PBMR Core Design

Presentation to the US DOE

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400 MWt Core Analysis

- Neutronics
- Thermohydraulics
- Source Term Analyses

Neutronics

General Engineering Specifications

Description	Units	Values
Design parameters		
Thermal power rating	MW	400
Fuelling regime		Multiple pass (6 x average)
Fuel		Low Enriched Uranium (LEU)
Assumed He bypass flow	%	19.4
Number of fuelling points		3
Primary coolant temperatures (in/out)	°C	482.4/900
Primary system pressure	kPa	8 952
Pebble bed packing fraction	-	0.61

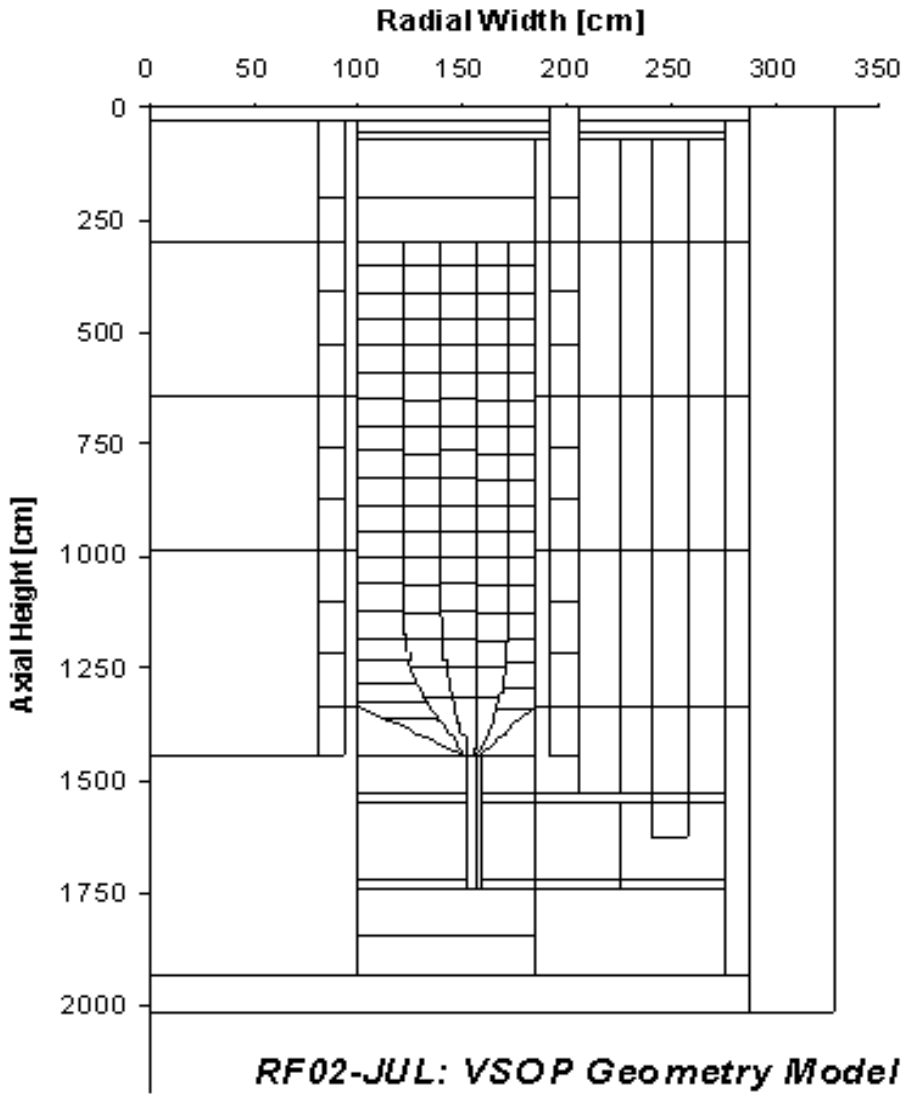
Neutronics

Specification

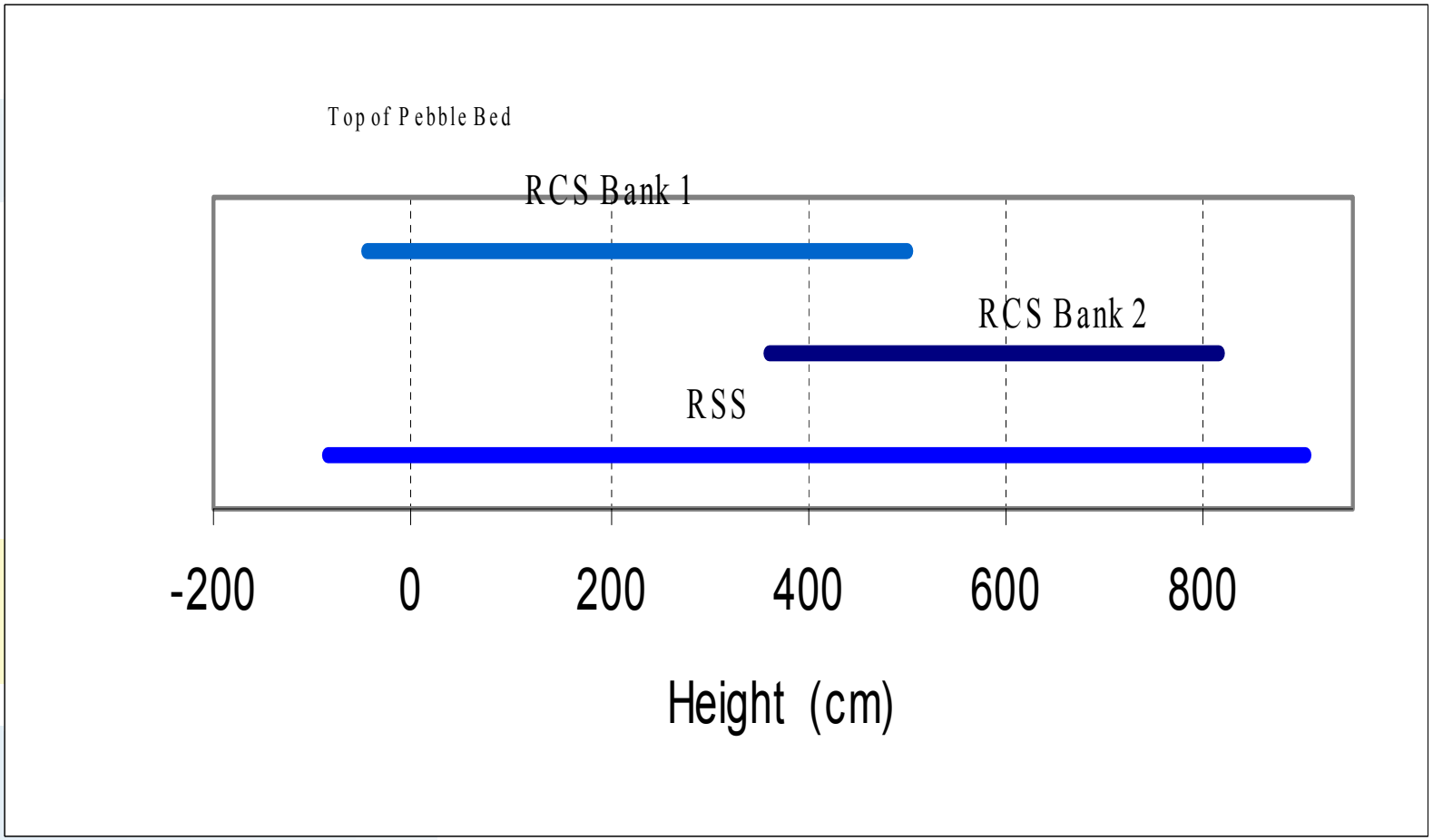
Description	Units	Value
Core thermal power	MW_t	400
Maximum fuel temperature under normal operating conditions (bypass flows included)	°C	1 130
Maximum fuel temperature in an LBE (nominal or best estimation)	°C	1 500
Load follow capability (Xenon override)	% power	100 – 40 – 100
Maximum power production per pebble	kW	4.5
Reactivity shutdown margin at 100 °C (RSS alone)	$\%\Delta k$	≥ 1
Number of control rods (upper position)		12
Number of control rods (lower position when inserted)		12
Effective length of control rods (both upper and lower)	m	6.5
Number of RSS positions in centre reflector		8
Uncertainty addition on reactivity demand	%	5%
Uncertainty subtraction on control units worth	%	5%

