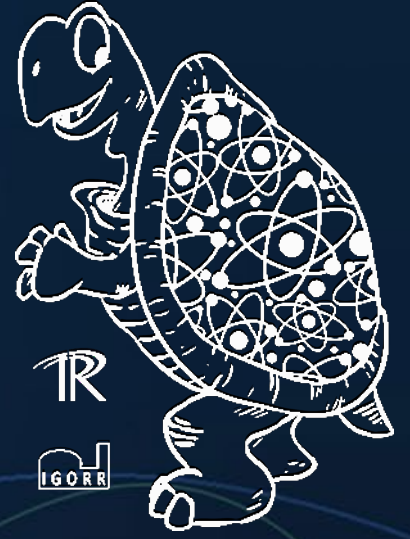
NBSR Path to Equilibrium Core



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National Institute of Standards and Technology
U.S. Department of Commerce

NIST CENTER FOR NEUTRON RESEARCH

Disclaimer

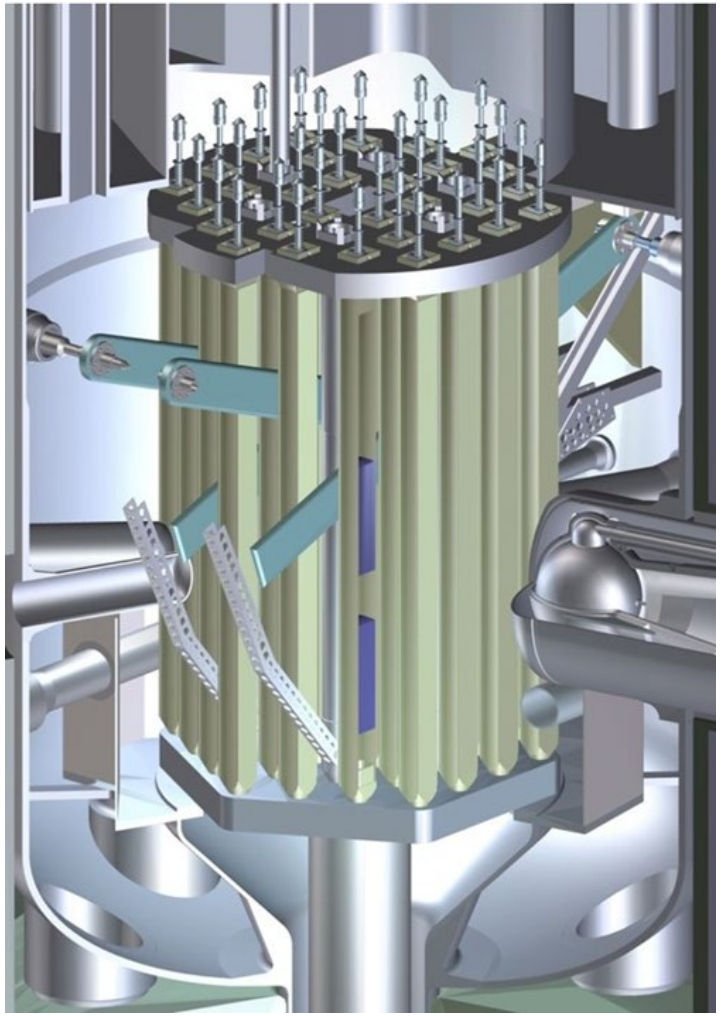
Certain commercial equipment, instruments, or materials are identified in this study in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply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

Outline

- **Introduction**
  - National Bureau of Standards Reactor
  - Startup Core
- **Limitations**
  - Technical Limitations
  - Administrative Limiting Conditions
- **Alternative Fuel Management Scheme Framework**
- **Recovery Fuel Management Scheme**
- **New Startup Core – Cycle 655**
- **Cycle 656**
- **Summary and Discussion**

