Advanced Fuel Assembly Potential Design

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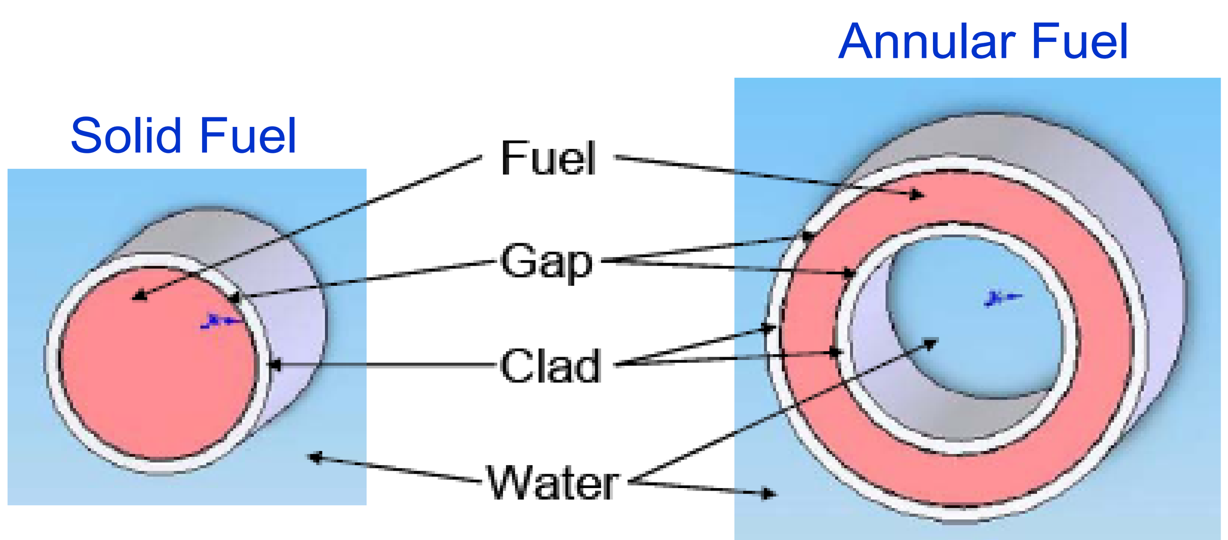
Introduction

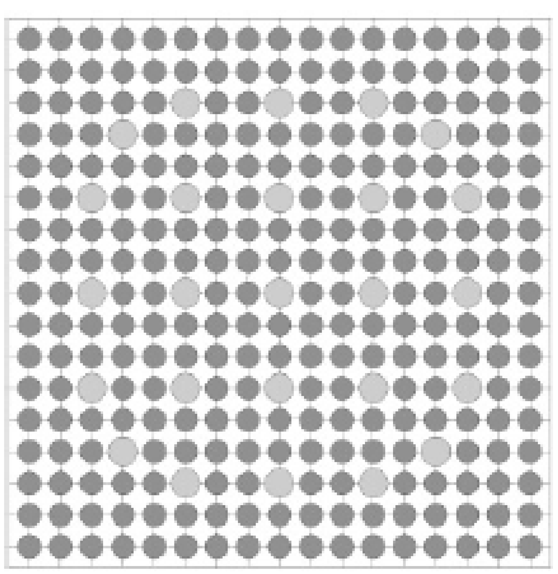
•The use of internally and externally cooled annular fuel will substantially increase the power extracted in PWRs (up to 50%) with the same vessel volume/cooling system and subsequently will reduce the cost of power plants.

•However if UO_2 is used, the assembly will have to be enriched higher (~8-9%) than the current legal limit of 5 weight % U-235.

