Stakeholder Outcomes: Task 1

“The Quest for TREAT Benchmarks”

John D. Bess
Changho Lee
March DeHart
Kaichao Sun
Tom Downar
Volkan Seker
Kevan Weaver
Doug Burns
Ed Larsen
Bill Martin
Yunlin Xu

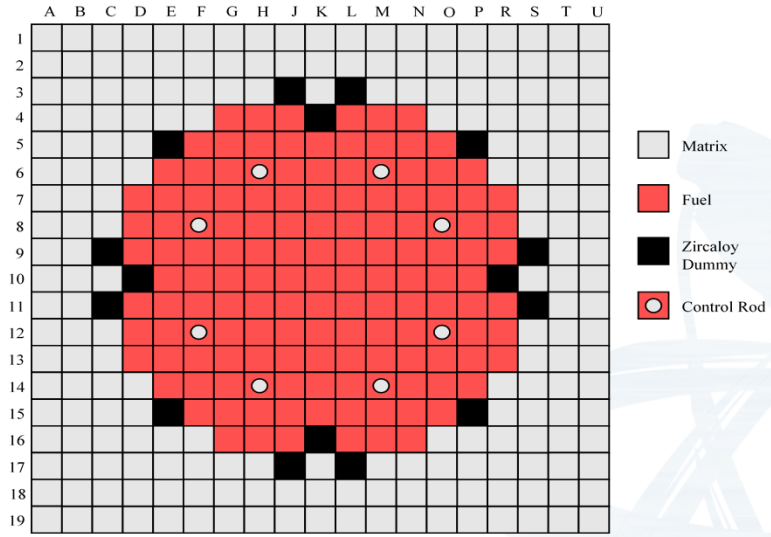
MIT TREAT Workshop
Cambridge, MA
November 2-3, 2016

This presentation was prepared at Idaho National Laboratory for the U.S. Department of Energy under Contract Number (DE-AC07-05ID14517)

Outline

- The Benchmark
- Steady-State Results
  - Monte Carlo
  - Deterministic
- Transient Analyses
  - Ongoing
- Significant Challenge
  - Hodoscope
  - Other voided regions
- Path Forward

