Measurement and Modeling of Void Effects on Multiplication in a Homogeneous Thermal Reactor

Robert D. Busch
University of New Mexico

Problem

- Density changes in fissile material can have a significant effect on the multiplication factor.
- Introduction of non-homogeneities into a system create variations in neutron production, absorption, leakage, and moderation.
- For nuclear criticality safety, it is important to be able to accurately determine the effect of small voids in thermal systems.

Criticality Safety

- Often these effects are calculated with our computer models and associated cross sections sets, but there are very few benchmarks that provide experimental information on small void effects (non-homogeneities) in a process.

Void Effects in AGN-201M Reactor

- Performed on the University of New Mexico's AGN-201M Nuclear Reactor.
- The reactor is effectively a homogeneous, thermal system utilizing $U(19.75)O_2$ in a polyethylene matrix.
- The experiment involved taking out some of the fuel disks from the reactor and inserting a small set of plastic spacers before replacing the disks.
- Because the system is operated at low-power levels with minimal burnup, the fuel can actually be safely handled.

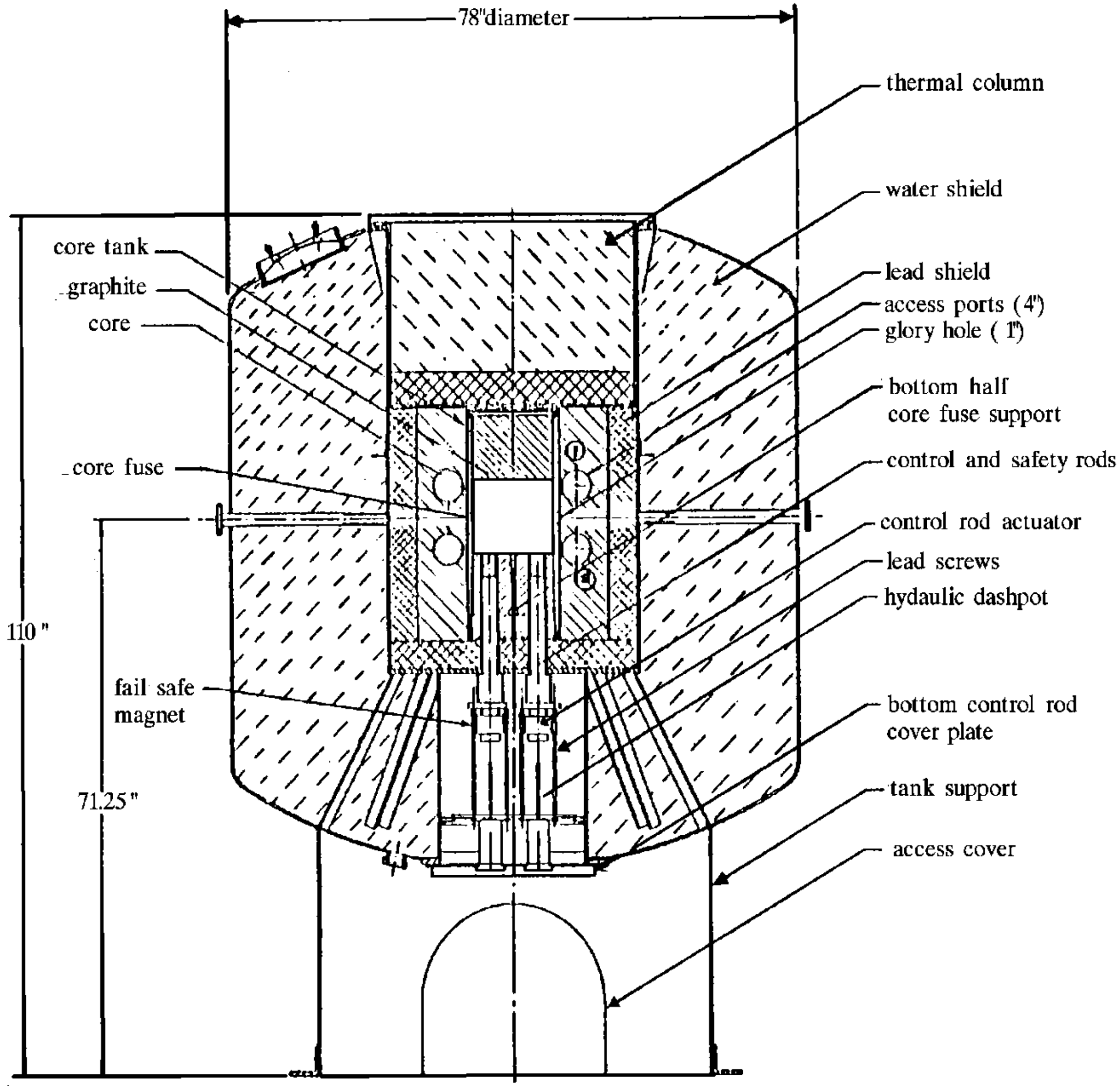
Void Effects in AGN-201M Reactor

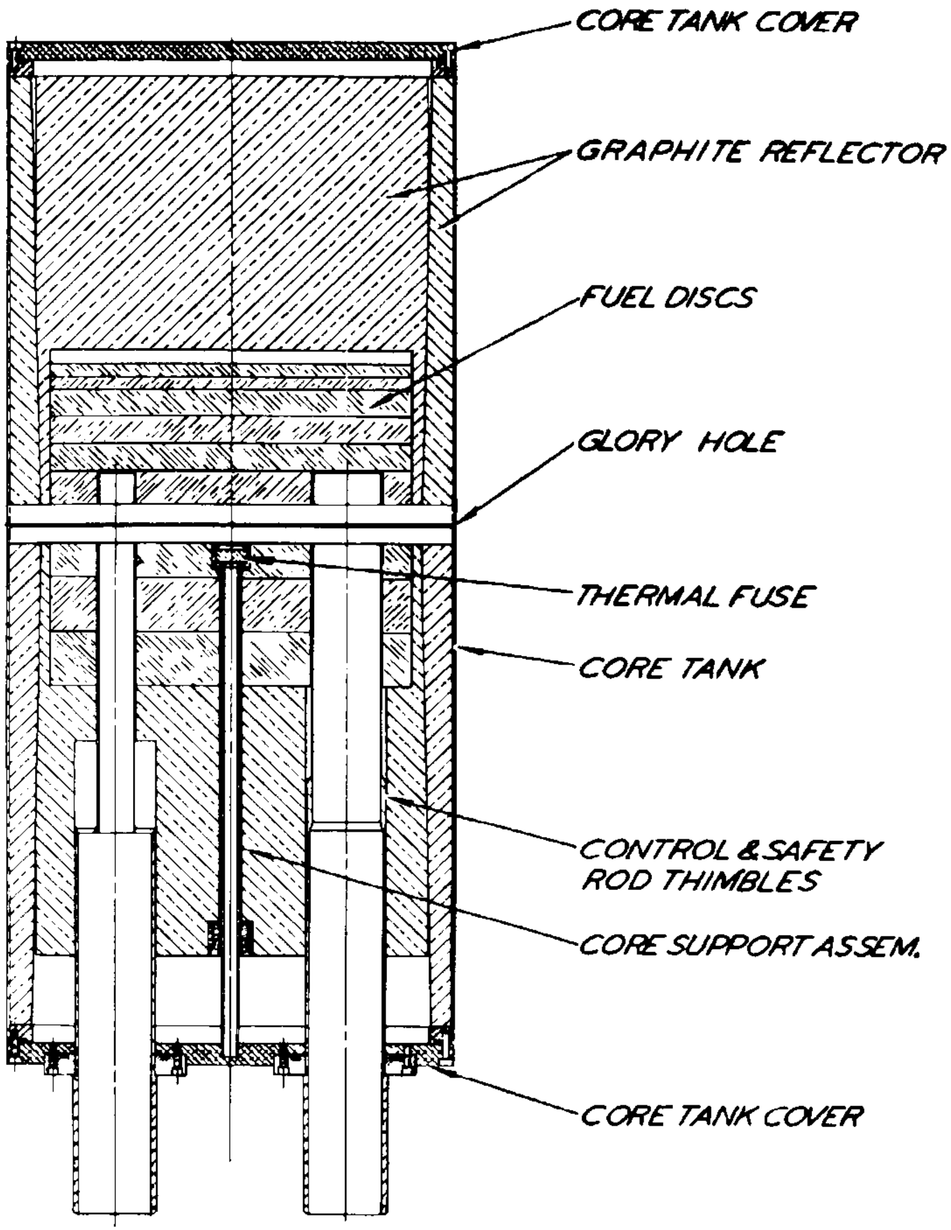
- The small plastic spacers created small perturbations in the system geometry and allowed for measurement of changes due primarily to decrease in moderation and production.
- As the spacers were moved away from the center of the system, the reactivity effect of the void is determined from critical rod positions and from positive period measurements.
- After each set of measurements, the spacers are moved upward to the next fuel disk, and the process is repeated.

