Core Design Studies for a BWR-Based Small Modular Reactor with Long-Life Core

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Outline of the Talk

- Introduction
- NMR-50 Design Concepts
- Core Design objective and Constraints
- Design Approaches and Analysis Methods
- Core Design and Performance Characteristics
- Summary and Conclusions

Introduction of the NMR-50

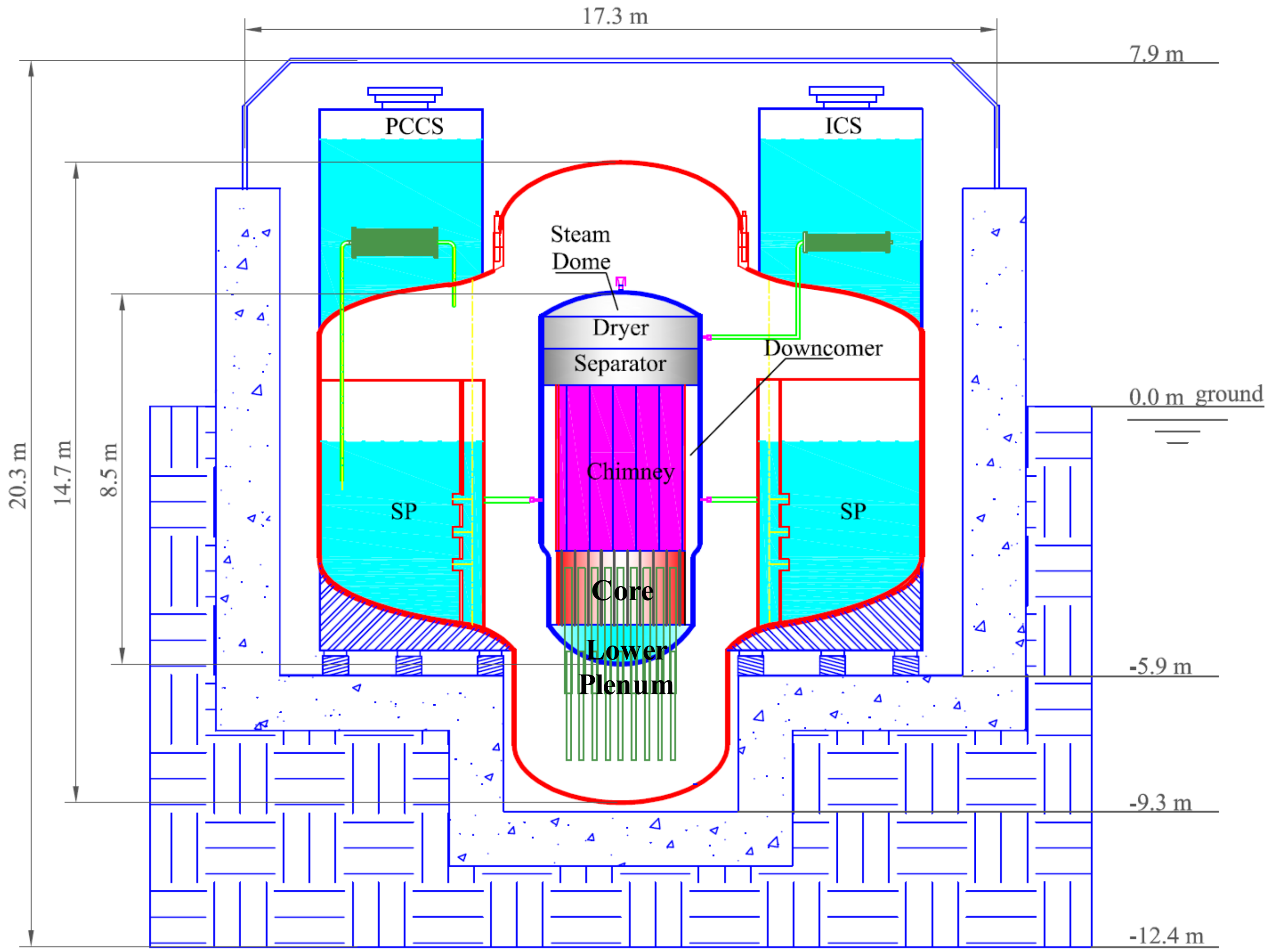
- NMR-50 is a small modular reactor with long-life core – 50 MWe Novel Modular Reactor.
- Research labs at Purdue University take the leading role of the NMR-50 development.
- NMR-50 is an renovated design based on GE's SBWR-600[1] and Purdue's SBWR-200[2].
- NMR-50 combines passive safety feature of the latest BWR technologies on small and modular scale.
- NMR-50 is favorable to be deployed in remote or isolated areas.