The Benchmark



Evaluators

Internal Reviewers

Thomas Downar
Volkan Seker

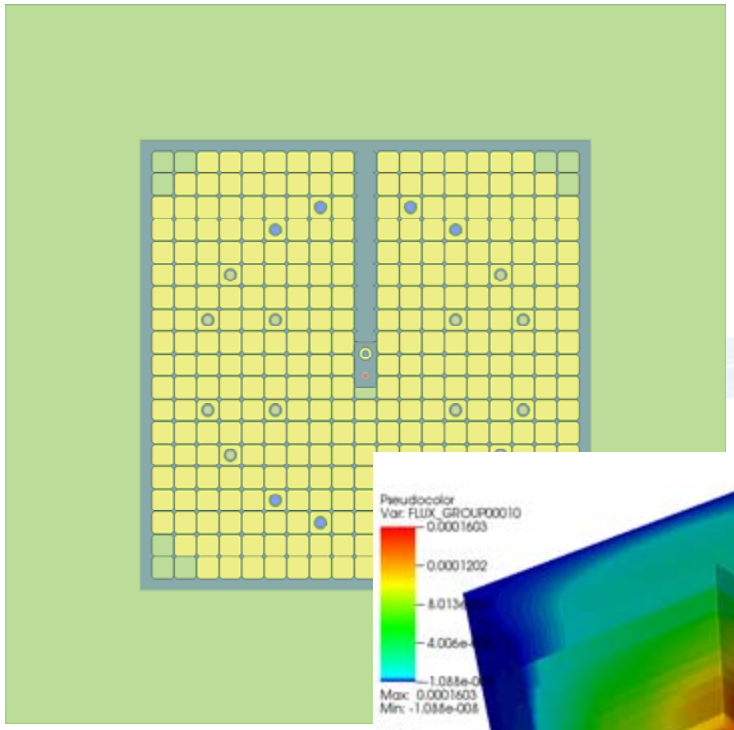
University of Michigan

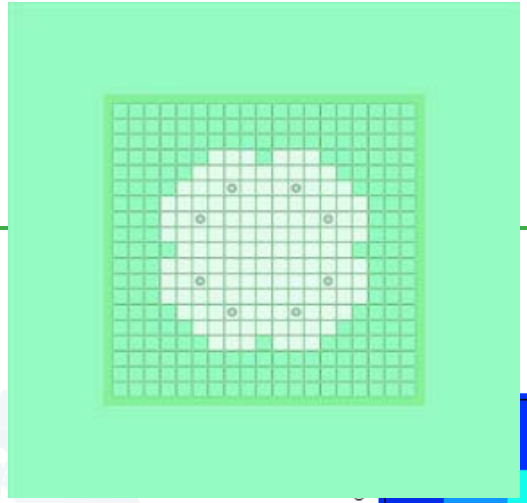
Independent Reviewer

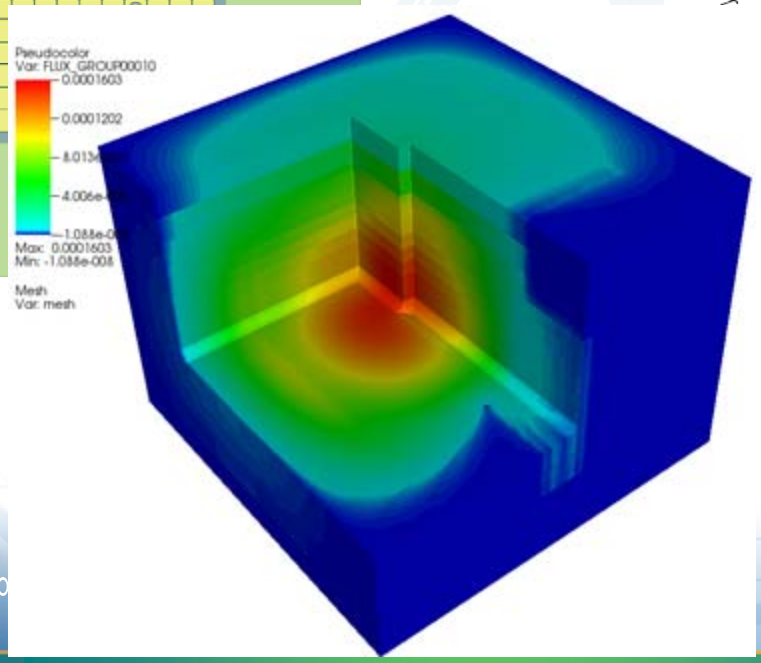
John Bess, INL
Richard Lell, ANL

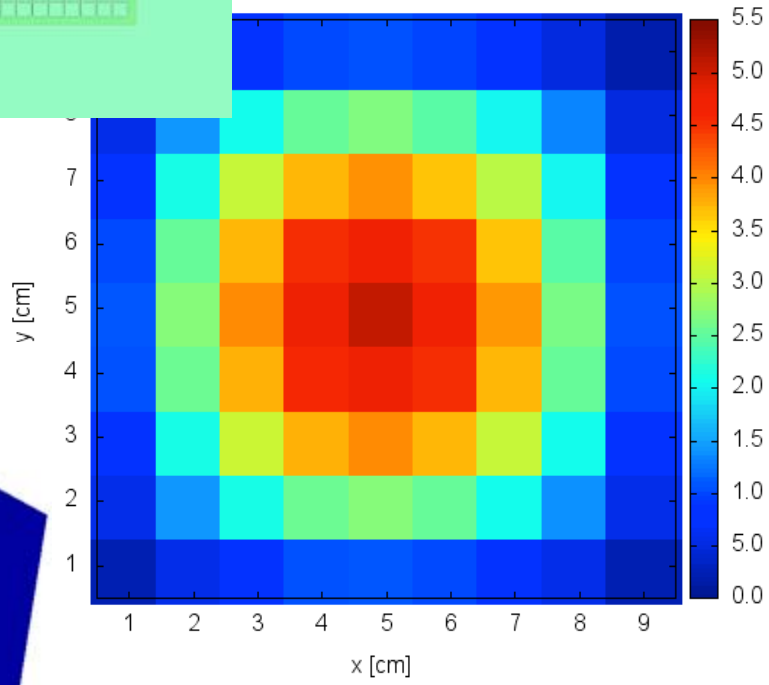
Configuration	Fuel Assemblies	Control Rod Assemblies	Zirconium Assemblies	Types of Measurement
Minimum Critical Mass (MCM)	133	8	16	Temperature Coefficient
MCM+	135	8	16	Flux Distribution
M8CAL	318	20	0	Rod Worth Data

The Models



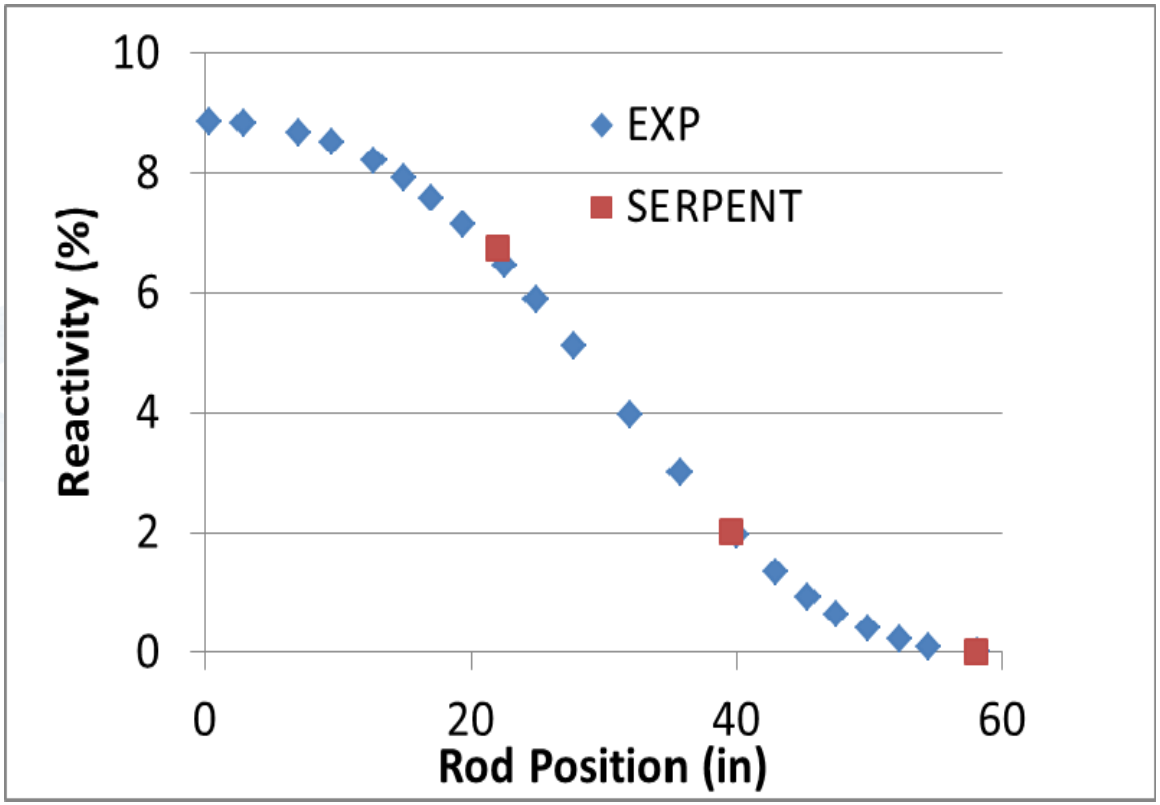



Pseudocolor
Var: FLUX_GROUP00010
0.0001603
0.0001202
Max: 0.0001603
Mesh
Var: mesh