Neutronics

VSOP Geometry Model

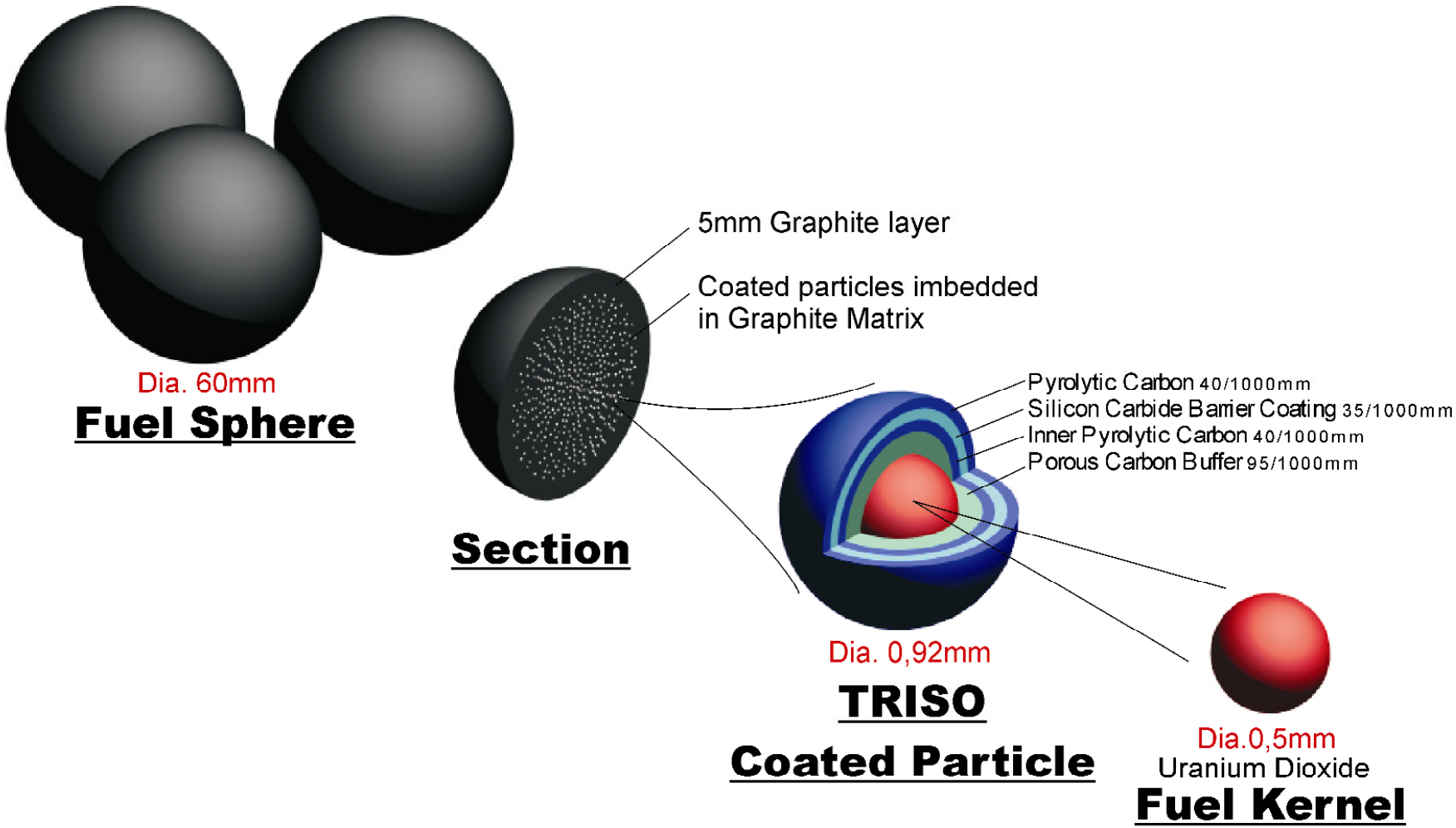


RCSS Position: Inserted



Neutronics

Fuel Sphere

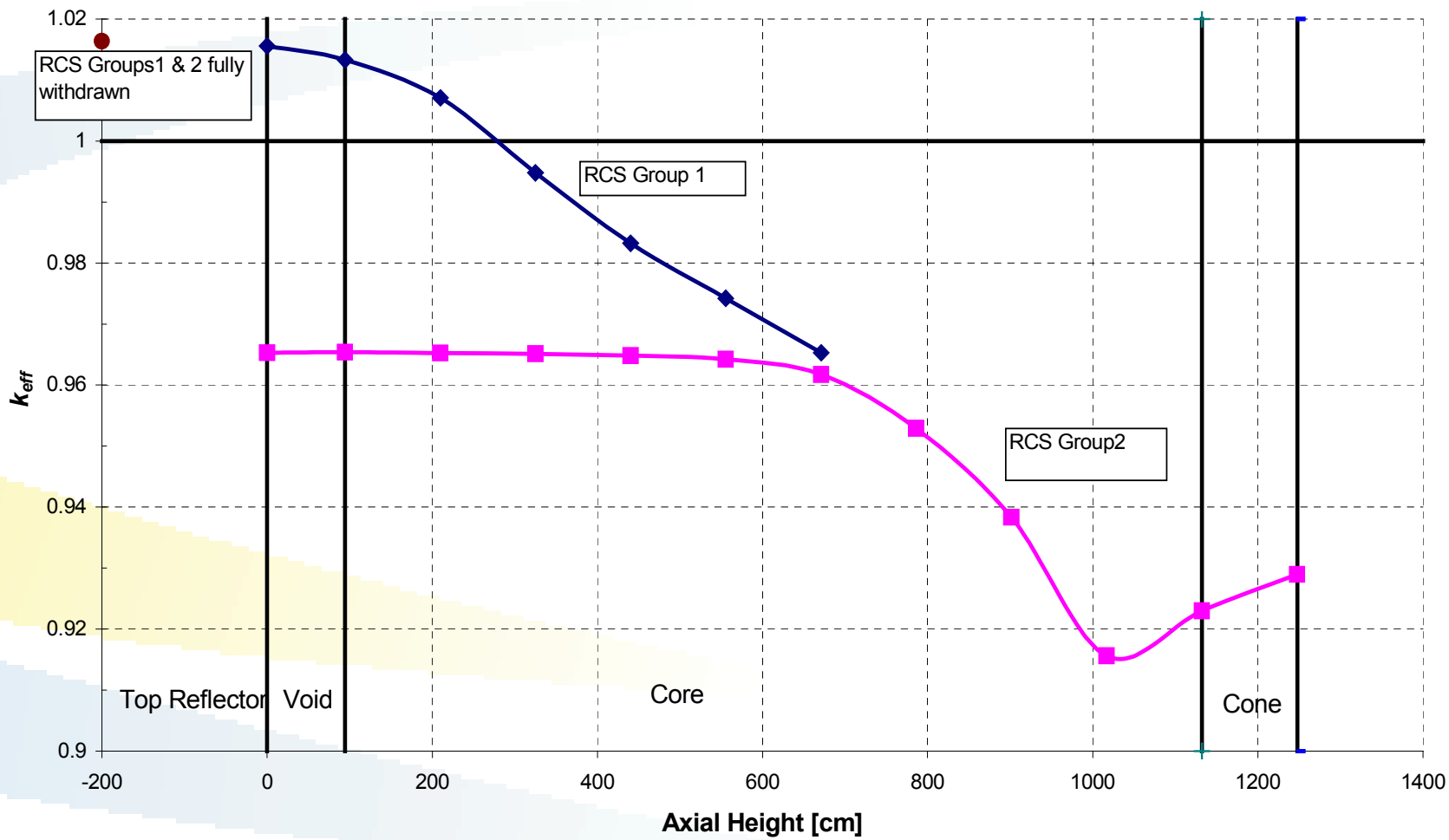


Neutronics

Fuel Specifications

Description	Units	Values
Fuel spheres		
Pebble radius	cm	3
Thickness of fuel free zone	cm	0.5
Density of graphite in matrix/fuel free zone	g/cm^3	1.73
Enrichment of uranium (the result of VSOP equilibrium calculation)	%	9.6
Coated particles		
Particle diameter	μm	920
Coated particle density	g/cm^3	10.4
Coating material		C/C/SiC/C
Layer thickness	μm	95/40/35/40
Layer densities	g/cm^3	1.05/1.90/3.18/1.90
Enrichment	%	9.6
Heavy Metal Content	g	9
Design Burn-up	MWd/t	95 000

Reactivity Worths of RCS Banks



Neutronics

P B M R

Isodeltic Temperature Coefficients of Reactivity

Temperature Coefficients at Operating Conditions	Unit	Value
Fuel (Doppler coefficient of ^{238}U)	$\Delta k/°C$	-3.30E-05
Moderator	$\Delta k/°C$	-3.36E-05
Central graphite reflector	$\Delta k/°C$	1.48E-05
Outer reflectors	$\Delta k/°C$	1.76E-05
TOTAL	$\Delta k/°C$	-3.42E-05

Neutronics

Reactivity Balance at Cold Conditions (100°C) for RSS Only

Description	After 4 days
	%Δk
Requirement	
Xenon decay	4.31
Operating temperature down to 100 ºC	2.79
Uncertainties (5%)	0.36
Total requirement	**7.46**
Capability	
Eight RSS inserted	9.87
Uncertainties (5%)	-0.53
Total Capability	**9.34**
Reactivity reserve margin (Capability – Requirement)	**1.88**

