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YALINA-Booster Conversion Project

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National Nuclear Security Administration

YALINA-Booster Conversion Project

Project Objectives (Phase I)

- **Perform experimental and analytical studies to characterize the YALINA-Booster subcritical assembly using different neutron sources. The studies include:**
  - **Subcriticality levels from different fuel loadings**
  - **Experimental methods for measuring the subcriticality level**
  - **Spatial neutron flux distributions and neutron spectra**
  - **Transmutation rates in different neutron spectra**
  - **Kinetic parameters**
  - **Time dependent reaction rates**
- **Replace the high enriched uranium of the Booster zone with low enriched uranium in two steps while adjusting the subcritical assembly configuration to achieve the same subcriticality level.**
- **Perform the previous experimental and analytical studies to characterize the new configurations.**

YALINA-Booster Studies

- Compositions and densities of the YALINA-Booster materials were determined based on measurements and chemical analyses. Assembly dimensions were checked. The obtained information were used to define YALINA-Booster specifications for the IAEA benchmark activity.
- Detailed calculational models for Monte Carlo and deterministic computer codes have been developed.
- The generated models have been used for performing analytical studies. The obtained results have been compared with the experimental results. The comparison shows a good agreement.
- Further studies are under way to complete the analytical and experimental studies as planned for the two phases of the project.
- The first conversion step for reducing the uranium enrichment of the booster zone was completed successfully and the second step is underway.

YALINA Booster Analyses

- Three detailed models have been generated and tested based on the current YALINA Booster specifications:
  - MCNP/MCNPX/MCB Monte Carlo Model
  - MONK Monte Carlo Model (Continuous energy, Quasi-continuous energy library 13193 groups, and Multigroup library-172 groups).
  - ERANOS/ECCO/VARIANT Deterministic Model (Multigroup library-172 groups)
- Different nuclear data libraries, JEF2.2, JEF3.1, ENDF/B-VI.0,.6,.8, and ENDF/B-VII have been used for the analyses.
- K_{eff}, and K_s analyses; direct and indirect β calculation, and kinetic analyses have been performed.

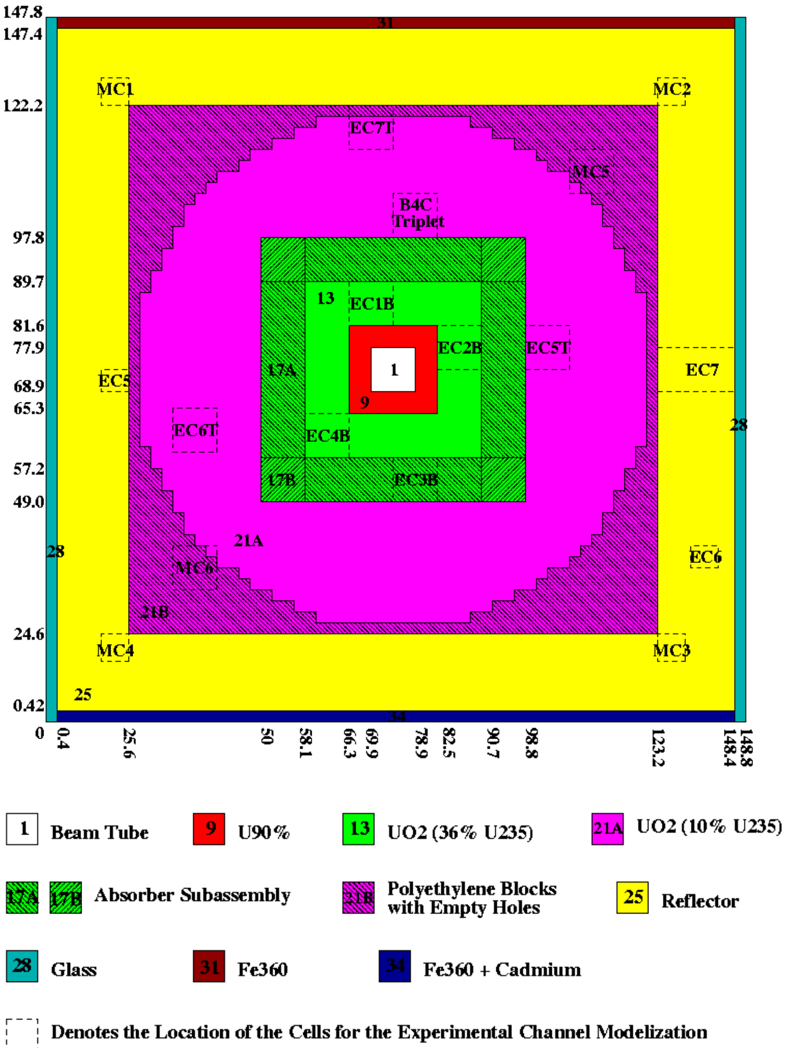
YALINA-Booster Conversion Study

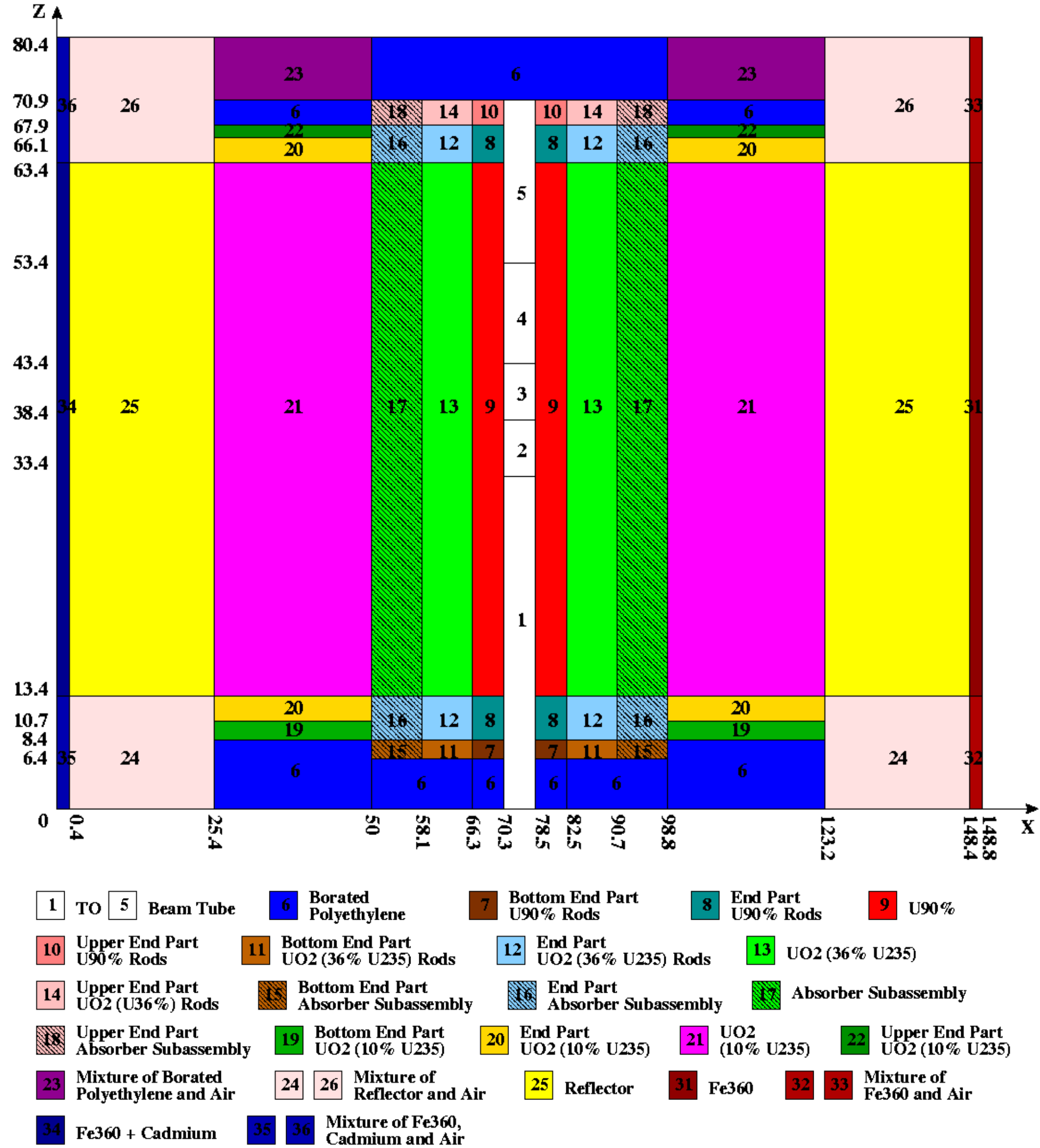
- In the first step, the 90% enriched fuel is replaced with 36% enriched fuel in the booster zone.
- The number of EK-10 fuel rods is increased to obtain the original multiplication factor.
- The analytical and the experimental work were done in a parametric way while maintaining the symmetrical arrangement of the fuel loading.
- In the second step, the 36% enriched fuel is replaced with 21% enrich fuel in the booster zone.
- The interface zone geometry is changed from square to circular to maintain the same multiplication factor .

