OAK RIDGE National Laboratory

SCALE 6.2.4 Validation for Radiation Shielding Applications

Mathieu Dupont, Cihangir Celik, Douglas Peplow, Georgeta Radulescu

SCALE Users' Group Workshop

August 4, 2021

ORNL is managed by UT-Battelle LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

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SCALE MAVRIC Validation Motivation

SCALE MAVRIC Validation Motivation

- SCALE is a group of modules used to model nuclear reactors
- To demonstrate SCALE's accuracy, the different modules must be validated against real-life situations
- Starting in 2020, three validation reports (Criticality Safety, Reactor Physics and Radiation Shielding) are to be published for each SCALE major release
- MAVRIC (Monaco with Automated Variance Reduction using Importance Calculations) is the SCALE radiation shielding sequence
- MAVRIC characteristics: Continuous energy or multigroup physics, Denovo deterministic solver for variance reduction (CADIS/FW-CADIS)

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Overview of the Validation Report

Overview of the Validation Report

- MAVRIC is tested against 8 different benchmarks from ICSBEP, SINBAD and/or peer-reviewed articles
- Different results, such as neutron flux, foil activation rate and gamma skyshine were computed
- Different materials of interaction, including iron, polyethylene, water, cadmium, lead, air, and soil were used in the problems
- Agreement of MAVRIC with experiments (and MCNP when available) was compared

Overview of the Validation Report

Section in report	Benchmark	Origin	Radiation of interest	Source	Material interaction of interest	Quantity of interest
2.1	Neutron transmission through an iron sphere	Annals of Nuclear Energy (1993)	Neutron	^{252}Cf	Fe	Neutron flux spectrum
2.2	Neutrons through a heavy water sphere	Annals of Nuclear Energy (1997)	Neutron	^{252}Cf	Heavy water	Neutron flux spectrum
2.3	Concrete Labyrinth	ICSBEP (2007)	Neutron	^{252}Cf	Concrete (borated), PE, Cd	Counts per second in Bonner sphere
2.4	Am-Be Neutrons Leakage Through Several Materials	Nuclear Science and Engineering (1971)	Neutron	Am-Be	PE, Be, Pb, Nb, Mo, Ta, W	Neutron flux spectrum
2.5	D-T Neutrons through an Iron Sphere	SINBAD (2006)	Neutron	D-T	Fe	Neutron flux spectrum
2.6	Graphite shielding measurements	Nuclear Science and Engineering (1996)	Neutron	^{252}Cf	Paraffin, steel, PE	Neutron dose rate
2.7	Skyshine Benchmark	SINBAD (2012)	Gamma	^{60}Co	Air, soil	Gamma dose rate skyshine
2.8	SILENE Critical assembly benchmark	ICSBEP (2016)	Neutron	Uranyl nitrate solution	Foils (Co, Au, In, Fe, Mn, Mg, Ni)	Neutron activation

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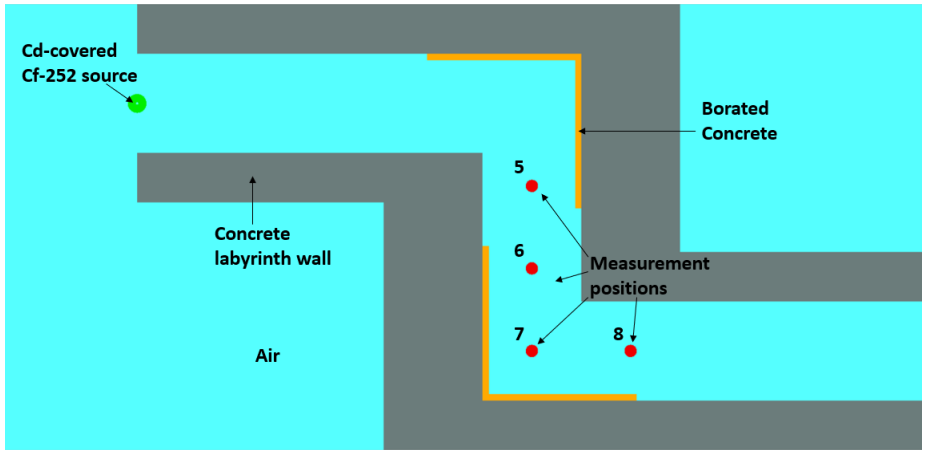
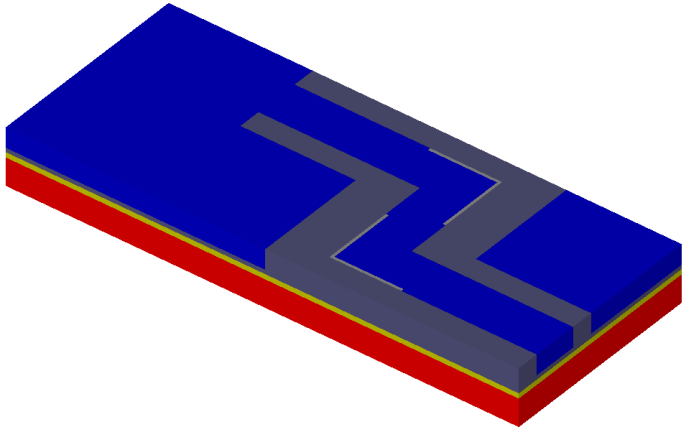
Concrete Labyrinth Benchmark: Introduction

