COLLEGE OF ENGINEERING
NUCLEAR ENGINEERING & RADIOLOGICAL SCIENCES
UNIVERSITY OF MICHIGAN

Sampler-Polaris-PARCS Pin Power Uncertainy & Polaris-PARCS BWR Detector Modeling

SCALE Users Group
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Overview

- Sampler-Polaris-PARCS Pin Power Uncertainty
  - Goals & Expectations
  - Development of Models
  - Results & Discussion
- Update on BEAVRS Modeling with Polaris-PARCS
- Polaris-PARCS Hatch Depletion Detector Modeling
  - Detector XS & Modeling in PARCS
  - Comparisons to previous results
- Future SFR modeling & Hybrid Depletion
- Summary/Conclusions

Pin Pow UQ: Goals & Expectations

- Goal – Quantify the pin power uncertainty in PARCS using pin power reconstruction
- PWR Fuel
  - Generally the same enrichment in each pin throughout assembly
  - Watts Bar – Three Enrichments, Five Pyrex configurations
- Expect *Assembly* power to dictate the pin power uncertainty
  - U-235 XS uncertainty
- Watts Bar HZP Startup tests used for comparison
  - Limit the number of Sampler-Polaris calculations

Description of Watts Bar Unit 1

	H	G	F	E	D	C	B	A
8	2.1	2.6 20	2.1	2.6 20	2.1	2.6 20	2.1	3.1 12
9	2.6 20	2.1	2.6 24	2.1	2.6 20	2.1	3.1 24	3.1
10	2.1	2.6 24	2.1	2.6 20	2.1	2.6 16	2.1	3.1 8
11	2.6 20	2.1	2.6 20	2.1	2.6 20	2.1	3.1 16	3.1
12	2.1	2.6 20	2.1	2.6 20	2.6	2.6 24	3.1	
13	2.6 20	2.1	2.6 16	2.1	2.6 24	3.1 12	3.1	
14	2.1	3.1 24	2.1	3.1 16	3.1	3.1		
15	3.1 12	3.1	3.1 8	3.1	Enrichment Number of Pyrex Rods			

- 3411 MW_t with 193 Assemblies
- Bank D (Circles) Inserted to 167 steps
- Critical with 1285 ppm boron

UQ Analysis w/ SCALE

- The statistical sampling sequence Sampler is part of the SCALE code system*
- Random values for the input multigroup cross sections are determined by using the XSUSA program to sample uncertainty data provided in the SCALE covariance library.
- Using these samples, Sampler computes perturbed self-shielded cross sections and propagates the perturbed nuclear data through any specified SCALE analysis sequence including those for criticality safety, lattice physics with depletion, and shielding calculations.
- After perturbation, these cross sections are used in PARCS calculations.
- After running a large number of perturbed calculations, we can perform some statistical analysis of the output distributions provides uncertainties and correlations in the desired responses, due to nuclear data uncertainties.

**A STATISTICAL SAMPLING METHOD FOR UNCERTAINTY ANALYSIS WITH SCALE AND XSUSA, M. L. WILLIAMS, G. ILAS, M. A. JESSEE,B. T. REARDEN, et al., Nuclear Technology, Vol. 183, Sep 2013.*

UQ Analysis w/ SCALE

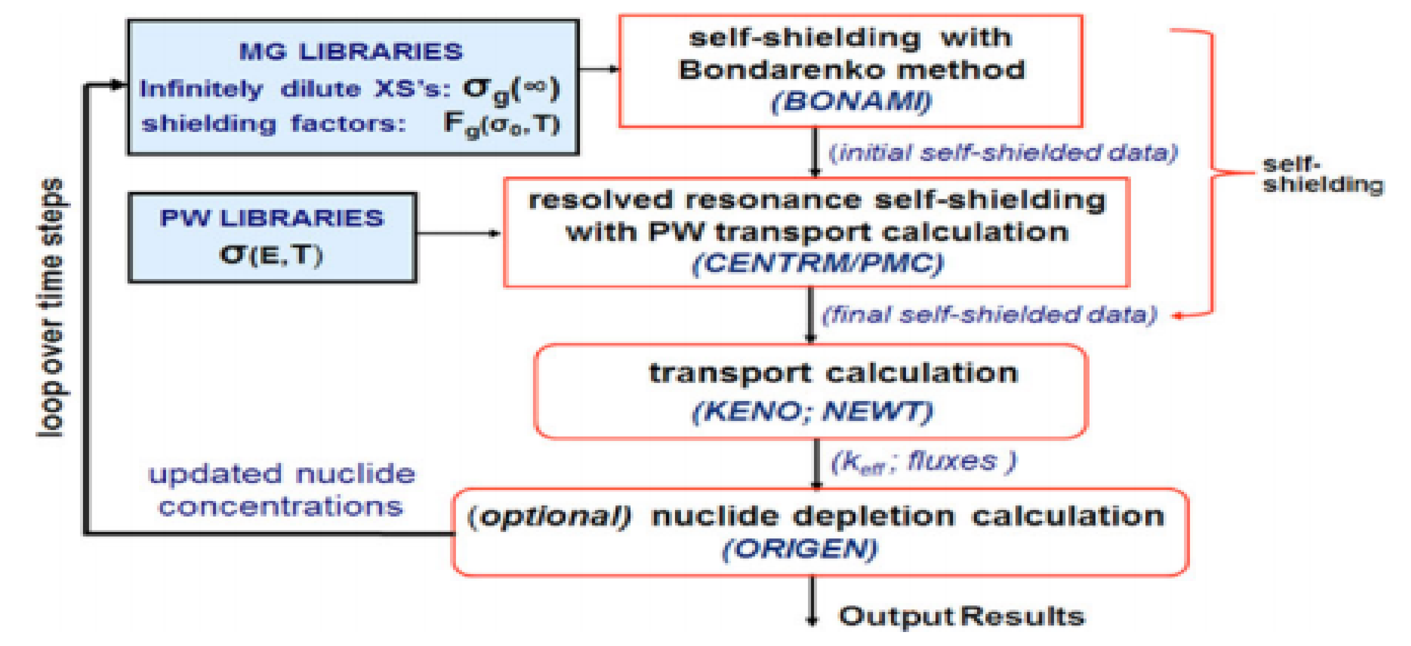


Fig. 1. Flow chart of a SCALE MG computation sequence.