Neutronics

Reactivity Balance at Cold Conditions (100°C) for RCS Only

Description	After 4 Days
	%Δk
Requirement	
Withdrawal of RCS	1.3
Xenon decay	3.01
Operating temperature down to 100 °C	2.79
Uncertainties (5%)	0.36
Total requirement	**7.46**
Capability	
12 Top rods inserted	4.62
12 Bottom rods inserted additionally	5.01
One rod removed	
Uncertainties (5%)	-0.48
Total capability	**9.15**
Reactivity reserve margin	
(Capability – Requirement)	**1.69**

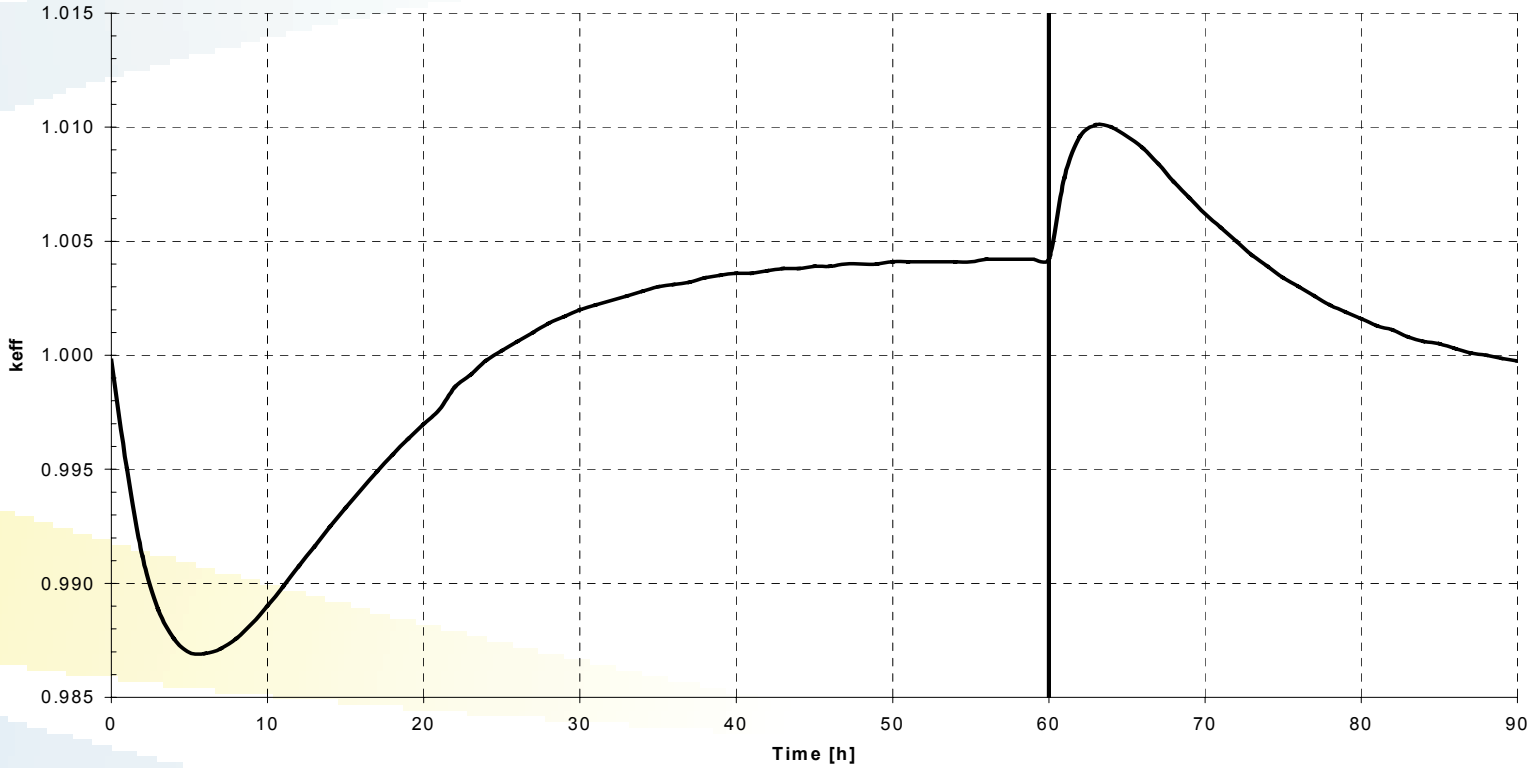
Neutronics

Reactivity Balance at Cold Conditions (100°C) for RCS and RSS Combined

Description	After 4 days
	%Δk
Requirement	
Xenon decay	4.31
Operating temperature down to 100 ºC	2.79
Uncertainties (5%)	0.36
Total requirement	**7.46**
Capability	
12 Top rods inserted	4.62
12 Bottom rods inserted additionally	5.01
Nine RSS inserted	10.78
Uncertainties (5%)	-1.02
Total Capability	**19.39**
Reactivity reserve margin (Capability – Requirement)	**11.93**

