Validation of MCNP6 Model of The Jordan Research and Training Reactor (JRTR) for Calculations of Neutronics Parameters

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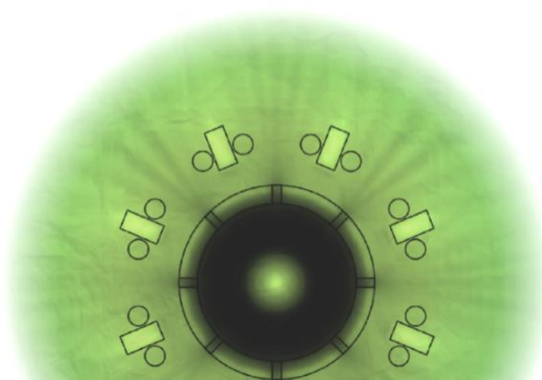


Outlines

- Introduction to JRTR
- JRTR MCNP6 computational model
- Validation of the JRTR MCNP6 model
- Neutron Flux Distribution in the core
- Neutron Spectrum in Irradiation Holes
- Summary

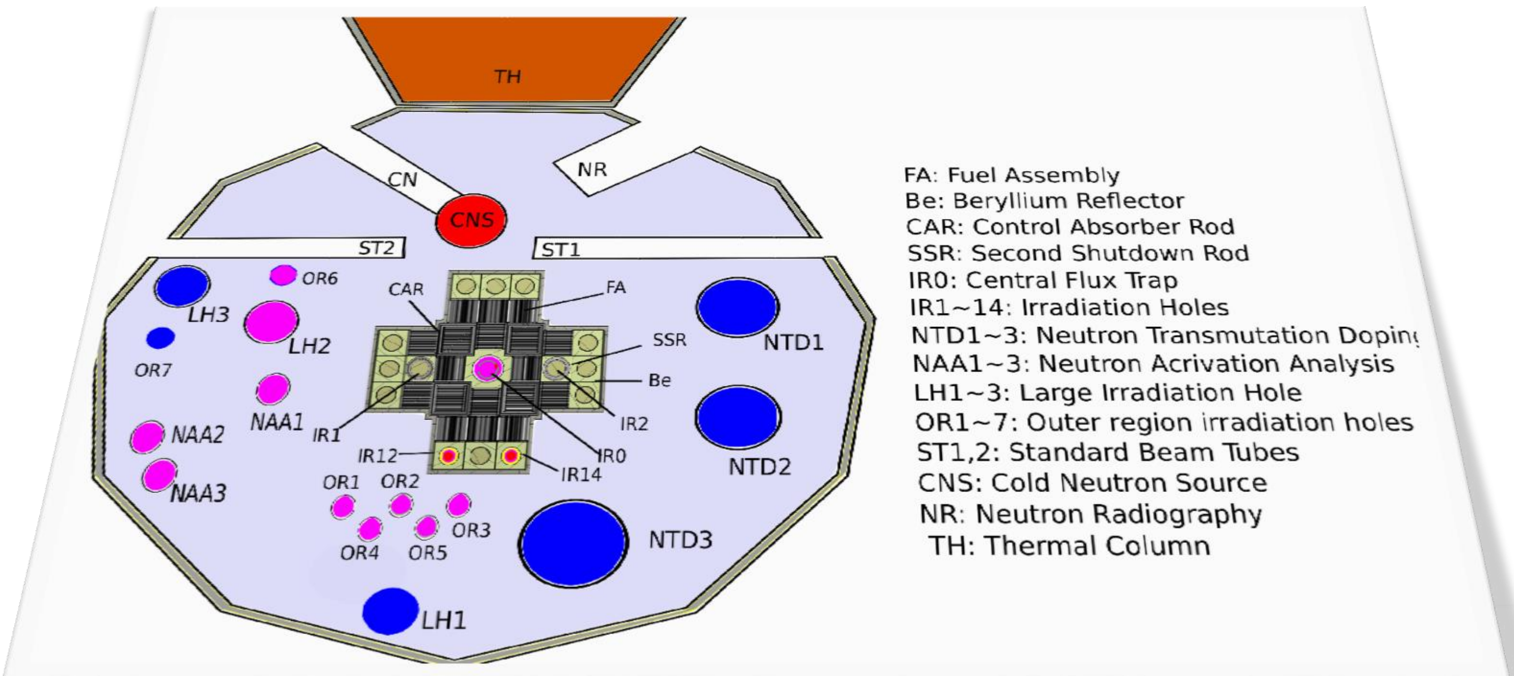
Introduction to JRTR

- The Jordan Research and Training Reactor (JRTR) will be the first nuclear reactor in Jordan and will be mainly utilized for the purpose of training and education as well as radioisotope production.
- The JRTR is a multi-purpose open-tank-in-pool type reactor with nominal power of 5 MW upgradable to 10 MW.
- It uses low enriched (LEU) Uranium Silicide (U_3Si_2) as a fuel with enrichment of 19.75 wt%.
- The JRTR core consists of standard MTR plate-type fuel assemblies; each assembly is composed of 21 fuel plates. Each fuel plate is composed of a central fuel region – the fuel meat, surrounded by aluminum cladding.
- The fuel meat is made of fine and homogeneous dispersion of U_3Si_2 particles in a continuous aluminum matrix with a uranium density of 4.8 gU/cm^3.