1. GENERAL ELECTRIC, "Simplified Boiling Water Reactor Standard Safety Analysis Report (SSAR)," 25A5113 Rev. A, August, (1992).
2. D.R. TINKLER and T.J. DOWNAR, "The Neutronics Design and Analysis of A 200-MW (Electric) Simplified Boiling Water Reactor Core," *Nuclear Technology*, **142** (3), p. 230-242 (2003).

Comparison of Key Design Parameters of Several LWR-Based SMRs

SMR		NMR-50	NuScale	mPower	IRIS
Type		Simplified BWR	Integral PWR	Integral PWR	Integral PWR
Primary coolant system		Two-phase natural circulation	Single phase Natural circulation	Forced circulation	Forced circulation
Rating		50 MWe	45 MWe	125 MWe	335 MWe
Primary system pressure		7.171 MPa	12.76 MPa	14 MPa	15.5 MPa
Reactor vessel	Height	8.5 m	13.7 m	23 m	21.3 m
	Diameter	3.48 m	2.7 m	3.6 m	6.78 m
Refueling cycle		10 years	2 years	5 years	2.5 - 4 years
Enrichment		5%	<4.95%	5%	4.95%

Schematic View of Passive Safety Systems of NMR-50



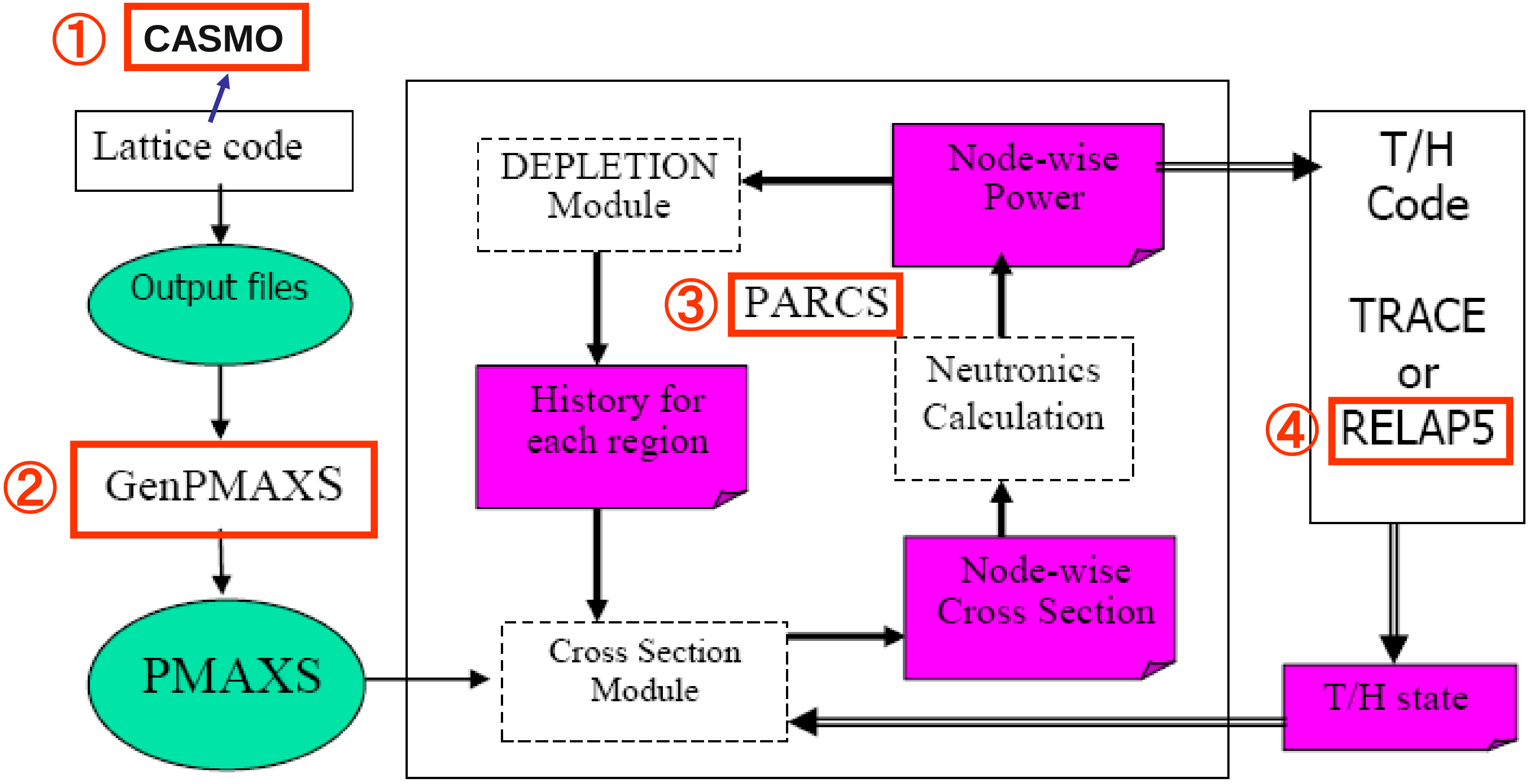
Ref. M. Ishii et al., “Double Passively Safe Novel Modular Reactor 50”, NUEP CFP Narrative 3493, (2012)