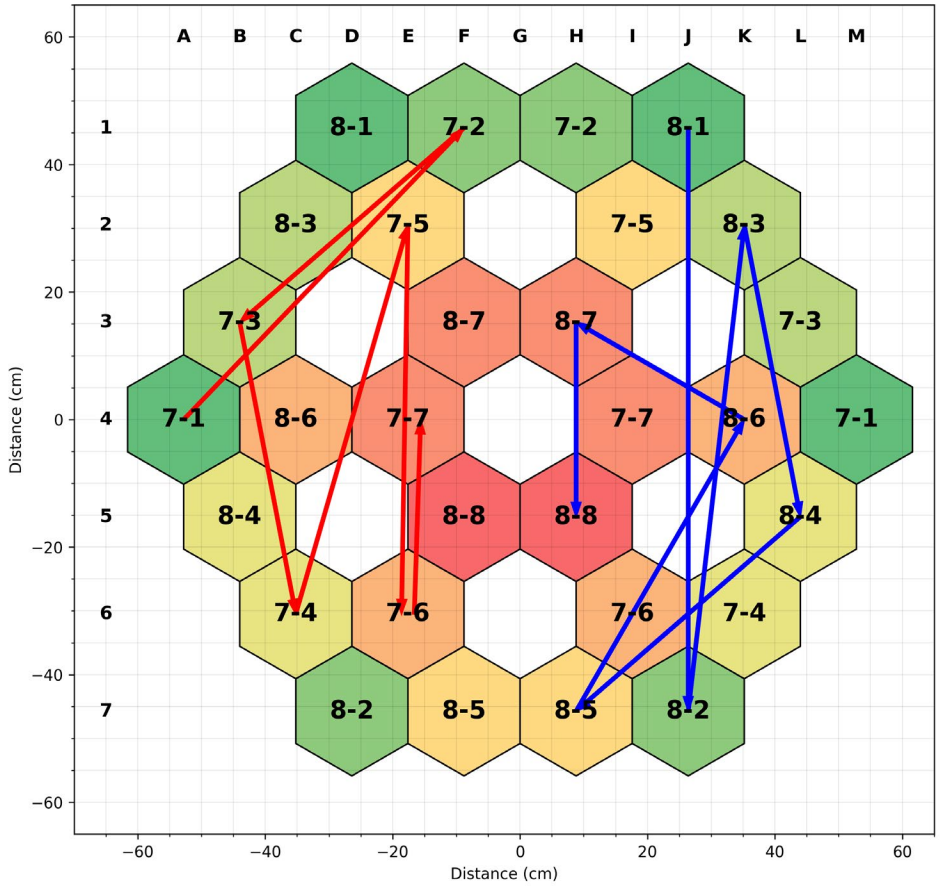
National Bureau of Standards Reactor

- **NCNR is one of the USA's primary resources for neutron research**
- **First criticality in 1967**
- **Originally designed for 10 MW operation**
  - Relicensed at 20 MW
- **Heavy water cooled and moderated**
- **February 3, 2021, partial fuel melting incident**
- **More than 2 years recovery period**
- **Restart authorized in March, 2023**
- **Currently in low-power testing mode**



Introduction

- After the incident in February 2021, debris found on several fuel elements
- All fuel in Cycle 655 are deemed unusable
- Original Fuel Management Scheme (OFMS)
- New core can be constructed utilizing
  - Burned elements (mostly 7th-Cycle)
  - Limited number of fresh fuel elements
- Limitations
  - Technical
  - Administrative



Technical Limitations

- **The confines of NBSR Technical Specifications and UFSAR**
  - Up to 45.0 kilograms ^{235}Uranium of any enrichment & less than 5.0 kilograms fresh.
  - NBSR is authorized steady-state power levels up to a maximum of 20 megawatts (thermal).
  - The reactor fuel cladding temperature shall not exceed 842°F (450°C) for any operating conditions of power and flow.
  - The maximum core excess reactivity shall not exceed 15% Δρ.
  - The reactor shall not be operated unless the shutdown margin provided by the shim arms is greater than 0.757% Δρ ($1.00) with:
    - In any core condition, and
    - All movable experiments in their most reactive condition