Introduction to JRTR

- The reactor core consists of 18 fuel assemblies which have the same U-235 enrichment and uses 4 different fuel densities for the initial core.
- The JRTR has 4 control absorber rods (CARs) to control the reactor using Hafnium absorber, and 2 second shutdown rods for safe trip of the reactor using Boron Carbide.
- The reactor is light water moderated and cooled and reflected with two types of reflector, beryllium in the core region and heavy water in the region outside the core.
- The JRTR has a central flux trap, 4 beam ports, a thermal column, and several irradiation holes in core and outside of the core which will be utilized in the future.

JRTR Core Configuration Top View With The Irradiation Positions

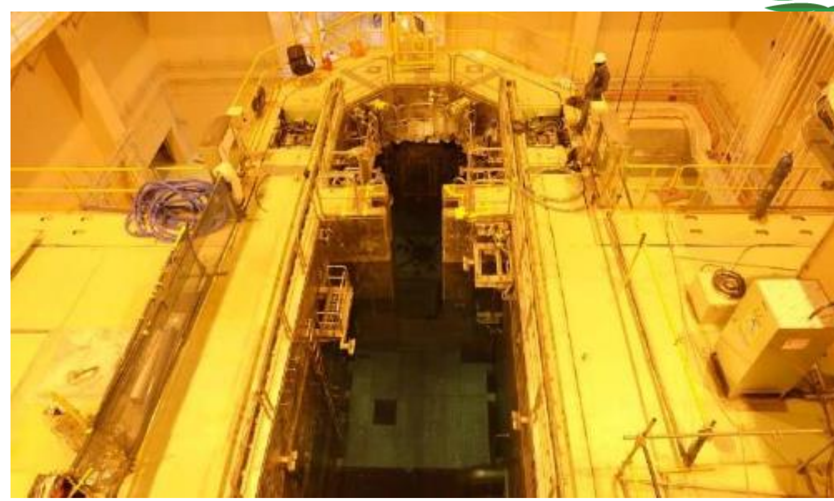


Major Parameters of the JRTR Core, Fuel Assembly, and Fuel Plate

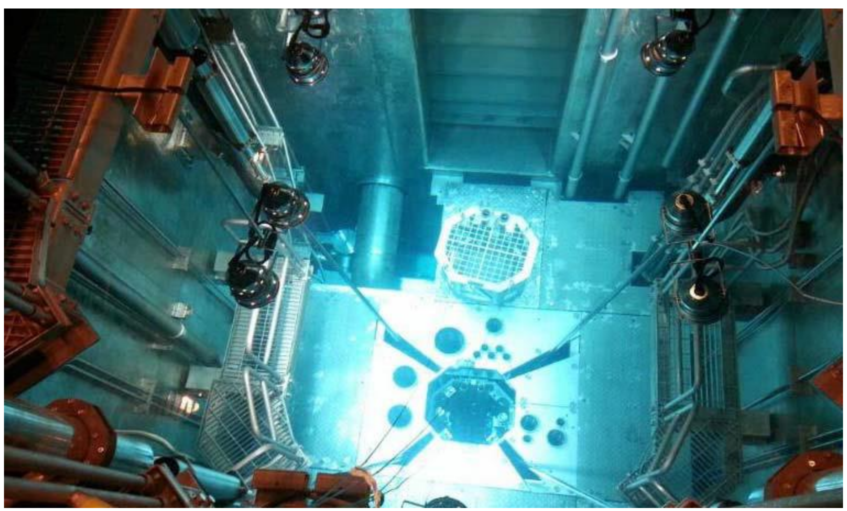
Reactor Core	Data
Number of fuel assembly sites	18
Number of irradiation sites in the Be reflector	12
Number of control absorber rods	4 (Hf)
Number of second shutdown rods	2 (B_4C)
Reactor power	5 MW
Fuel Meat, Plate and Assembly	**Data**
Fuel meat thickness	0.51 mm
Cladding thickness	0.38 mm
Fuel plate length	680 mm
Number of fuel plate/Fuel assembly	21
Material Property	**Data**
Fuel meat	U_3Si_2–Al
Fuel meat density	6.543 g/cm^3
Cladding	aluminum alloy

