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RZ MODEL – MYRRHA CRITICAL MODE

sck cen
Belgian Nuclear Research Centre

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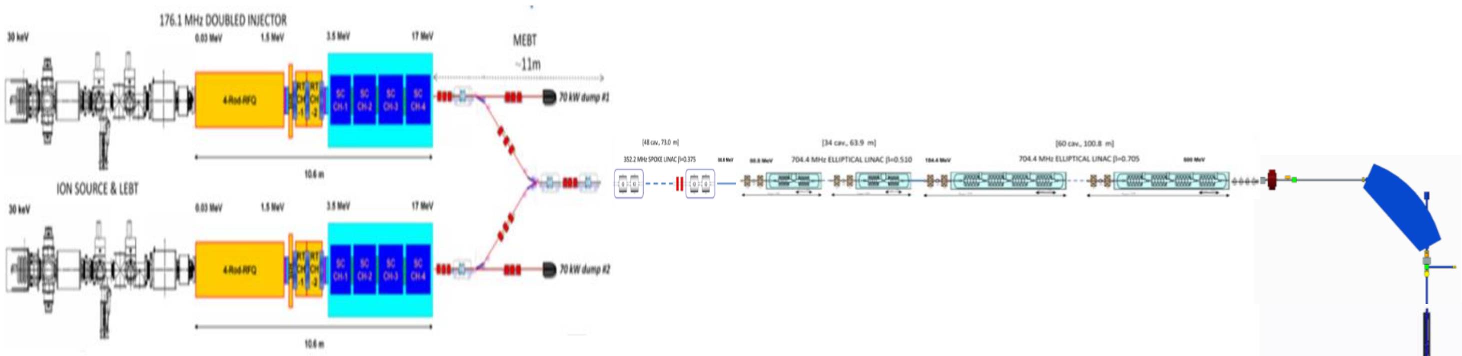
MYRRHA

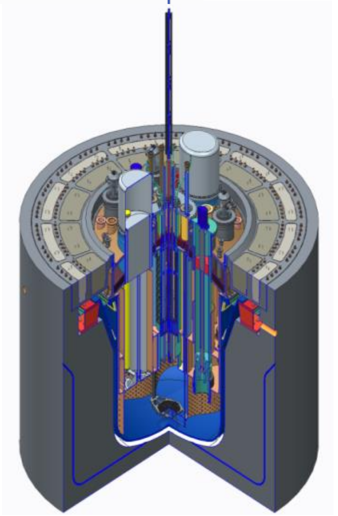
MYRRHA

An Accelerator Driven System



Target	
main reaction	spallation
output	$2{\cdot}10^{17}$ n/s
material	LBE (coolant)

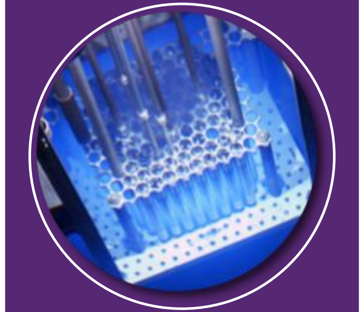
Accelerator	
particles	protons
beam energy	600 MeV
beam current	2 - 4 mA



Reactor	
power	70 MW_{th}
k_{eff}	0.95
spectrum	fast
coolant	LBE

MYRRHA

APPLICATIONS



Fission GEN IV

Small Modular Reactor

Spent Nuclear Fuel

Fundamental research

Radioisotopes

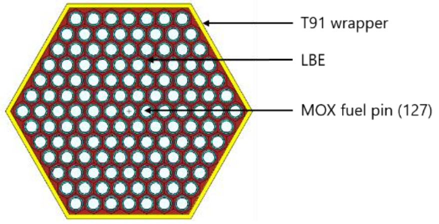
Fusion

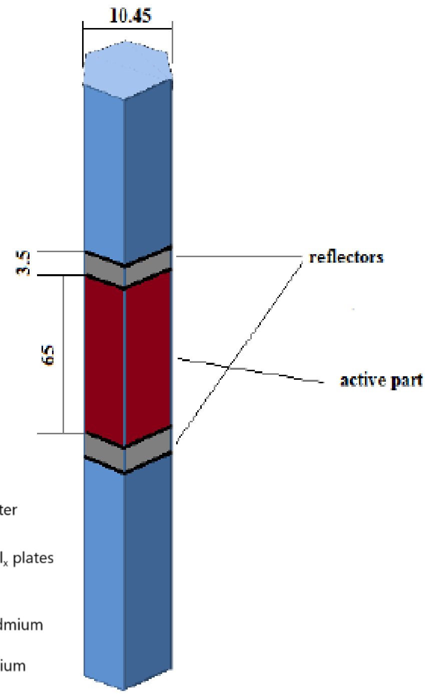
MYRRHA

CORE LAYOUT CONFIGURATIONS BoL – V 1.8

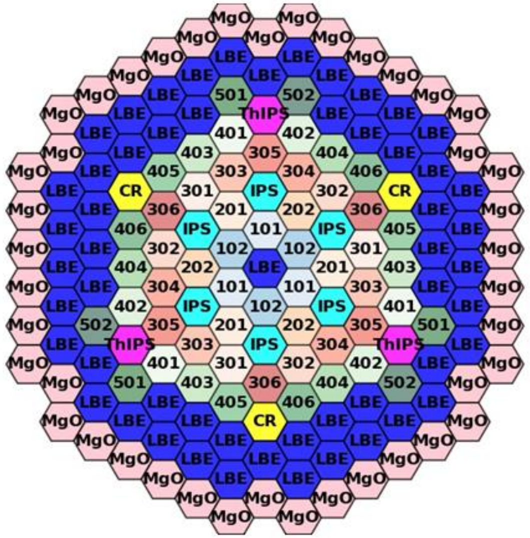
Common features

- Hexagonal assemblies – 127 fuel elements
- MOX fuel – 65 cm long
- Boron carbide B4C control rod bundles
- In-pile sections (IPSs) for material testing and experiments with fast neutron fluxes
- In-pile sections for production of molybdenum-99 (thermal islands)
- Dummy assemblies filled with LBE
- Reflector assemblies with bundles of magnesium oxide rods