Technical Limitations

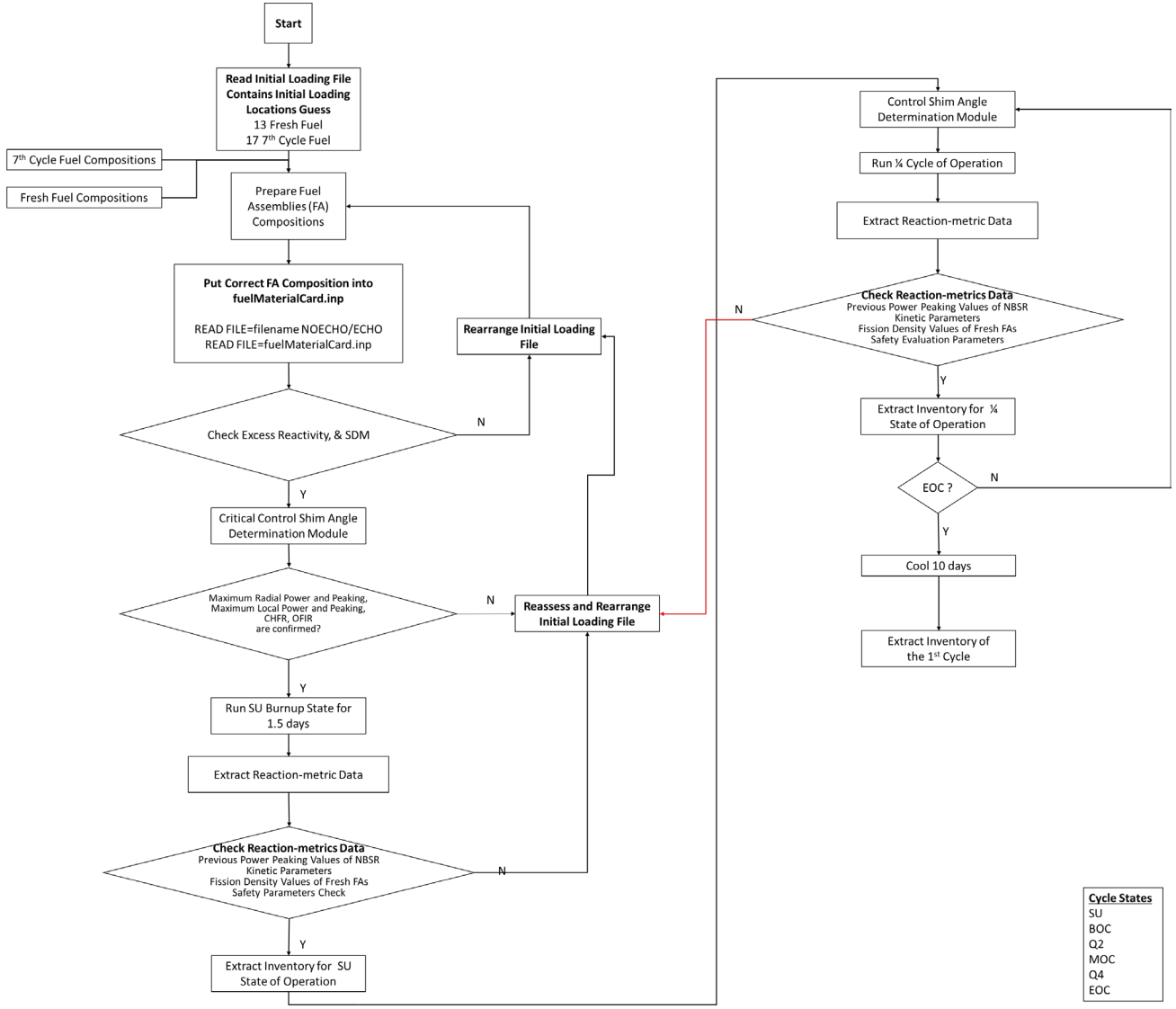
- **The confines of NBSR Technical Specifications and UFSAR**
  - The reactor shall not operate unless all grid positions are filled
  - The average fission density shall not exceed 2×10^{27} fissions/m^3 (73% theoretical burnup)
  - The reactivity insertion rate shall not exceed 5×10^{-4} $\Delta\rho$/sec .
  - The minimum CHFR is dictated by the 80/80 statistic
    - minimum CHFR of 1.19 for an 80% probability of no departure from nucleate boiling (DNB)
    - 1.78 for a 99.9% probability of no DNB

Administrative Limiting Conditions

- **The NBSR inventory has limited number of 7th cycle elements**
- **Only limited inventory being unirradiated or not self-protecting. (10 CFR 73.60 for details)**
- **Time constraints**

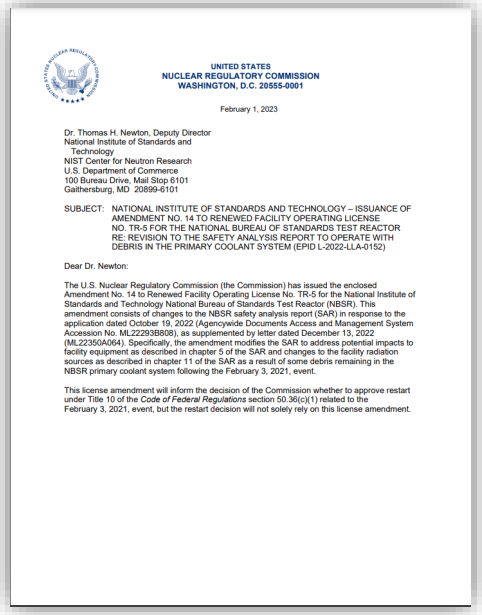
Alternative Fuel Management Scheme Framework

- **Why is it developed?**
  - For trial multiple schemes
  - Easy to assess
  - Reassessment of reloading in the operation
  - Using for the following cycles
- **Assessed Criteria**
  - Excess reactivity at SU
  - Enough Shim Reactivity (Worth)
  - Maximum power peaking
  - Minimum CHFR
  - Minimum OFIR



License Amendment Requests (LARs)

- **“Operate with Debris in the Primary Coolant System” (ML23020A911)**
- **“Alternative Fuel Management Scheme” (ML23055A300, ML23033A114, ML23033A115, and ML23033A119)**



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

February 1, 2023

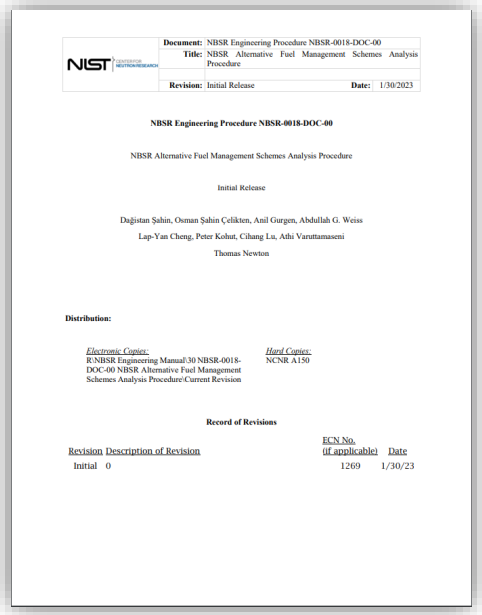
Dr. Thomas H. Newton, Deputy Director
National Institute of Standards and Technology
NIST Center for Neutron Research
U.S. Department of Commerce
100 Bureau Drive, Mail Stop 6101
Gaithersburg, MD 20899-6101

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.