Photos of JRTR

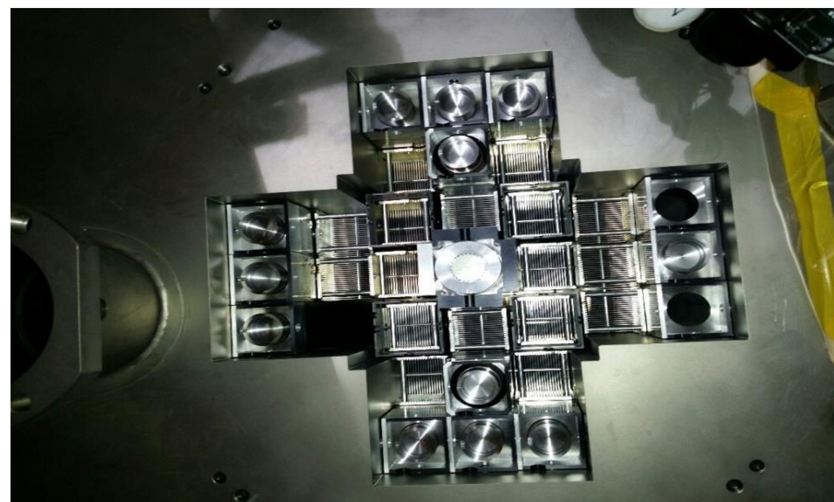
Site Overview



Reactor Building

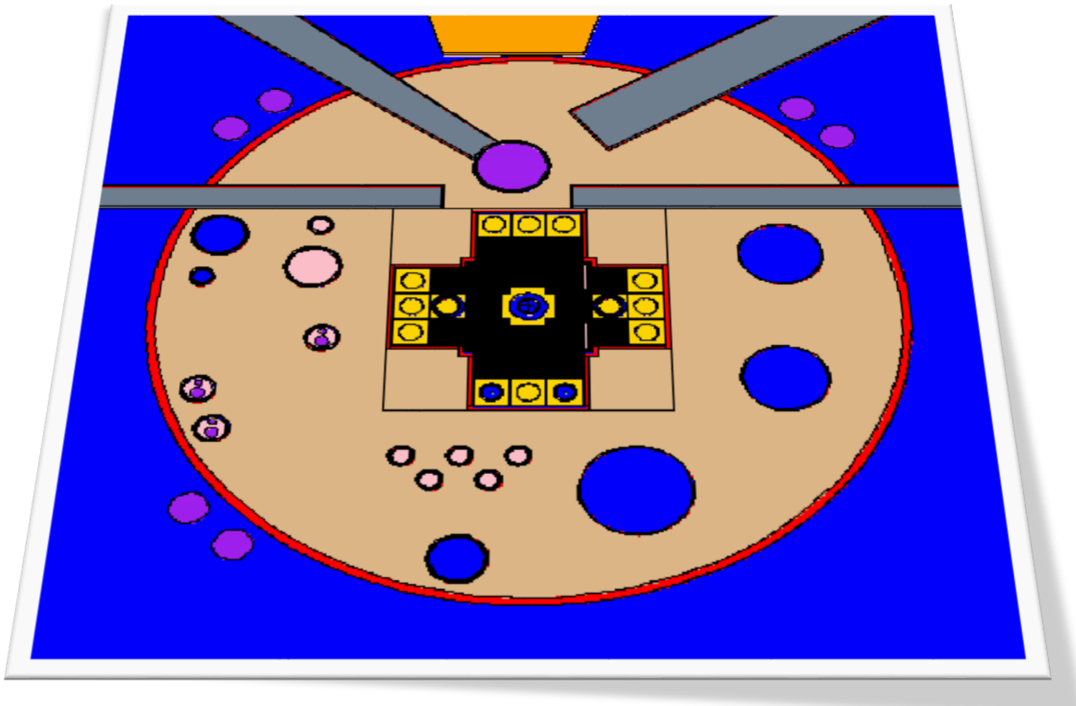


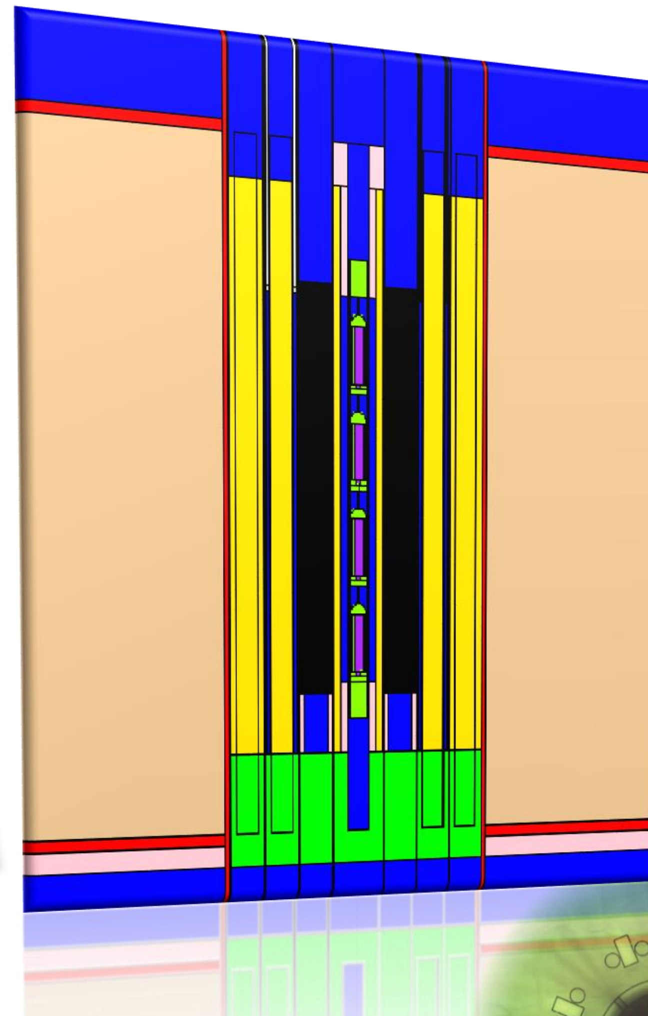
Reactor Pool



Core with Dummy FA

JRTR Model Top and Side View Using MCNP6





Validation of The JRTR MCNP6 Model

- The design and calculation of the neutronic parameters of the JRTR were performed using McCARD Code which is Monte Carlo neutron and photon transport simulation code has been developed for the neutronics design of nuclear reactors.
- A new computational model has been developed for JRTR using the MCNP6 Monte Carlo code
- The JRTR MCNP6 computational model is validated by comparing the results with the reference results obtained by McCARD for the most important neutronic parameters of the core, i.e. k-eff, power peaking factors, kinetics parameters, control rod worths, neutron flux profiles.

Validation Results/1
Calculated values of k_{eff} and β_{eff} and Λ

Calculated values of k_{eff} using different cross-section libraries

Library/Code	MCNP6	McCARD	Difference pcm
ENDF/B-VII.0	1.00486 ± 0.00014	1.00444 ± 0.00011	-41.88
Code/Library	JEFF-3.1	ENDF/B-VII.0	Difference pcm
MCNP6	1.00384 ± 0.00013	1.00486 ± 0.00014	101.80

Estimated values of β_{eff} and Λ using different cross-section libraries

