LA-UR-11-05077

Approved for public release;
distribution is unlimited.

Title:	The Rossi Alpha Validation Suite for MCNP
Author(s):	Russell D. Mosteller Brian C. Kiedrowski
Intended for:	International Conference on Nuclear Criticality 2011 Edinburgh, Scotland September 19-22, 2011

The Rossi α Validation Suite for MCNP

Russell D. Mosteller
Theoretical Design Division

and

Brian C. Kiedrowski
Computational Physics Division

Los Alamos National Laboratory

To Be Presented at ICNC 2011
"International Conference on Nuclear Criticality"
Edinburgh, Scotland September 19 - 22, 2011

A Rossi α validation suite has been created for the MCNP Monte Carlo code. The suite includes 13 cases based on specifications given in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*. The cases are divided into four categories of fuel – ^{233}U, highly enriched uranium, intermediate enriched uranium, and plutonium. The cases also cover fast, intermediate, and thermal spectra. Succinct descriptions are provided for each case, along with computed values for Rossi α using ENDF/B-VI, ENDF/B-VII.0, and ENDF/B-VII.1β3 nuclear data libraries.

The Rossi α Validation Suite for MCNP

Russell D. Mosteller and Brian C. Kiedrowski

Los Alamos National Laboratory

mosteller@ lanl.gov, bckiedro@lanl.gov

Presented at ICNC 2011
"International Conference on Nuclear Criticality"
Edinburgh, Scotland September 19-22, 2011

Overview of Presentation

Introduction

Rossi α

Rossi α Validation Suite

Rossi α Results from ENDF/B-VI, ENDF/B-VII.0, and ENDF/B-VII.1β3

Benchmark versus Experimental Values for Rossi α

Summary and Conclusions

Introduction

More than a dozen verification and validation suites have been developed for the MCNP Monte Carlo code, including

- Regression / Installation
- Criticality (described in paper on Thursday morning)
- Radiation Shielding / Dose
- Electrons
- Photons
- Variance Reduction

MCNP5 version 1.60, released from RSICC in November 2010, is capable of computing Rossi α in its criticality calculations

A Rossi α validation suite has been developed for MCNP and is described in this paper

Rossi α

Rossi α characterizes the exponential rate of change in the population of prompt neutrons that cause fission:

$$n_{pf}(t) = n_{pf}(0)e^{\alpha_R t}$$

where n_{pf} is the population of prompt neutrons that cause fission, t is time, and α_R is Rossi alpha

Rossi α is zero at prompt critical, negative below it, and positive above it

In the 1950s, Bruno Rossi developed a technique to measure Rossi α using correlated fission chains in configurations that are close to delayed critical

Rossi α (Continued)

It is straightforward to show that, for systems at or very close to delayed critical,

$$\alpha_R = \frac{k_p - 1}{\Lambda_{pf}} \cong -\frac{\beta_{eff}}{\Lambda_{pf}}$$

where k_p is the multiplication factor for prompt neutrons, Λ_{pf} is the generation time for prompt neutrons that produce fission, and β_{eff} is the effective delayed-neutron fraction.

MCNP5 1.60 calculates β_{eff} and Λ_{pf} during its criticality calculation and then determines α_R as the negative ratio of those two parameters

Rossi α Validation Suite

The Rossi α validation suite contains 13 cases, including cases with ^{233}U, highly enriched uranium (HEU), intermediate enriched uranium (IEU), and plutonium fuel

The suite includes cases with fast, intermediate, and thermal spectra

Some of the cases are unreflected, while others are reflected by normal uranium, depleted uranium, thorium, copper, or water

Specifications for all of the cases are taken from the benchmark models in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*

Measured values for Rossi α are taken from the *Handbook*, the CSEWG Benchmark Book, a journal article, or the log books for the experiments

^{233}U Cases

Name	Spectrum	Geometry	Moderator	Reflector
Jezebel-233	Fast	Spherical	None	None
Flattop-23	Fast	Spherical	None	Normal U

Jezebel-233 is a bare sphere with a radius of 5.9838 cm and a ^{233}U content of 98.13 wt.%

Flattop-23 is a sphere with a radius of 4.2058 cm, surrounded by an annulus of normal uranium that is 15.7078 cm thick. The inner sphere is 98.13 wt.% ^{233}U.