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

Initial Release

Dağıstan Şahin, Osman Şahin Çelikten, Anil Gurgen, Abdullah G. Weiss
Lap-Yan Cheng, Peter Kohut, Cihang Lu, Athi Varuttamaseni
Thomas Newton

Distribution:

Electronic Copies:
R:\NBSR Engineering Manual\30 NBSR-0018-DOC-00 NBSR Alternative Fuel Management Schemes Analysis Procedure\Current Revision

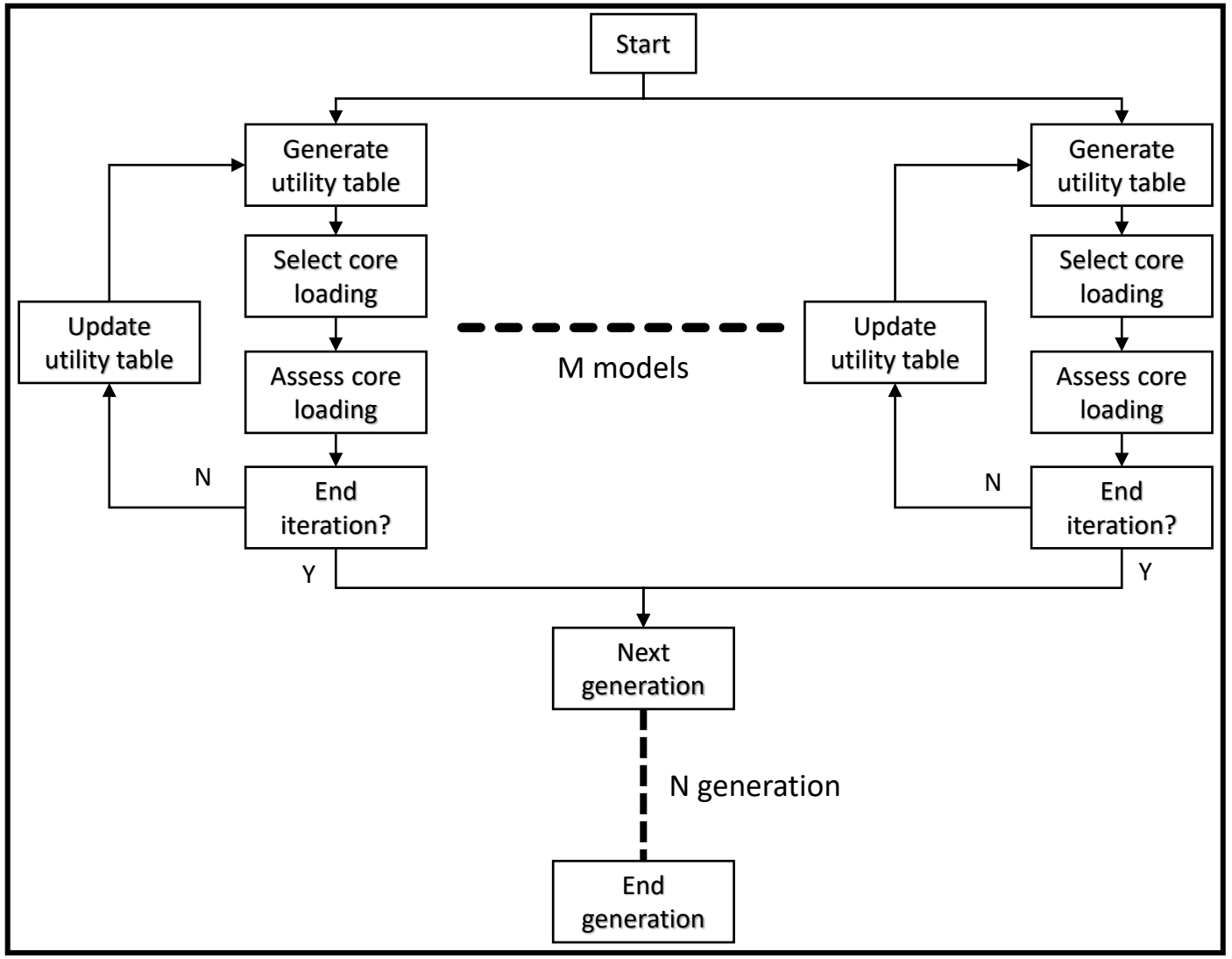
Hard Copies:
NCNR A150

Record of Revisions

Revision	Description of Revision	ECN No. (if applicable)	Date
Initial	0	1269	1/30/23

