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NIST Neutron Source Preconceptual Design

This paper is dedicated to the memory of Robert E. Williams

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Disclaimer

Certain commercial equipment, instruments, or materials are identified in this study in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

Introduction: NCNR & NBSR

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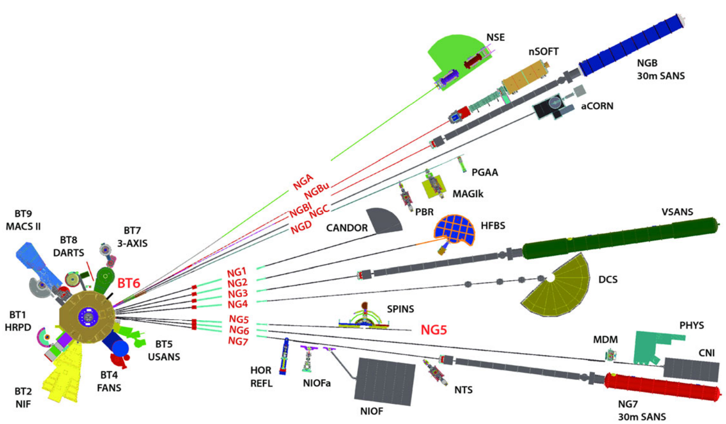
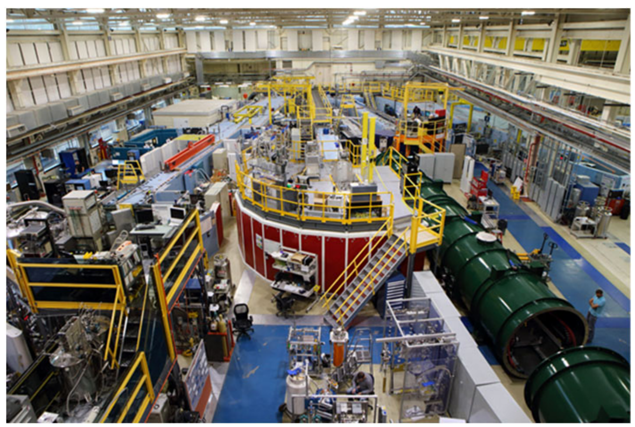
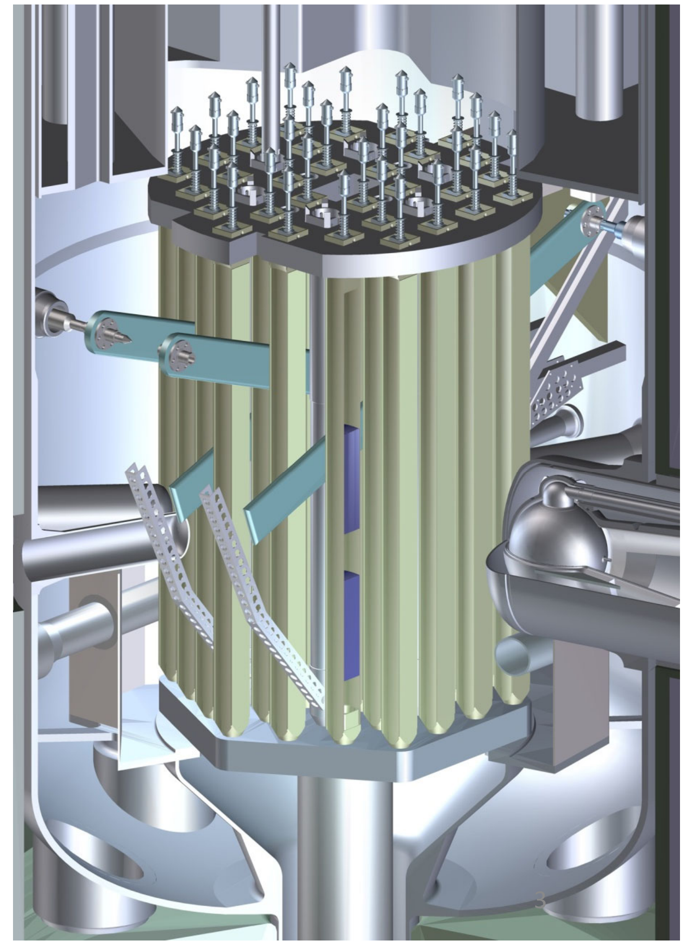
- NCNR is one of the USA primary resources for neutron research
- NBSR history of successful operation since 1967
- NBSR license to expire in 2029
- New NIST neutron source (NNS) is conceptualized
- Neutronics, Thermal Hydraulic, Beam Delivery and Facilities







