Establishing a Serpent Model for I²S-LWR First Core Analysis

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Objectives

- Model first fuel cycle of the Integral Inherently Safe Light Water Reactor (I^2S-LWR)
- Verify that Serpent models are valid
- Compare results from other code packages (done by other I^2S-LWR groups) with Serpent results

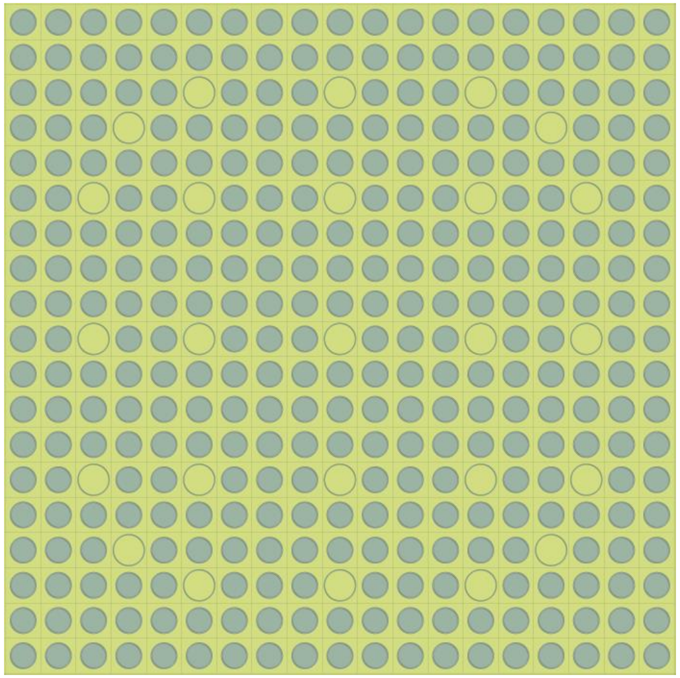
Geometry

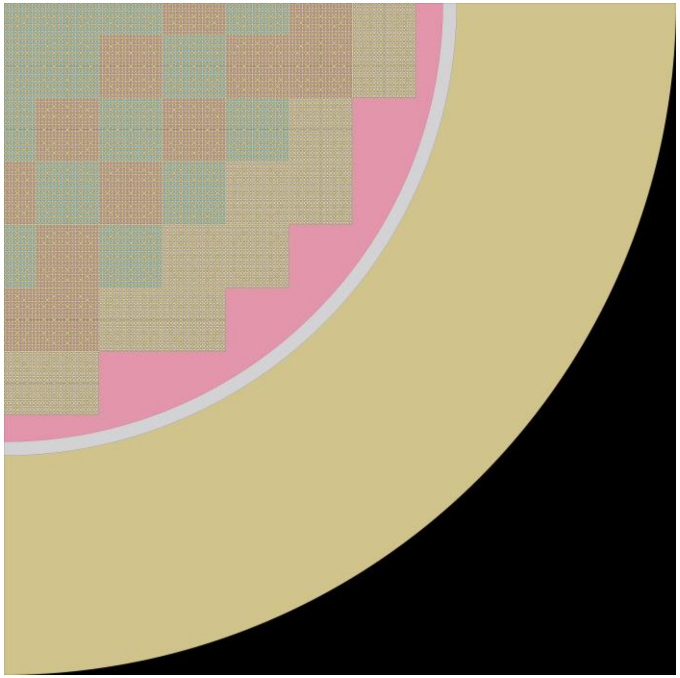
Quantity [unit]	Value
Fuel outer radius (diameter) [cm]	0.40513 (0.81026)
IFBA coating outer radius [cm]	0.4057226
Outer gas gap radius (diameter) [cm]	0.41656 (0.83312)
Cladding outer radius (diameter) [cm]	0.4572 (0.9144)
Fuel pin pitch [cm]	1.21006
Fuel assembly layout [-]	19x19
Fuel pins per assembly [-]	336
Guide tubes per assembly [-]	24
Instrumentation tubes per assembly [-]	1
IFBA fuel pins per assembly [-]	0, 84, 100, 156
Non-IFBA fuel pins per assembly [-]	336, 252, 236, 180
Fuel assembly pitch [cm]	23.1013
Interassembly gap [cm]	0.11016
Reflector outer radius (diameter) [cm]	160 (320)
Core barrel outer radius (diameter) [cm]	165 (330)
Downcomer radius (diameter) [cm]	245 (490)

Input Parameters

Parameter	Value
Inlet coolant temperature	298 ^{o}C
Inlet coolant density	0.73085 g/cm^3
Outlet coolant temperature	330.5 ^{o}C
Outlet coolant density	0.64965 g/cm^3
Core thermal power rating	2850 MWt
Nominal pressure	15.51 MPa

Serpent Geometry Renderings via “plot”





