The NIST Research Reactor (NBSR) and the Cold Neutron Sources *and a few other things we do at ROE*

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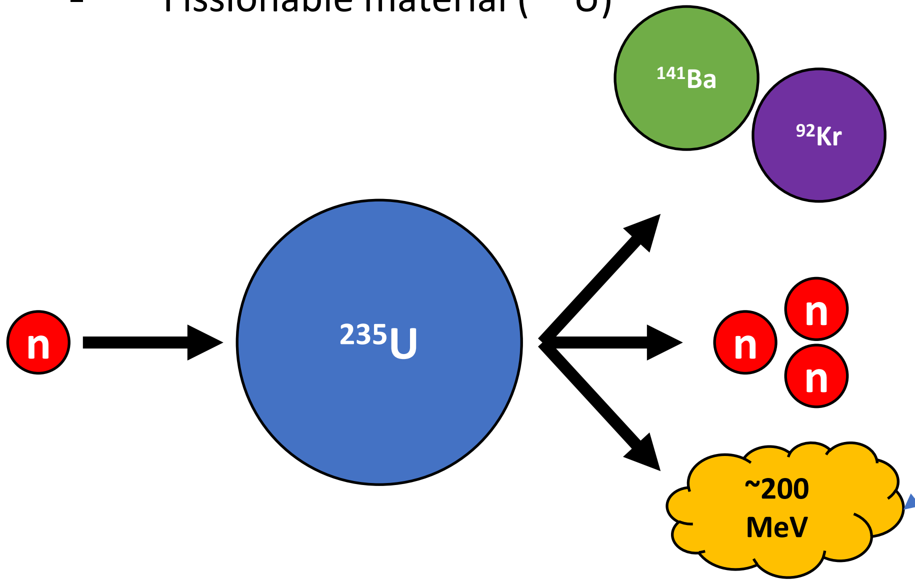
100 Bureau Dr., 20899 Gaithersburg, MD, USA

Outline

- Nuclear fission basics (What is a nuclear reactor?)
- NBSR Description & History
- Cold Sources
- Current Developments
- Q/A

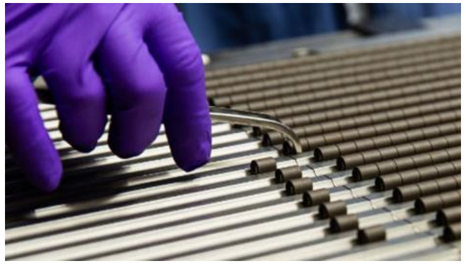
Nuclear Fission & Fuel

- Breaking an atom apart
  - Releases a lot of thermal energy
  - Also releases fission products (other isotopes)
  - Usually done with a fuel
    - Fissile material (^{235}U)
    - Fissionable material (^{238}U)



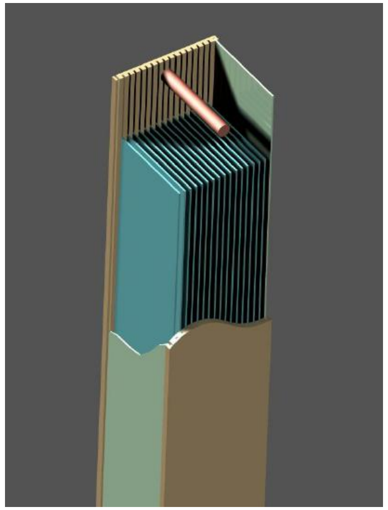
We can boil water with this!

Pellets



Pebbles

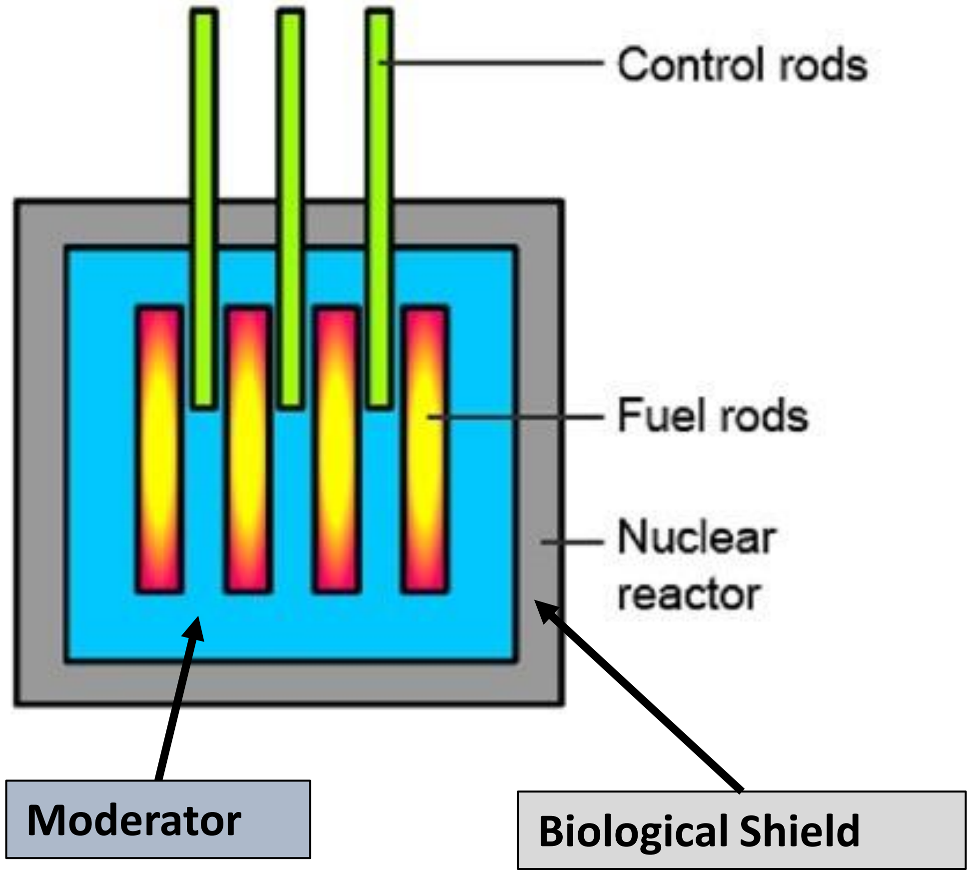
Plates



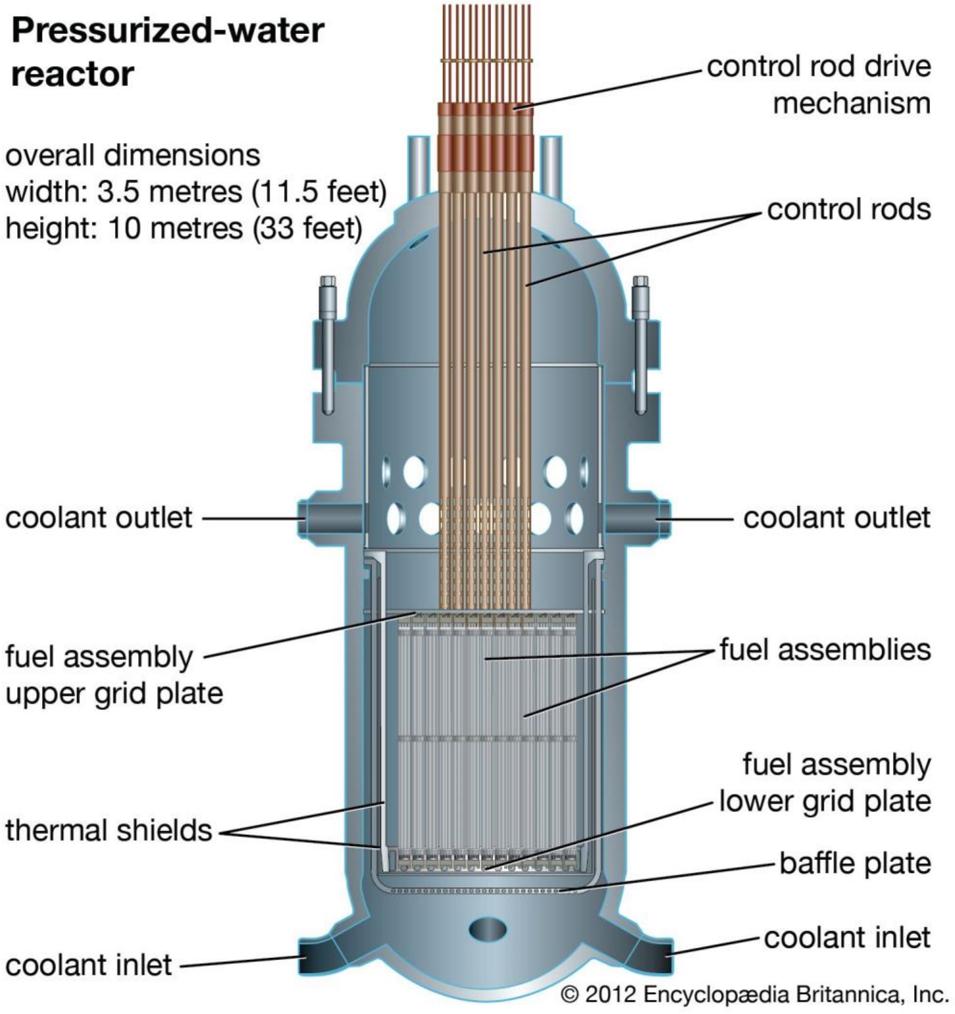
Molten Salt

Nuclear Reactors

- Contain fuel, coolant, and (if thermal spectrum) moderator
- Also must contain a form of control on the neutron population
  - Control/shim rods/arms
  - Made of strong neutron absorbers (Cd, B, Hf)
- Radiation shielding, detectors, and a neutron source (to initialize the chain rxn) are also needed



Types of Nuclear Reactors Water systems



https://www.britannica.com/technology/nuclear-reactor/Types-of-reactors

Types of Nuclear Reactors Pebble bed systems

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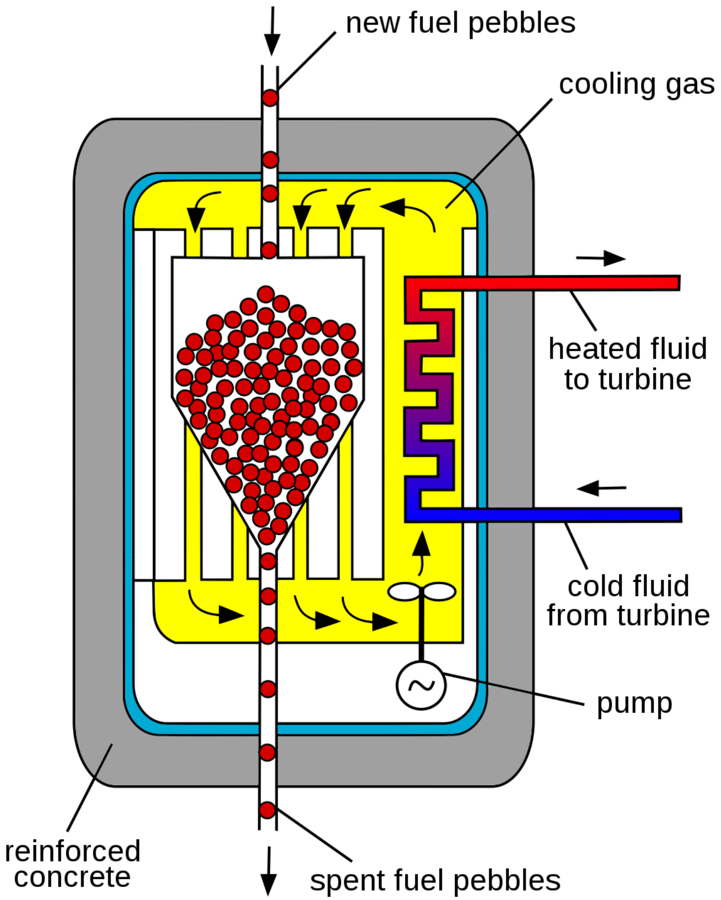
Pebble bed reactor scheme



https://upload.wikimedia.org/wikipedia/commons/thumb/0/0f/Pebble_bed_reactor_scheme_%28English%29.svg/1200px-Pebble_bed_reactor_scheme_%28English%29.svg.png

Types of Nuclear Reactors Molten salt systems

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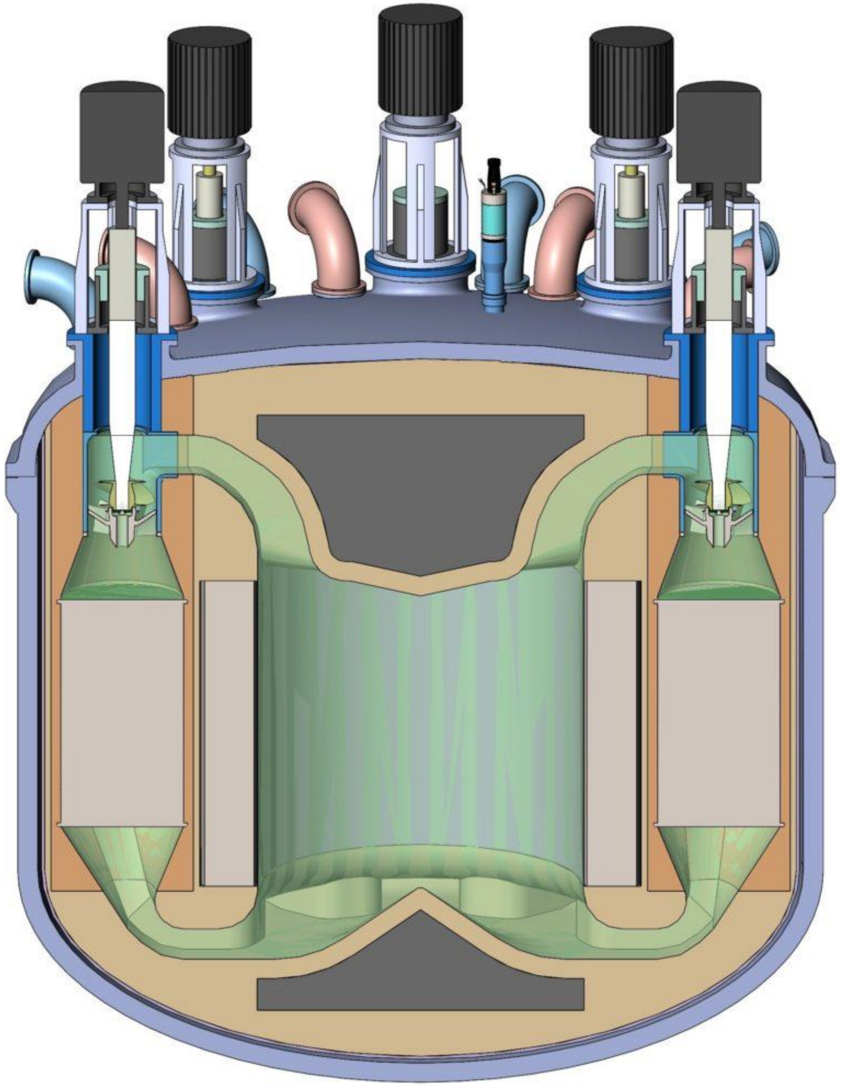
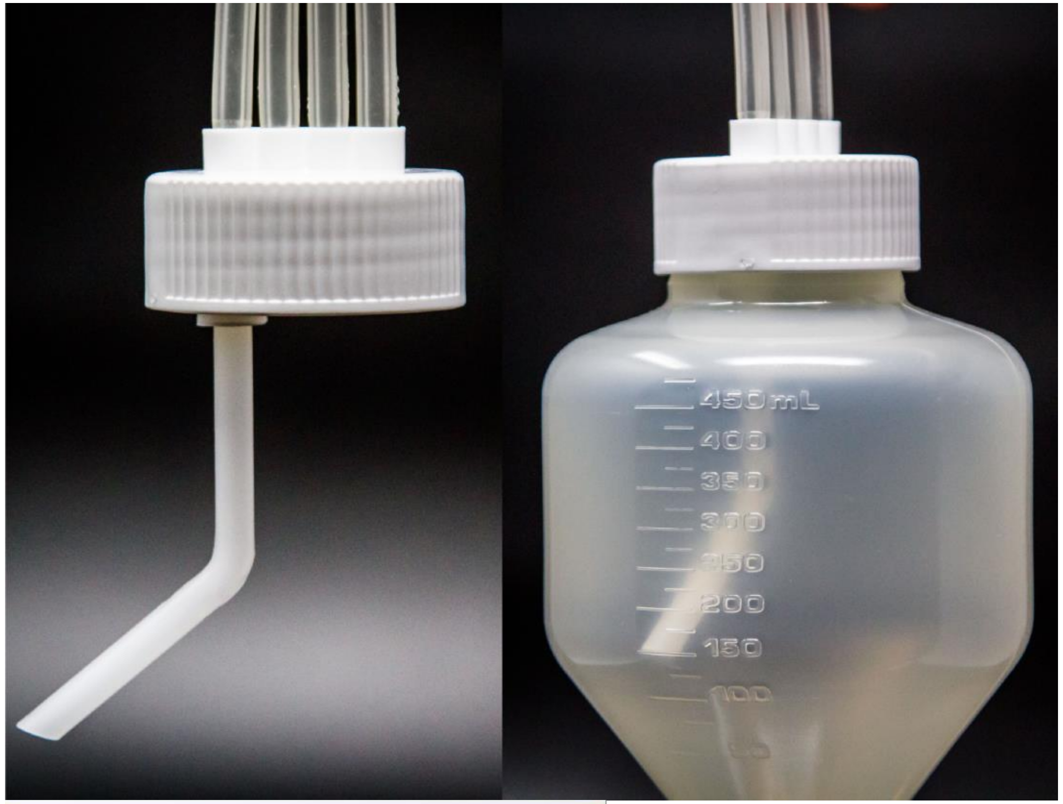


https://www.terrapower.com/wp-content/uploads/2020/12/MCFR_image-edited-1024x1024.jpg