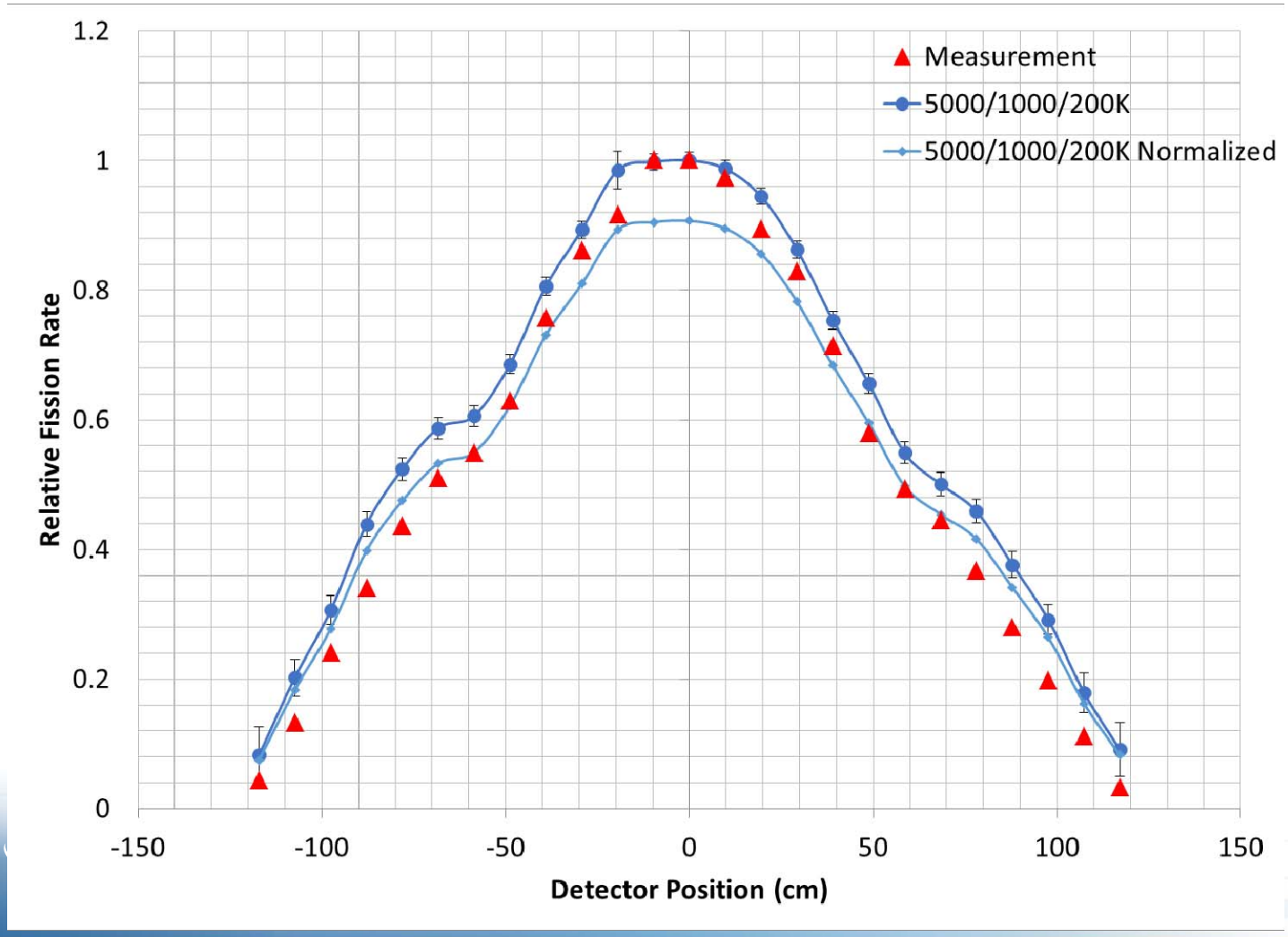

y [cm]
x [cm]
1
2
3
4
5
6
7
8
9
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
5.0
0.0

Serpent TREAT Reactivity Calculations

CORE	K-effective
MCM	1.00413 ± 20 pcm
MCM+	1.00171± 20 pcm
M8CAL	1.00394 ± 20 pcm



Serpent TREAT M8CAL Flux Calculations



Uncertainty Quantification

Parameter(s) perturbed	Sample size	Average k_{eff}	Relative uncertainty
All parameters listed in Table 1	300	$1.0073 \pm 1.1749E-5$	$1273.4 \pm 1.2pcm$
The five parameters below	1200	$1.0069 \pm 5.8865E-6$	$1171.6 \pm 0.6pcm$
Boron content	300	$1.0044 \pm 1.1806E-5$	$1093.9 \pm 1.2pcm$
Flat to flat distance of fuel block	300	$1.0064 \pm 1.1763E-5$	$222.7 \pm 1.2pcm$
Standard fuel assembly outer radius	300	$1.0041 \pm 1.1770E-5$	$30.6 \pm 1.2pcm$
Al-6063 can thickness	300	$1.0044 \pm 1.1788E-5$	$335.6 \pm 1.2pcm$
Zr-3 can thickness	300	$1.0040 \pm 1.1845E-5$	$894.2 \pm 1.2pcm$