- Near Moscow, Russia, 1982
- Goal: to obtain benchmark data for code validation for accelerator design
- Cf-252 source placed at the entrance of the structure
- Neutron flux measured by Bonner spheres of different sizes at different positions
- A lot of cases, involving different maze configurations, different materials



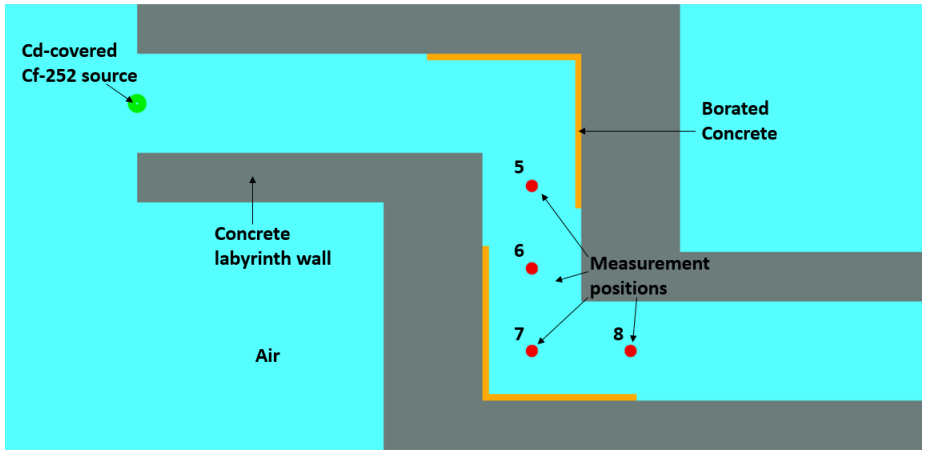
Concrete Labyrinth geometry for Case 4B



Concrete Labyrinth SCALE model overview

Concrete Labyrinth Benchmark: Introduction

- SCALE model built with ICSBEP information
- Case 4B is shown, 4 measurement positions, 7 Bonner spheres
- Cf-252 source bare or covered by Cadmium layer
- 2-step calculation:
  - Detector response function
  - Count rates in Bonner sphere at each location



