NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

NIST Neutron Source Preconceptual Design

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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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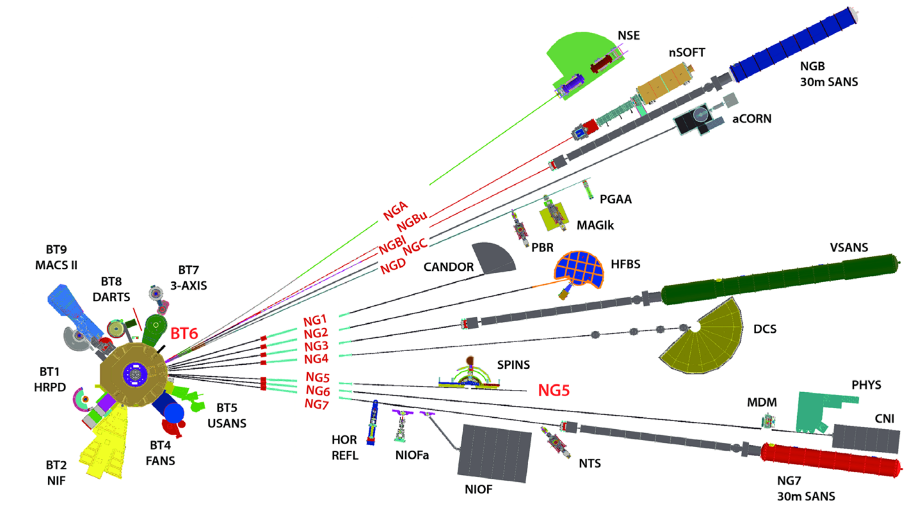
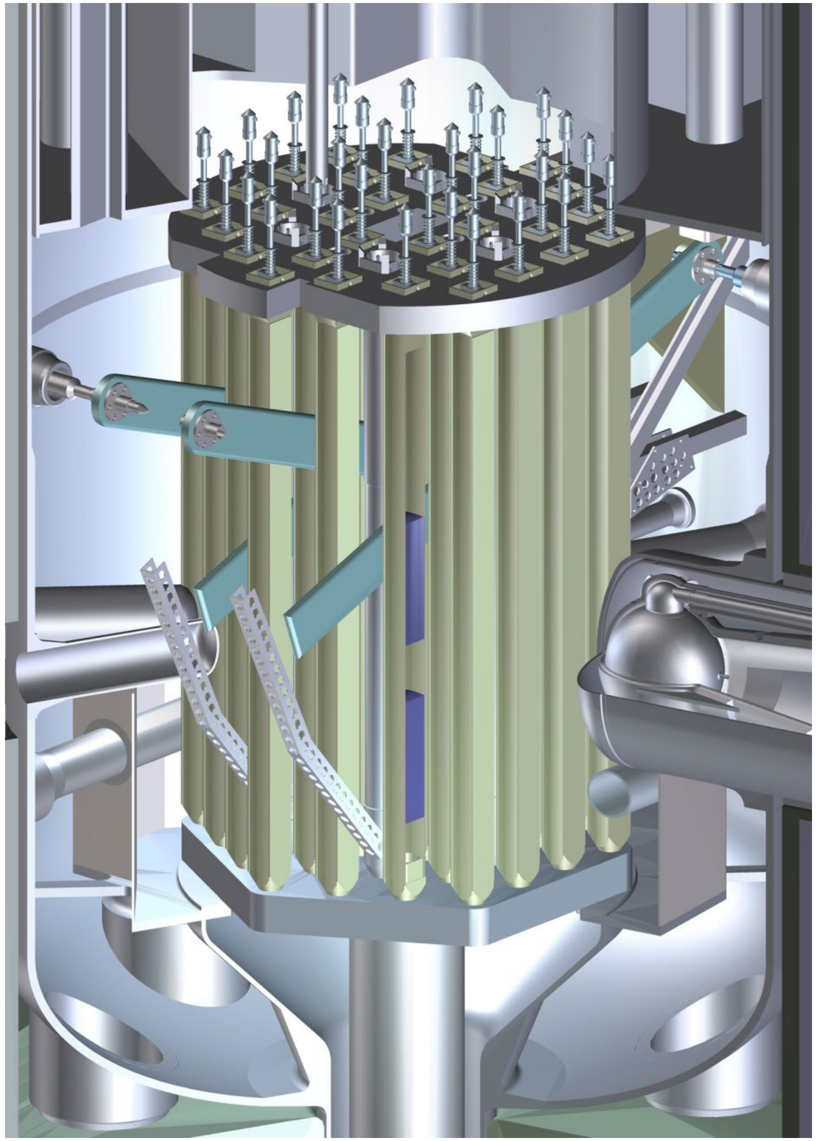
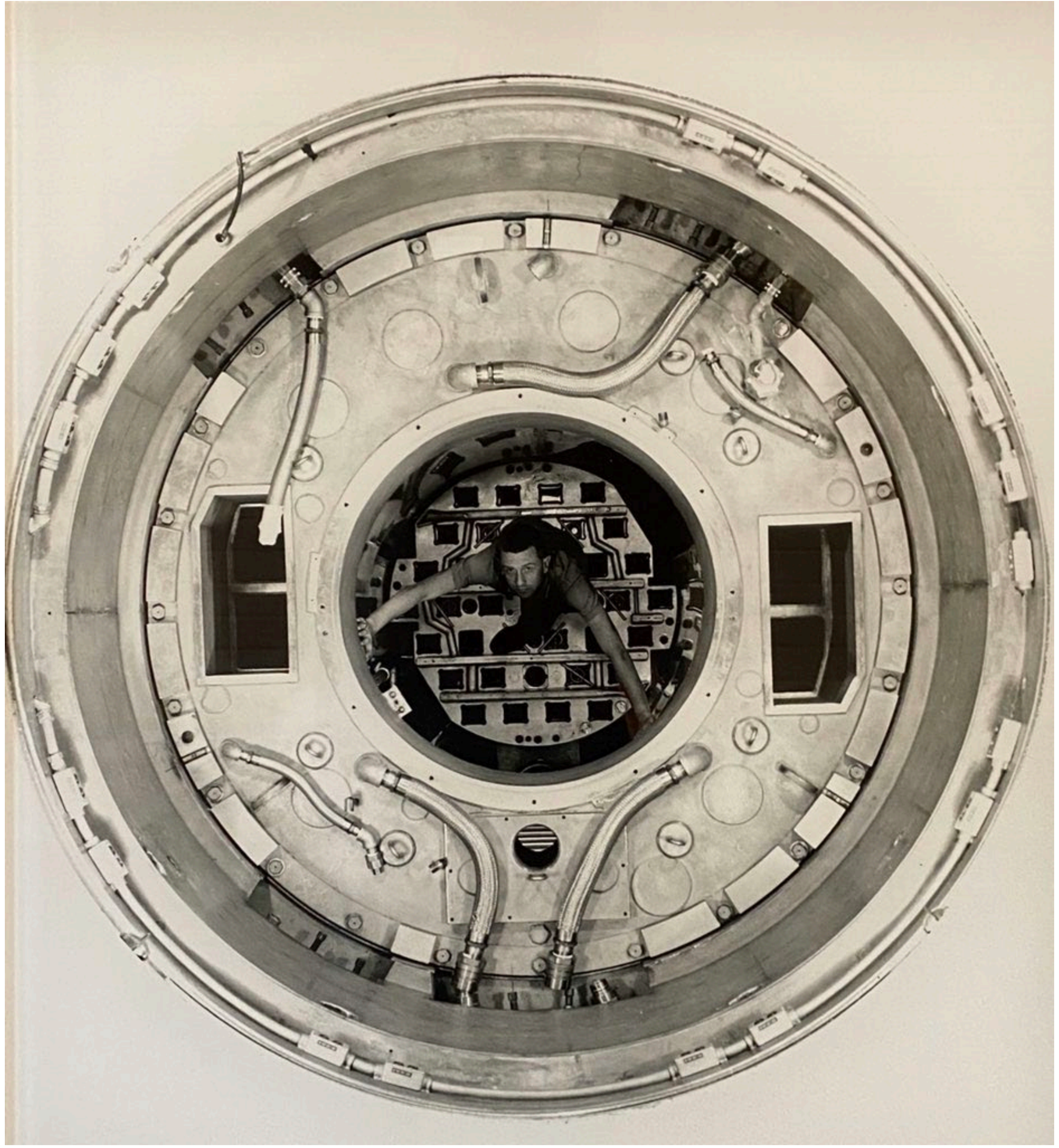
- NCNR is one of the USA's primary resources for neutron research
- NBSR history of successful operation since 1967
- NBSR license to expire in 2029, extension is planned
- Replacement => **N**IST **N**eutron **S**ource (NNS) is conceptualized.
- Neutronics, thermal-hydraulic, beam delivery, and facilities design activities are ongoing.





The NBSR Core Characteristics

- HEU fuel (93% ^{235}U) – U_3O_8+Al
  - 350 g ^{235}U/fuel element
  - 34 plates: 11”×2.5”×0.02”
  - Heavy water coolant (D_2O)
- 30 Fuel Elements
  - ~38-day fuel cycle at 20 MW
  - 4 fresh elements per cycle (usually) with a management scheme to shuffle other elements in the core
  - ~960 g of ^{235}U consumed per cycle
  - 7 or 8 cycles per element depending on where it is loaded initially
- Axially split-core, Argonne CP-5 class
  - Material Test Reactor
  - BTs and CNS(s) are at the thermal neutron flux trap elevation
  - BT fluxes ~ 1.5×10^{14} n/cm^2-s



The NBSR History

- Designed in 1960s (included a beam port for a single cold source)
- It first reached criticality on December 7th, 1967
- Initial license was 10 MW
- Upgraded to 20 MW in 1985

The NBSR Instruments Layout

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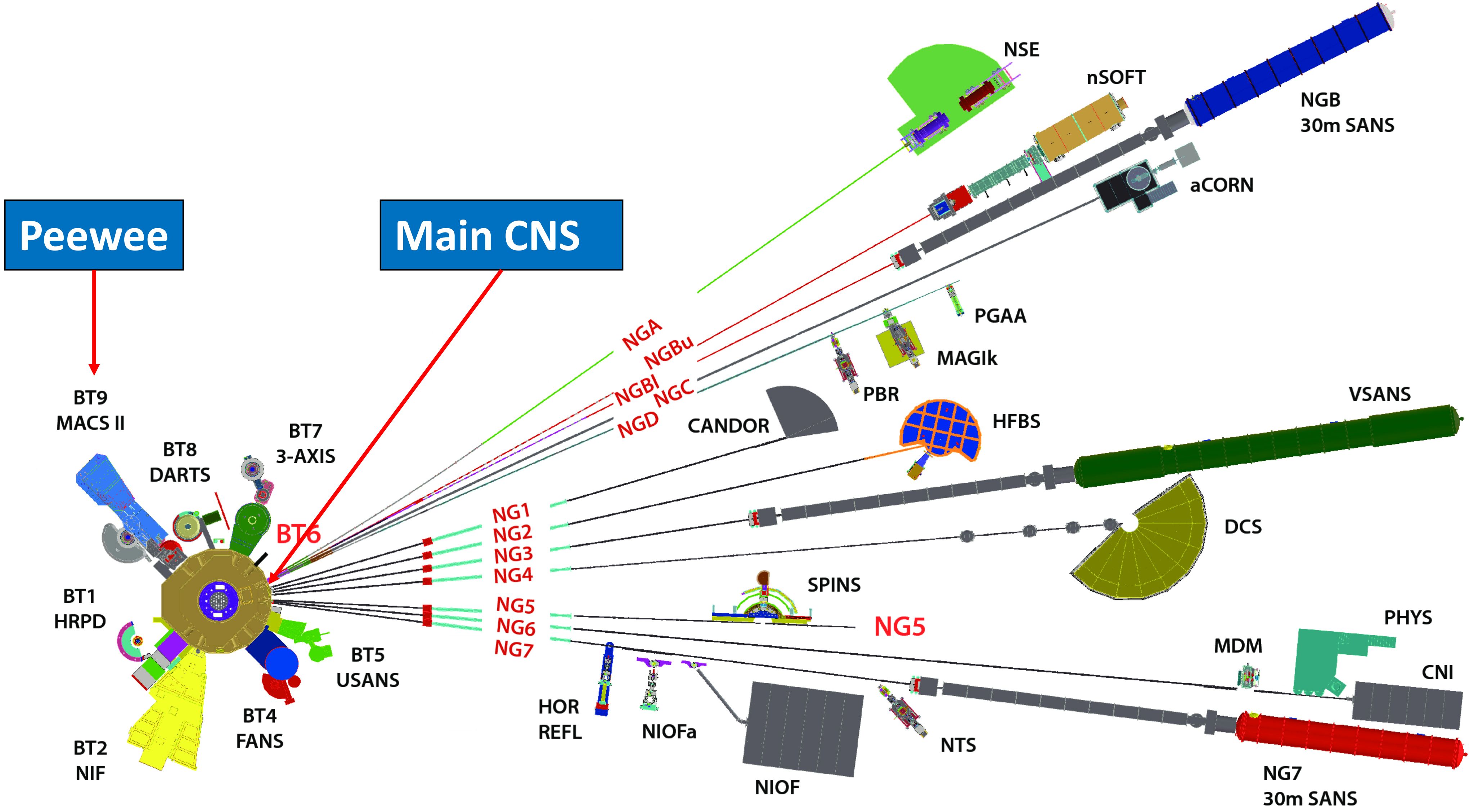