Table 2. TREAT minimum critical core uncertainty analysis summary

- **Reference k_{eff} : 1.00413 ± 0.0002.**
- **Boron content and Zr-3 can thickness were recognised as the two most significant factors.**
- **Perturbations of flat to flat distance of fuel block caused shift in the mean k_{eff} value.**

PARCS TREAT Calculations

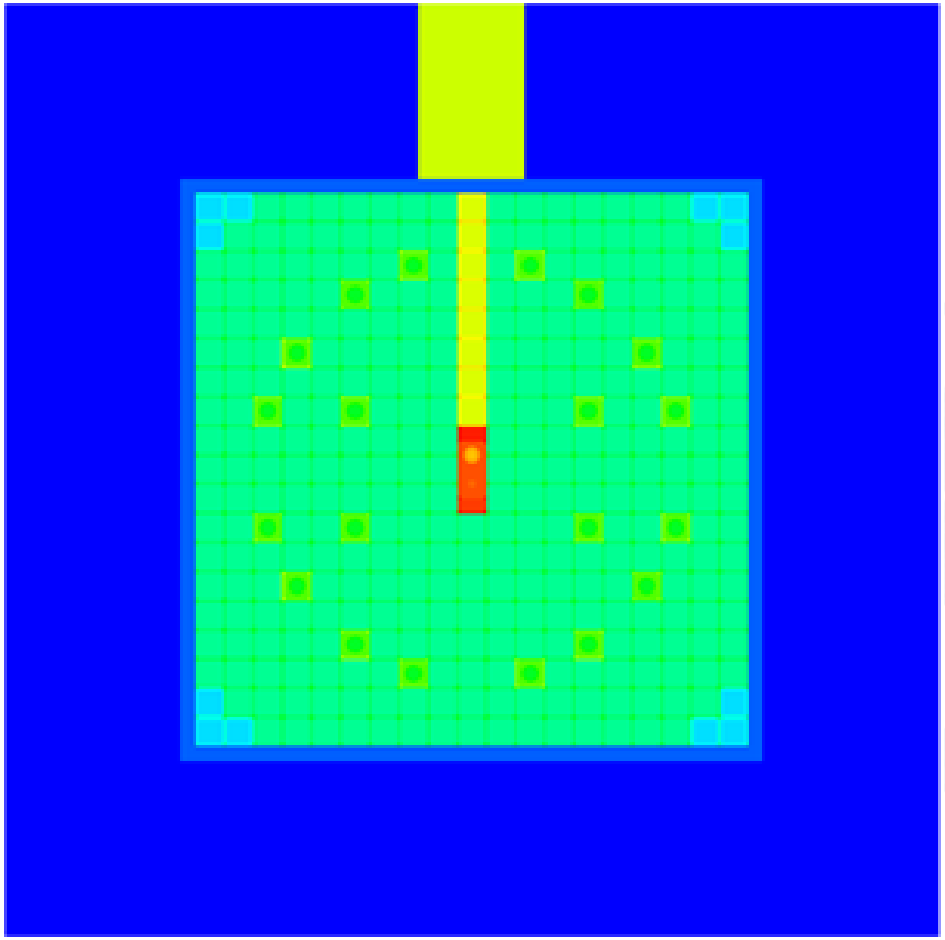
- **Serpent Cross Section Generation**

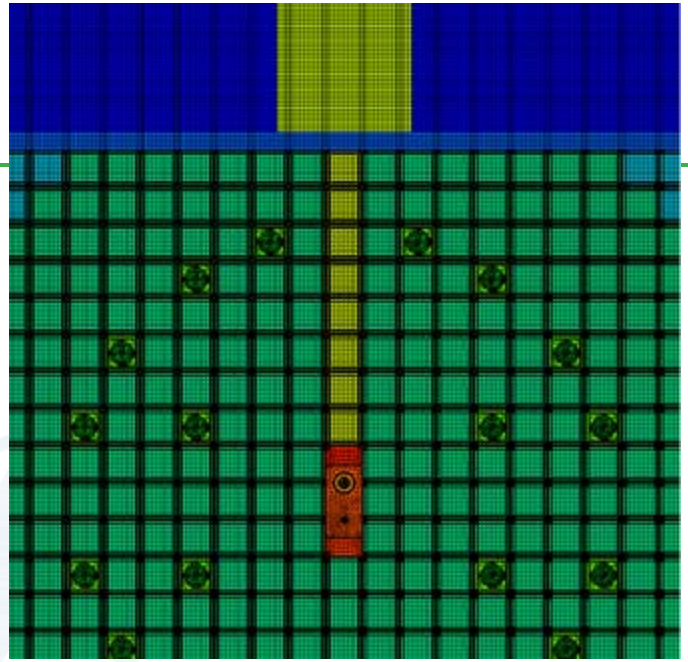
Core	Serpent	PARCS
MCM	1.00413 ± 20 pcm	1.00177
MCM+	1.00171± 20 pcm	0.99769
M8CAL	1.00394 ± 20 pcm	1.04821