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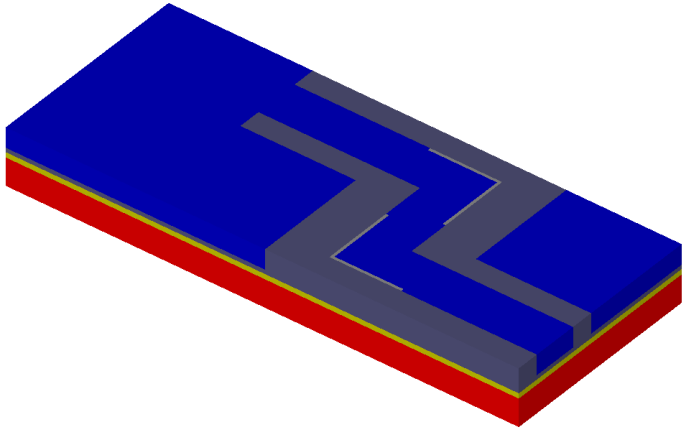
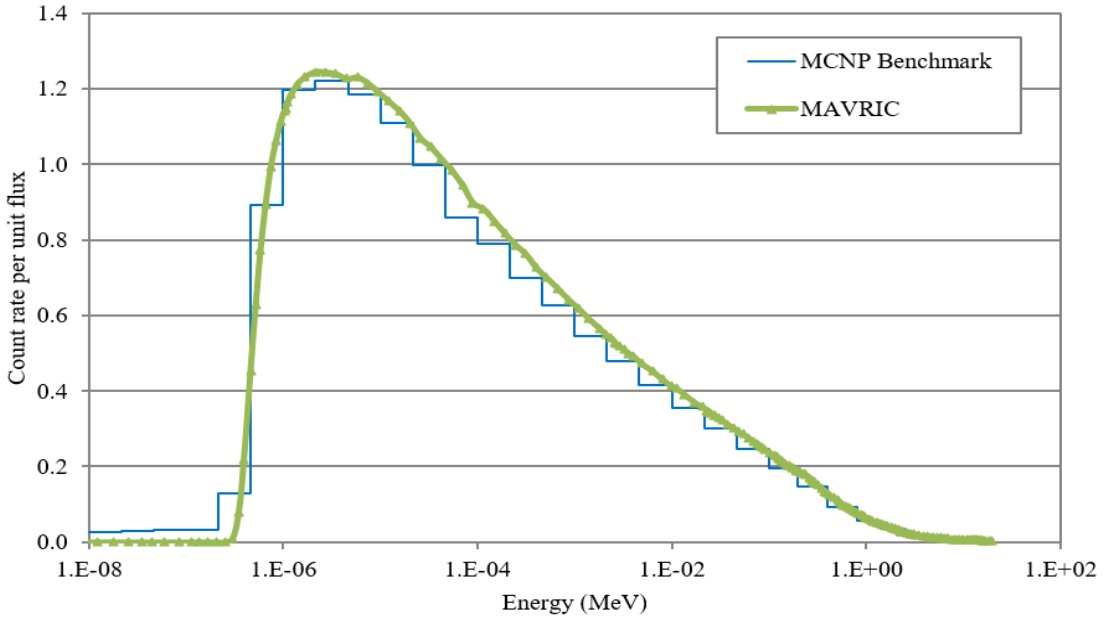