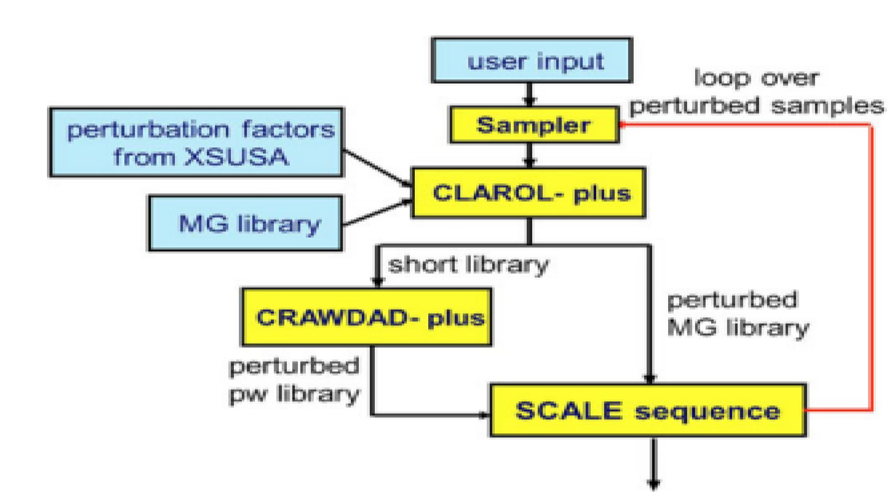
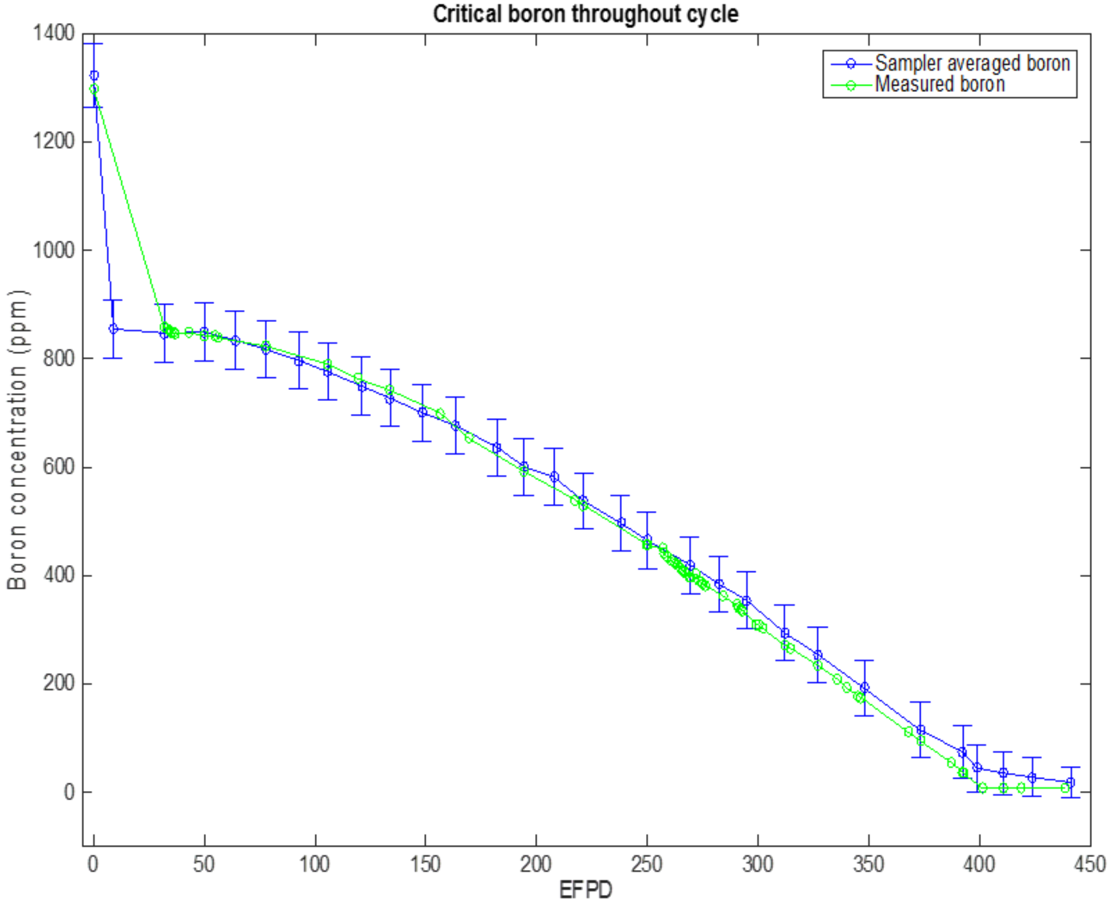


Fig. 2. Sampler sequence flow chart.

- A comprehensive library of nuclear data covariance information has been developed for SCALE by using available covariance from ENDF/JENDL
- First order perturbation theory used to calculate sensitivity coefficients. The coefficients are then folded with nuclear data covariances to obtain the response uncertainty.
- We are using ENDF7.0 covariance data.