https://issuu.com/sanisure/docs/cap2v8_catalog_2020?fr=sNzgyNDc2NzYzMw



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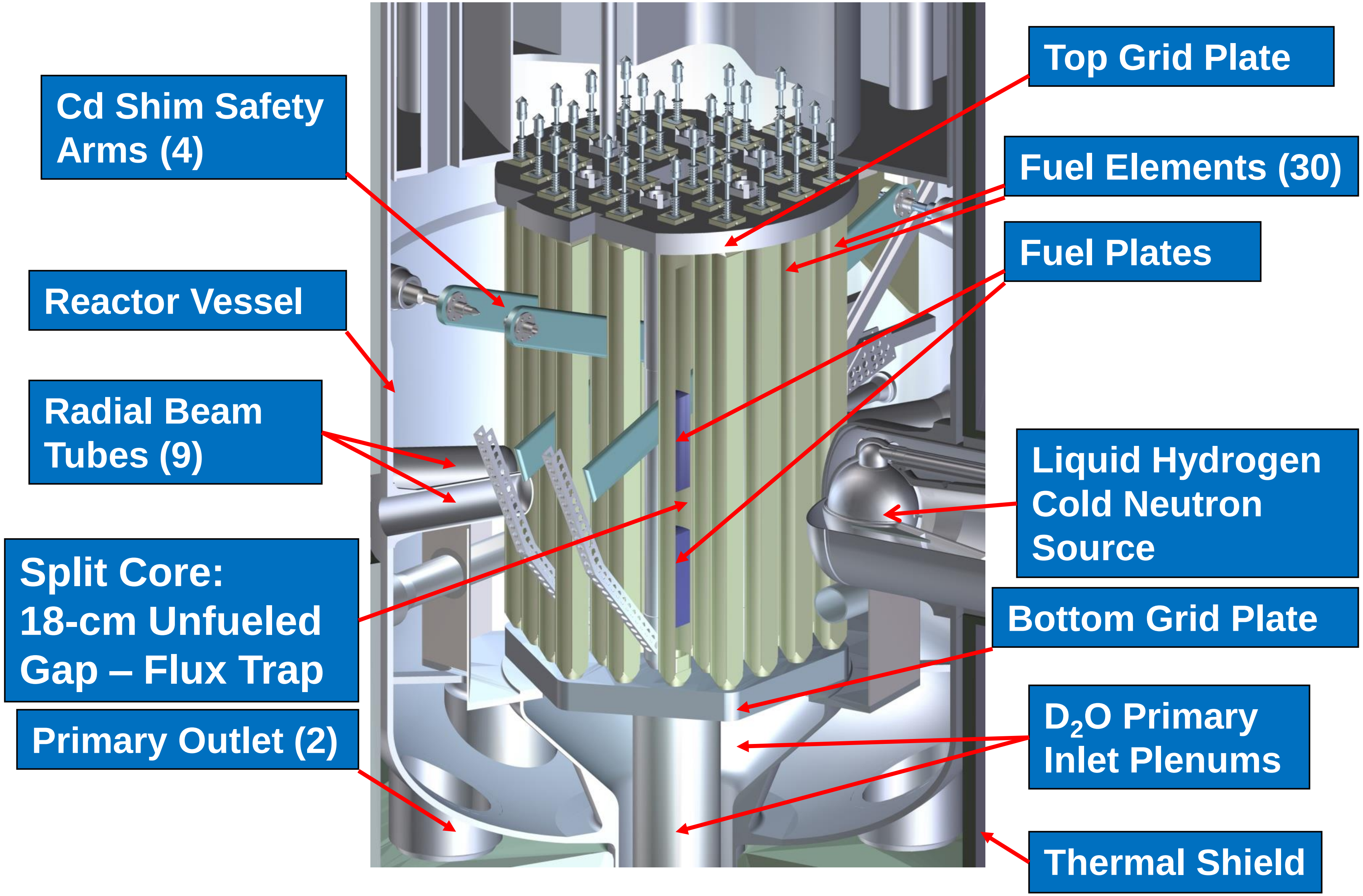
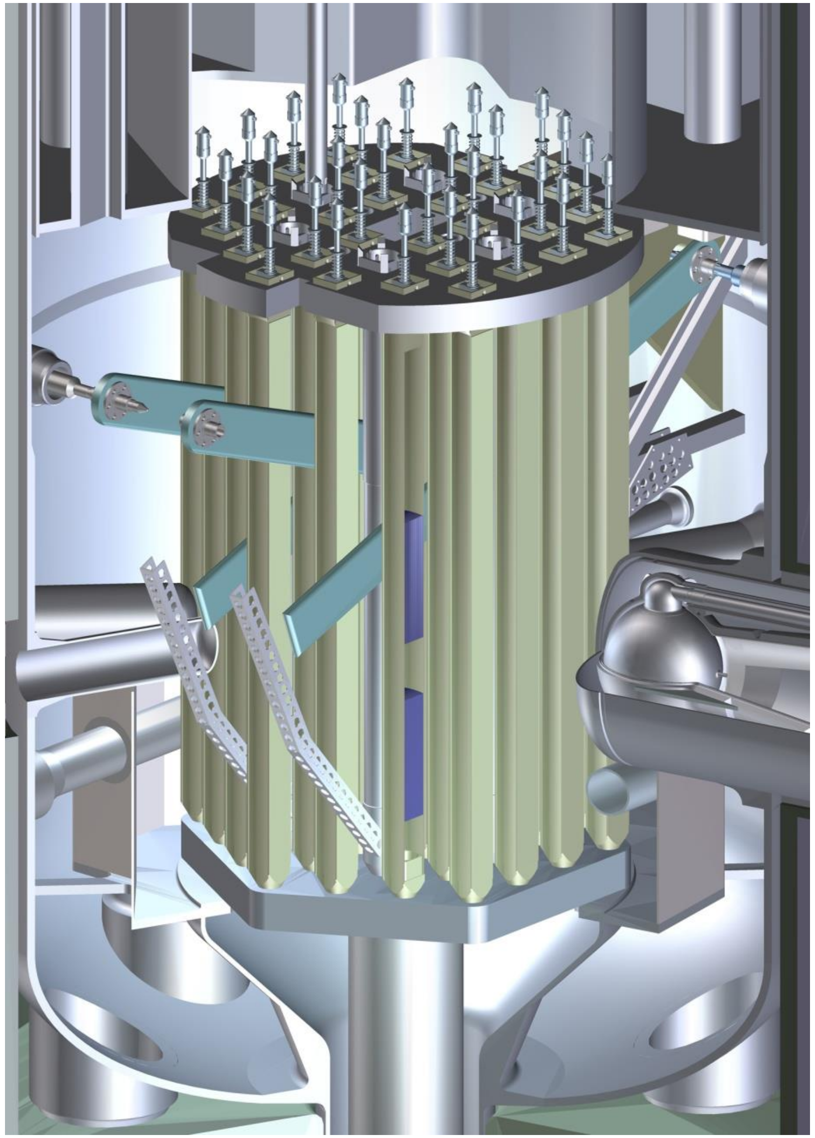
The NBSR Overview



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
  - 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
- Originally it was a 10 MW reactor
- Converted to 20 MW in 1985
- Cold Neutron Facility
  - D_2O cold neutron source (CNS) installed in 1987
  - LH_2 CNS installed in 1995
  - An advanced LH_2 CNS installed in 2002
  - Peewee (smaller CNS) installed in 2012 in BT-9
  - An upcoming cold source upgrade is planned for 2023

The NBSR Instruments Layout

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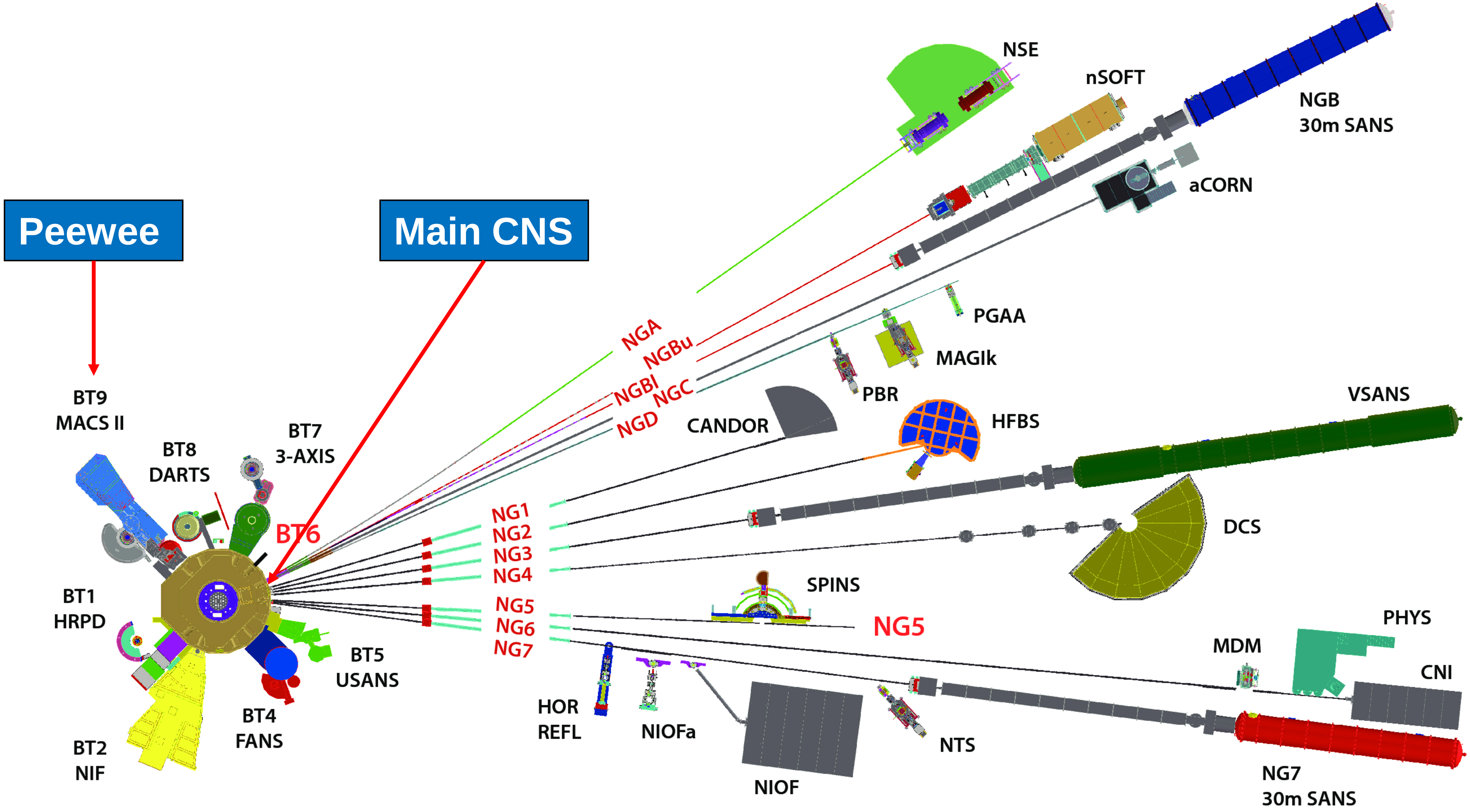
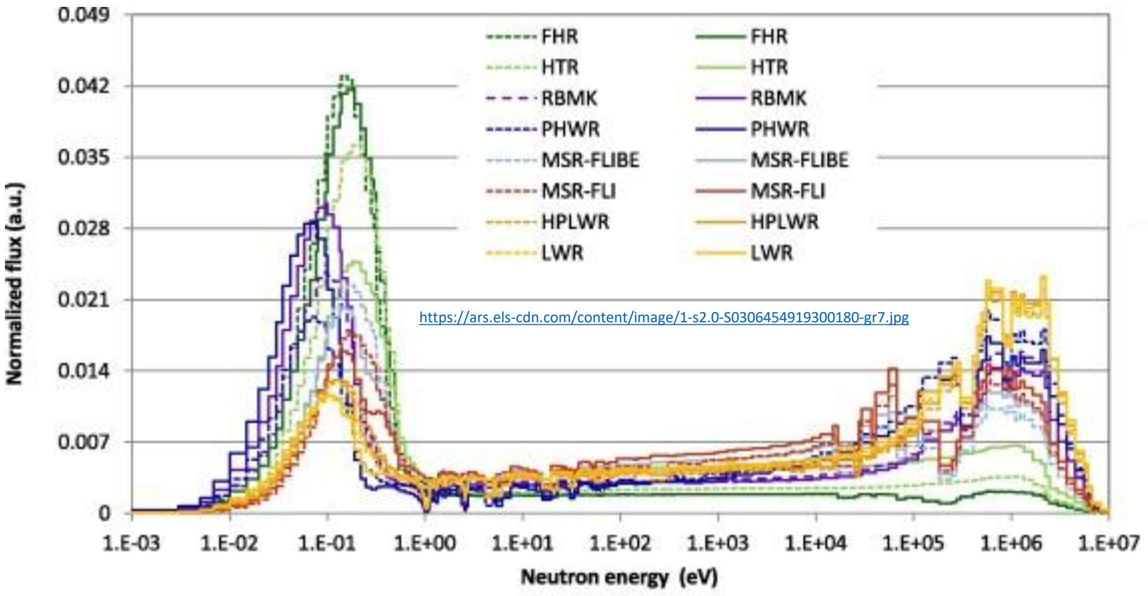
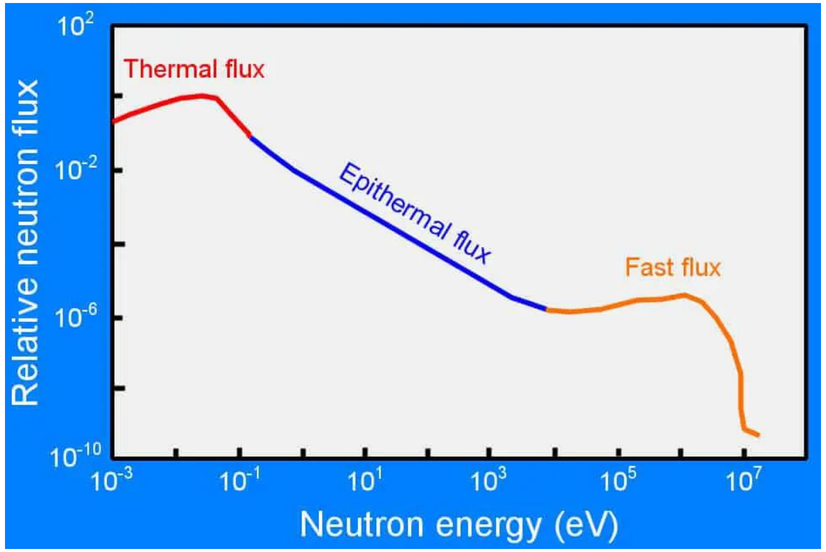
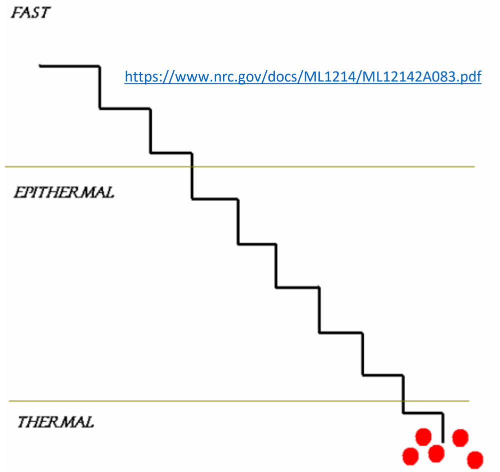


Neutron Thermalization

- Fission neutrons are ~2 MeV (fast)
- Thermalized (20 – 400 meV) via scattering off of the D_2O moderator in the core
  - D_2O is ~320 K (115 °F), which is what dictates the thermal energy of the neutrons
  - Can be calculated with particle kinematics (classical mechanics formulae)
- To reach lower energies, you introduce a cryogenic facility, the cold neutron source (CNS)
  - Currently liquid hydrogen (LH_2) at 20 K.







Neutron Flux in the NBSR Flux Trap (10 MW)

Obtained from NBSR-9 SAR

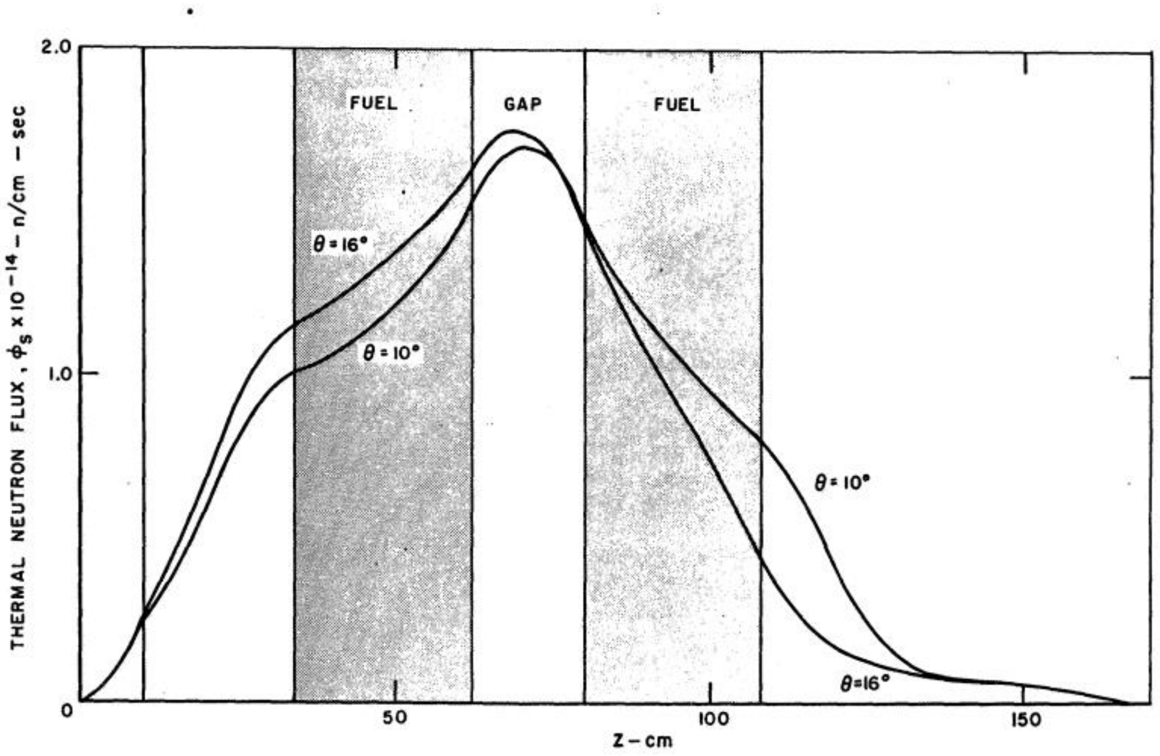


Figure 4.13 Vertical distribution of thermal neutron flux along core centerline for two shim arm positions (θ = 10° and θ = 16°).

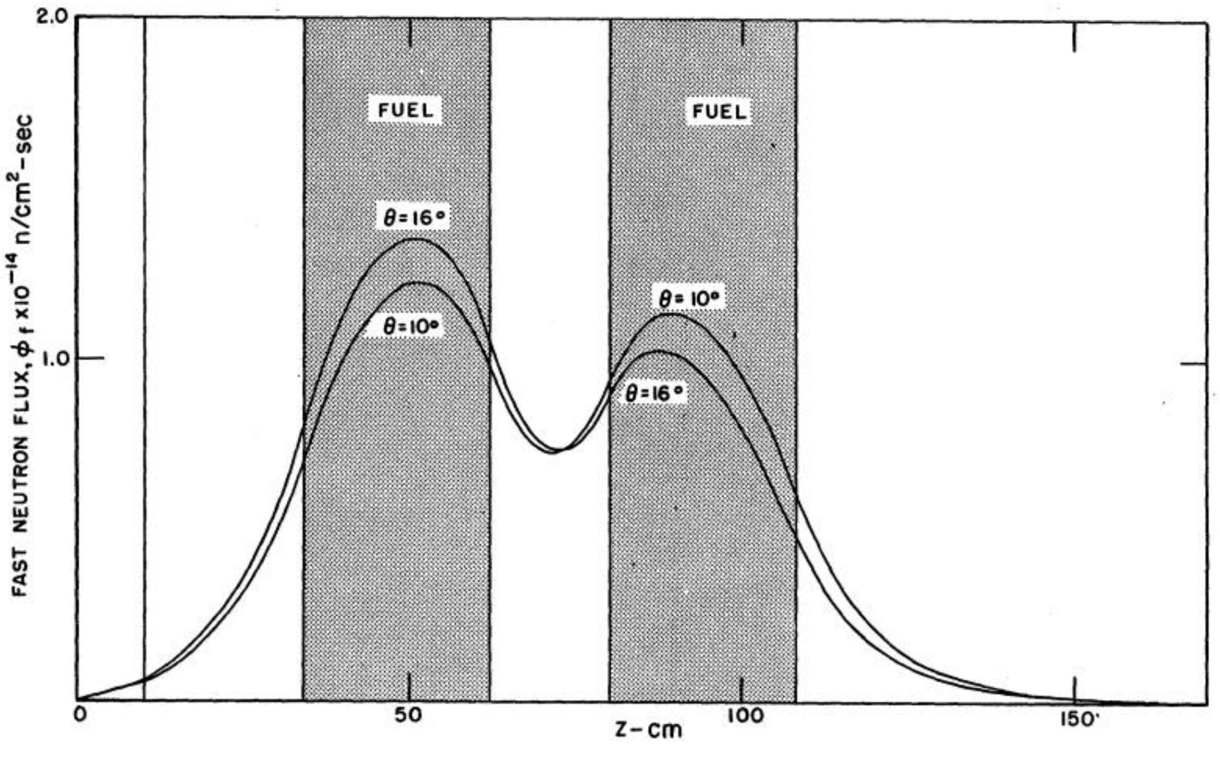


Figure 4.14 Vertical distribution of fast neutron flux along core centerline for two shim arm positions (θ = 10° and θ = 16°).

How do we produce cold neutrons?

