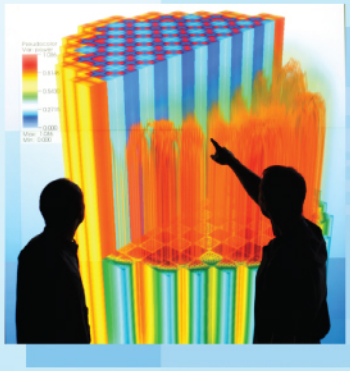
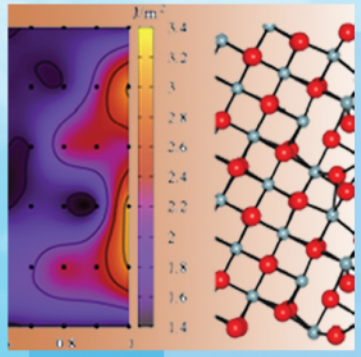
CASL-U-2014-0136-000

Power uprates
and plant life extension



Engineering design
and analysis

Science-enabling
high performance
computing



Fundamental science

Plant operational data

Consortium for Advanced Simulation of LWRs

Presentation Poster:

The SPn Axial Transport Solver for 2D/1D in MPACT

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U.S. DEPARTMENT OF ENERGY | Nuclear Energy

The SP_n Axial Transport Solver for 2D/1D in MPACT

Shane G. Stimpson – The University of Michigan

Mentor: B. Collins **With:** M. Jessee **Program:** NESLS CASL, Reactor and Nuclear Systems Division

Introduction

- The 2D/1D scheme in MPACT, which decomposes 3D geometries into an axial stack of radial planes, has been used to successfully solve a number of challenge problems within CASL
- Method of characteristics (MOC) is used radially and nodal methods are used axially
- Primary axial solver has been the two-node nodal expansion method (NEM), which is based on the diffusion equation
- In general, diffusion solutions are sufficiently accurate and have been used for decades, but more difficult problems require higher fidelity solvers
- To more accurately represent the polar dependence of the angular flux, a simplified P_n (SP_n) axial solver has been implemented

Governing Equations

- Angular Flux Expansion [1]:

$$\psi_g(x,\mu) \approx \sum_{n=0}^{N} \frac{2n+1}{2} P_n(\mu)\psi_{n,g}(x)$$

- Moment Equation(s):

$$\frac{d}{dx}\left[\frac{n}{2n+1}\psi_{n-1}(x) + \frac{n+1}{2n+1}\psi_{n+1}(x)\right] + \Sigma_t\psi_n(x) = \Sigma_{sn}\psi_n(x) + Q(x)\delta_{n,0}$$

- Boundary Conditions:

Bottom

$$\int_{-1}^{0} |\mu| P_n(\mu)\psi^b(\mu)d\mu$$

Top

$$\int_{0}^{1} \mu P_n(\mu)\psi^b(\mu)d\mu$$

- SP1 yields the diffusion equation
- SP3 can be simplified to two moment equations ($0^{th}, 2^{nd}$)
- SP5 has three moment equations ($0^{th}, 2^{nd}, 4^{th}$)
- Both SP3 and SP5 implementations use a one-node NEM kernel for spatial expansion, which uses a quarter Legendre expansion for the flux and quadratic expansion for the source

Single Assembly Benchmark Case

- Single 17x17 pin assembly with quarter symmetry (9x9 pin)
- 6 Zircaloy and 2 Inconel spacers
- Explicit gap, nozzle, and core plates
- Results shown for transport-corrected (TC) and P2 scattering
- Run with 480 processors on Titan

Table 1. Single Assembly Results

		Eigenvalue	Diff. (pcm)	RMS (%)	Max (%)	Iter.	Time (min.)
	KENO-CE	1.17572	---	---	---	---	---
TC	NEM	1.17581	8	0.620	1.427	11	1.649
	SP3	1.17582	10	0.518	1.265	11	1.679
	SP5	1.17582	10	0.513	1.265	11	1.751
P2	NEM	1.17469	-103	0.566	1.237	10	3.959
	SP3	1.17472	-100	0.459	0.857	11	4.207
	SP5	1.17472	-100	0.453	0.849	10	4.050

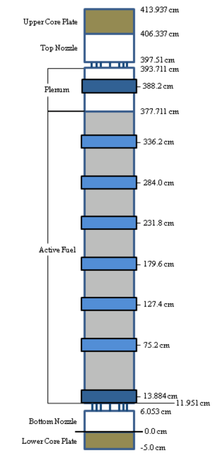

Figure 1. Single Assembly Axial Geometry [2]