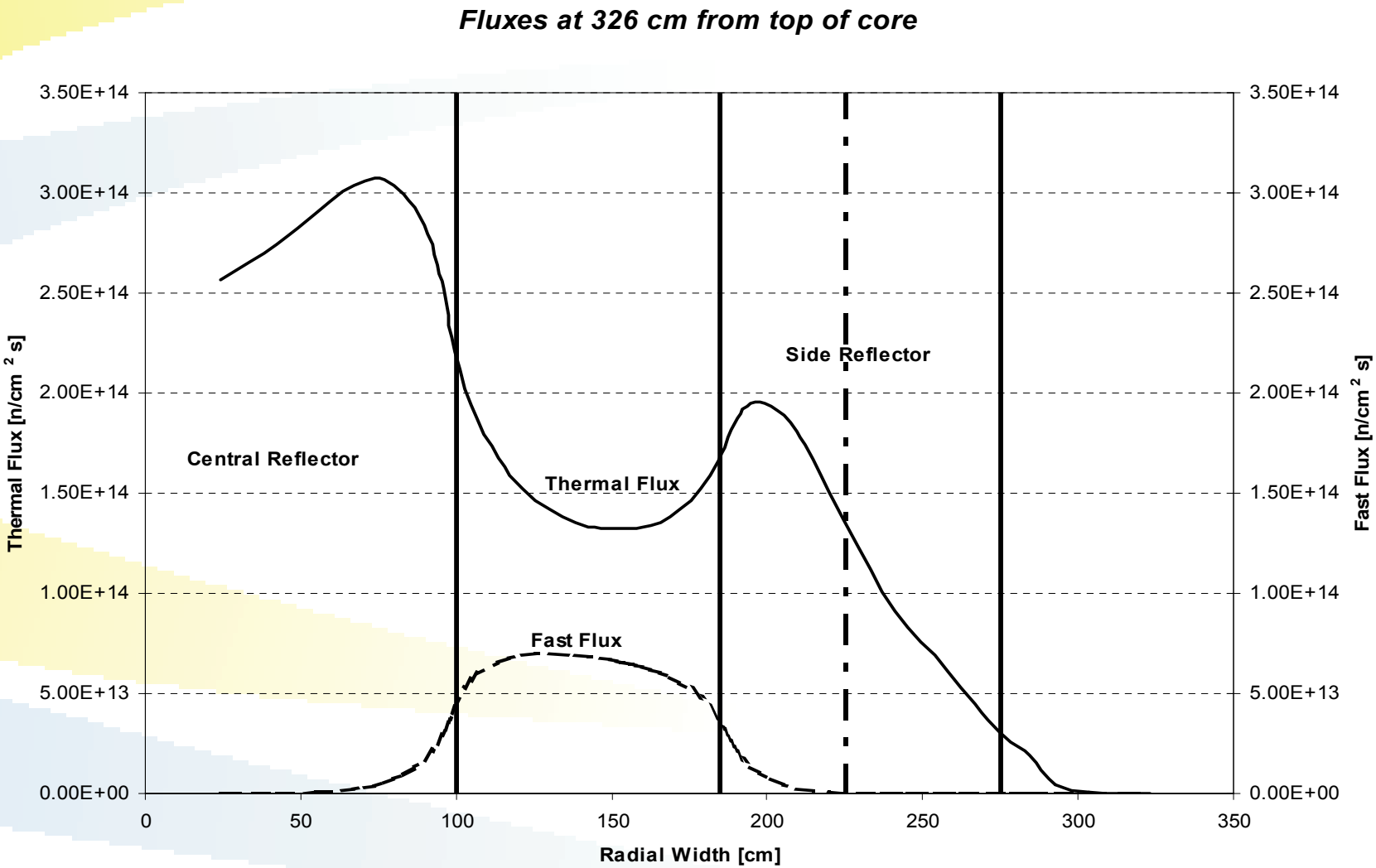
Neutronics

Xe Reactivity Requirement for 100-40-100% Load Following



Neutronics

Radial Distribution of Neutron Flux



Neutronics

P B M R

Volume Average Neutron Flux in Core

	Units	Value
Average Thermal Flux (< 1.86 eV)	n/cm2.s	7.90E+13
Average Fast Flux (> 0.1 MeV)	(n/cm2.s)	3.26E+13