Design of NNS

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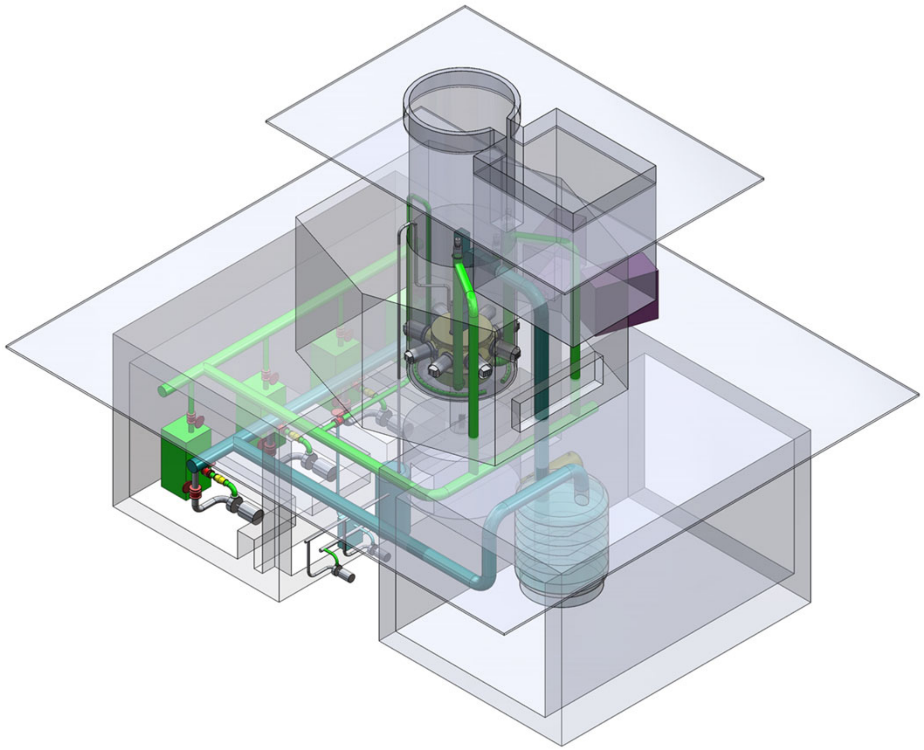
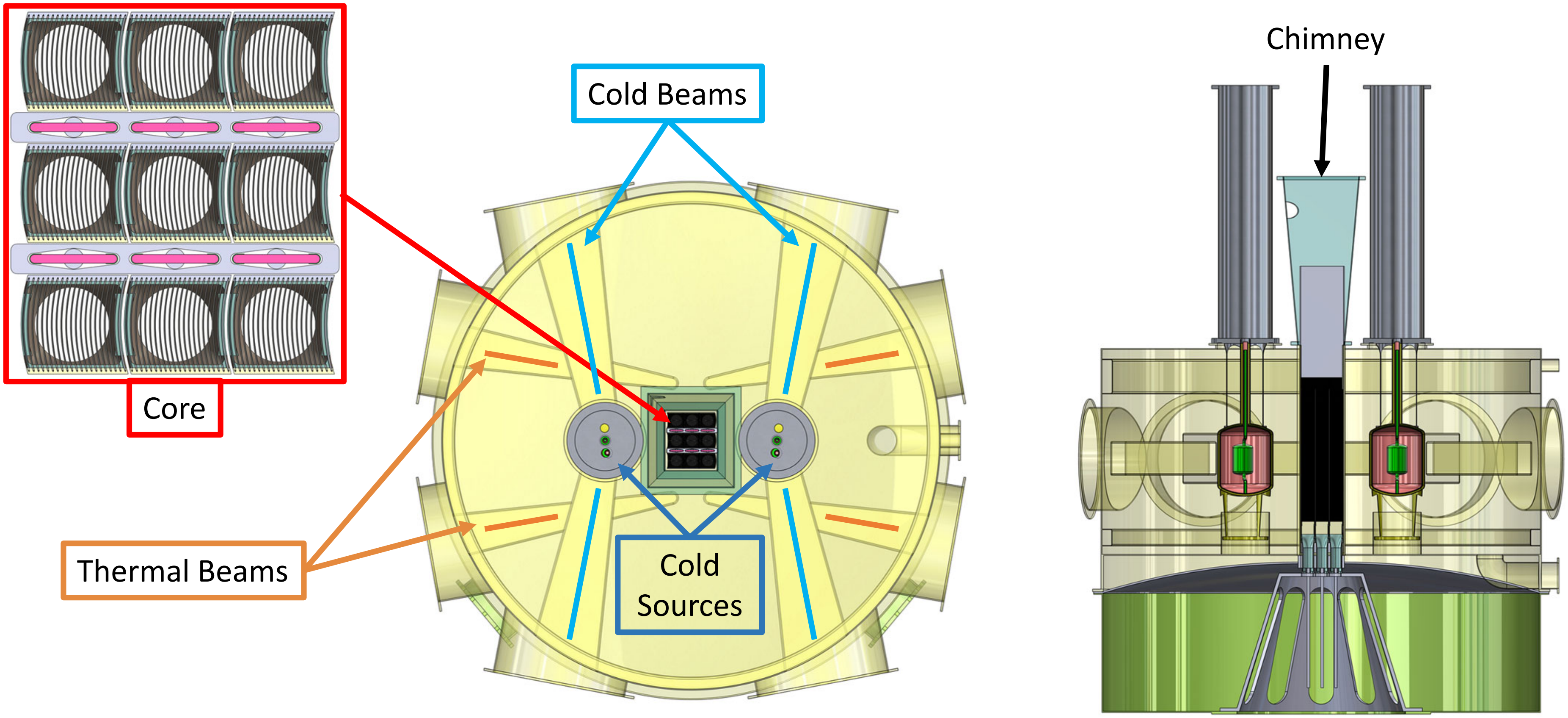
- Influenced by several reactors designed for neutron science
- Nominal power of 20 MW
- U-10Mo LEU (or U3Si2)
- Light-water-cooled compact reactor core
- Surrounded by heavy-water in the reflector tank
- 2 Cold Neutron Sources
- 8 Thermal Neutron Beams



Reactor Pool and Primary Coolant System

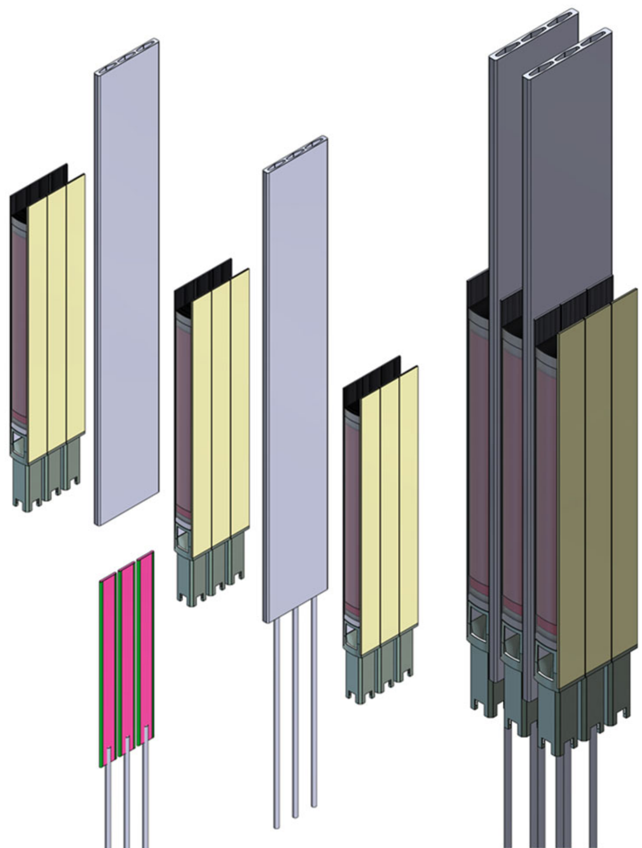
Design of NNS



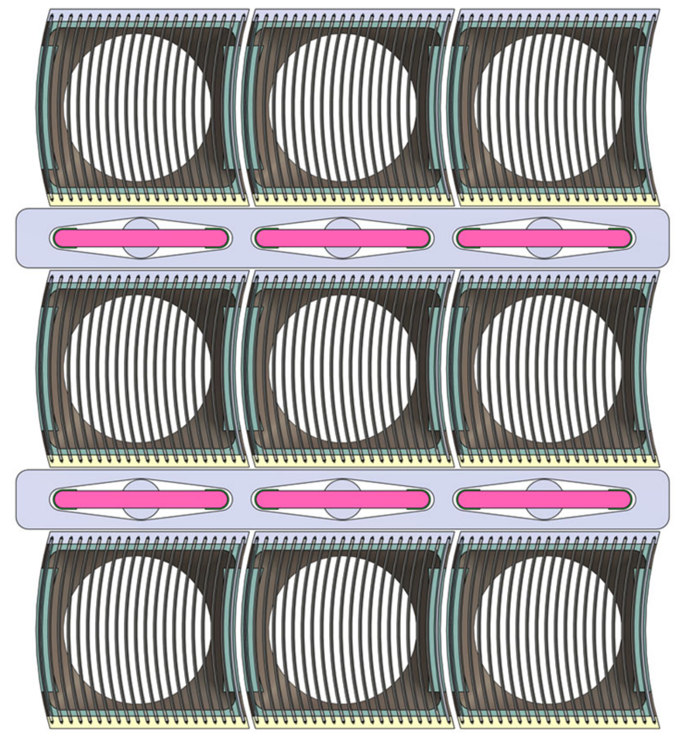
Reflector Tank with the core, cold sources, and beam tubes