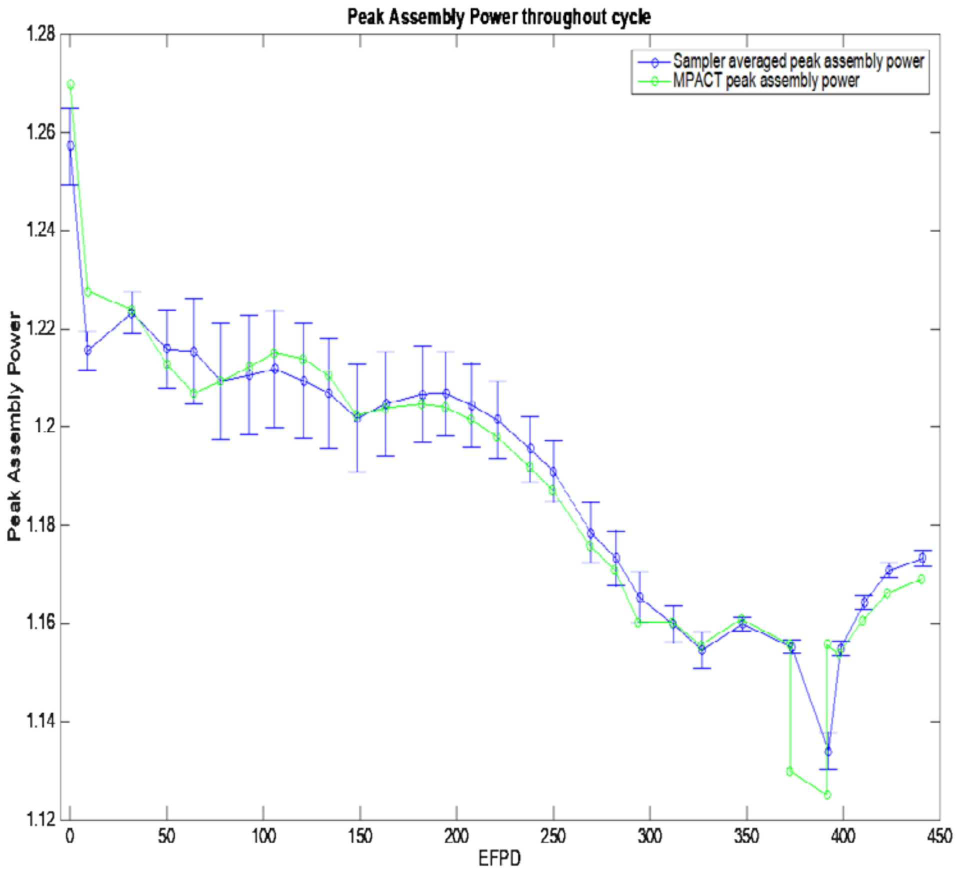
Model Development

- Polaris XS generated for HZP and Depletion
  - Previous experience with Sampler-Polaris for cycle 1 depletion
- Models compared to Plant data,
  - Confidence in models



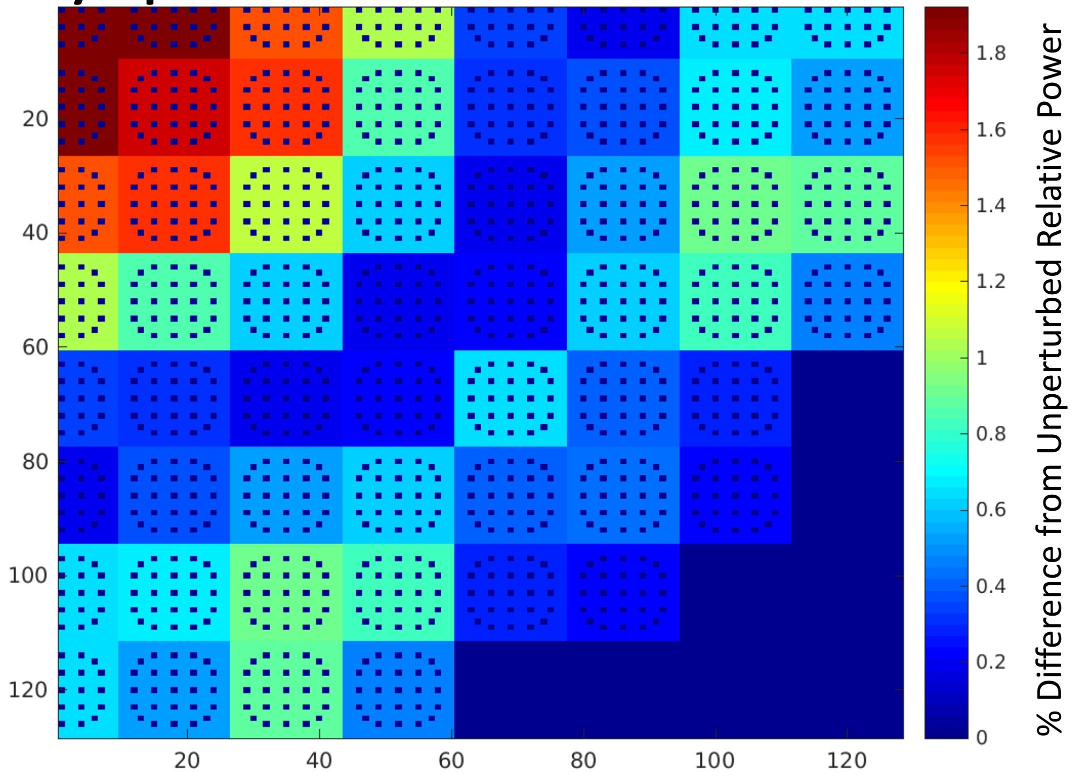
Model Development

- Power shape compared to MPACT solutions
  - Agreement in power shape and k-eff encouraging
- Planning to model cycles 2 and 3 in the future.



