Activities in Upgrading the NBSR Model

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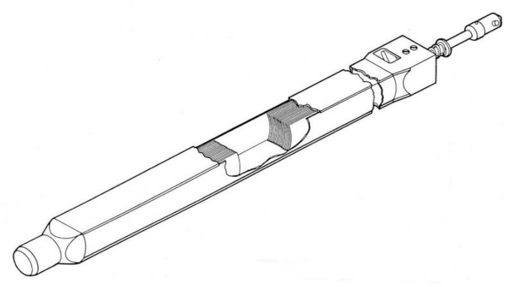
INTRODUCTION

- The NIST (National Institute of Standards and Technology) research reactor (NBSR) successfully modeled using the MCNP code to determine neutronics properties throughout a fuel cycle
- Reactor analysis completed for high-enriched uranium fuel (HEU) and a proposed conversion to low-enriched uranium fuel (LEU)
- Analyses provided conservative estimates for power and reactivity safety parameters for both the HEU and LEU cores
- Model upgraded to increase material composition from 60 to 900

BACKGROUND

- New fuel composition model has been proposed that would improve safety analysis results. The original model assumed large, uniform compositions in each of the upper and lower fueled halves of the fuel elements (60 total)
- Relatively small number does not consider presence of multiple plates in each fuel element, nor any axial and transverse distribution



- Importance of more detailed model:
  - Increase demonstrated safety margin
  - Reduce calculated maximum fission density—a parameter that influences LEU fuel qualification
- 60-composition analysis showed:
  - Thermal flux peaks in the unfueled mid-plane gap, there is a plate-to-plate self-shielding having an impact on the power distribution
  - Power-related safety parameters calculated conservatively since doing depletion over an entire half-element (uniform composition) neglects burnup effects near the mid-plane → higher power density have higher rate of burnup that feeds back to reducing power density
  - With uniform depletion in half-element peak power density is over-predicted

HEU/LEU CORE MODELING – 60 COMPOSITION

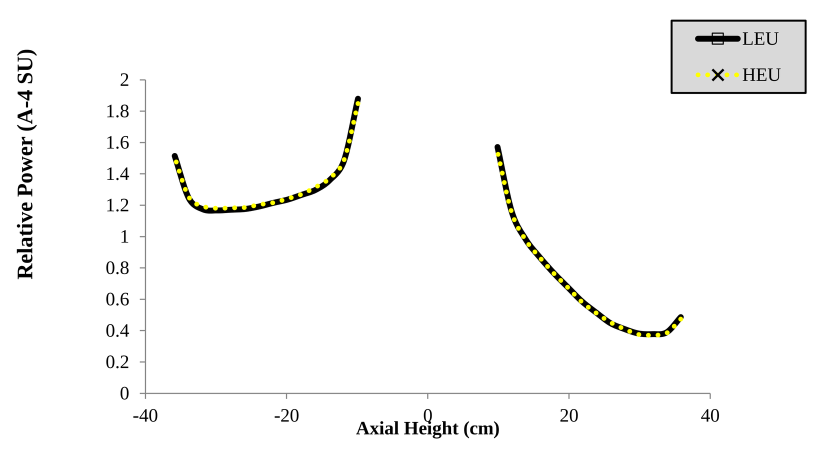
Fuel Management Scheme

- Fuel management scheme determines how fuel elements undergo burnup
- Fuel management scheme (below): fresh fuel goes from D-1 to D-7 to C-2, … to F-5 (eight cycles) where it is discharged (seven cycles marked as 7-1,…). Time dependent change with burnup can be obtained by looking at fuel elements at different spatial positions

Fuel Management Scheme

	A	B	C	D	E	F	G	H	I	J	K	L	M
				COLD SOURCE									
1				8-1		7-2		7-2		8-1			
2			8-3		7-5		<>		7-5		8-3		
3		7-3		<>		8-7		8-7		<>		7-3	
4	7-1		8-6		7-7		<>		7-7		8-6		7-1
5		8-4		<>		8-8		8-8		<>		8-4	
6			7-4		7-6		<>		7-6		7-4		
7				8-2		8-5		8-5		8-2			

- Neutron flux peaks in the unfueled gap at the midplane of the core. Thermal flux peaking utilized by beam tubes and cold neutron sources for various experiments
- Relative axial power distribution for fresh HEU and LEU fuel elements demonstrates how the midplane flux increases the power in the region of the fuel plates closest to the gap. The difference between upper and lower portions of the fuel element is due to the location of the shim arms



Relative Axial Power Distribution, Fresh Fuel (A-4)

HEU/LEU CORE MODELING – 900 COMPOSITION

Composition Zones

- Power calculated on 14x3 mesh (2x2 cm) for each plate (17) in each half-element
- Five axial composition zones per half-element
- Composition zones for outer plates (1/17), next inner plates (2/16) and middle plates (3-15); total 3 plate types
- 15 zones per half-element → 900 composition

