Calculation of Inventories, Power Distributions and Neutronic Parameters for the NBSR using MCNPX

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Developing Inventories with MCNPX using the BURN Option

- MCNPX is a general radiation transport computer code
  - Developed and maintained at LANL
  - Originally a merger of MCNP and LAHET
    - MCNPX includes latest version of MCNP
    - LAHET is a transport code for high energy physics
    - Allows the transport of numerous particles
  - MONTEBURNS was incorporated for the BURN option in version 2.6.0
  - CINDER'90 was included for the burnup calculations

Warning - Bug in MCNPX 2.6.0

The MAT card lists the material numbers to be included in BURN
The material numbers must be sequentially increasing at this time

Invalid Input – Reads 50% of Volumes Incorrectly

```
MAT=151,152,153,154,155,156,157,161,162,163,164,165,166,167,168,
    251,252,253,254,255,256,257,261,262,263,264,265,266,267,268,
    171,172,173,174,175,176,177,181,182,183,184,185,186,187,188,
    271,272,273,274,275,276,277,281,282,283,284,285,286,287,288
```

Valid Input – Reads Volumes Correctly

```
MAT=151,152,153,154,155,156,157,161,162,163,164,165,166,167,168,
    171,172,173,174,175,176,177,181,182,183,184,185,186,187,188,
    251,252,253,254,255,256,257,261,262,263,264,265,266,267,268,
    271,272,273,274,275,276,277,281,282,283,284,285,286,287,288
```

– LANL says the problem will be fixed in the next version of MCNPX

Methodology Development

- MCNPX model
  - Starting Point: model used with MCNP5/MONTEBURNS
  - Increase number of fuel compositions from 30 to 60
  - 11-day cooling period modeled explicitly
  - Shim arm movement during cycle burnup modeled in a stepwise manner
  - Some changes to geometry and compositions
    - Added new cold neutron source
    - Added spent fuel chute
    - Added coolant dump
  - Used ENDF70 libraries whenever possible

Same Issues in MCNPX as in MONTEBURNS

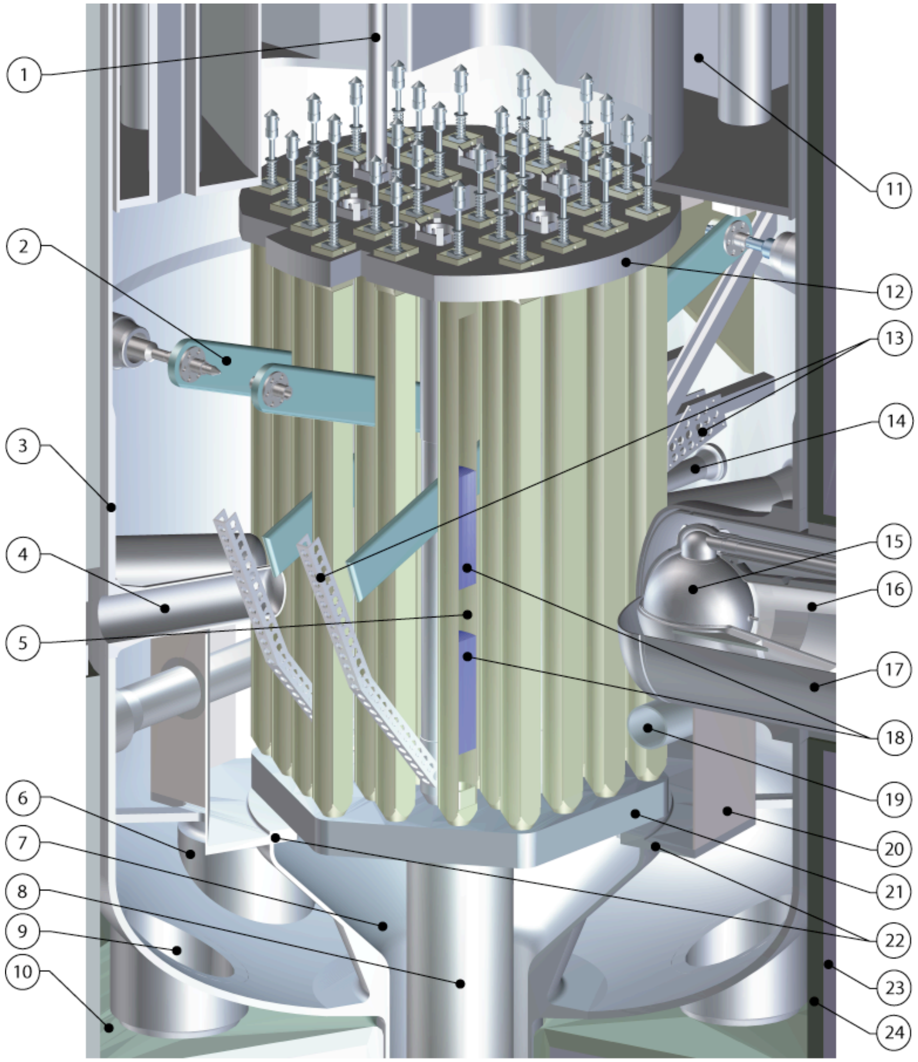
- Isotopes not in the ENDF libraries
  - Any isotope returned from CINDER'90 that is not in the libraries are lost to the calculation
  - This results in a decrease in the total mass of the fuel
  - For the NBSR this was ~1.2% per cycle using MONTEBURNS and older libraries
  - Presently ~0.02% per cycle using MCNPX and ENDF70 libraries
- MCNPX is a static calculation
  - The shim arms are set in one position during the calculation
  - The burnup is determined by interaction rates with the inventories at the beginning of the calculation
  - Any time dependence is handled in a stepwise fashion

