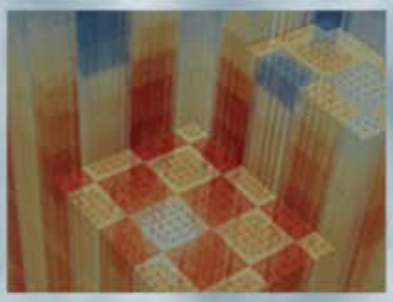
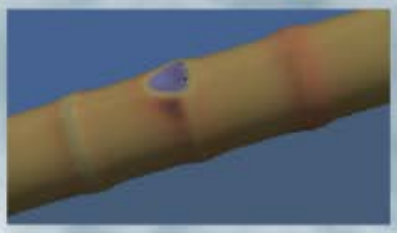
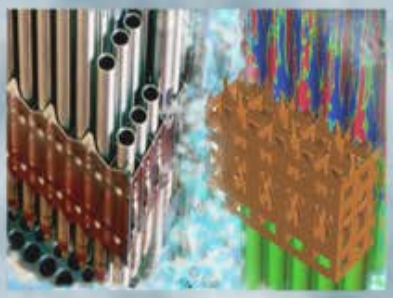
CASL-U-2015-0248-000

Modeling Boiling Water Reactor Designs using MPACT







Andrew P. Fitzgerald
Brendan Kochunas
Daniel Jabaay
Thomas Downar
University of Michigan

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Andrew P. Fitzgerald[1], Dr. Brendan Kochunas[1], Daniel Jabaay[1], Prof. Thomas Downar[1]
1. Department of Nuclear Engineering and Radiological Sciences
University of Michigan

The Consortium for Advanced Simulation of LWRs
A DOE Energy Innovation Hub

Introduction/Motivation

As part of the CASL project [1], the MPACT code [2] has been developed as a tool for LWR analysis. Current activities are focused on extending the capability of MPACT to model Boiling Water Reactors (BWRs). BWRs are much more complex than Pressurized Water Reactors (PWRs) geometrically. The fuel assembly designs in BWRs include structures such as water rods/channels, a channel box, and cruciform control blades. BWRs also have varying coolant density (void) in the axial direction presenting additional complexity. The following studies were used to assess MPACT's ability to model some of these additional geometric complexities in BWRs.

Methods

MPACT uses the method of characteristics (MOC) to solve the neutron transport equation.

$$\vec{\Omega}\cdot\nabla\varphi(\vec{r},\vec{\Omega},E)+\Sigma_t(\vec{r},E)\varphi(\vec{r},\vec{\Omega},E)=\frac{\chi(E)}{4\pi k_{eff}}\int_0^\infty \nu\Sigma_f(\vec{r},E')\int_0^{4\pi}\varphi(\vec{r},\vec{\Omega}',E')d\Omega' dE'$$
$$+\int_0^\infty\int_0^{4\pi}\Sigma_s(\vec{r},\vec{\Omega}'\cdot\vec{\Omega},E'\rightarrow E)\varphi(\vec{r},\vec{\Omega}',E')d\Omega' dE'$$

This involves ray tracing through the spatial mesh and evaluation of MOC equations on the ray segments.

$$\frac{d\varphi}{ds}(\vec{r}_o+s\vec{\Omega},\vec{\Omega})+\Sigma_{t,g}(\vec{r}_o+s\vec{\Omega})\varphi_g(\vec{r}_o+s\vec{\Omega},\vec{\Omega})=q_g(\vec{r}_o+s\vec{\Omega},\vec{\Omega})$$

$$\varphi^{out}_{i,g,m,k}=\varphi^{in}_{i,g,m,k}\exp(-\Sigma_{t,i,g}s_{i,k,m})+\frac{q_{i,g}}{\Sigma_{t,i,g}}\left[1-\exp(-\Sigma_{t,i,g}s_{i,k,m})\right] \qquad \bar{\varphi}_{i,g,m,k}=\frac{\varphi^{in}_{i,g,m,k}-\varphi^{out}_{i,g,m,k}}{\Sigma_{t,i,g}s_{i,m,k}}+\frac{q_{i,g}}{\Sigma_{t,i,g}}$$

To demonstrate MPACT's initial capability to model BWRs, several different lattice designs were analyzed, including an ATRIUM™ 10 design, and lattices from the Peach Bottom Unit 2 Reactor Cycles 1 and 2.

ATRIUM™ 10 simulations were compared against several different deterministic transport codes [4] and Peach Bottom simulations were compared against KENO [3] solutions where the model approximated the channel box corners as square.