ERANOS Deterministic Analyses

- Deterministic calculational models were created for ERANOS (European Reactor Analysis Optimized code System) analyses.
- Cross-section data libraries with a 53 energy group structure have been processed with the ECCO code of ERANOS based on JEF2.2, JEF3.1, and ENDF/B-VI.8 nuclear data files.
- Flux calculations are performed in XYZ with the VARIANT module of ERANOS. For complementary studies, calculations are also performed in RZ geometry with the S_n BISTRO code.
- The VARIANT method is also the basis of the time-dependent module KIN3D of ERANOS used for the kinetic calculations.
- The analyses were performed for YALINA-Booster loaded with 1141 and 902 EK-10 rods.

Deterministic Model of YALINA-Booster with 1141 EK-10 Fuel Rods





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ERANOS Analytical & Experimental Results

Effective Multiplication factor and reactivity

Configuration	JEF3.1	ENDF/B-VI.8	Measured
1141	0.973028 -2772 pcm	0.972233 -2856 pcm	EC5T, EC6T , EC7T ~ -2750 pcm
902	0.932845 -7199 pcm	0.932305 -7261 pcm	EC6T ~ -7400 pcm

Kinetic Parameters

Configuration	1141		902	
Data Library	JEF3.1	ENDF/B-VI.8	JEF3.1	ENDF/B-VI.8
β_{eff}	753.3	753.4	761.2	761.4
Λ_{eff}	50.4	50.3	49.3	49.2

Source Multiplication Factors of YALINA-Booster

Configuration	Source	JEF3.1		ENDF/B-VI.8	
		k_S, ρ_S [pcm] (1)	k_S, ρ_S [pcm] (2)	k_S, ρ_S [pcm] (1)	k_S, ρ_S [pcm] (2)
1141	D-T	0.989047 -1107.5	0.989121 -1099.8	0.988810 -1131.6	0.988886 -1123.8
	D-D	0.981535 -1881.3)	0.981548 -1879.9	0.981131 -1923.2)	0.981140 -1922.2
	Cf-252	0.980832 -1954.2	0.980844 -1953.0	0.980438 -1995.2	0.980445 -1994.5
902	D-T	0.974738 -2591.6	0.975113 -2552.2	0.973891 -2680.8	0.974267 -2641.2
	D-D	0.958254 -4356.5	0.958279 -4353.7	0.958205 -4361.9)	0.958219 -4360.3
	Cf-252	0.957439 -4445.3	0.957469 -4442.0	0.957411 -4448.3	0.957445 -4444.7

(1) $$k_S = \frac{\langle F\Phi_S \rangle}{\langle A\Phi_S \rangle - \langle P_{n,xn}\Phi_S \rangle}$$

(2) $$k_S = \frac{\langle F\Phi_S \rangle + \langle P_{n,xn}\Phi_S \rangle}{\langle A\Phi_S \rangle}$$

YALINA-Booster 1141 Configuration
Area Ratio Method Correction Factor (Glasstone Approach)

Channel	$A_{tot} = \langle \sigma_d \tilde{\Phi} \rangle$	$A_p = \langle \sigma_d \tilde{\Phi}_p \rangle$	$\frac{A_p}{A_d} = \frac{A_p}{(A_{tot} - A_p)}$	$\rho_{calc\_chx} = -\frac{A_p}{A_d} \times \hat{\beta}_{eff}$	k_{calc_chx}	$CF_{calc,chx} = \frac{\rho_{calc,ref}}{\rho_{calc,chx}}$ (*)
EC1B	9.85301E+10	7.97757E+10	4.25372E+00	-3204	0.968953	0.86513
EC2B	1.27372E+11	1.02295E+11	4.07925E+00	-3073	0.970189	0.90213
EC3B	8.75570E+11	6.94140E+11	3.82594E+00	-2882	0.971988	0.96186
EC4B	1.40509E+11	1.11241E+11	3.80081E+00	-2863	0.972167	0.96822
EC5T	3.66863E+13	2.89297E+13	3.72965E+00	-2809	0.972674	0.98669
EC6T	3.43634E+13	2.66007E+13	3.42673E+00	-2581	0.974837	1.07391
EC7T	2.68736E+13	2.06433E+13	3.31338E+00	-2496	0.975649	1.11065
EC8R	1.75263E+13	1.34172E+13	3.26524E+00	-2460	0.975995	1.12702
EC9R	3.84508E+12	2.93693E+12	3.23394E+00	-2436	0.976219	1.13793