Calculations

- After experimental data was obtained, the results are compared with calculations using PARTISN [1] and the 16 group Hansen-Roach cross section library.
- In addition, hand calculations are used to evaluate changes in buckling and give additional insight into the physics of the experiment.

UNM AGN-201M Reactor





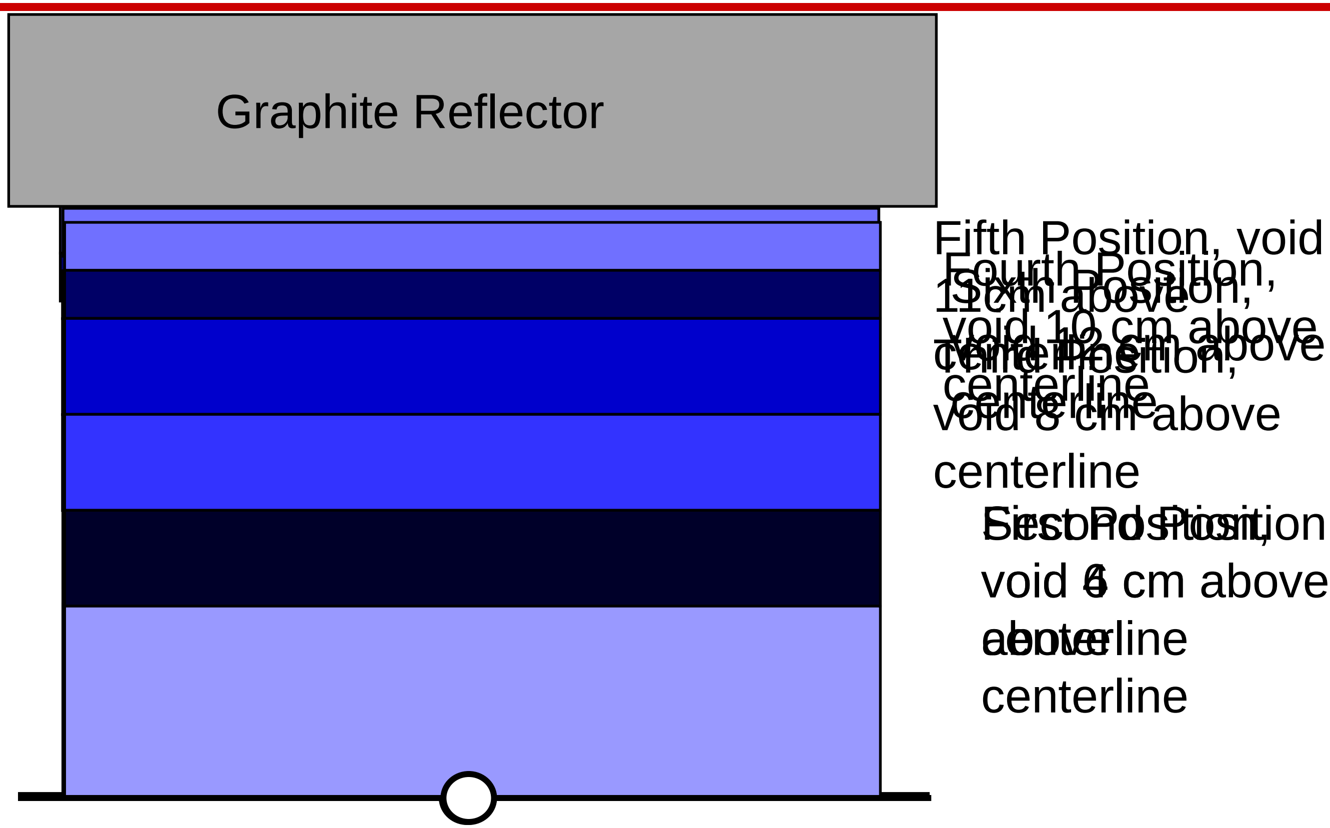
UNM AGN-201M Reactor Core and Reflector


Graphite Plug –
Top Reflector

Fuel Disk

Top of Control Rod cans and Fuel Disk

Void Locations

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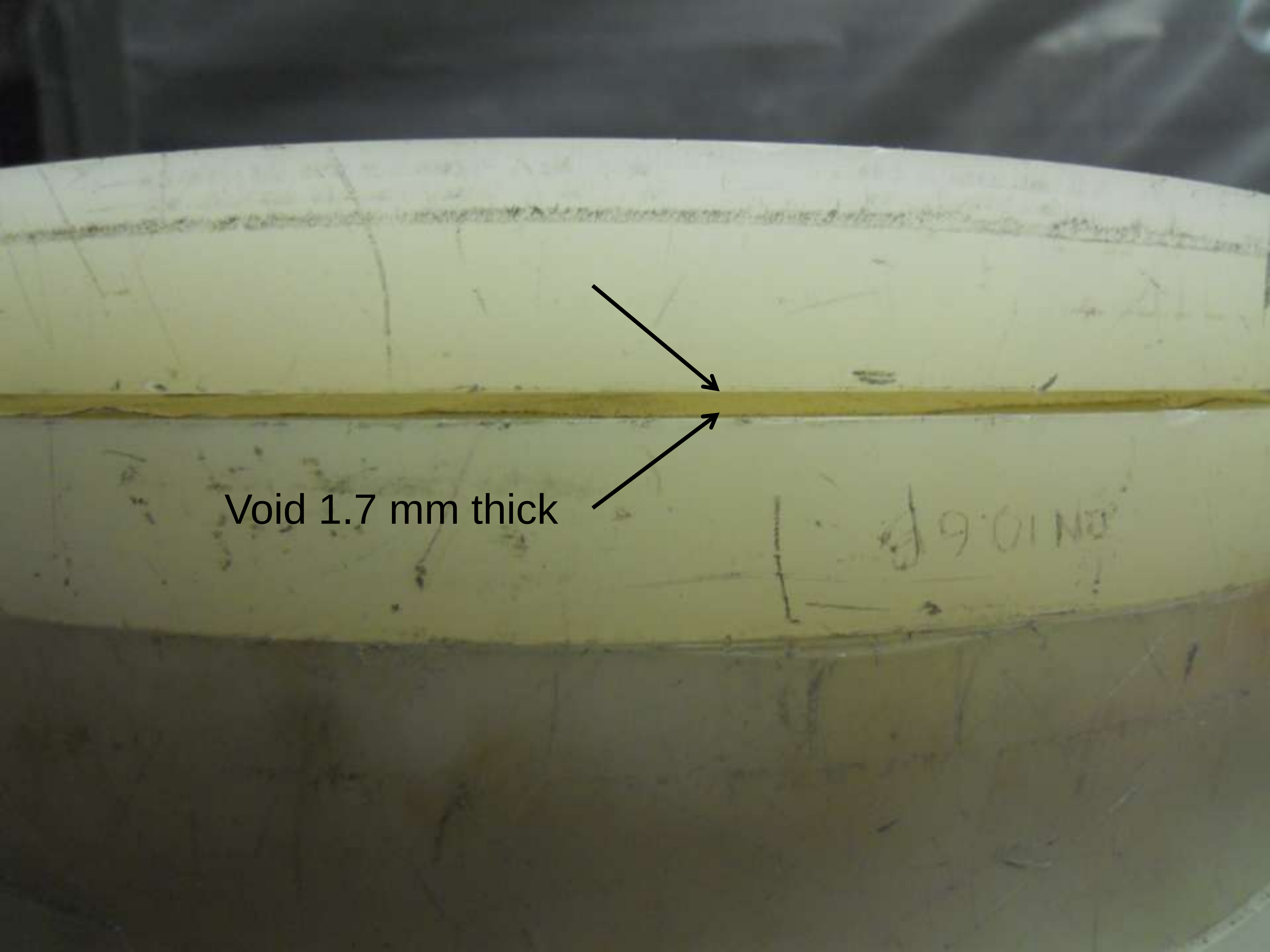