Design of NNS

- Nine fuel assemblies (FA) in a 3x3 array
- Each FA contains 21 U-10Mo fuel plates
- 19.75% enriched Y-12 fuel wrapped with ~8 µm thick zirconium foil
- Six control blades placed in two guide boxes
- Core horizontally divided into three rows
- 64 coolant channels at each row
- Optimize fuel cycle length & maintain a negative reactivity feedback

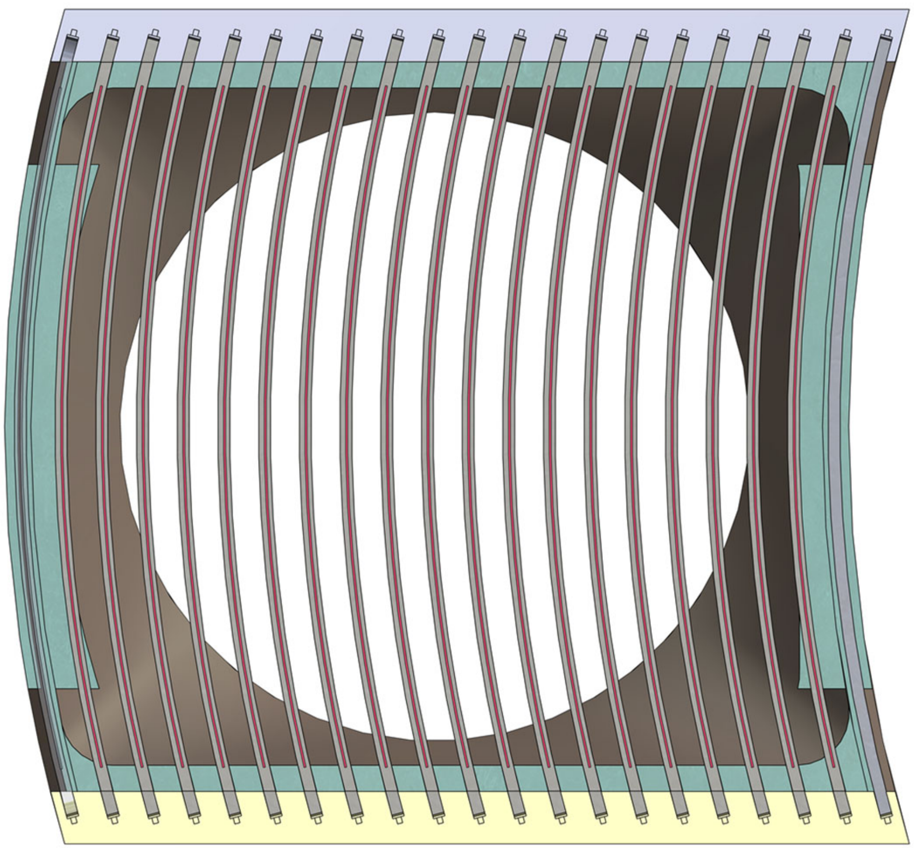


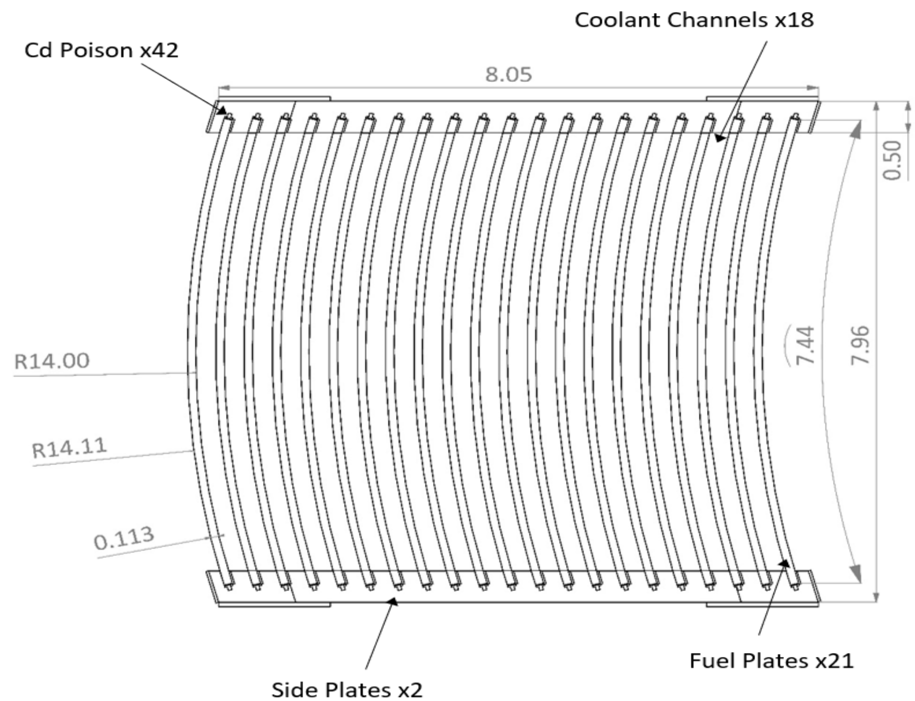
Fuel Assembly



Reactor Core

Design of NNS



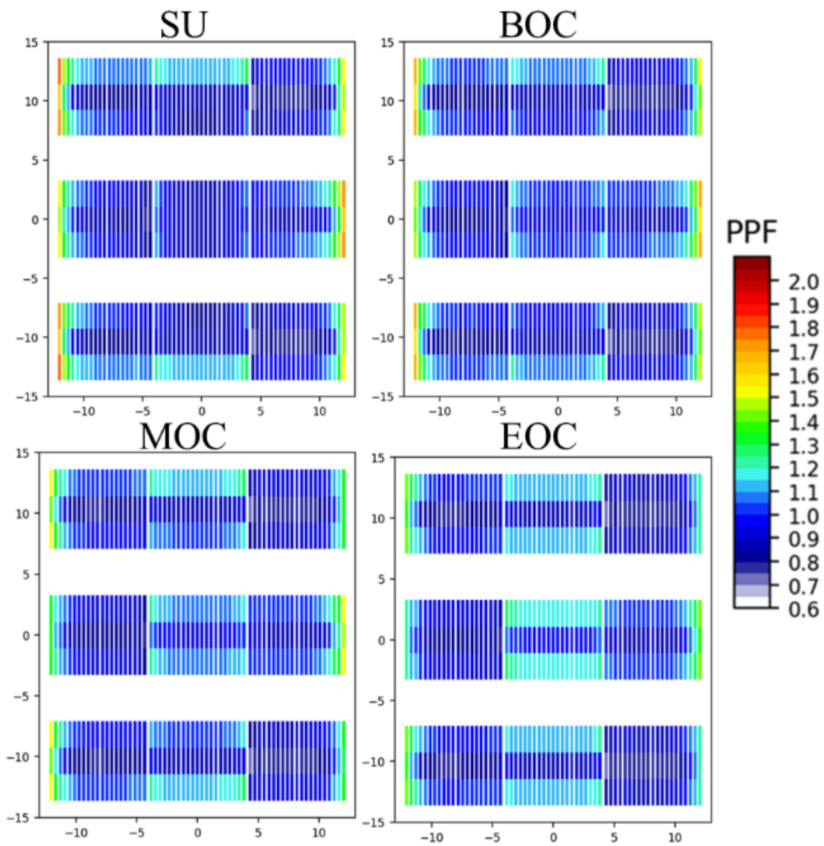