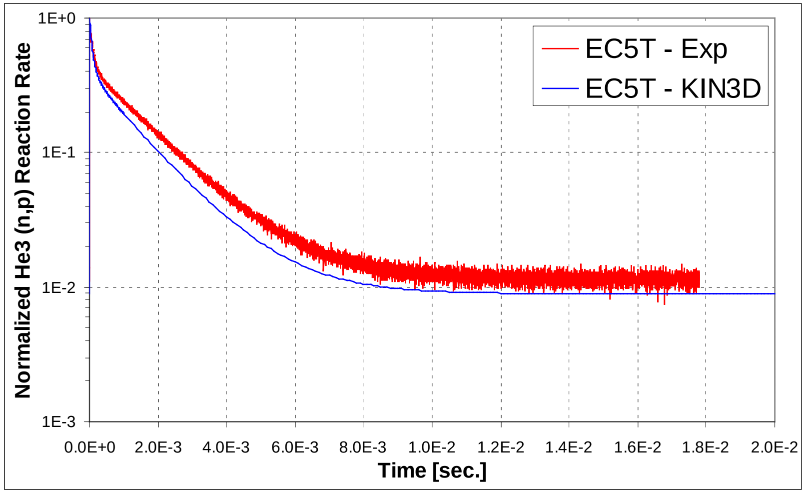
(x) **Estimation of Spatial Correction Factors for Area Ratio Reactivity Measurements.**

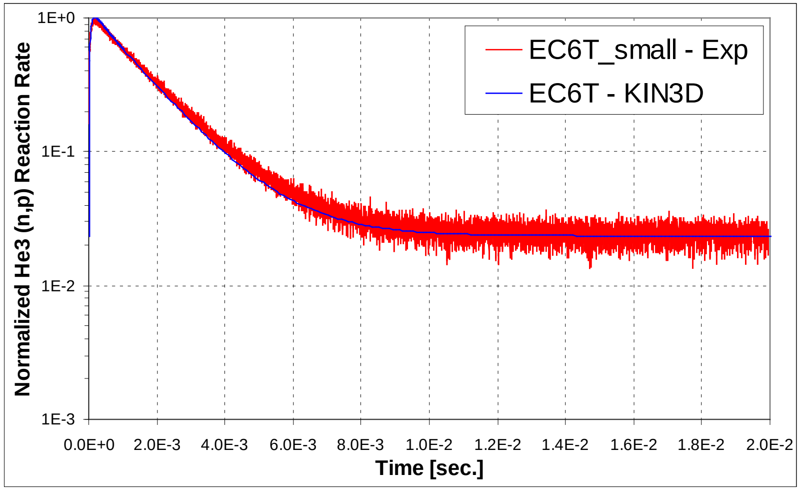
$$\frac{\rho_{calc,chx}}{\rho_{calc,ref}} = \frac{\rho_{meas,chx}}{\rho_{meas,ref}} \quad \Rightarrow \quad \rho_{meas,ref} = \rho_{meas,chx} \times \frac{\rho_{calc,ref}}{\rho_{calc,chx}} = \rho_{meas,chx} \times CF_{calc,chx}$$

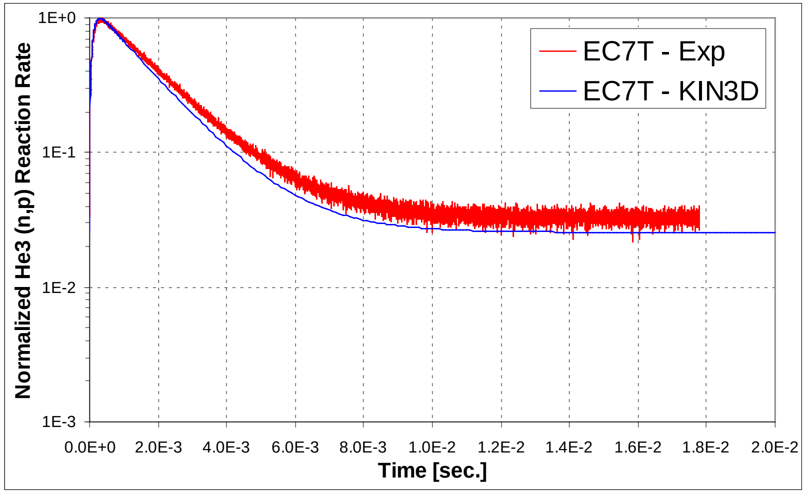
YALINA-Booster 1141 Configuration Corrected Measured Area Ratio Method Values He-3 (n,p) Detector Responses to a D-D Pulse JEF3.1 Correction Factors

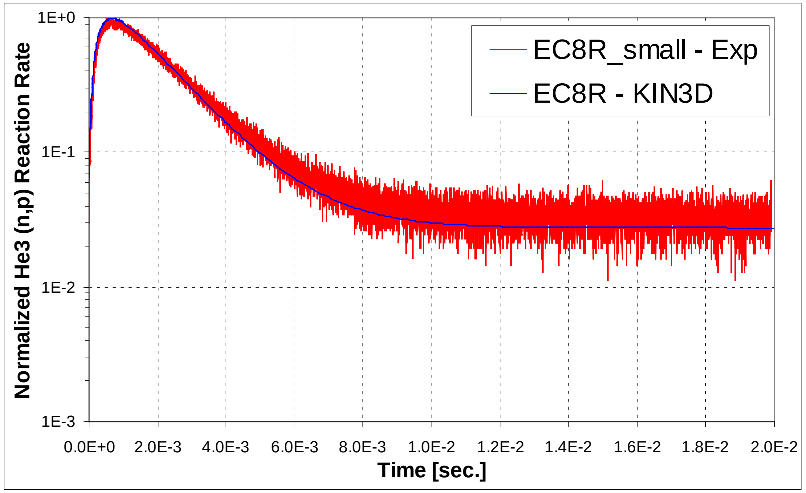
Channel	Measured by Area Ratio	Corrected Values
EC5T	0.97318 (-2756 pcm)	0.97353 (-2719 pcm)
EC6T	0.97513 (-2550 pcm)	0.97335 (-2738 pcm)
EC7T	0.97535 (-2528 pcm)	0.97269 (-2808 pcm)

ERANOS D-D Pulse Simulation of YALINA-Booster 1141 Configuration with JEF 3.1 Nuclear Data

