Release of New MCNP **S(α,β) Library ... ENDF/B-VII.0**", LA-UR-08-3628 (**2008**).

Recent V&V Work

- **Very thorough testing of MCNP6.1 on many computer platforms:**

  Brown, Kiedrowski, Bull, "Verification of MCNP5-1.60 and MCNP6.1 for Criticality Safety Applications", LA-UR-13-22196 (2013).

  Conclusions:

  1.MCNP5-1.60 and MCNP6.1 perform correctly for criticality safety applications.

  2.For a few cases, there are small differences using newer compilers. Strictly due to computer roundoff & not a concern.

  3.MCNP5-1.60 and MCNP6.1 yield the same results on different computer platforms – Mac OS X, Linux, and Windows – for criticality safety applications.

  4.MCNP5-1.60 and MCNP6.1 yield the same results using OpenMP threading and/or MPI message-passing parallelism.

- **MCNP6.1 impact on criticality calculation results ➜ none**

  –All MCNP5 KCODE criticality features preserved, + new features

  –Matches results with MCNP5 for criticality suites

Verification / Validation Suites

- **MCNP V&V Suites**

– **VALIDATION_CRITICALITY**	31 ICSBEP experiment benchmarks
– **VALIDATION_CRIT_EXPANDED**	119 ICSBEP experiments
– **CRIT_LANL_SBCS**	194 ICSBEP experiments, from LANL crit-safety group
– **VERIFICATION_KEFF**	75 analytic benchmarks, exact solutions
– **VALIDATION_ROSSI_ALPHA**	Rossi alpha vs experiment
– **VALIDATION_ACODE**	static-alpha eigenvalue benchmarks
– **POINT_KINETICS**	reactor kinetics parameters
– **KOBAYASHI**	void & duct streaming, with point detectors, exact solutions
– **VALIDATION_SHIELDING**	19 shielding/dose experiments
– **REGRESSION**	66 code test problems
– many others for MCNP6	electrons, protons, muons, high-energy physics, delayed particles, magnetic fields, point detectors, MCNP6/Partisn weight window generator, unstructured mesh & ABAQUS linkage, photons, pulse height tallies, string theory models

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

MCNP6 & Exact Results for Analytic V&V Suite

Table I. MCNP6.1 Results for Analytic Keff Benchmarks

Case	Name	Analytic Exact keff	MCNP_Results keff	std
prob11	Ua-1-0-IN	2.25000	2.25000	0.00000
prob14	Ua-1-0-SP	1.00000	1.00006	0.00010
prob18	Uc-H2O(2)-1-0-SP	1.00000	1.00005	0.00011
prob23	UD2O-1-0-CY	1.00000	1.00000	0.00006
prob32	PUa-1-1-SL	1.00000	0.99995	0.00011
prob41	UD2Ob-1-1-SP	1.00000	1.00003	0.00007
prob44	PU-2-0-IN	2.68377	2.68377	0.00003
prob54	URRa-2-0-SL	1.00000	1.00007	0.00013
prob63	URRd-H2Ob(1)-2-0-ISLC	1.00000	0.99993	0.00006
prob75	URR-6-0-IN	1.60000	1.59999	0.00001