The NBSR Guide Hall

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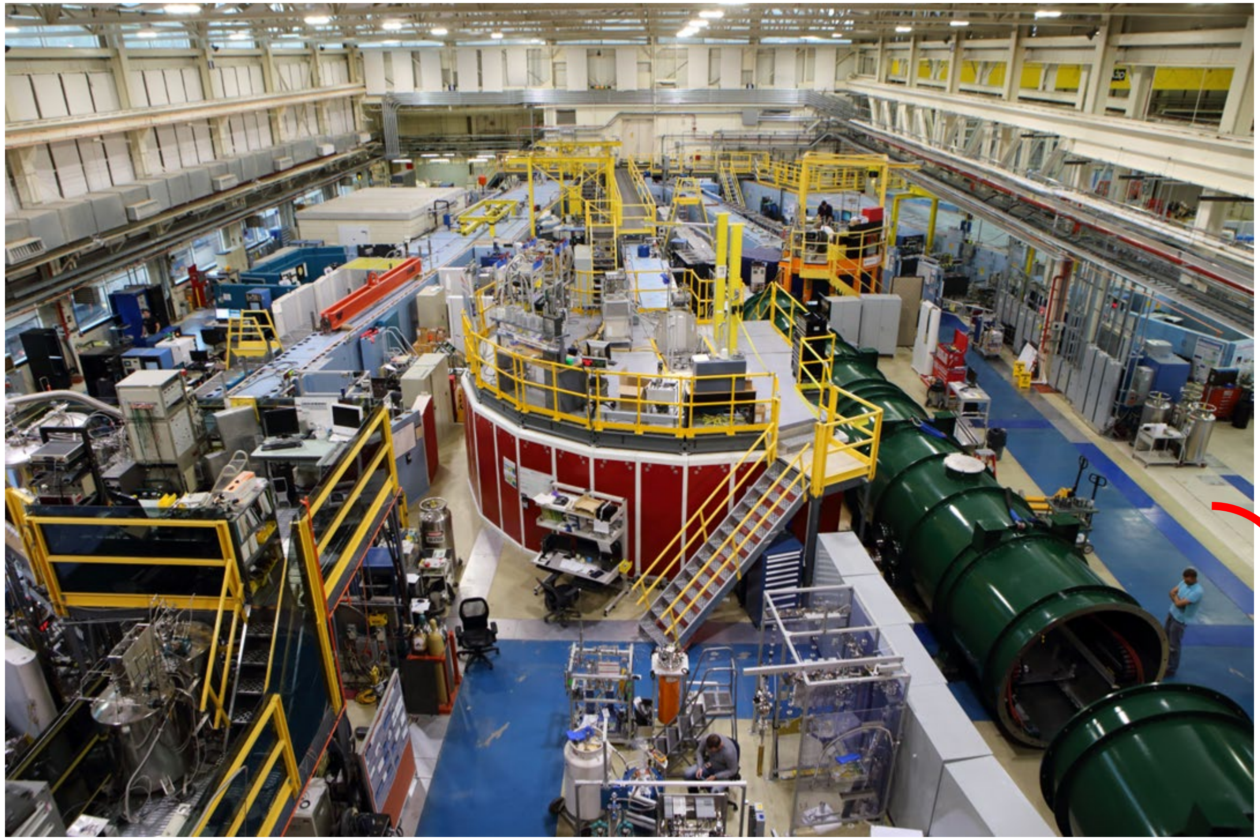
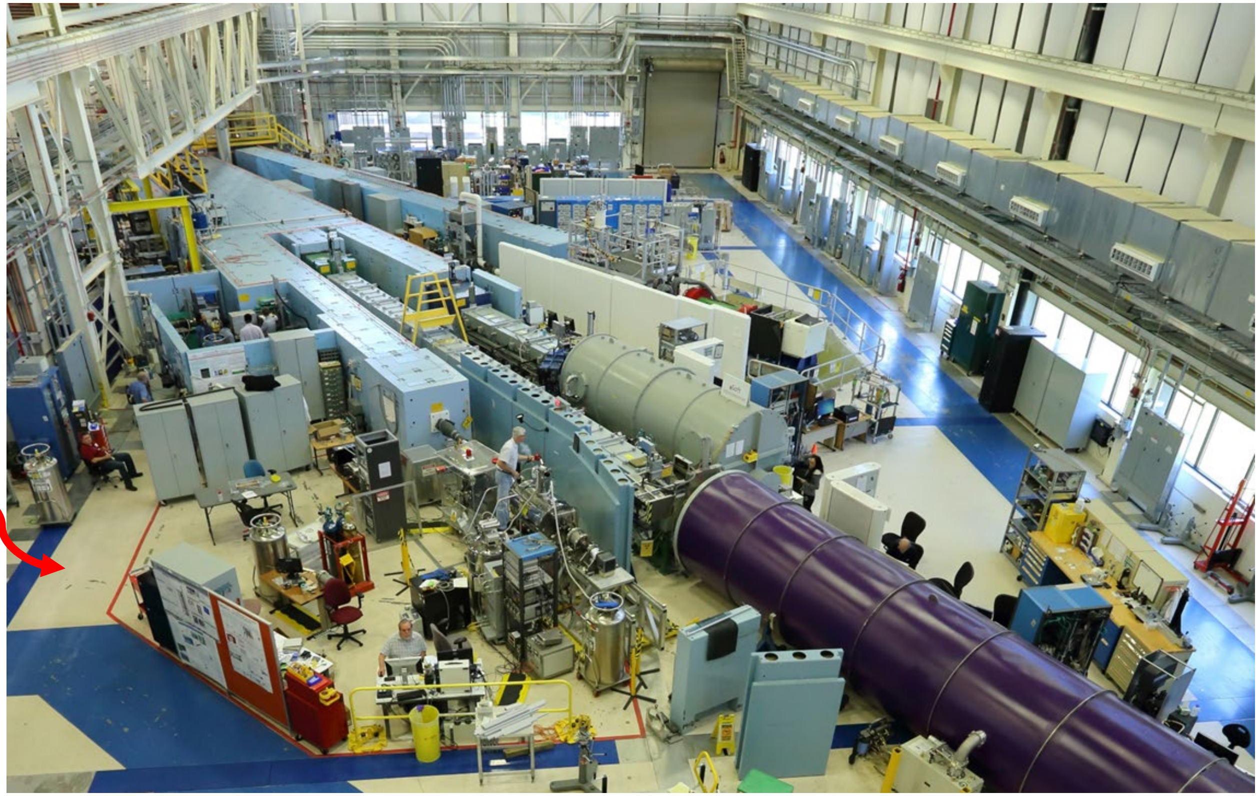
East

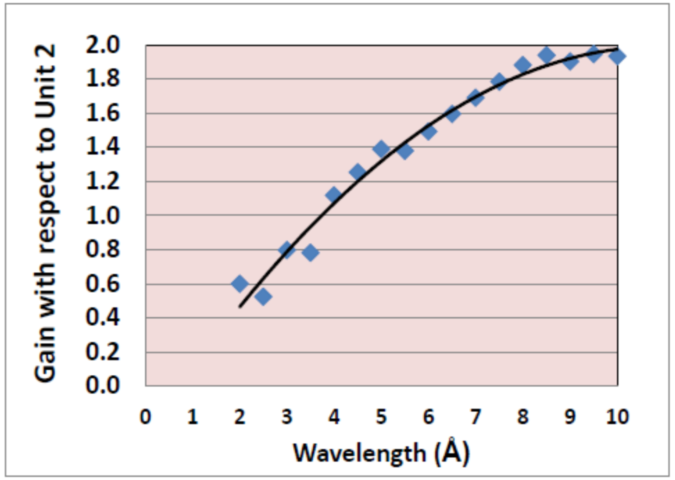


West

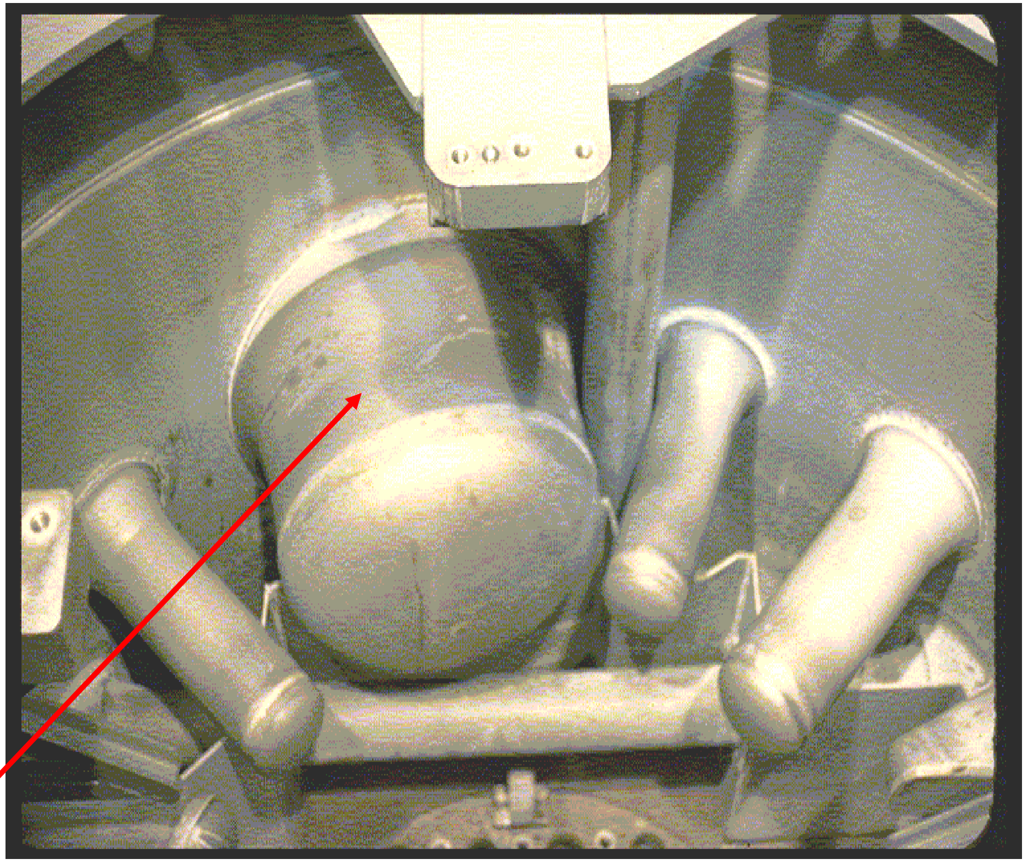


The Cold Source Through the years

1. D_2O tank (1967)
2. D2O cold neutron source (CNS) installed in 1987
   Gain of 3-5
3. LH2 CNS installed in 1995
   Gain of ~6x
4. An advanced LH2 CNS installed in 2002
   Gain of ~2x
5. Peewee (smaller CNS) installed in 2012 in BT-9
6. An upcoming cold source upgrade is planned for 2024



55 cm Diameter



NBSR Replacement

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- A study on future options for the NCNR -> replacement reactor is the best option
  - Refurbish and Replace NBSR Internals
    - No advancement as a neutron source, and similar cost to building a new reactor.
  - Keep NBSR Operational
    - long-term uncertainty in the condition of the reactor
  - Spallation Source
    - Steady-state reactor sources are complementary to pulsed accelerator-based neutron sources
  - New Core inside NBSR
    - Retains the ageing issues of NBSR, and it is likely as expensive as a new reactor.
  - New Reactor
    - A clean slate: ultimately the best path forward. Allows "Ideal' neutron source design

Modeling Approach

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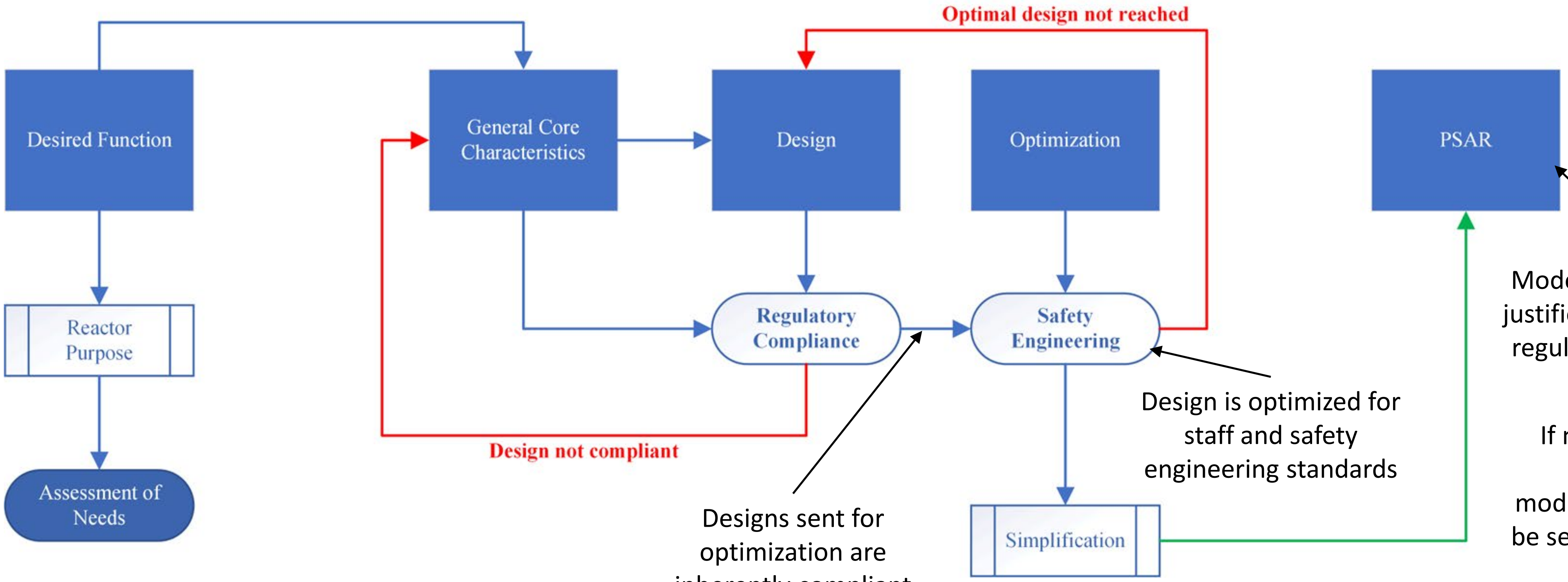
- Proposed design approach with emphasis on modeling development and acceptance processes
- Physics decomposition is suggested to reduce costs and efforts for validations
- Emphasis is placed on regulatory compliance and pre-engagement activities
- Suggested optimization process encourages sensitivity coefficients/behavior computations as a function of varying design parameters
- Factors of safety recommendations are given for both input uncertainties and sensitivity metrics.