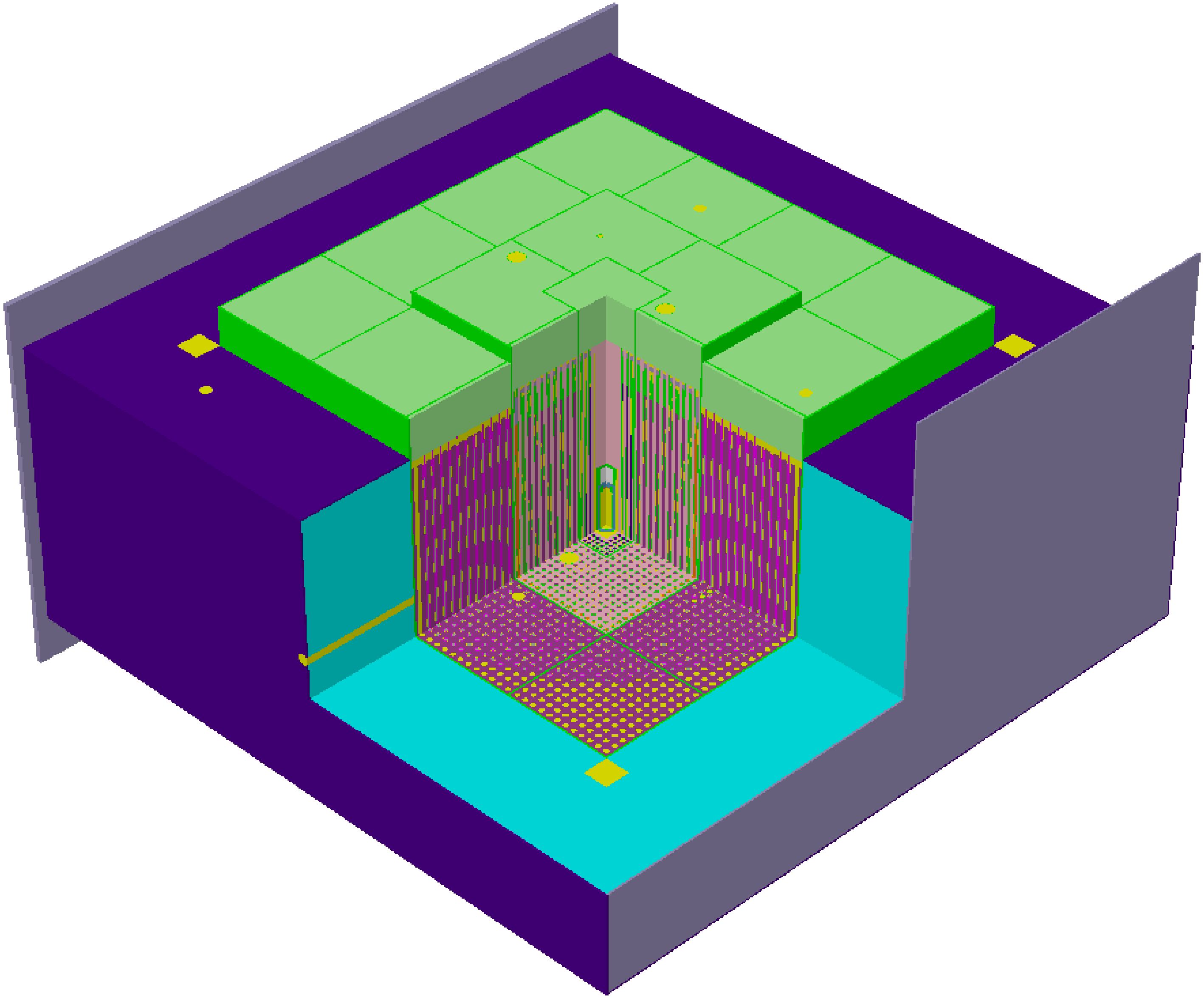




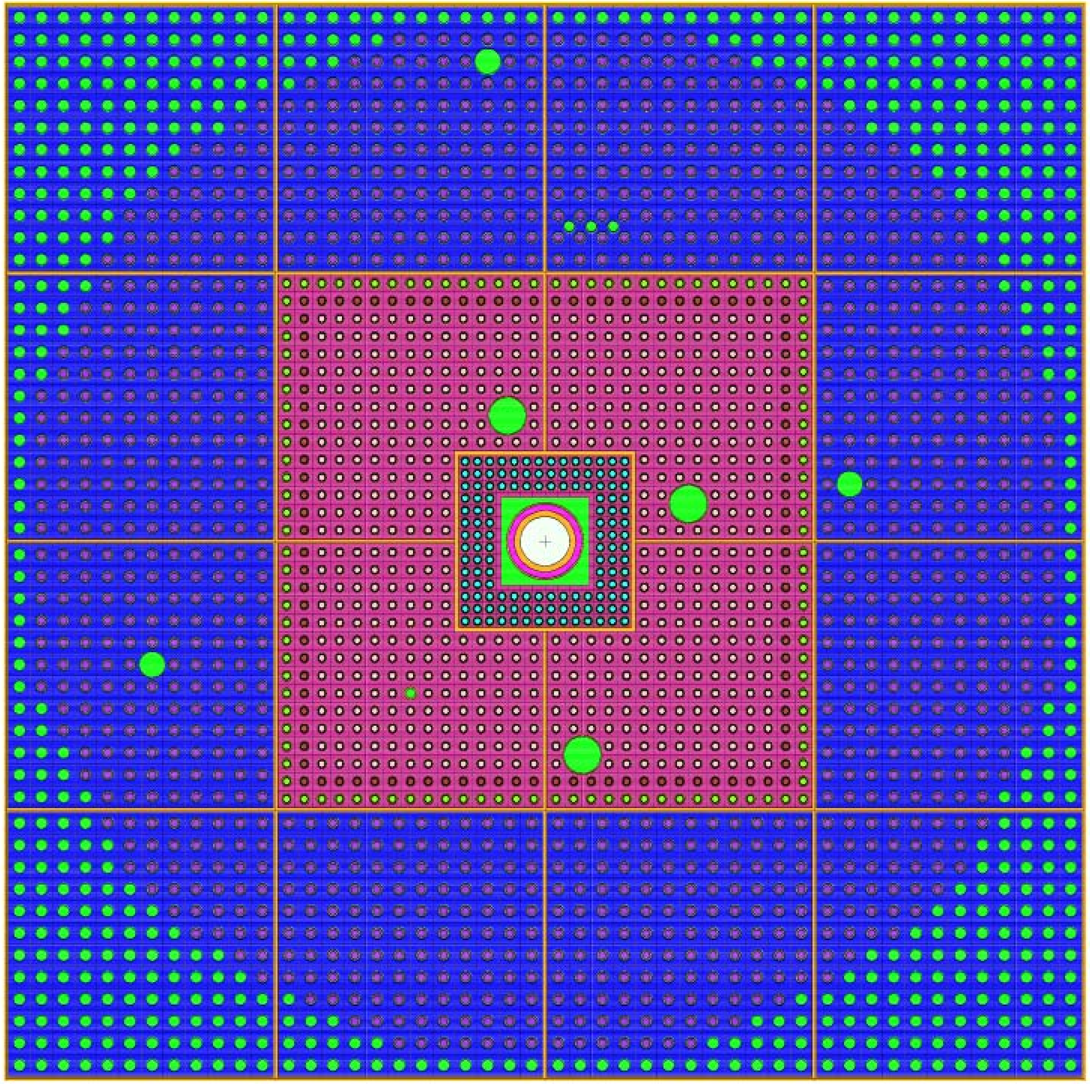




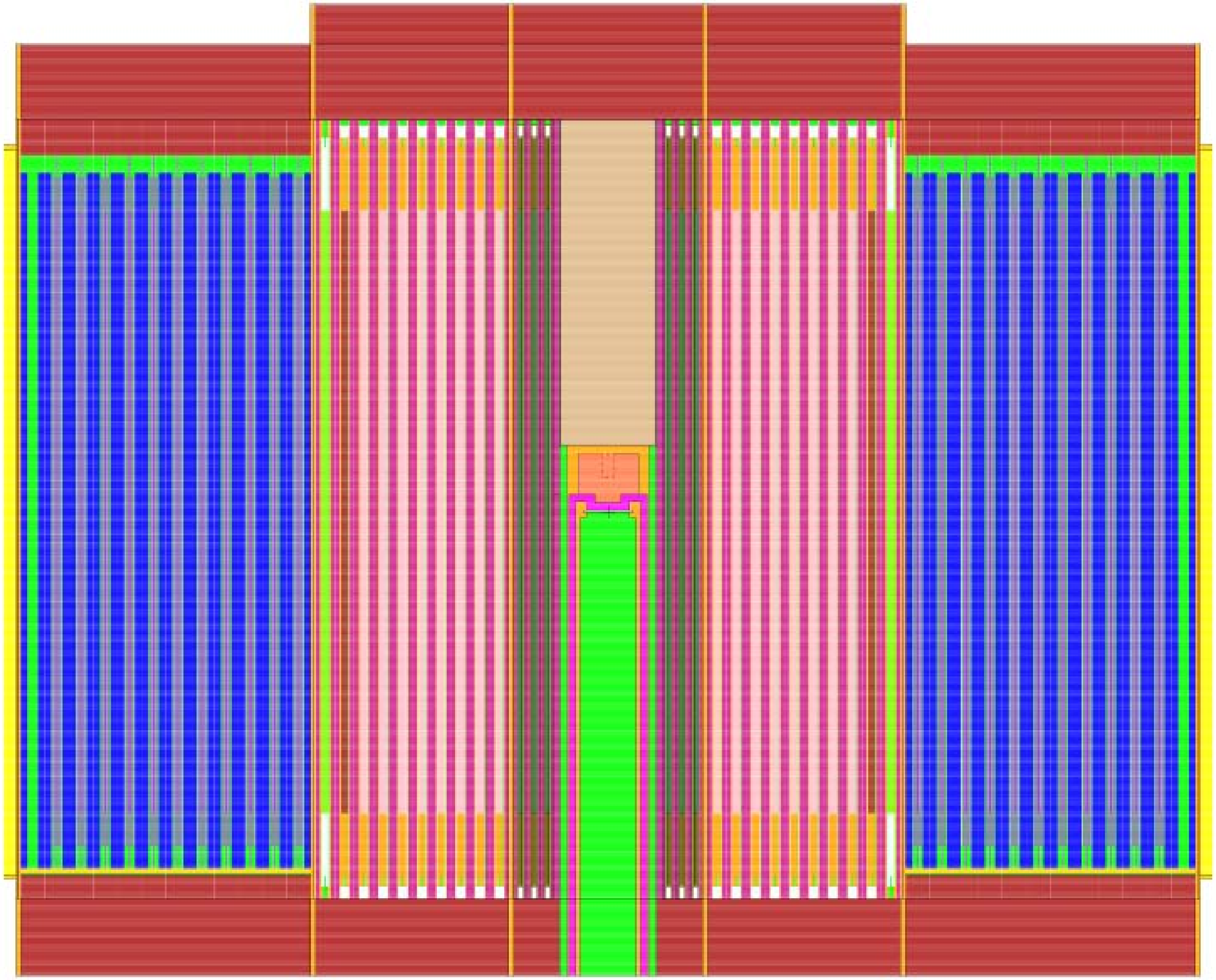
Isometric View of MONK Model



X-Y Cross Section of the MCNP/MCNPX YALINA Booster Model



Y-Z Cross Section of the MCNP/MCNPX YALINA Booster Model at X = 0.87