Void 1.7 mm thick

Void Reactivity Measurements

- The effect of the void (0.17 cm by 12.8) cm radius on the reactivity of the system was measured in two ways:
- Positive period measurements as the system was brought to critical. This effectively determined the excess reactivity for the system in each configuration.
- Final control rod positions for the critical configuration. This was determined from the critical position of the fine rod with the other 3 control rods fully inserted. Based on the fine rod position and the associated calibration curve, the reactivity was calculated.
- Both methods used the original core configuration as the reference point for the base reactivity.

Comparison of Void Reactivity by different methods

Position of Spacers	Distance above Centerline	Reactivity Worth Rod Position ($)	Reactivity Worth Positive Period ($)
Between 100 and 101	4 cm	-$0.395	-$0.399
Between 101 and 102	6 cm	-$0.351	-$0.354
Between 102 and 103	8 cm	-$0.287	-$0.284
Between 103 and 104	10 cm	-$0.223	-$0.214
Between 104 and 105	11 cm	-$0.193	-$0.185

Conclusions on Experiment

- Both methods provide similar results.
- The positive period measurements are less prone to error as these involve curve fits to power trace data, while the Fine Control Rod positions at critical are somewhat subjective.
- For the remainder of the analysis, the positive period values will be used to compare with calculated values.

Conclusions on Experiment (cont'd)

- As expected the void has a negative reactivity effect (i.e., decreased k-eff), but with decreasing impact as the void is moved away from the centerline.
- This is expected as the decrease in effective numbers of moderator and fuel atoms around the void means fewer neutrons available to cause fissions.
- As the impact of fission (its importance function) is related to the square of the flux (in one group perturbation theory), the impact of fewer fissions decreases with distance from the centerline.

PARTISN (DANT) Model

- Partisn model constructed with glory hole in axial direction rather than radial.
- Hansen-Roach 16 group library
- With 4 control rods fully inserted, calculated k-eff was 1.005703.
- Actual k-effective in this configuration should be 1.002500.

PARTISN (DANT) Model

- Deviation likely due to different alignment of the glory hole and the inability to model aluminum control rod cans and other support pieces in the core region.
- PARTISN was used due to the ability of deterministic codes to give precise values of k-effective that can be used to create self-consistent Δk values.