Proposed Design Approach



Models/correlations are justified and adjusted per regulator feedback here

Design is optimized for staff and safety engineering standards

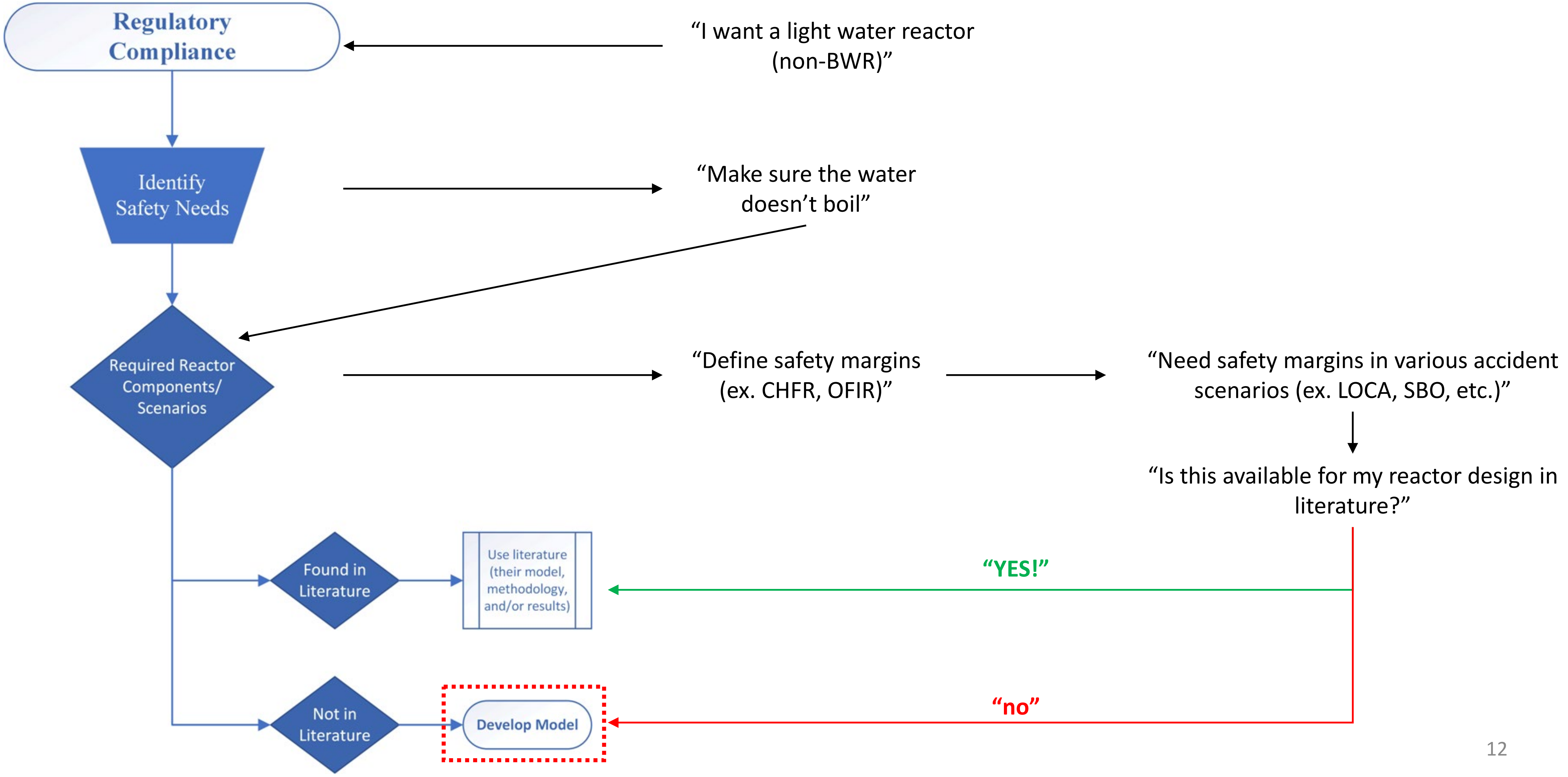
If no optimization is needed: models/correlations can be selected in the design stage

Designs sent for optimization are inherently compliant

Regulatory only receives verified & validated results in an easily digestible form

*Recommendation
Detailed methodology discussions should be saved for PSAR and forthcoming discussions

Regulatory Compliance



Design of NNS

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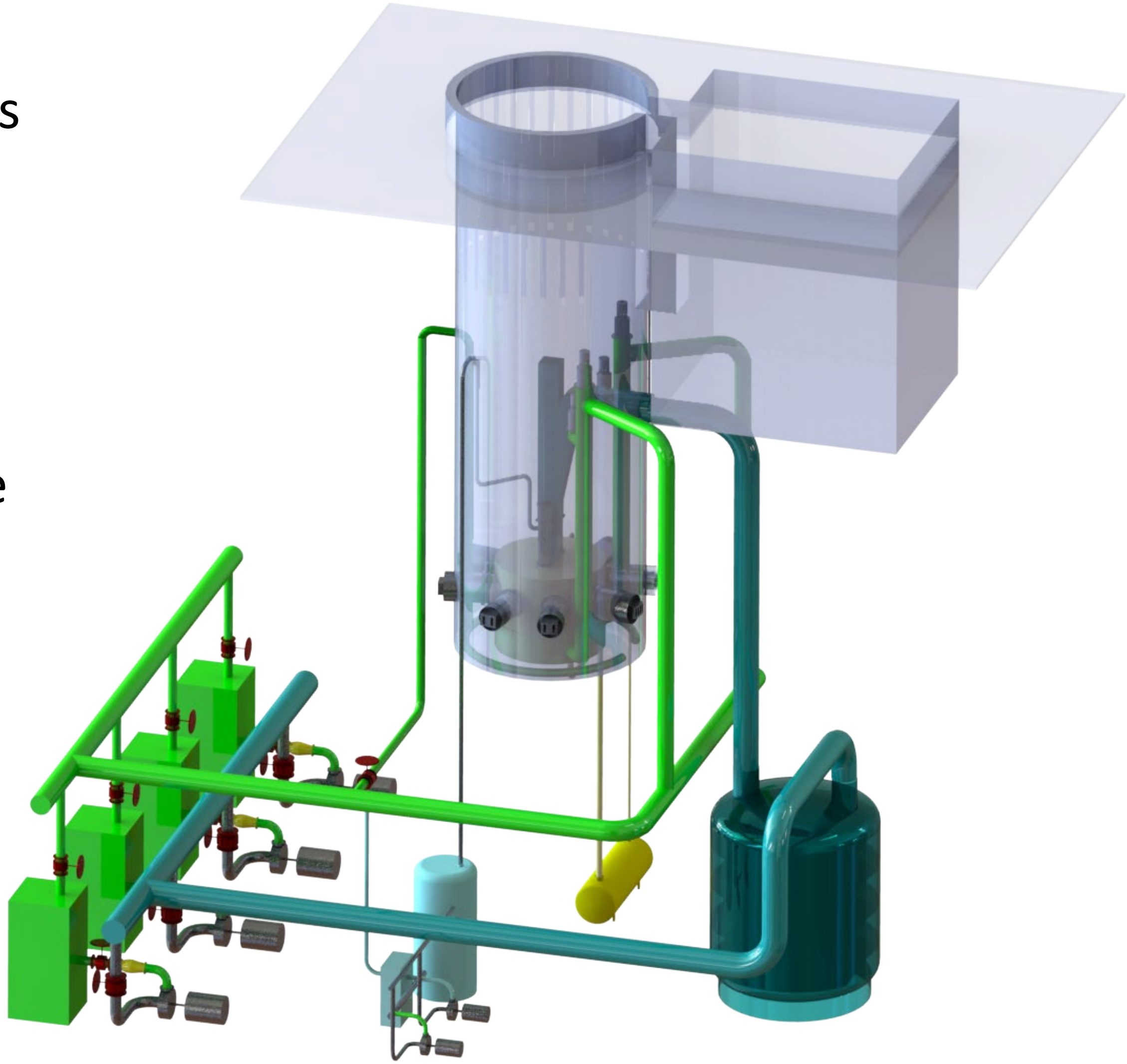
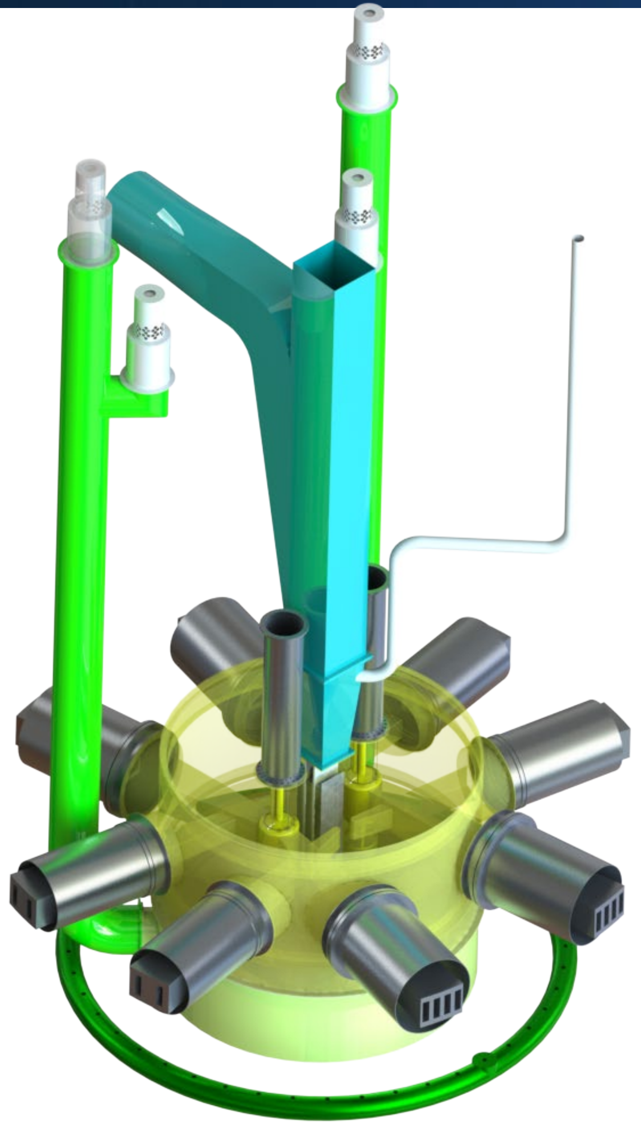
- Function is to provide cold and thermal neutron beams that meet the current and anticipated needs of the neutron science community with high availability
- Based on proven technologies
- Ignore concept level details, mechanical and structural components
- Utilize operational experience on High Performance Research Reactors in the US and abroad
- Optimize the reactor for neutron research
- Establish design specifications and requirements based on a manufacturable design
- Pre-engage with regulator to ensure design specifications meets licensing requirements



Reactor Pool and Primary Coolant System

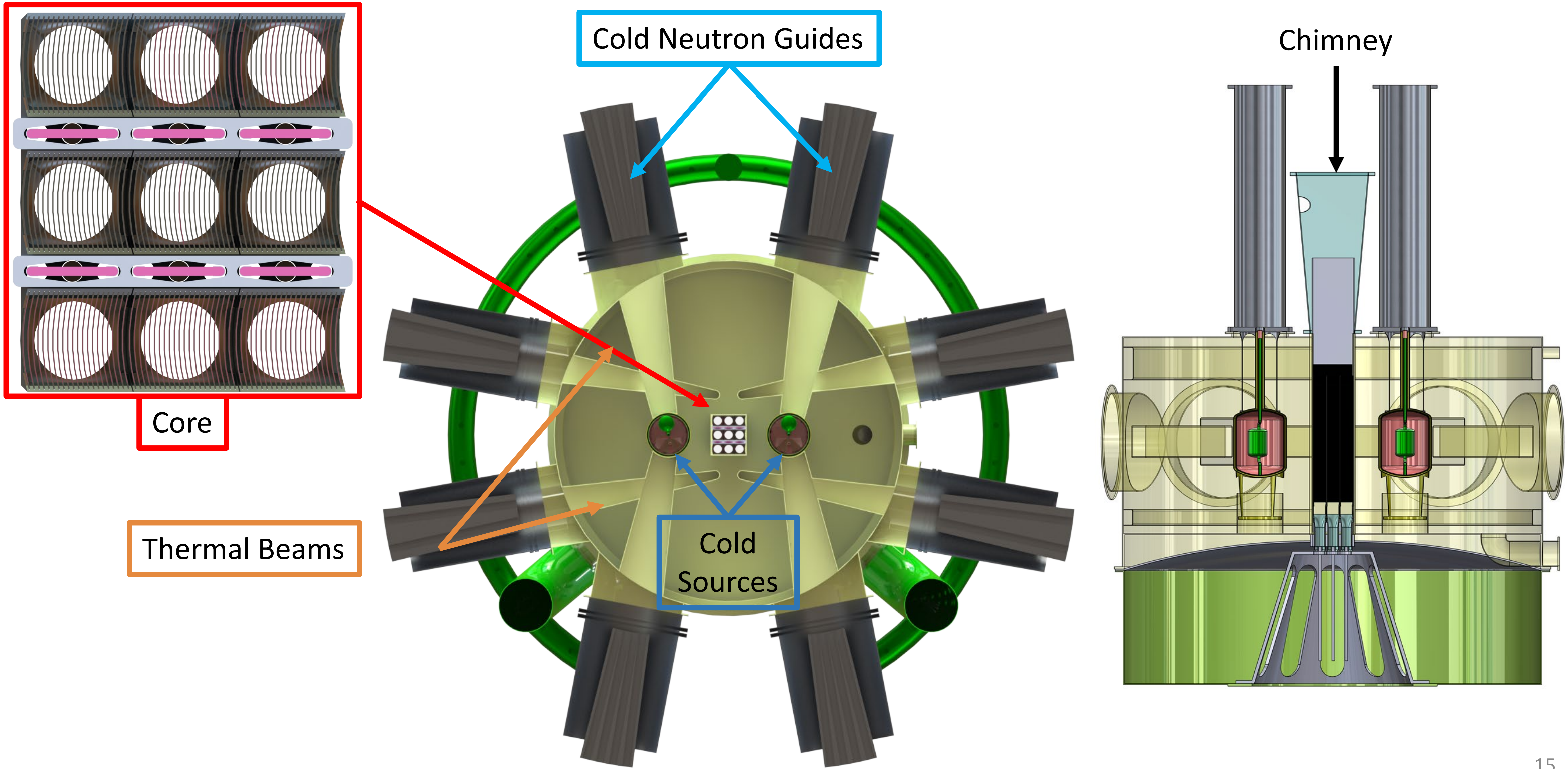
Design of NNS



Reflector tank with surrounding features

- Maximize thermal neutron density outside the core
- Avoid unproven, untested, or any new technology unless for substantial safety gain
- Influenced by several reactors designed for neutron science
- Nominal power of 20 MW
- U-10Mo LEU (or U_3Si_2 ,U-ZrH etc.), utilize “qualified” fuel
- Light-water-cooled compact reactor core
- Surrounded by heavy-water reflector tank
- 2 Cold Neutron Sources
- 8 Thermal Neutron Beams
- 40 days operating cycle