Georgia Tech

I^2S–LWR

IFBA Patterns Used

GT	2	2	1	GT	2	1	GT	2	1
2	1	1	1	2	1	1	2	1	1
2	1	1	1	2	1	1	2	1	1
1	1	1	1	1	1	1	1	1	1
GT	2	2	1	GT	2	1	GT	2	1
2	1	1	1	2	1	2	2	1	1
1	1	1	1	1	2	GT	1	1	1
GT	2	2	1	GT	2	1	1	1	1
2	1	1	1	2	1	1	1	1	1
1	1	1	1	1	1	1	1	1	2

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GT	2	2	2	GT	2	2	GT	2	1
2	1	1	1	2	1	1	2	1	2
2	1	1	1	2	1	1	2	1	2
2	1	1	1	2	1	1	2	1	1
GT	2	2	2	GT	2	2	GT	2	1
2	1	1	1	2	1	2	2	1	2
2	1	1	1	2	2	GT	2	1	1
GT	2	2	2	GT	2	2	1	2	1
2	1	1	1	2	1	1	2	1	1
1	2	2	1	1	2	1	1	1	2

100*

GT	2	2	2	GT	2	2	GT	2	1
2	1	1	1	2	1	1	2	1	2
2	1	1	1	2	1	1	2	1	2
2	1	1	1	2	1	1	2	1	1
GT	2	2	2	GT	2	2	GT	2	1
2	1	1	1	2	1	2	2	1	2
2	1	1	1	2	2	GT	2	1	1
GT	2	2	2	GT	2	2	1	2	1
2	1	1	1	2	1	1	2	1	1
1	2	2	1	1	2	1	1	1	2

156

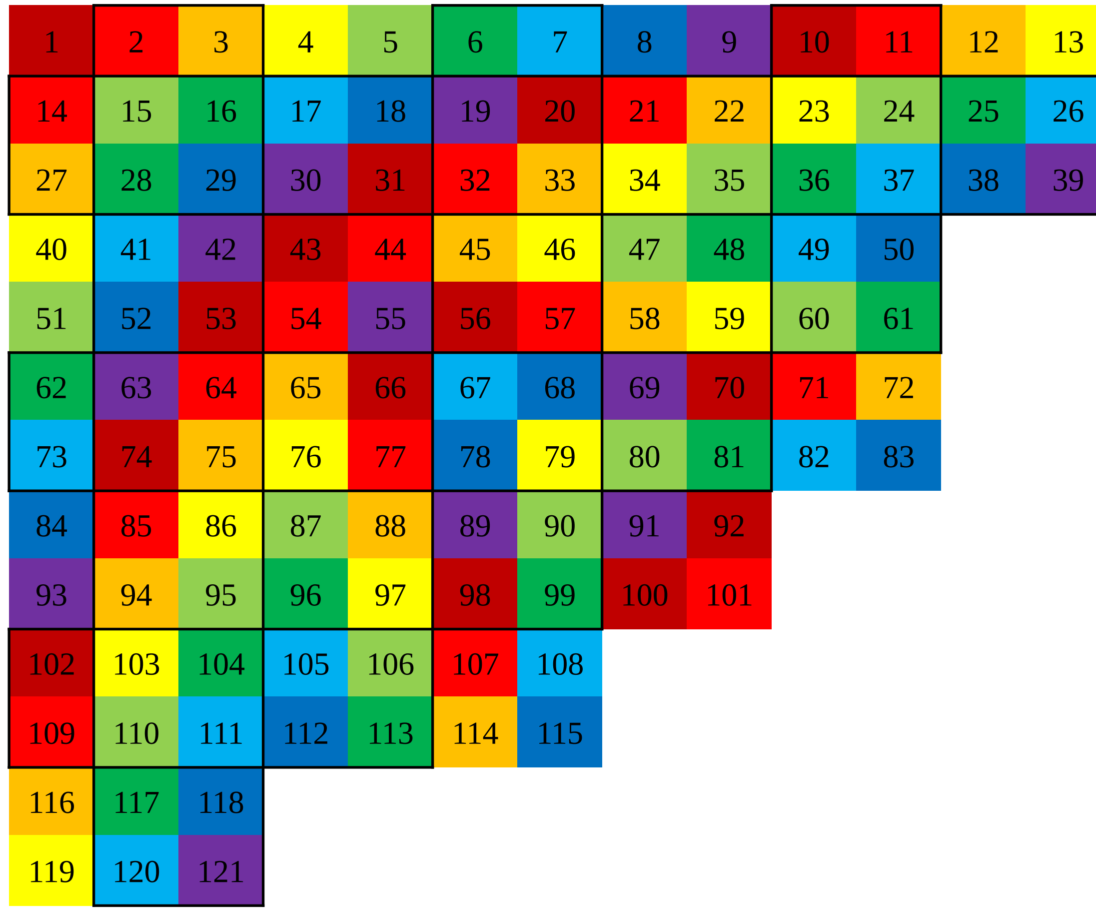
Proposed 12 Month First Core Loading

L	L (84)	L	M (156)	L	M (100)	H
L (84)	L	M (100)	L	M (156)	M	H
L	M (100)	L	M (156)	L	H (84)	
M (156)	L	M (156)	L	H (100)	H	
L	M (156)	L	H (100)	H		
M (100)	M	H (84)	H			
H	H					