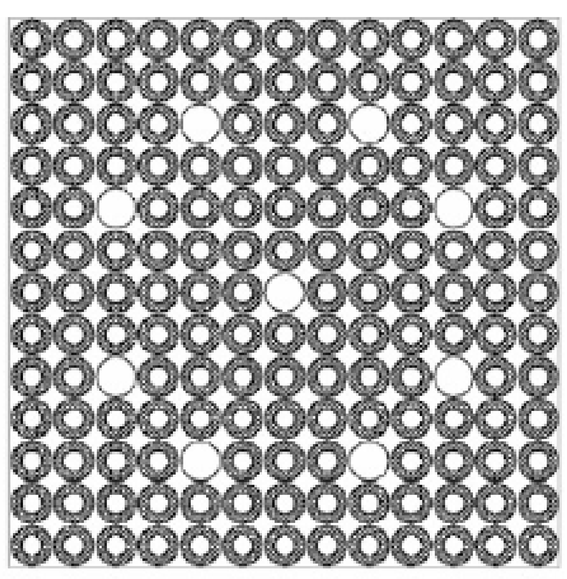
•The work featured here proposes swapping out the UO_2 with higher density UN in order to stay below this 5% enrichment limit.



Solid Fuel 17x17



Annular Fuel 13x13



Geometric Design Parameters

	17x17 Solid Fuel	13x13 Annular Fuel
Pin Outer Radius (cm)	0.4761	0.7684
Outer Clad Inner Radius (cm)	0.4191	0.7112
Fuel Outer Radius (cm)	0.4122	0.7050
Fuel Inner Radius (cm)	-	0.4950
Inner Clad Outer Radius (cm)	-	0.4888
Pin Inner Radius (cm)	-	0.4317
Pin Pitch (cm)	1.2626	1.6510

Constraints

Geometric

•Current PWR Fuel Assembly Dimension Envelope

Neutronic

•Equivalent 18 month 3 batch fuel cycle

•Hydrogen to Heavy Metal Ratio

Fuel Attributes

	UO2	UN
Theoretical Density (g/cm³)	10.96	14.32
HM Atom Density (g/cm³)	9.67	13.52
Specific Heat (J/kg K)	270 (at 200°C)	205 (at 28°C)
Melting Point (°C)	~2800	~2700
Thermal Conductivity (W/m K)	7.19 (at 200°C) 3.35 (at 1000°C)	4 (at 200°C) 20 (at 1000°C)
Linear Thermal Expansion Coefficient (1/K)	10100000 (at 940°C)	9400000 (at 1000°C)
Swelling Rate (normalized to UO2)	1.00	0.80
Fission Gas Release (normalized to UO2)	1.00	0.45