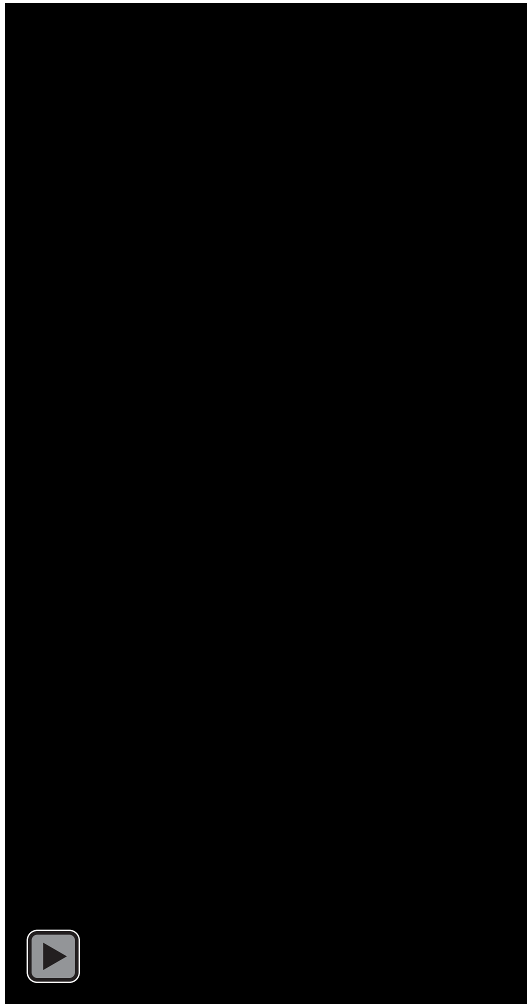
Design of NNS

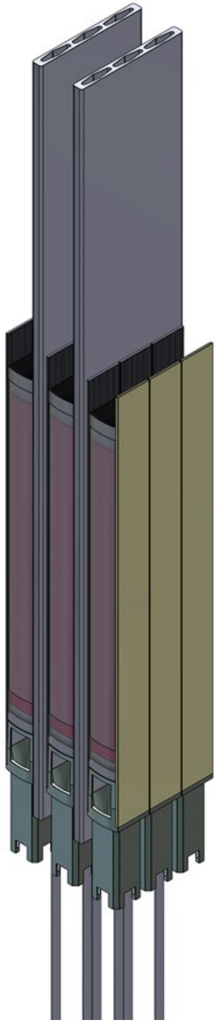


Reflector Tank with the core, cold sources, and beam tubes

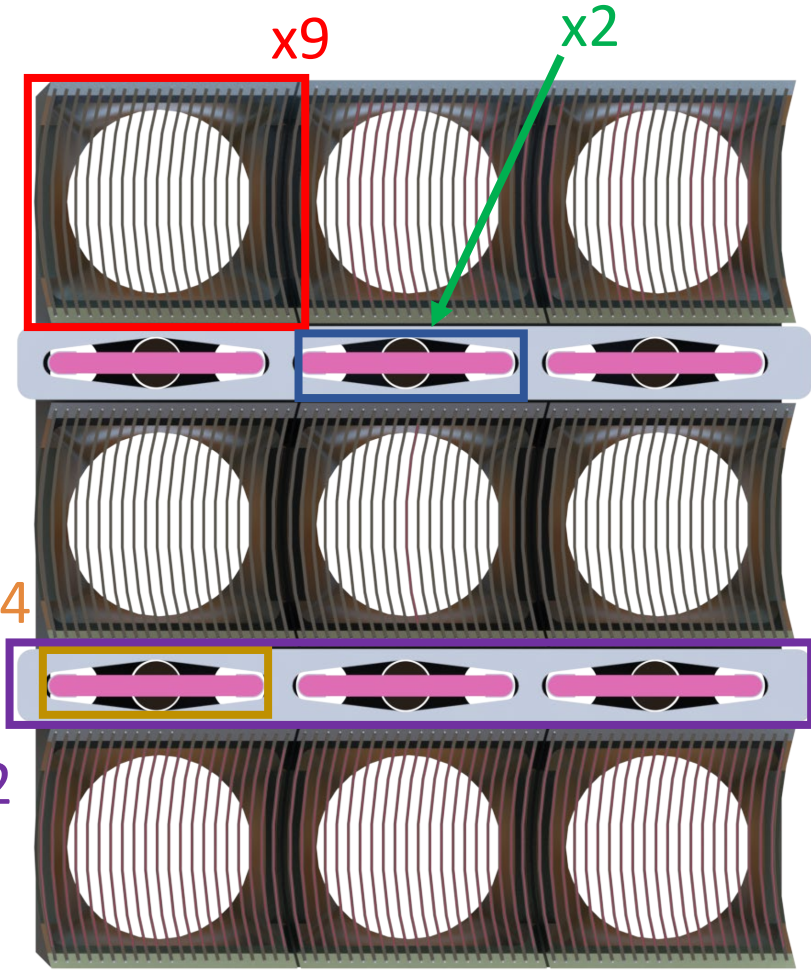
Design of NNS

- 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
- Four control blades and two safety blades placed in the center within two guide boxes
- Core horizontally divided into three rows
- 64 coolant channels at each row
- Optimize fuel cycle length & maintain a negative reactivity feedback



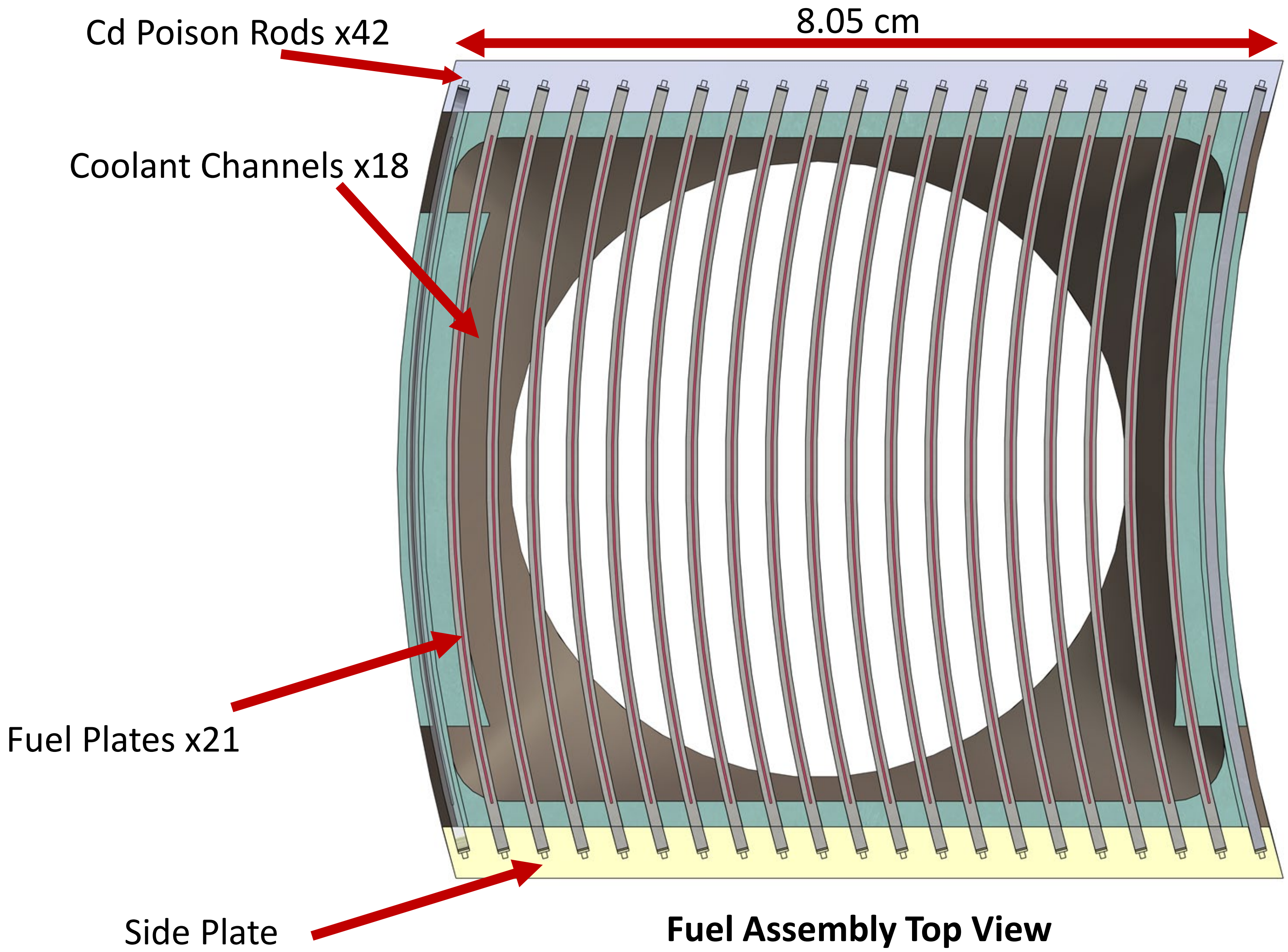


Fuel Assembly



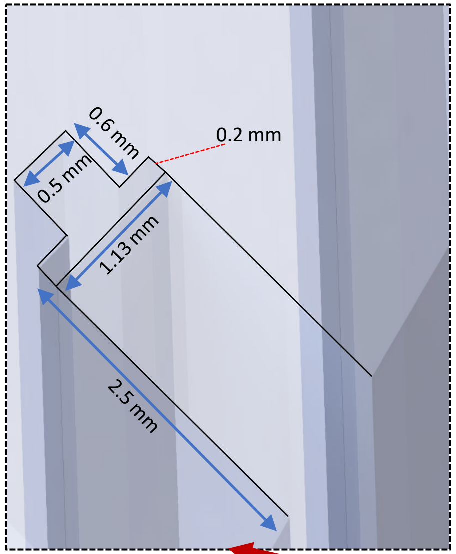
Reactor Core

Design of NNS



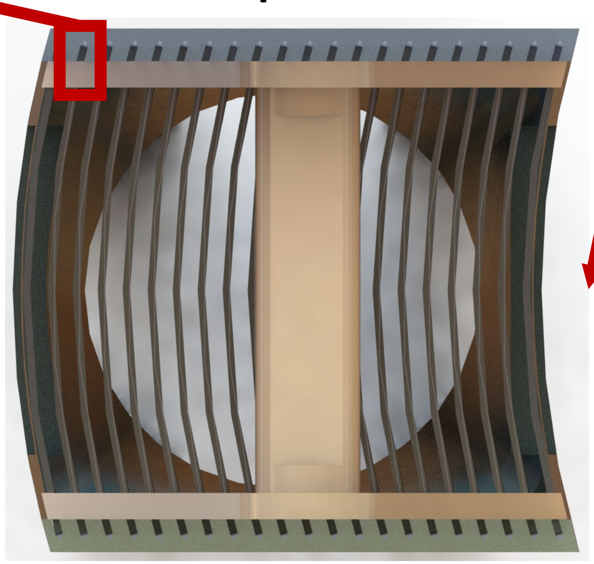
Fuel Assembly Top View

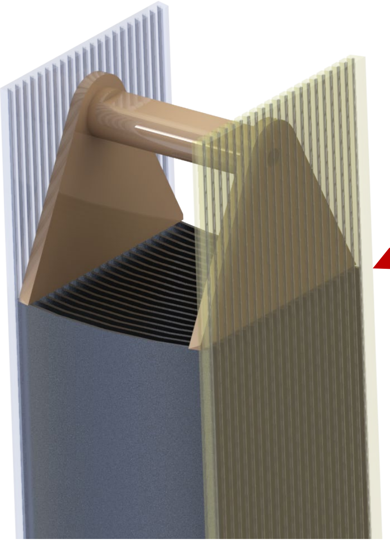
Fuel Assembly Details

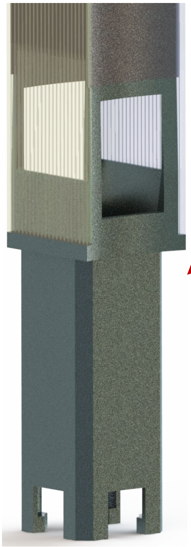


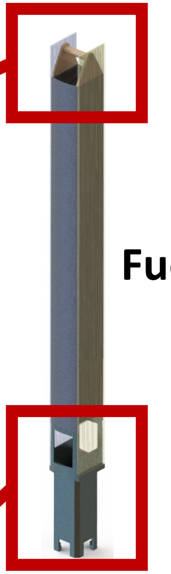
Fuel Plate

Top View









Fuel Assembly

Nuclear Design of NNS

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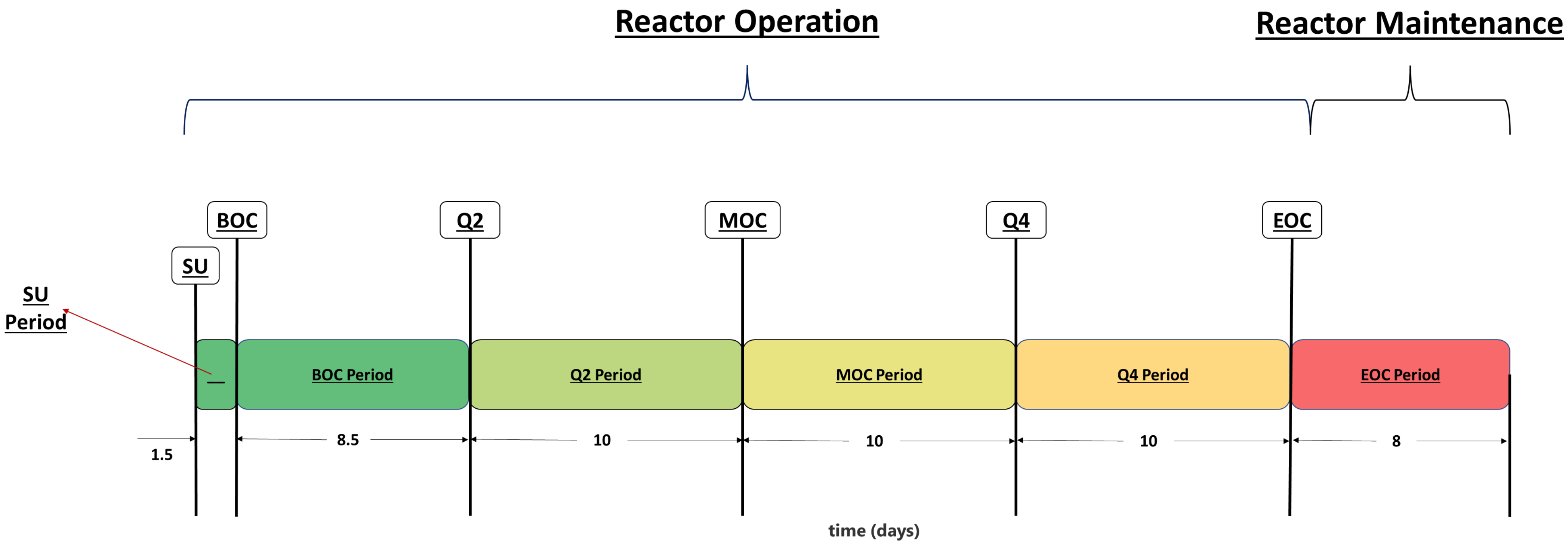
- The number of FAs for any core loading is 9
- The reactor has two independent and diverse shutdown systems.
  - Safety Blades
  - Reflector Dump system
- Designed as a high leakage core with a compact structure
- Neutronics analysis is performed via the Monte Carlo N-particle Code (MCNP) & ENDF/B VIII.0
- The thermal treatment of the materials has not been used
- Burnable poison Cd-rods in fuel assemblies not optimized
- Core size, width/height not fully optimized for maximum cold source brightness
- Cold source size/locations not fully optimized for maximum brightness

Fuel Cycle States Analyzed



SU is the startup cycle state starts with the 0th day of a cycle. In this state, either the initial core loading compositions

BOC cycle state covers the first one-quarter of a 40–day cycle of operation.