Neutronics

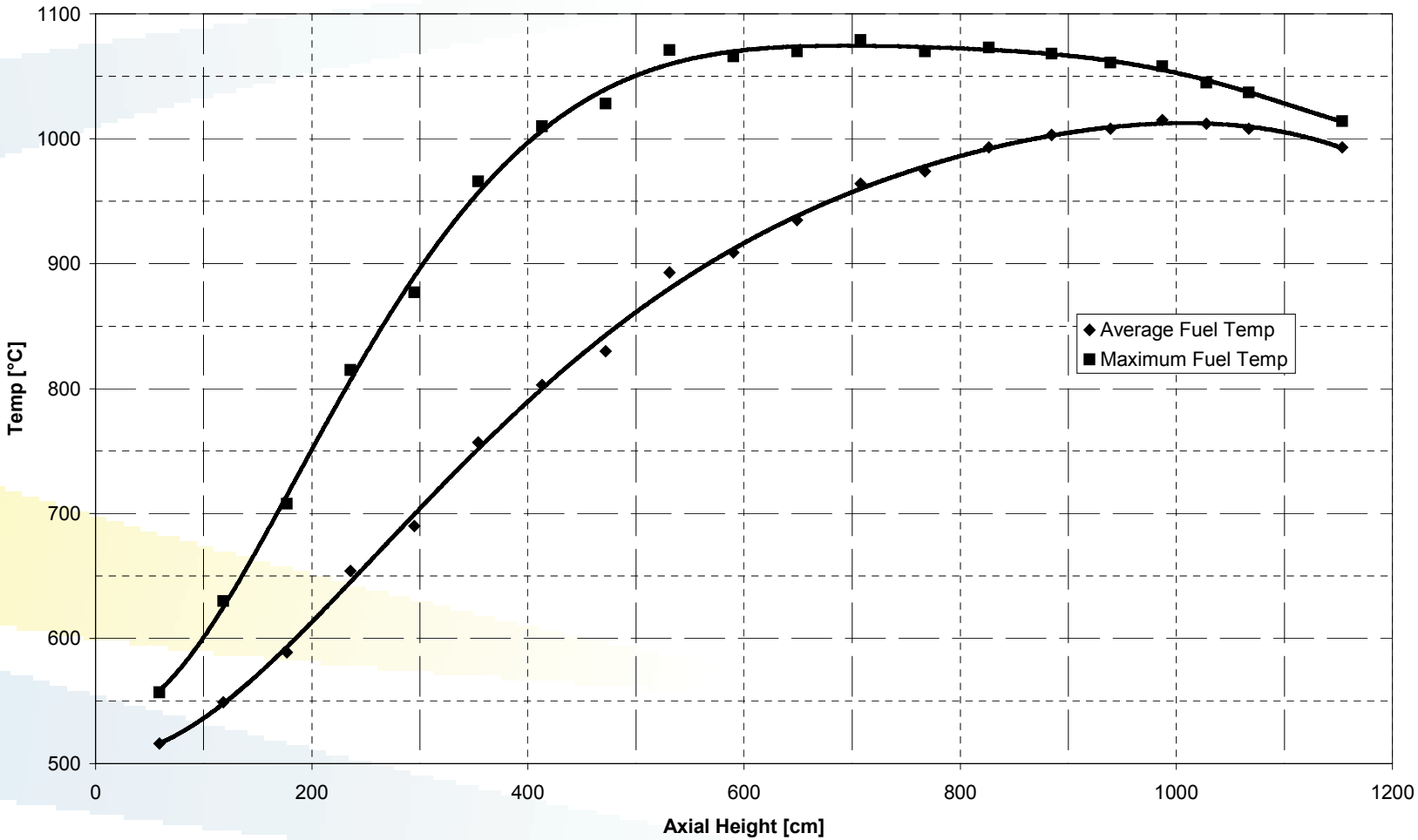
Fast Flux Fluence (> 0.1 MeV) on Graphite Structures

Description	Units	Value
Fuel spheres	$10^{21}/cm^2$	2.65
Maximum upper reflector edge (35 EFPY)	$10^{22}/cm^2$	0.21
Maximum outer reflector side (35 EFPY)	$10^{22}/cm^2$	3.85
Maximum inner reflector side (35 EFPY)	$10^{22}/cm^2$	4.73
Maximum lower reflector edge (35 EFPY)	$10^{22}/cm^2$	0.53