Fuel Assembly

Power Distributions

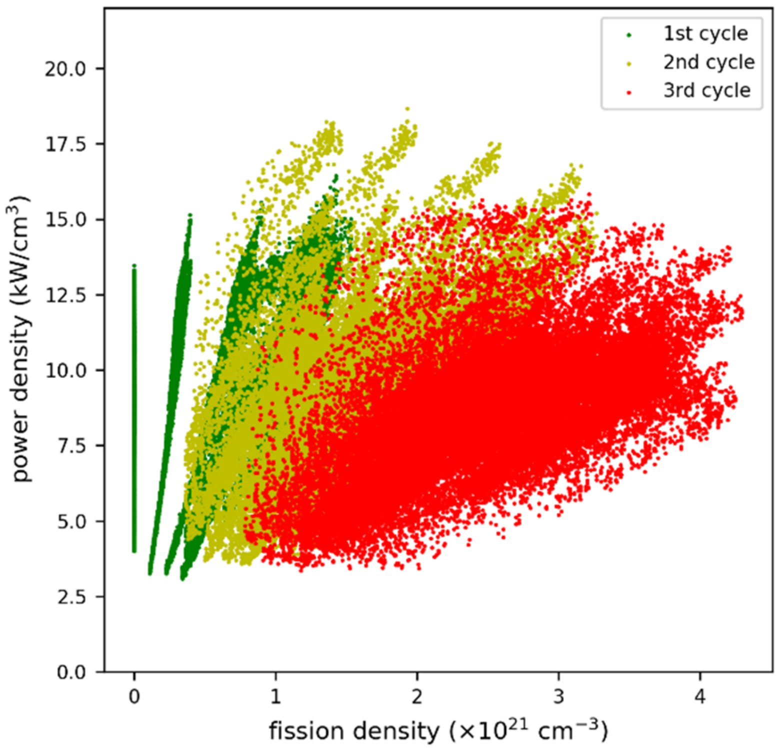
$$\text{PPF} = \frac{\dot{Q}_{plate}}{\langle \dot{Q}_{plate} \rangle}$$

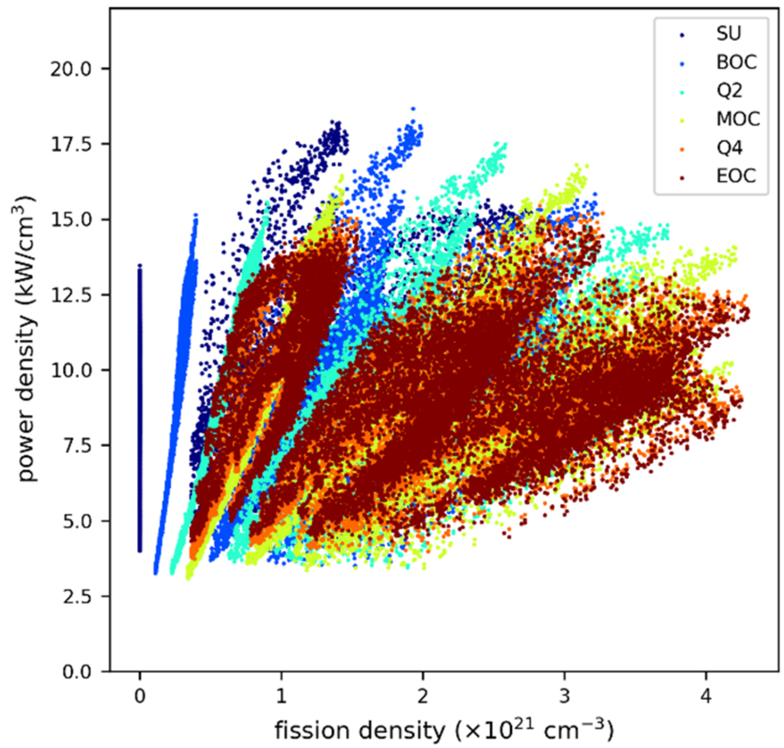
- SU = Startup
- BOC = Beginning of Cycle
- MOC = Middle of Cycle
- EOC = End of Cycle



Power Peaking Factors (PPFs) in each fuel plate at each cycle state

Fission & Power Densities

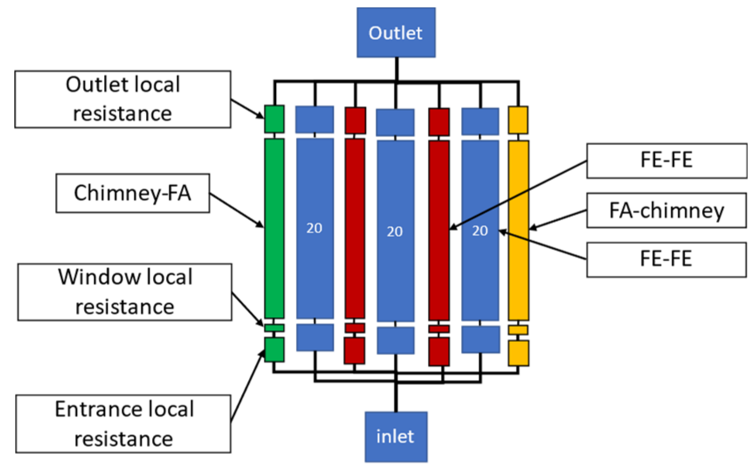




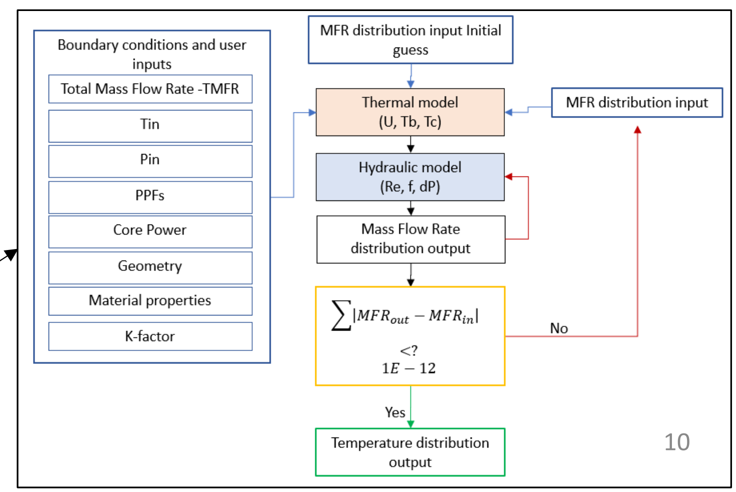
Fission densities throughout the core at multiple cycles and multiple cycle states