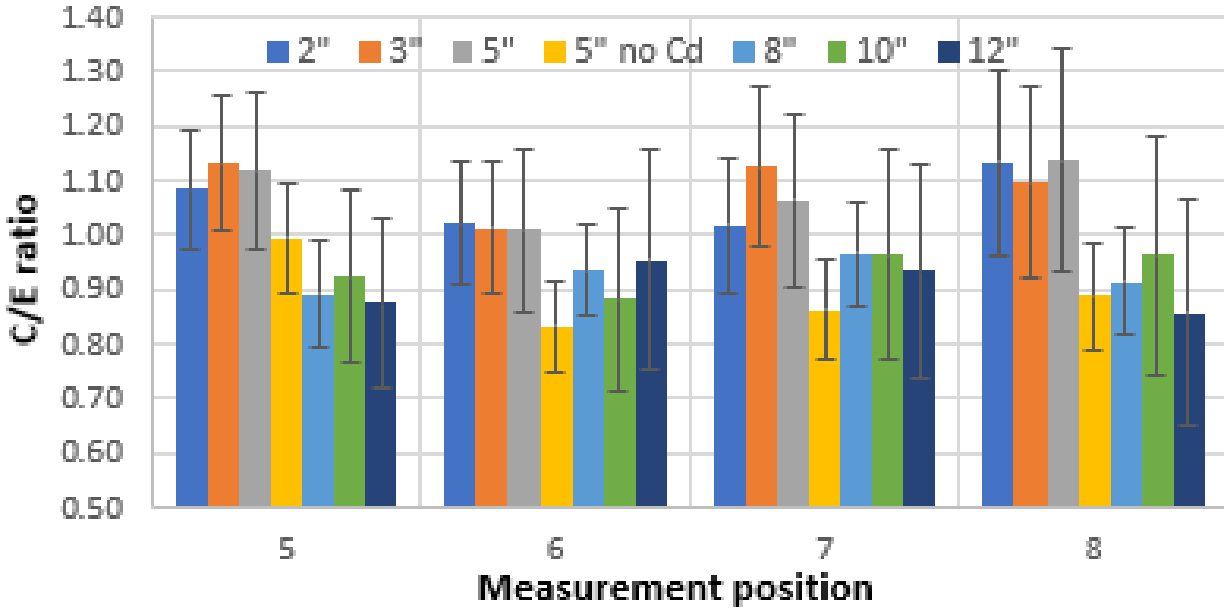
Concrete Labyrinth SCALE model overview

Concrete Labyrinth Benchmark: Results



Bonner Sphere detector response function example

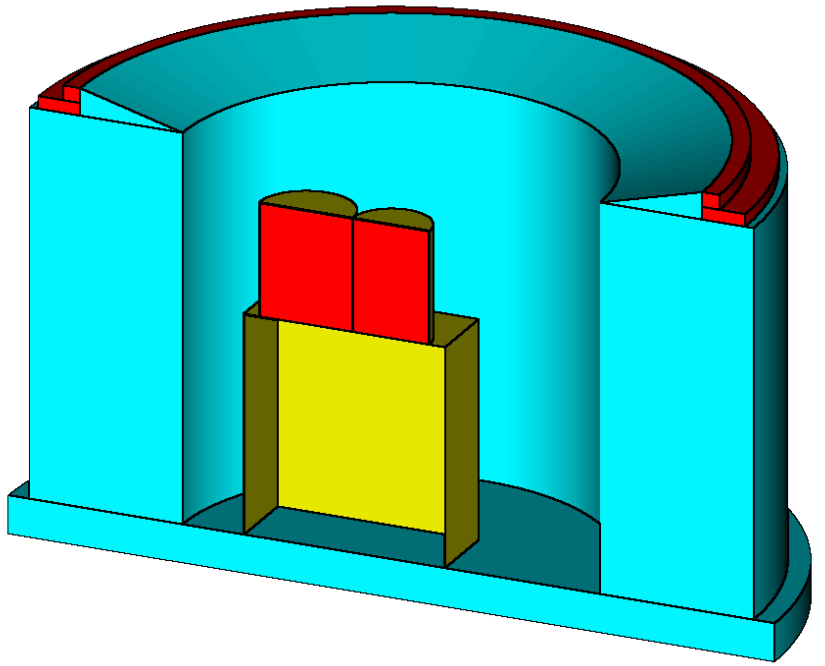
- **Good agreement between MAVRIC and MCNP, and MAVRIC and experiment**



Case 4B C/E calculation results ratios

Photon Skyshine Benchmark: Introduction

- Kansas State University, USA, 1977
- Goal: to measure exposure rates due to long-distance skyshine radiation
- 3 Co-60 sources were placed inside a concrete silo
- Measured exposure rates at distances from 50 meters to 700 meters



Silo SCALE model overview

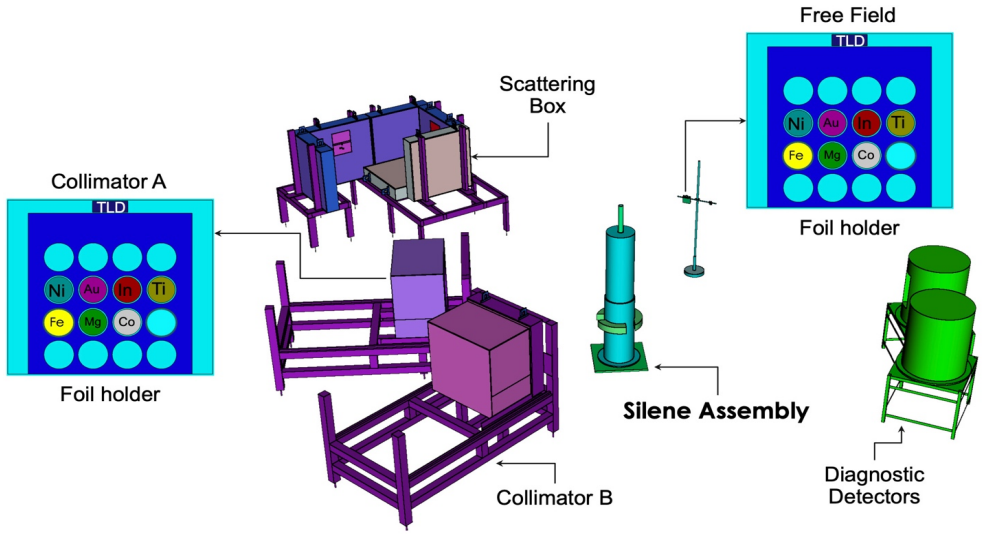
Photon Skyshine Benchmark: Results

^{60}Co Source Activity (Ci)	Distance to Source (m)	Measured Exposure Rate (μR/h/Ci)	Calculated Exposure Rate (μR/h/Ci)	Relative Difference (%)
10.33	50	24.24	25.3687	4.66
	100	9.660	9.6360	-0.25
	200	2.425	2.5583	5.50
229.1	300	0.760	0.8844	16.37
	400	0.310	0.3474	12.06
	500	0.117	0.1459	24.70
3804	600	0.0542	0.0583	7.56
	700	0.0244	0.0249	2.05