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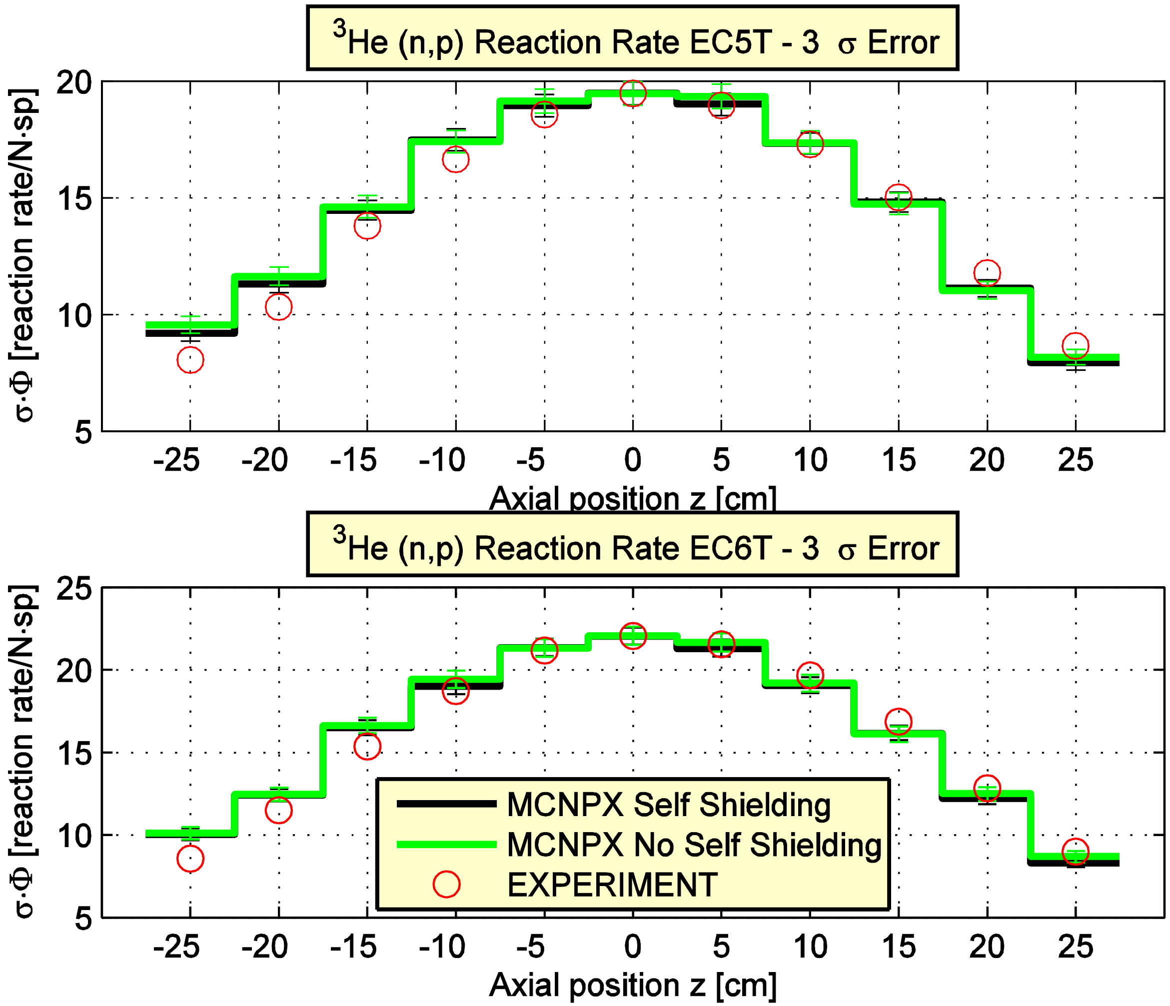
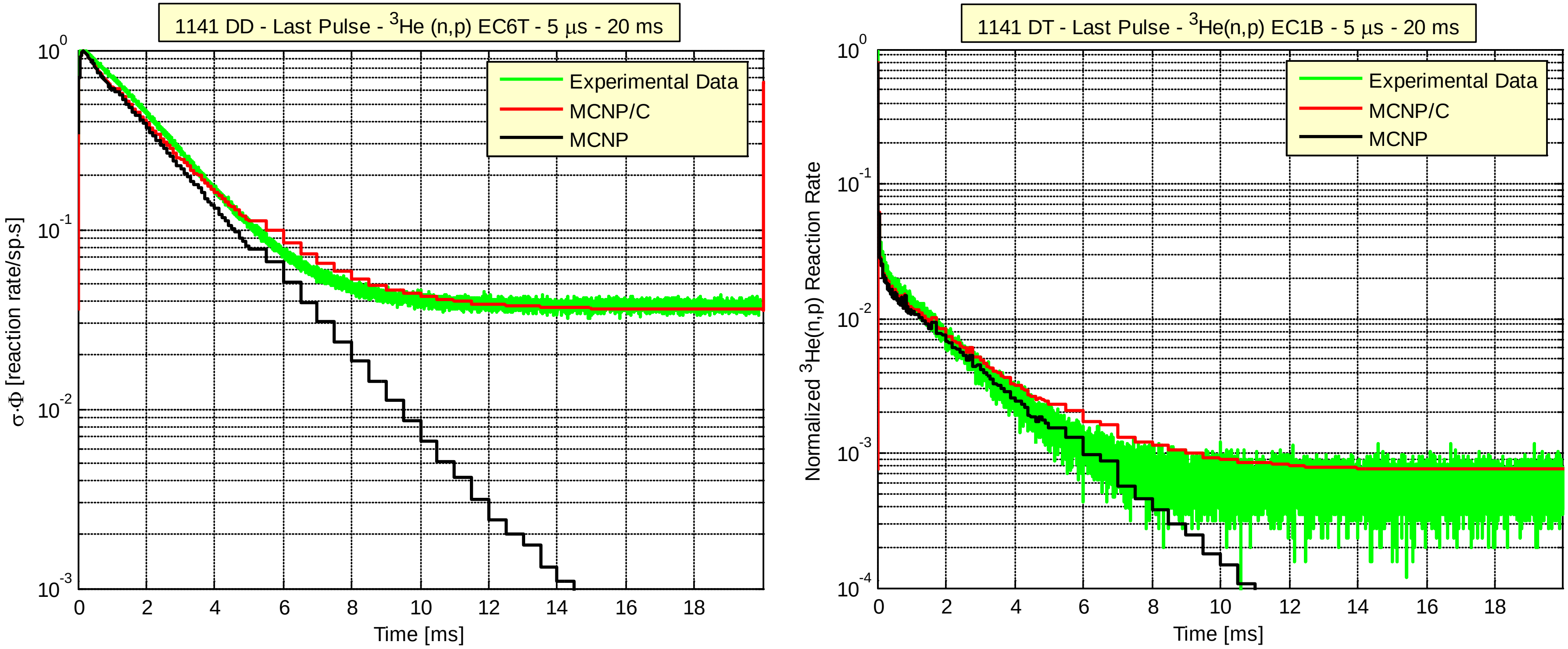
MONTE Carlo Results for YALINA-Booster 1141 Configuration, ENDF/B-VI.6, MCNPX2.6b

Computer Code	Nuclear Data Files	K_{eff} Criticality Calculation	K_s D-D Neutron source	K_s D-T Neutron source	β [pcm]	l_p [μs]	Λ [ms]