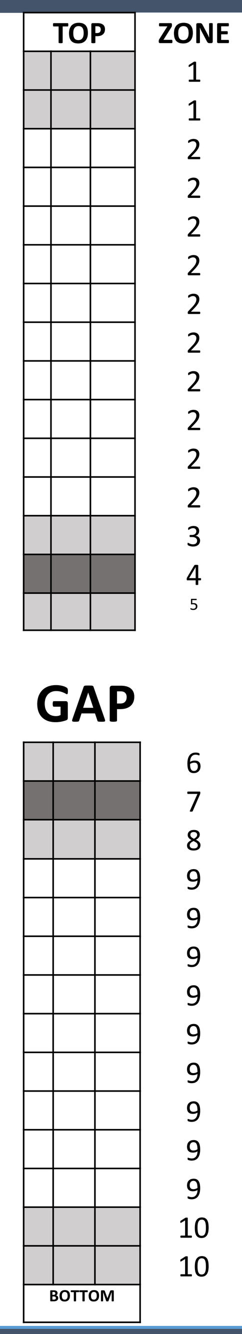


Plate No.								
Composition Zone								
1	2	3	4	…	14	15	16	17
1	2	3	3	3	3	3	2	1

RESULTS

- Equilibrium HEU/LEU core model established with 900 composition zones; several calculations compared with the 60-zone model

Reactivity Values, (%Δk/k)

HEU CORE - SU		Composition Zones		
		60	900	Measured
Shutdown reactivity		-18.2	-18.3	
SDM	Shim 1 out	-12.1	-12.3	
SDM	Shim 2 out	-11.1	-11.4	
SDM	Shim 3 out	-10.1	-10.1	
SDM	Shim 4 out	-11.6	-11.7	
Excess reactivity		6.7	6.8	6.2

LEU CORE - SU		Composition Zones	
		60	900
Shutdown reactivity		-18.3	-17.9
SDM	Shim 1 out	-12.2	-11.9
SDM	Shim 2 out	-11.2	-10.9
SDM	Shim 3 out	-10.8	-10.3
SDM	Shim 4 out	-11.9	-11.6
Excess reactivity		6.30	6.48

Total Shim Arms Worth (%Δk/k)

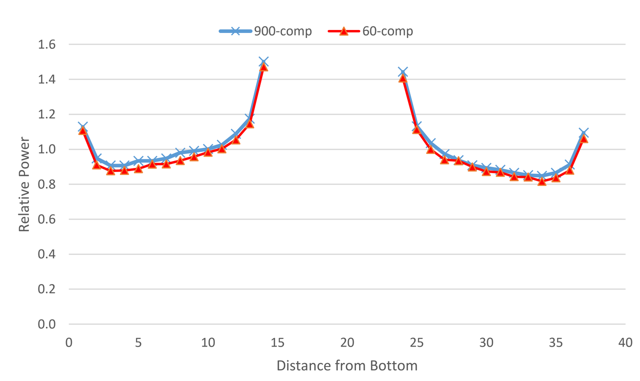
Composition Zones		SU		EOC	
	Measured	60	900	60	900
Total shim arms worth	23.7 (9/95) 24.1 (5/02)	24.9	25.2	27.2	27.4

- Radial Power Distribution – HEU map indicates excellent agreement between 60 and 900 composition at SU (shown) and EOC

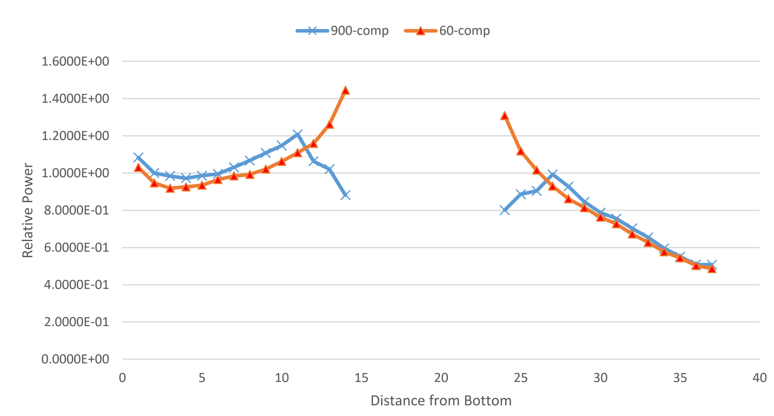
Average Radial Relative Core Power at SU

	A	B	C	D	E	F	G	H	I	J	K	L	M
		60 zones →		1.02		1.11		1.17		1.06			
1		900 zones →		1.00		1.10		1.15		1.06			
			1.09		1.14				1.11		1.01		
2			1.09		1.12				1.10		1.04		
		0.99				1.09		1.08				0.98	
3		1.00				1.08		1.07				0.99	
	0.94		0.95		1.02				1.01		0.92		0.92
4	0.97		0.96		1.02				1.00		0.93		0.95
		0.93				0.89		0.89				0.91	
5		0.95				0.89		0.89				0.93	
			0.92		0.94				0.97		0.97		
6			0.94		0.95				0.97		0.98		
				0.97		0.95		0.95		1.04			
7				0.98		0.95		0.95		1.01			

- Axial power distribution (HEU core) clearly shows the effect of local burnup as a function of the burnup cycle



Axial Relative Power for Fresh Fuel Element D-1 (Cycle 1)



Axial Relative Power for Fuel Element F-5 (Cycle 8)

CONCLUSION

- Local burnup has a great impact on the power density as the thermal flux peaks in the midplane gap leading to high burnup in the fuel zones near the mid-plane gap
- Consequent power density reduction effect can only be captured by having more composition zones near the midplane
- 60-composition model calculates power-related safety parameters conservatively since higher burnup rate near the gap reduces power density