- **Good agreement between MAVRIC and experiment for low and high ranges sources**
- **The mid-range discrepancy could be attributed to a lack of data on the topography of the hill where the measurements took place**

SILENE Critical Assembly Benchmark: Introduction

- CEA Valduc, France, 2010
- Goal: to perform Criticality Accident Alarm Systems (CAAs) validation and analysis
- Highly enriched Uranyl nitrate solution used to perform critical pulses similar to criticality accidents
- Neutron and gamma doses are measured from activated foils with different shielding conditions and materials
- Only pulse 1 was tested in this report (Bare pulse)



SILENE Pulse 1 SCALE model overview

SILENE Critical Assembly Benchmark: Introduction

Position	Reaction	Measured Activity (Bq/g)	Calculated Activity (Bq/g)	C/E
Free Field	^{59}Co (n,γ) ^{60}Co	6.620e1	7.676e1	**1.16**
	^{197}Au (n,γ) ^{198}Au	6.950e4	7.790e4	**1.12**
	^{115}In (n,γ) ^{116}In	8.780e6	9.193e6	**1.05**
	^{115}In (n,n'γ) ^{115m}In	6.860e3	6.817e3	**0.99**
	^{54}Fe (n,p) ^{54}Mn	1.961e-1	2.012e-1	**1.03**
	^{56}Fe (n,p) ^{56}Mn + ^{55}Mn (n,γ) ^{56}Mn	2.403e3	2.603e3	**1.08**
	^{24}Mg (n,p) ^{24}Na	5.910e1	6.970e1	**1.18**
	^{58}Ni (n,p) ^{58}Co	1.299e1	1.359e1	**1.05**

- **Good agreement between MAVRIC and experiment**

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Summary and Conclusions

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- 8 different benchmarks were selected to create a shielding validation report
- Models used were obtained from previous publications or created specifically
- Overall, very good agreement MAVRIC/experiment, MAVRIC/MCNP when available
- Main discrepancies attributed to measurement uncertainties
- SCALE 6.2.4 shielding module MAVRIC is validated for accurate and safe use
- The validation report will be available in the next few months

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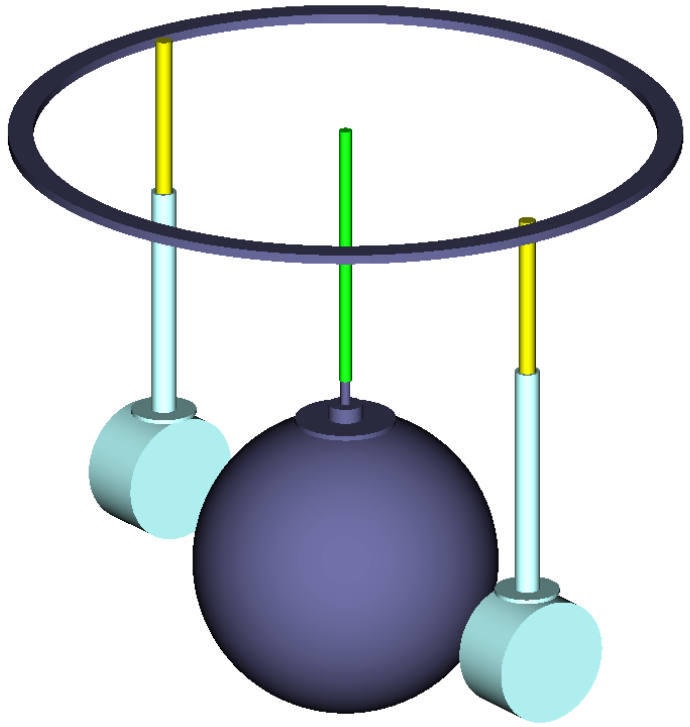
SCALE 6.3 Validation Report planned additions

SCALE 6.3 Validation Report planned additions

- New Benchmarks/Cases
  - Addition of more cases from the SILENE ICSBEP benchmark (more foils, different shielding materials)
  - Addition of new benchmarks
    - Fission rates from ICSBEP FUND-NIST-CF-MULT-FISS-001 and 002 and potential others)
    - H.B. Robinson Unit 2 Cycle 9 benchmark from SINBAD
- Comparisons
  - ENDF/B-VII.1 and ENDF/B-VIII.0 cross-section libraries
  - MAVRIC-MONACO and MAVRIC-SHIFT



Fission Rates SCALE model overview

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Questions?

This work was supported by the Nuclear Regulatory commission (NRC)