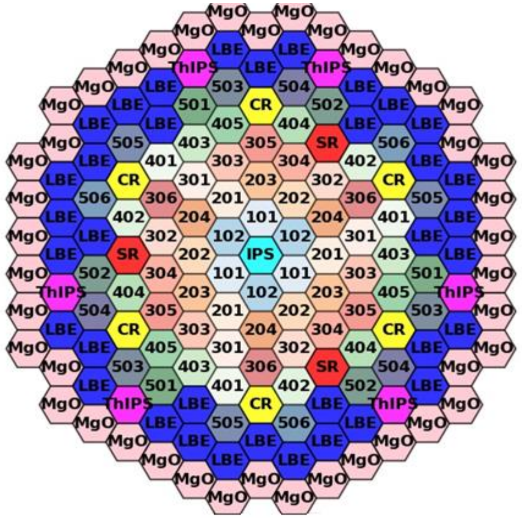


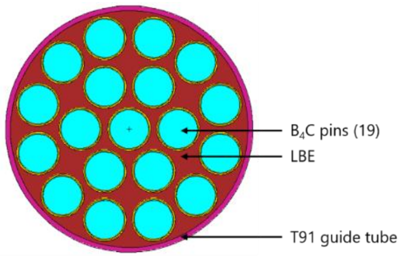


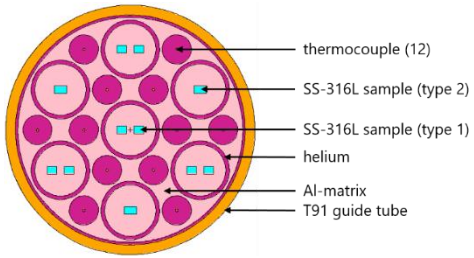
Subcritical mode

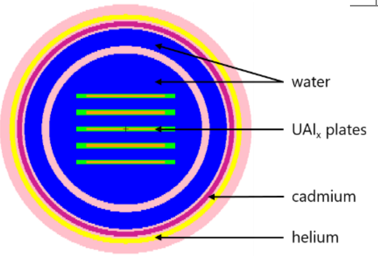


Critical mode









MYRRHA

Critical vs subcritical mode

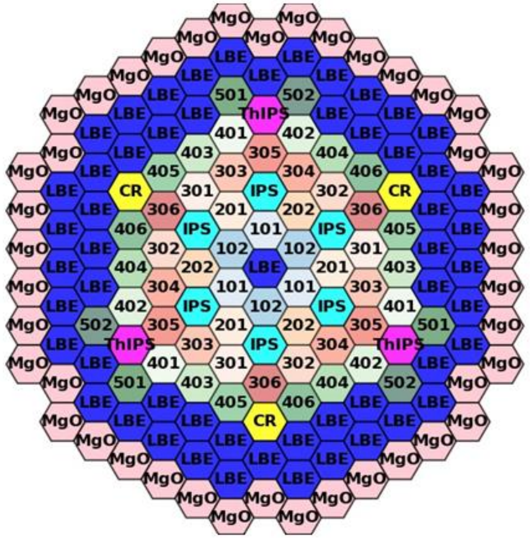
Assembly	Subcritical mode	Critical mode
STA	1	-
FA	54	69
Fast IPS	6	1
ThIPS	3	6
CR	3	6
SR	-	3
Dummy	54	36
Reflector	42	42

Peaking factor	Subcritical	Critical
radial	1.8	1.69
axial	1.34	1.22

SUBCRITICAL

- ❑ No safety rods required
- ❑ Proton source + beam window
- ❑ High peaking factors
  → peaked power
- ❑ High and hard flux in core center profiles
  → MA transmutation

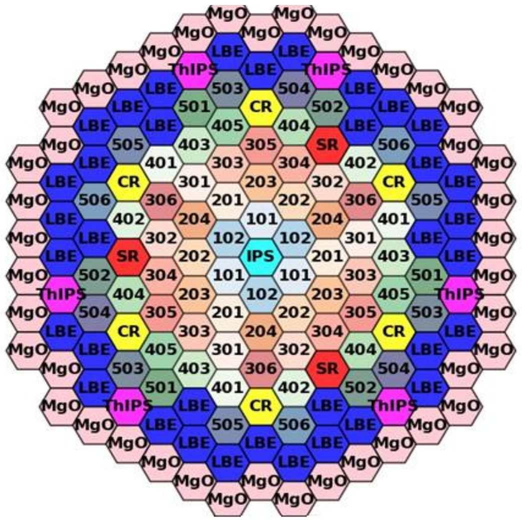
Subcritical mode



CRITICAL

- ❑ Safety rods required
- ❑ No external source required
- ❑ Lower and softer neutron flux in core center
- ❑ Lower peaking factors

Critical mode

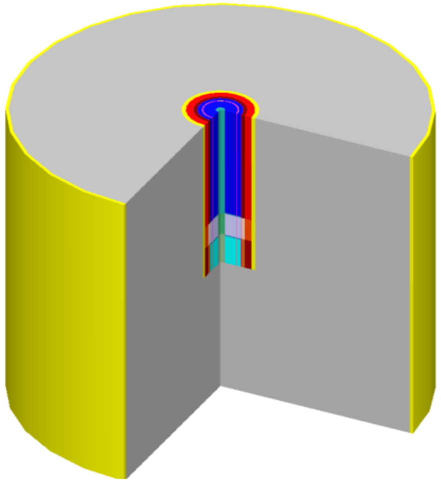


RZ MODEL

RZ MODEL

WHAT AND WHY?