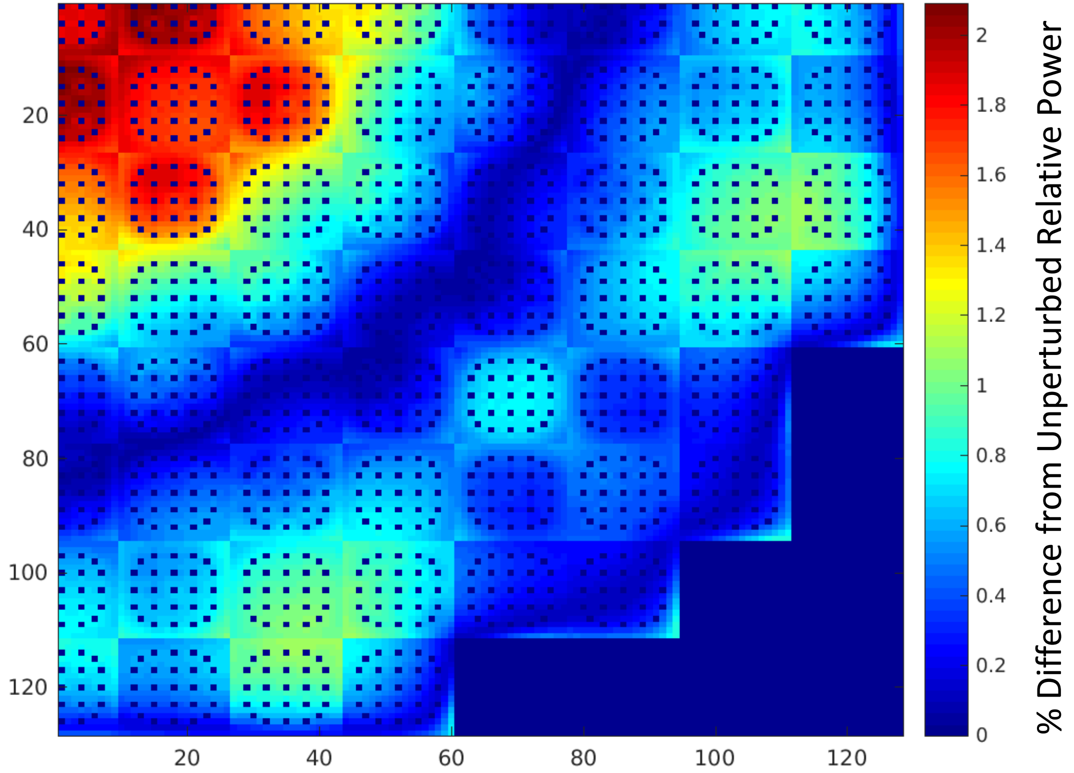
UQ in PARCS HZP assembly power

- Uncertainty appears to increase in:
  - Center of the core
  - A few assemblies near the edge
- Fast Flux level appears to correlate
  - 2.25E10 – 3.1E10 [n/cm^2/s]



UQ in PARCS HZP pin power

- Local spectra observed clearly
  - Interassembly gap effect appears to be spectrum dependent
- A multigroup flux spectrum would give more information



Pin Pow UQ: Discussion

- Propagation of Sampler-Polaris pin power uncertainty through PARCS was successful
- Pin power uncertainty not driven solely by the assembly power level
  - Pin flux → pin power uncertainty is noticeable.
- Flux spectrum appears to directly impact the uncertainty
  - U-235 fission & U-238 capture uncertainty should dominate

Pin Pow UQ: Future Efforts

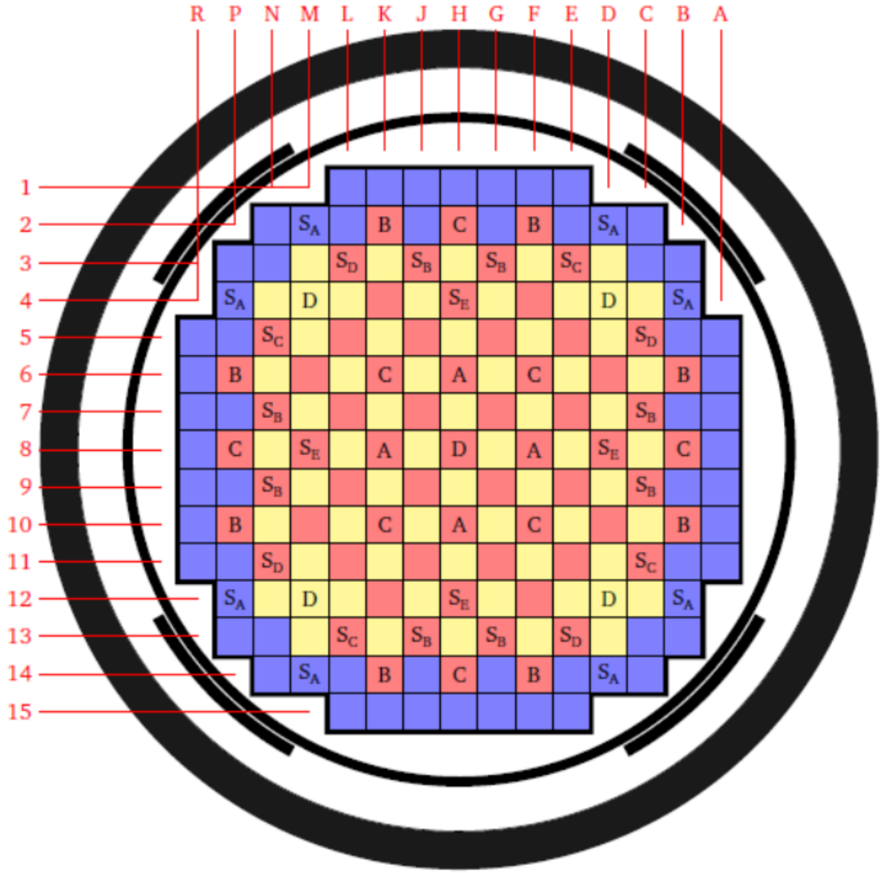
- PWR Detector calculations in PARCS are very similar to the pin power calculations
  - Expect the detector XS uncertainty will propagate well
- Uncertainty in the detector response would be useful in regulatory or safety decision making
  - Highly uncertain detector calculations in high power region could indicate potential issue

BEAVRS: Status of Modeling/Calcs

- Originally developed by Dan O'Grady & Prof. T. Kozlowski, Univ of IL
- Effort to audit models and update to new PARCS v3.3.1
- Rerunning various lattice models through Polaris
- HZP cases agree well; includes Triton results
- Depletion audit is ongoing

BEAVRS: Overview

- “Sanitized” Data from a WEC 4-Loop, 193 Assembly, 3411 MWt
- Cycle 1 Startup
    - Zero power
    - Rod insertion sequences with critical boron
- Polaris, Triton, HELIOS v1.10 results compared



BEAVRS: Hot Zero Power Results, Criticals

- In general consistent agreement
- Case 5 has most of the rods inserted, challenging configuration

Case	Boron	Rods	Polaris	Triton	Helios
[-]	[ppm]	[-]	[Δpcm]	[Δpcm]	[Δpcm]
1	975	D @ 213	-18.3	-287.6	23.5
2	902	D @ 0	127.4	-84.5	139.8
3	810	C,D @ 0	74.8	-74.7	121.1
4	686	A-D @ 0	-96.7	-139.4	-57.2
5	508	A-D,SD,SE @ 0	**-830.3**	-347.6	**-1015**

BEAVRS: Hot Zero Power Results, Rod Worth

- Reasonable comparison to measurements
- Bank D differences similar to PARCS Watts Bar 1 model