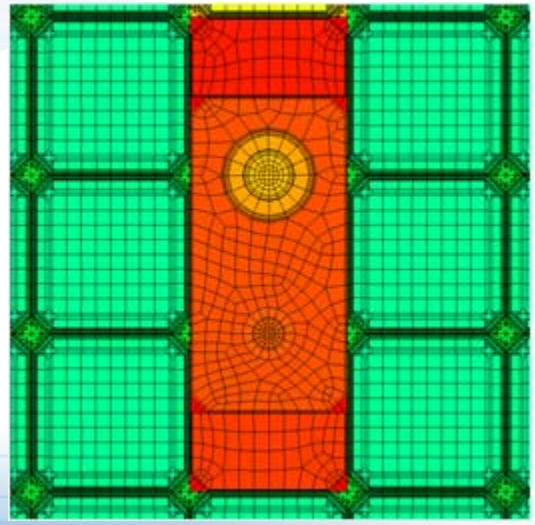
- **If Extracted from 3D M8CAL Model**

	k_{eff}
SERPENT	1.00394 ± 20 pcm
PARCS	1.01167
Diff	773 pcm

PROTEUS Meshing





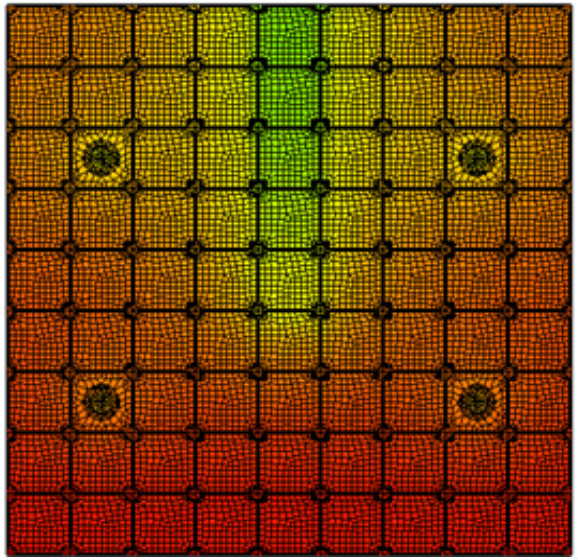


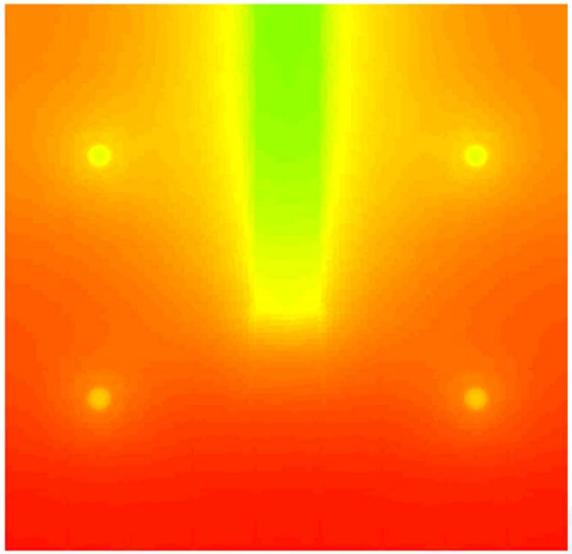
PROTEUS MCM Eigenvalue Solutions

Case	Serpent	PROTEUS	
		Angle	Δk(pcm)
2D Fuel Element (FE)	1.66673 (± 3)	L5T15	-32
2D Core w/o PGR	1.29939 (±15)	L5T15	-167
2D Core w/ PGR	1.23041 (±22)	L5T15	337
3D Single FE	1.45473 (±20)	L5T15	220
		L9T15	196
		L15T15	174
3D 2x2 (3FE,1CE)	1.27926 (±21)	L5T15	120
3D 2x2 (2FE,2CE)	1.16952 (±21)	L5T15	143
3D Core (15x15) w/o PGR	1.19798 (±27)		
3D Full Core	1.00357 (±27)		
	1.00424 (±38)	L5T15	407 **
		L15T25	

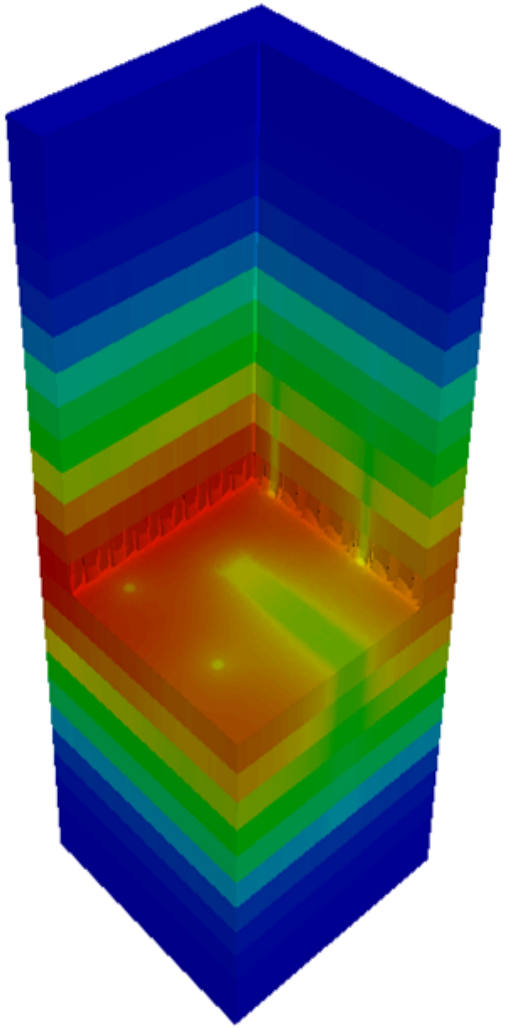
**** Eigenvalue difference is expected to be reduced with higher angular order**