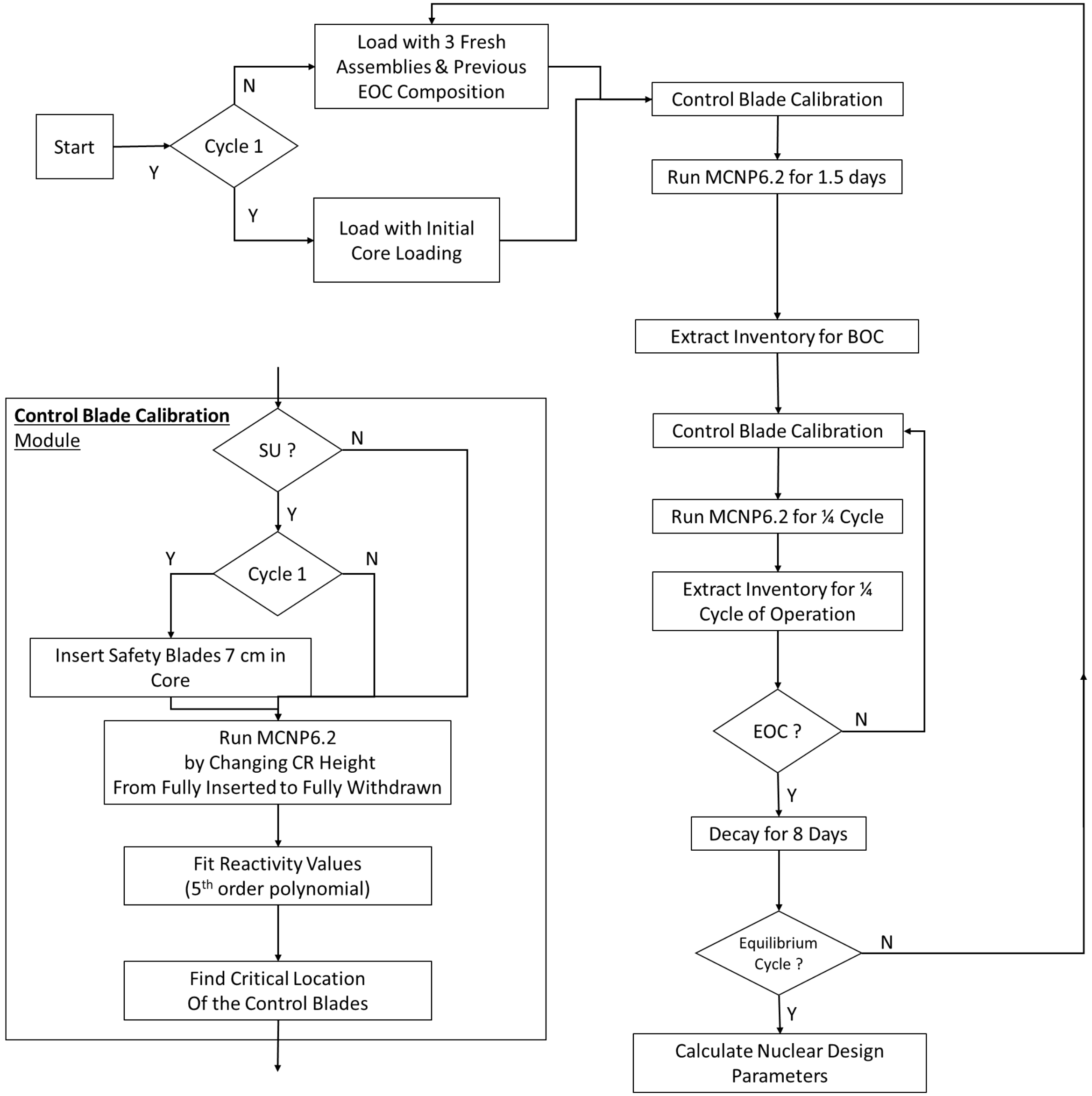
Q2 cycle state is designed to eliminate possible errors that can arise from the constant location of the control blades while moving from the BOC to the MOC cycle state.

MOC cycle state covers the third quarter of a 40-days cycle operation starting from the exact middle of the operating cycle.

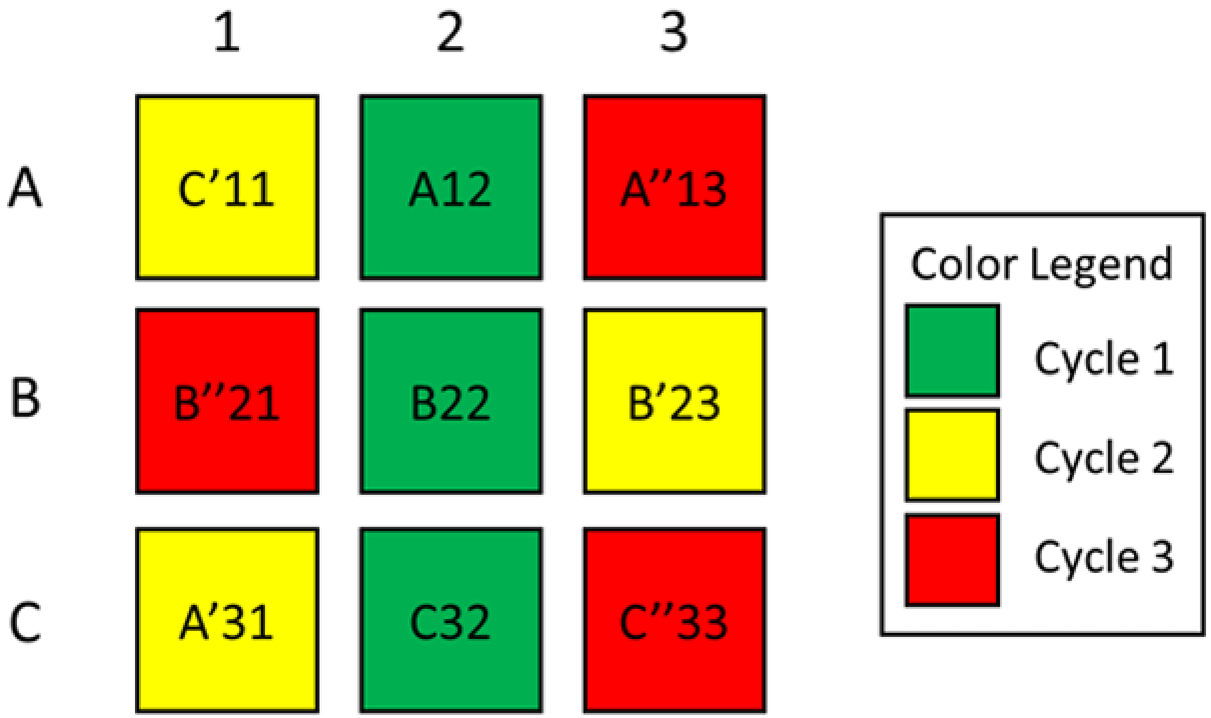
Q4 cycle state covers the last quarter of a 40–day cycle of operation.

EOC cycle state is the final part of a cycle that covers 8 days of decaying of short-lived isotopes in the maintenance period of the reactor prior to the next operational cycle.