Previous vs. Present Methods

	Previous	Present
Codes	MONTEBURNS/ MCNP5/ORIGEN2	MCNPX
Starting Inventory	Hand calculation	From MONTEBURNS
Number of Materials	30	60
Decay during refueling	Adjusted outside codes from EOC inventories	Modeled Explicitly in MCNPX
Shim Arm Position	Fixed at -12 degrees	Fixed at positions representing 3 states of the core
Number of Calculations per Cycle	1	3
Cross Section Libraries	ENDF66 or ENDF60 wherever possible	ENDF70 wherever possible
Number of Isotopes	63 max (55 av)	210 max (198 av)

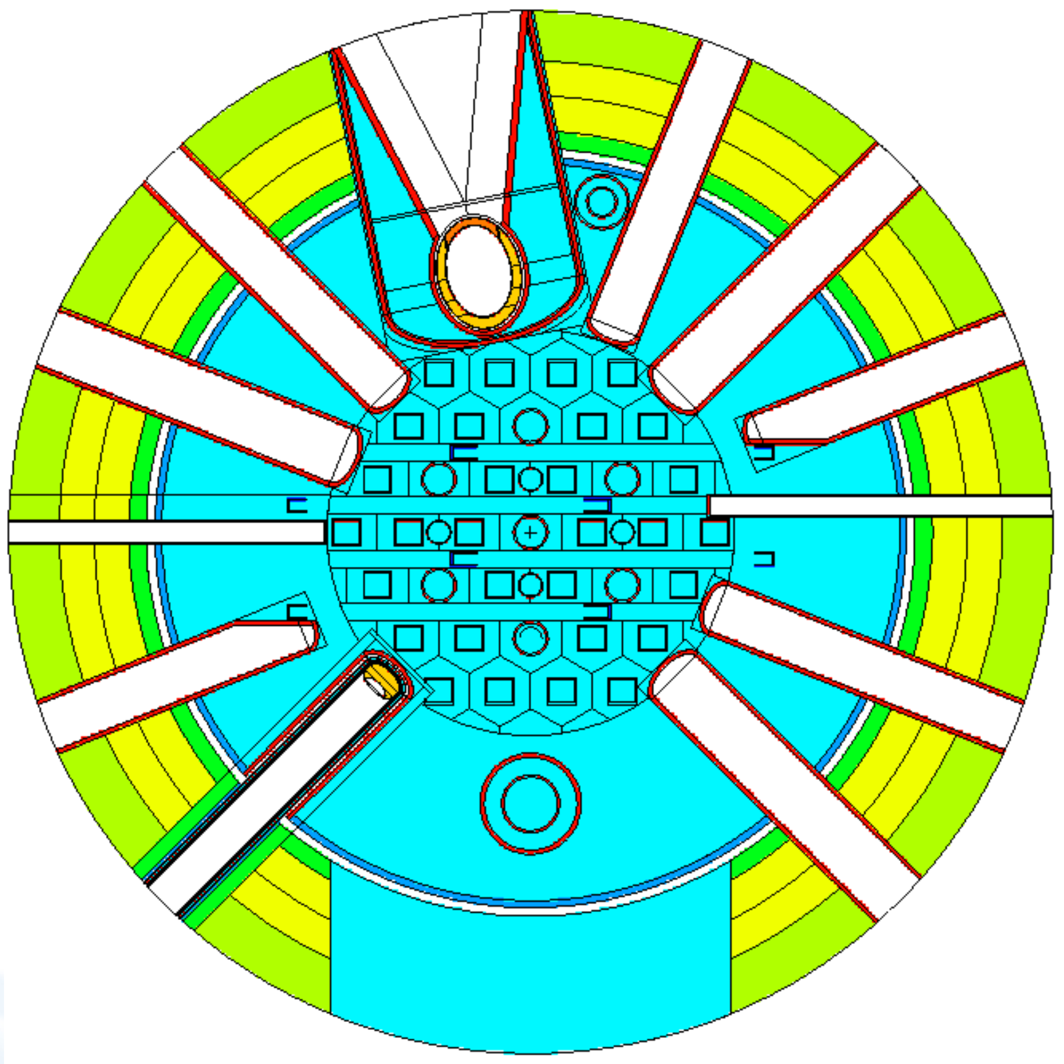
What are We Trying to Analyze?