MCNP6.1, Intel-12 F90 - All results match

VALIDATION_CRITICALITY – F90 Compilers – Differences

mcnp5-1.60 + ENDF/B-VII.0		mcnp5+Int-10		mcnp5_Int-11		mcnp5_Int-12		mcnp6_Int-12	
		deltak	std	keff	std	deltak	std	deltak	std
U233 Benchmarks	JEZ233	0.0000	(8)	0.9989	(5)	0.0000	(8)	0.0000	(8)
	FLAT23	0.0000	(9)	0.9990	(7)	0.0000	(9)	0.0000	(9)
	UMF5C2	0.0000	(8)	0.9931	(5)	0.0000	(8)	0.0000	(8)
	FLSTF1	0.0000	(15)	0.9830	(11)	0.0000	(15)	0.0000	(15)
	SB25	0.0000	(14)	1.0053	(10)	0.0000	(14)	0.0000	(14)
	ORNL11	0.0000	(5)	1.0018	(4)	0.0000	(5)	0.0000	(5)
HEU Benchmarks	GODIVA	0.0000	(8)	0.9995	(5)	0.0000	(8)	0.0000	(8)
	TT2C11	0.0010	(10)	1.0008	(7)	0.0000	(9)	0.0000	(9)
	FLAT25	0.0000	(9)	1.0034	(7)	0.0000	(9)	0.0000	(9)
	GODIVR	0.0000	(9)	0.9990	(7)	0.0000	(9)	0.0000	(9)
	UH3C6	0.0000	(11)	0.9950	(8)	0.0000	(11)	0.0000	(11)
	ZEUS2	0.0002	(9)	0.9972	(7)	0.0000	(9)	0.0000	(9)
	SB5RN3	0.0000	(18)	0.9985	(13)	0.0000	(18)	0.0000	(18)
	ORNL10	0.0000	(5)	0.9993	(4)	0.0000	(5)	0.0000	(5)
IEU Benchmarks	IMF03	0.0000	(8)	1.0029	(5)	0.0000	(8)	0.0000	(8)
	BIGTEN	0.0000	(7)	0.9945	(5)	0.0000	(7)	0.0000	(7)
	IMF04	0.0000	(8)	1.0067	(5)	0.0000	(8)	0.0000	(8)
	ZEBR8H	-0.0001	(7)	1.0196	(5)	0.0000	(7)	0.0000	(7)
	ICT2C3	0.0000	(9)	1.0037	(7)	0.0000	(9)	0.0000	(9)
	STACY36	0.0000	(8)	0.9994	(5)	0.0000	(8)	0.0000	(8)
LEU Benchmarks	BAWXI2	0.0000	(9)	1.0013	(7)	0.0000	(9)	0.0000	(9)
	LST2C2	0.0000	(8)	0.9940	(5)	0.0000	(8)	0.0000	(8)
Pu Benchmarks	JEZPU	0.0000	(8)	1.0002	(5)	0.0000	(8)	0.0000	(8)
	JEZ240	0.0000	(8)	1.0002	(5)	0.0000	(8)	0.0000	(8)
	PUBTNS	0.0000	(8)	0.9996	(5)	0.0000	(8)	0.0000	(8)
	FLATPU	0.0000	(9)	1.0005	(7)	0.0000	(9)	0.0000	(9)
	THOR	0.0000	(9)	0.9980	(7)	0.0000	(9)	0.0000	(9)
	PUSH2O	0.0000	(9)	1.0012	(7)	0.0000	(9)	0.0000	(9)
	HISHPG	0.0004	(7)	1.0118	(5)	0.0000	(8)	0.0000	(8)
	PNL2	0.0000	(12)	1.0046	(9)	0.0000	(12)	0.0000	(12)
	PNL33	0.0000	(9)	1.0065	(7)	0.0000	(9)	0.0000	(9)
Wall-clock:		34.7 min		34.0 min		30.5 min		38.5 min	
Rel. Speed:		0.98		1.00		1.11		0.88	

Summary of Verification Results

VERIFICATION_KEFF Suite – 10 analytical problems with exact K_{eff} results

- MCNP6.1, Intel-12 F90 — All results match

VALIDATION_CRITICALITY Suite – 31 ICSBEP Cases, ENDF/B-VII.0

- MCNP5 Intel-10 vs Intel-12: — 4 diffs, within statistics
- MCNP5 & MCNP6, Intel-12: — All results match

VALIDATION_CRIT_EXPANDED Suite – 119 ICSBEP Cases, ENDF/B-VII.0

Shortened Problems

- MCNP5 Intel-10 vs Intel-12: — 1 diff, within statistics
- MCNP5 & MCNP6, Intel-12: — All results match

Standard Problems

- MCNP5 & MCNP6, Intel-12: — 4 diffs, within statistics

CRIT_LANL_SBCS Suite – 194 ICSBEP Cases, ENDF/B-VI

MCNP5 vs MCNP6, Intel-10.1: — 187 match, 4 diffs < 1σ, 3 diffs < 2σ

MCNP5 (2013, Int-12) vs MCNP5 (2003, Int-9)

142 match, 42 diffs < 1σ, 10 diffs < 2σ

Conclusions

- MCNP6 ⇔ MCNP5, for standard criticality calculations
- MCNP6 impact on Criticality Calculations ➜ none
  - All KCODE criticality features same as for MCNP5
  - Matches results with MCNP5 for criticality suites
- MCNP6 currently runs ~ 20-30% slower than MCNP5 for criticality calcs
  - MCNP-2020 project underway, already providing improvements
  - Goal: 2X speedup over MCNP5 within 1-2 years
- Monte Carlo team will support MCNP6,
  no new features or releases of MCNP5 or MCNPX
- All new MCNP verification/validation/qualification efforts
  should be directed toward MCNP6, not MCNP5
- You need to plan for MCNP5 ➜ MCNP6 transition over the next few years

Questions ?