Parameter	Library/Code	MCNP6	McCARD	Difference[%]
Λ (µs)	ENDF/B-VII.0	123.3 ± 0.63	141 ± 567	12.57
β_{eff} (pcm)		716.5 ± 14	715.6 ± 249	-0.12
Parameter	Code/ Library	JEFF-3.1	ENDF/B-VII.0	Difference [%]
Λ (µs)	MCNP6	122.9 ± 0.64	123.3 ± 0.63	0.30
β_{eff} (pcm)		738.0 ± 15	716.5 ± 14	-3.01

Validation Results/2
Neutron Fluxes in the irradiation positions

Irradiation Position	Neutron Flux (n/cm^2s)					
	Code	Thermal Flux (E<0.625 eV)		Fast Flux (E>1.0 MeV)		Material in the hole
		Maximum	Average	Maximum	Average	
IR0	McCARD	1.70×10^{14}	1.00×10^{14}	2.70×10^{13}	1.60×10^{13}	Dummy Rig
	MCNP6	1.66×10^{14}	9.58×10^{13}	2.69×10^{13}	1.62×10^{13}	
	Diff %	2.30	4.21	0.49	-1.20	
IR1	McCARD	1.20×10^{14}	7.70×10^{13}	2.40×10^{13}	1.50×10^{13}	Be Plug
	MCNP6	1.22×10^{14}	7.60×10^{13}	2.39×10^{13}	1.46×10^{13}	
	Diff %	-1.77	1.35	0.36	2.90	
IR2	McCARD	1.20×10^{14}	7.50×10^{13}	2.40×10^{13}	1.40×10^{13}	Be Plug
	MCNP6	1.20×10^{14}	7.49×10^{13}	2.39×10^{13}	1.44×10^{13}	
	Diff %	-0.33	0.10	0.48	-3.04	
IR12	McCARD	6.60×10^{13}	4.90×10^{13}	1.30×10^{13}	8.50×10^{12}	MoO_3 Rig
	MCNP6	6.56×10^{13}	4.40×10^{13}	1.29×10^{13}	8.36×10^{12}	
	Diff %	0.60	10.26	0.55	1.61	
IR14	McCARD	6.90×10^{13}	5.10×10^{13}	1.30×10^{13}	8.70×10^{12}	TeO_2 Rig
	MCNP6	6.79×10^{13}	4.71×10^{13}	1.31×10^{13}	8.60×10^{12}	
	Diff %	1.55	7.69	-1.00	1.10	