- RZ model is a homogenized simplified model of a reactor
- Concentric cylinders
- We assume symmetry of properties in all directions
- Useful for deterministic codes (simple geometry)
- Easy to distribute → ⬆ research



RZ model v 1.6
P. Romojario 2016

RZ MODEL

CALCULATION METHODOLOGY

Heterogeneous model
(**MCNP + SERPENT + OpenMC**)

Homogeneous model
(**MCNP + OpenMC + Serpent**)

RZ model
(**Serpent**)

Nuclear data library:
JEFF-3.3

Particle transport & sensitivity calculations :
Serpent2 – 7G

Important parameters:
Keff, Beff, sensitivities, neutron spectra

RZ MODEL
CALCULATION METHODOLOGY

$$\langle N_j \rangle = \frac{\sum_i V_i N_{i,j}}{\sum_i V_i}$$

$\langle N_j \rangle$: atomic composition in at/cm/b of nuclide j averaged over the volume of all materials in the selected homogenization region

V_i: volume of material i in cm³ in the selected homogenization region

$N_{i,j}$: atomic composition in at/cm/b of nuclide j un material i

$$\langle \rho \rangle = \sum_i \langle N_j \rangle$$

$\langle \rho \rangle$: volume-averaged material atomic density in the homog. region

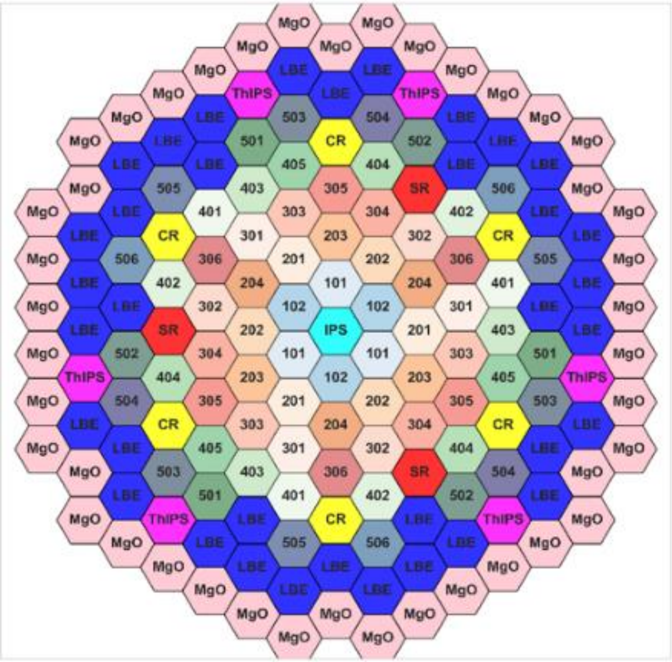
$$\langle T \rangle = \frac{\sum_i V_i T_i}{\sum_i V_i}$$

$\langle T \rangle$: volume-averaged material temperature

		Area (cm²)	Height (cm)	Volume (cm³)	Density (at/b/cm)	Temperature (K)
FA	Top	94.57	254	24020.78	3.745381E-02	600
	Upper reflector	94.57	3.5	331.00	3.709204E-02	700
	Middle	94.57	65	6147.05	5.426907E-02	800
	Lower reflector	94.57	3.5	331.00	3.709204E-02	700
	Bottom	94.57	111.5	10544.56	4.617310E-02	600
IPS	Top	94.57	257.5	24351.78	4.711609E-02	600
	Middle	94.57	65	6147.05	4.403813E-02	650
	Bottom	94.57	115	10875.55	3.089478E-02	600
Thermal island	Top	94.57	257.5	24351.78	7.753269E-02	300
	Middle	94.57	65	6147.05	7.823904E-02	300
	Bottom	94.57	115	10875.55	4.257130E-02	300
CR	Top	94.57	257.5	24351.78	3.638115E-02	600
	Middle	94.57	65	6147.05	2.922820E-02	650
	Bottom	94.57	115	10875.55	4.014485E-02	600
SR	Top	94.57	257.5	24351.78	5.199215E-02	600
	Middle	94.57	65	6147.05	4.322756E-02	650
	Bottom	94.57	115	10875.55	4.201838E-02	600
Dummy	Top	94.57	257.5	24351.78	3.720034E-02	600
	Middle	94.57	65	6147.05	3.407538E-02	650
	Bottom	94.57	115	10875.55	4.304517E-02	600
Reflector	Top	94.57	257.5	24351.78	3.778243E-02	600
	Middle	94.57	65	6147.05	7.796185E-02	650
	Bottom	94.57	115	10875.55	6.725266E-02	600
STA	LBE + wrapper	-	282.415	9990.69	4.798150E-02	600
	Bottom	94.57	155.085	14666.39	3.407533E-02	600
SS jacket	Top	94.57	257.5	24351.78	6.353354E-02	600
	Middle	94.57	65	6147.05	8.491454E-02	600
	Bottom	94.57	115	10875.55	8.491454E-02	600

SANDA – Homogenized neutronics model of MYRRHA v1.8.
L.Fiorito, A. Hernández Solis & P Romojaro (2021)