Thermal-hydraulics Review

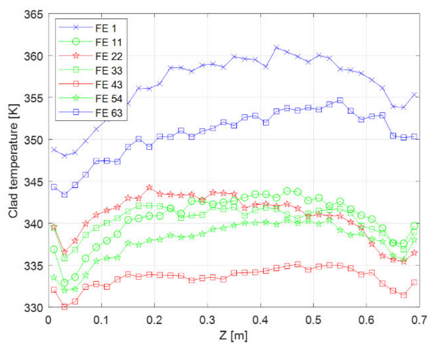
- Coolant channel is approximated with a rectangular channel
- The channel gap is constant
- The coolant velocity is the average velocity at the cross section
- The generated heat dissipates symmetrically from each side of the fuel element
- The power density is uniform within a fuel cell element
- The specific heat at each cell is evaluated at the inlet temperature of the cell
- Uses pressure drop equation which is the integrated version of the 1-D momentum equation
- there are 4 different channel types in the hydraulics model



Currently being refined

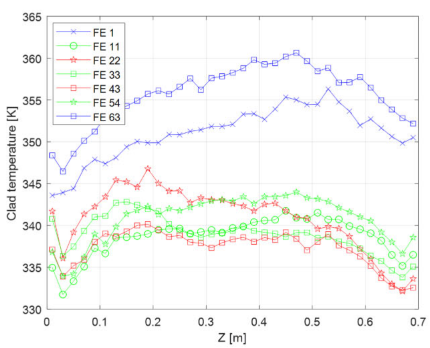


Thermal-hydraulics Results

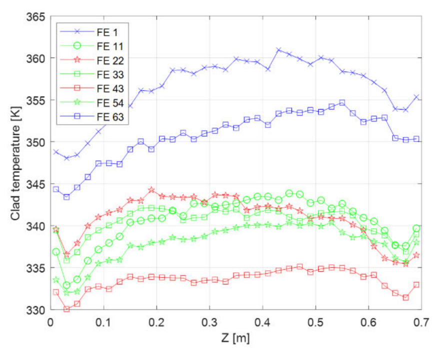


Row A

Power Distribution	Maximum Bulk Temperature			Maximum Cladding Wall Temperature		
	Value (K)	Channel #	Row	Value (K)	Channel #	Row
Uniform	326.7	33	B	346.4	33	B
SU	332.5	2	C	360.9	1	C
BOC	332.4	2	A	360.5	1	A
MOC	332.9	63	B	358.4	63	B
EOC	329.8	63	B	355	63	B



Row B



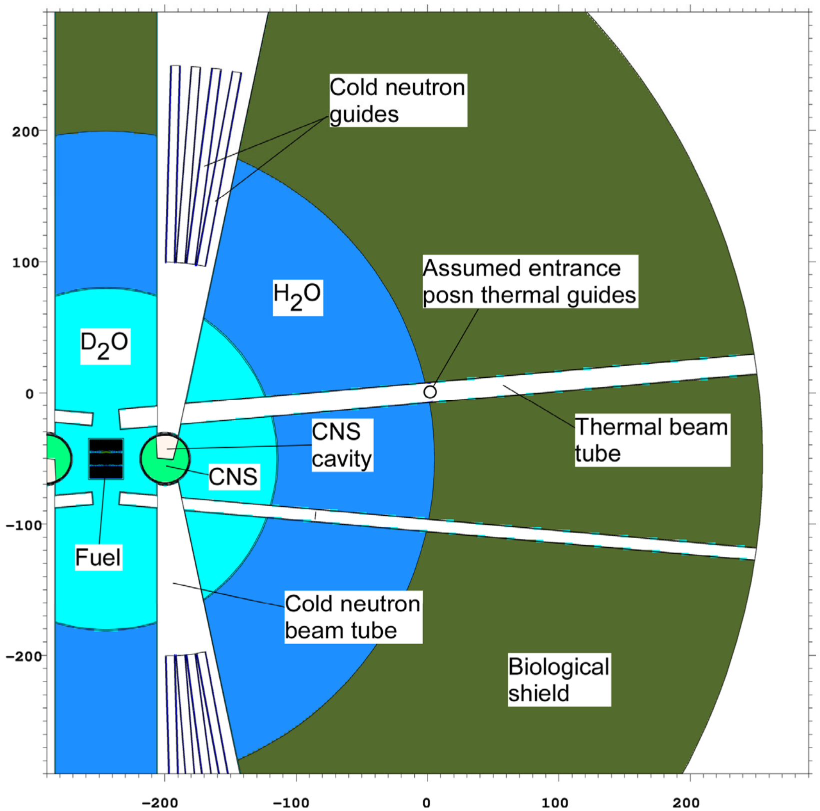
Row C

Cladding Temperatures for Multiple Fuel Elements at SU

Power Distribution	20 MW Core	
	mCHFR	mOFIR
Uniform	4.02	20.1
SU	2.22	12.9
BOC	2.18	13.6
MOC	2.42	15.2
EOC	2.61	15.1

CHFR computed with Sudo-Kaminaga correlations
OFIR computed with Saha-Zuber correlation

Proposed Cold Neutron Instruments



Plan view through the fuel center of the reactor core

Instrument type	Total Number	End position
Small-Angle Neutron Scattering (SANS)	2-3	YES
Reflectometer (CANDOR type)	2	YES
Cold Neutron Imaging (CNI)	2	YES
Cold 3-Axis (CN3X)	2	YES
Backscattering (BS)	2	YES/NO?
Neutron Spin-Echo (NSE) (Mezei-type)	1	YES
Neutron Spin-Echo (NSE) (WASP type)	1	YES
High current physics experimental position (Physics)	1	YES
Prompt Gamma Activation Analysis (PGAA)	1	YES
Neutron Depth Profiling (NDP)	1	YES
Materials Diffractometer (λ > 0.3 nm)?	1?	YES
Interferometer	1?	NO
Monochromatic Physical Measurements Laboratory (PML) positions	2-3?	NO
Miscellaneous monochromatic/ test positions	2-3?	NO
Very Small-Angle Neutron Scattering (vSANS)	1	YES
TOTAL	22-25	16-18