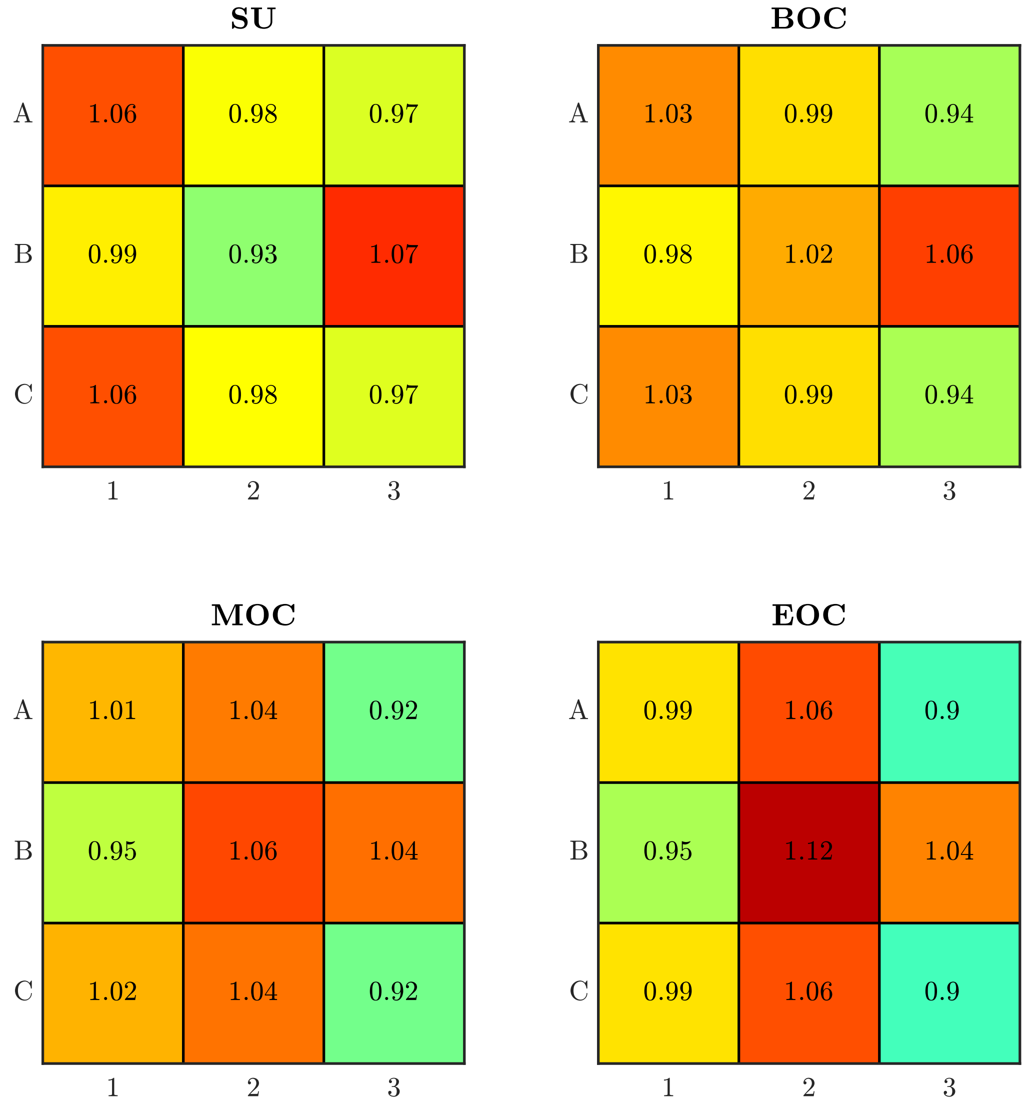
Equilibrium Core



Core Power Analyses

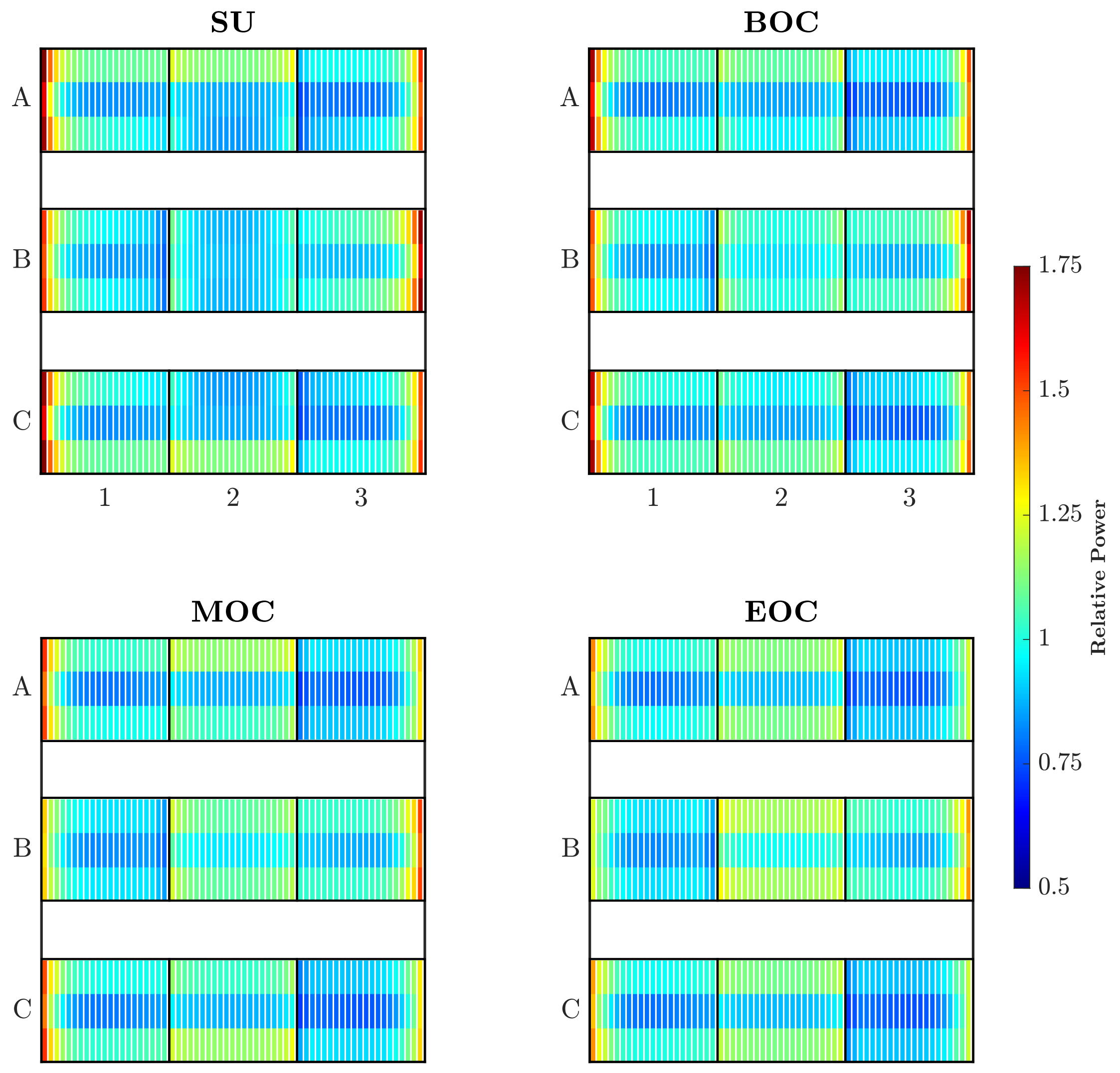


NNS Current Fuel Management Scheme

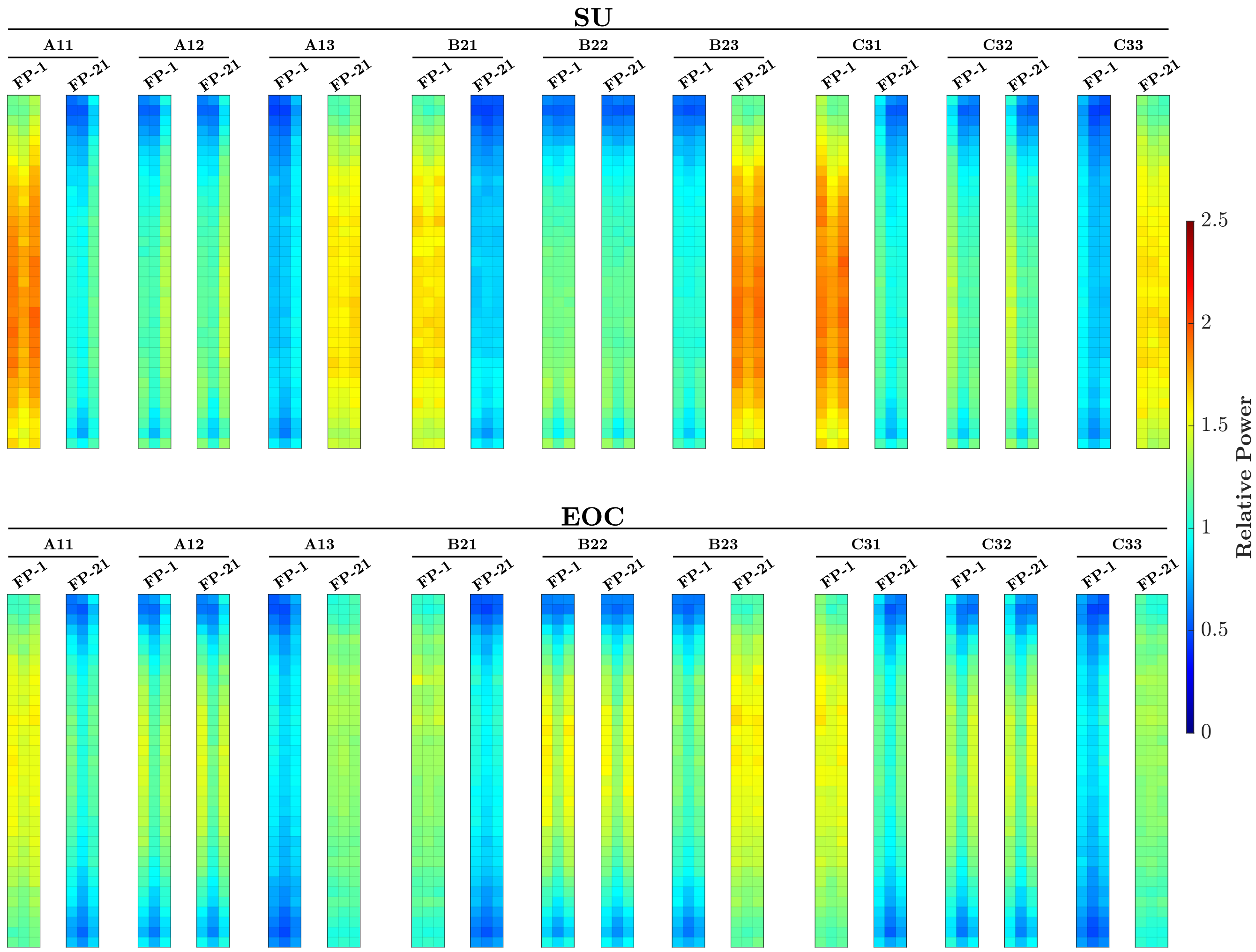


Normalized Power Heatmap of Assemblies in Each Cycle State

Core Power Analyses

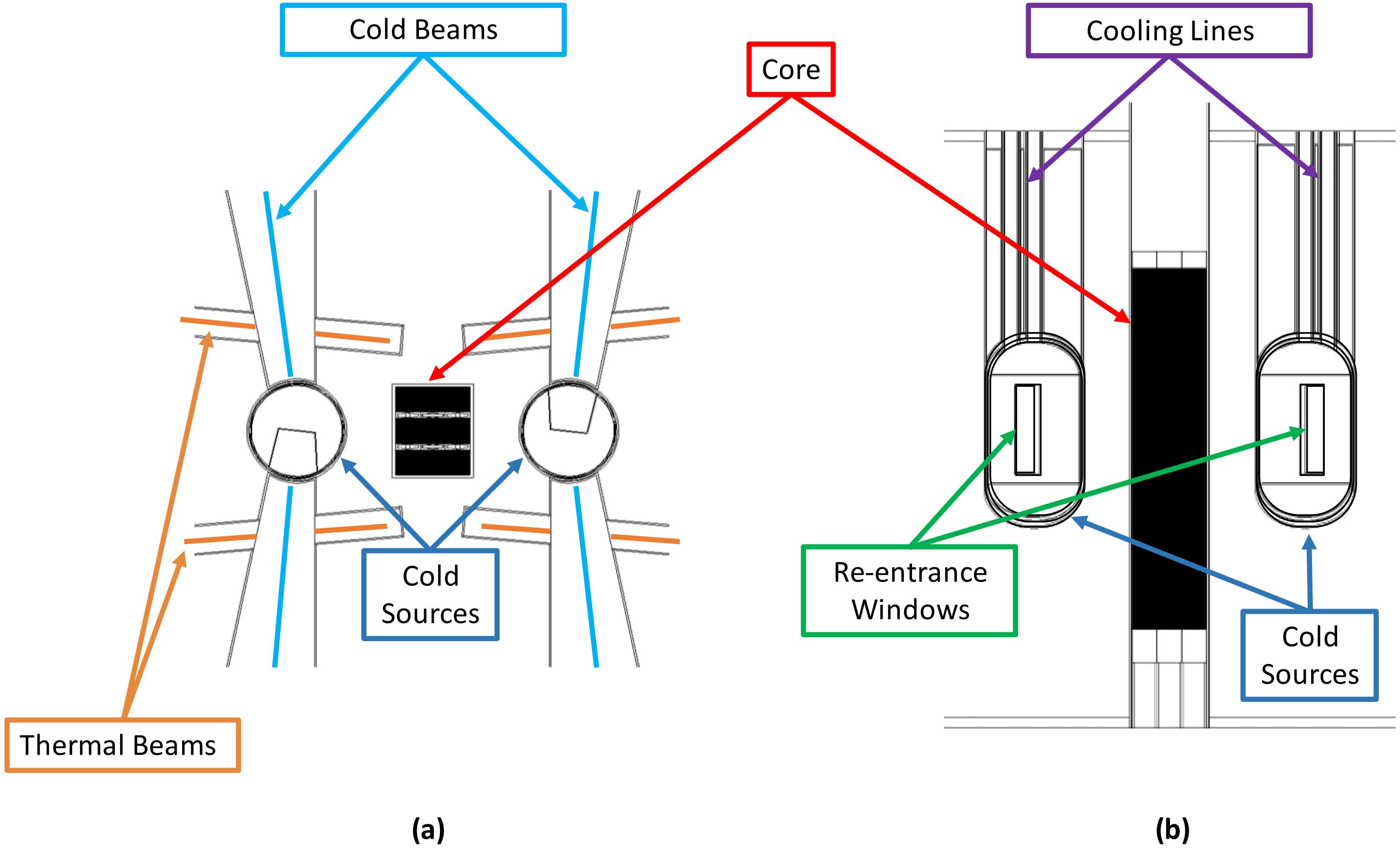


Axial-averaged relative powers of each fuel plate



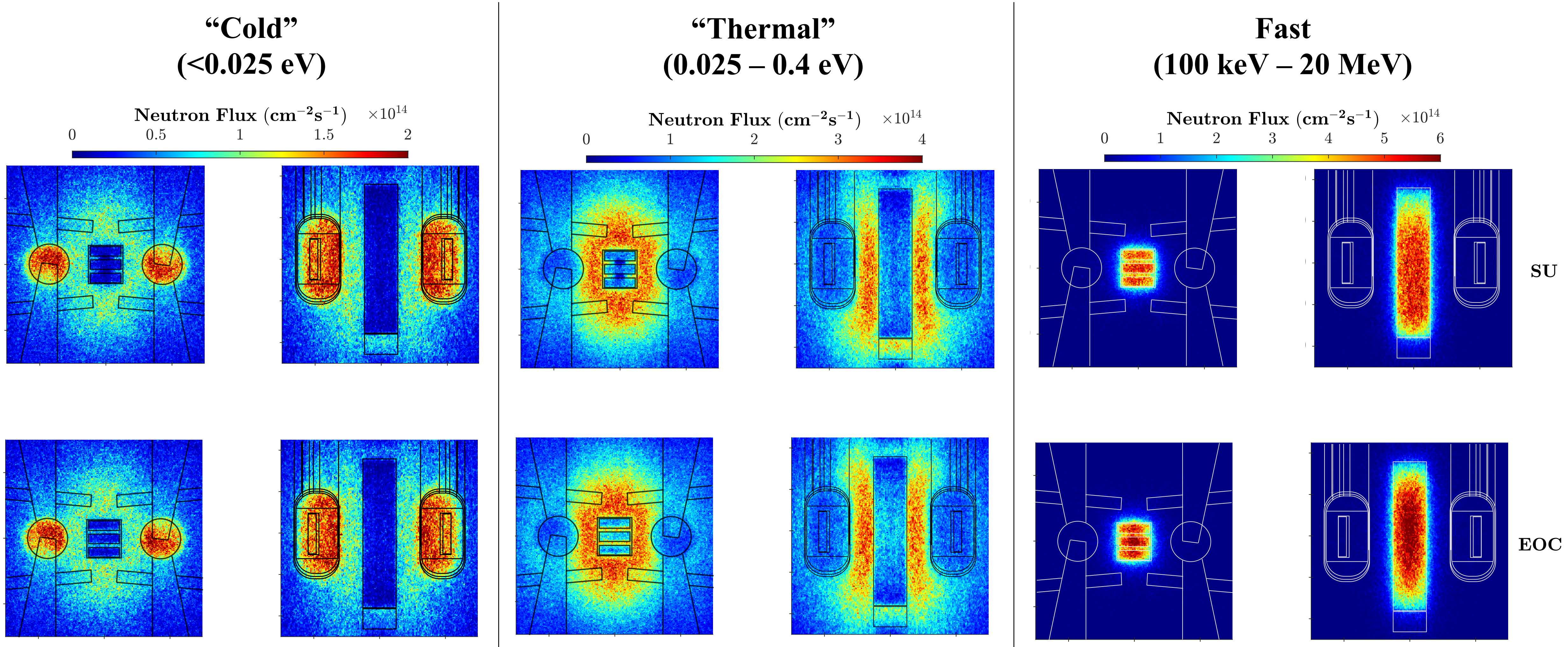
Detailed relative power distributions of the 1st and last fuel plate in each assembly

Core Neutron Density Distributions

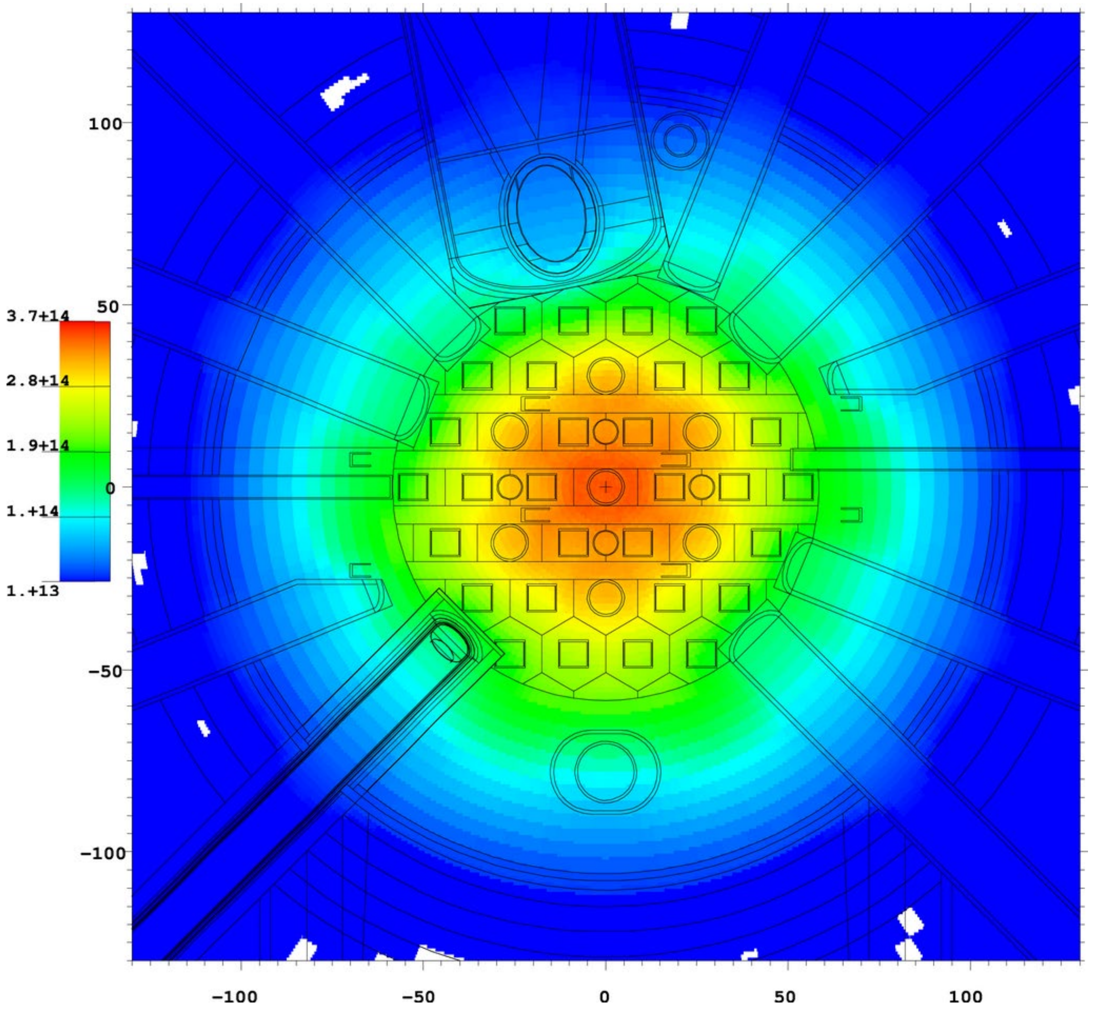


Representation of the core, CNSs, and their peripheral components in (a) the planar view and in (b) the elevation view