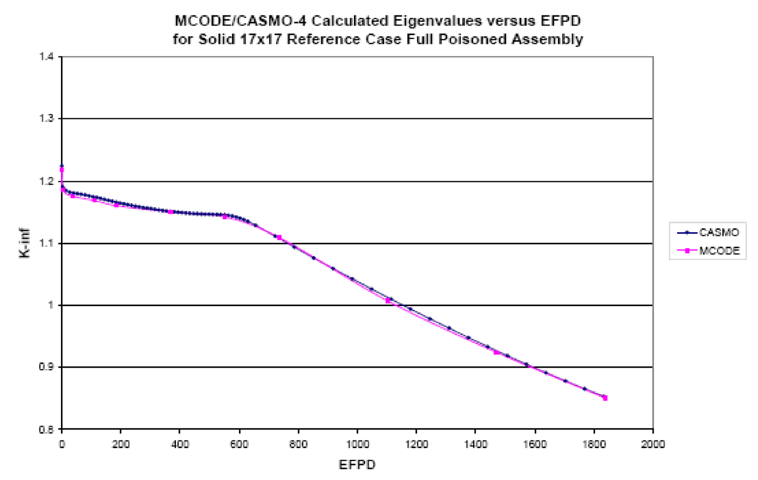
Calculations and Results

Computational Tools

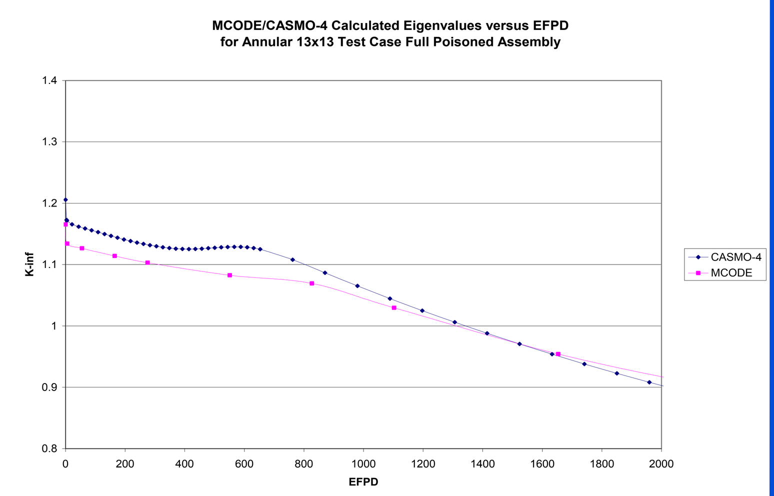
MCODE Version 1.0 (MCNP4C + ORIGEN2.1)
- •Stochastic
- •~2 days of running time per simulation

CASMO-4
- •Deterministic
- •~2 min of running time per simulation

Solid Fuel



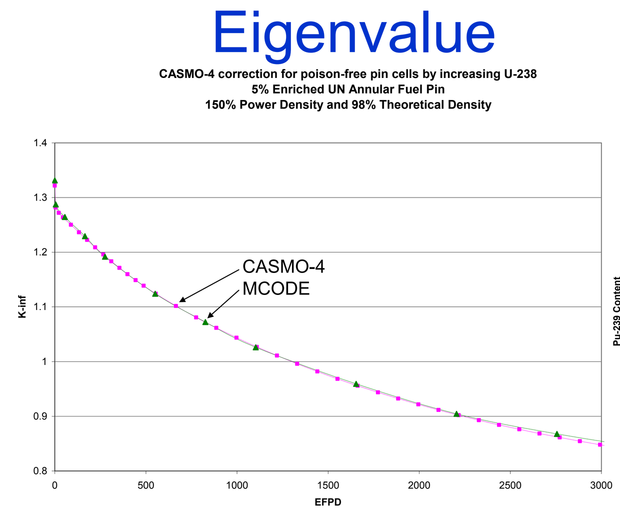
Annular Fuel



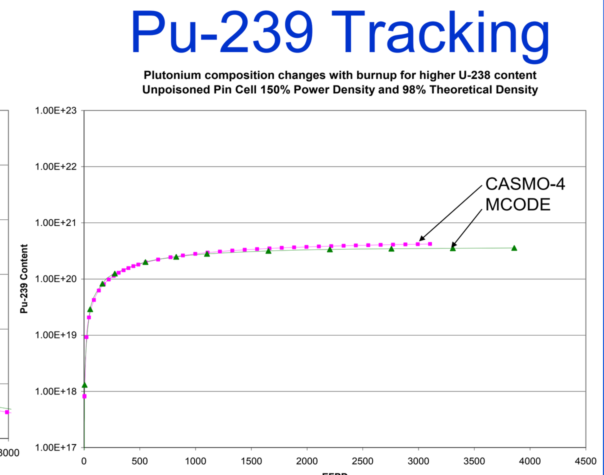
What is CASMO missing?
•The secondary Pu-239 buildup rim region in the interior of the annular fuel
•This underprediction of U-238 absorption leads to incorrect lifetime eigenvalue results

An artificial increase of the U-238 number density by 25% for the unpoisoned pins and 35% for the poisoned pins in the CASMO input deck gives quite good agreement with the MCODE generated data.