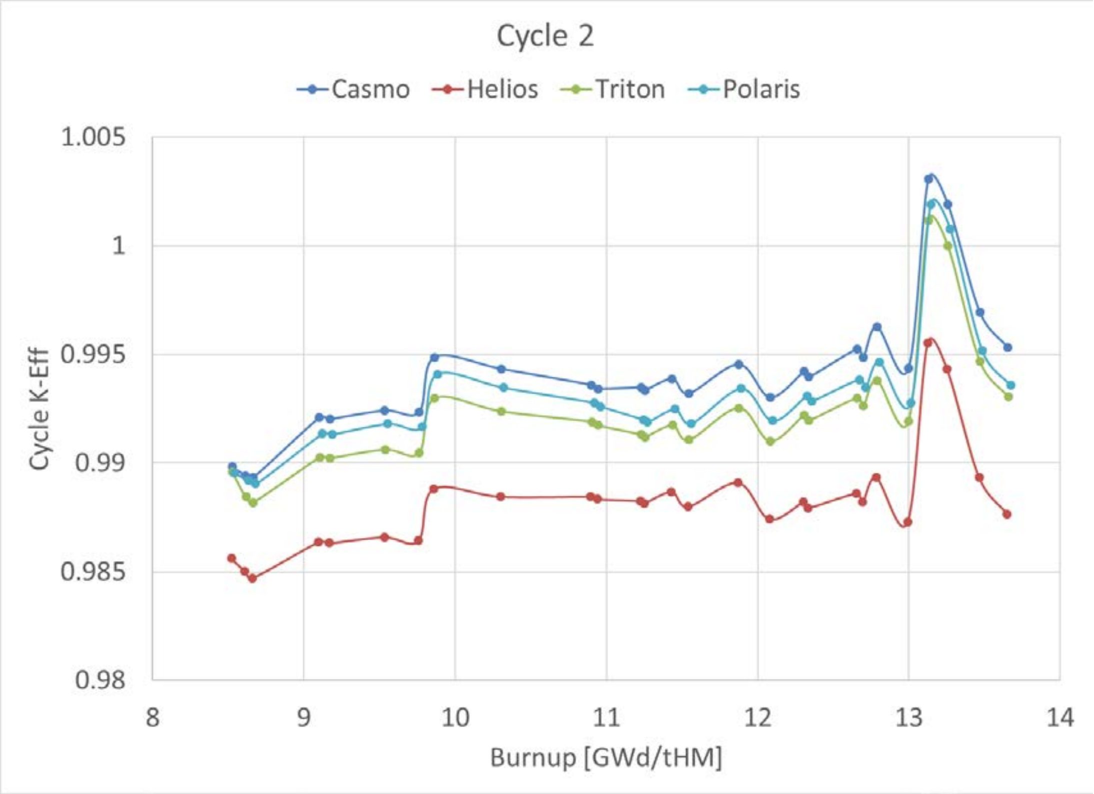
Worth	Measurement	Polaris	Triton	Helios
[bank]	[pcm]	[Δpcm]	[Δpcm]	[Δpcm]
A	788	5	-53	-28
B	1203	-4	-70	-111
C	1171	185	17	213
D	548	-179	-128	-309
SE	461	-142	-83	-236
SD	772	-10	-62	-67
SC	1099	-46	-166	-136

Hatch Depletion: Overview

- Edwin Hatch Unit 1, Startup Depletion Modeling
- Under development and use since 2012
- Addition of Polaris results
  - Comparison to conventional detector approach
  - New Polaris approach for gamma detectors
- Focusing on cycles 2-3
- Polaris, Triton, Casmo-4, Helios v1.10 compared

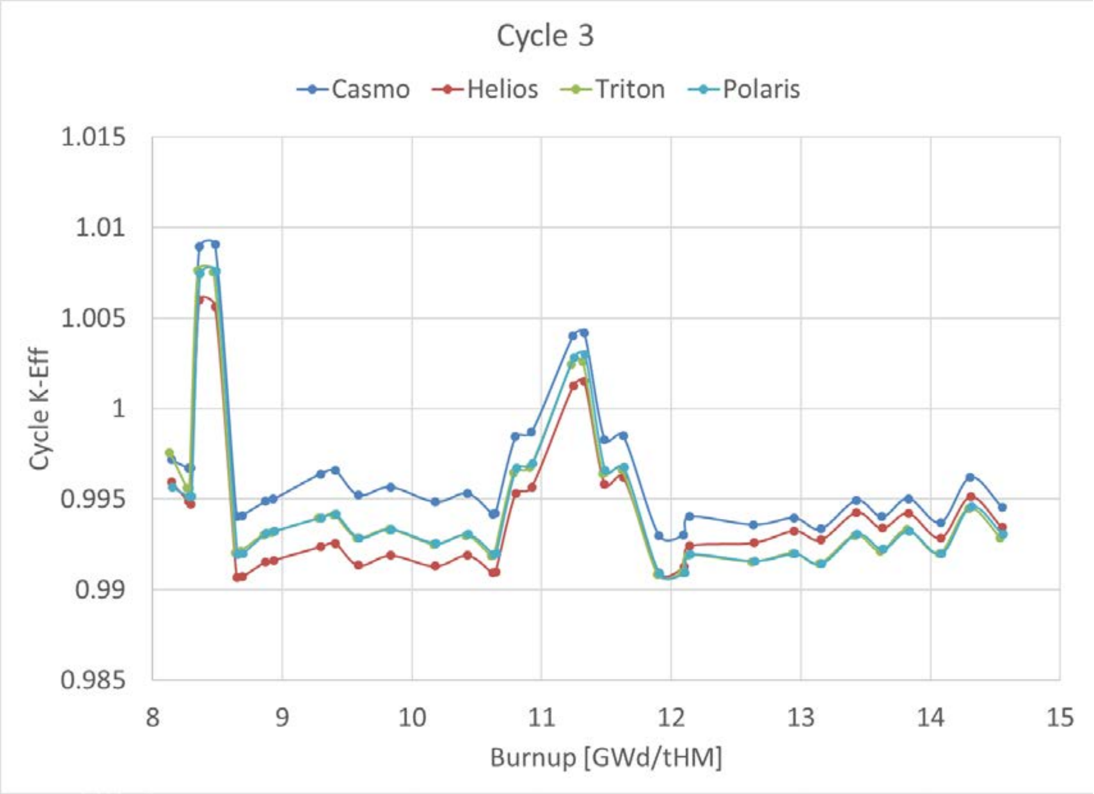
Hatch Depletion: Cycle 2 K-eff

- Ideally, ±500 pcm from critical
- New Polaris results fall within the exisiting cross section sets
- Bump at the end still unexplained