Core Design Objective and Constraints

Parameter	Value
Thermal power (MW)	165.0
Cycle length (years)	10.0
Maximum fuel enrichment (wt. %)	5.0
Total power peaking factor	2.73
Axial power peaking factor	1.45
MFLPD (kW/m)	45.0
MCPR	1.32

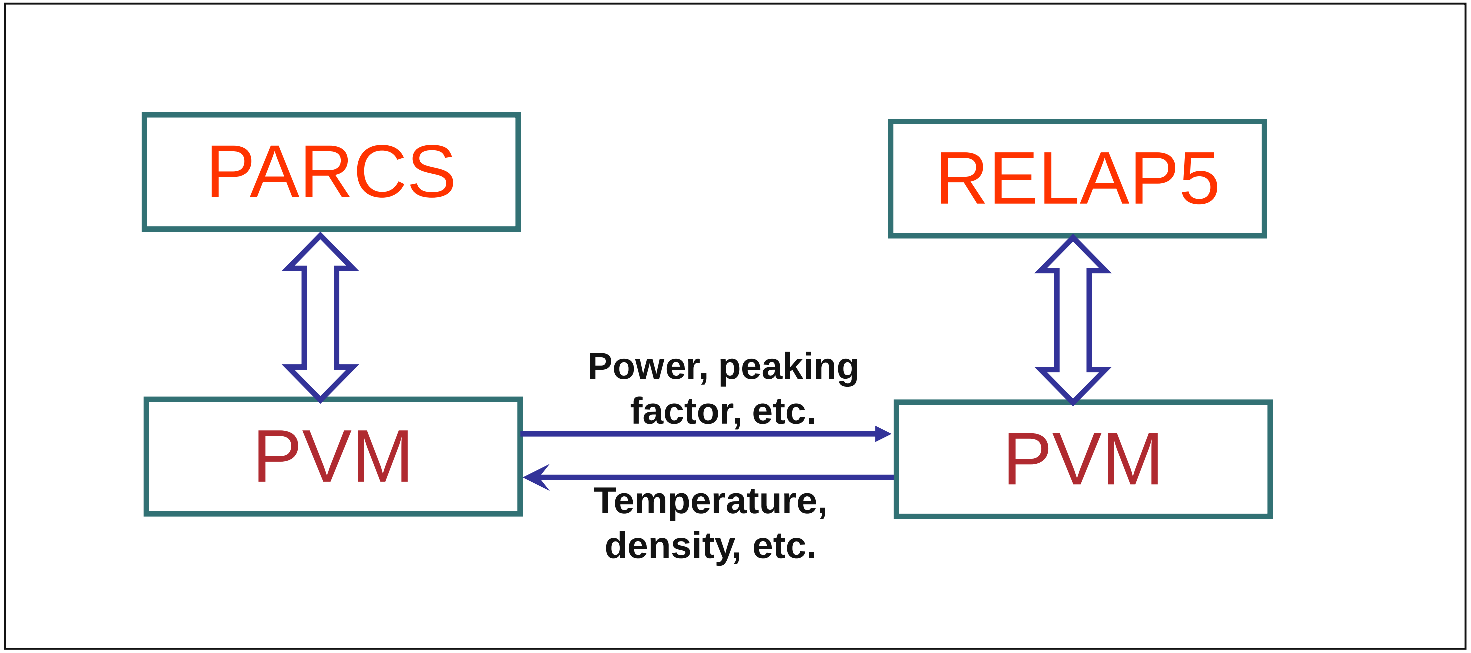
- Maximum fuel linear power density (MFLPD)
  - Characterize the limit of peak clad temperature during LOCA
- Minimum critical power ratio (MCPR)
  - Characterize the critical heat flux when the water dryout occurs in BWR