RZ MODEL



MgO MgO
MgO MgO MgO
MgO LBE LBE MgO
MgO ThIPS LBE ThIPS MgO
MgO LBE 503 504 LBE MgO
MgO LBE 501 CR 502 LBE MgO
LBE LBE 405 404 LBE LBE
MgO 505 403 305 SR 506 MgO
MgO LBE 401 303 304 402 LBE MgO
LBE CR 301 203 302 CR LBE
MgO 506 306 201 202 306 505 MgO
LBE 402 204 101 204 401 LBE
MgO LBE 302 102 102 301 LBE MgO
LBE SR 202 IPS 201 403 LBE
MgO 502 304 101 101 303 501 MgO
ThIPS 404 203 102 203 405 ThIPS
MgO 504 305 201 202 305 503 MgO
LBE CR 303 204 304 CR LBE
MgO LBE 405 301 302 404 LBE MgO
MgO 503 403 306 SR 504 MgO
LBE 501 401 402 502 LBE
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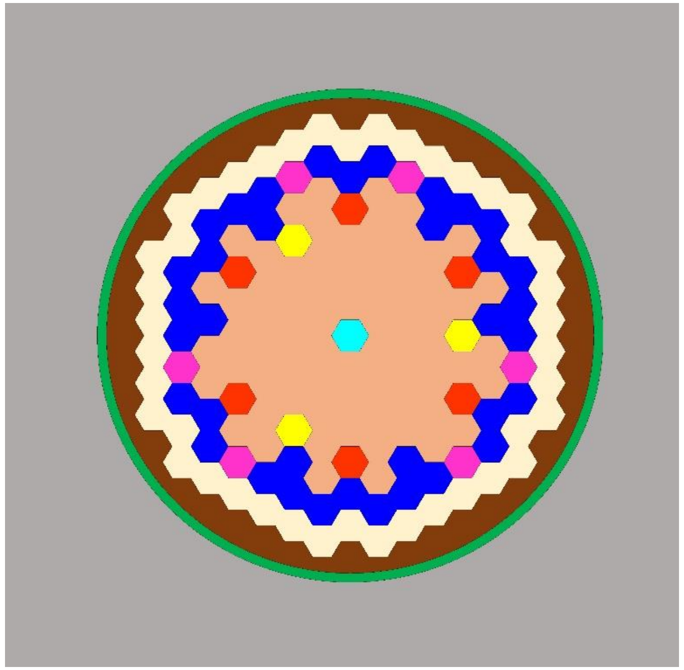
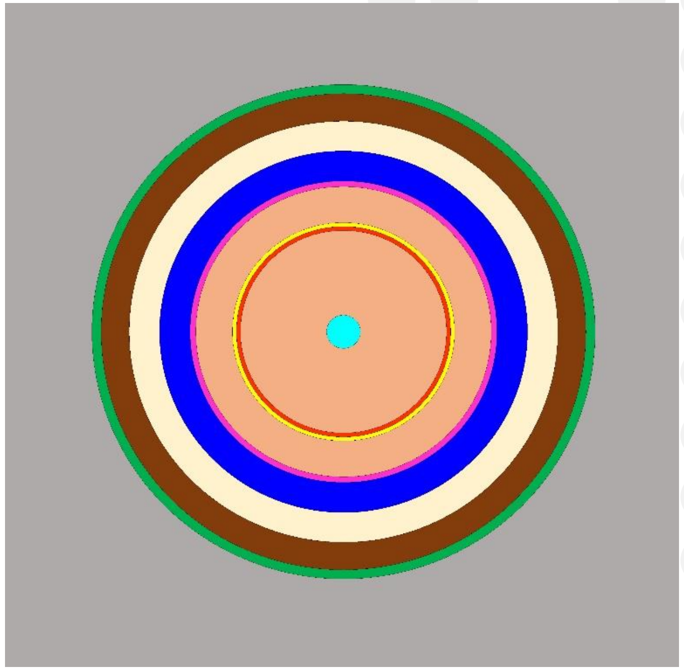
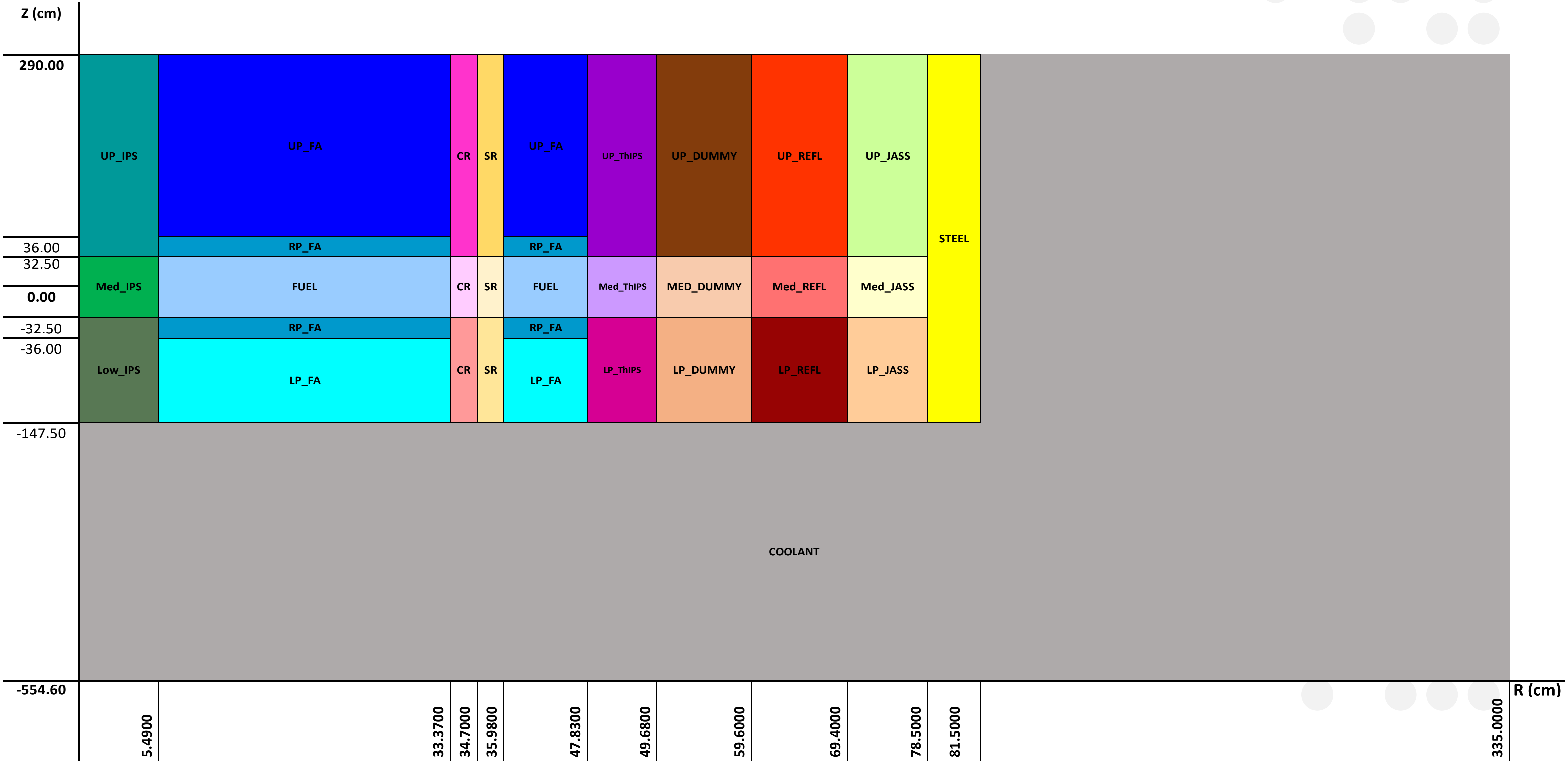
MgO MgO