Legend
L - Lowest enrichment (2.6 w/o)
M- Middle enrichment (3.0 w/o)
H - Highest enrichment (3.8 w/o)
(###) - Number of IFBA rods

Burnable Fuel Materials

- 121 Quarter Core, Quarter Assembly Locations
- 65 fuel materials groups
- For IFBA sections: 91 unique burnable fuel materials



Axial Fuel Arrangement

- 10 Axial Sections
  - Blankets: 2.5 w% enriched ^{235}U
  - Fuel: coated with 2.5 mg/in ^{10}B IFBA
    - Assumed density of 6.07 g/cc ZrB_2, 60 a% ^{10}B, thickness of 5.926 µm
  - Cutback: fuel without IFBA coating

Blanket	6 in
Cutback	9 in
Fuel 7	12 in
Fuel 6	18 in
Fuel 5	21 in
Fuel 4	21 in
Fuel 3	21 in
Fuel 2	18 in
Fuel 1	12 in
Blanket	6 in

Burnable Materials Summary

- Fuel Materials:
  - 65 in each axial section of blanket (2) and cutback (1)
  - 91 in each of the 7 axial section of fuel (IFBA-coated rods tracked as a separate fuel material)
  - 832 fuel regions to be tracked

- IFBA coatings
  - 26 in each of the 7 axial section of IFBA-coated fuel
  - 182 IFBA regions to be tracked

- Total number of burnable materials to be tracked: 1014

Computer Clusters Used (our Research Group)

- About 500 cores total
- Several 8 processor nodes
  - 4 have 8 GB RAM per processor
  - 18 have 2 GB RAM per processor
- One larger node with 32 processors
  - 8 GB RAM per processor (256 GB total)

Runtime Parameters

- Serpent version used for these runs: 2.1.23
- k Calculations
  - 2 GB systems can only be used with jobs without uniquely defined fuel / IFBA materials
- Depletion runs
  - Cannot be run with 2 GB processors (too memory intensive)
  - Only the 8 GB nodes can be used
  - Serpent's estimated relative CPU usage: 97.5 % (approaching limit)
- For both eigenvalue and depletion calculations on both the 2 and 8 GB nodes, jobs run at ~1650 particles/processor/second for tasks using OpenMP with 8 tasks
  - In the eigenvalue cases, 2 and 8 GB processor simulation rate was the same

BOL Radial Power Profile

1.058	0.949	0.951	1.054	1.019	0.892	0.879	0.989	1.046	1.051	1.062	1.233	0.902
0.949	1.067	1.068	1.008	0.985	1.000	0.976	0.898	0.938	1.168	1.182	1.172	0.821
0.951	1.068	1.070	1.011	0.988	1.006	0.986	0.909	0.942	1.137	1.083	0.965	0.633
1.054	1.008	1.011	1.052	1.024	0.909	0.912	1.031	1.061	1.129	0.925		
1.019	0.985	0.988	1.024	1.009	0.922	0.949	1.080	1.084	1.078	0.800		
0.892	1.000	1.006	0.909	0.922	1.052	1.100	1.209	1.144	1.086	0.778		
0.879	0.976	0.986	0.912	0.949	1.100	1.137	1.188	1.044	0.904	0.603		
0.989	0.898	0.909	1.031	1.080	1.209	1.188	1.203	0.964				
1.046	0.938	0.942	1.061	1.084	1.144	1.044	0.964	0.702				
1.051	1.168	1.137	1.129	1.078	1.086	0.904						
1.062	1.182	1.083	0.925	0.800	0.778	0.603						
1.233	1.172	0.965										
0.902	0.821	0.633										