MCNPX	ENDF/B-6.6	0.97972±4	0.98690	099145	760±8	54±2	56±2
MCNPX	JEFF-3.1	0.98008±9	-	-	728±12	-	-
MCNP5	ENDF/B-6.6	0.98016±9	-	-	766±18	-	-
MONK9a	DICE ENDF/B-6.0	0.97730±10	0.98610±20	0.99060±20	-	48±5	49±5

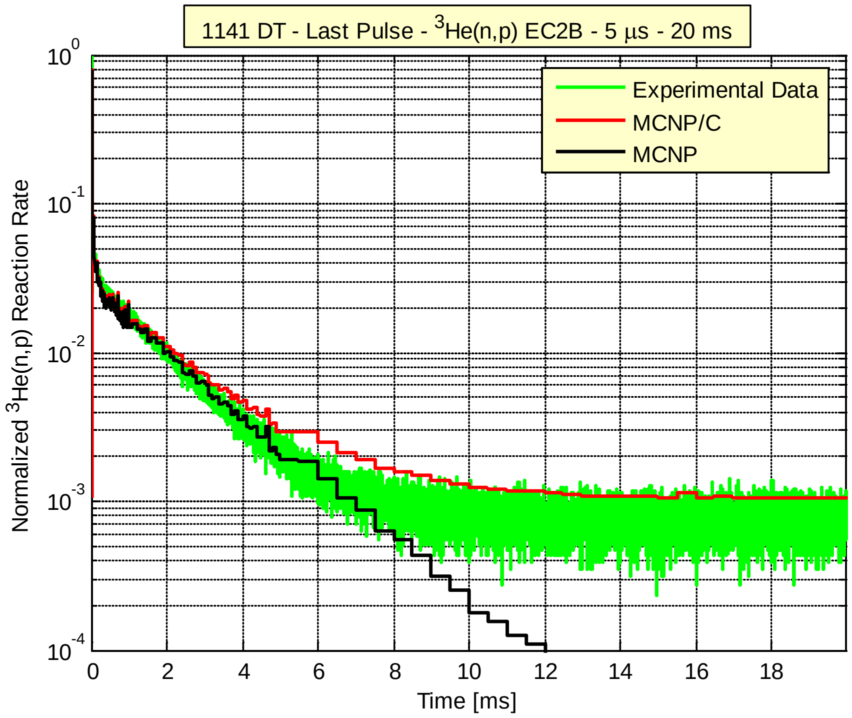
^{3}He Detector Response Calculated by MCNP Compared to the Experimental Measurements