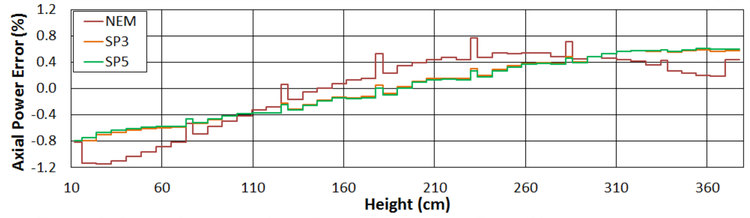

Figure 2. Single Assembly Axial Power Distribution Error (%)

3x3 Assembly Benchmark Case

- Same axial geometry
- 3x3 assembly configuration with control rod in center assembly
- P2 scattering for radial solver
- Run with 2160 processors on Titan

2.1	2.6 20 PY	2.1
2.6 20 PY	2.1 RCCA	2.6 20 PY
2.1	2.6 20 PY	2.1

Figure 3. 3x3 Assembly Radial Geometry [2]

Table 2. 3x3 Assembly Results

	Eigenvalue	Diff. (pcm)	RMS (%)	Max (%)	Iter.	Time (min.)
KENO-CE	0.99938	---	---	---	---	---
NEM	0.99803	-135	1.014	2.088	9	7.986
SP3	0.99806	-132	0.836	1.975	9	8.051
SP5	0.99806	-132	0.828	2.049	9	8.125

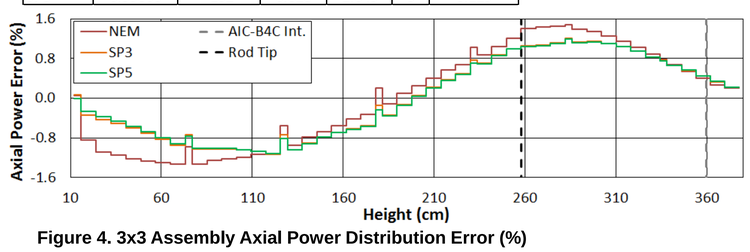

Figure 4. 3x3 Assembly Axial Power Distribution Error (%)

Quarter-Core Benchmark Case

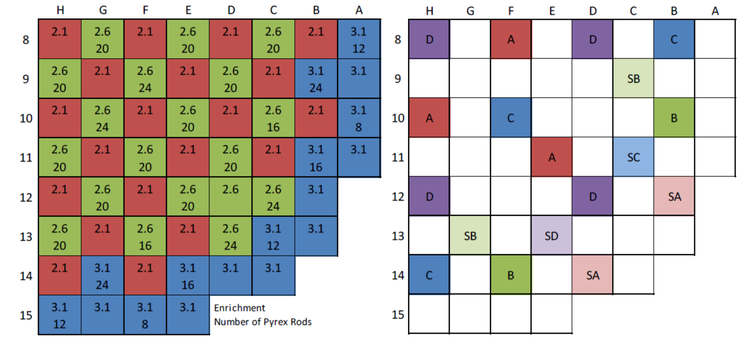

Figure 5. Quarter-Core Assembly Layout and Control Rod Bank Locations [2]

- All cases completed with 2784 processors on Titan
- Initial Critical
  - Boron Concentration: 1300 ppm
  - ARO except Bank D, which is at 167 steps (230 is fully withdrawn)

Table 3. Quarter-Core Initial Critical Results

	Eigenvalue	Diff. (pcm)	RMS (%)	Max (%)	Iter.	Time (hours)
KENO-CE	1.00050	---	---	---	---	---
NEM	0.99942	-108	0.807	2.956	13	3.557
SP3	0.99944	-106	0.721	2.828	13	3.525
SP5	0.99944	-106	0.720	2.899	13	3.556

- Rod Bank Critical Configurations

Table 4. Quarter-Core Rod Bank Critical Results with SP3

Critical Description	Boron Conc. (ppm)	Control Rod Bank (Steps Withdrawn)								Eigenvalue	Diff. (pcm)
		SA	SB	SC	SD	A	B	C	D		
ARO	1299	230	230	230	230	230	230	230	230	0.99965	-35
Bank SA	1177	0	230	230	230	230	230	230	69	0.99796	-204
Bank SB	1177	230	0	230	230	230	230	230	134	0.99844	-156
Bank SC	1177	230	230	0	230	230	230	230	71	0.99859	-141
Bank SD	1177	230	230	230	0	230	230	230	71	0.99854	-146
Bank A	1177	230	230	230	230	0	230	230	97	0.99785	-215
Bank B	1177	230	230	230	230	230	0	230	113	0.99813	-187
Bank C	1177	230	230	230	230	230	230	0	119	0.99811	-189
Bank D	1177	230	230	230	230	230	230	230	18	0.99831	-169

Acknowledgments

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[1] Ryan G. McClarren. "Theoretical Aspects of the Simplified P_n Equations." Transport Theory and Statistical Physics, 39(2-4), 73-109 (2011).

[2] Andrew T. Godfrey. "VERA Core Physics Benchmark Progression Problem Specifications (Rev. 2)," Tech. Rep. CASL-U-2012-0131-002, ORNL, (2013).

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