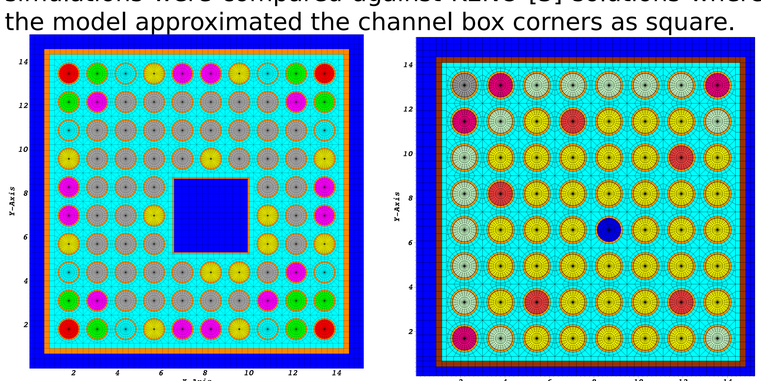
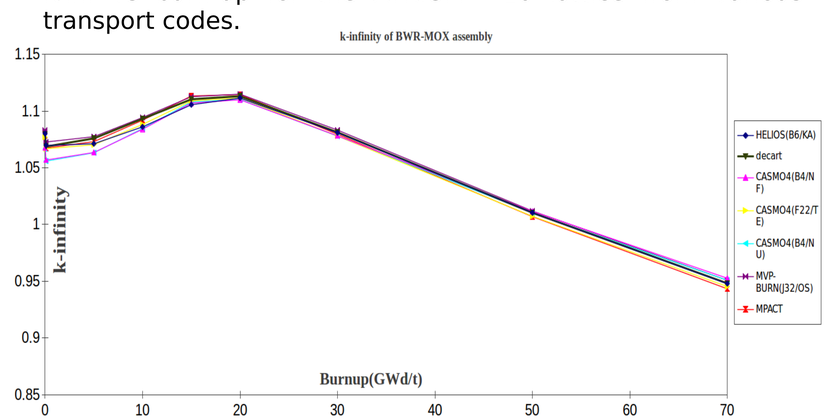


Figure 1. ATRIUM™ 10 10x10 with 3x3 square water channel lattice design[4](left). Peach Bottom assembly type 4 8x8 with small water rod lattice design[5](right). Both images generated by MPACT.

Results

ATRIUM™ 10:
K-inf vs burn-up for the ATRIUM™ 10 lattice from various transport codes.



One thing to note is that each of the codes was run using different cross-section libraries and there is large variation in the nuclear data which can account for some of the observed difference.

Code	HELIOS (B6/KA)	CASMO4 (B4/NF)	CASMO4 (F22/TE)	CASMO4 (B4/NU)	MVP-BURN (J32/OS)	DeCART	MPACT
Max Diff. From Avg. (pcm)	456.1	-827.9	-392.8	-921.9	762.1	563.4	-595.29

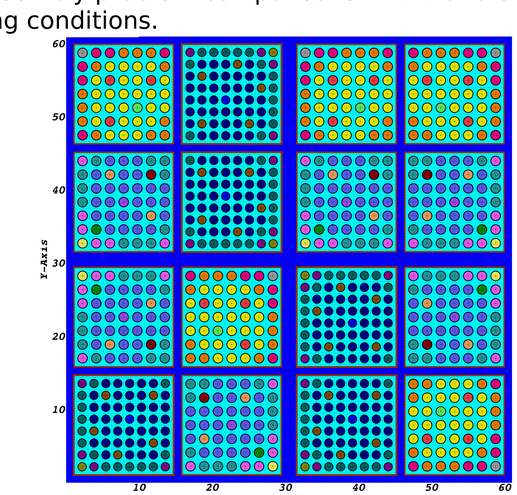
Peach Bottom:
The various Peach Bottom lattice designs were simulated at hot zero power conditions. The KENO solution has a statistical uncertainty of ±2 pcm in k-eff and max. uncertainty of 0.04% on the relative fission rate distribution. In the comparison of the MPACT and KENO solutions the observed maximum difference in k-eff is 222 pcm, and maximum pin power difference is 1.68%.

	k-eff	k-eff	Difference k(pcm)	Max pin power diff	RMS pin power diff
Case Name	KENO	MPACT	KENO-MPACT	MPACT-KENO	MPACT-KENO
Type 1	1.054467	1.0536389	82.81	0.84%	0.30%
Type 2a	1.1066	1.1045006	209.94	1.63%	0.76%
Type2b	1.147151	1.1454353	171.57	1.52%	0.73%
Type 3	1.0418	1.0395796	222.04	1.68%	0.81%
Type 3e	1.093657	1.0918321	182.49	1.59%	0.77%
Type 3de	1.15515	1.1535785	157.15	1.53%	0.73%
Type 4 Chan1	1.102061	1.1009433	111.77	1.54%	0.65%
Type 4 Chan2	1.099931	1.0987805	115.05	1.57%	0.63%
Type 5	1.114888	1.1142865	60.15	1.52%	0.66%
Type 6	1.104011	1.1030708	94.02	1.43%	0.62%

Conclusions and Future work

MPACT is shown to have the ability to model some BWR features such as (square) channel boxes, water rods, and water channels with reasonable accuracy. The ATRIUM™ 10 comparison has shown MPACT can predict k-inf with similar accuracy as other codes. The Peach Bottom lattices were compared against Monte-Carlo solutions from KENO and were shown to have k within 220 pcm, and pin power within 1.6%.

Future work will consist of comparisons using more faithful channel box geometry, problems with BWR control blades and multi-assembly problem comparisons in 2-D and 3-D at various operating conditions.



Auto-rotated 4x4 mini-core using Peach Bottom assembly types 2,3,4 using MPACT.

Acknowledgements

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[2] *MPACT Theory Manual*, v2.0.0, University of Michigan, 2015.
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