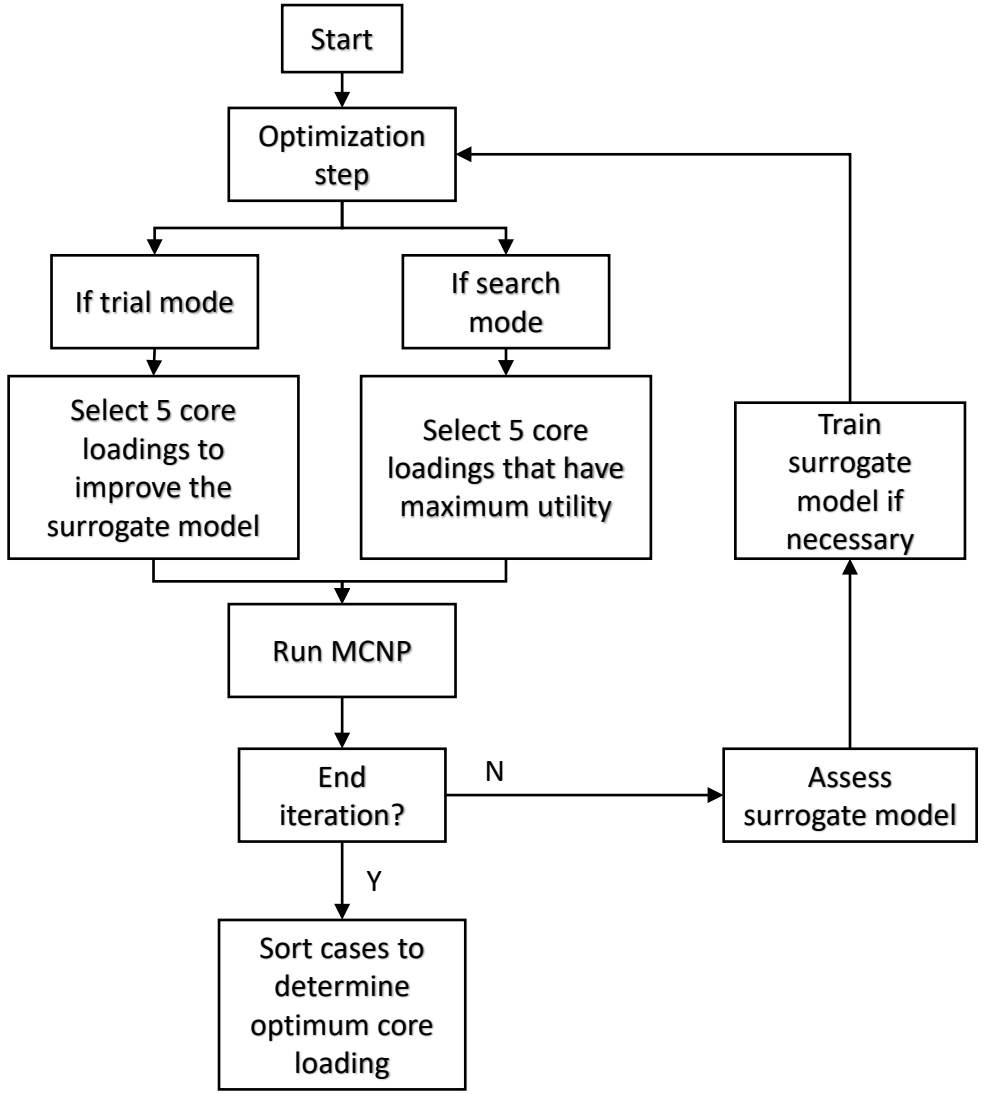
Core Loading Optimization Strategy

- **Metaheuristic combinatorial optimization**
- **Optimize excess reactivity, maximum PPF, and core PPF balance for a cycle**
- **Fast-response surrogate model of MCNP**
  - Voting ensemble regressor for robustness
- **Single-solution model (Exploitation)**
  - Updating utility tables based on the reward/penalty
- **Population model (Exploration)**
  - Recombination of utility tables of better solutions