PROTEUS Partial M8CAL Eigenvalue Solutions



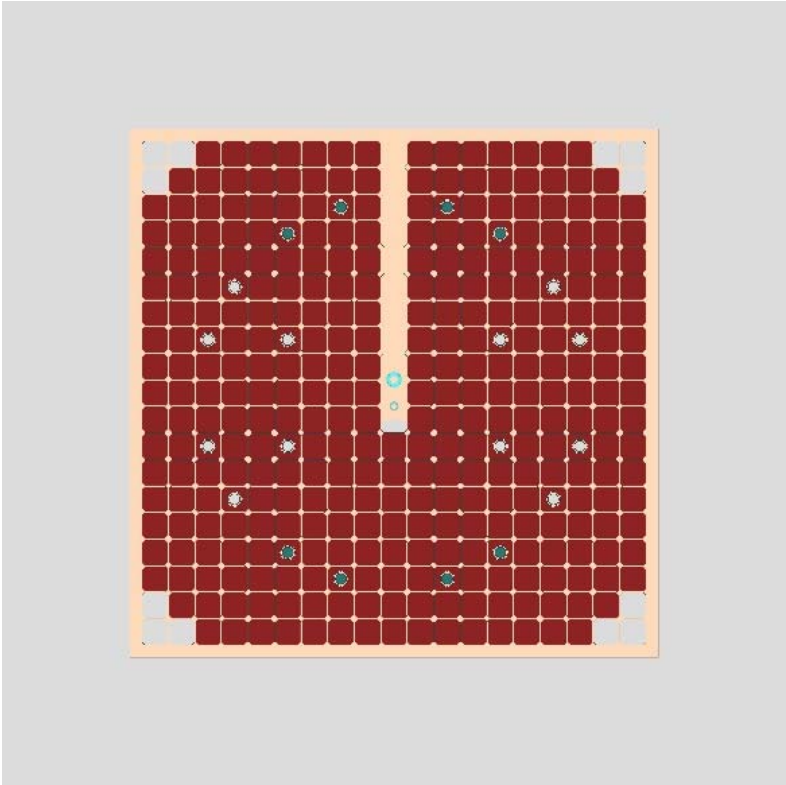


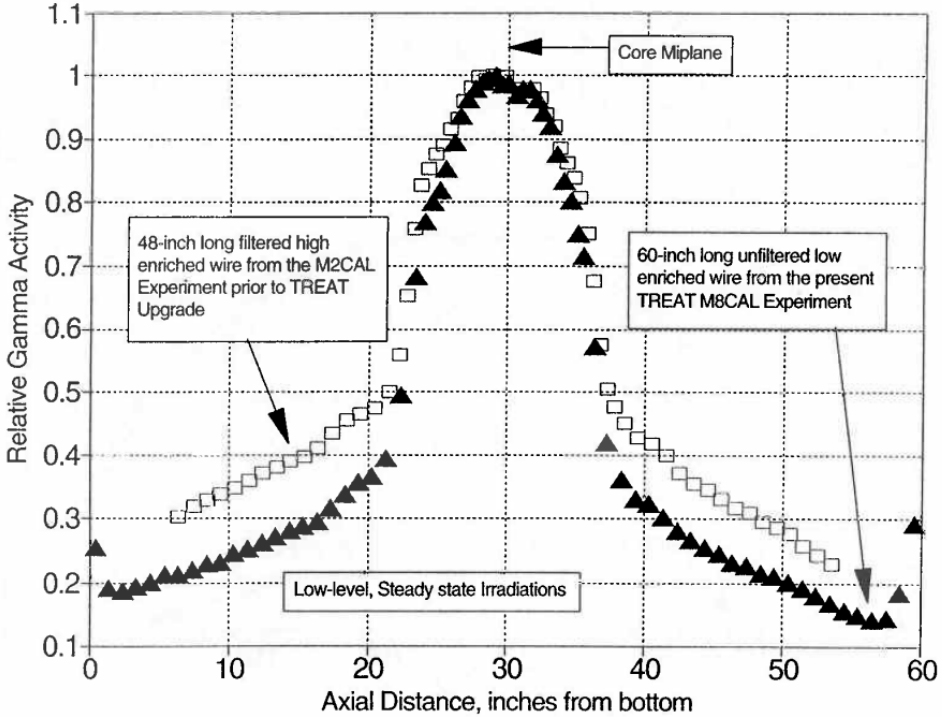
(b)

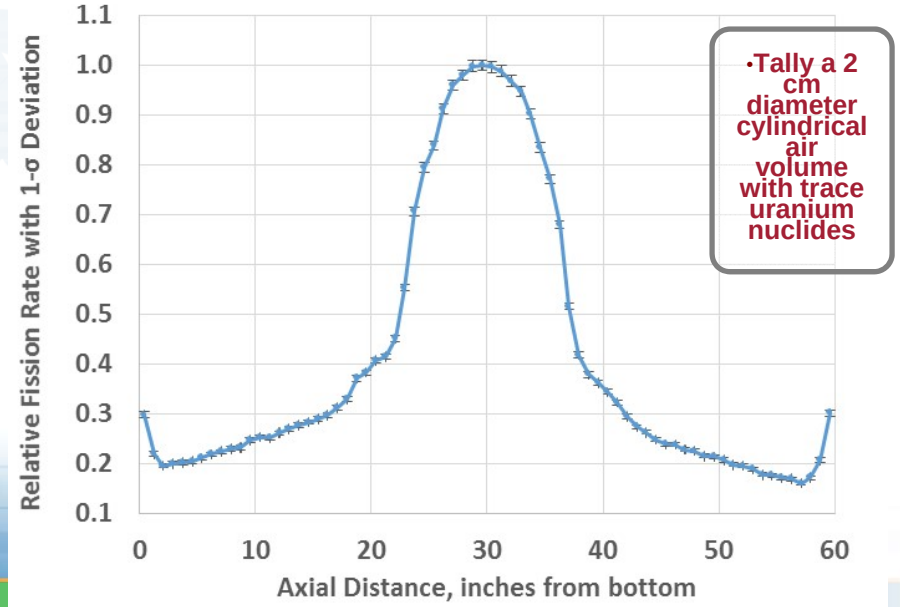


Case	Serpent	PROTEUS	
		Angle	Δk(pcm)
3D Partial Core	1.37609 (±16)	L5T15	214
		L15T15	168
		L5T25	192
		L15T25	147