BOL Radial Power Profile

Peak Value
1.233

1.058	0.949	0.951	1.054	1.019	0.892	0.879	0.989	1.046	1.051	1.062	1.233	0.902
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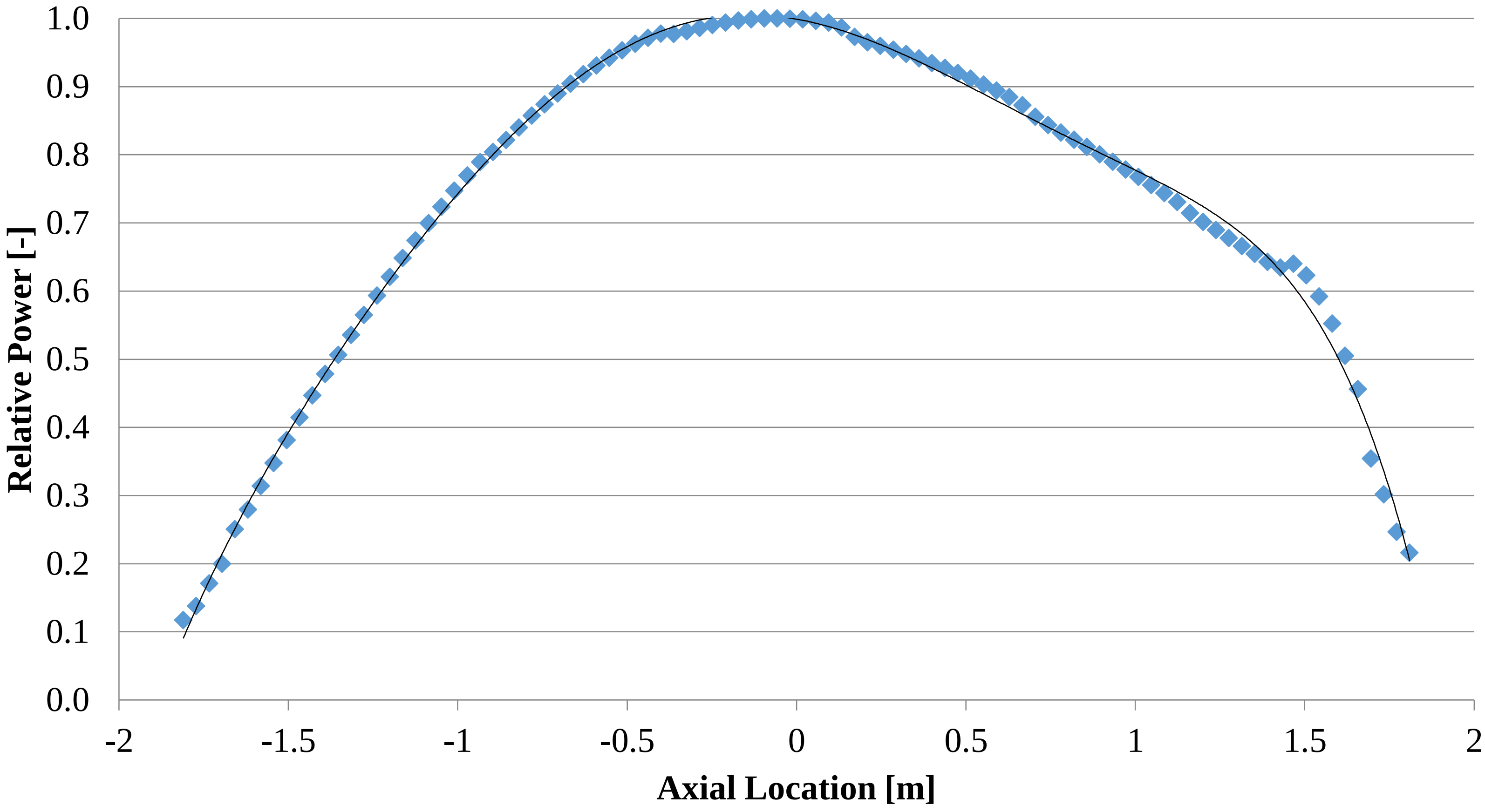
Thermal Hydraulics Iteration

- Curve-fit a 6th degree polynomial for axial power profile from Serpent output file (96 detector meshes axially – every 1.5 in or 3.81 cm)
- 1D single channel analysis C++ code produces coolant data based on this power profile (384 axial locations – every 0.375 in or 0.9525 cm) based on the following parameters:
  - Power profile shape
  - Inlet temperature fixed (298 °C)
  - Outlet temperature fixed (330.5 °C)
- The 384 axial locations are collapsed by averaging coolant temperature and density into their corresponding 10 axial sections described previously

BOL Axial Power Profile



Other Burnup Steps Early in First Cycle

- BOL AO: +0.46%
  - HZP AO likely higher; potential challenge bringing to power
  - With burnup, AO moves lower in the core (does become negative later in cycle)
- Critical boron decreases sharply initially, comes back up slightly, then decreases again as one would expect
- Radial peaking decreases through the first few burnup steps

Ongoing Work

- Completing depletion of fuel scheme previously described
  - Find critical boron concentration of i^{th} and $(i+1)^{th}$ steps
  - Find coolant profile at these steps
  - Deplete from i to (i+1) using average critical boron concentration and coolant property profile

Future Work

- Potential automated coupling (to some degree) between Serpent and thermal hydraulics iteration?

End of Presentation

- Thank you for listening.

- Questions? Comments? Suggestions?