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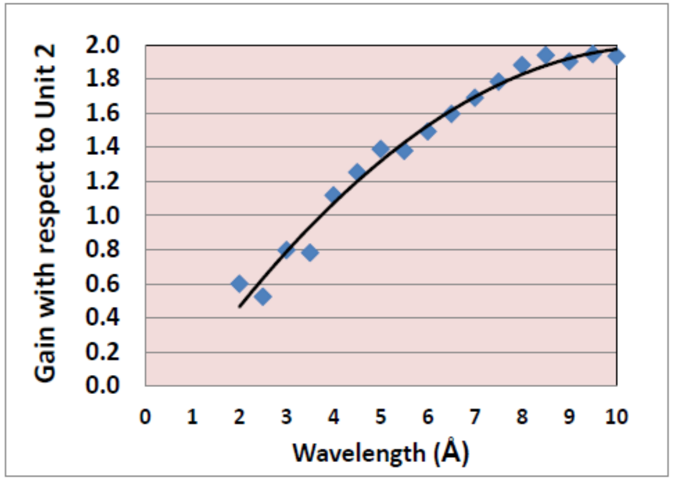
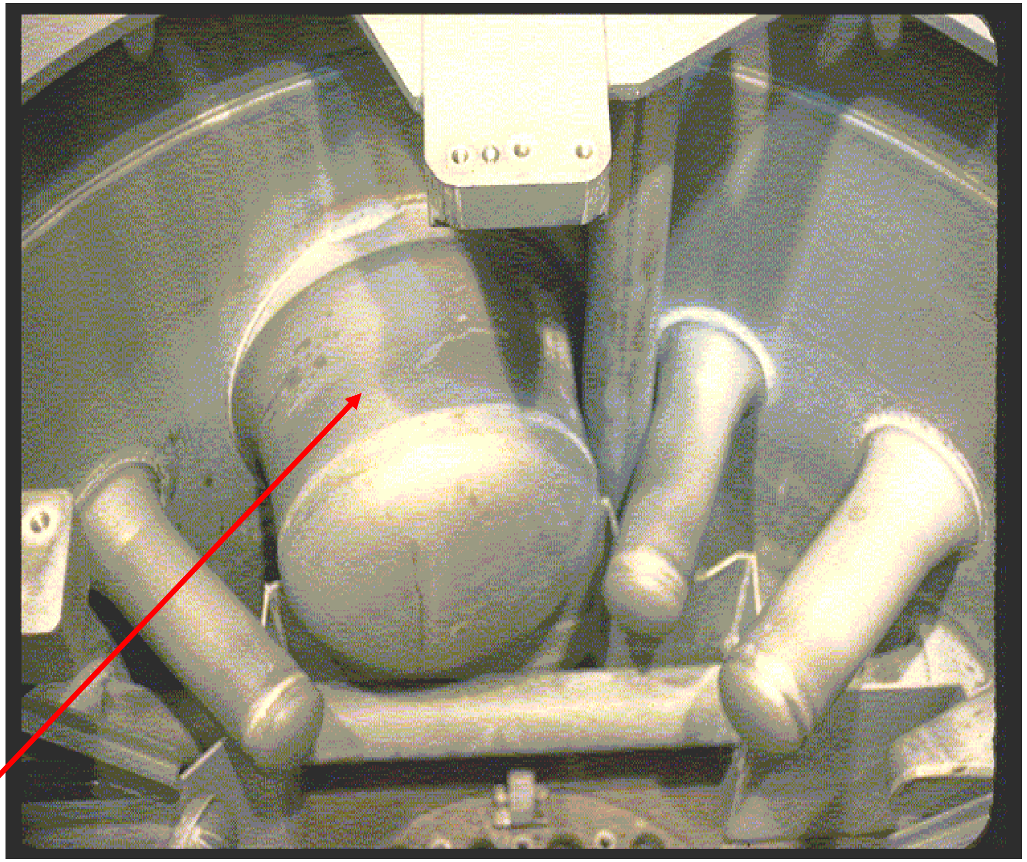
- Fission neutrons are ~2 MeV (fast)
- Thermalized (20 – 400 meV) via scattering off of the D_2O moderator in the core
  - D_2O is ~320 K (115 °F), which is what dictates the thermal energy of the neutrons
- To reach lower energies, you introduce a cryogenic facility, the cold neutron source (CNS)
  - Currently liquid hydrogen (LH_2) at 20 K.

Installation of LH_2 CNS (Nov. 2001)

The Cold Source Through the years

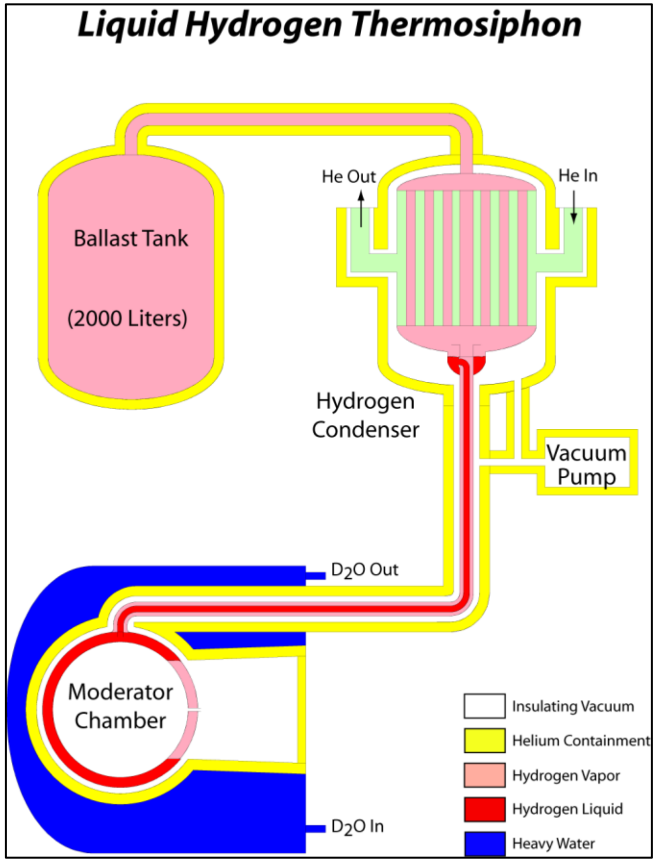
1. D_2O tank (1967)
2. D_2O Ice (1987)
    - Gain of 3-5x in brightness
3. Unit 1 LH_2 (1995)
    - Gain of ~6x
4. Unit 2 LH_2 (2002)
    - Gain of ~2x
5. LD_2 (Planned for 2023)
    - 

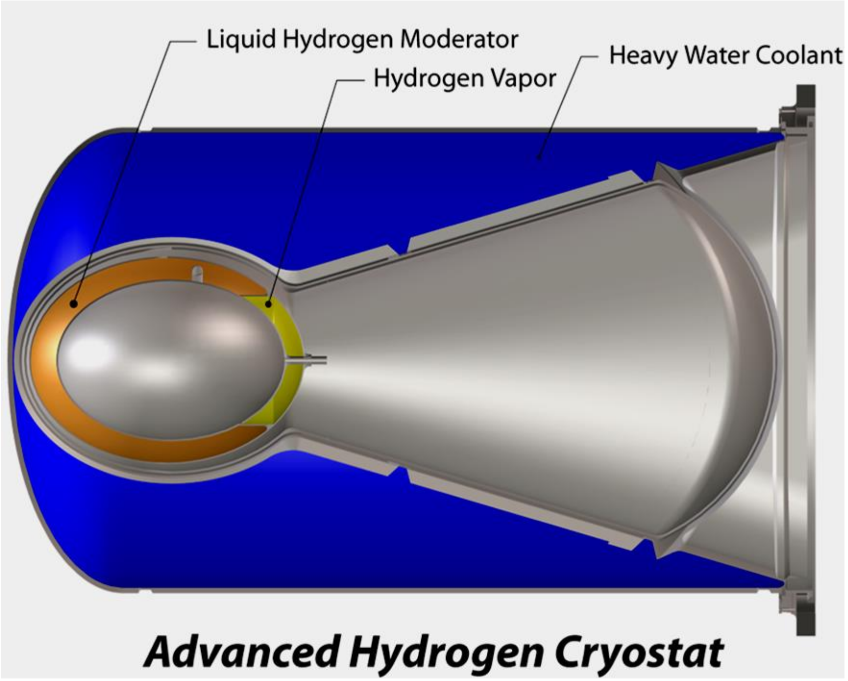
55 cm Diameter



The Current Cold Source Unit 2

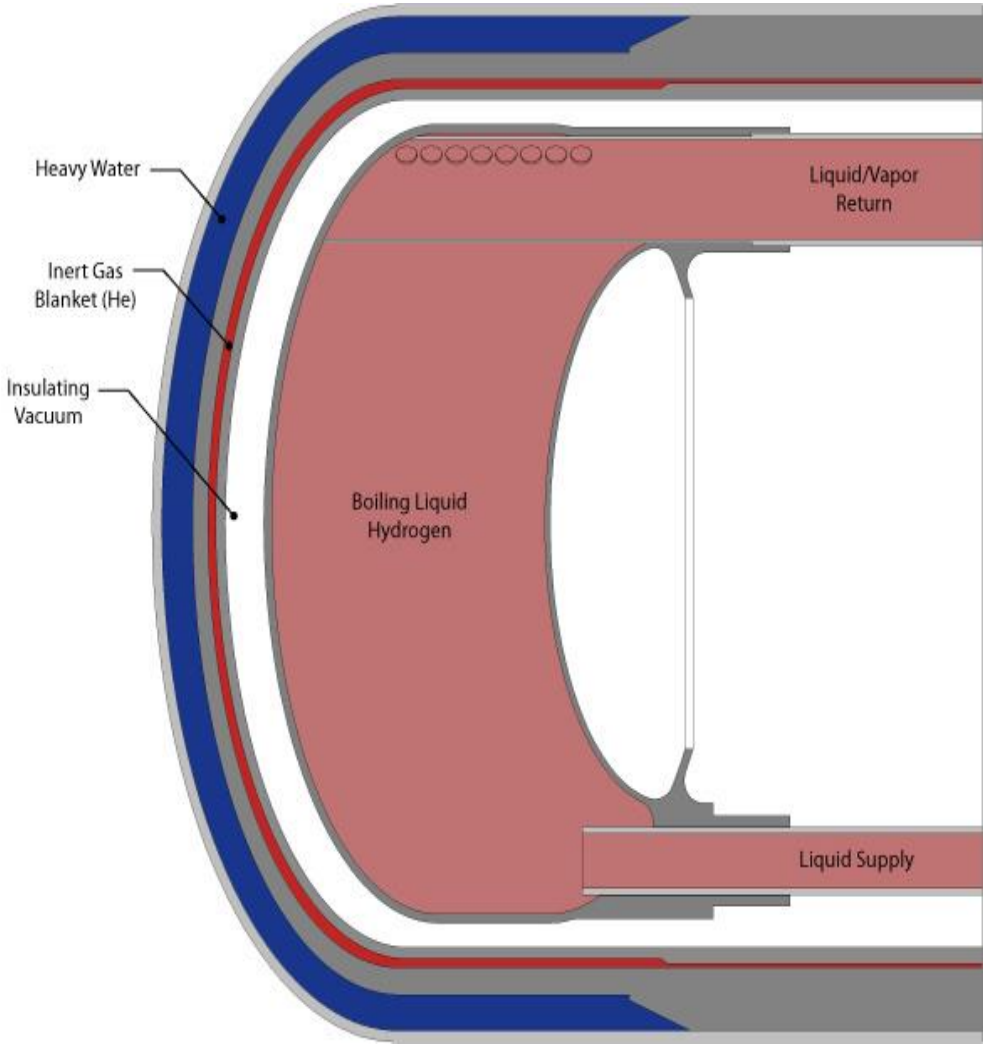
- Passively safe and simple to operate (and reliable)
- Utilizes a thermosiphon system to supply the CNS with LH_2
- Closed system
- He containments





The OTHER Cold Source Peewee

- "Peewee" installed on BT-9 (MACS-II)
  - 11 cm ID, ½ L volume
  - Gain of ~1.7 over being directly installed on Unit 2
  - 14.6 cm D_2O jacket and its own H_2 tank
  - Condenser is cooled in parallel with Unit 2
- Operating successfully since April 2012

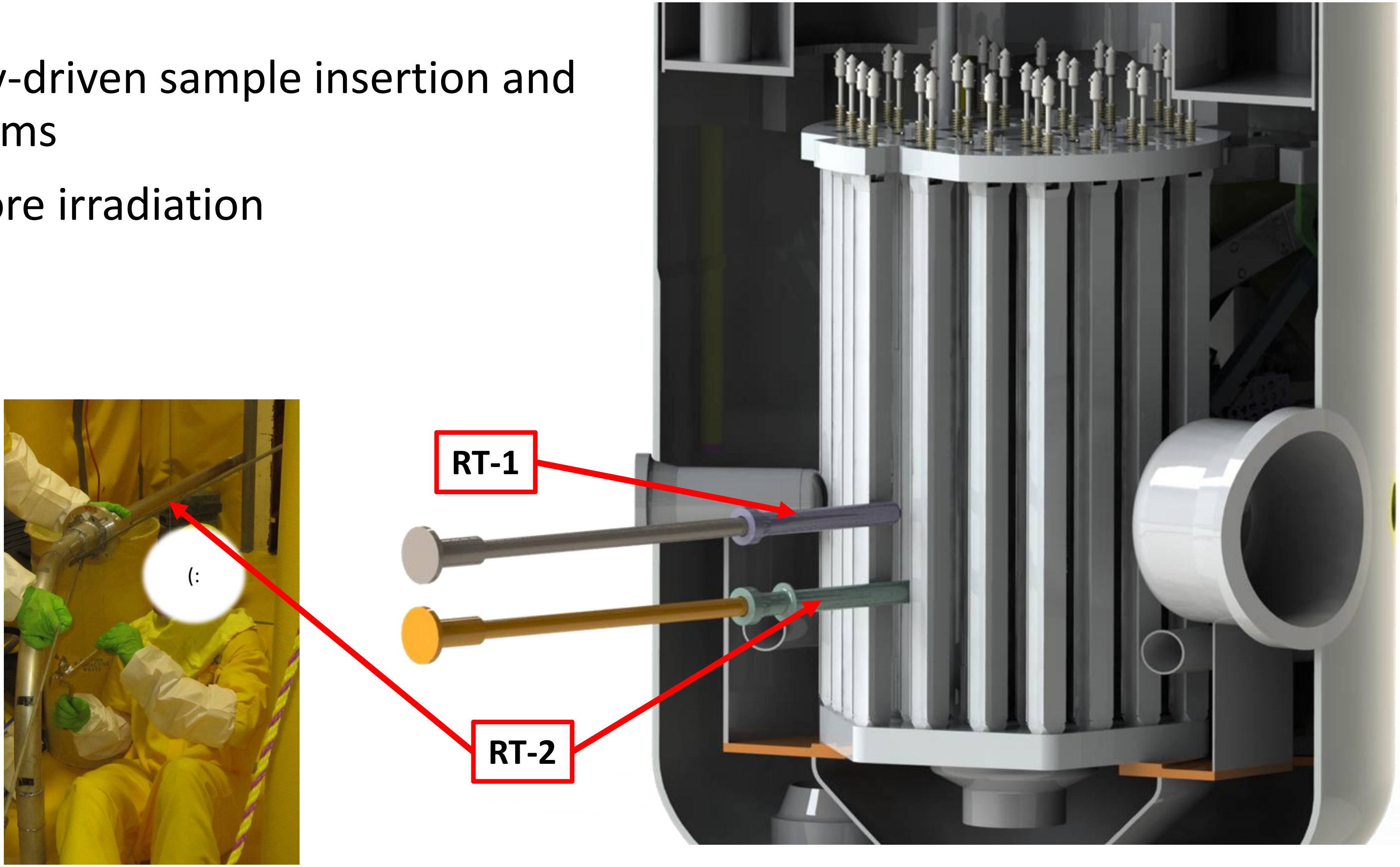


The OTHER Cold Source Peewee

Installation of peewee (Sep. 2011)

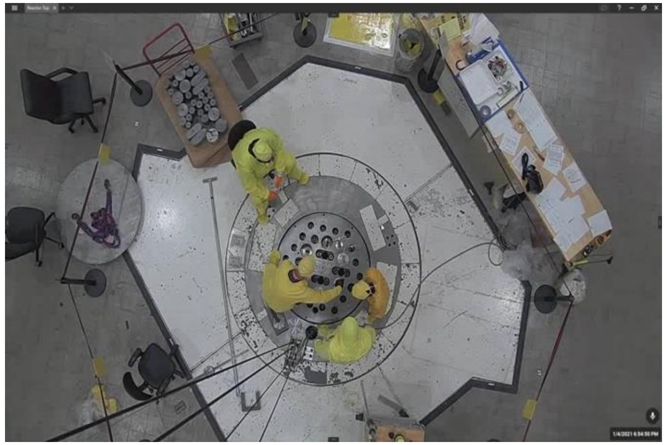
We Also Have Rabbit Tubes

- Pneumatically-driven sample insertion and removal systems
- Used for in-core irradiation



Developments NBSR Recovery

- February 3rd refueling accident
- Cleaning of primary system was conducted
- Fuel loading analysis completed
  - Currently updated to meet operations developments
- New training program developed
- New Reactor aging management program developed
- Obtained restart authorization from NRC!
- Restarted safely
- Currently doing low-power testing



Developments NBSR Recovery

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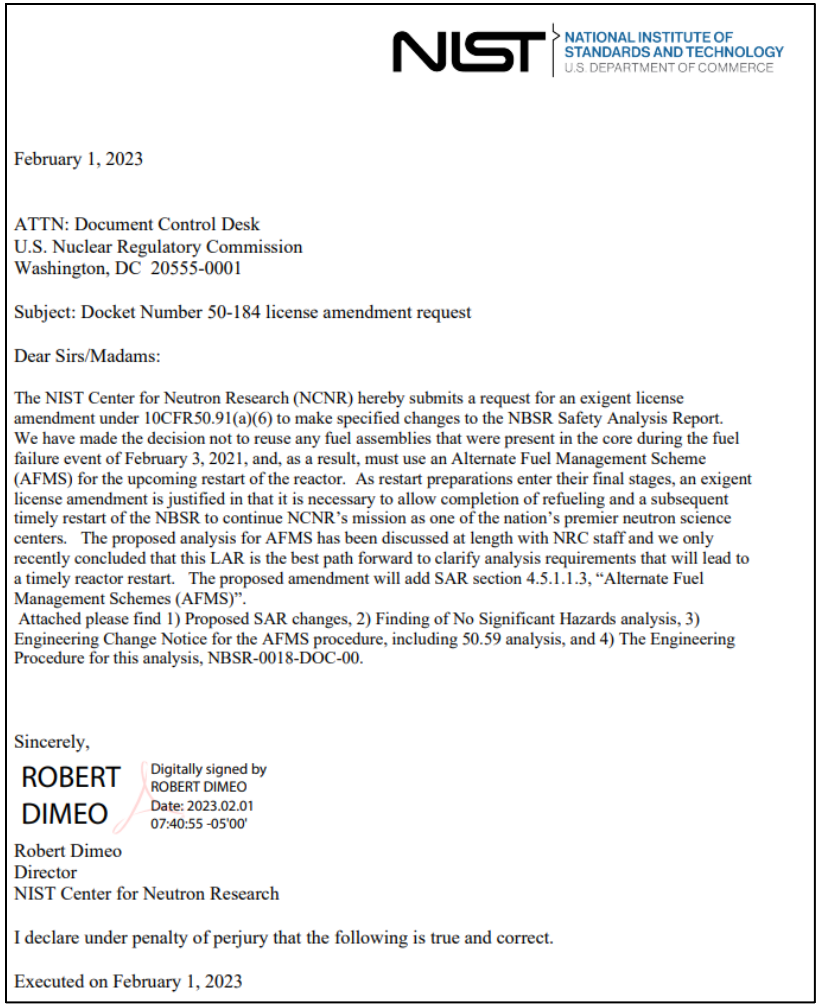
Can operate with alternative fuel management schemes



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

February 1, 2023

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Docket Number 50-184 license amendment request

Dear Sirs/Madams:

The NIST Center for Neutron Research (NCNR) hereby submits a request for an exigent license amendment under 10CFR50.91(a)(6) to make specified changes to the NBSR Safety Analysis Report. We have made the decision not to reuse any fuel assemblies that were present in the core during the fuel failure event of February 3, 2021, and, as a result, must use an Alternate Fuel Management Scheme (AFMS) for the upcoming restart of the reactor. As restart preparations enter their final stages, an exigent license amendment is justified in that it is necessary to allow completion of refueling and a subsequent timely restart of the NBSR to continue NCNR's mission as one of the nation's premier neutron science centers. The proposed analysis for AFMS has been discussed at length with NRC staff and we only recently concluded that this LAR is the best path forward to clarify analysis requirements that will lead to a timely reactor restart. The proposed amendment will add SAR section 4.5.1.1.3, "Alternate Fuel Management Schemes (AFMS)".
Attached please find 1) Proposed SAR changes, 2) Finding of No Significant Hazards analysis, 3) Engineering Change Notice for the AFMS procedure, including 50.59 analysis, and 4) The Engineering Procedure for this analysis, NBSR-0018-DOC-00.