Proposed Cold Neutron Instruments

Proposed Thermal Neutron Instruments

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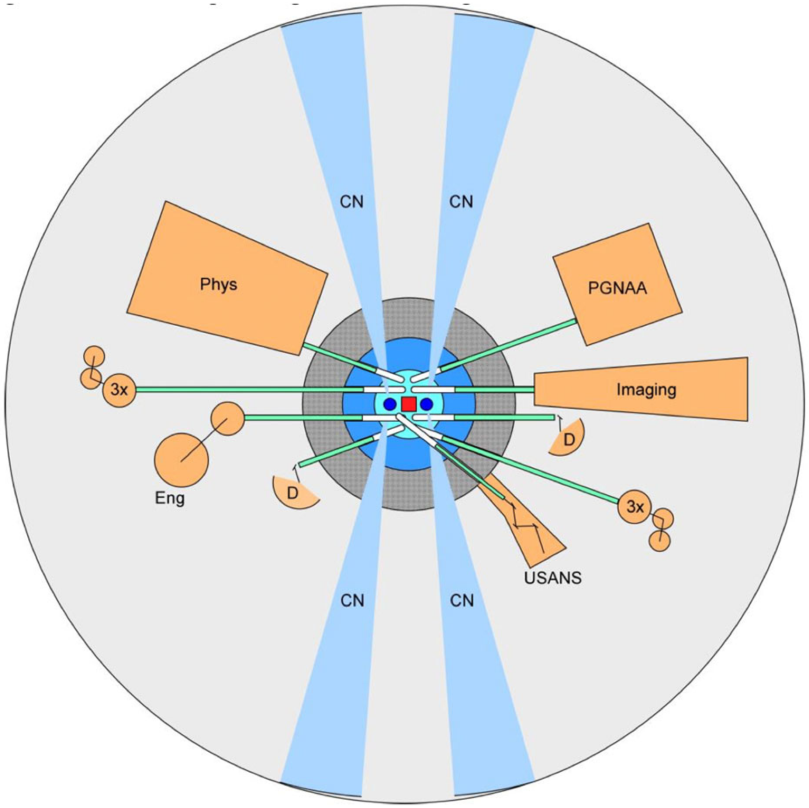


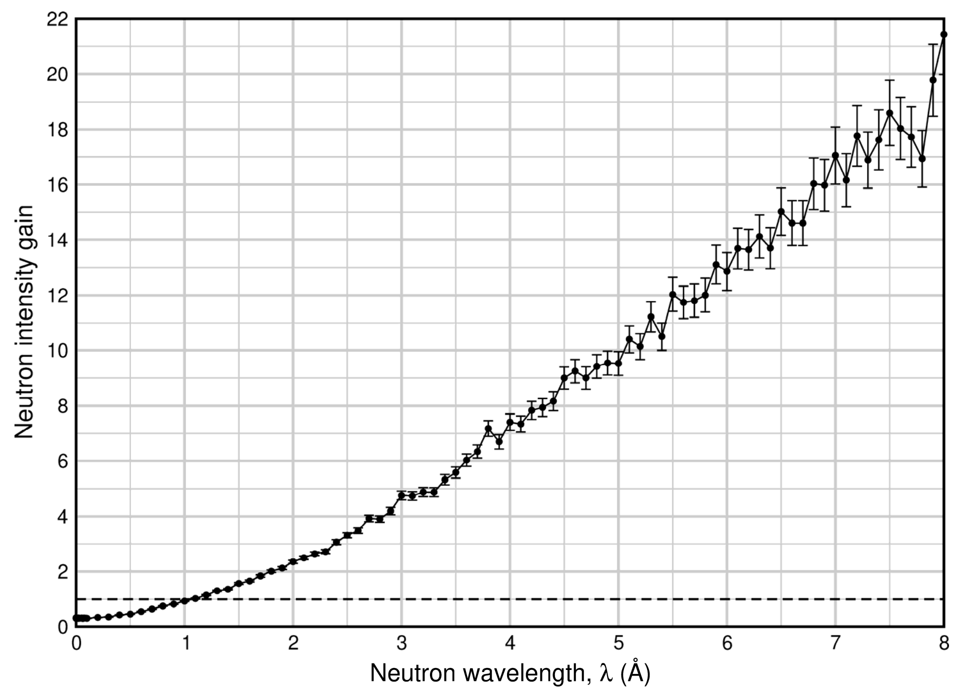
View of Potential Thermal Instruments

Instrument Type	Abbreviation
Prompt Gamma Neutron Activation Analysis	PGNAA
Neutron Microscope	Imaging
High-Resolution powder diffractometer	D
Triple Axis Spectrometer	3X
Ultra-Small Angle Neutron Scattering	USANS
High Throughput Fast Powder Diffractometer	D
White Beam Engineering Diffractometer (with CANDOR-type detector)	ENG
High Current Physics Experimental Position	PHYS

Proposed Thermal Neutron Instruments

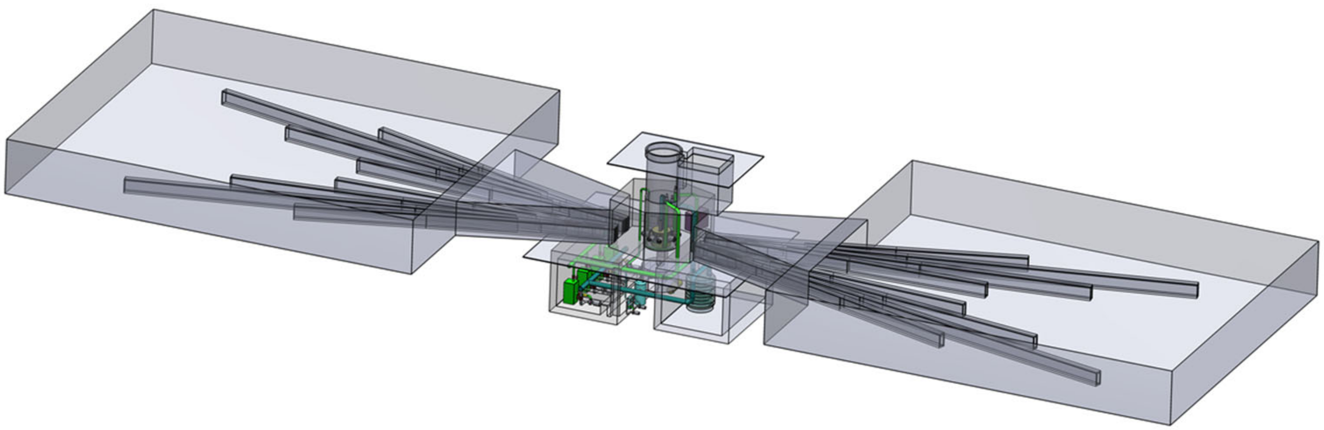
Performance Comparison

- Peak unperturbed reflector thermal neutron flux
  - NBSR 2×10^{14} $cm^{-2}s^{-1}$
  - NNS 5×10^{14} $cm^{-2}s^{-1}$
- Total cold neutron (λ > 0.4 nm) current gain between 6.5 and 8.4
- Gain at the instruments may be further enhanced
- Potential for a significant boost in the cold neutron experimental output
- Pool Type Reactor => simple maintenance
- Modular design for long term aging management



Conclusions & Future Work

- Basic neutronics and thermal-hydraulics analysis results showing the feasibility & safety
- Optimization studies to finalize optimum core designs
- Detailed analysis of core neutronics
- Complete CFD analysis and primary cooling system design
- Structural analysis
- Fuel evaluations U3Si2, U3O8 etc.



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Questions??