RZ MODEL


Z (cm)
290.00
36.00
32.50
0.00
-32.50
-36.00
-147.50
-554.60
UP_IPS
UP_FA
CR
SR
UP_FA
UP_ThIPS
UP_DUMMY
UP_REFL
UP_JASS
RP_FA
RP_FA
STEEL
Med_IPS
FUEL
CR
SR
FUEL
Med_ThIPS
MED_DUMMY
Med_REFL
Med_JASS
RP_FA
RP_FA
Low_IPS
LP_FA
CR
SR
LP_FA
LP_ThIPS
LP_DUMMY
LP_REFL
LP_JASS
COOLANT
R (cm)
5.4900
33.3700
34.7000
35.9800
47.8300
49.6800
59.6000
69.4000
78.5000
81.5000
335.0000

VERIFICATION

VERIFICATION

CHANDA PROJECT

Total $\frac{\delta k_{eff}}{k_{eff}} = 0.945\%$ ~1000 pcm

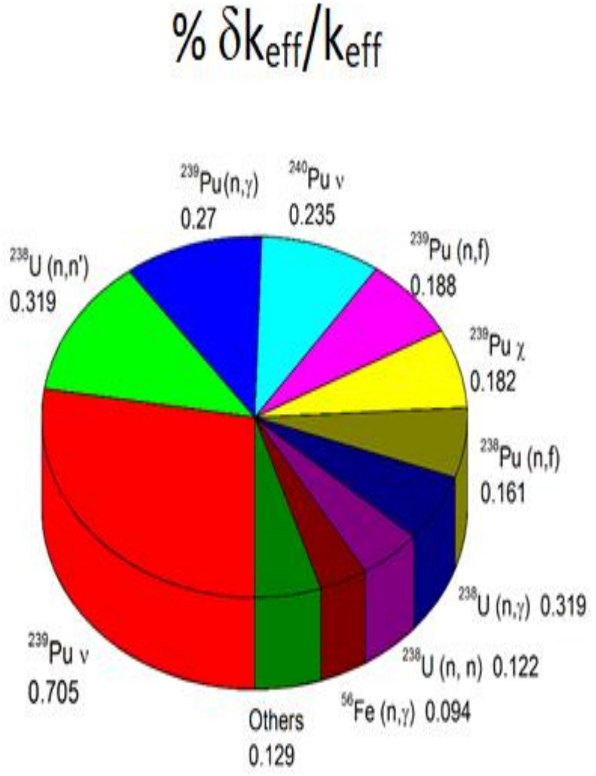
Target accuracy : $\frac{\delta k_{eff}}{k_{eff}} \sim 300\ pcm$ (<β_{eff})

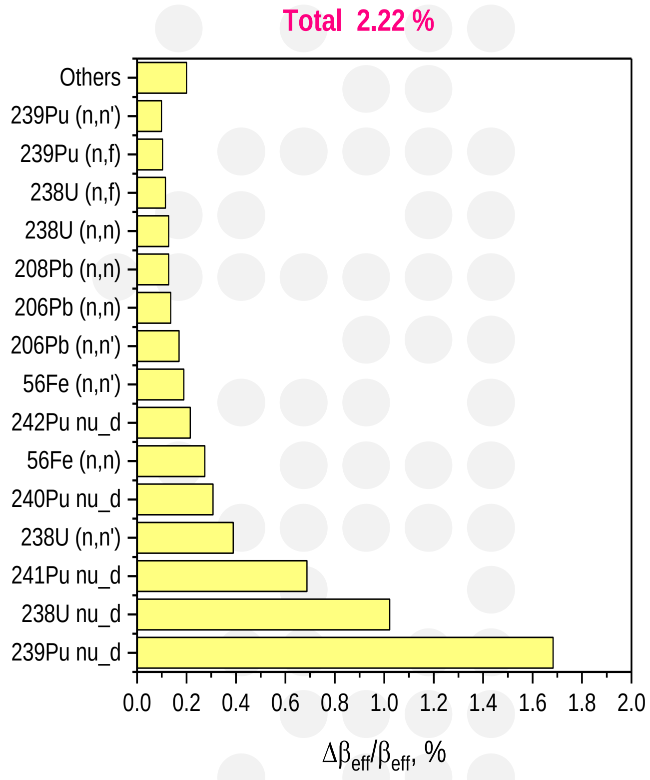
$k_{eff} = 1.000719 \pm 0.00001$

$\beta_{eff} = 328 \pm 1$ pcm

MYRRHA – k_{eff} ISC (%/%)		
Quantity		JEFF-3.3
^{239}Pu	ν	$0.696 \pm 2.9\cdot10^{-6}$
^{239}Pu	(n,f)	$0.482 \pm 2.9\cdot10^{-6}$
^{238}U	(n,γ)	$-0.112 \pm 3.7\cdot10^{-7}$
^{241}Pu	ν	$0.091 \pm 4.5\cdot10^{-7}$
^{240}Pu	ν	$0.081 \pm 4.5\cdot10^{-7}$
^{238}U	ν	$0.070 \pm 6.1\cdot10^{-7}$
^{241}Pu	(n,f)	$0.064 \pm 4.6\cdot10^{-7}$
^{240}Pu	(n,f)	$0.055 \pm 4.6\cdot10^{-7}$
^{239}Pu	(n,γ)	$-0.053 \pm 3.1\cdot10^{-7}$
^{209}Bi	(n,n)	$0.052 \pm 1.1\cdot10^{-5}$