Sincerely,

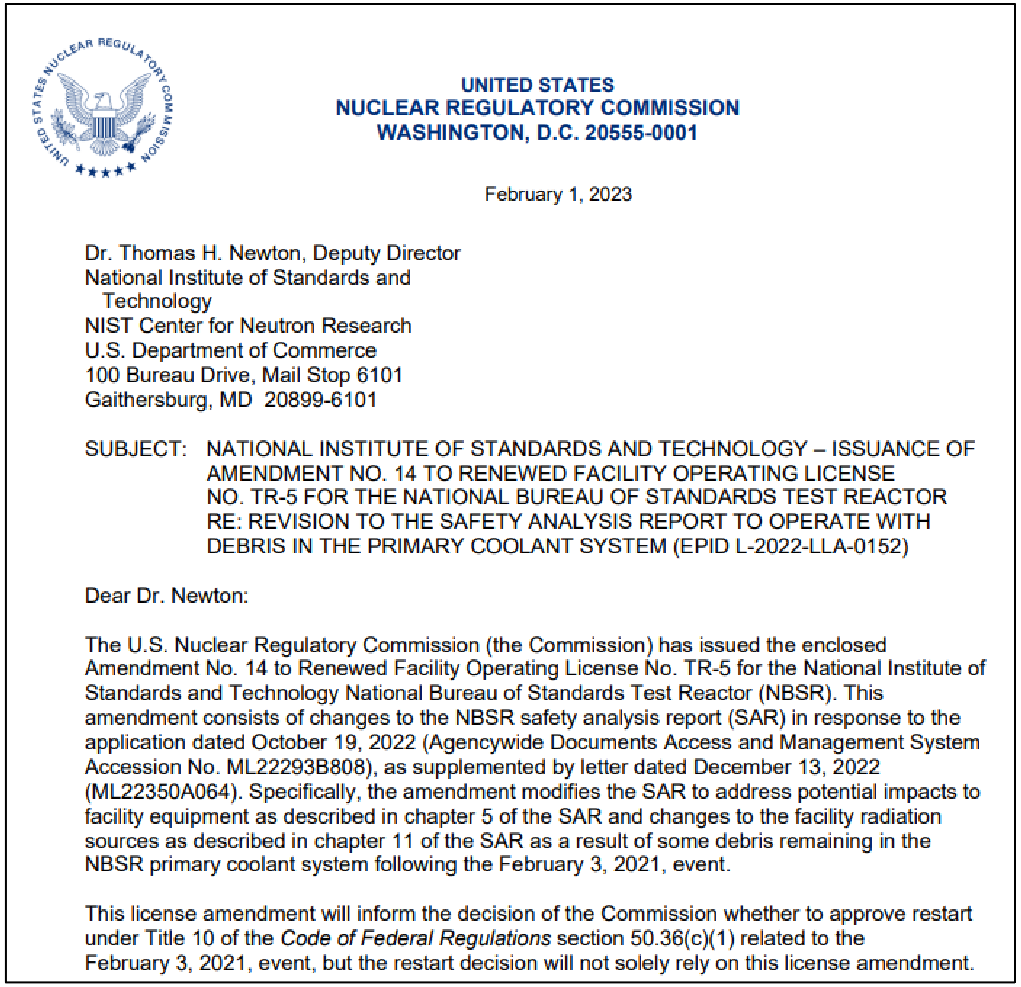
ROBERT DIMEO Digitally signed by ROBERT DIMEO Date: 2023.02.01 07:40:55 -05'00'

Robert Dimeo
Director
NIST Center for Neutron Research

I declare under penalty of perjury that the following is true and correct.

Executed on February 1, 2023

Can operate with loose fuel in the water



UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

February 1, 2023

Dr. Thomas H. Newton, Deputy Director
National Institute of Standards and Technology
NIST Center for Neutron Research
U.S. Department of Commerce
100 Bureau Drive, Mail Stop 6101
Gaithersburg, MD 20899-6101

SUBJECT: NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY – ISSUANCE OF AMENDMENT NO. 14 TO RENEWED FACILITY OPERATING LICENSE NO. TR-5 FOR THE NATIONAL BUREAU OF STANDARDS TEST REACTOR RE: REVISION TO THE SAFETY ANALYSIS REPORT TO OPERATE WITH DEBRIS IN THE PRIMARY COOLANT SYSTEM (EPID L-2022-LLA-0152)

Dear Dr. Newton:

The U.S. Nuclear Regulatory Commission (the Commission) has issued the enclosed Amendment No. 14 to Renewed Facility Operating License No. TR-5 for the National Institute of Standards and Technology National Bureau of Standards Test Reactor (NBSR). This amendment consists of changes to the NBSR safety analysis report (SAR) in response to the application dated October 19, 2022 (Agencywide Documents Access and Management System Accession No. ML22293B808), as supplemented by letter dated December 13, 2022 (ML22350A064). Specifically, the amendment modifies the SAR to address potential impacts to facility equipment as described in chapter 5 of the SAR and changes to the facility radiation sources as described in chapter 11 of the SAR as a result of some debris remaining in the NBSR primary coolant system following the February 3, 2021, event.

This license amendment will inform the decision of the Commission whether to approve restart under Title 10 of the *Code of Federal Regulations* section 50.36(c)(1) related to the February 3, 2021, event, but the restart decision will not solely rely on this license amendment.

Developments NBSR Engineering Procedures

NIST | CENTER FOR NEUTRON RESEARCH

NIST CENTER FOR NEUTRON RESEARCH	**Document:**	NBSR Engineering Procedure NBSR-0018-DOC-00		
	Title:	NBSR Alternative Fuel Management Schemes Analysis Procedure		
	Revision:	Initial Release	**Date:**	1/30/2023

NBSR Engineering Procedure NBSR-0018-DOC-00

NBSR Alternative Fuel Management Schemes Analysis Procedure

Revision 1

Dağistan Şahin, Osman Şahin Çelikten, Anil Gurgen, Abdullah G. Weiss

Lap-Yan Cheng, Peter Kohut, Cihang Lu, Athi Varuttamaseni

Thomas Newton

Distribution:

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NCNR A150

Record of Revisions

Revision	Description of Revision	ECN No. (if applicable)	Date
Initial	0	1269	1/30/23
1	Incorporate expanded range tables for CHFR and OFIR correlations	1294	6/1/2023

Developments NBSR Engineering Procedures

NIST CENTER FOR NEUTRON RESEARCH

Document:	NBSR Engineering Procedure NBSR-19-DOC-00
Title:	Reliability, Availability, Maintainability and Safety (RAMS) in engineering projects
Revision:	Initial Release **Date:** 3/01/2023

NBSR Engineering Procedure NBSR-19-DOC-00

NBSR Engineering procedure for

Reliability, Availability, Maintainability and Safety (RAMS) in engineering projects

Initial Release

	Name	Signature	Date
Drafted by:	Yehonatan Zino		/ /
Reviewed by:	James Whipple		/ /
Reviewed by:	Dağistan Şahin		/ /
CRE:	Paul Brand		/ /
CRO:	Randy Strader		/ /
Approved by:	Thomas Newton		/ /

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Revision	Description of Revision	ECN No. (if applicable)	Date
Initial	0	1293	5/5/2023

Document:	NBSR Engineering Procedure NBSR-0020-DOC-00
Title:	NBSR Spent Fuel Shipment Analysis Procedure
Revision:	Initial Release **Date:** 6/6/2023

NBSR Engineering Procedure NBSR-0020-DOC-00

NBSR Spent Fuel Shipment Analysis Procedure

Initial Release

Abdullah G. Weiss, Dağistan Şahin

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Revision	Description of Revision	ECN No. (if applicable)	Date
Initial	0	1298	6/6/23

Document:	NBSR Engineering Procedure NBSR-0021-DOC-00
Title:	Vibrations Monitoring Guide
Revision:	Initial Release **Date:** 6/7/2023

NBSR Engineering Procedure NBSR-0021-DOC-00

Vibrations Monitoring Guide

Initial Release

Abdullah G. Weiss, Samuel J. MacDavid, Anil Gurgen, Dağistan Şahin

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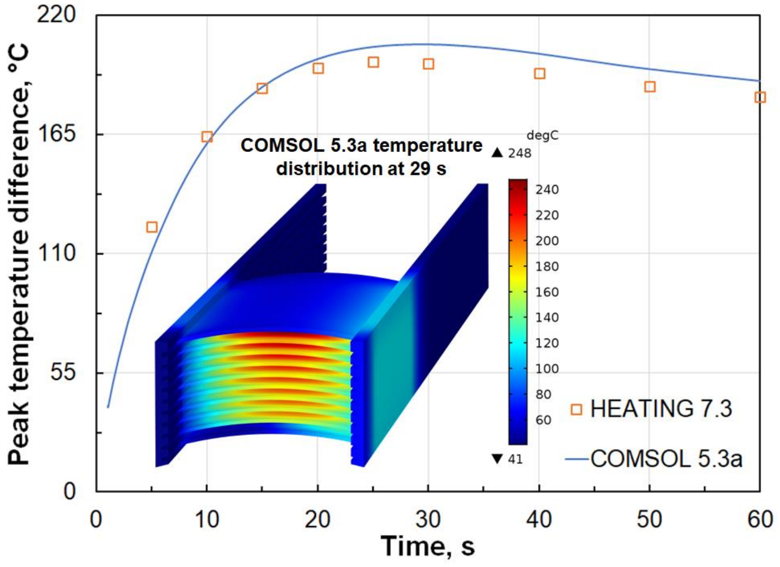
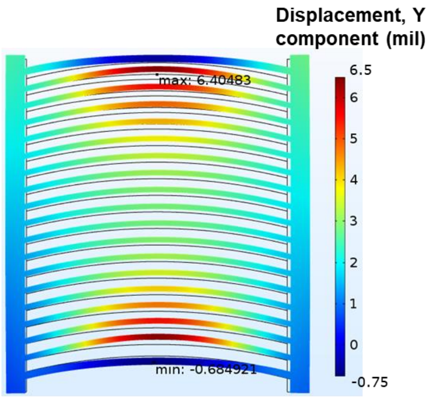
Record of Revisions

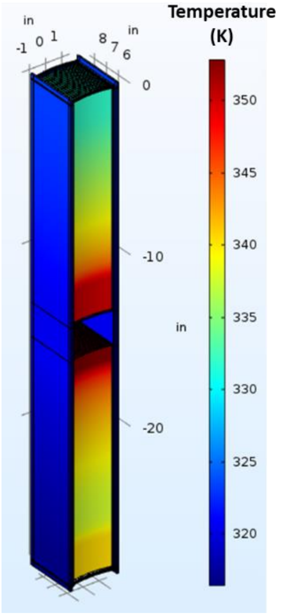
Revision	Description of Revision	ECN No. (if applicable)	Date
Initial	0	1299	6/7/23

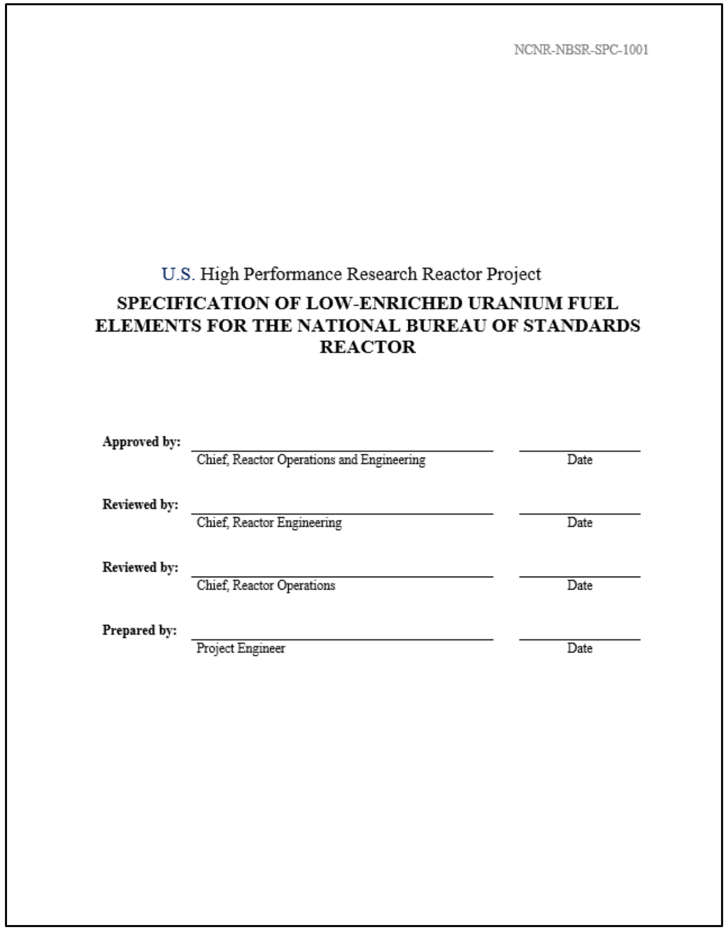
Developments LEU Conversion

- US High Performance Research Reactors Conversion Program
  - Collaboration with several DOE laboratories (ANL, INL, BNL, ORNL)
  - To meet US and international non-proliferation goals
- Converting to U-10Mo HALEU (19.75% enrichment)
- Finished the first revision of the drawings and fuel specification document for the NBSR U-10Mo.








NCNR-NBSR-SPC-1001

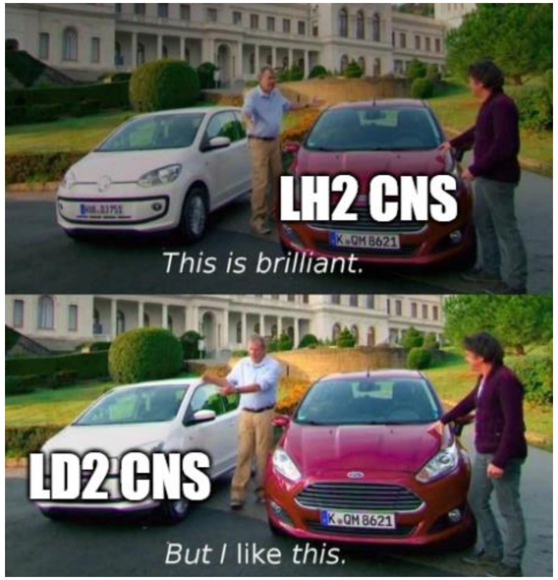
U.S. High Performance Research Reactor Project

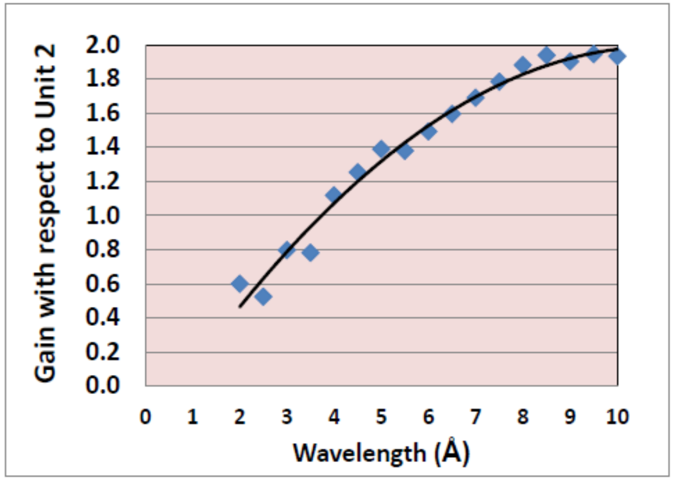
SPECIFICATION OF LOW-ENRICHED URANIUM FUEL ELEMENTS FOR THE NATIONAL BUREAU OF STANDARDS REACTOR

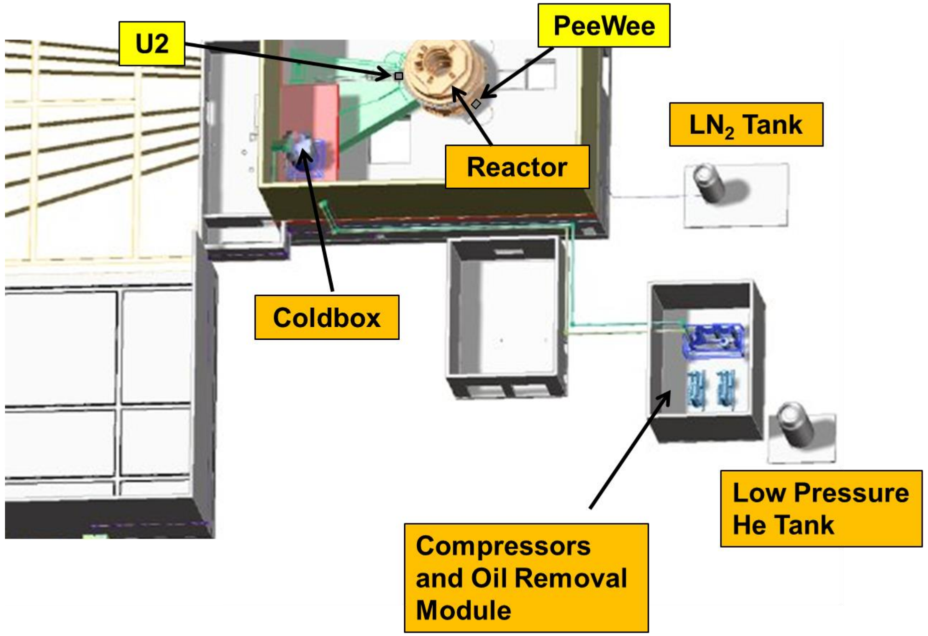
Approved by:	Chief, Reactor Operations and Engineering	Date
Reviewed by:	Chief, Reactor Engineering	Date
Reviewed by:	Chief, Reactor Operations	Date
Prepared by:	Project Engineer	Date

Developments Cold Source Upgrade

- Planned NBSR LEU conversion results in 10% reduction in thermal and cold neutron beams, which can be mitigated by replacing LH_2 to LD_2.
- Support for some of these modifications comes from US NNSA
- Increase in cryogenic heat load to ~4 kW
- Already purchased and installed a new 7 kW fridge to accommodate the heat load increase.