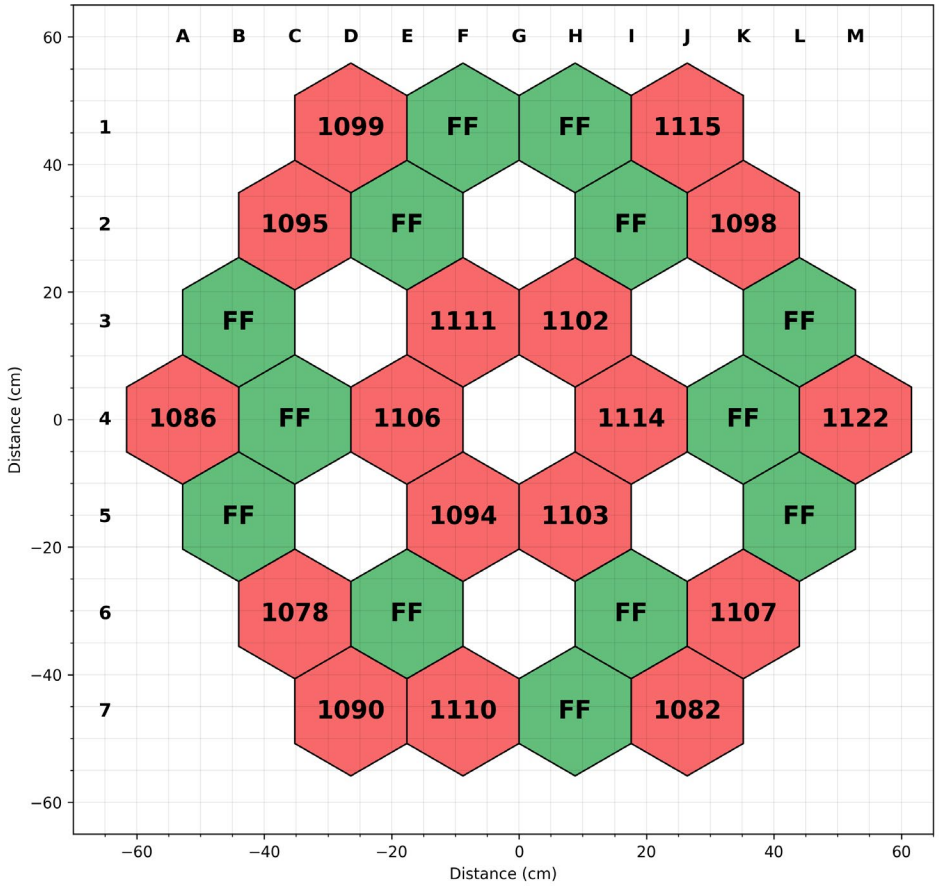


Core Loading Optimization Strategy

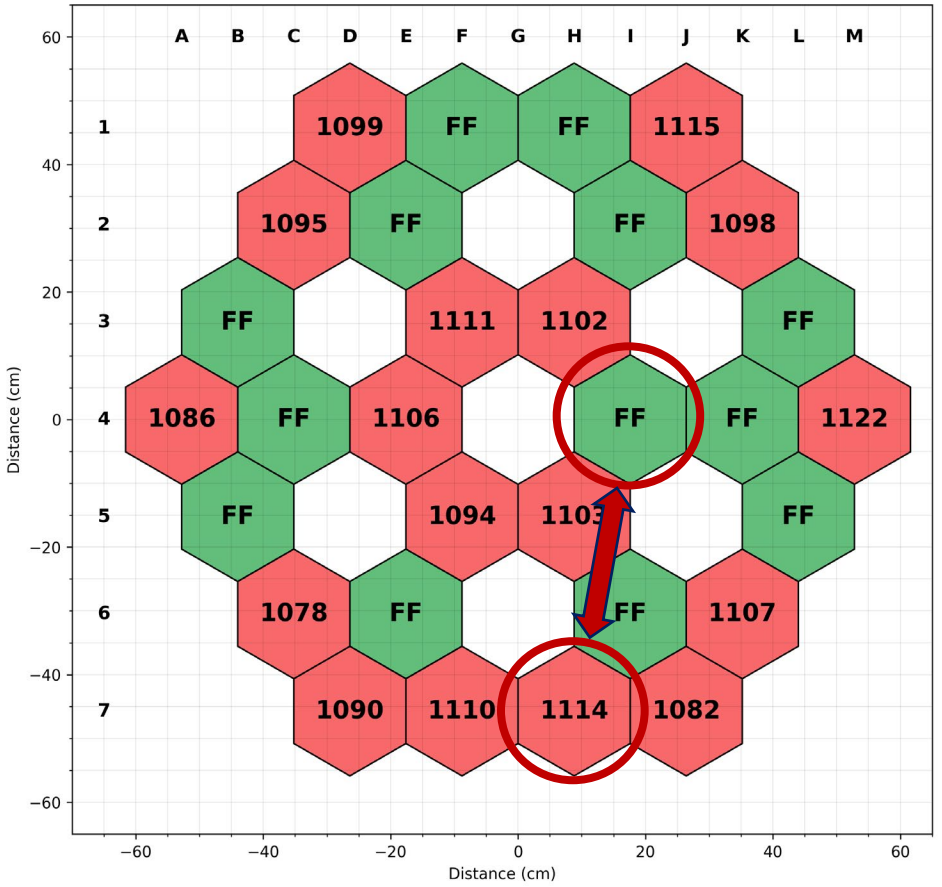
- **Optimizer model is fully coupled with MCNP**
  - Update initial loading file, processing of MCNP output
- **Active learning strategy**
  - Propose core loading schemes to improve the surrogate model
  - Re-train the surrogate model if necessary
- **Search for the optimal core**
  - Longer search to approximate the global optimum of the surrogate model
  - Run MCNP for actual values