MYRRHA – β_{eff} ISC (%/%)		
Quantity		JEFF-3.3
^{239}Pu	ν_p	$-0.594 \pm 9.8\cdot10^{-6}$
^{239}Pu	ν_d	$0.413 \pm 9.9\cdot10^{-6}$
^{238}U	ν_d	$0.297 \pm 6.7\cdot10^{-5}$
^{238}U	(n,f)	$0.192 \pm 7.5\cdot10^{-5}$
^{239}Pu	(n,f)	$-0.167 \pm 3.0\cdot10^{-4}$
^{241}Pu	ν_d	$0.131 \pm 3.3\cdot10^{-5}$
^{238}U	ν_p	$-0.126 \pm 9.2\cdot10^{-8}$
^{240}Pu	ν_p	$-0.116 \pm 6.0\cdot10^{-7}$
^{241}Pu	ν_p	$-0.068 \pm 5.4\cdot10^{-6}$
^{240}Pu	ν_d	$0.063 \pm 1.4\cdot10^{-5}$

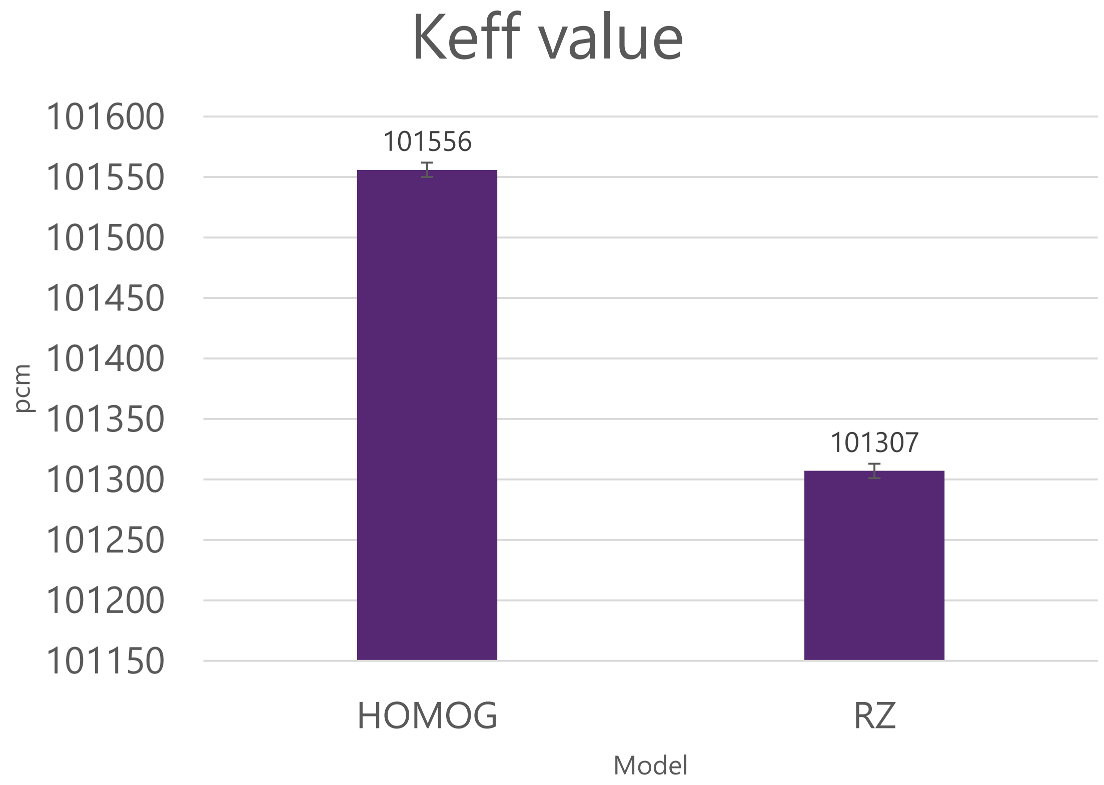


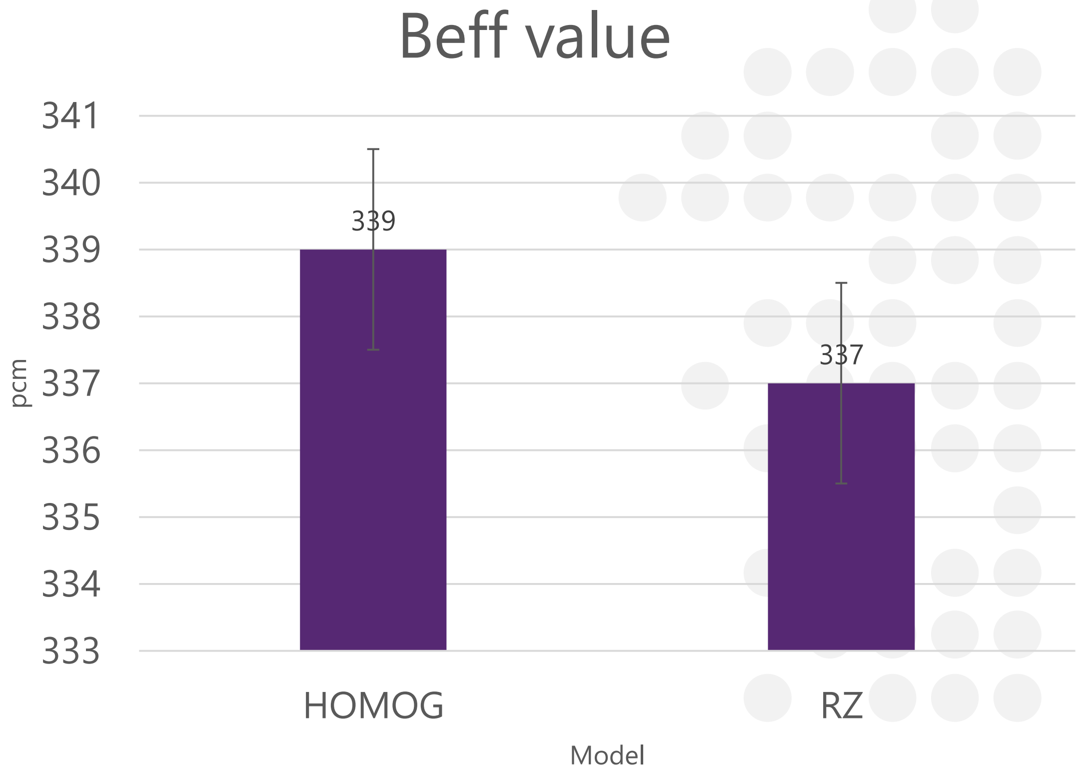


VERIFICATION

PARAMETERS COMPARISON

MODEL	KEFF	BEFF	LEFF
HOMOG	101556 +/- 2pcm	339 +/- 0.6 pcm	0.6851 +/- 0.0005 µsec