Validation Results/3
Power peaking factors

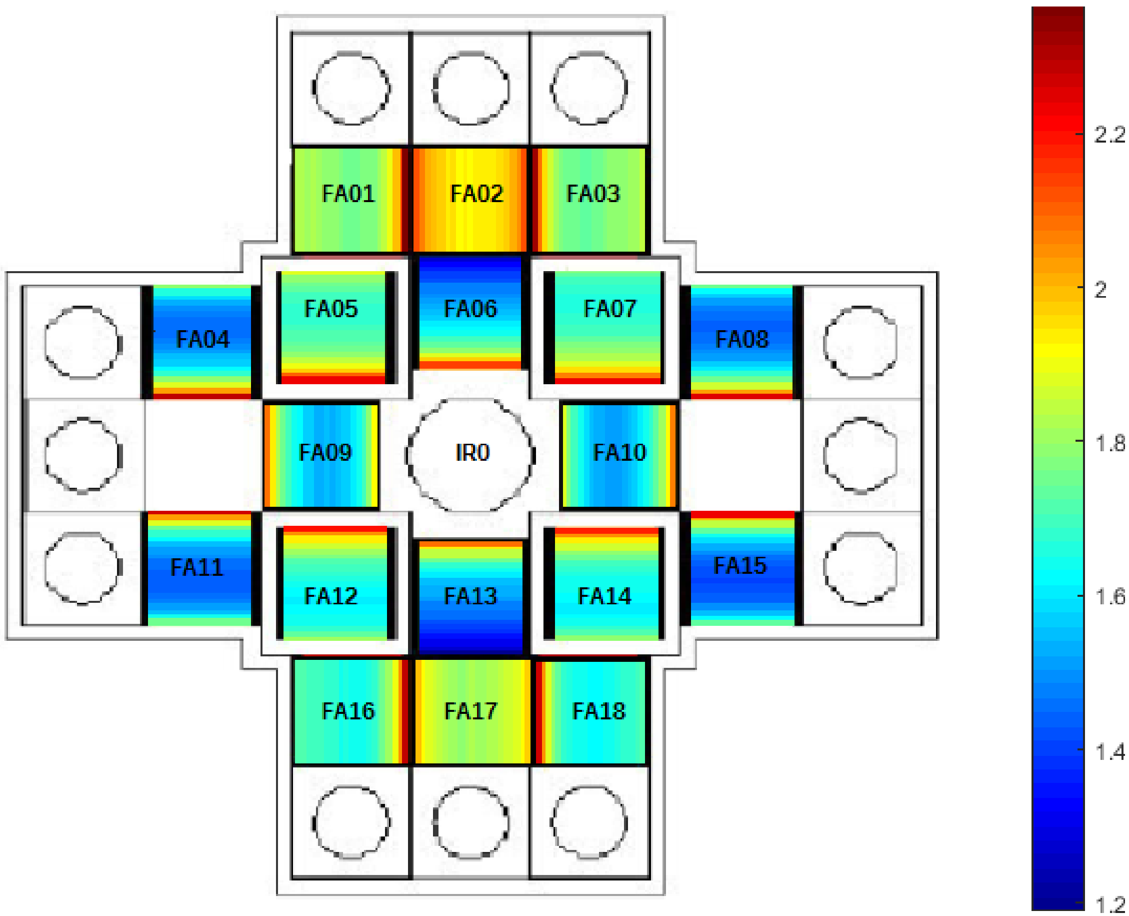
Radial Peaking Factors

	FA01	**FA02**	**FA03**	
	1.14	1.24	1.14	
	1.15	1.25	1.14	
	-0.91	-0.50	0.00	
FA04	**FA05**	**FA06**	**FA07**	**FA08**
0.98	0.95	0.87	0.95	0.99
1.00	0.95	0.86	0.94	0.98
-2.12	0.10	1.02	0.92	0.67
	FA09		**FA10**	
	0.90		0.91	
	0.90		0.89	
	0.06		1.94	
FA11	**FA12**	**FA13**	**FA14**	**FA15**
0.97	0.92	0.84	0.93	0.98
0.98	0.92	0.83	0.92	0.97
-1.36	-0.11	0.77	1.25	1.01
FA ID	**FA16**	**FA17**	**FA18**	
Fr McCARD	1.06	1.16	1.07	
Fr MCNP6	1.08	1.16	1.07	
Diff %	-1.83	-0.28	0.25	