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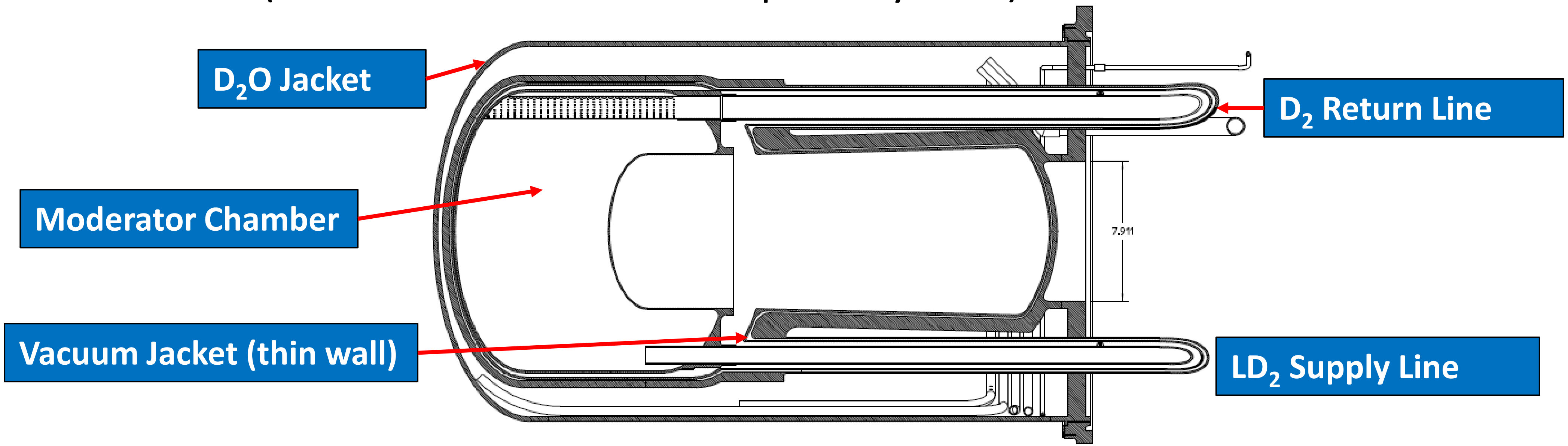
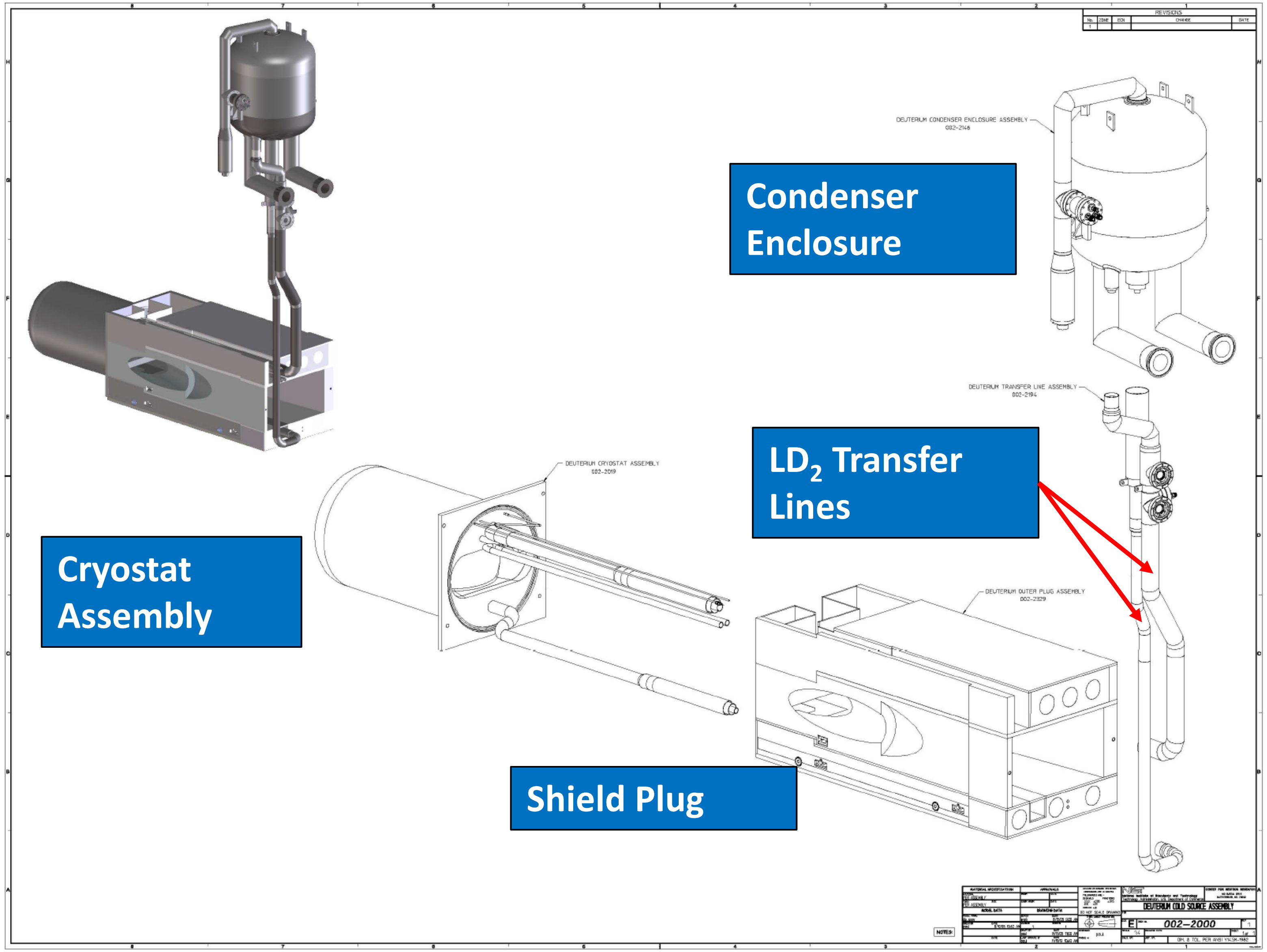
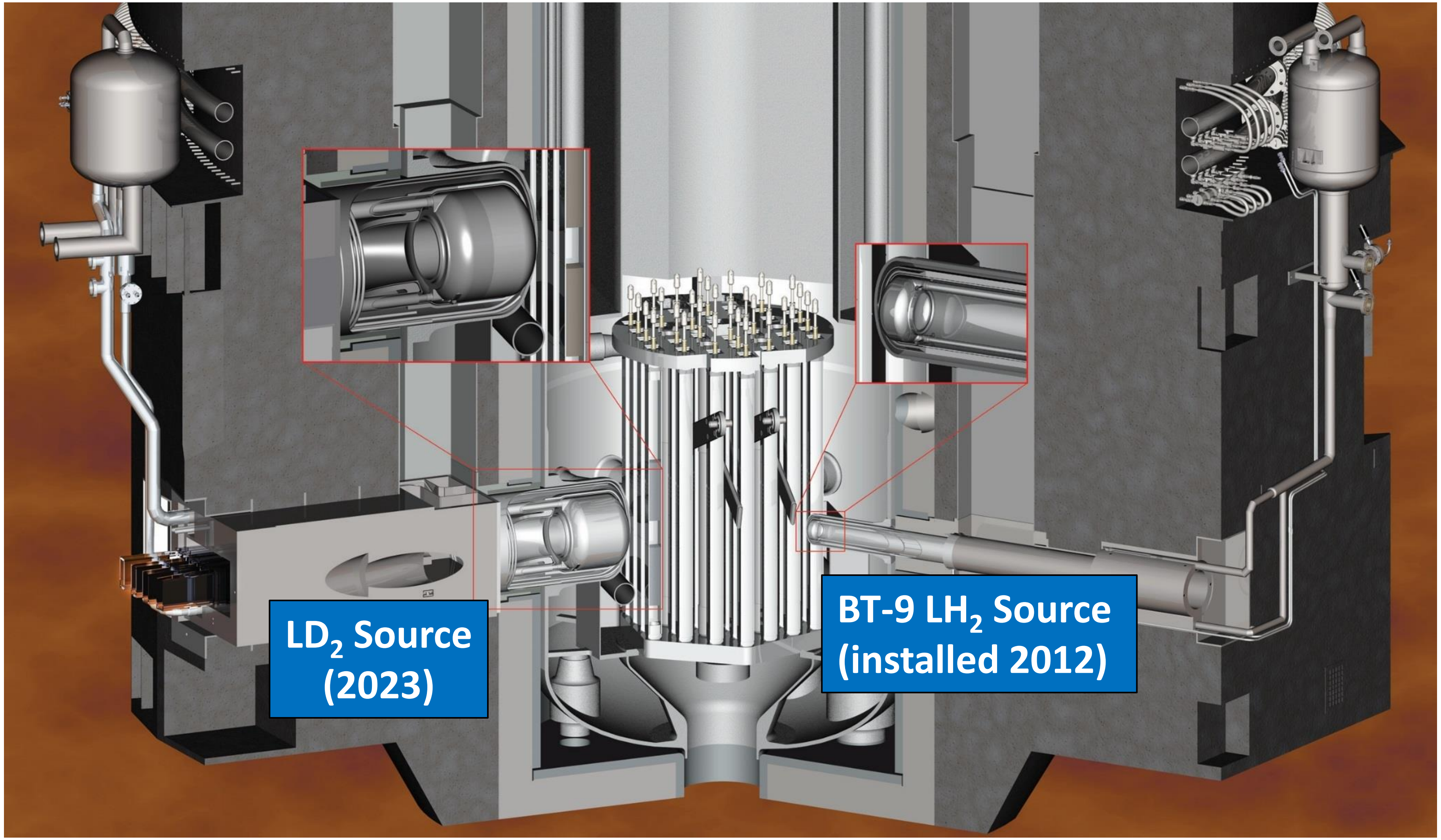


Developments Cold Source Upgrade



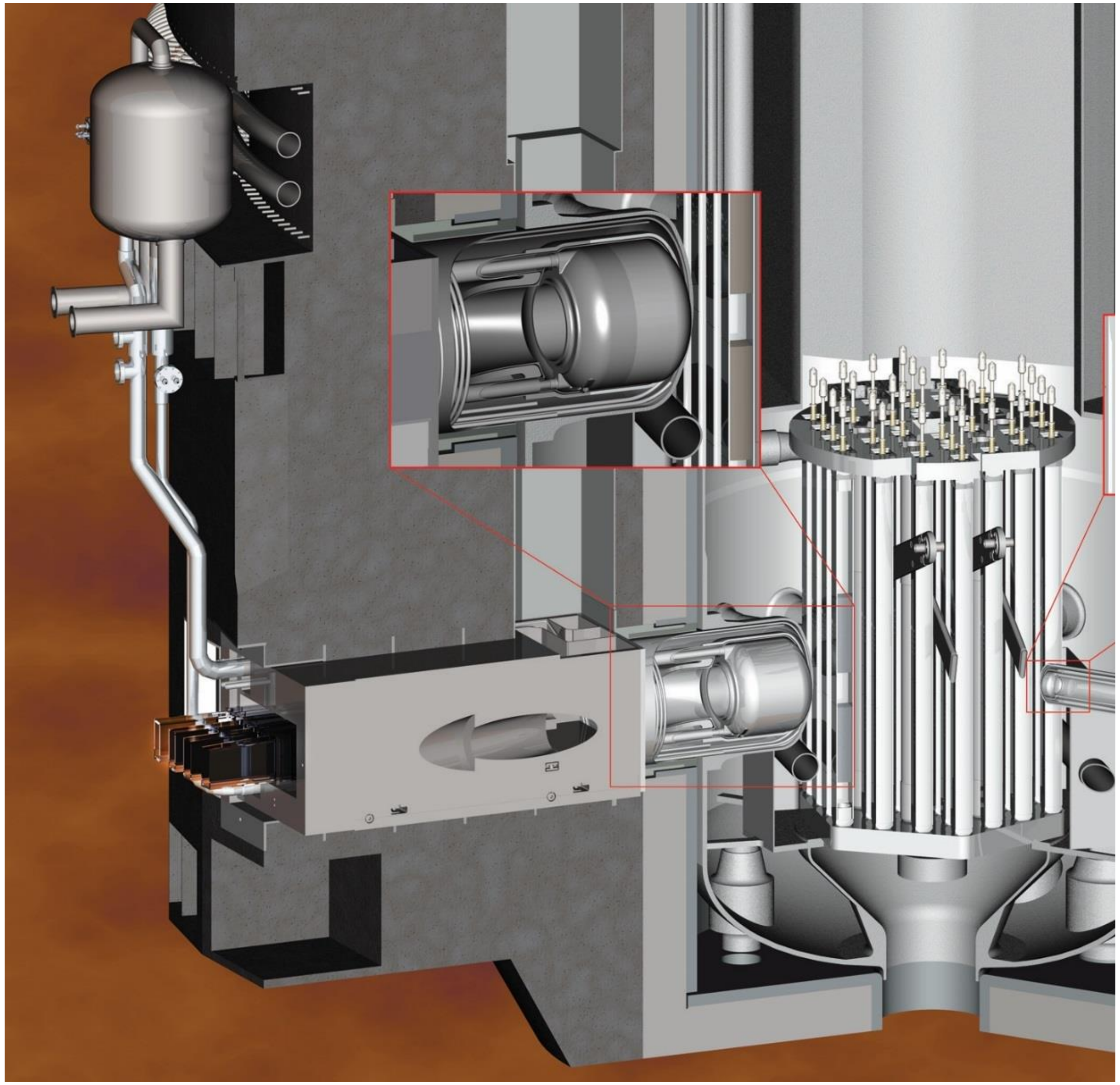
Developments Cold Source Upgrade



Developments Cold Source Upgrade

Radiation source	Unit 2		PeeWee		LD_2	
	H_2	Al	H_2	Al	D_2	Al
Neutrons	104	3	33	1	440	6
Beta Particles		308		29		567
Gamma rays	185	815	25	74	1053	1538
Subtotal	281	1080	58	104	1493	2111
Total cryogenic heat load [w]	1361		162		3604	

	LH_2 (PeeWee)	**LH_2 (Unit 2)**	**LD_2 (Proposed)**
Operating Pressure (kPa)	200	100	100 - 200
B.P. (K)	23.0	20.4	23.2 – 25.9
M.P (K)	14	13.8	18.8 - 19.0
Density (kg/m3)	67.5	70	164 - 157
Geometry	Disk	Elliptical Annulus	Cylindrical
Dimensions (cm)	11	32 x 24	40 x 40
Wall Thickness (mm)	4.5	2.3	3.2
Liquid Volume (L)	0.45	5	35
Mass (kg)	0.03	0.32	5.2
Al Mass (kg)	0.14	0.28	7.2
Heat Load (kW)	0.16	1.2	3.6



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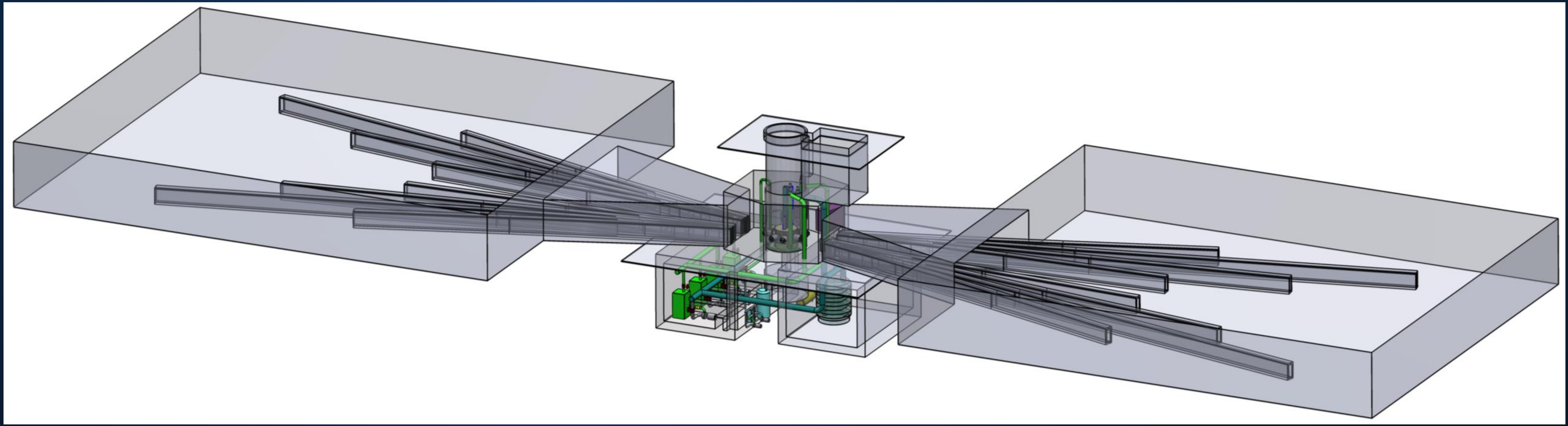
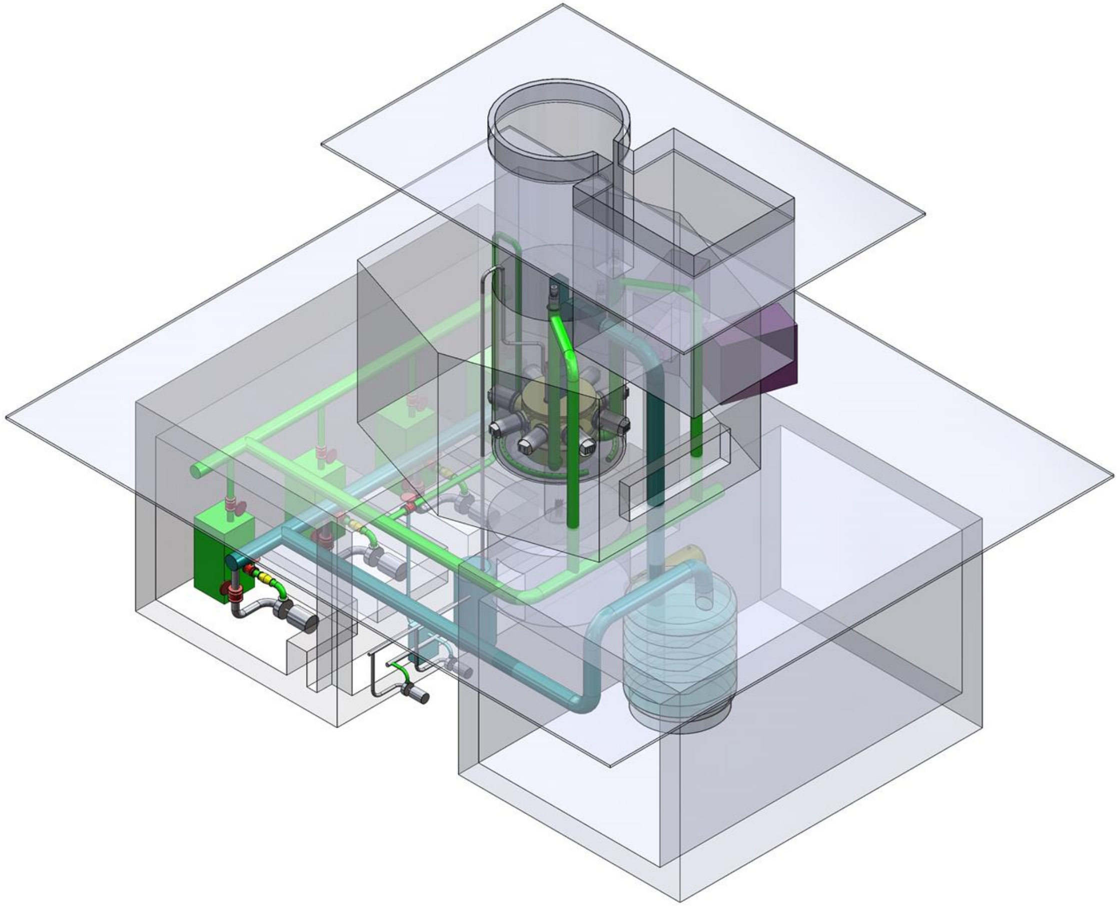


The Future

The New Reactor: NIST Neutron Source (NNS)

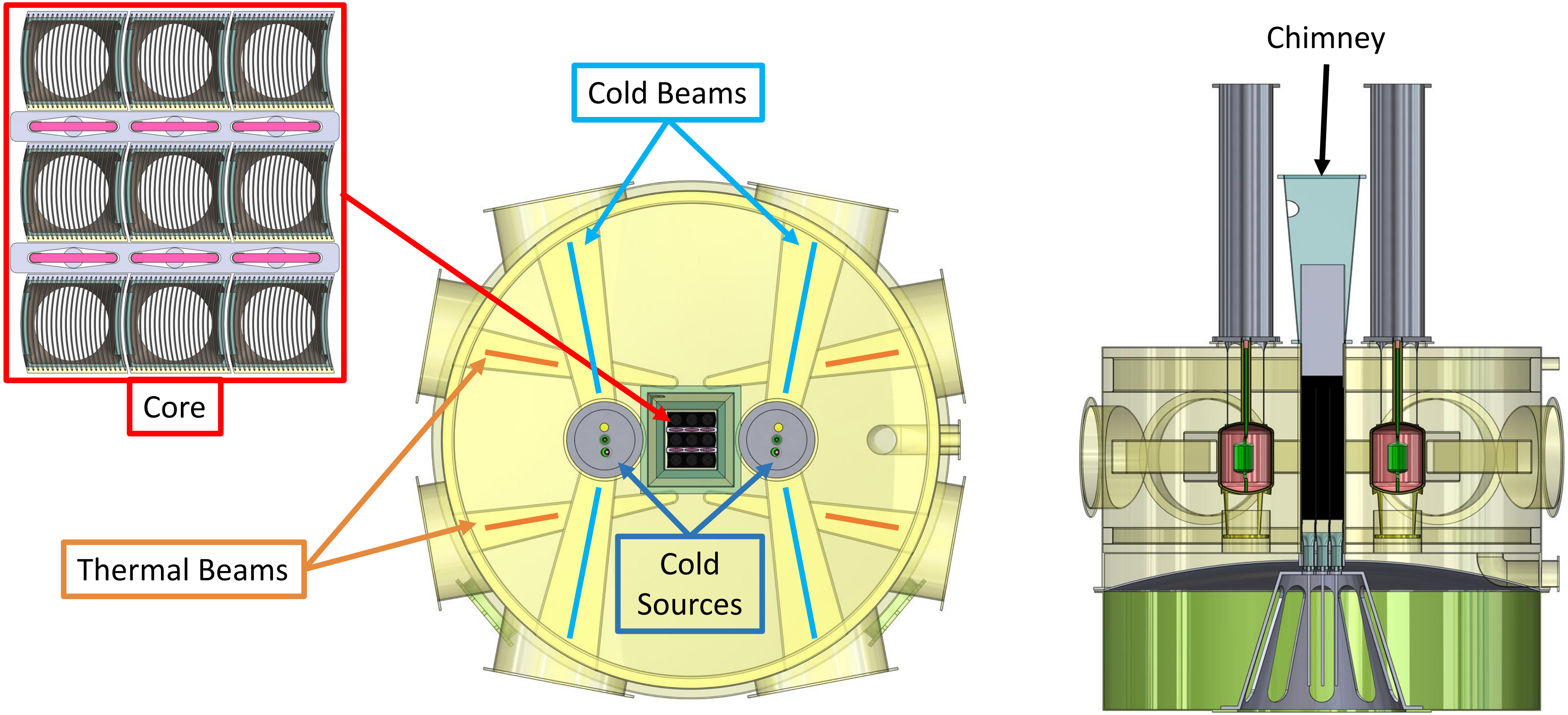
Design of NNS

- 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
- 40 days operating cycle