NBSR



1	Poisoned Hold Down Tube (1 of 7)	13	Shim Arm Guide Extension # 3
2	Shim Arm #2	14	RT-3 Pneumatic Tube
3	Reactor Vessel	15	Cold Source Moderator Chamber
4	BT-2 Thimble	16	Cold Source Insulating Vacuum
5	Element Unfueled Gap	17	Cold Source D_2O Cooling Jacket
6	D_2O Outlet (1 of 2)	18	Fuel Plates, Upper and Lower Sections
7	D_2O Inlet - Outer Plenum	19	Through Tube (North)
8	D_2O Inlet – Inner Plenum	20	Heavy Water Holdup Pan
9	Fuel Transfer Chute Opening	21	Lower Grid Plate
10	CO_2 Filled Region	22	Outer Plenum Flange
11	Inner Reserve Tank	23	Steel (Thermal Shield)
12	Upper Grid Plate w/30 Elements	24	Lead (Thermal Shield)

Planar View at Core Midplane



Planar View at Core Midplane with Fuel Management Scheme

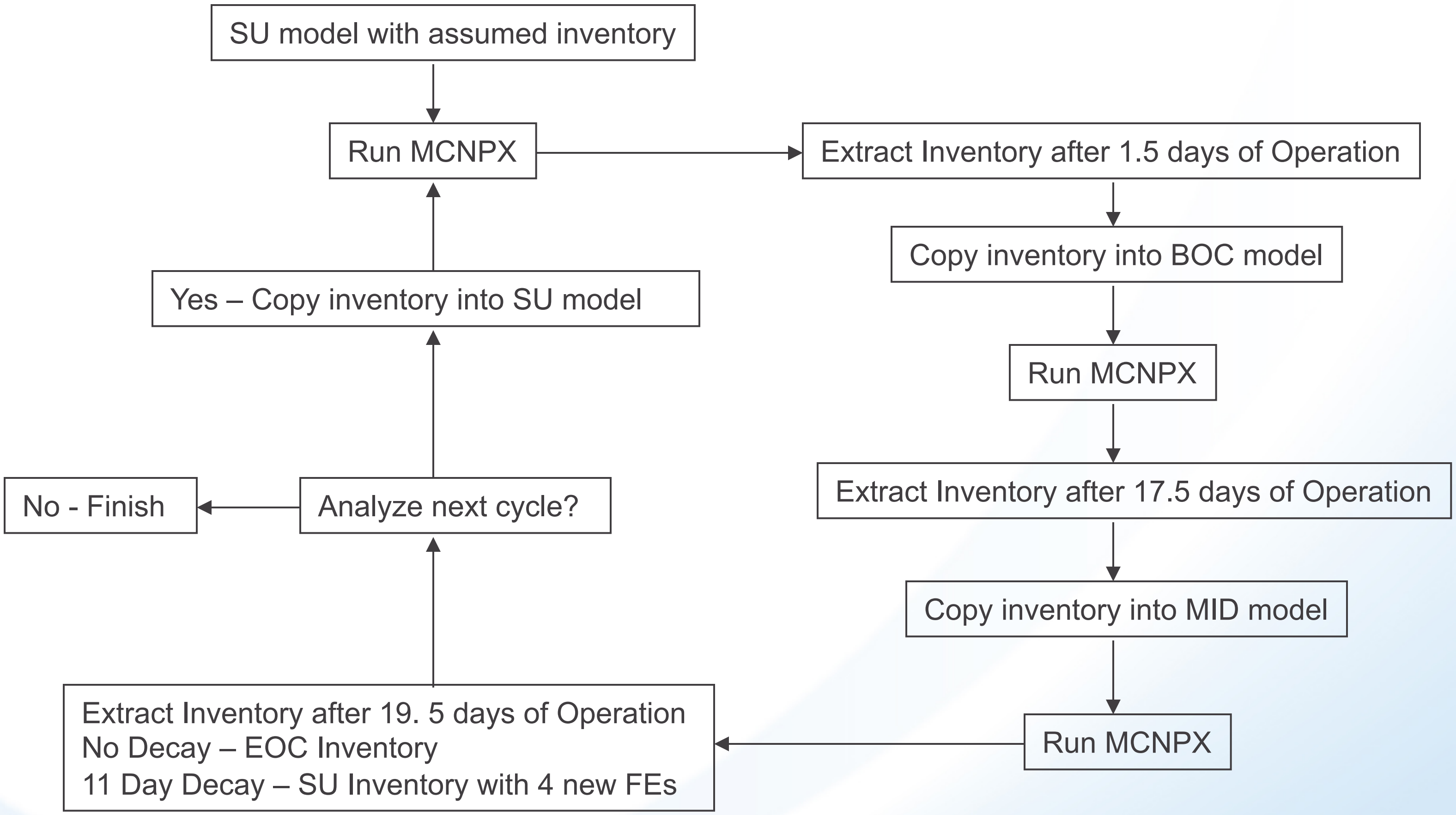
COLD SOURCE

			8-1W		7-2W		7-2E		8-1E			
		8-3W		7-5W		<>		7-5E		8-3E		
	7-3W		<>		8-7W		8-7E		<>		7-3E	
7-1W		8-6W		7-7W		<>		7-7E		8-6E		7-1E
	8-4W		<>		8-8W		8-8E		<>		8-4E	
		7-4W		7-6W		<RR>		7-6E		7-4E		
			8-2W		8-5W		8-5E		8-2E			

Shim Arm Positions

Core States	Comments	Days into Cycle	Angle from Horizontal	Angle set for BURN
			(degrees)	(degrees)
SU	Startup, 4 fresh FEs; No ^{135}Xe or other short lived isotopes	0	-19.7	-17.0
BOC	^{135}Xe in equilibrium	1.5	-14.6	-11.9
MID	Half way through the cycle	19	-9.2	-4.6
EOC	End of the cycle	38.5	0	