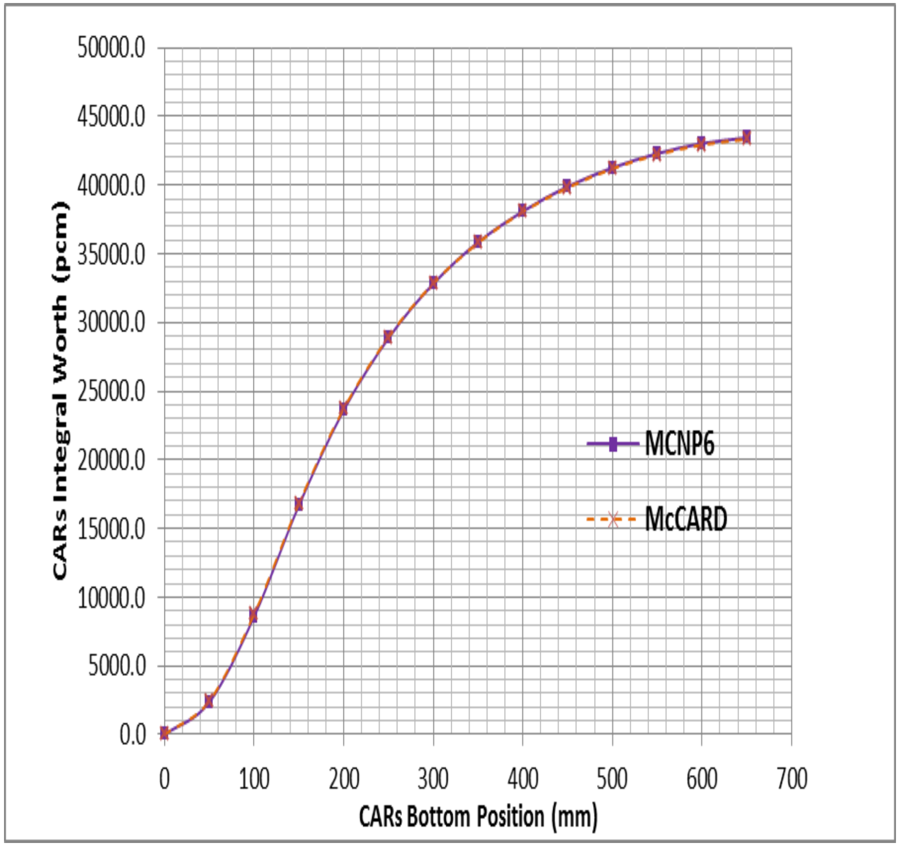
Total Peaking Factors

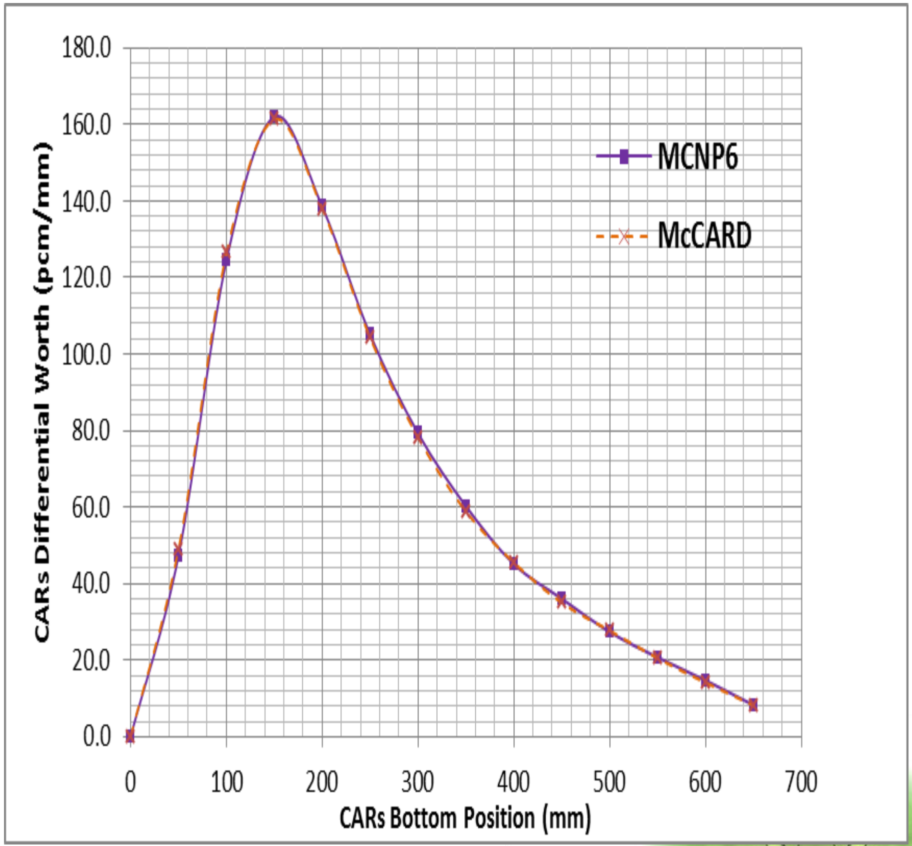
	FA01	**FA02**	**FA03**	
	2.30	2.13	2.33	
	2.35	2.13	2.31	
	-2.34	0.18	0.69	
FA04	**FA05**	**FA06**	**FA07**	**FA08**
2.24	2.23	2.16	2.24	2.26
2.26	2.23	2.12	2.22	2.23
-1.11	0.16	1.84	0.90	1.32
	FA09		**FA10**	
	2.12		2.11	
	2.07		2.06	
	2.30		2.48	
FA11	**FA12**	**FA13**	**FA14**	**FA15**
2.22	2.20	2.11	2.20	2.27
2.24	2.18	2.07	2.17	2.21
-1.07	0.89	2.02	1.20	2.51
FA ID	**FA16**	**FA17**	**FA18**	
Fq McCARD	2.23	1.99	2.26	
Fq MCNP6	2.27	1.99	2.25	
Diff %	-1.96	-0.02	0.22	