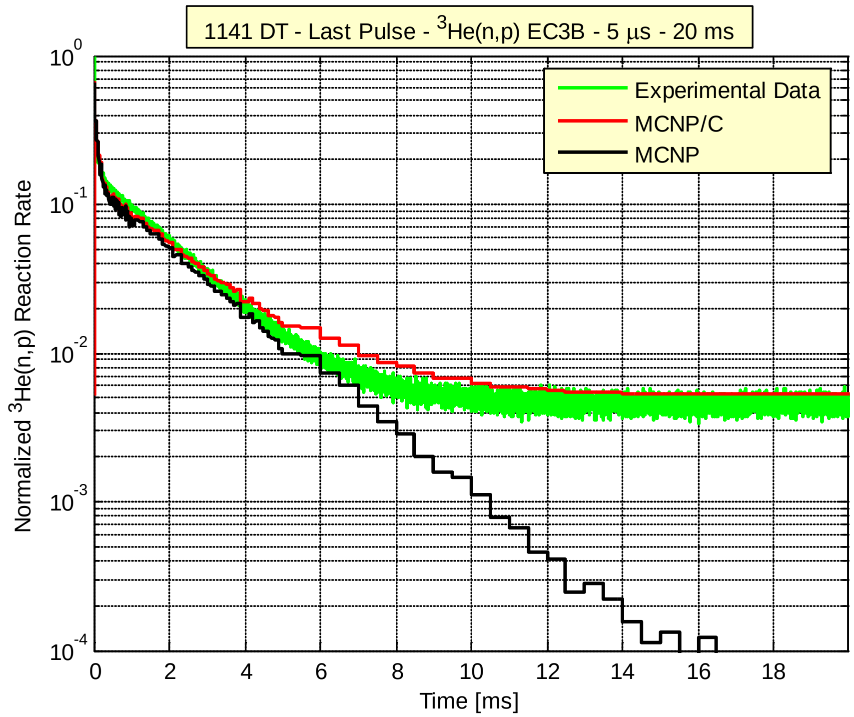


MCNPX Results & Experimental Measurements for YALINA-Booster 1141 Configuration, ENDF/B-VI.6

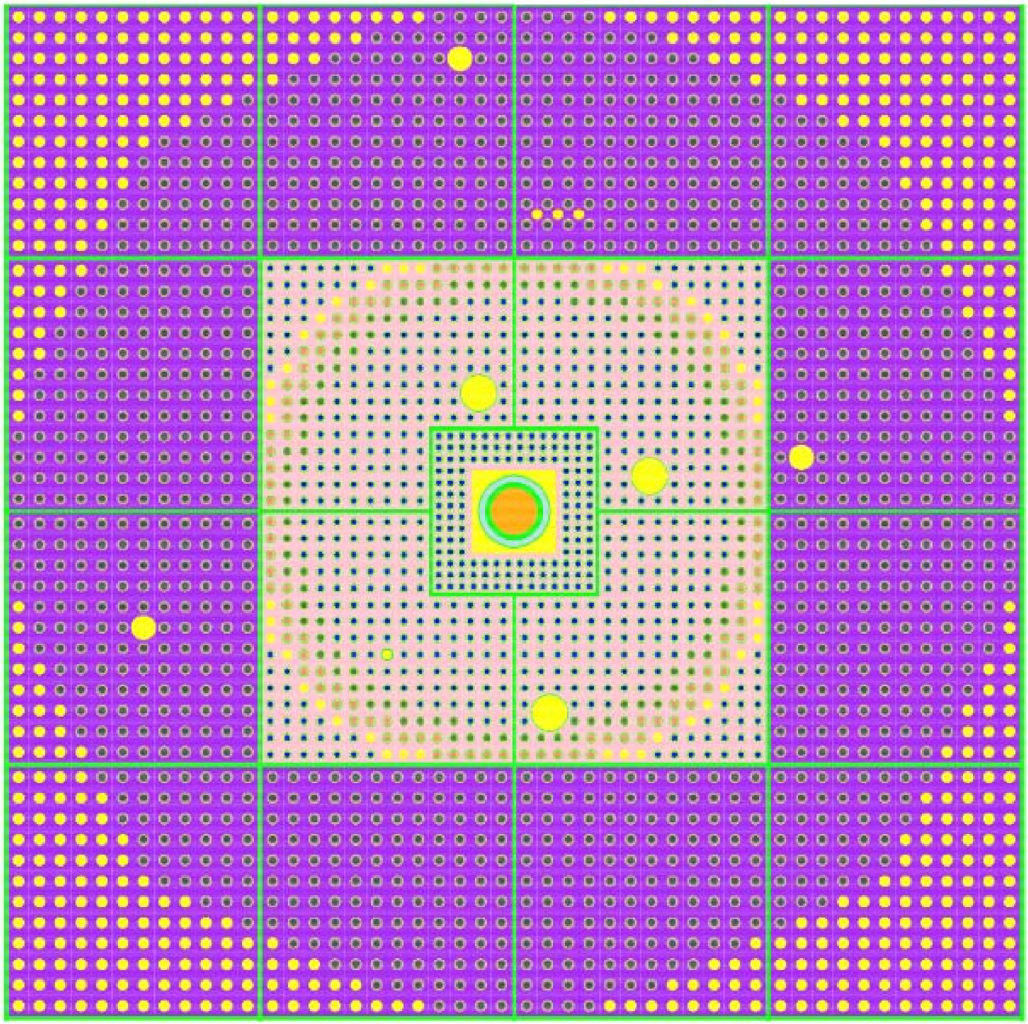


MCNPX Results & Experimental Measurements for YALINA-Booster 1141 Configuration, ENDF/B-VI.6