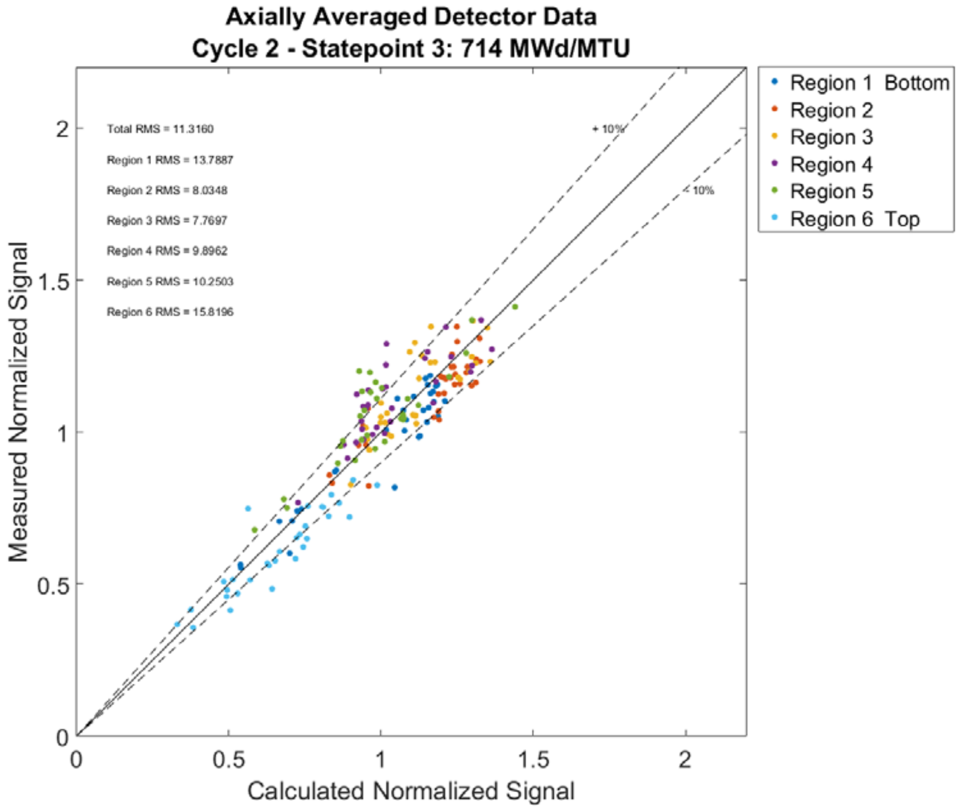


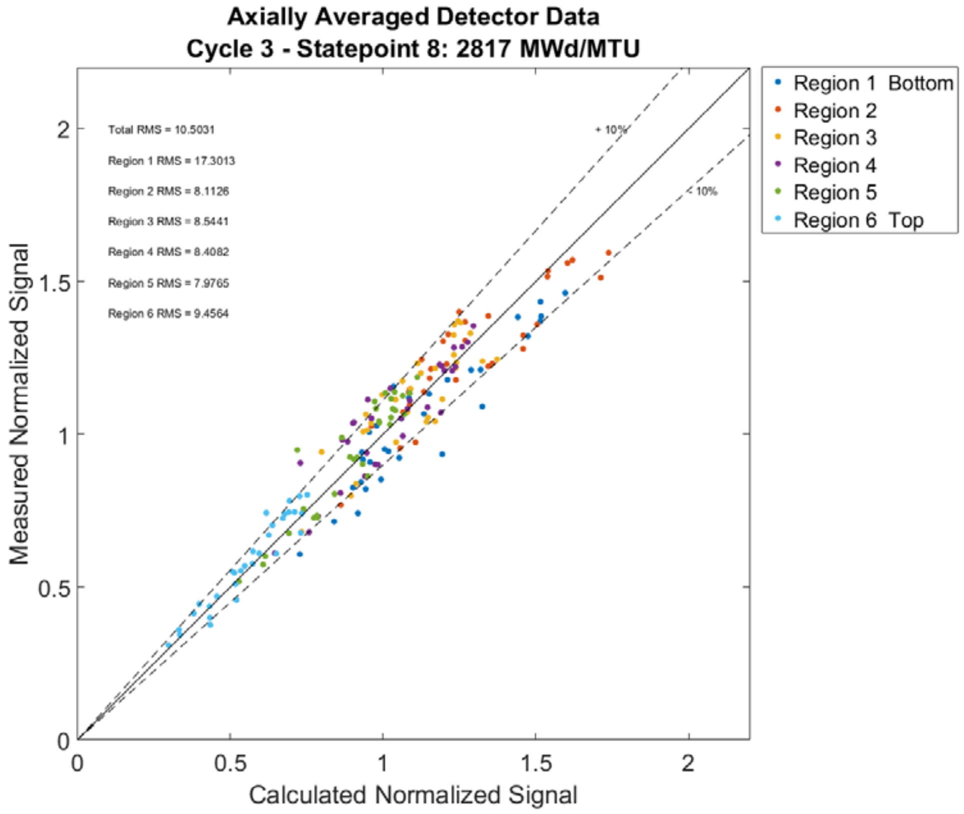
Hatch Depletion: Cycle 3 K-eff

- Overall Bias from critical is similar to cycle 2
- Polaris / Triton results very similar
- Similar trends for each cross section set to cycle 2



Hatch Depletion: Detector Response





Hatch Depl: Triton Detector Response

- Agreement goal is < 5% RMS
- Actual RMS around 10%, including gamma detectors
- Average error slightly lower

Cycle	Det Calc	RMS [%]	Ave [%]	Max [%]	Min [%]
2	8	11.31	8.47	46.50	0.00
2	13	11.60	8.73	49.36	0.01
3	3	9.14	6.36	48.11	0.02
3	4	9.55	6.67	51.21	0.01
3	5-G	10.87	8.60	42.62	0.00
3	6-G	9.94	7.84	34.62	0.00
3	7-G	9.70	7.58	35.62	0.02
3	8-G	9.48	7.10	32.39	0.02
Overall		10.20	7.67	42.55	0.01

Hatch Depl: Polaris Detector Response

- Agreement goal is < 5% RMS
- Actual RMS around 10%, including gamma detectors
- Compared to Triton
  - Improved cycle 2 responses
  - Increased error in cycle 3

Cycle	Det Calc	RMS [%]	Ave [%]	Max [%]	Min [%]
2	8	9.68	7.13	103.96	0.05
2	13	9.36	7.06	92.95	0.02
3	3	6.75	5.20	46.67	0.00
3	4	6.57	5.25	32.88	0.04
3	5-G	12.95	10.61	49.34	0.02
3	6-G	11.28	9.20	55.95	0.03
3	7-G	11.07	8.88	53.93	0.02
3	8-G	9.97	7.84	54.04	0.00
Overall		9.70	7.65	61.22	0.02