OpenMC – M8CAL



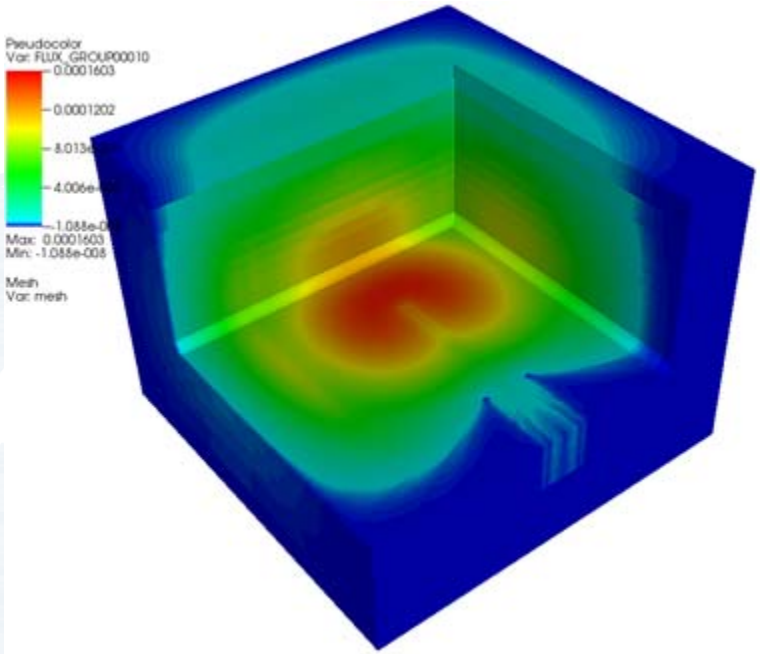




Status of OpenMC Transient Modeling

- Installed Transition Rate (TR) Matrix Method in OpenMC 0.7.0 (UM OTF Doppler version)
- Verified using sample problem supplied by TRMM author Ben Betzler
- Investigated infinite lattice (3x3 assemblies) benchmark problem (homogeneous fuel)
  - Validated fidelity vs heterogeneous simulations w/ Serpent (UM) and OpenMC (MIT).
  - Cataloged sensitivity of trace isotopes on k_{eff}
  - Need homogeneous assemblies for TRMM finite core simulations to minimize phase space
- Initial results for minimum critical core (9x9 TR Matrix, 13.5 x 13.5 assemblies, vacuum boundary) look reasonable

Greatest Challenge with Deterministic Modeling – The Void Space



Significant ongoing effort and methods development to update codes to handle this problem

Steady-State Benchmark

MCM

M8CAL

Preliminary Benchmark Report Needs

- **Section 1**
  - **Experiment Description**
    - **Add additional content**
    - **Create "TREAT Template" for all TREAT benchmark evaluations**
    - **Create Experiment Specific Sections**
- **Section 2**
  - **Uncertainty Evaluation**
    - **Provide additional description and explanation**
- **Section 3**
  - **Provide the benchmark model**
    - **Evaluate simplification biases**

Bias Evaluation for Benchmark

Detailed Model

$\sim k_{exp}$

Remove "Room Return"

Δk

Remove Impurities

Δk

Simplify Geometry

Δk

Adjusted k_{eff}

1σ Uncertainty

Path Forward – IRPhEP Review Process

- **Initial Start-Up Physics Testing Benchmark Report**
  - **MCM, MCM+**
  - **Criticality, Temperature Coefficient, Flux Distributions**
  - **Available for others to evaluate additional original start-up measurements**
- **M8CAL Benchmark Report**
  - **Criticality, Rod Worths**
  - **Later add <u>natural</u> and <u>shaped</u> transient benchmark analysis**
  - **Available for others to evaluate additional M8CAL series data**
  - **<u>Jump-start benchmark activities for TREAT restart!!!</u>**

Path Forward – Transient Benchmarks

1.2	Transient (TR)	
1.2.1	Survey available TREAT TR data for benchmark problem	T. Downar, UM
1.2.2	Preliminary TR modeling of candidate problems	T. Downar, UM
1.2.3	Down-select to two problems for benchmark evaluation	T. Downar, UM
1.2.4	Perform TR modeling with deterministic U.S. NRC codes PARCS/AGREE	T. Downar, UM
1.2.5	Perform TR modeling with deterministic NEAMS code PROTEUS	C. Lee, ANL
1.2.6	**Perform TR modeling with Monte Carlo code OPENMC**	**W. Martin, UM**
1.2.7	Benchmark level evaluation of selected problems	T. Downar, UM
1.2.7	Evaluation of uncertainties in selected problems	T. Downar, UM
1.2.8	Preparation of IRPhE Documentation	T. Downar, UM
1.2.9	Submission of TR benchmark for peer review	T. Downar, UM