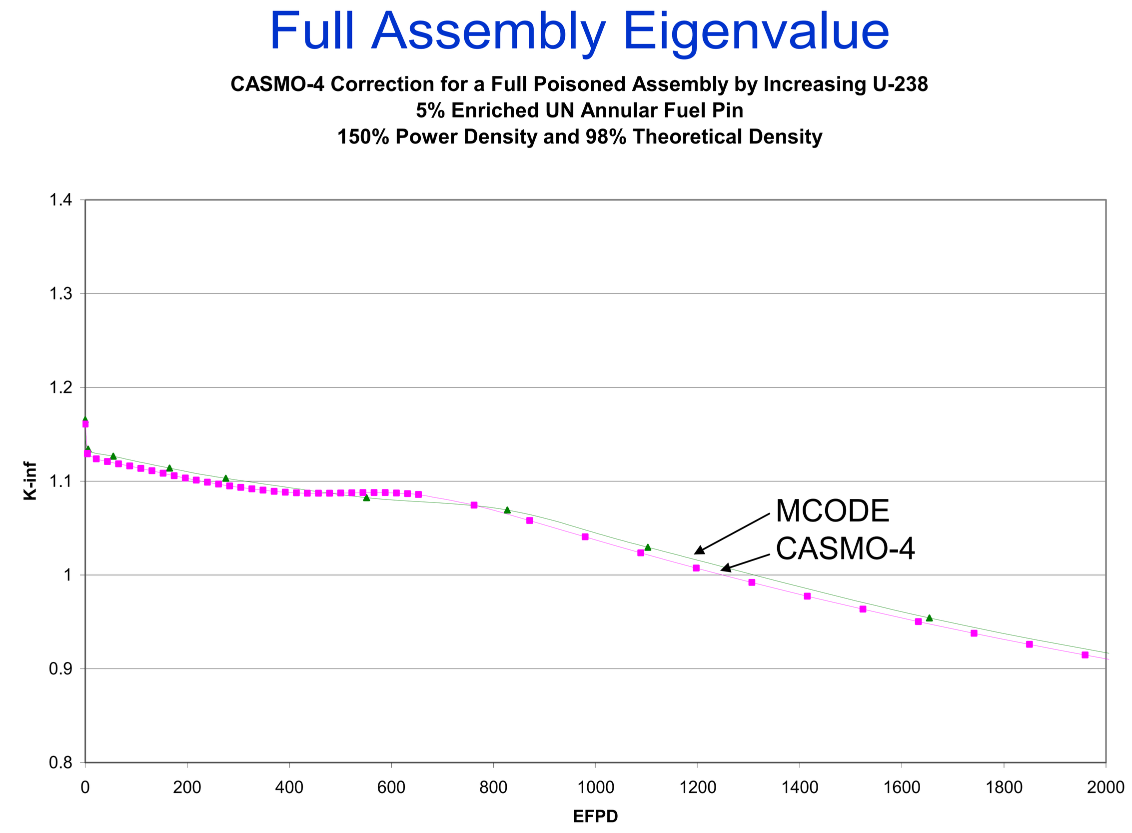
Eigenvalue



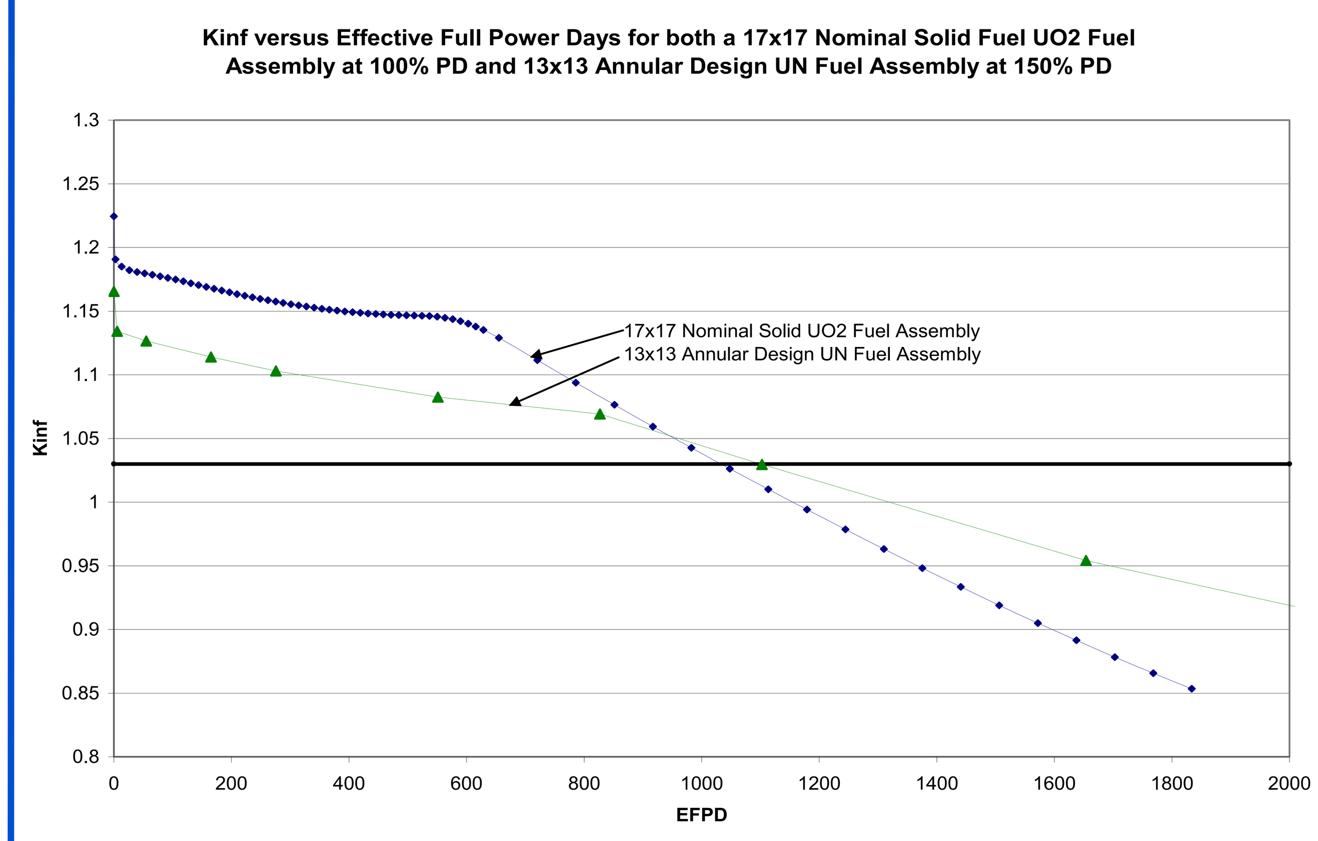
Pu-239 Tracking



Full Assembly Eigenvalue



Conclusions



•Due to its higher density, UN is able to pack almost 40% more uranium in the same volume than UO_2. Hence, the larger inventory of U-235 needed to sustain the nuclear fuel cycle length can be provided within a lower enrichment than would be needed in UO_2.

•As shown by CASMO4's predictions above, the 5% enriched UN annular fuel assembly operated at 150% power density had reached the minimum multiplication factor of 1.03 in about 50 effective-full-power-days after that of the nominal 17x17 solid fuel pin assembly operated at 100% power density.

•Thus a successful design has been created which can produce 50% more electricity than the existing standard!

Reactivity Coefficients

	17x17 Reference	13x13 Annular
FTC (1/K)	-2.505E-5	-2.436E-5
MTC (1/K)	-2.382E-4	-3.573E-4
Boron Worth (Δρ)	6.320E-2	4.358E-2
Void Coefficient (1/%void)	-7.249E-4	-1.084E-3

•The higher heavy metal loading of UN annular fuel did not have a large impact upon feedback coefficients.

•The approximately 30% higher moderator temperature coefficient (MTC) for the annular fuel is due to the higher U-235 content which gives rise to a harder spectrum and subsequently a more negative MTC.

•Further evaluation is needed to assess impact of changes in feedback coefficients, shutdown margin and the water reaction.

Nitrogen Enrichment

•The appreciable parasitic neutron absorption cross section of N-14 at thermal energies has the potential to negatively impact the neutronic performance of the fuel assembly.

•Therefore an enrichment trade-off study was conducted with varying enrichments of N-14 and N-15 isotopes in order to discern the macroscopic effect on fuel performance.

% of N-14	% of N-15	Increase in BOL Eigenvalue
100	0	0.0%
90	10	0.7%
80	20	1.4%
70	30	2.0%
60	40	2.6%
50	50	3.3%
40	60	4.0%
30	70	4.9%
20	80	5.7%
10	90	6.3%
0	100	7.2%

•As shown above, fully enriching the nitrogen matrix in the N-15 isotope will allow for an approximate 7% gain in the beginning of life eigenvalue for the annular fuel assembly.

•Before incorporation into the final design, the increased costs from nitrogen enrichment will have to be weighed against the fuel performance benefit of less parasitic absorption.