Reactor Pool and Primary Coolant System

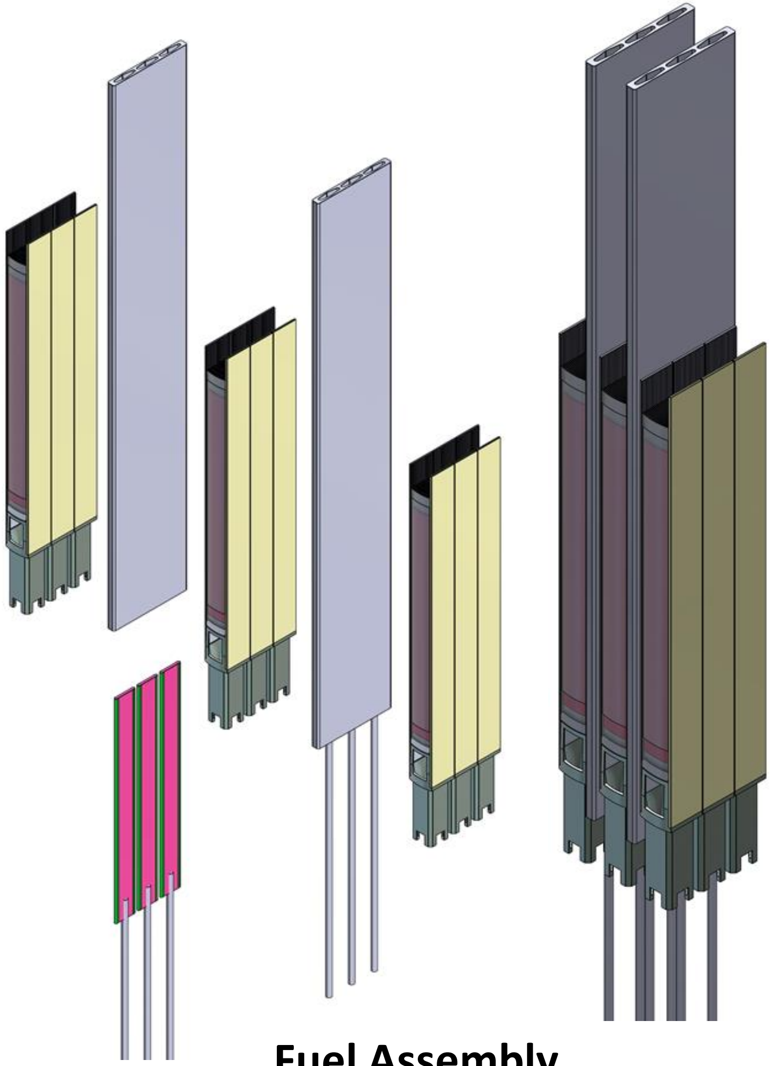
Developments New Reactor (NNS)



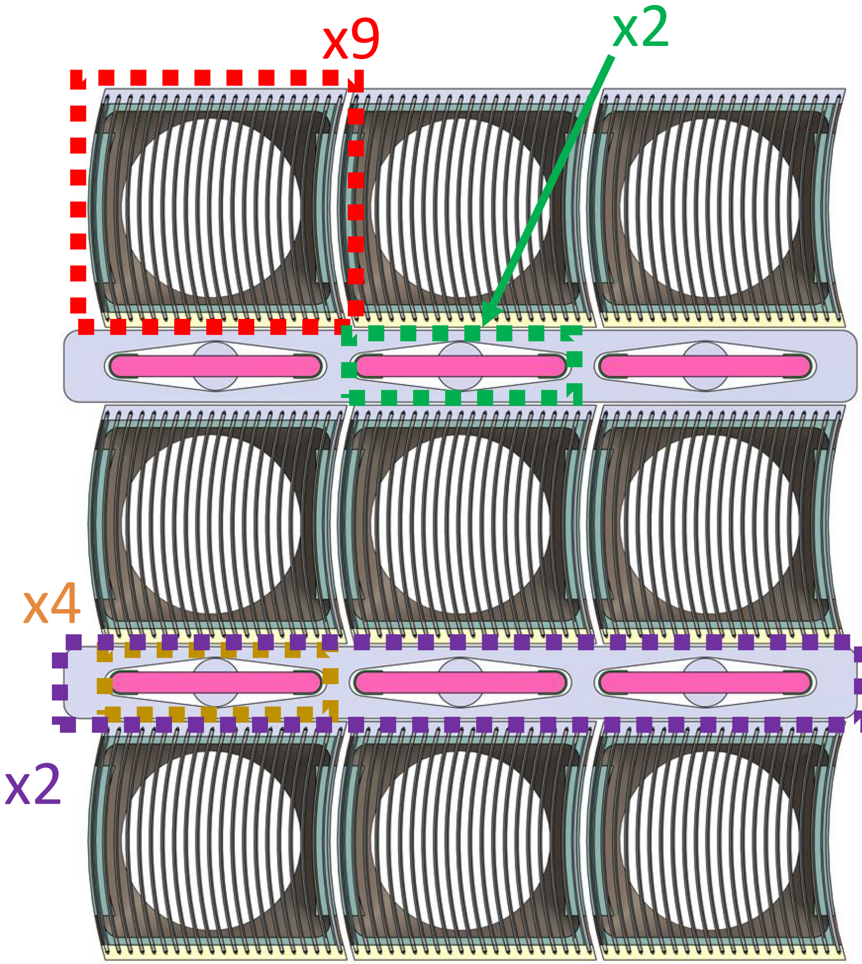
Reflector Tank with the core, cold sources, and beam tubes

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

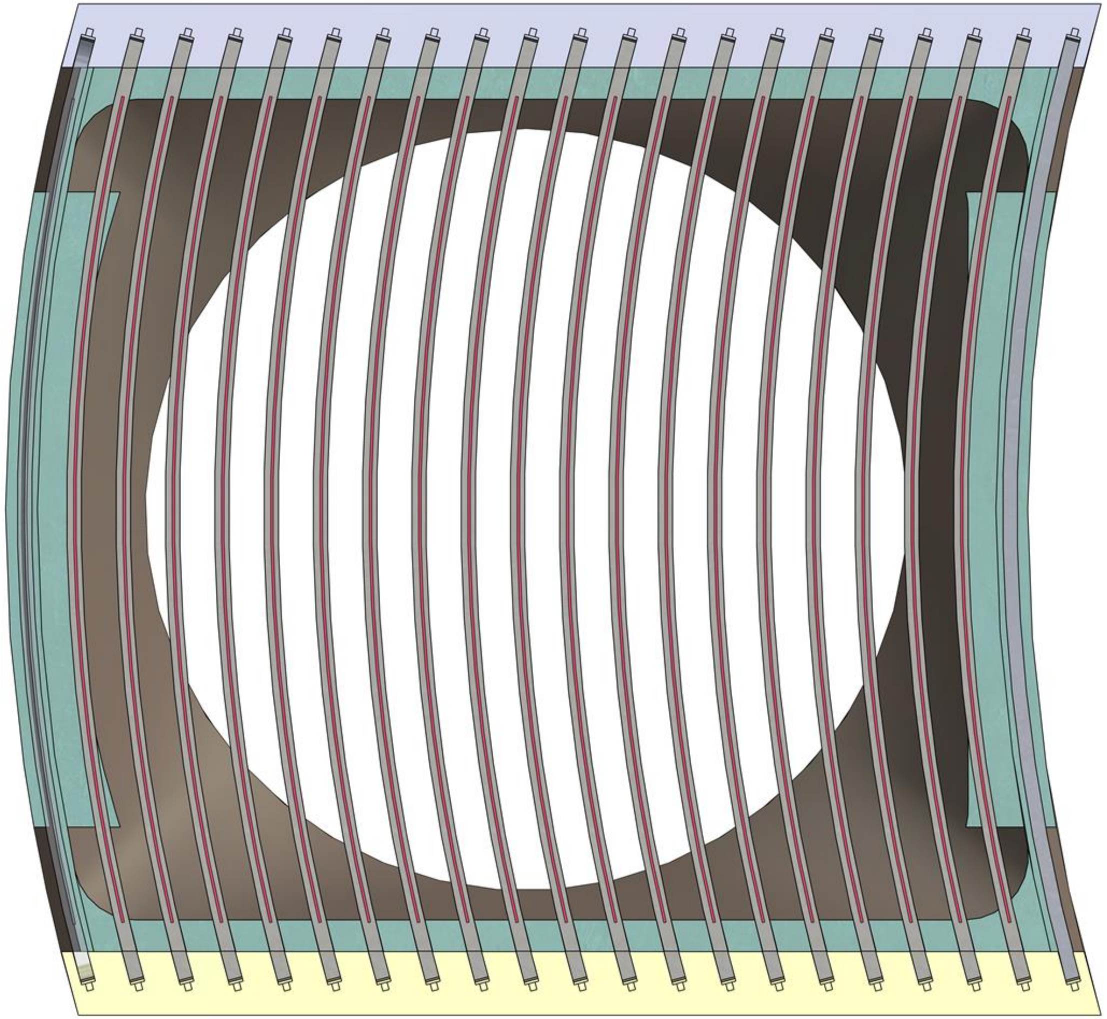


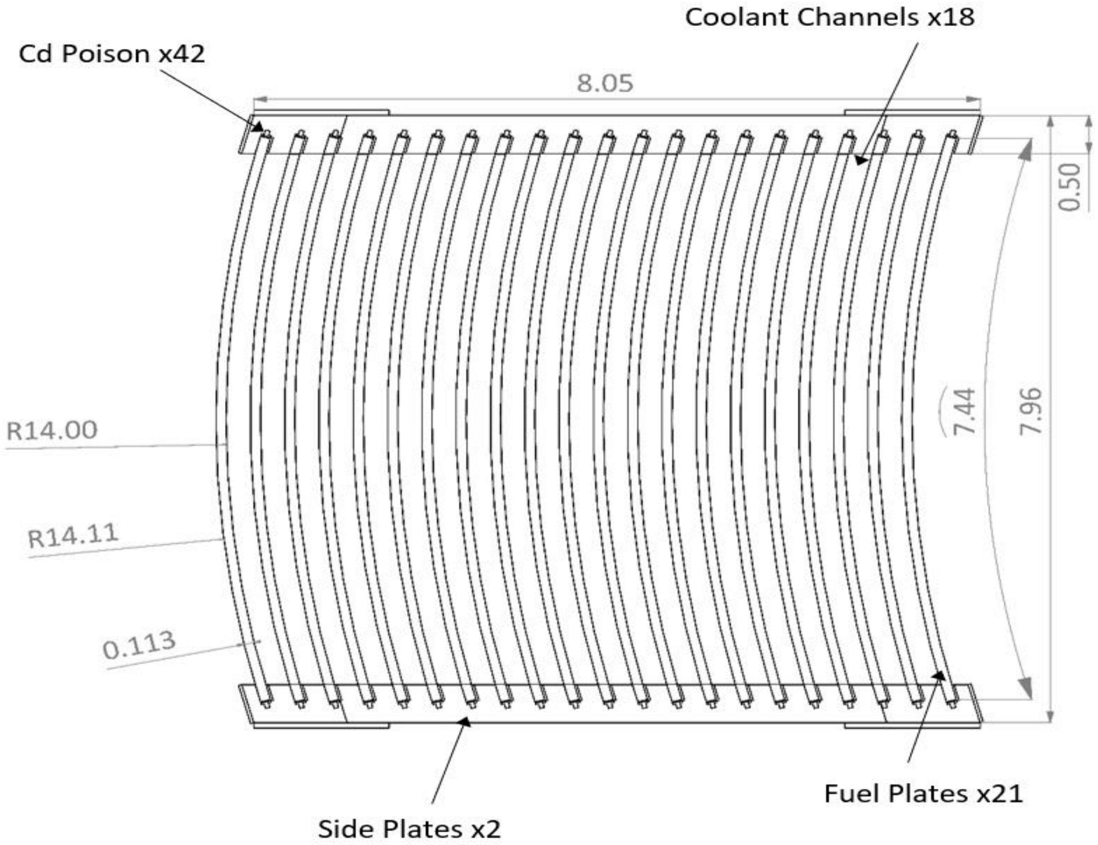
Fuel Assembly



Reactor Core

Design of NNS





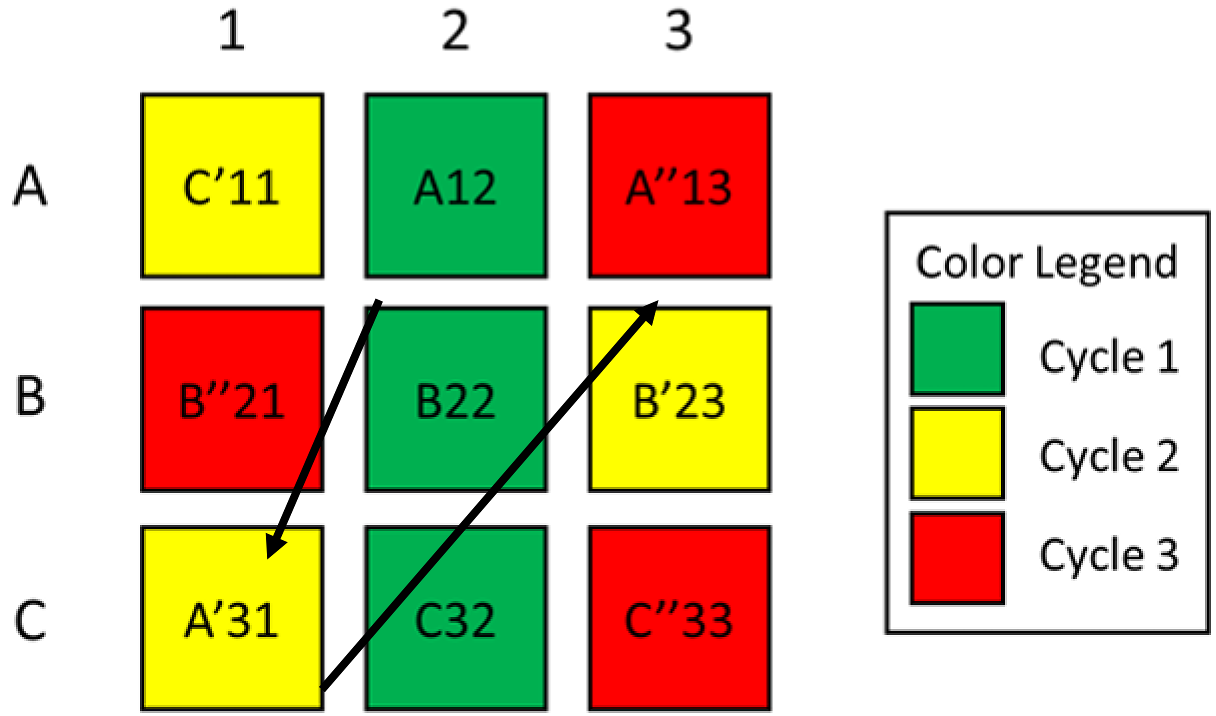
Fuel Assembly

Core Neutronics Analyses

For example… $A12 \rightarrow A'31 \rightarrow A''13$

$B22 \rightarrow B'23 \rightarrow B''21$

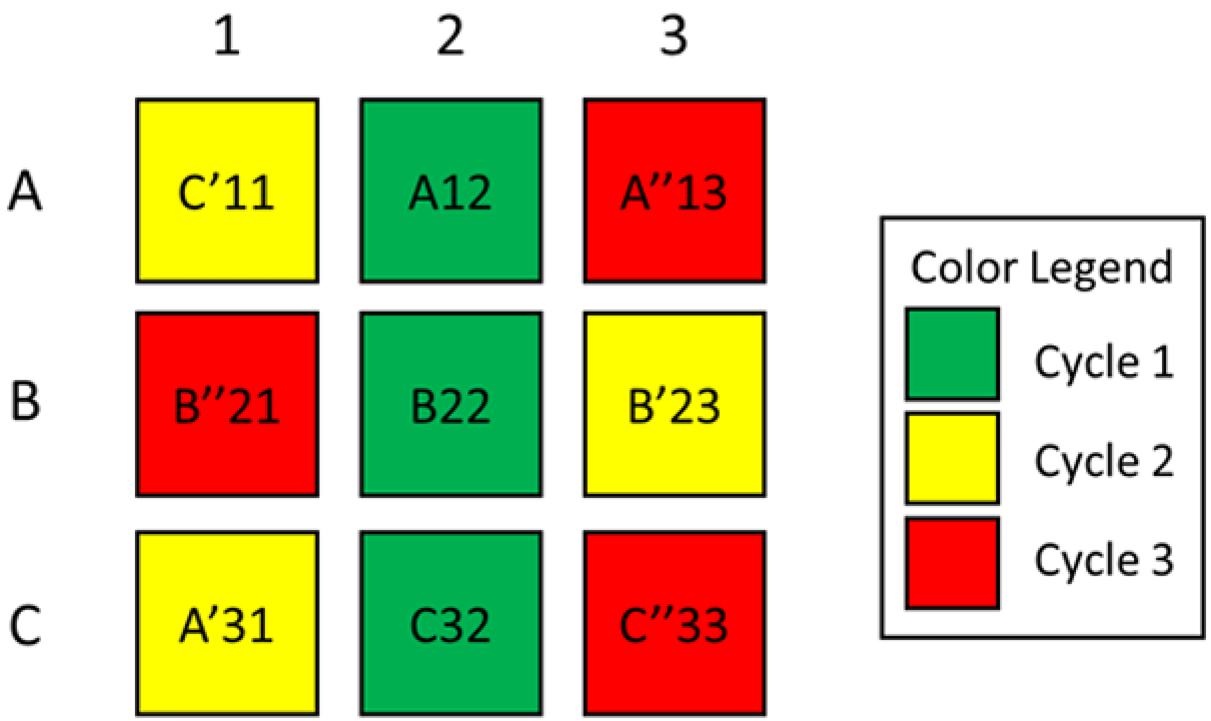
$C32 \rightarrow C'11 \rightarrow C''33$