Flow Chart for Inventory Determination with MCNPX

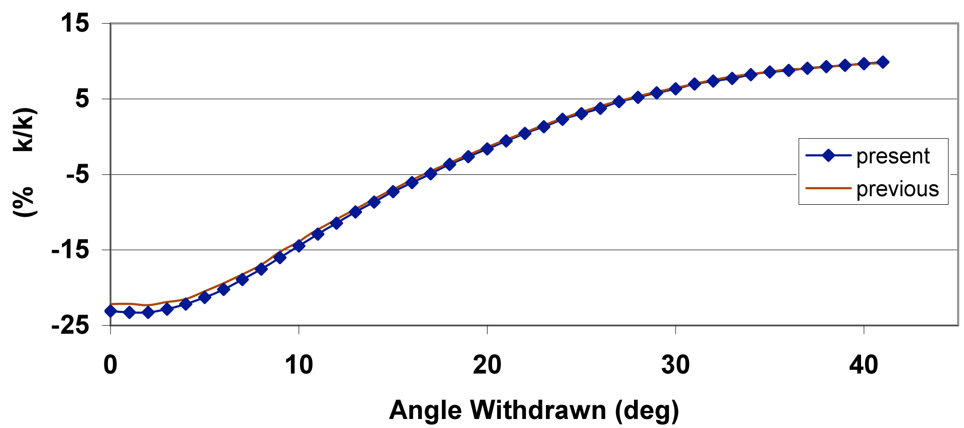


Now That we Have Inventories, on to Neutronics Analyses

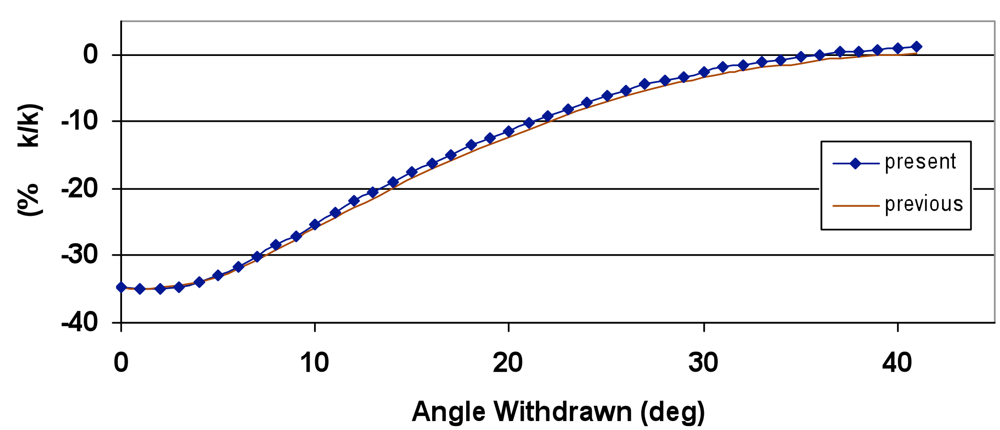
- Fuel element inventories for startup, beginning-, middle-, and end-of cycle equilibrium core
- Power distributions
- Shim arm reactivity
- Reactivity feedback effects
- Shutdown and other reactivity calculations

Effect of Methodology on Shim Arm Worth

Shim Arm Worth at SU



Shim Arm Worth at EOC



Excess Reactivity and Shutdown Margin, % $\Delta k/k$ (SU Core)

	Previous Method	Present Method
All Shim Arms In	-17.1	-17.4
Shim Arm 1 out	-11.4	-11.3
Shim Arm 2 out	-9.4	-9.9
Shim Arm 3 out	-9.7	-9.4
Shim Arm 4 out	-11.1	-11.0
All Shim Arms out	6.6	7.2

Effect of Voiding Various Regions of the NBSR

	Δk/k(%)/liter	
	Previous Method	Present Method
SU with 6 - 3½ inch thimbles voided	-0.042	-0.044
SU with FEs voided	-0.035	-0.015
SU with gaps voided	-0.049	-0.029
EOC with 6 - 3½ inch thimbles voided	-0.031	-0.037
EOC with FEs voided	-0.029	-0.018
EOC with gaps voided	-0.012	-0.022