Design and Analysis Code System



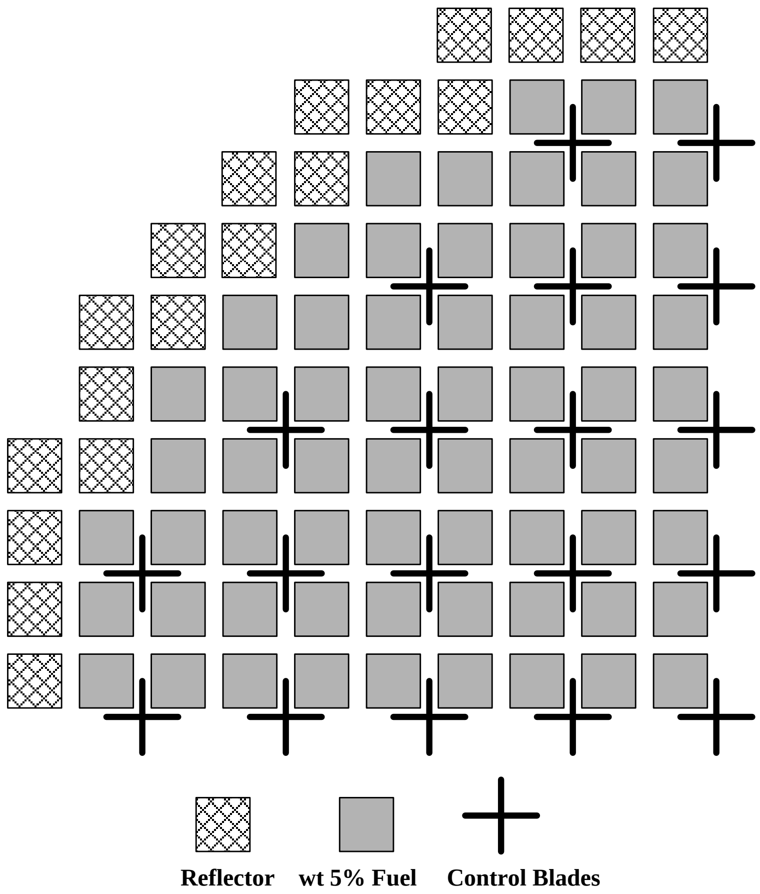
Ref. Y. Xu and T. Downar, "GenPMAXS-V6: Code for Generating the PARCS Cross Section Interface File PMAXS", GenPMAXS manual, University of Michigan, March (2012)

Parallel Virtual Machine (PVM)



The messages coupling PARCS and Relap5 are transferred via PVM.