RZ	101307 +/- 2 pcm	337 +/- 0.5 pcm	0.6890 +/- 0.0003 µsec

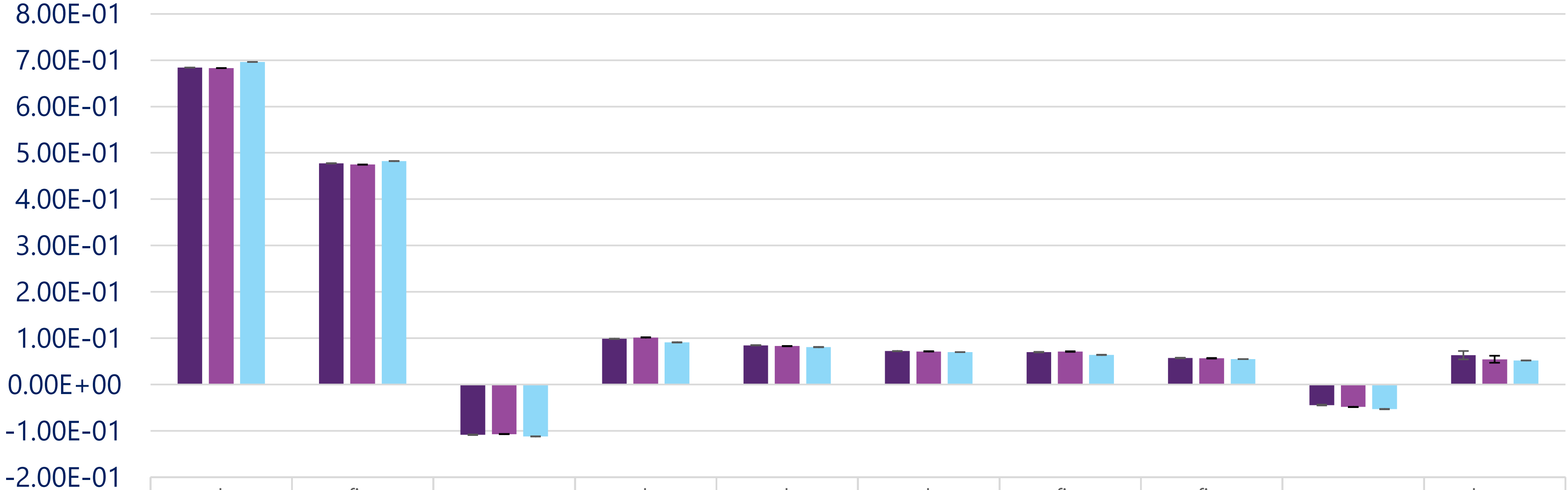




VERIFICATION

SENSITIVITY COMPARISON

Homog Vs RZ model - Sensitivity Keff

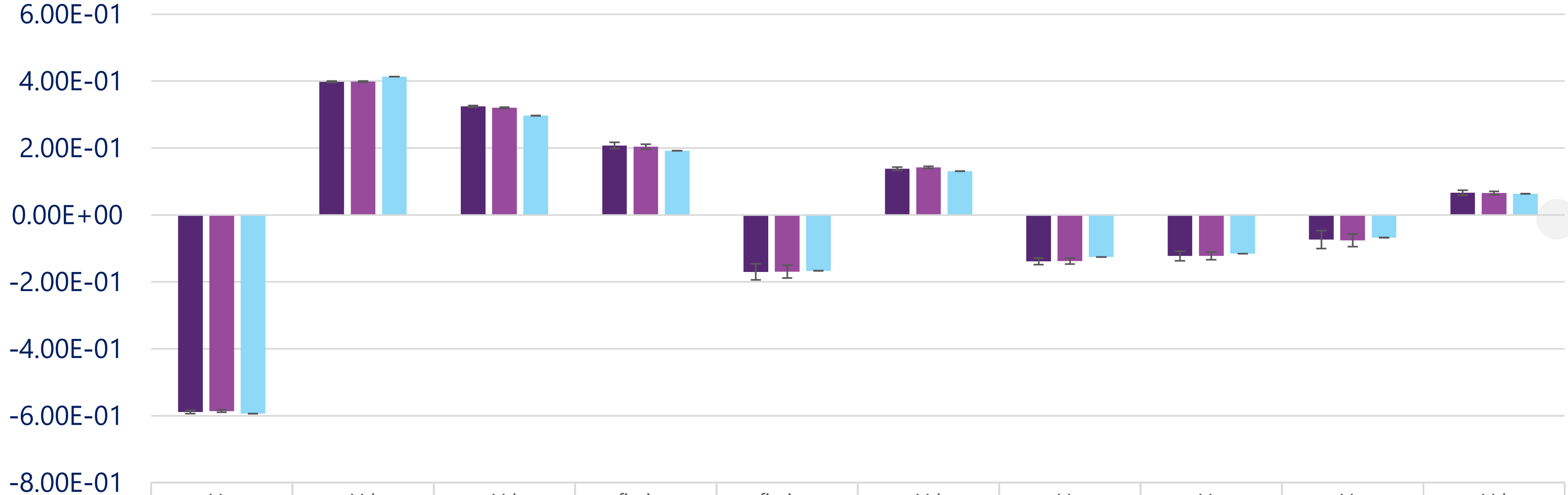


	nubar Pu_239	fiss Pu_239	capt U_238	nubar Pu_241	nubar Pu_240	nubar U_238	fiss Pu_241	fiss Pu_240	capt Pu_239	ela scat Bi_209
HOMG	6.84E-01	4.77E-01	-1.08E-01	9.88E-02	8.48E-02	7.22E-02	6.99E-02	5.75E-02	-4.41E-02	6.33E-02
RZ	6.83E-01	4.75E-01	-1.07E-01	1.02E-01	8.33E-02	7.16E-02	7.15E-02	5.66E-02	-4.82E-02	5.46E-02
CHANDA	6.96E-01	4.82E-01	-1.12E-01	9.10E-02	8.10E-02	7.00E-02	6.40E-02	5.50E-02	-5.30E-02	5.20E-02