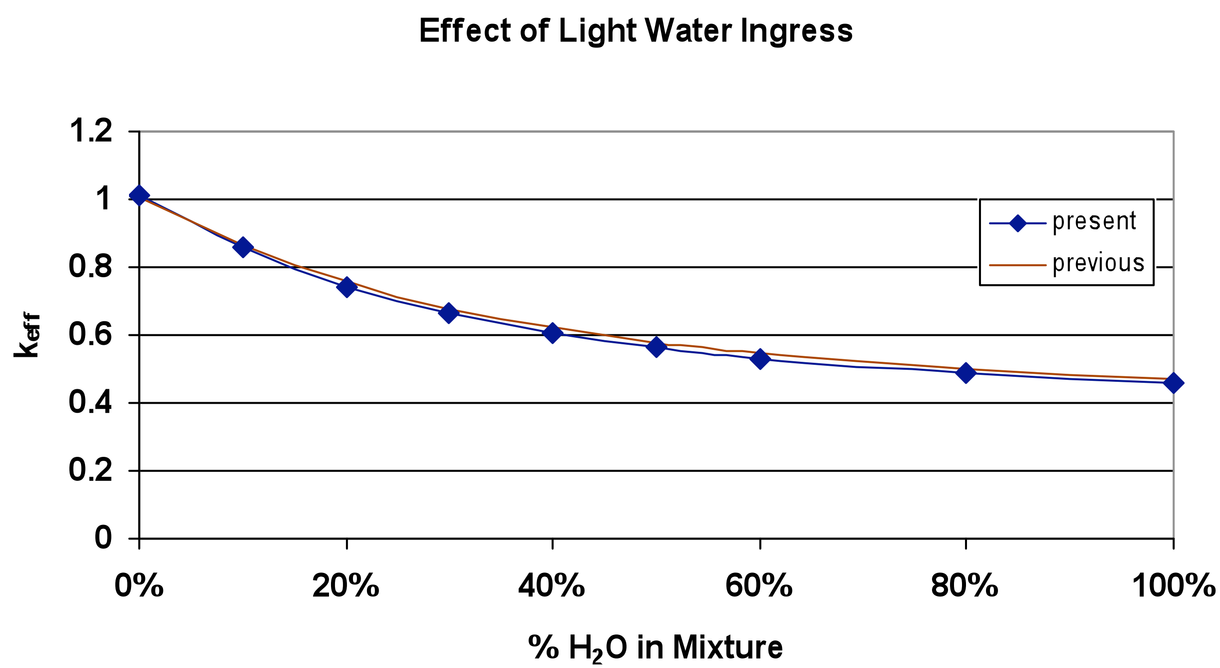
Coolant Temperature Coefficient (pcm/°C) (Range 46-100°C)

	Previous Method	Present Method
SU Core		
Change kernel only	-9.1	-7.9
Change density only	-22.2	-25.0
Total	-31.3	-32.9
EOC Core		
Change kernel only	-6.9	-8.5
Change density only	-18.3	-23.6
Total	-25.2	-32.1

Reactivity Change Due to Flooding, % $\Delta k/k$

Flooded Region	SU Core		EOC	
	Previous	Present	Previous	Present
All tubes and cold source	3.06	2.58	2.78	2.24
Cold source	0.45	0.30	0.49	0.19
All tubes	2.35	2.31	2.23	2.05
Radial beam tubes	1.75	1.60	1.88	1.58
Tangential beam tubes	0.76	0.71	0.32	0.37
Pneumatic beam tubes	0.18	0.20	0.09	0.13

Effect of Methodology on Light Water Ingress



Effect of Method on ^{235}U Burn (%Change from Previous to Present)

	A	B	C	D	E	F	G	H	I	J	K	L	M
				COLD SOURCE									
1				-1.7		-2.1		4.5		5.6			
2			8.3		2.1		<>		4.5		11.2		
3		1.2		<>		1.3		1.8		<>		1.2	
4	2.5		7		1.7		<>		2		3.6		0.6
5		-0.6		<>		-3.2		-4.3		<>		-3.8	
6			-2.6		-5.7		<RR>		-13.6		-1.9		
7				-11		-9.1		-10.4		-12.2			

Radial Power Distribution at SU

Upper Core

	A	B	C	D	E	F	G	H	I	J	K	L	M
				COLD SOURCE									
1				0.97		1.06		1.11		1.01			
2			0.96		1.02		<>		0.94		0.82		
3		0.75		<>		0.93		0.90		<>		0.71	
4	0.65		0.72		0.83		<>		0.82		0.71		0.64
5		0.67		<>		0.74		0.75		<>		0.69	
6			0.72		0.80		<RR>		0.86		0.85		
7				0.88		0.88		0.90		0.95			

Lower Core

	A	B	C	D	E	F	G	H	I	J	K	L	M
				COLD SOURCE									
1				1.05		1.16		1.20		1.14			
2			1.23		1.28		<>		1.29		1.26		
3		1.23		<>		1.29		1.29		<>		1.23	
4	1.24		1.21		1.24		<>		1.22		1.17		1.19
5		1.21		<>		1.06		1.05		<>		1.15	
6			1.12		1.08		<RR>		1.07		1.09		
7				1.03		0.97		0.98		1.04			

Conclusions

- MCNPX with BURN option and ENDF70 cross section libraries yields similar neutronic results as MONTEBURNS with ENDF66 and ENDF60 librarires
- The methodology presented here allows for movement of the shim arms in a stepwise fashion
- Changes in the ^{235}U and radial power distributions are largely due to the model enhancements and not to the methodology