Single-batch Core Design for NMR-50

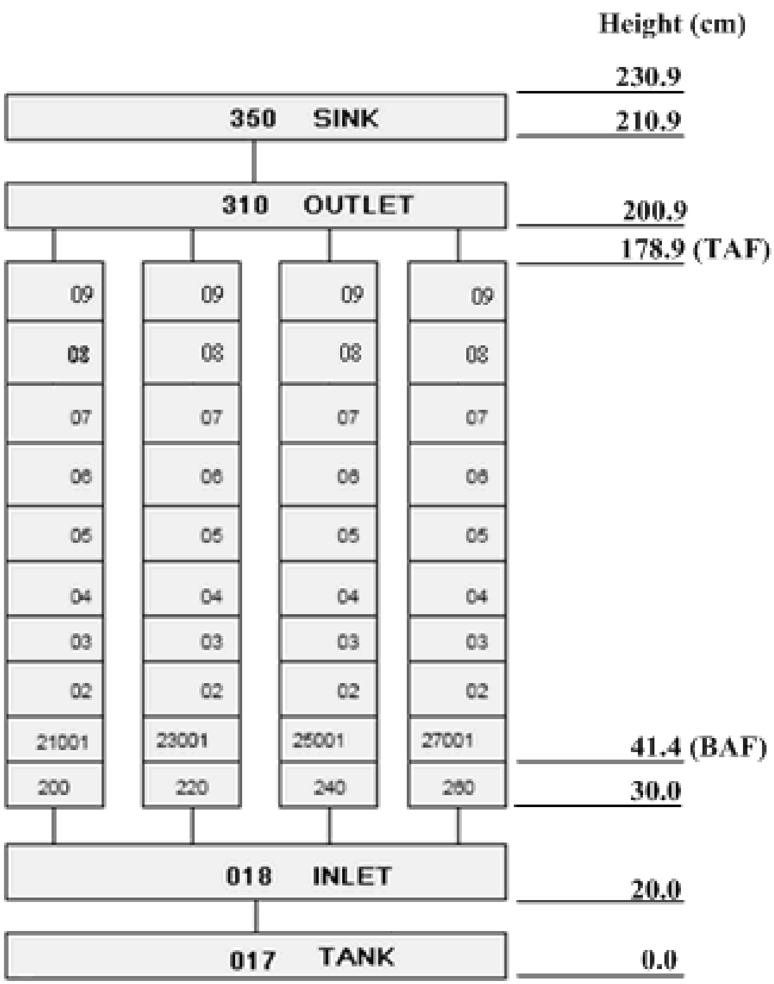


NMR-50 Core design parameters
(Prepared for PARCS input)

Core Property	Parameter
Assembly layout	18 x 18
Active fuel length (m)	1.372
Bottom reflector length (m)	0.1524
Top reflector length (m)	0.1524
Equivalent core diameter (m)	2.73
Number of fuel assemblies	256
Control blades	57

Radial view of quarter core configuration

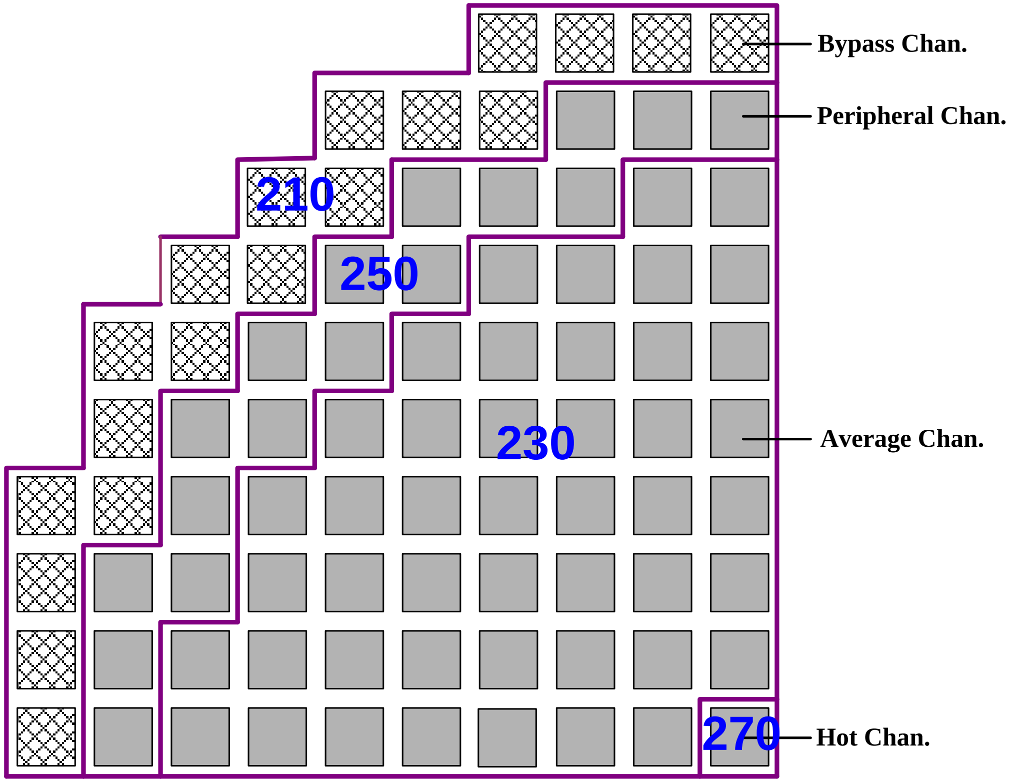
Simplified T/H Model for NMR-50 Core



Some T/H design parameters (Prepared for RELAP5 input)