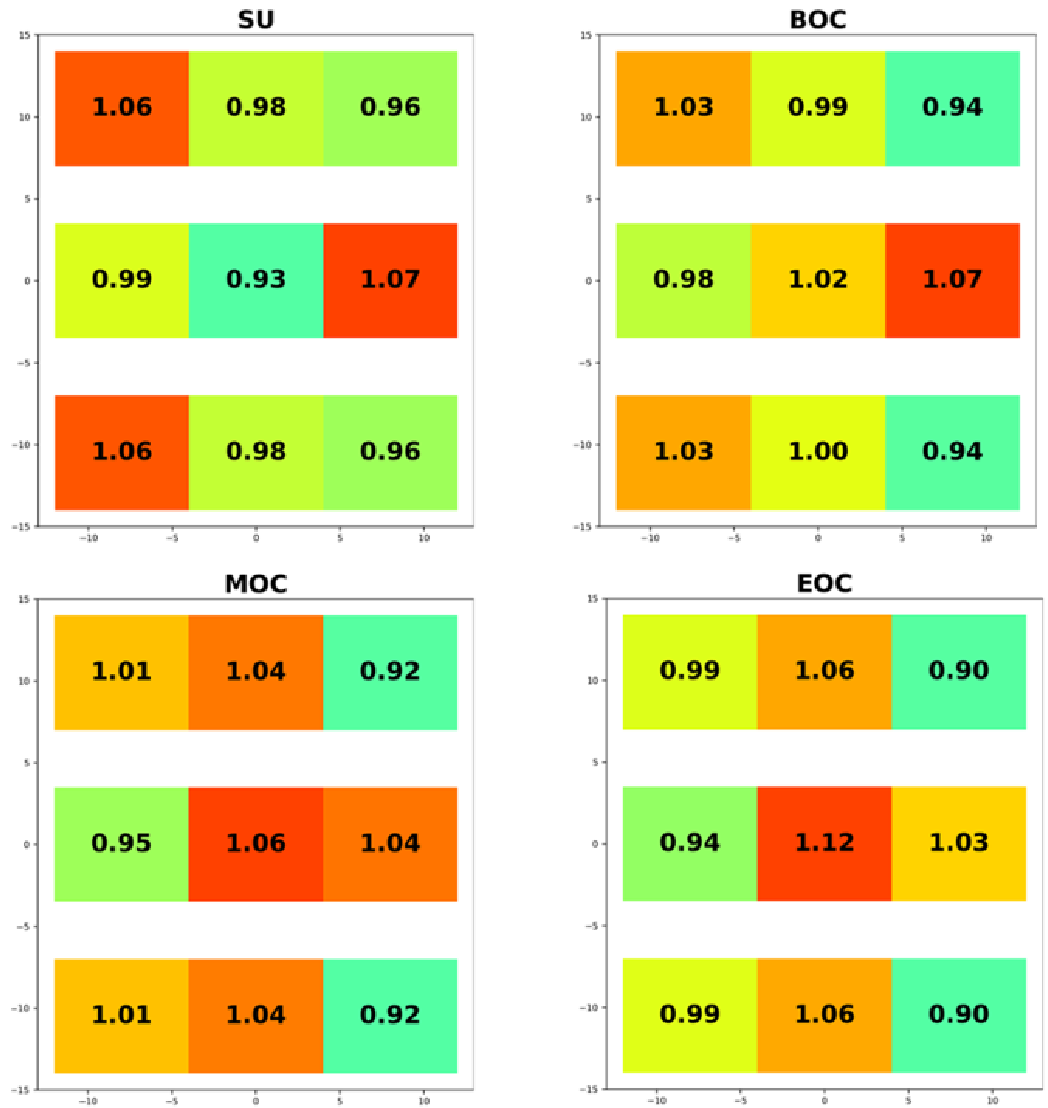
NNS Current Fuel Management Scheme

- The first letter (A,B,C) refers to the original row the fresh fuel element was located
- The numbers (11,12,13 etc.) refer to the row and column with regards to the 9x9 matrix
- Apostrophes and colors refer to the cycle number

Core Neutronics Analyses



NNS Current Fuel Management Scheme

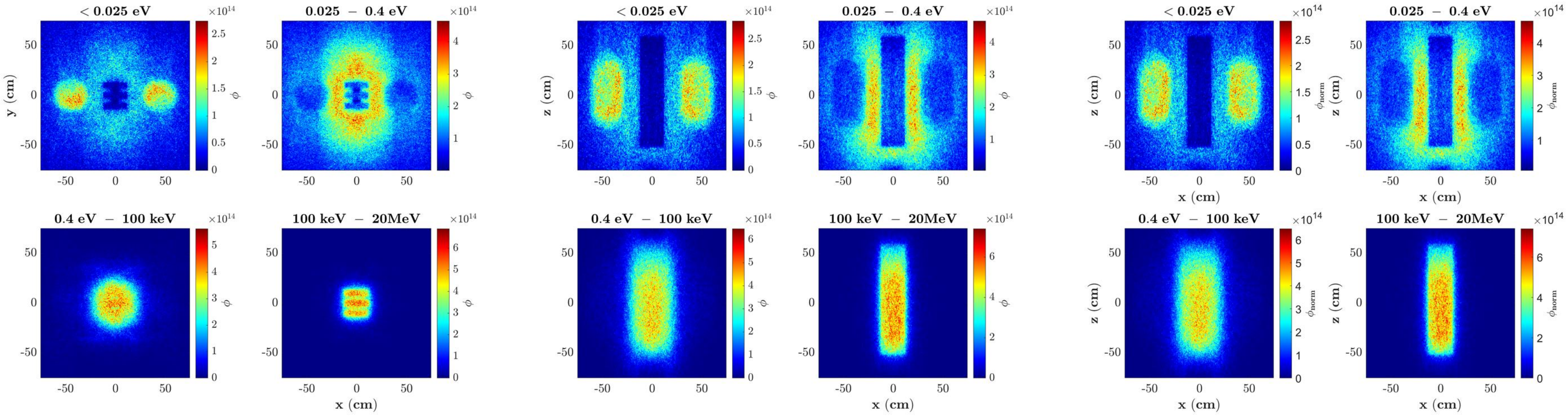


Normalized Power Heatmap of Assemblies in Each Cycle State

Core Neutron Density Distributions

cold and thermal (<0.025 eV), thermal and epi-thermal (0.025 – 0.4 eV)

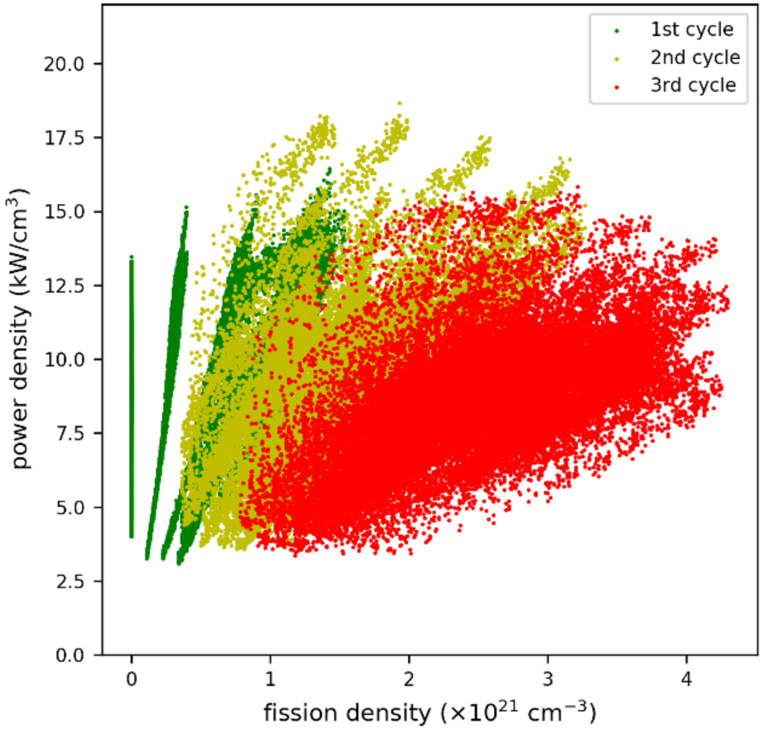
intermediate neutrons (0.4 eV – 100 keV) and fast neutrons (100 keV – 20 MeV).

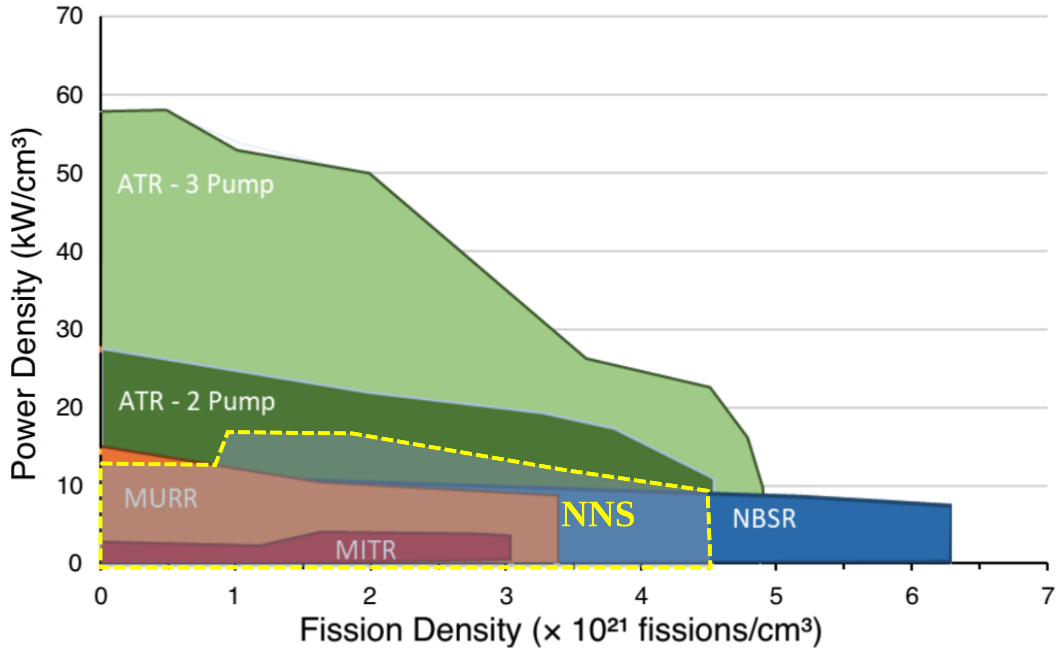


The neutron distribution radial (top-view, left image) and (b) axial (side-view) profiles at the SU state

Fission Density Discharge

Elevated power densities for 2nd cycle FAs are observed with values greater than 18 kW/cm^3 and are accompanied with fission densities in the range of 1.5 – 2 × 10^{21} cm^{-3}. The 3rd cycle fuel assemblies have suppressed power densities with elevated fission densities in excess of 3 × 10^{21} cm^{-3}. The maximum fission density is found to be 4.47 × 10^{21} cm^{-3}.

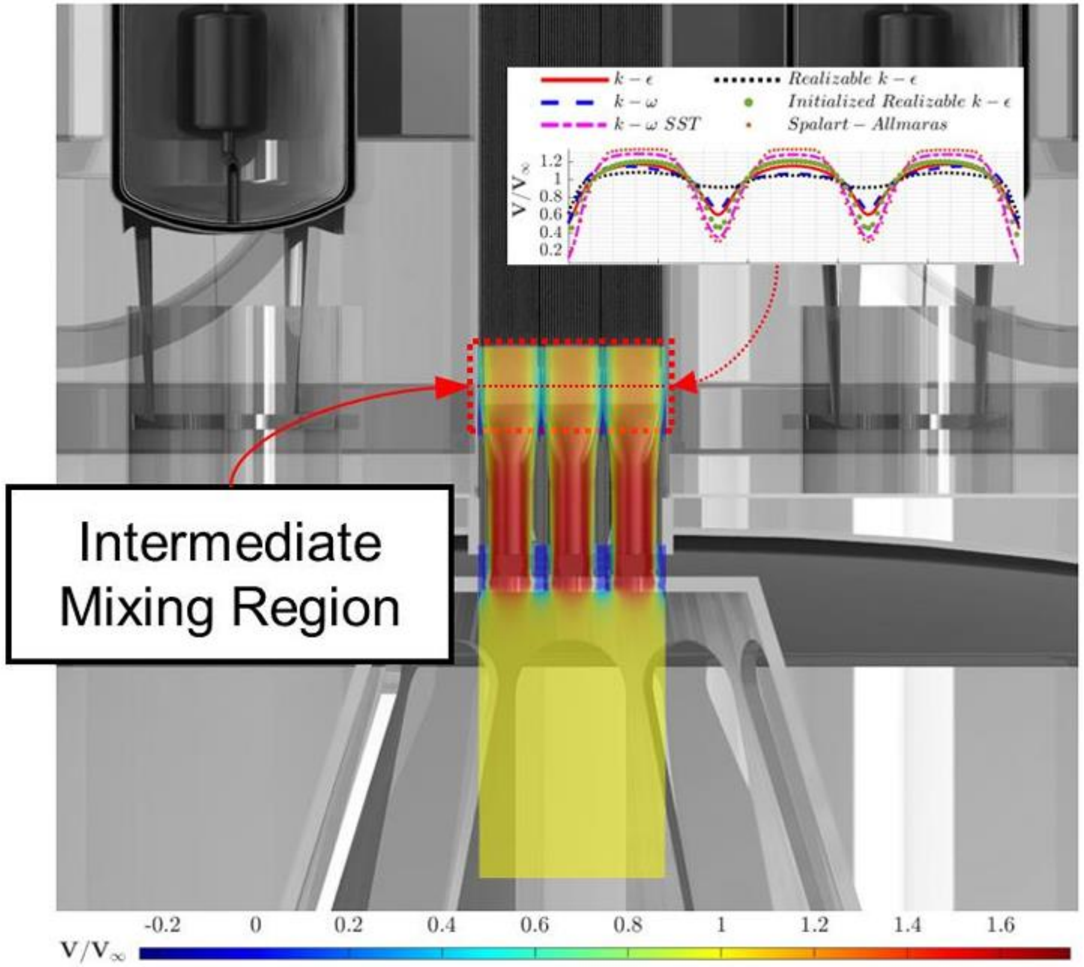




Power and Fission Density Profiles in other USHPRR (modified and reproduced)

Core Thermal Hydraulics

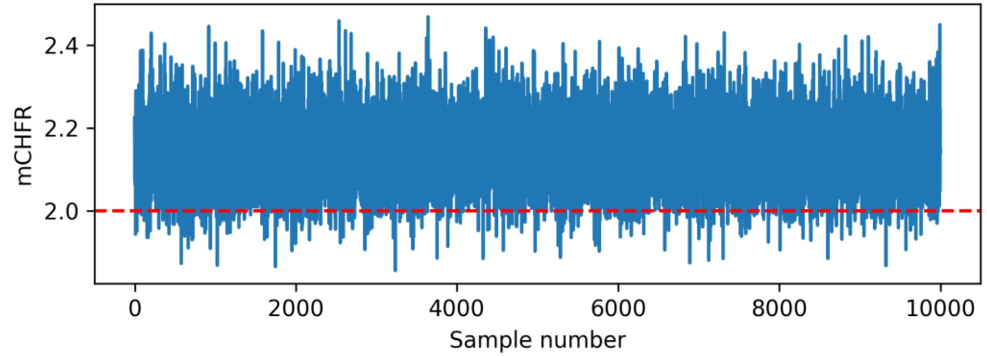
- Current CFD models the NNS inlet using RANS models (e.g., $\mathrm{k}-\epsilon$, realizable $k-\epsilon$, $k-\omega$, $k-\omega$ SST, and Spallart−Allmaras)
- Coolant channel is approximated with a rectangular channel with a flow area
- Previous analyses have measured a CHFR of 2.18 for BOC and MOFIR of 12.9 at SU.
- Maximum bulk temperature was nearly uniform in all channels and remained below 333 K, however maximum cladding temperature was approximately 370 K during SU.
- Results are sensitive to selected RANS model

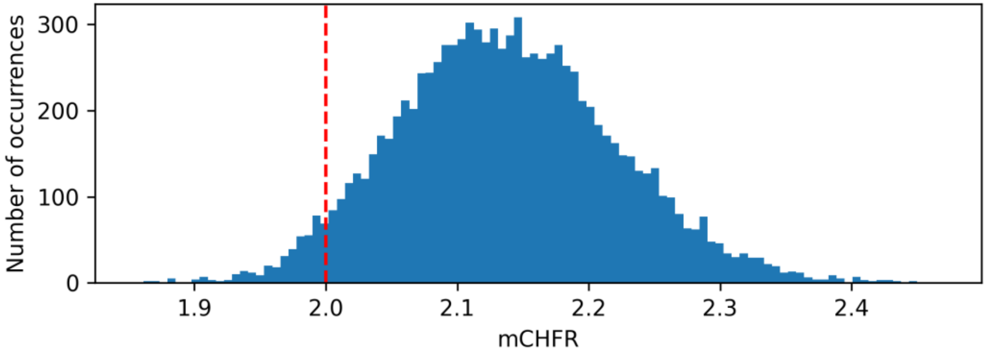


CFD Model of Normalized Streamwise Velocity Profile of NNS Inlet

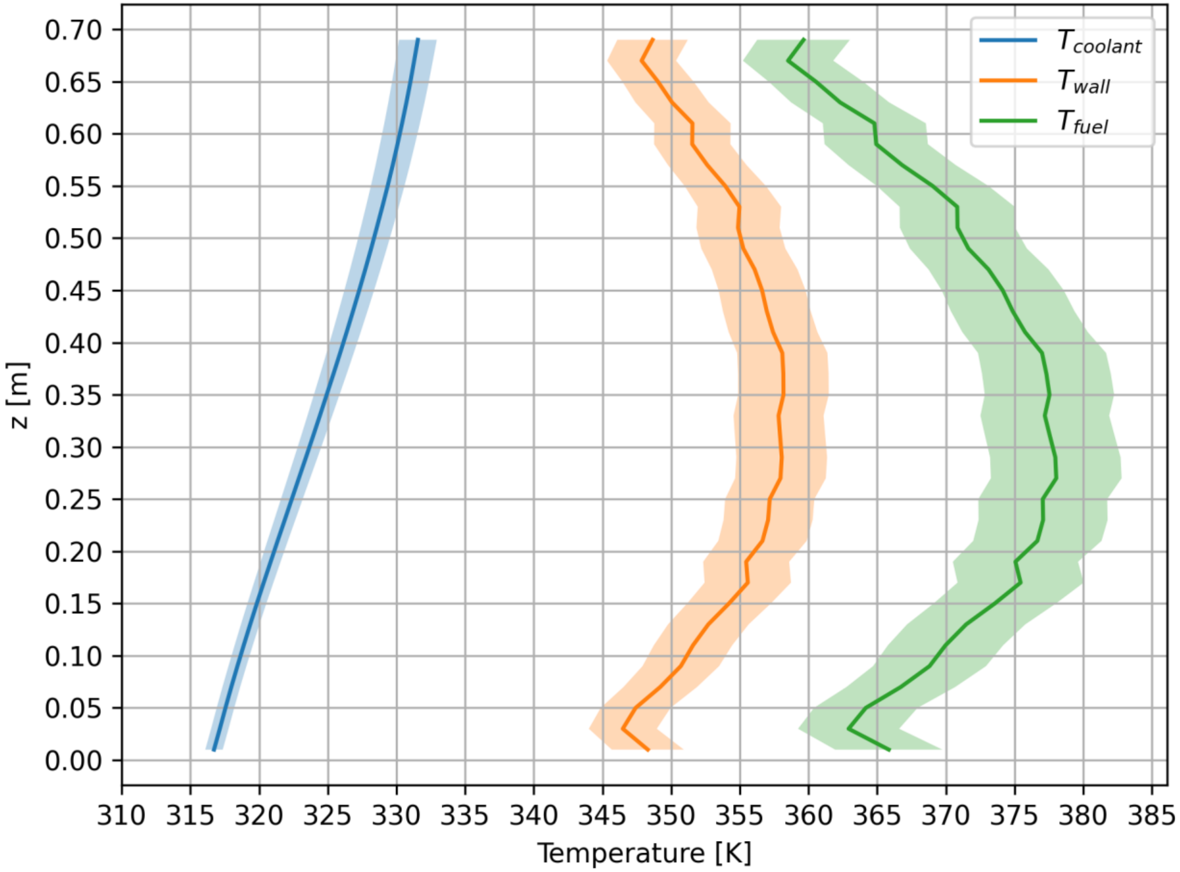
Core Thermal Hydraulics

- In-house developed thermal-hydraulics solver for the reactor core
- Probability of observing a mCHFR of less than 2.0 is 4.2% for the steady-state operation