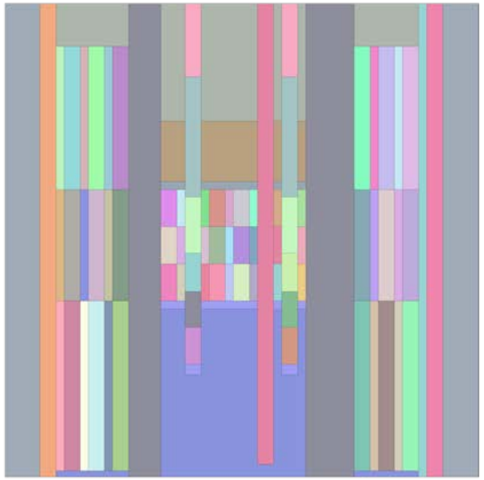
Hatch Depl: Polaris Gamma Detector

- Agreement goal is < 5% RMS
- Actual RMS around 10%, including gamma detectors
- Compared Triton/Polaris
  - Increase in cycle 2 error
  - Dramatic improvement in cycle 3
- Gamma corrected detector appears to function as desired

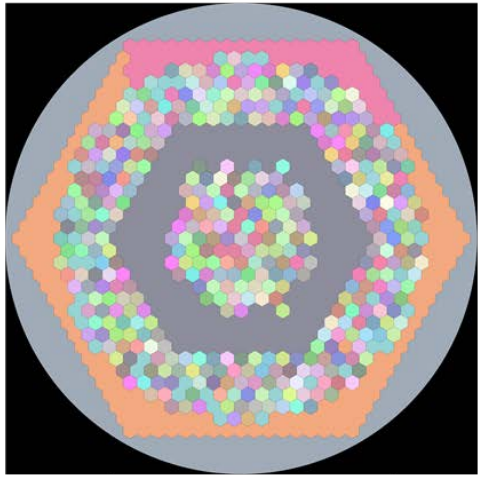
Cycle	Det Calc	RMS [%]	Ave [%]	Max [%]	Min [%]
2	8	12.20	9.88	80.54	0.05
2	13	13.34	11.05	74.68	0.01
3	3	11.12	8.23	56.65	0.01
3	4	11.36	8.62	48.28	0.07
3	5-G	5.66	3.89	32.20	0.01
3	6-G	5.46	3.96	25.73	0.02
3	7-G	5.20	3.68	27.41	0.01
3	8-G	6.32	4.39	32.95	0.02
Overall		8.83	6.71	47.31	0.02

SFR Modeling Capabilities: EBR-2

- Tasked by NRC to develop EBR-2 and SFR capability for PARCS
- Utilizing Triton/Shift sequence for XS generation
- Regulatory interest in transient modeling, reactivity coefficients, rod worths



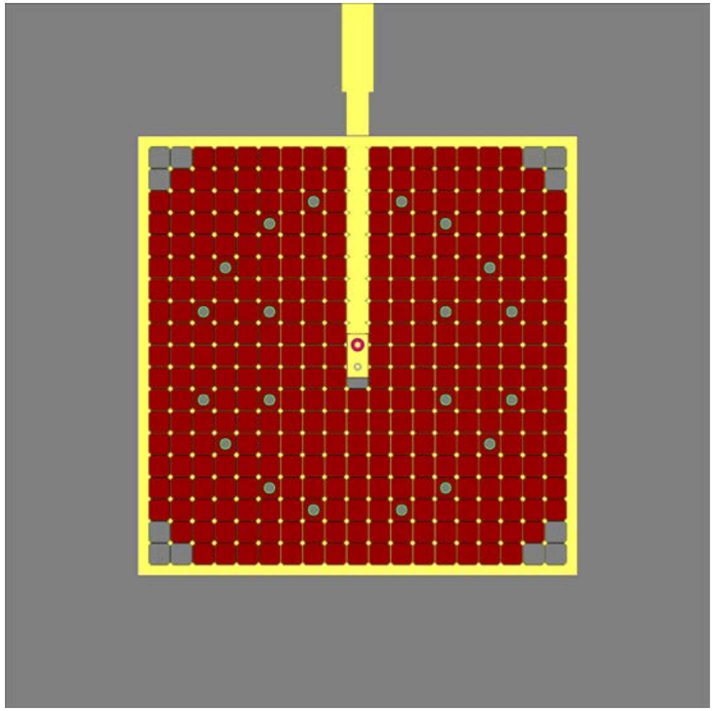
X-Z axial slice



X-Y radial slice

SFR Modeling specifics: Based off TREAT Effort

- Full core Monte Carlo XS generation
  - Node-wise XS has better transport information
- "Quasi-Diffusion"-like use of Eddington Factors
  - Directional dependent diffusion coefficient
  - Capture high leakage