New Startup Core – Cycle 655



Opt53



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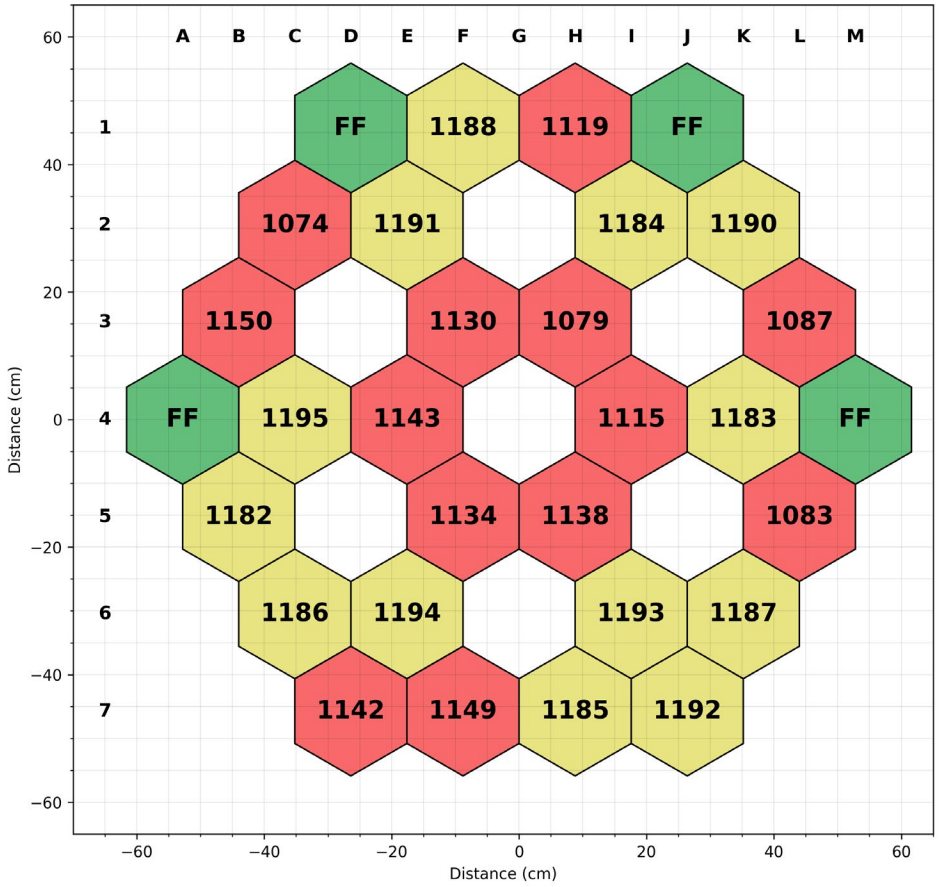
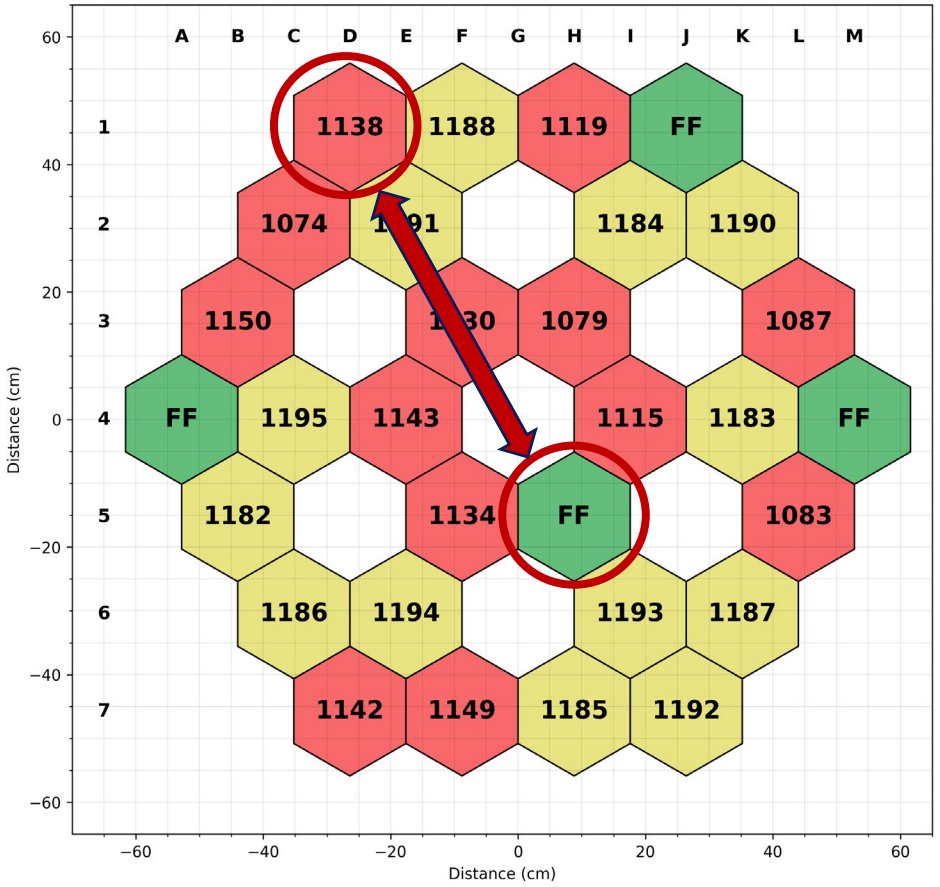
Cycle 656