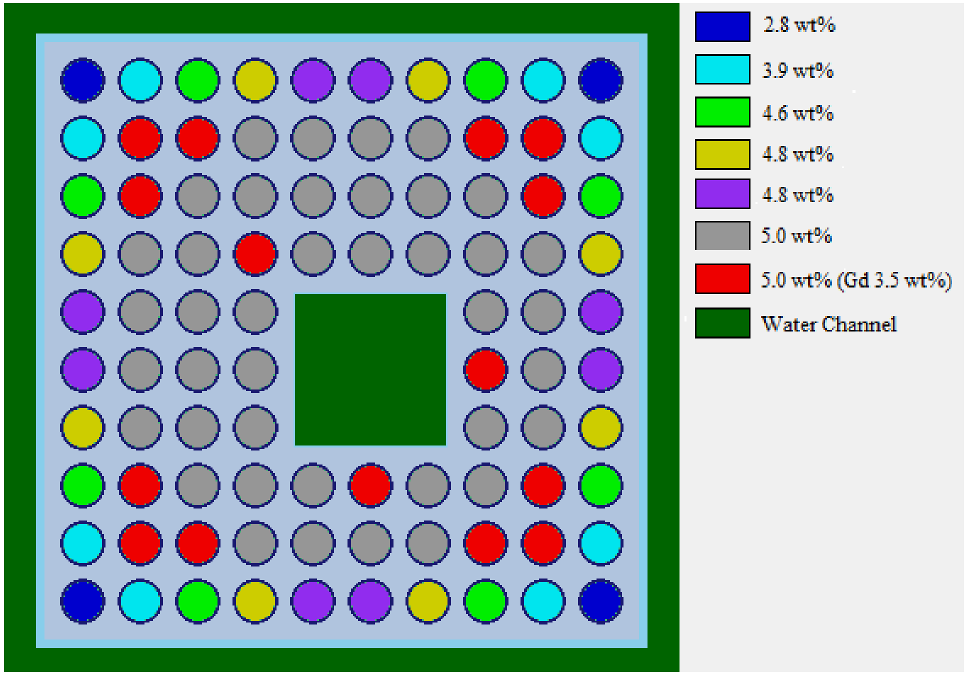
Core Property	Parameter
Core coolant rate (kg/h)	2.23 x 10^6
Power density (kW/liter)	20.75
Core pressure (MPa)	7.178
Active fuel length (m)	1.372
Average coolant exit quality	0.143
Core average coolant void fraction	0.455
Coolant saturation Temp. (^oC)	287.3
Coolant Inlet Temp. (^oC)	278.5
Total flow area (m^2)	4.013
Bypass flow area (m^2)	1.763

Radial Mapping of Neutronics and T/H Model



Relap5 volume	Channel type	Number of assemblies
210	Bypass channel (reflector)	n/a
230	Average channel	184
250	Peripheral channel	68
270	Hot channel	4

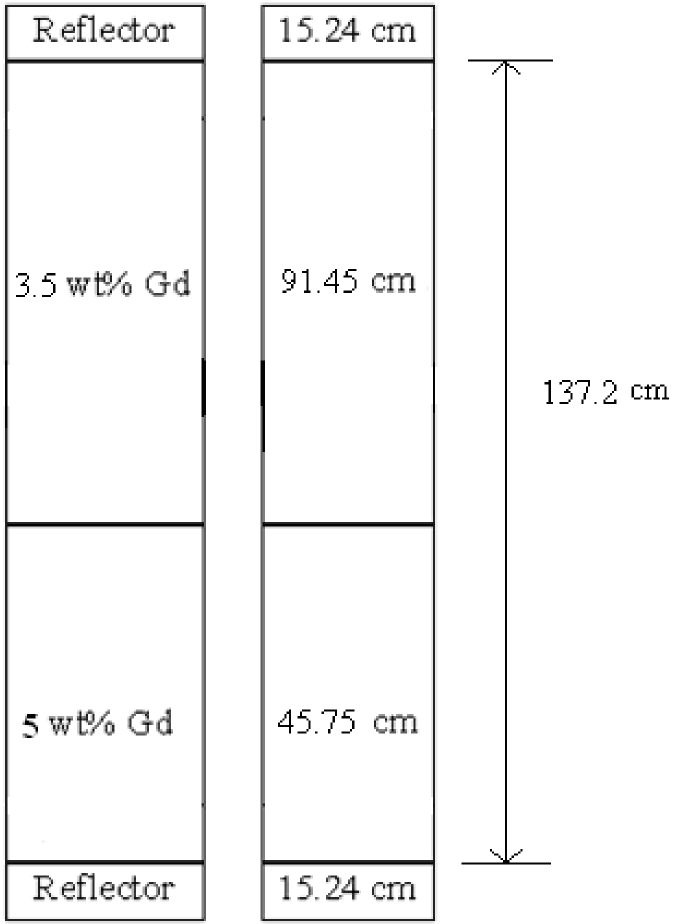
The NMR-50 Fuel Assembly (similar to AREVA Atrium-10B)