Validation Results/4
Power peaking factors

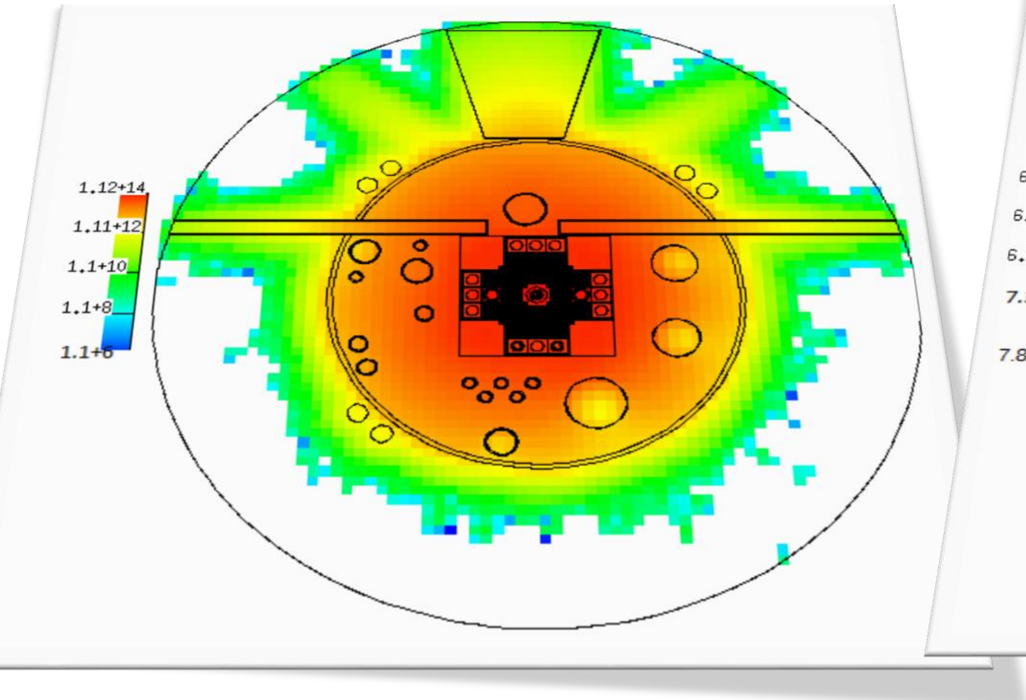


Validation Results/5
Reactivity Worth of CARs

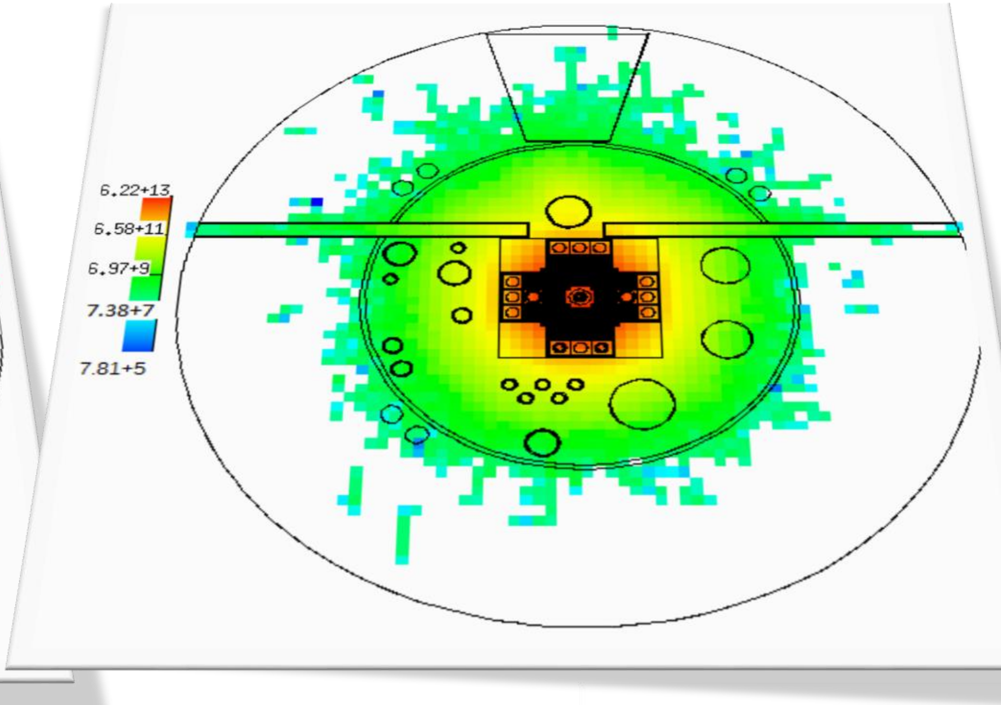




Thermal and Fast Flux Distribution

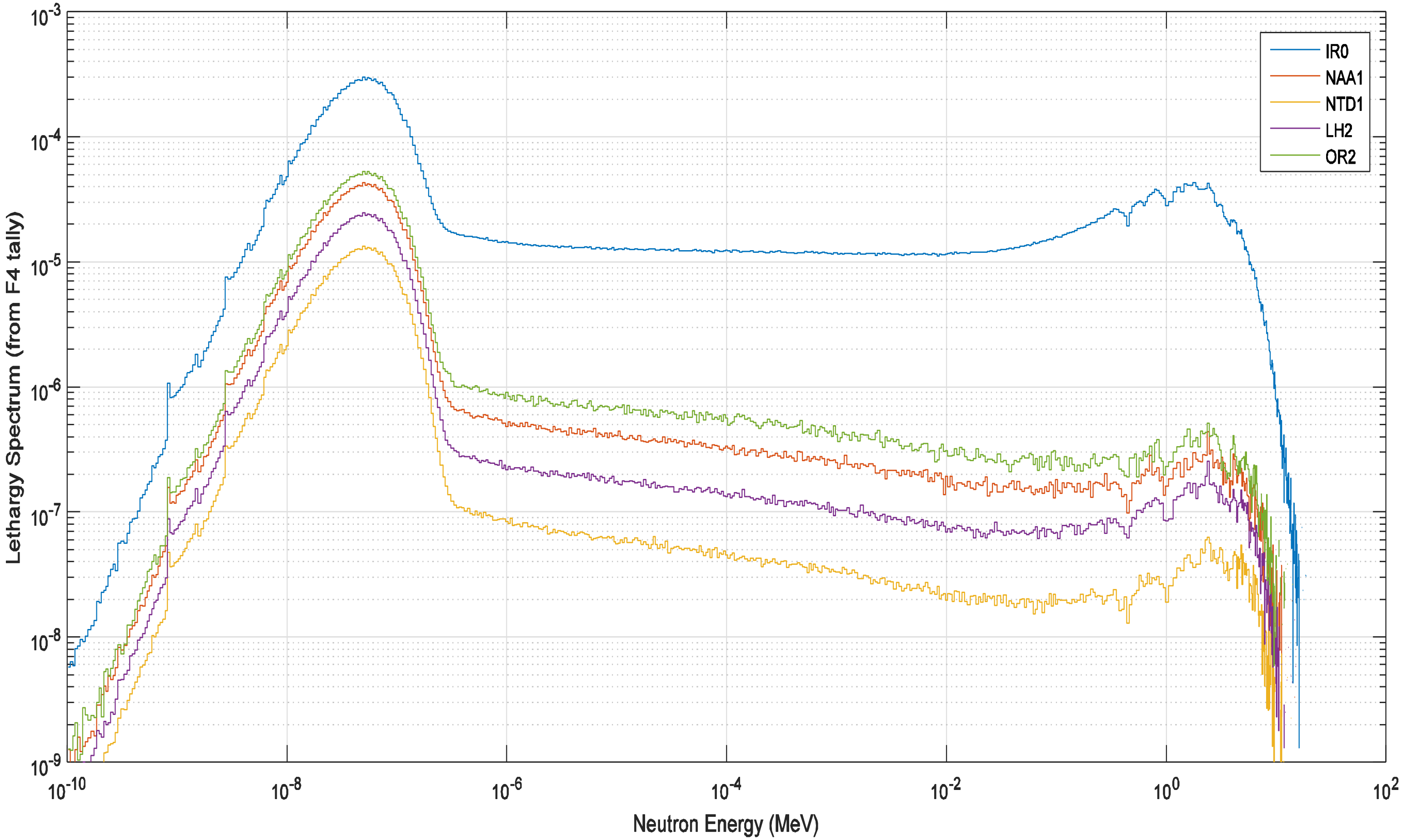


Thermal Flux



Fast Flux

Neutron Spectrum of the Irradiation Holes



Summary

- Computational model of the JRTR was developed using MCNP6 and was validated by comparing the results of the calculations with the reference values reported in the final safety analysis report of JRTR, that were calculated by the McCARD code.
- The core geometry and the material properties are modeled well by applying the same assumptions used in the reference model.
- When the reactor enters the stage of Reactor Performance Tests, which will be very soon, the measurements of the physical parameters of the core will be performed, which would then serve for final experimental verification of our calculations and potentially even serve as experimental reactor physics benchmark.
- In future works this model will be further investigated and will be used to study the neutronic characteristics of the irradiation holes of JRTR as well as the core burnup calculation since MCNP6 has the capability for depletion calculations.

Thank You