Case125



M12510

Recovery Fuel Management Scheme

4 Fuel Elements Case

			1		2		3		4		5		6		7		8		9		10	
			ORDER 13		ORDER 4		ORDER 4		ORDER 4		ORDER 4		ORDER 4		ORDER 4		ORDER 4		ORDER 4		ORDER 4	
Cycle	U-235		Cycle 655		Cycle 656		Cycle 657		Cycle 658		Cycle 659		Cycle 660		Cycle 661		Cycle 662		Cycle 663		Cycle 664	
Burned	mass			mass		mass		mass		mass		mass		mass		mass		mass		mass		mass
0	350		13	4550	4	1400	4	1400	4	1400	4	1400	4	1400	4	1400	4	1400	4	1400	4	1400
1	318			0	13	4134	4	1272	4	1272	4	1272	4	1272	4	1272	4	1272	4	1272	4	1272
2	286			0		0	13	3718	4	1144	4	1144	4	1144	4	1144	4	1144	4	1144	4	1144
3	254			0		0		0	13	3302	4	1016	4	1016	4	1016	4	1016	4	1016	4	1016
4	222			0		0		0		0	10	2220	4	888	4	888	4	888	4	888	4	888
5	190			0		0		0		0		0	6	1140	4	760	4	760	4	760	4	760
6	158			0		0		0		0		0		0	4	632	4	632	4	632	4	632
7	126		17	2142	13	1638	9	1134	5	630	4	504	4	504	2	252	2	252	2	252	2	252
		# of Elemen	30		30		30		30		30		30		30		30		30		30	
		Total Mass		6692		7172		7524		7748		7556		7364		7364		7364		7364		7364
		Difference From Origin		-688		-208		144		368		176		-16		-16		-16		-16		-16
		7th cycle needed		54																		
		7th cycle available		53																		

5 Fuel Elements Case

			1		2		3		4		5		6		7		8		9		10	
			ORDER 13		ORDER 5		ORDER 4		ORDER 4		ORDER 4		ORDER 4		ORDER 4		ORDER 4		ORDER 4		ORDER 4	
Cycle	U-235		Cycle 655		Cycle 656		Cycle 657		Cycle 658		Cycle 659		Cycle 660		Cycle 661		Cycle 662		Cycle 663		Cycle 664	
Burned	mass			mass		mass		mass		mass		mass		mass		mass		mass		mass		mass
0	350		13	4550	5	1750	4	1400	4	1400	4	1400	4	1400	4	1400	4	1400	4	1400	4	1400
1	318			0	13	4134	5	1590	4	1272	4	1272	4	1272	4	1272	4	1272	4	1272	4	1272
2	286			0		0	13	3718	5	1430	4	1144	4	1144	4	1144	4	1144	4	1144	4	1144
3	254			0		0		0	13	3302	5	1270	4	1016	4	1016	4	1016	4	1016	4	1016
4	222			0		0		0		0	10	2220	4	888	4	888	4	888	4	888	4	888
5	190			0		0		0		0		0	6	1140	4	760	4	760	4	760	4	760
6	158			0		0		0		0		0		0	4	632	4	632	4	632	4	632
7	126		17	2142	12	1512	8	1008	4	504	3	378	4	504	2	252	2	252	2	252	2	252
		# of Elemen	30		30		30		30		30		30		30		30		30		30	
		Total Mass		6692		7396		7716		7908		7684		7364		7364		7364		7364		7364
		Difference From Origin		-688		16		336		528		304		-16		-16		-16		-16		-16
		7th cycle needed		50																		
		7th cycle available		53																		

Summary and Discussion

- **Although All technical and administrative limitations, NBSR cores were constructed with seventeen 7th-cycle and thirteen fresh fuel elements and became critical on March 16, 2023, after Feb 2021.**
- **The measurements and the calculated results with AFMS were acceptable. Calculated results are conservative**
- **A core loading framework was developed:**
  - Alternative Fuel Management Scheme (AFMS)
- **An optimization algorithm was developed by using Machine Learning algorithms (Not included in the AFMS procedures, used internally for initial load determination only):**
  - AFMS Optimizer
  - Automatically configure cores, try, and assess.
  - Gradually learning by each core configuration

Summary and Discussion

- **Cycles 655 and 656 were prepared with AFMS**
- **Waiting for the full power operation to complete the next cycles**
- **Expecting the approximate OFMS loading can be reached after 662 but the OFMS loading mass could be reached 2 cycles earlier if the *4 Fuel Element Case is adopted***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