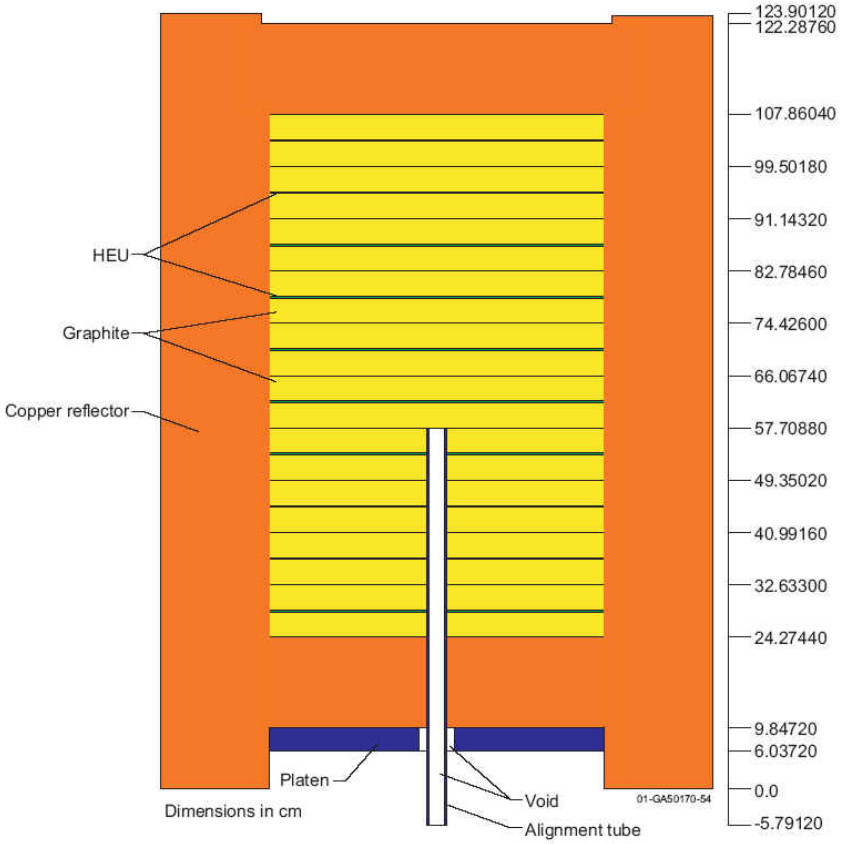
HEU Cases

Name	Spectrum	Geometry	Moderator	Reflector
Godiva	Fast	Spherical	None	None
Flattop-25	Fast	Spherical	None	Normal U
Zeus-1	Intermediate	Cylindrical	Graphite	Copper
Zeus-5	Fast	Cylindrical	None	Copper
Zeus-6	Fast	Cylindrical	Iron	Copper

Godiva is a bare sphere with a radius of 8.7407 cm and a ^{235}U content of 93.71 wt.%

Flattop-25 is a sphere with a radius of 6.1156 cm, surrounded by an annulus of normal uranium that is 18.0086 cm thick. The inner sphere is 93.24 wt.% ^{233}U.

HEU Cases (Continued)



Zeus-1

The Zeus cases contain stacked platters of HEU separated by graphite platters (Zeus-1), iron platters (Zeus-6), or nothing (Zeus-5). They are enclosed in a copper reflector. The outer radius of the platters is 26.67 cm, and the average thickness of the copper reflector is slightly less than 14.5 cm. The ^{235}U content varies slightly from case to case but is a little higher than 93 wt.% for all of them.

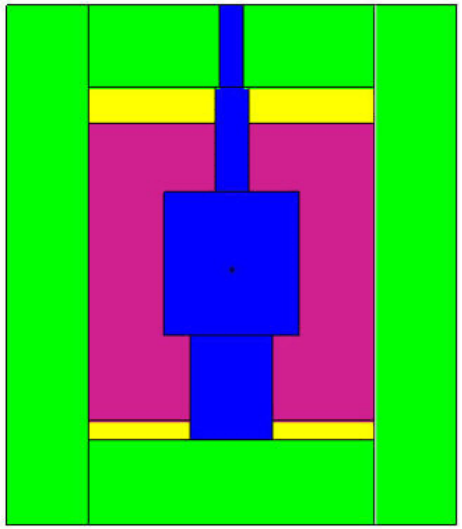
IEU Cases

Name	Spectrum	Geometry	Moderator	Reflector
Big Ten	Fast	Cylindrical	None	Depleted U
STACY-30	Thermal	Spherical	Water	None
STACY-46	Thermal	Cylindrical	Water	Water

The STACY cases are uranium-nitrate solutions with enrichments of 9.97 wt.%, contained in a cylindrical tank made of stainless steel 304. The inner radius of the tank is 29.5 cm, and it is 0.3 cm thick. The annular reflector for STACY-46 is 30 cm thick.

The STACY cases are characterized as IEU rather than LEU because the MCNP validation suits use 5 wt.% as the dividing line between them. 5 wt.% is the upper limit on enrichment for LWRs in the United States.

IEU Cases (Continued)



Big Ten is a stack of concentric cylinders. The inner and outer radii of the depleted uranium are 26.67 and 41.91 cm, respectively. The total length of the configuration is 96.52 cm.

10 Wt.% U

Natural U

Depleted U

Homogenized HEU and Natural U

Los Alamos NATIONAL LABORATORY EST.1943

NNSA

Plutonium Cases

Name	Spectrum	Geometry	Moderator	Reflector
Jezebel	Fast	Spherical	None	None
Flattop-Pu	Fast	Spherical	None	Normal U
Thor	Fast	Mixed	None	Thorium

Jezebel is a bare sphere with a radius of 6.3849 cm and a ^{240}Pu content of 4.5 wt.%.