TREAT Modeling: Basis for SFR Approach

Serpent k-eff: 1.00454

		0.656	0.646	0.642	0.632	0.620	0.610	0.610		0.609	0.609	0.618	0.631	0.639	0.644	0.655		
	0.701	0.680	0.672	0.655	0.628	0.595	0.566	0.603		0.603	0.567	0.593	0.628	0.653	0.672	0.680	0.703	
0.754	0.736	0.741	0.739	0.696	0.632	0.597	0.365	0.633		0.633	0.367	0.599	0.630	0.694	0.741	0.745	0.738	0.754
0.805	0.803	0.829	0.837	0.769	0.436	0.705	0.724	0.750		0.751	0.728	0.704	0.436	0.769	0.837	0.832	0.804	0.804
0.874	0.884	0.927	0.954	0.934	0.893	0.909	0.912	0.876		0.877	0.914	0.912	0.896	0.937	0.955	0.931	0.888	0.875
0.944	0.966	1.024	0.743	1.103	1.108	1.097	1.059	0.974		0.973	1.060	1.099	1.110	1.105	0.745	1.028	0.969	0.944
1.005	1.037	1.112	1.183	1.236	1.251	1.230	1.162	1.032		1.033	1.164	1.232	1.252	1.238	1.186	1.112	1.038	1.005
1.056	1.096	0.819	1.274	1.337	0.935	1.319	1.225	1.037		1.038	1.226	1.322	0.939	1.339	1.279	0.821	1.100	1.060
1.094	1.146	1.244	1.344	1.412	1.429	1.389	1.260	0.978		0.979	1.259	1.385	1.430	1.413	1.346	1.245	1.147	1.099
1.113	1.172	1.281	1.384	1.457	1.481	1.445	1.310	0.987		0.987	1.305	1.440	1.480	1.457	1.387	1.280	1.173	1.116
1.113	1.170	1.276	1.383	1.463	1.497	1.480	1.385	1.156		1.154	1.380	1.477	1.497	1.464	1.385	1.276	1.170	1.117
1.093	1.144	0.859	1.347	1.432	1.021	1.483	1.445	1.362	1.310	1.359	1.445	1.482	1.022	1.431	1.349	0.861	1.147	1.098
1.058	1.101	1.190	1.283	1.361	1.412	1.441	1.447	1.433	1.422	1.432	1.448	1.441	1.411	1.362	1.286	1.195	1.105	1.059
1.006	1.044	1.120	0.822	1.244	1.288	1.332	1.367	1.386	1.392	1.385	1.367	1.330	1.287	1.244	0.823	1.121	1.043	1.008
0.945	0.970	1.030	1.074	1.074	1.059	1.131	1.203	1.250	1.268	1.251	1.205	1.132	1.060	1.074	1.077	1.032	0.971	0.946
0.882	0.892	0.933	0.955	0.894	0.524	0.888	0.962	1.050	1.095	1.050	0.961	0.886	0.525	0.898	0.957	0.935	0.892	0.883
0.836	0.825	0.845	0.856	0.823	0.770	0.758	0.482	0.864	0.932	0.863	0.482	0.756	0.770	0.825	0.859	0.848	0.827	0.836
	0.796	0.781	0.787	0.784	0.773	0.751	0.739	0.800	0.835	0.799	0.738	0.749	0.772	0.784	0.788	0.783	0.795	
		0.762	0.764	0.771	0.778	0.781	0.787	0.806	0.816	0.806	0.788	0.781	0.780	0.774	0.764	0.765		

PARCS k-eff: 1.00480 (+26 pcm)

		0.70	0.87	1.09	1.35	1.59	1.35	0.56		0.55	1.33	1.57	1.35	1.09	0.87	0.70		
	0.44	0.49	0.57	0.69	0.82	0.88	0.82	0.85		0.85	0.81	0.88	0.81	0.69	0.58	0.48	0.43	
0.27	0.29	0.33	0.37	0.43	0.48	0.51	0.51	0.55		0.56	0.53	0.50	0.48	0.42	0.36	0.33	0.30	0.27
0.16	0.19	0.22	0.22	0.24	0.27	0.27	0.30	0.35		0.35	0.28	0.28	0.26	0.24	0.23	0.21	0.19	0.16
0.10	0.11	0.12	013	0.13	0.14	0.15	0.17	0.21		0.22	0.16	0.15	0.13	0.13	0.12	0.12	0.11	0.10
0.05	0.06	0.06	0.06	0.06	0.07	0.07	0.10	0.14		0.13	0.09	0.07	0.07	0.06	0.06	0.05	0.05	0.04
0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.06		0.06	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.00
-0.03	-0.03	-0.03	-0.03	-0.02	-0.03	-0.02	-0.01	0.00		0.00	-0.01	-0.02	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
-0.05	-0.06	-0.06	-0.06	-0.06	-0.06	-0.05	-0.06	-0.04		-0.04	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
-0.08	-0.08	-0.08	-0.08	-0.09	-0.09	-0.09	-0.09	-0.08		-0.08	-0.08	-0.09	-0.09	-0.09	-0.09	-0.09	-0.08	-0.08
-0.10	-0.10	-0.10	-0.10	-0.11	-0.11	-0.11	-0.11	-0.11		-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.10	-0.10
-0.11	-0.12	-0.12	-0.12	-0.12	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.12	-0.13	-0.12	-0.12	-0.12	-0.12
-0.13	-0.13	-0.14	-0.13	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14	-0.13	-0.13	-0.13
-0.14	-0.13	-0.14	-0.15	-0.15	-0.15	-0.15	-0.15	-0.16	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.14	-0.14	-0.14
-0.14	-0.15	-0.14	-0.15	-0.15	-0.16	-0.16	-0.16	-0.16	-0.17	-0.16	-0.16	-0.16	-0.16	-0.15	-0.15	-0.14	-0.14	-0.14
-0.15	-0.15	-0.15	-0.15	-0.16	-0.16	-0.16	-0.16	-0.16	-0.16	-0.17	-0.16	-0.17	-0.17	-0.16	-0.16	-0.15	-0.14	-0.15
-0.14	-0.14	-0.15	-0.15	-0.16	-0.16	-0.17	-0.16	-0.17	-0.17	-0.16	-0.16	-0.17	-0.17	-0.16	-0.16	-0.15	-0.14	-0.15
	-0.14	-0.15	-0.16	-0.17	-0.16	-0.16	-0.17	-0.18	-0.18	-0.17	-0.17	-0.17	-0.17	-0.17	-0.16	-0.14	-0.14	
		-0.16	-0.17	-0.17	-0.18	-0.18	-0.17	-0.17	-0.17	-0.18	-0.18	-0.17	-0.18	-0.18	-0.17	-0.15		

High leakage slot captured correctly. Max Err PARCS: 1.6%

SFR Modeling: XS Treatment, the final piece

- LWR Simulators improving the XS treatment
  - CASMO-SIMULATE uses a "hybrid" microscopic depletion which treats subset of isotopic vector
- PARCS development task includes a similar effort, BUT, can this be used to treat SFR XS?
  - Well-known (ANL, W. S. Yang), that use of microscopic XS significantly improve the accuracy of the "node-wise" macroscopic XS.

$$\Sigma_{node} = \Sigma_{lattice} + \sum_{i=1}^{N_{treated\ isotopes}} \sigma_i \Delta N_i \quad \Rightarrow \quad \Sigma_{node} = \Sigma_{lattice\ residual} + \sum_{i=1}^{N_{treated\ isotopes}} \sigma_i N_i$$

Summary / Conclusions

- Sampler-Polaris-PARCS sequence for pin power uncertainty tested successfully.
  - Plan to extend to detector XS this coming year.
- Further confirmation of Polaris-PARCS using BEAVRS
  - BEAVRS depletion and detector calculations ongoing
- New gamma detector treatment in Polaris provides improved agreement to Hatch detector response
- SFR Modeling moving along well