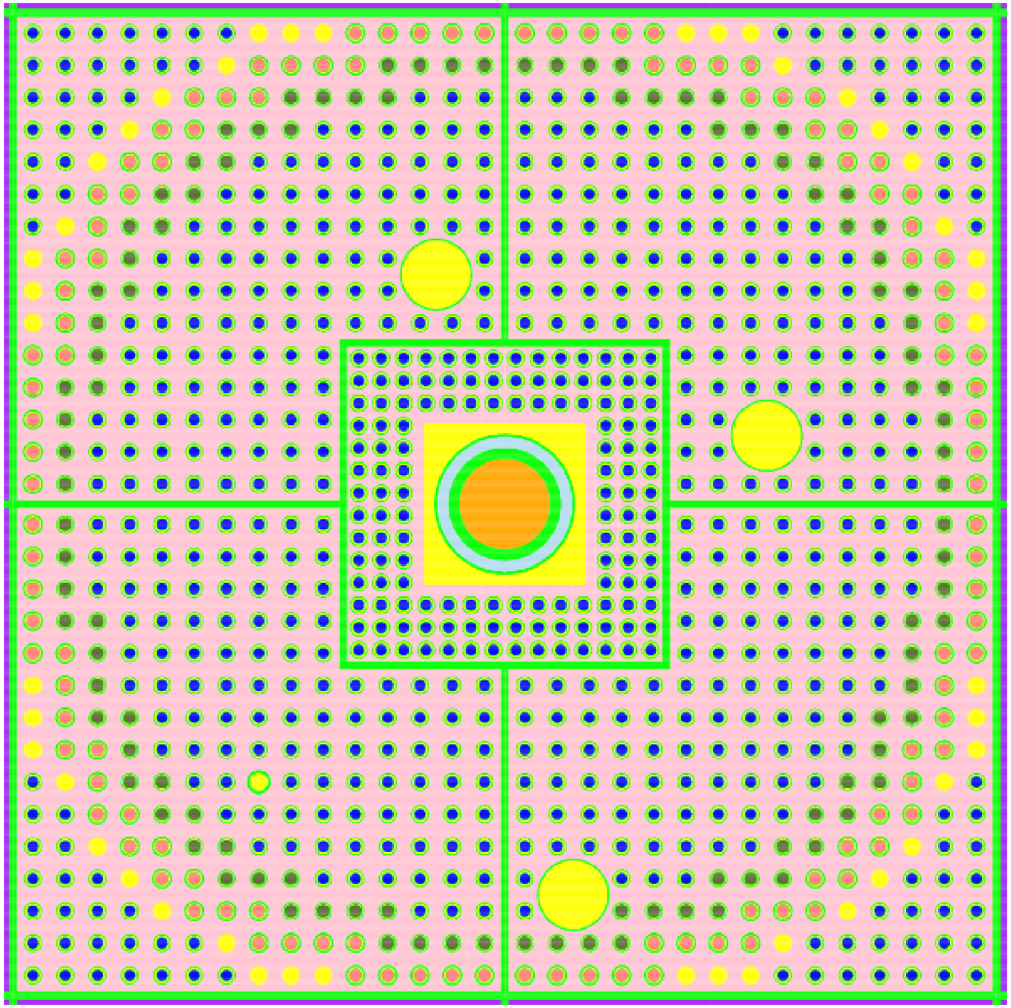




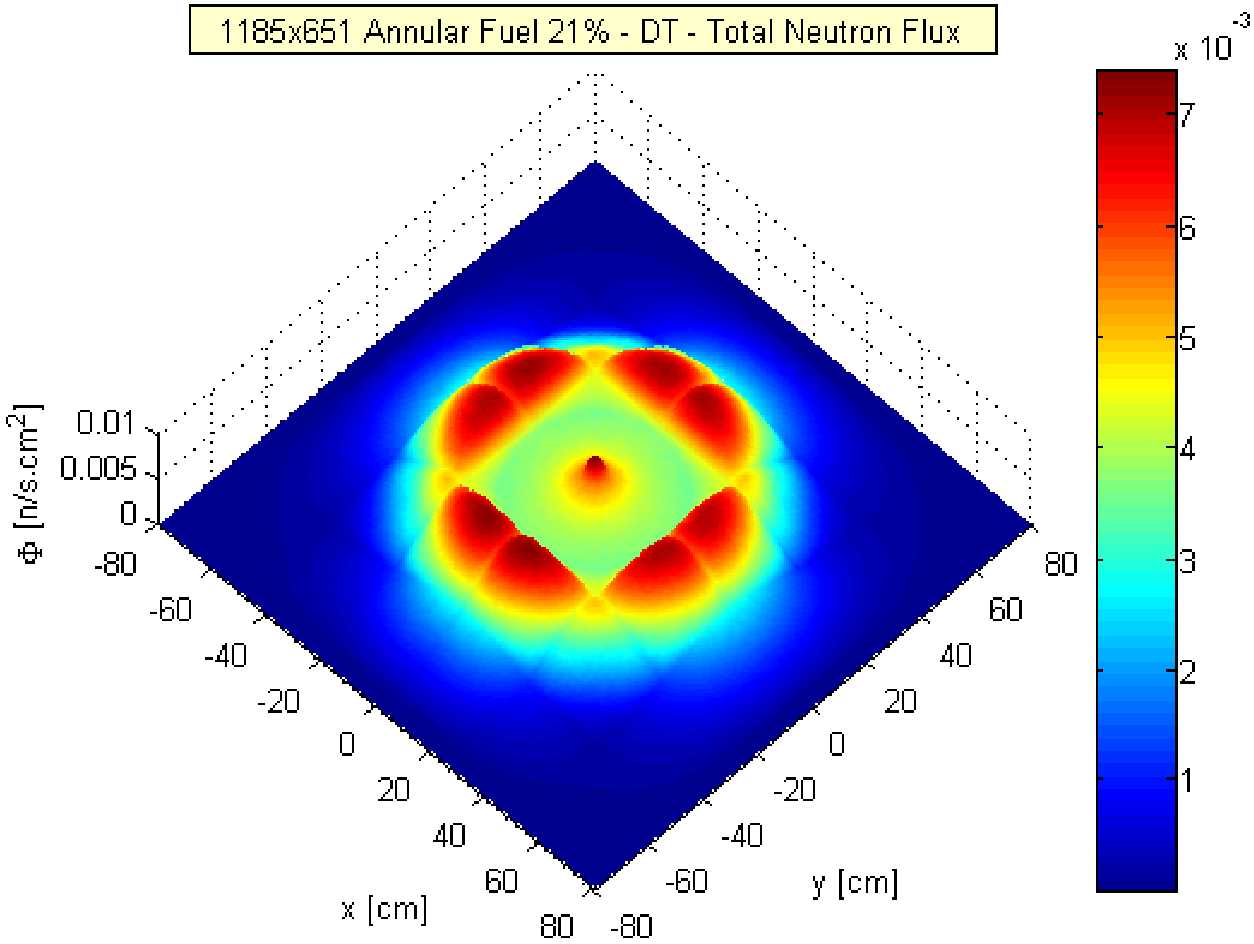
Horizontal Section of MCNPX Geometrical Model of YALINA-Booster Configuration with 21% Enriched Fuel Rods in the Booster Zone Shown Without the Graphite Reflector



Horizontal Section of MCNPX Geometrical Model of YALINA-Booster Zone with 21% Enriched Fuel Rods Featuring the New Configuration of the Interface Zone



Total Neutron Flux Map of the YALINA-Booster Configuration with 21% enriched uranium oxide fuel in the Booster Zone



Conclusions

- ERANOS Deterministic Analyses were completed successfully for the of YALINA-Booster loaded with 1141 and 902 EK-10 rods.
- The obtained reactivity values for YALINA-Booster 1141, and YALINA-Booster 902 configurations show an excellent agreement with the measurements, difference of 200 pcm.
- The highest k_S values are obtained with the D-T neutron source because of the extra neutrons from the (n, xn) reactions and the higher number of neutrons per fission reaction.
- The calculated detector responses to a D-D neutron pulse with the KIN3D code of ERANOS show a good agreement with the measurements.
- The Bell & Glasstone approach has been used to calculate the spatial correction factors for the measured reactivity values. The corrected values are very close to the calculated value.
- Monte Carlo models were developed and used successfully for analyzing YALINA-Booster.

Conclusions (continued)

- The obtained analytical and the experimental results show good agreement.
- Analyses and experiments of YALINA-Booster with different fuel enrichments are being carried out utilizing the obtained experience from the past analyses.
- The first step for replacing the 90% enriched metallic uranium fuel with 36% enriched uranium oxide fuel was completed successfully where extra 44 EK-10 fuel rods (10% enriched uranium oxide fuel) were added in the thermal zone to maintain the assembly reactive without change.
- The second step for replacing the 36% enriched uranium oxide fuel with 21% enriched uranium oxide fuel required arrangement adjustment for the absorber zone to maintain the reactivity of the assembly without change.
- The project is progressing successfully and the second phase is focusing on ADS physics and using low enriched uranium fuel with new configuration.