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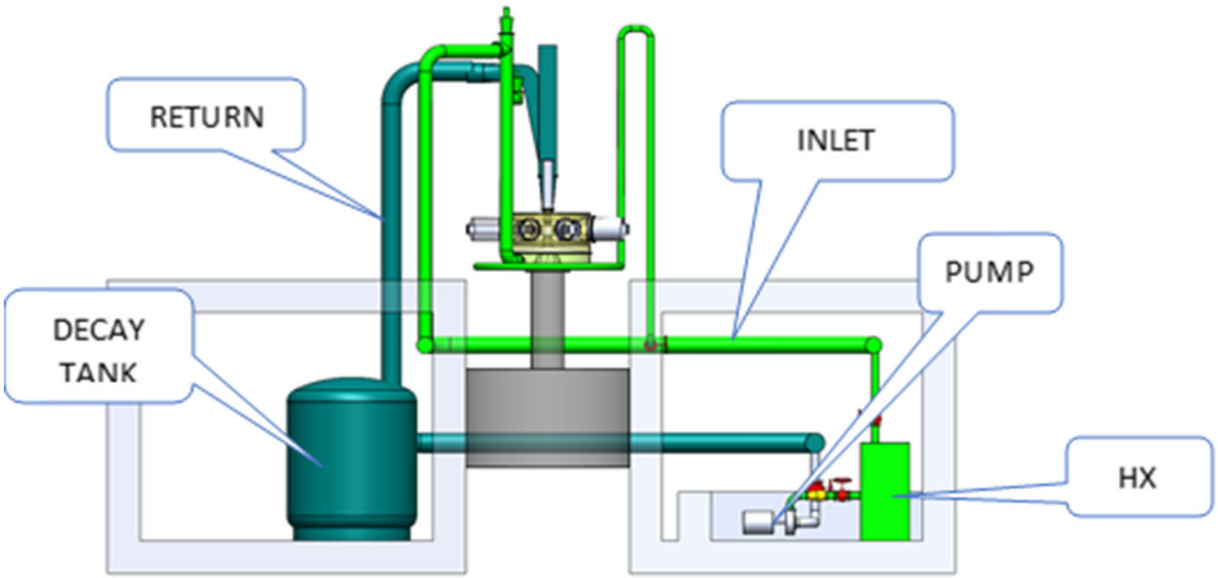
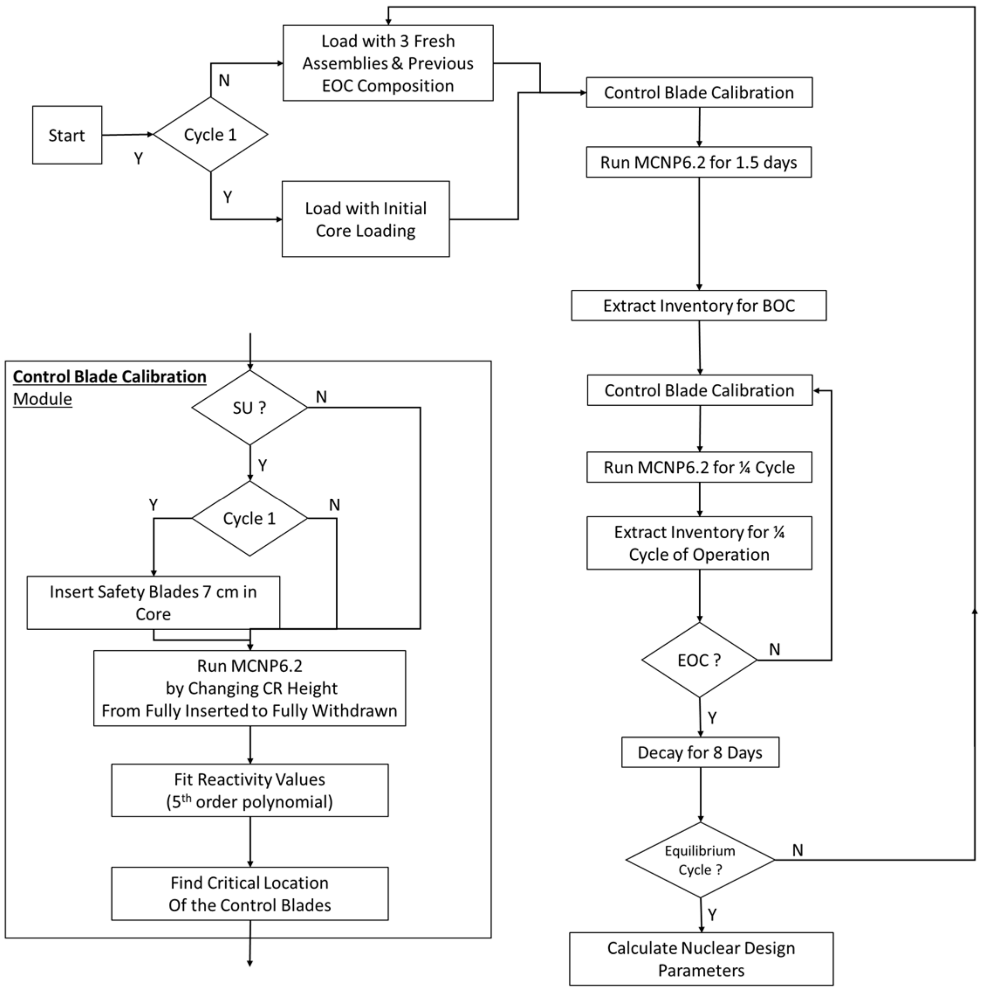
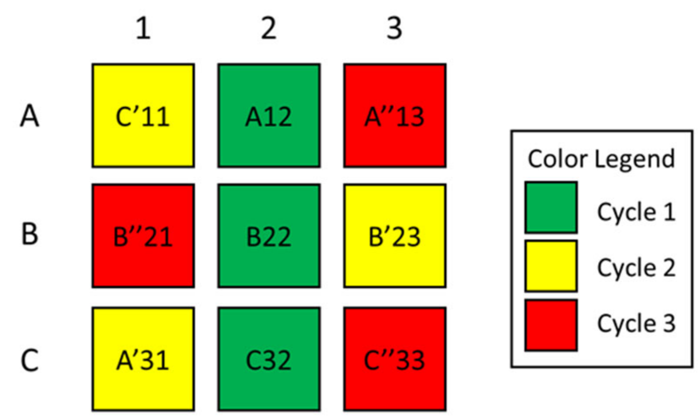