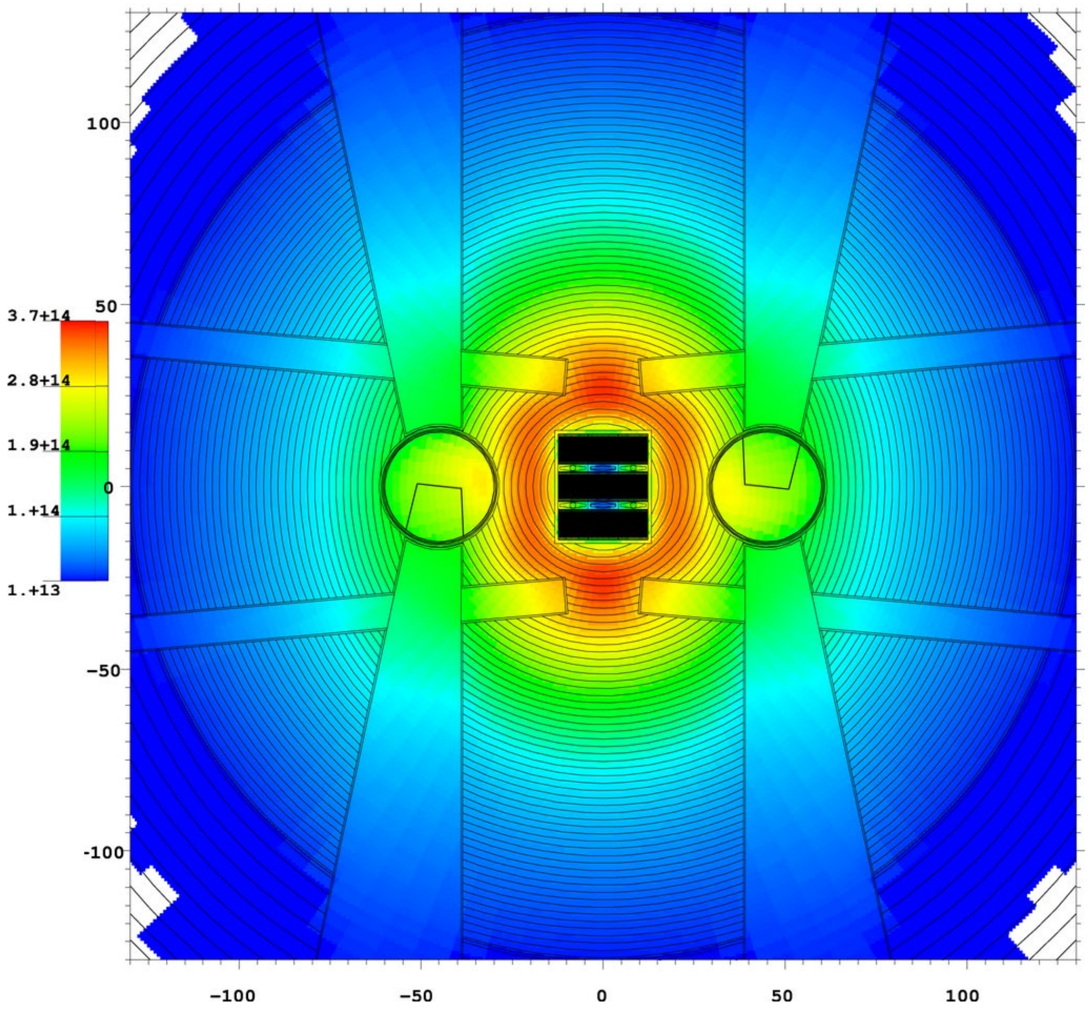
Core Neutron Flux Distributions



Thermal (<0.3eV) neutron flux

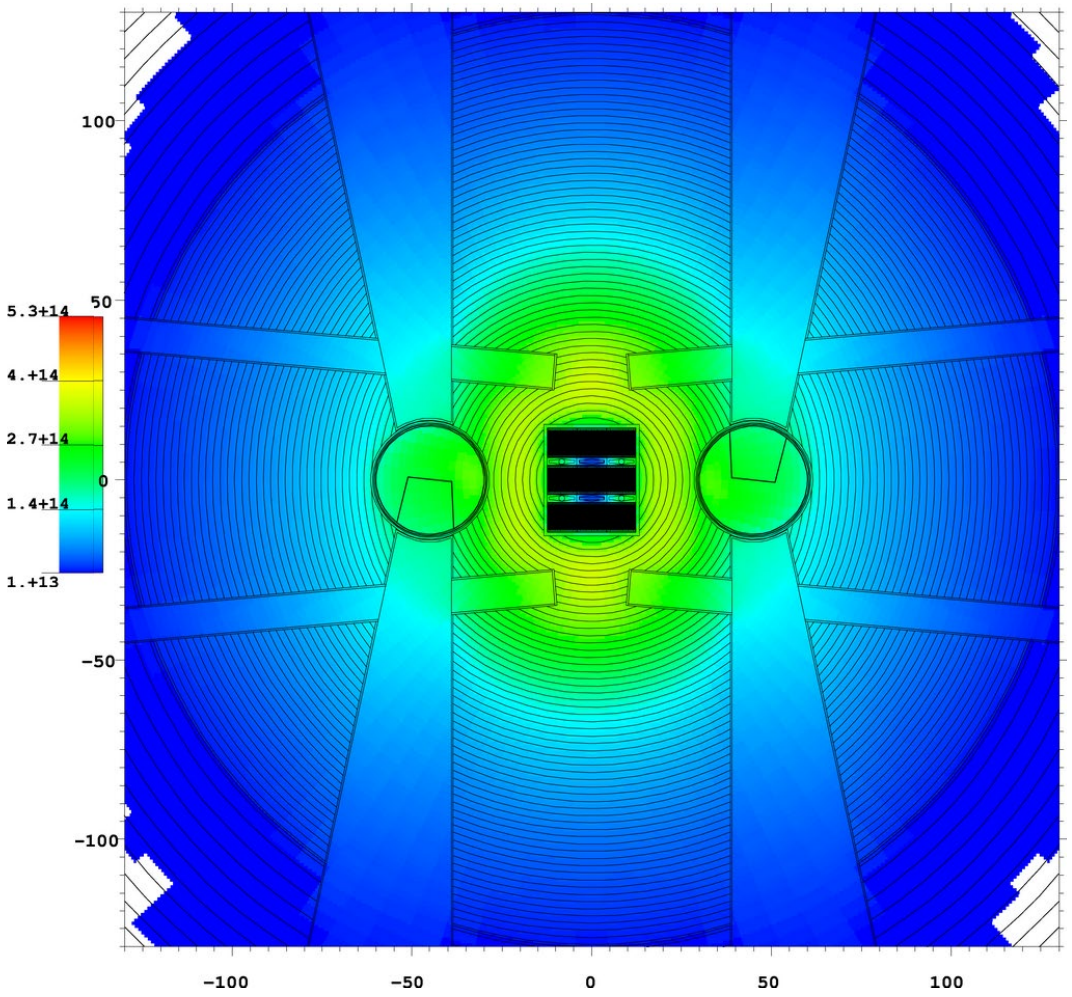


NBSR

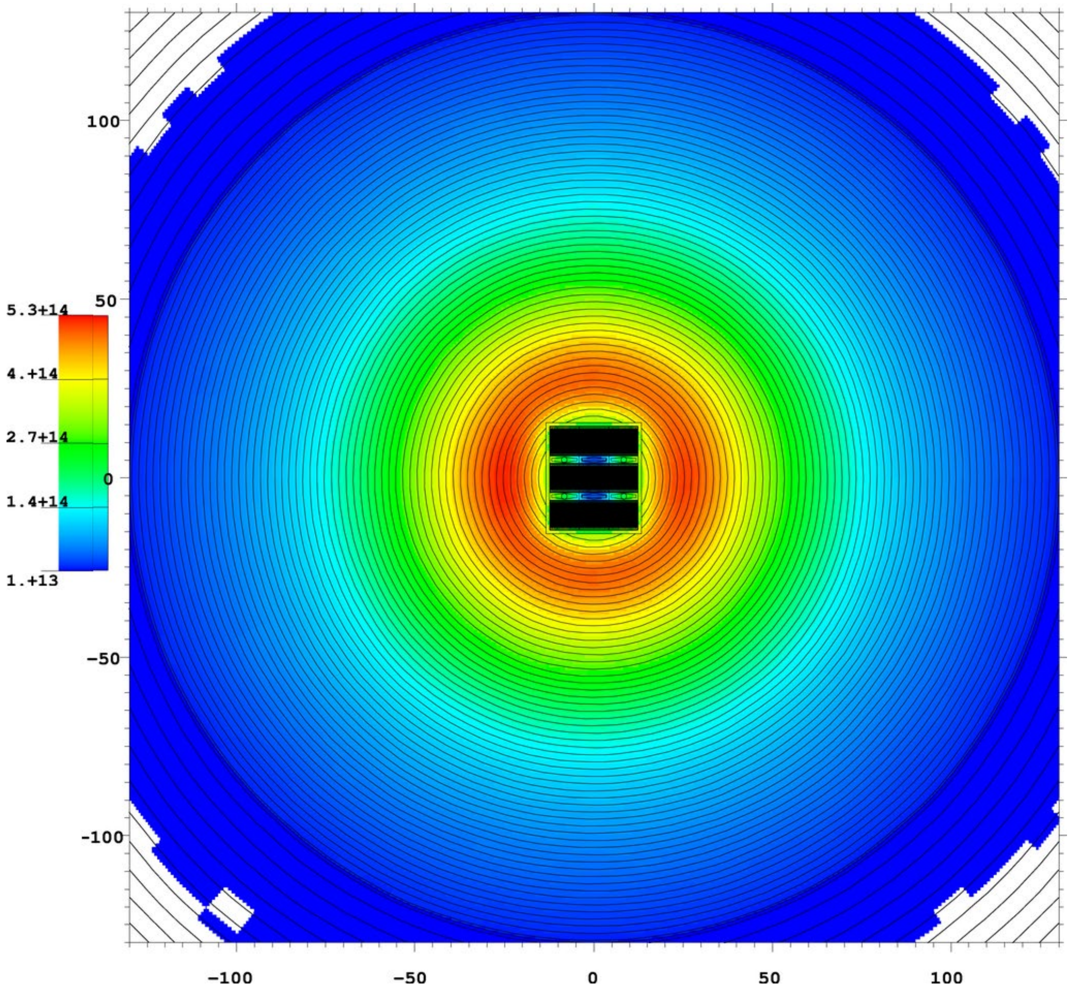


NNS

Perturbed & Unperturbed Neutron Flux



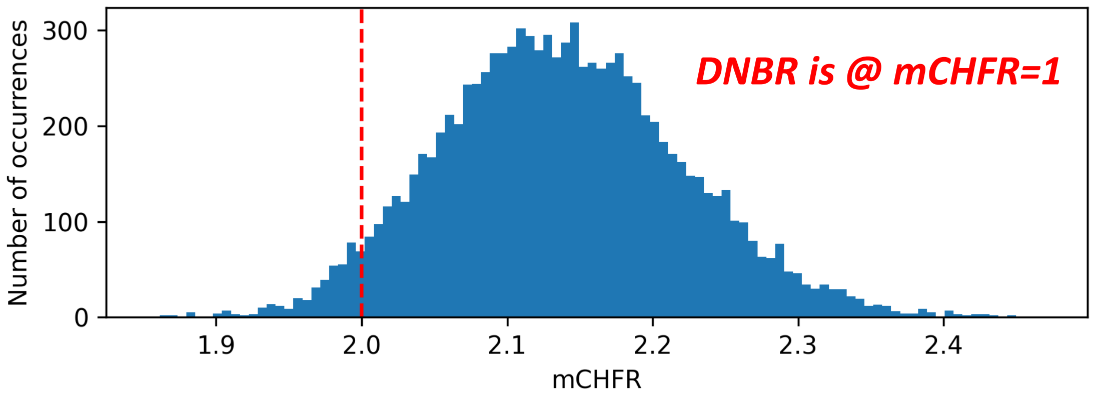
NNS
(Perturbed)