Flattop-Pu is a sphere with a radius of 4.5332 cm, surrounded by an annulus of normal uranium that is 19.6088 cm thick. The inner sphere is 4.83 wt.% ^{240}Pu.

Plutonium Cases (Continued)

Thor contains a sphere of plutonium inside a right circular cylinder of thorium. The radius of the sphere is 5.31 cm, and it contains 5.13 wt.% ^{240}Pu. The thorium cylinder has an outer radius of 26.67 cm, and it is 53.34 cm high (i.e., its height is the same as its diameter).

Results for ^{233}U and HEU Cases

Case Name	Rossi α (10^4 generations/second) at Critical			
	Measured	Calculated by MCNP5 1.60		
		ENDF/B-VI	ENDF/B-VII.0	ENDF/B-VII.1β3
Jezebel-233	-100 ± 1	-109 ± 1	-108 ± 1	-104 ± 1
Flattop-23	-26.7 ± 0.5	-30.9 ± 0.4	-30.2 ± 0.4	-28.6 ± 0.4
Godiva	-111 ± 2	-114 ± 1	-113 ± 1	-113 ± 1
Flattop-25	-38.2 ± 0.2	-40.9 ± 0.2	-39.7 ± 0.2	-39.6 ± 0.2
Zeus-1	-0.338 ± 0.008	-0.373 ± 0.002	-0.363 ± 0.002	-0.380 ± 0.002
Zeus-5	-7.96 ± 0.08	-10.94 ± 0.07	-10.76 ± 0.08	-10.77 ± 0.08
Zeus-6	-3.73 ± 0.05	-4.12 ± 0.03	-4.14 ± 0.03	-4.19 ± 0.03

ENDF/B-VII.1β3 produces improved results for the ^{233}U cases, but not for the HEU cases

Results for IEU and Plutonium Cases

Case Name	Rossi α (10^4 generations/second) at Critical			
	Measured	Calculated by MCNP5 1.60		
		ENDF/B-VI	ENDF/B-VII.0	ENDF/B-VII.1β3
Big Ten	-11.7 ± 0.1	-12.6 ± 0.1	-11.8 ± 0.1	-11.8 ± 0.1
STACY-30	-0.0127 ± 0.0003	-0.0133 ± 0.0003	-0.0133 ± 0.0003	-0.0127 ± 0.0003
STACY-46	-0.0106 ± 0.0004	-0.0110 ± 0.0002	-0.0104 ± 0.0002	-0.0109 ± 0.0002
Jezebel	-64 ± 1	-64 ± 1	-65 ± 1	-64 ± 1
Flattop-Pu	-21.4 ± 0.5	-21.6 ± 0.3	-21.0 ± 0.3	-20.8 ± 0.3
Thor	-19 ± 1	-20 ± 1	-20 ± 1	-21 ± 1

ENDF/B-VII.1β3 produces improved results for STACY-30 but not for the other cases

Measured Values versus “Benchmark” Values

Strictly speaking, calculated values should be compared to “benchmark” values rather than measured values

Benchmark values contain adjustments (viz., biases and additional uncertainties) that have been applied to the experimental values based on sensitivity studies and on simplifications incorporated into the benchmark model

The Handbook contains both detailed and benchmark models for 4 of the cases in the suite

Comparisons between results from the detailed and benchmark models allow a determination of the bias and additional uncertainty due to simplifications incorporated in the benchmark model (but **not** the additional uncertainties from sensitivity studies)

Comparison of Rossi α Results for Benchmark and Detailed Models

Case Name	Rossi α (10^4 generations/second) at Critical		
	Calculated by MCNP5 1.60 with ENDF/B-VII.0 Data		
	Benchmark	Detailed	Bias
Godiva	-113 ± 1	-115 ± 1	2 ± 1
Zeus-1	-0.363 ± 0.002	-0.379 ± 0.002	0.016 ± 0.003
Zeus-5	-10.76 ± 0.08	-10.75 ± 0.08	-0.01 ± 0.11
Big Ten	-11.8 ± 0.1	-11.9 ± 0.1	0.1 ± 0.1

Only 1 of the 4 cases shows a substantial bias (and it has a reactivity bias of -0.0020 Δk as well)

Summary and Conclusions

A Rossi α validation suite containing 13 cases has been created for MCNP

The cases in the suite encompass ^{233}U, HEU, IEU, and plutonium fuel as well as fast, intermediate, and thermal spectra

Specifications for all 13 cases are taken from the benchmark models in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*

Calculated results are compared to measured results rather than benchmark values, but the limited evidence available suggests that the difference between them should be small

Summary and Conclusions (Continued)

Results have been obtained for the cases in the suite using MCNP and nuclear data libraries based on ENDF/B-VI, ENDF/B-VII.0, and ENDF/B-VII.1β3

ENDF/B-VII.1β3 produces slight improvements for both ^{233}U cases and one IEU case relative to ENDF/B-VII.0, but the results are statistically indistinguishable for 8 of the other 10 cases