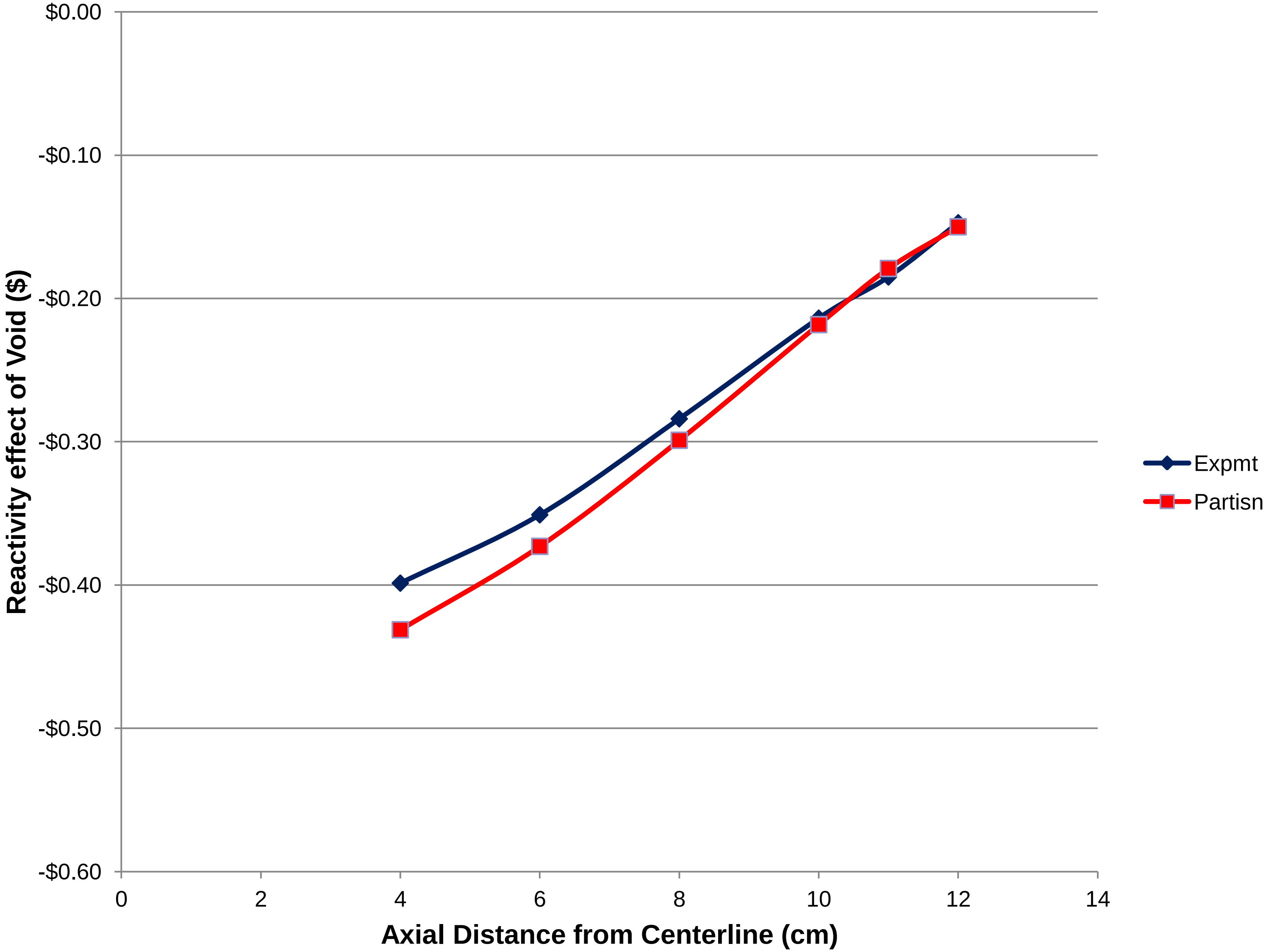
PARTISN Model of Voids

- Using the 1.005703 as the reference k-effective, models were created of the different void positions.
- Again due to the geometry limitations of PARTISN, the spacers could not be modeled, so the void was an empty region between two fuel disks.
- The reactivity effect of the spacers was added to the reactivity effect of the void location to obtain values comparable with experimental data.

Comparison of Void Reactivity by different methods

Position of Spacers	Distance above Centerline	PARTISN Worth ($)
Between 100 and 101	4 cm	-$0.432
Between 101 and 102	6 cm	-$0.373
Between 102 and 103	8 cm	-$0.299
Between 103 and 104	10 cm	-$0.218
Between 104 and 105	11 cm	-$0.179

Void Location versus Reactivity



Hand calculation

- Although the AGN is a reflected system, previous analyses of the AGN indicated that it could be treated as a bare system with a large extrapolation distance.
- If the core was treated alone, the extrapolated height of the reactor would be around 24.52 cm.
- To create the reflected flux profile, an extrapolated height of 42 cm has been found to match experimental results.

Hand calculation (continued)

- The presence of a void is expected to impact the production of neutrons in this system by reducing the effective fuel density.
- It is expected that the experimental results should match the profile of the importance function for neutron production, which for one-group theory is approximated by the square of the flux.
- Using the cosine shape and an extrapolated height of 42 cm, the square of the flux is plotted.

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Conclusions

- It was found that modeling of the reactivity effects using the PARTISN deterministic code and the 16 group Hansen-Roach cross section set provided very good estimates of the experimental values relative to void location.
- It was also determined that utilizing hand calculations while providing some insight into the various physical processes did not give adequate values.

Conclusions

- The lack of applicability of the hand calculations was due to the nature of the experiment; local changes made in a large homogeneous system do not translate to small global changes in that system.
- If changes are made globally (e.g., decreasing the material density by 0.5%), then hand calculations will likely provide adequate characterization of the changes.