Design Parameters of NMR-50 Fuel Assembly

Property	Parameter
Average U-235 wt%	4.75
Average Gd wt% in Gd rod	4.00
Fuel rod diameter (mm)	10.55
Water/Fuel ratio	2.33
Specific power (W/gU)	8.76
Cycle burnup (GWd/T)	33.40
Cycle length (years)	10.44
Local peaking factor	1.27
k_{inf} at BOC	1.06059

Axial Zoning of the Gd Fuel Rods



- ✓ Different Gd wt% in axial zones to counteract the reactivity penalty resulted from void in the upper region
- ✓ Two graphite reflectors are placed on bottom and top segment of the fuel rod
- ✓ The active fuel length for the fuel rod is 137.2 cm

Some Neutronics Results for <u>NMR-50</u> at BOC

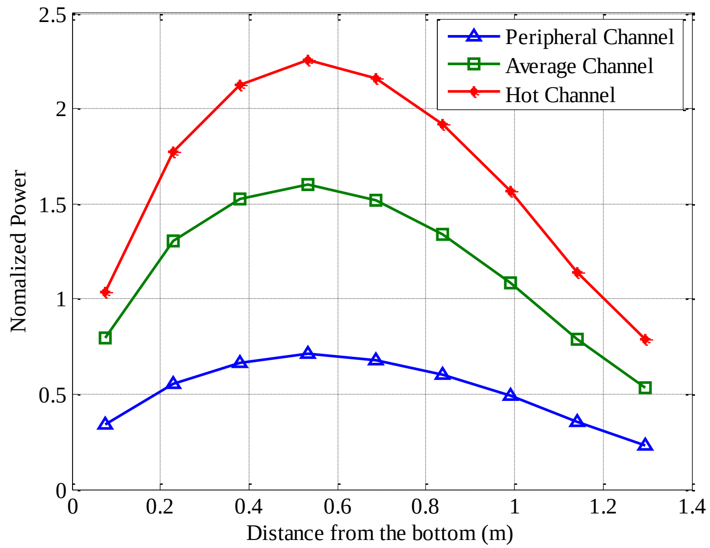
Initial CR Positions

			0	0
		0	0	0
	0	0	0	2192
0	0	0	2192	2392
0	0	2192	2392	2392

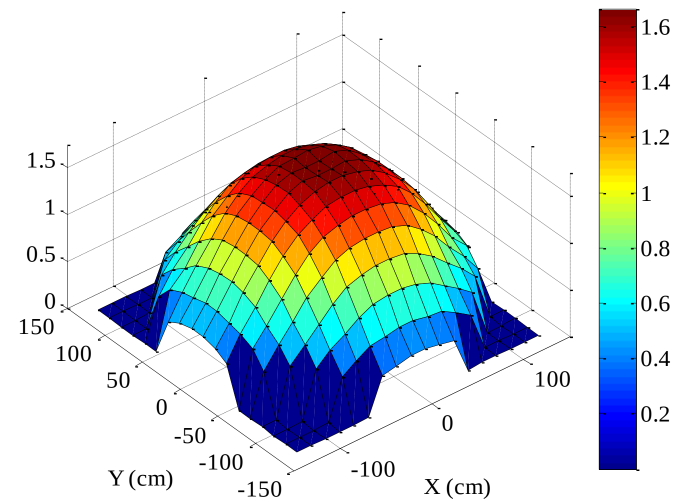
Final CR Positions

			0	0
		0	0	0
	0	0	0	229
0	0	0	229	249
0	0	229	249	270

Fig. Control rod insertion positions for criticality search at BOC. The notch value is 3192 for a fully inserted control blades and 0 for a fully withdrawn one.