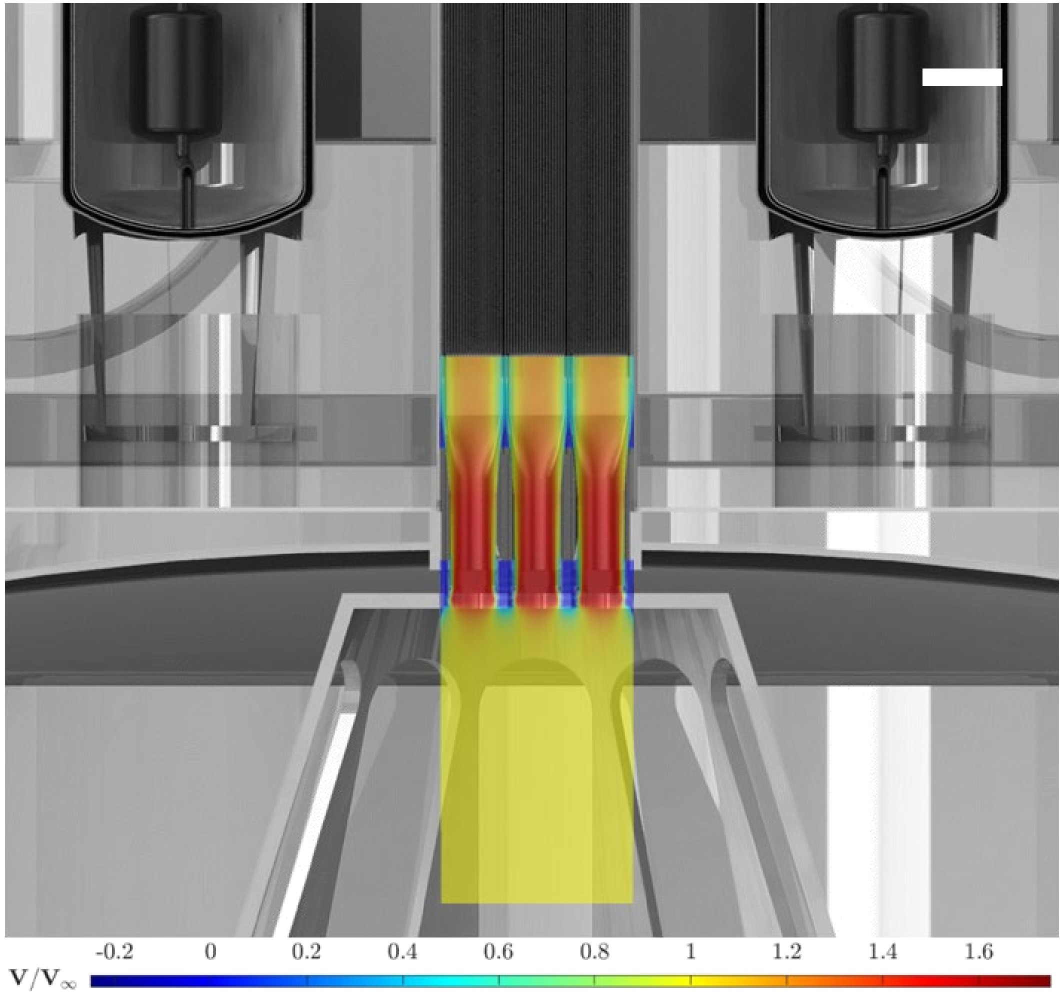


NNS
(Unperturbed)

Core Thermal Hydraulics Safety

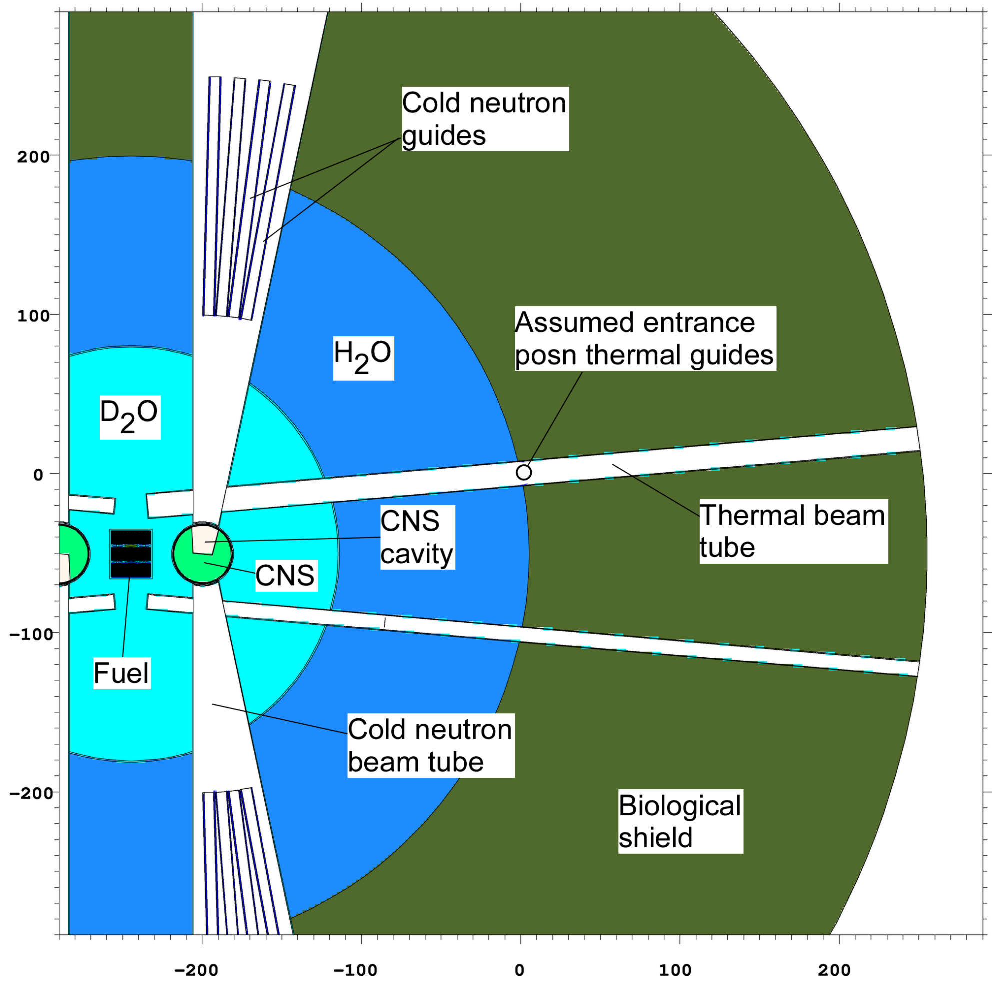
- Analyses show no departure from nucleate boiling (DNBR) at any cycle state.
- Maximum bulk temperature was nearly uniform in all channels and remains below 335 K.
- Maximum cladding temperature remains below 365K.
- CFD work is ongoing to assess the flow behavior at the inlet of the core (do we have undercooled channels?).
- Work is starting to assess the design of the chimney and the outlet of the NNS (how tall should it be? how should the outlet connection look?).





CFD Model of Normalized Streamwise Velocity Profile of NNS Inlet

Proposed Cold Neutron Instruments

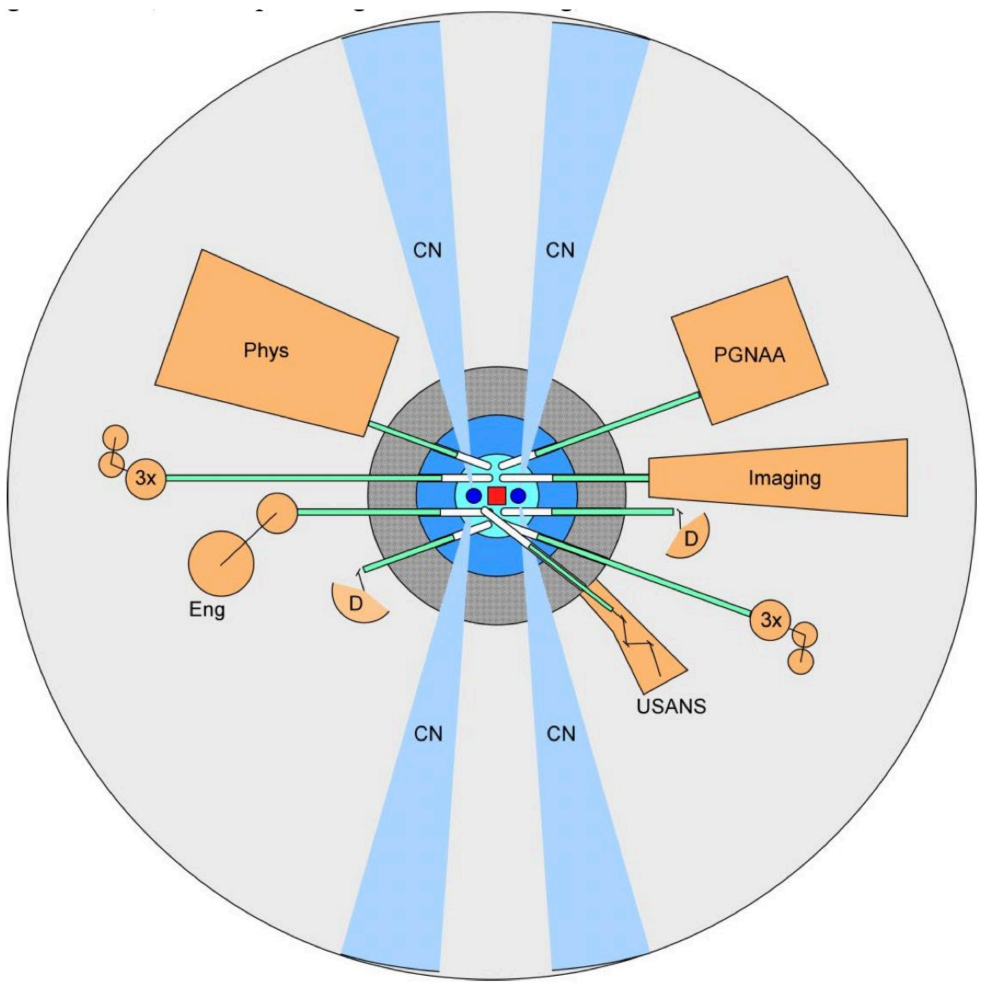


Plan view through the fuel center of the reactor core

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



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

Cold Source/ config	J_{tot} (all l) (s^{-1})	J_{tot} (l ≥ 4Å) (s^{-1})
NBSR LH_2 Unit 2 (all cold guides)	3.0×10^{13}	6.3×10^{12}
NNS (6 cm × 15 cm)	2.3×10^{14}	5.8×10^{13}
Gain NNS/NBSR Unit2	7.5	9.2

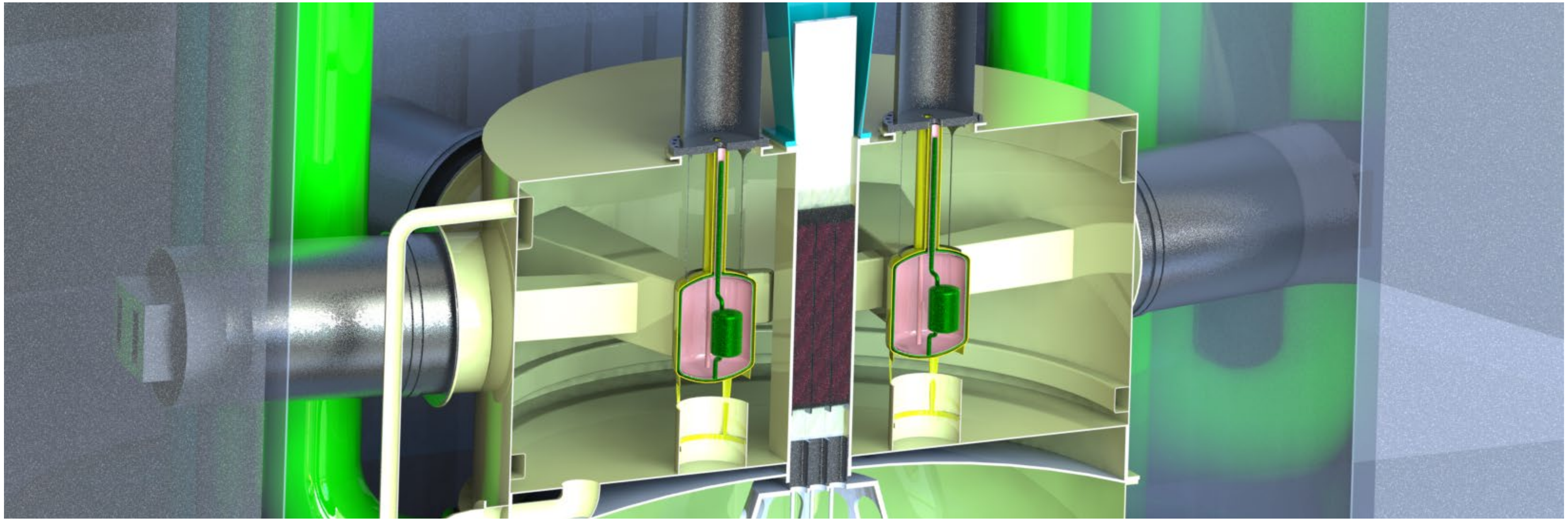
Cold Source/ config	J_{tot} (all l) (s^{-1})	J_{tot} (l ≥ 4Å) (s^{-1})
NBSR LH_2 Unit 2 (all cold guides)	3.0×10^{13}	6.3×10^{12}
NNS (6 cm × 20 cm)	2.8×10^{14}	7.0×10^{13}
Gain NNS/NBSR Unit2	9.1	11.1

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 at guide entrances **~10 wrt NBSR LH_2 CNS**
- 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

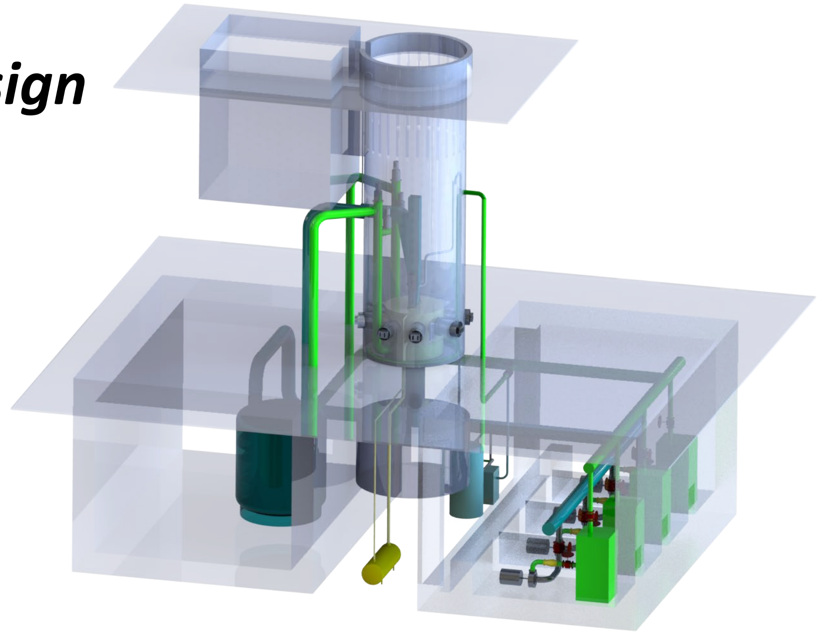
Conclusions & Future Work

- NRC pre-engagement for licensing requirements
- Evaluate potential (qualified or in the process) fuel, U-10Mo, U3Si2, UZrH etc.
- Engagement with National Laboratories for non-proliferation, safety, realistic concept design, optimization, manufacturability and maintenance etc.
- Collaborate with Universities and Scientific Community to identify needs, resolve complex design issues etc.



Communication and Publications

- NIST Technical Note Series “Pre-conceptual Design Activities of the NIST Neutron Source”
  - Neutronics Safety Assessments
  - Layout of Cold & Thermal Neutron Instruments
  - Assessments of the Cold and Thermal Neutron Beams
  - Thermal-hydraulics Safety Assessments
  - ***NIST Neutron Source Pre-Conceptual Design***



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Questions?

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