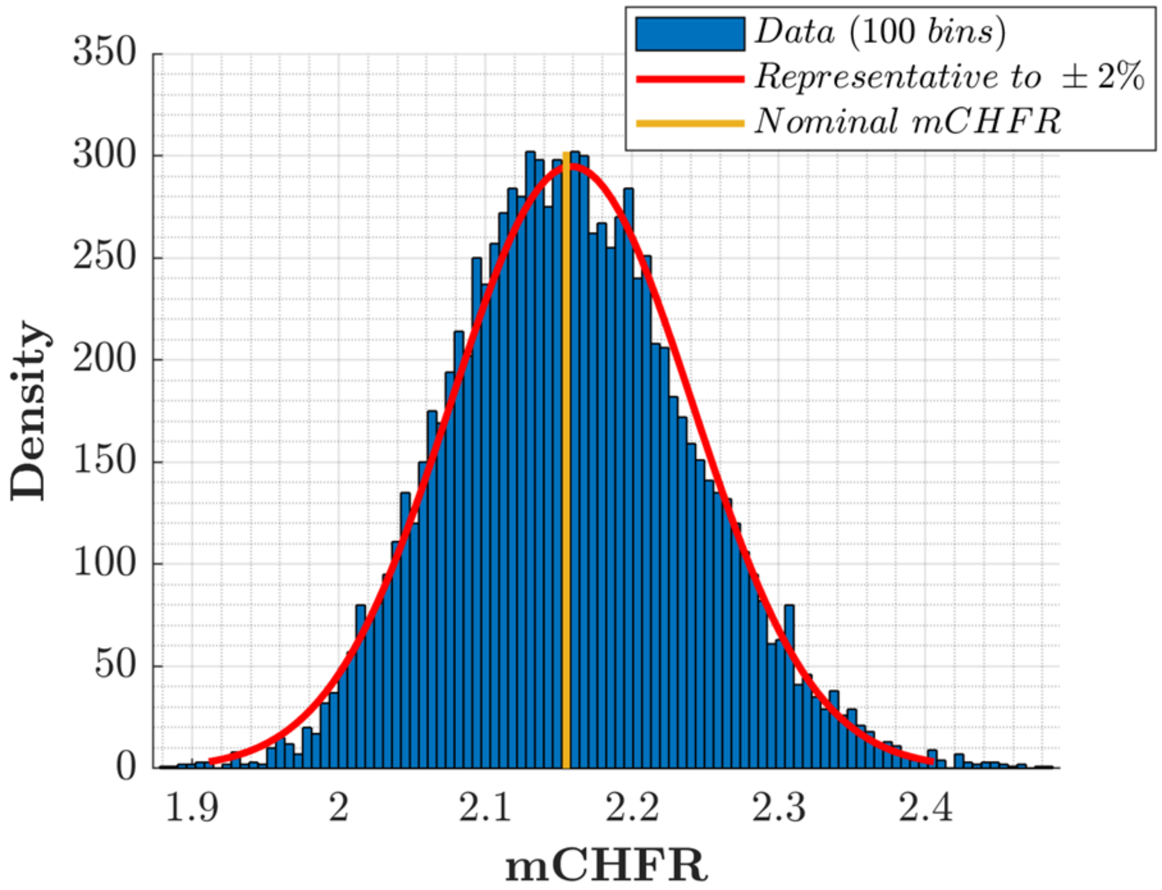


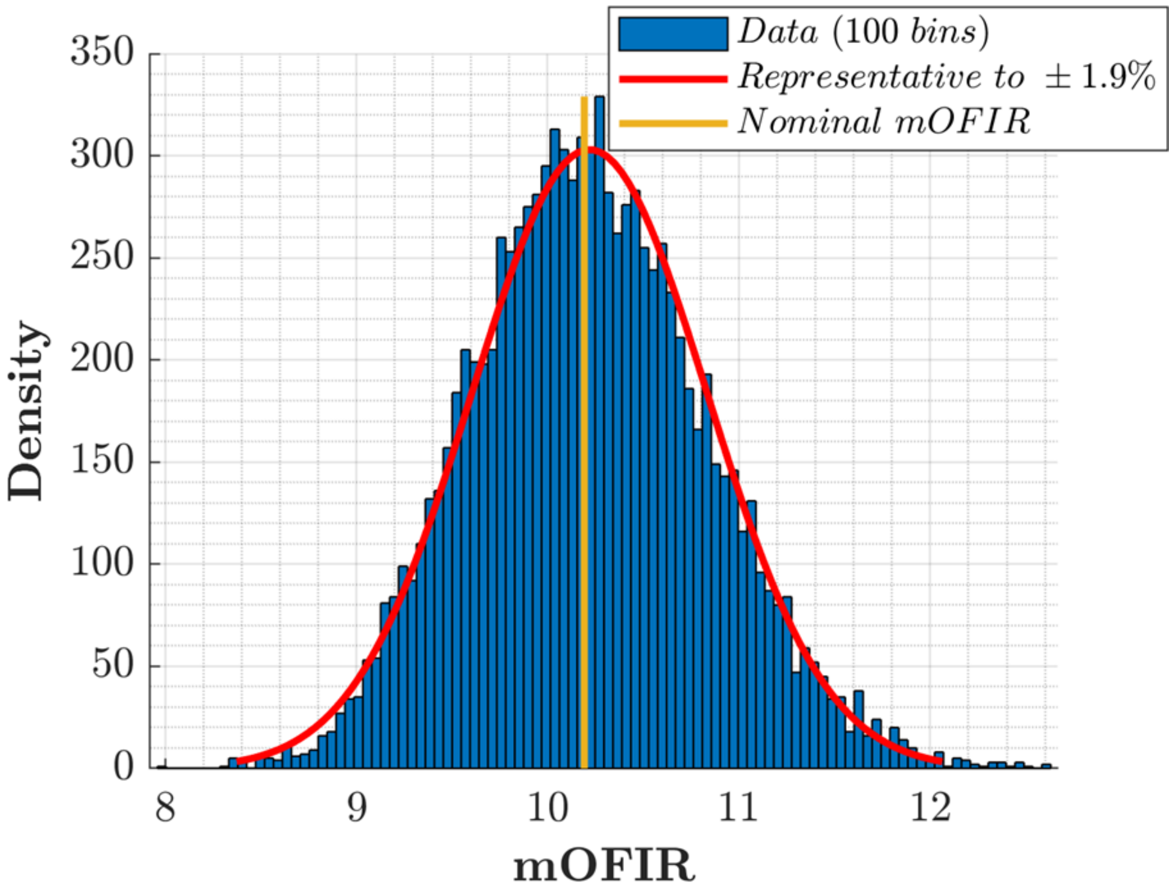
mCHFR distribution at BOC state



Axial distribution of temperature fields at the BOC state

Core Thermal Hydraulics

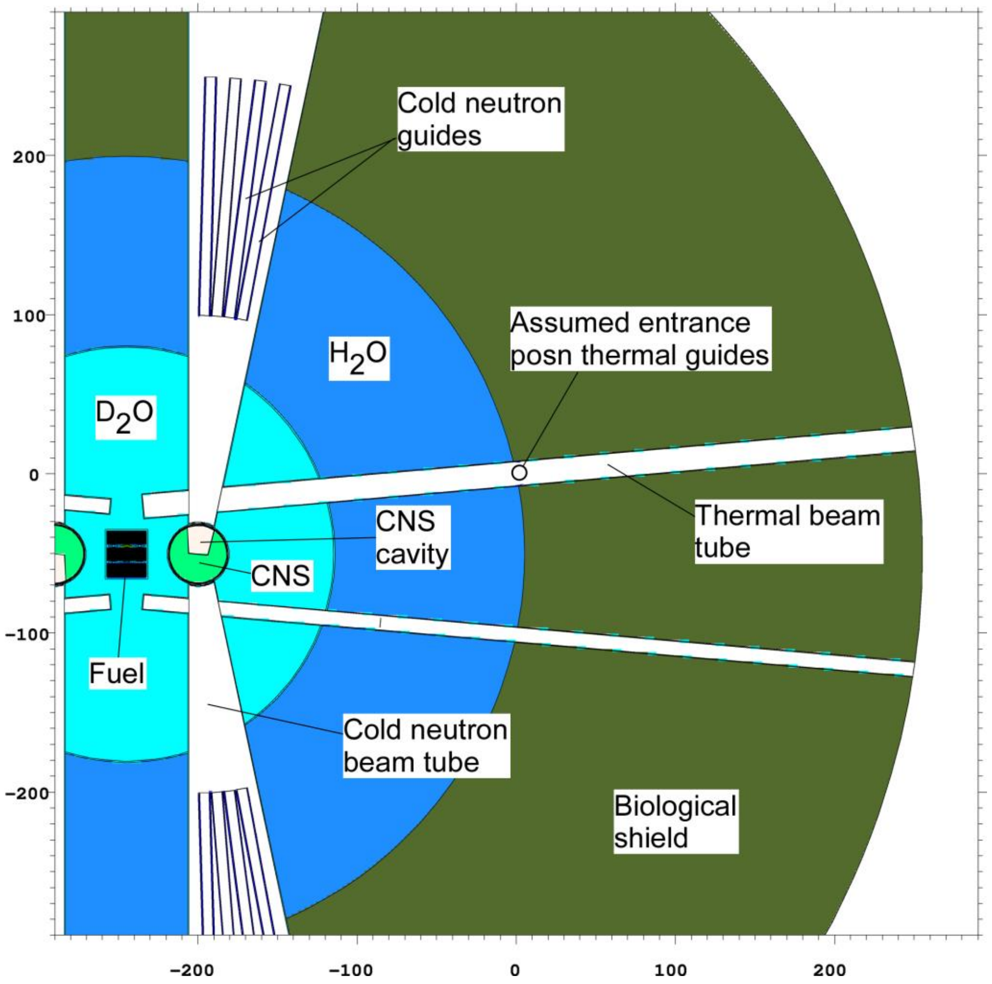




δ_{input}	2σ (95%)	3σ (99.7%)
δ_{mCHFR} (±2%)	7.4%	13.1%
δ_{mOFIR} (±2%)	11.9%	22.2%

±2% uncertainty on each δ_f comes from the Gaussian fit disagreement

Proposed Cold Neutron Instruments

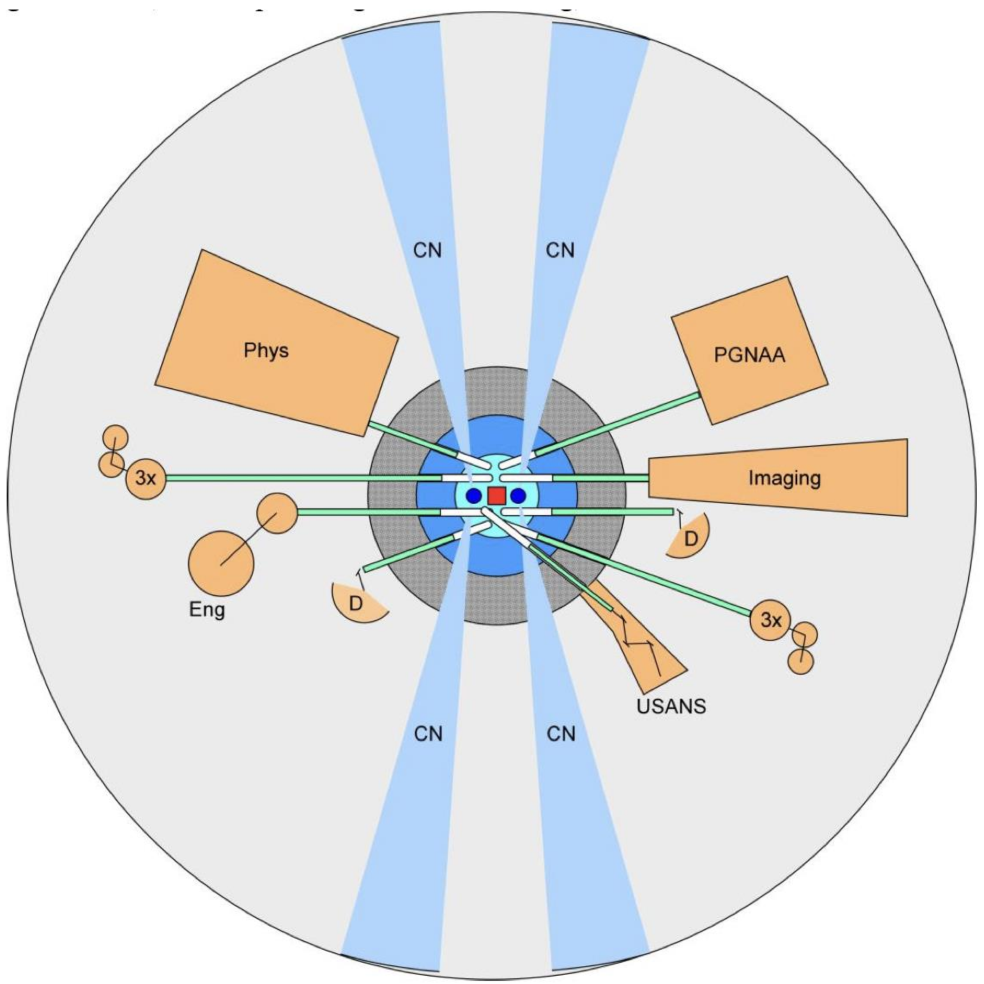


Plan view through the fuel center of the reactor core

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

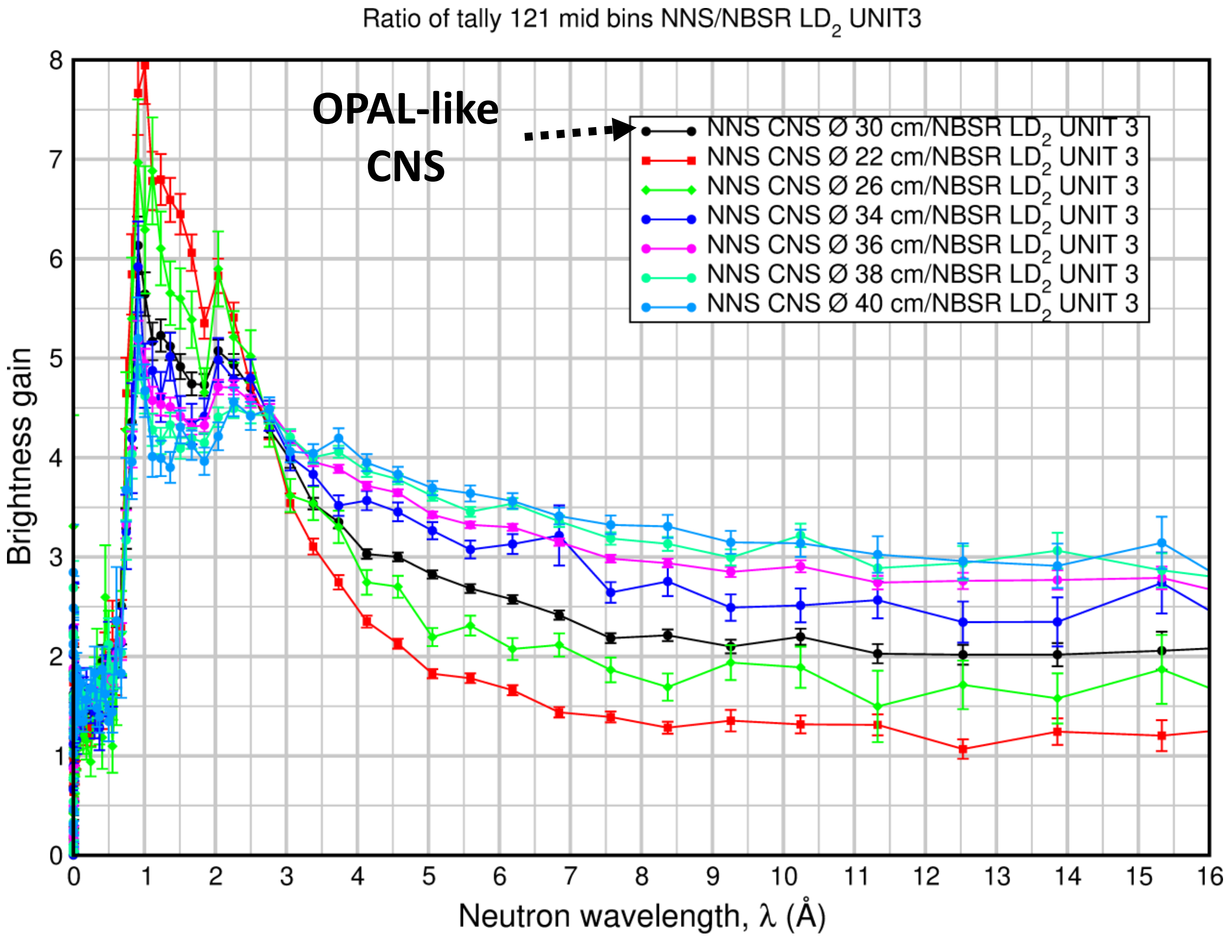
Performance Comparison

Cold Source/ config	J_{tot} (all λ) (s^{-1})	J_{tot} ($\lambda \geq 4$Å) (s^{-1})
NBSR LH_2 Unit 2 (all cold guides)	3.0×10^{13} (Ref. [i])	6.3×10^{12} (Ref. [i])
NNS (6 cm × 15 cm) (16 equivalent guide entrances)	2.3×10^{14}	5.8×10^{13}
Gain NNS/NBSR Unit2	7.5	9.2

Table 13. Estimated "useful" ($\mu > 0.99875$) neutron currents entering guide networks for NBSR (LH_2 Unit 2 cold source, guides NG-A to NG-7) versus NNS with 16 equivalent 6 cm × 15 cm guide entrances at 1.5 m from the cold source center.

Cold Source/ config	J_{tot} (all λ) (s^{-1})	J_{tot} ($\lambda \geq 4$Å) (s^{-1})
NBSR LH_2 Unit 2 (all cold guides)	3.0×10^{13} (Ref. [i])	6.3×10^{12} (Ref. [i])
NNS (6 cm × 20 cm) (16 equivalent guide entrances)	2.8×10^{14}	7.0×10^{13}
Gain NNS/NBSR Unit2	9.1	11.1

Table 14. Estimated "useful" ($\mu > 0.99875$) neutron currents entering guide networks for NBSR (LH_2 Unit 2 cold source, guides NG-A to NG-7) versus NNS with 16 equivalent 6 cm × 20 cm guide entrances at 1.5 m from the cold source center.



Courtesy of Jeremy C. Cook

NNS Publications (since Oct. 2022)

NIST CENTER FOR NEUTRON RESEARCH

1. D. Şahin, et al., "NIST Neutron Source Preconceptual Design", Proceedings of RERTR, Oct. 2022.
2. O. Çelikten, et al., "Highlights of Neutronics Analyses for the Pre-conceptual NIST Neutron Source Design", Proceedings of American Nuclear Society, Nov. 2022.
3. I.R. Baroukh, et al., "A Preliminary Thermal-hydraulics Analysis for the NIST Neutron Source", Proceedings of American Nuclear Society, Nov. 2022.
4. I.R. Baroukh, et al., "Preliminary CFD Investigations for the NIST Neutron Source", Proceedings of American Nuclear Society, Nov. 2022.
5. J.C. Cook, et al., "Proposed NIST Neutron Source User Facility", Proceedings of American Nuclear Society, Nov. 2022.
6. J.C. Cook, et al., "Neutron Delivery Systems Design of the Proposed NIST Neutron Source", Proceedings of American Nuclear Society, Nov. 2022.
7. D. Şahin, et al., "Pre-Conceptual Design of the NIST Neutron Source", Proceedings of RRFM, April 2023.
8. A.G. Weiss, et al., "Modeling Approach for the Design of the NIST Neutron Source", Proceedings of RRFM, April 2023.
9. O. Çelikten, et al., "Comparison of U_3Si_2 and U-10Mo LEU-fueled Reactor Cores for the Preconceptual NIST Neutron Source Design", Proceedings of ICONE30, May 2023.
10. J. Shen, et al., "Turbulence Model Sensitivity Analysis of Thermal-Hydraulic Properties on the Pre-Conceptual NIST Neutron Source Design", Proceedings of ICONE30, May 2023.
11. A.G. Weiss, et al., "Sensitivity Analyses of the Thermal-hydraulics Safety Margins in the Proposed NIST Neutron Source Design", Proceedings of ICONE30, May 2023.
12. Y. Shaposhnik, et al., "Alternative Reflectors for the NIST Neutron Source", In Transactions of TRTR/IGORR, June 2023.
13. A.G. Weiss, et al., "A Turbulence Model Sensitivity Analysis on the Hydraulic Behavior in the Inlet Plenum of the Proposed NIST Neutron Source Design", In Proceedings of NURETH-20, Aug. 2023.
14. A. Gurgen, et al., "Thermal-hydraulic Assessment of the Proposed NIST Neutron Source Design", In Proceedings of NURETH-20, Aug. 2023.

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Thank you for listening!

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Questions??

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