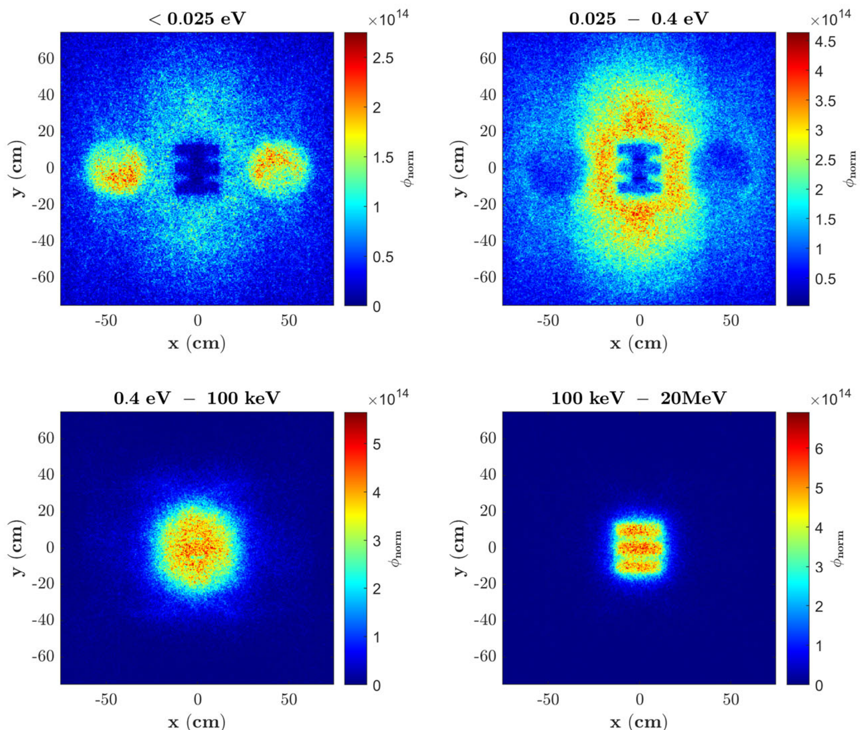
Elevation view of primary coolant system

Equilibrium Core Search

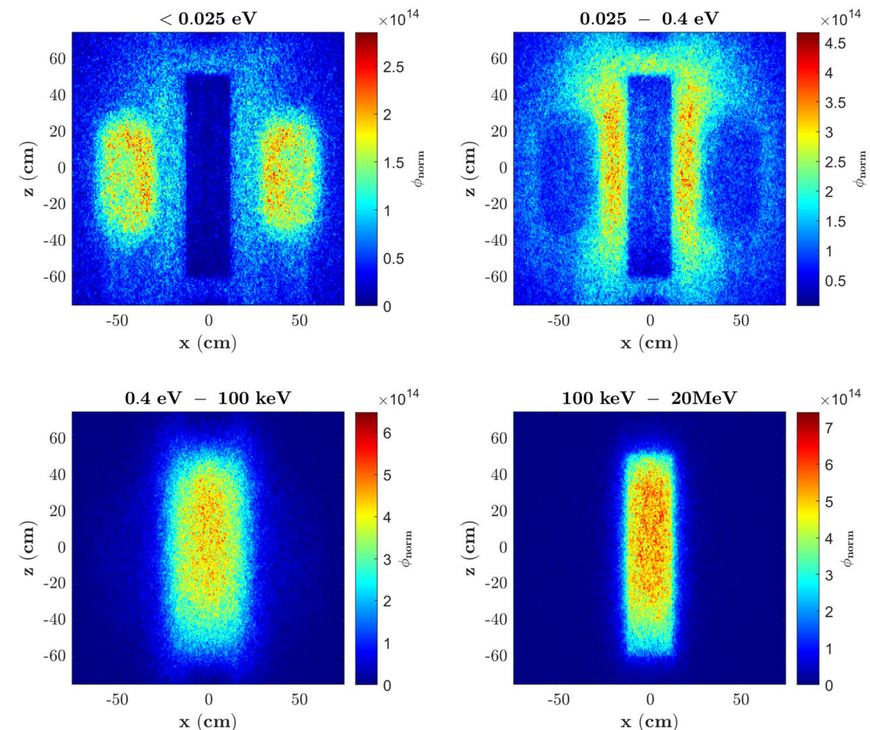




Flux Spatial Distributions

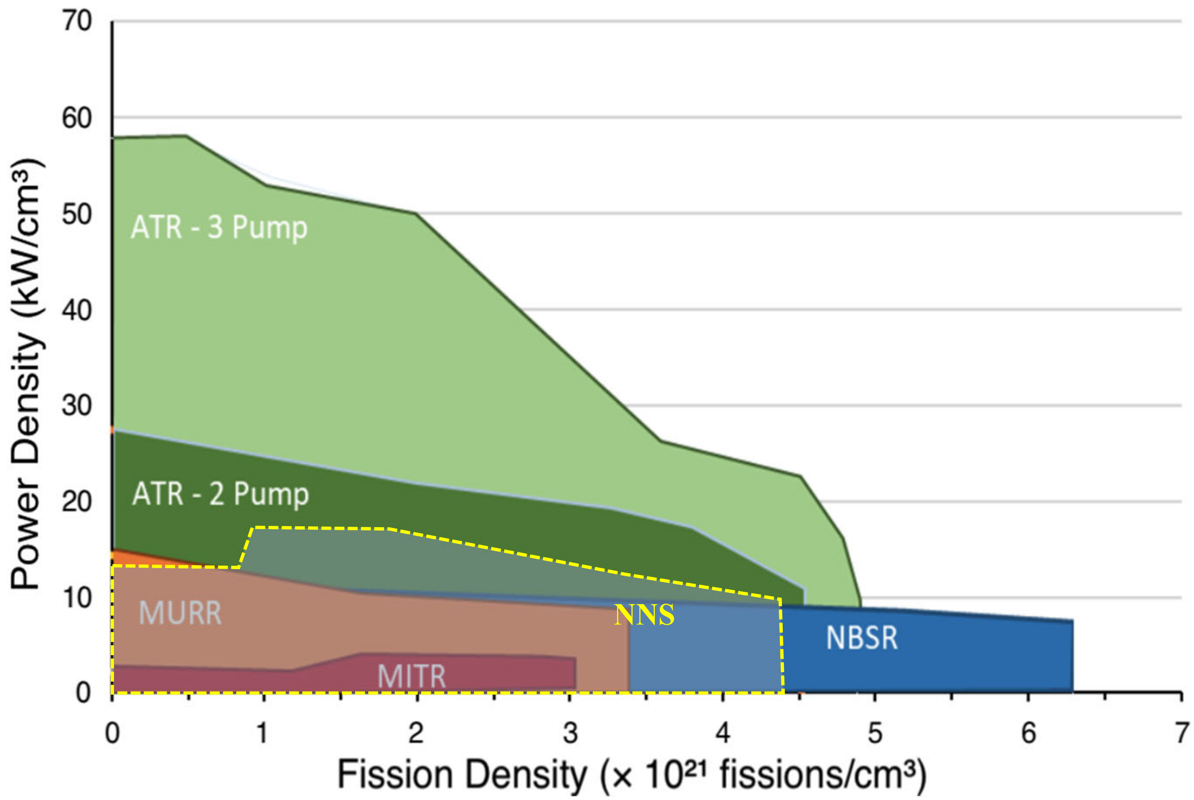


Radial View



Axial View

Comparison with Existing USHPRRs



Power and Fission Density Profiles in other USHPRR