HOMG RZ CHANDA

VERIFICATION
SENSITIVITY COMPARISON

Homog Vs RZ model - Sensitivity Beff

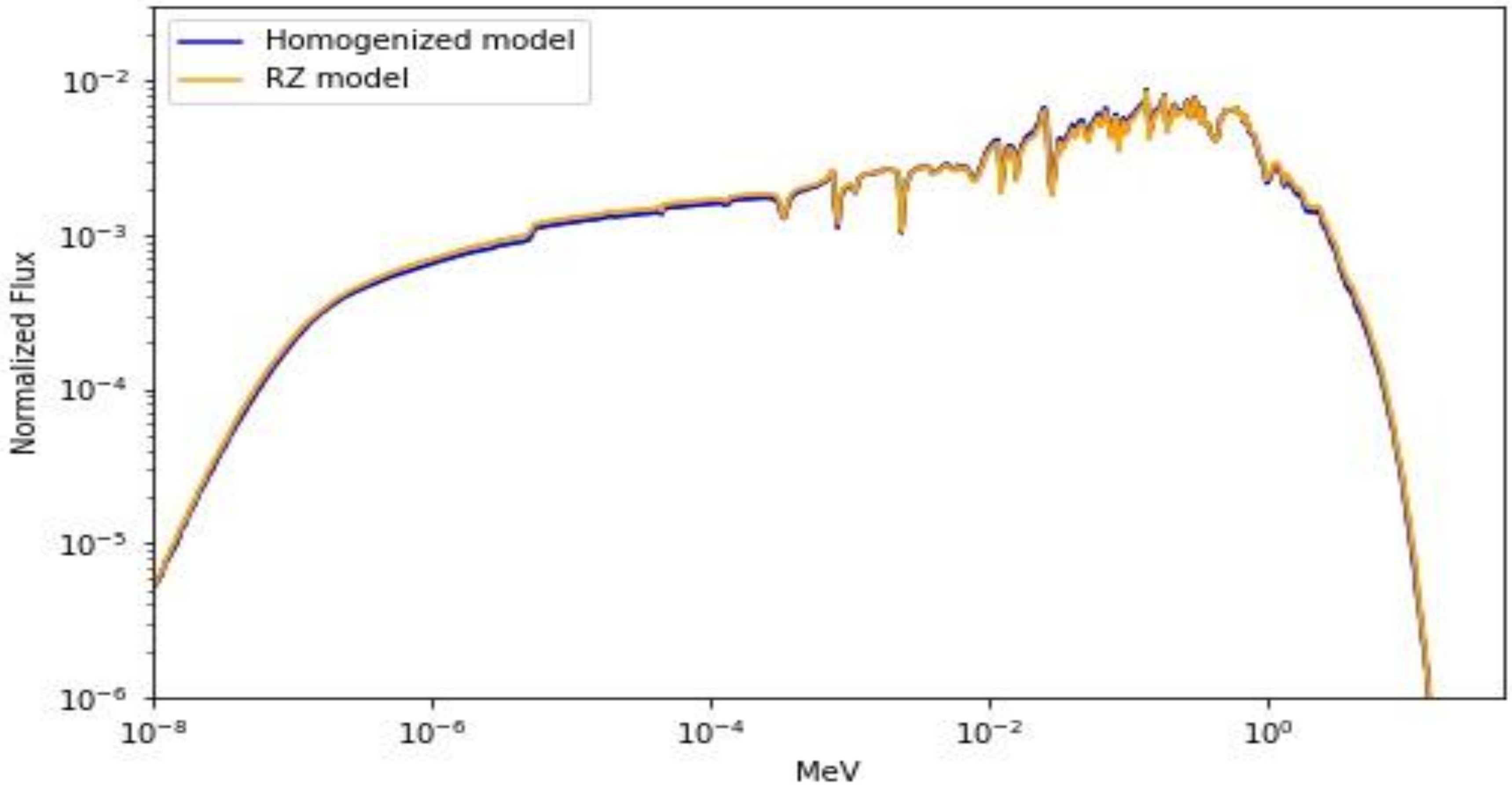


	Vp Pu_239	Vd Pu_239	Vd U_238	fission U_238	fission Pu_239	Vd Pu_241	Vp U_238	Vp Pu_240	Vp Pu_241	Vd Pu_240
HOMG	-5.89E-01	3.98E-01	3.24E-01	2.08E-01	-1.70E-01	1.38E-01	-1.39E-01	-1.23E-01	-7.36E-02	6.65E-02
RZ	-5.86E-01	3.98E-01	3.20E-01	2.04E-01	-1.69E-01	1.42E-01	-1.38E-01	-1.22E-01	-7.60E-02	6.59E-02
CHANDA	-5.94E-01	4.13E-01	2.97E-01	1.92E-01	-1.67E-01	1.31E-01	-1.26E-01	-1.16E-01	-6.80E-02	6.30E-02

HOMG RZ CHANDA

VERIFICATION

NEUTRON SPECTRA



CONCLUSIONS

MYRRHA v 1.8 RZ model developed

The implemented model gives a good approximation of Keff, Beff and their corresponding sensitivity values

Next steps: uncertainty propagation + TAR

The model will be distributed to the participants

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