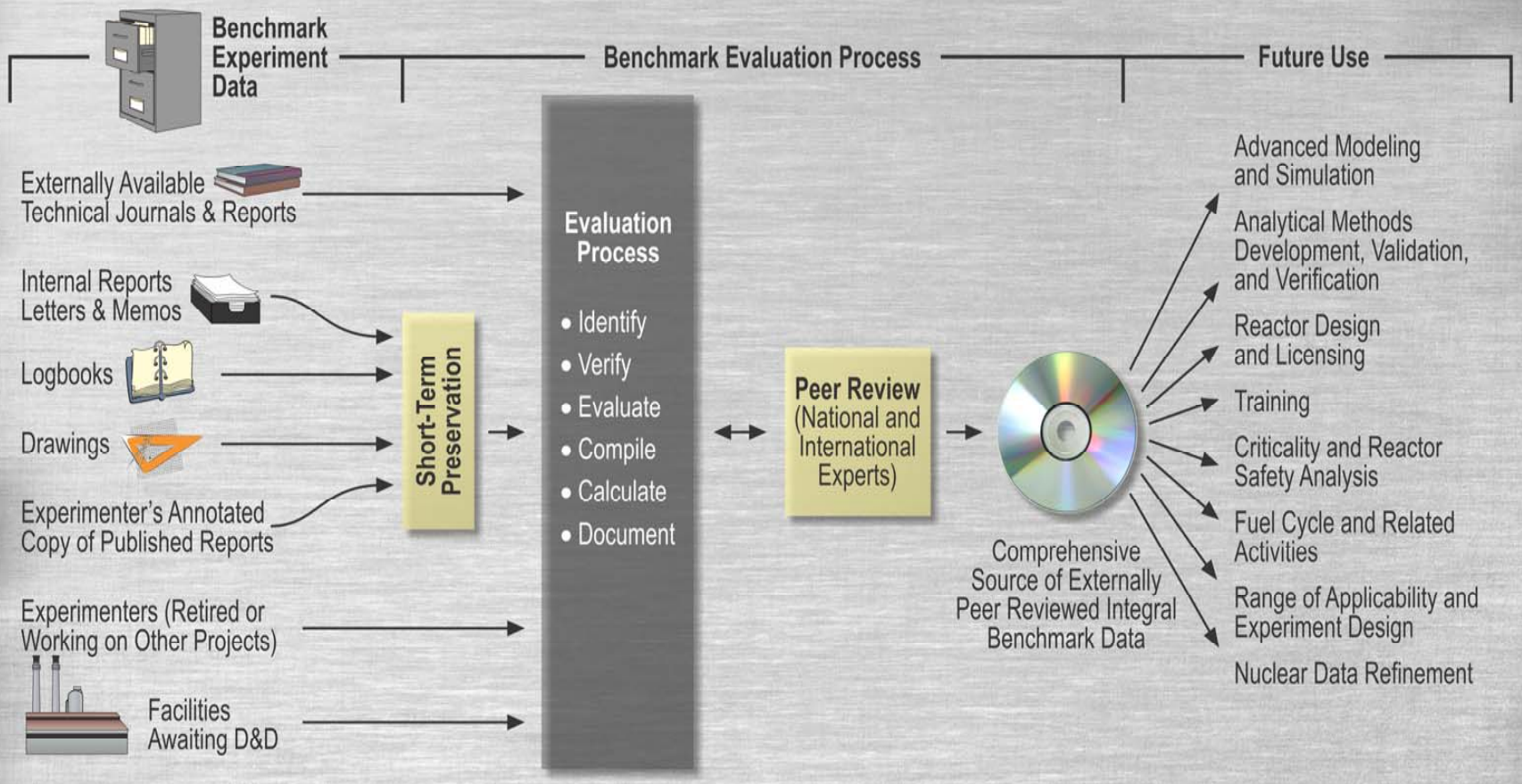
Questions?


THAT CONCLUDES MY TWO-HOUR PRESENTATION. ANY QUESTIONS?
www.dilbert.com scottadams@aol.com
DID YOU INTEND THE PRESENTATION TO BE INCOMPREHENSIBLE, OR DO YOU HAVE SOME SORT OF RARE "POWERPOINT" DISABILITY?
8/4/03 © 2003 United Feature Syndicate, Inc.
ARE THERE ANY QUESTIONS ABOUT THE CONTENT?
THERE WAS CONTENT?

Extra Slides

International Benchmark Programs

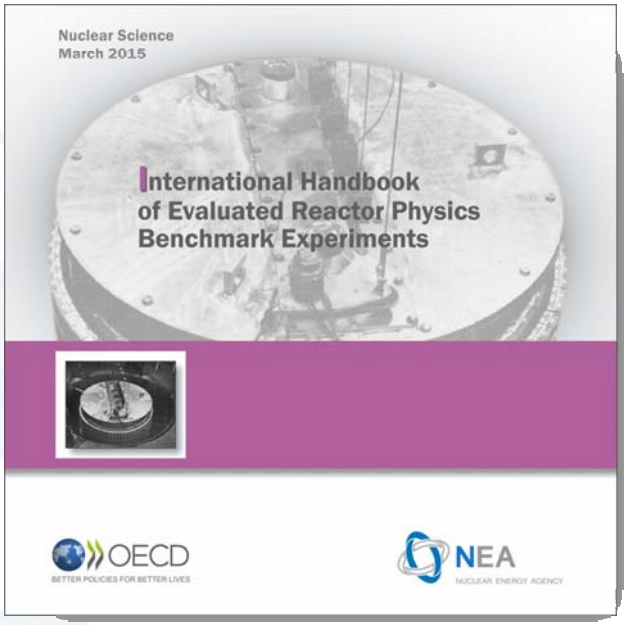
NEA — Nuclear Energy Agency
OECD — Better Policies for Better Lives
INL — Idaho National Laboratory



International Handbook of Evaluated Reactor Physics Benchmark Experiments

March 2015 Edition

- 20 Contributing Countries
- Data from 143 Experimental Series
  - 139 Approved Benchmarks
  - 4 DRAFT Benchmarks



http://irphep.inl.gov/
http://www.oecd-nea.org/science/wprs/irphe/