Axial power distribution for different flow channel



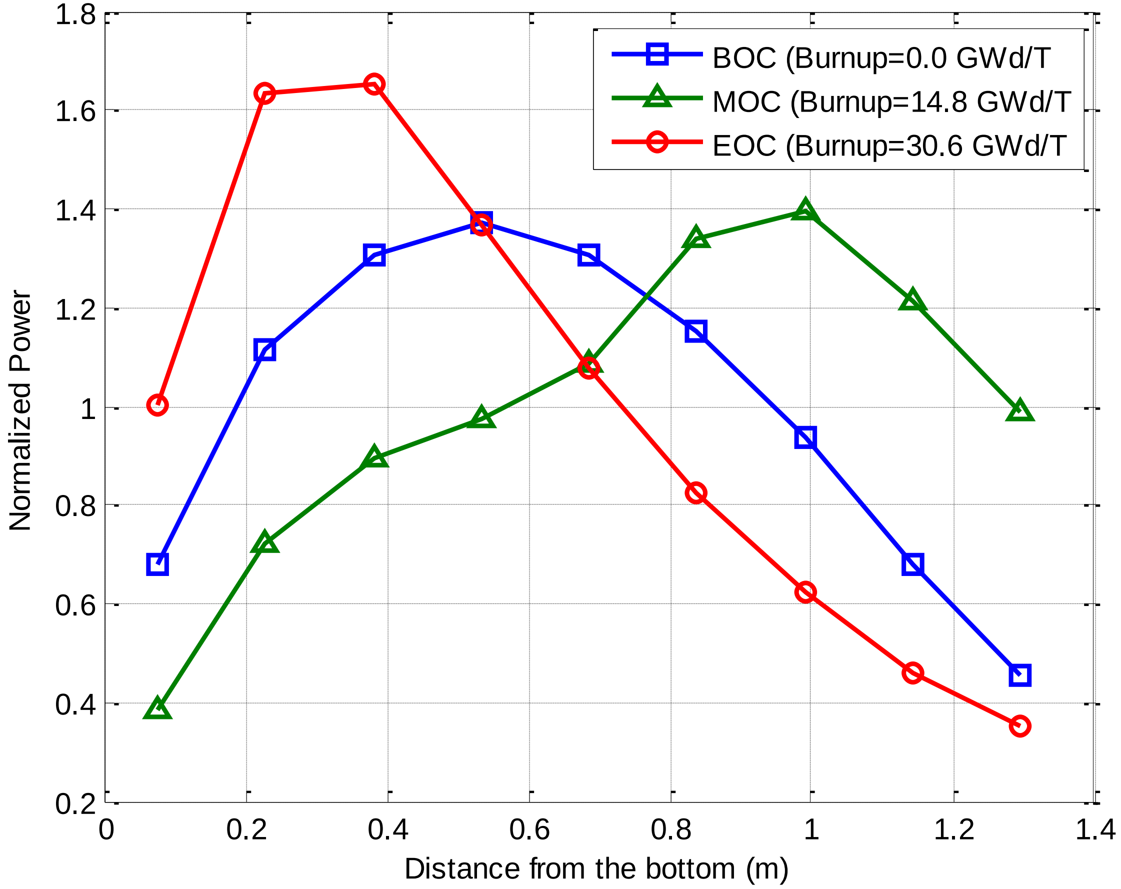
Radial power distribution

The T/H Performance of the NMR50 at BOC

Property	SBWR-600 [Ref.]	NMR-50
Average LPD (kW/m)	16.60	5.16
Total power peaking factor	2.73	2.98
MFLPD (kW/m)	45.30	15.36
MCPR (minimum)	1.32	2.25

Ref. Simplified Boiling Water Reactor Standard Safety Analysis Report (SSAR)," General Electric, 25A5113 Rev. A, August, 1992.

Core Average Axial Power Shape at BOC, MOC and EOC



Core Performance of NMR-50 in 10 Years Fuel Cycle Calculation

Burn time (years)	Avg. Burnup (GWd/T)	k_{eff}	Control blade notch[a]	MFLPD (kW/m)	MCPR
0.00	0.00	0.99988	1455	15.36	2.25
1.00	3.06	1.00560	14394	17.78	2.55
2.00	6.12	1.00135	28101	17.61	2.36
3.00	9.18	1.00062	40818	18.66	2.17
4.00	12.24	1.00005	38856	13.13	2.29
5.00	15.31	1.00010	34602	12.48	2.47
6.00	18.37	1.00009	27262	12.92	2.07
7.00	21.43	1.00009	23346	11.97	2.34
8.00	24.49	1.00010	19139	12.39	2.57
9.00	27.55	1.00011	14490	14.06	2.84
9.99	30.61	1.00010	7963	15.80	2.79

[a]The notch value is the sum of notches for all inserted control blades.

Summary of the Talk

- Core design studies were performed to develop a NMR-50 core to yield a 10-year cycle length with fuel enrichment less 5 wt.% while satisfying T/H design constraints.
- Parametric study on fuel assembly were carried out to select the optimized candidate to meet the design objective and constraints.
- The neutronics/TH coupled core calculation for the full fuel cycle are preformed with the developed NMR-50 model and some performance results are delivered.
- The desired 10 years fuel cycle length has been achieved with the present design without the violation of the key thermal hydraulics performance criterions.

Acknowledgement

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