Thermohydraulics

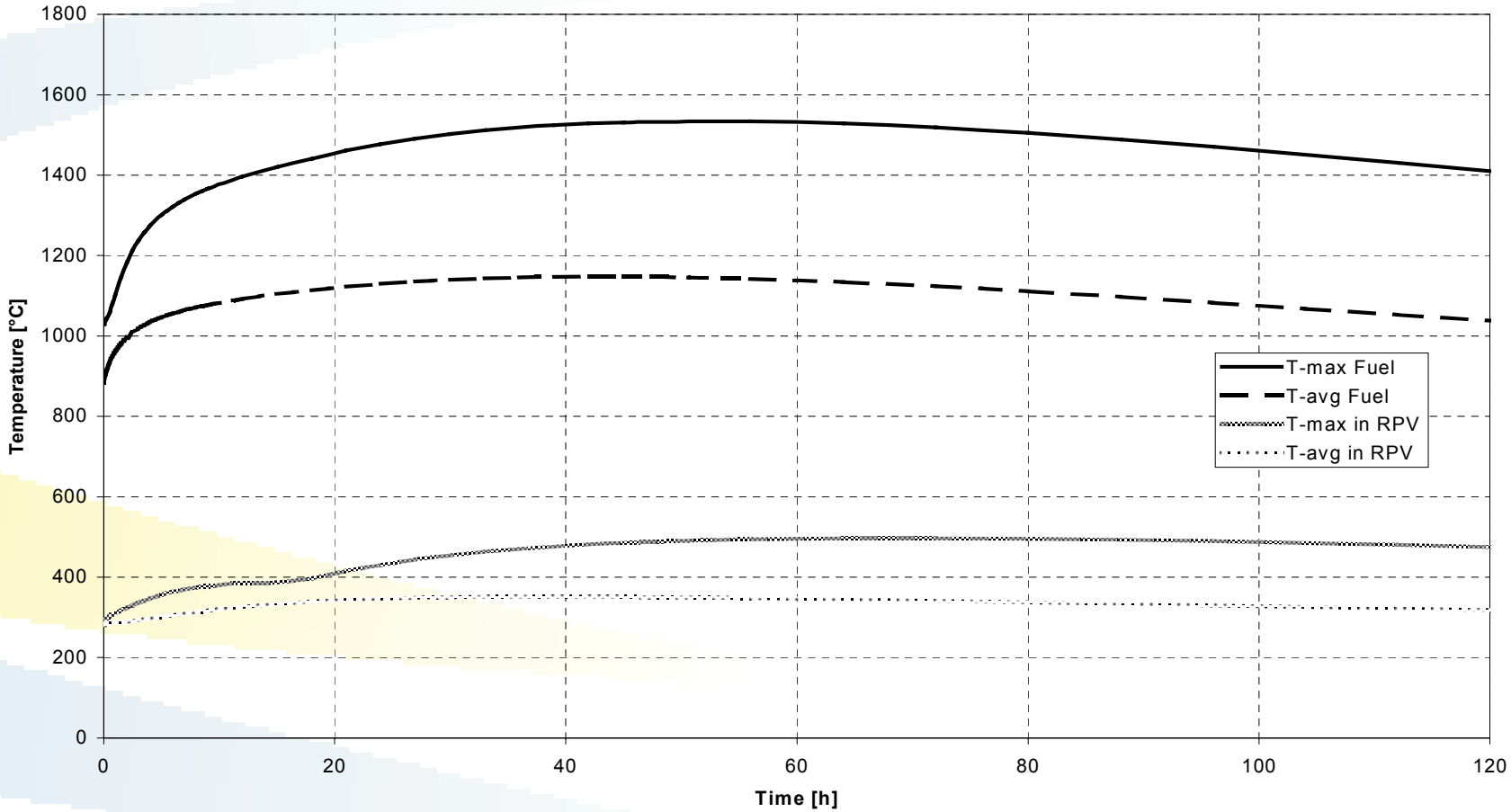
P B M R

Temperature of Fuel (average and maximum)



Thermohydraulics

Temperature History of Fuel and RPV Following a DLOFC Event



Thermohydraulics

Temperature of Fuel, Core Barrel and Reactor Pressure Vessel for Normal Operation, DLOFC and PLOFC

Maximum Fuel Temperature °C (Operation)	1079
Maximum Fuel Temperature °C (DLOFC)	1534
Maximum Fuel Temperature °C (PLOFC)	1380
Core Barrel °C (Operation)	428
Core Barrel °C (DLOFC)	654
Core Barrel °C (PLOFC)	589
RPV °C (Operation)	280
RPV °C (DLOFC)	506
RPV °C (PLOFC)	452

Operational Source Term Analyses

P B M R

Expected Metal Release Data

	^{137}Cs	^{134}Cs	^{110m}Ag	^{90}Sr
Release rate (atoms/s)	6.53×10^{12}	1.92×10^{11}	1.08×10^{11}	1.83×10^{8}
Activity released (Bq/s)	4 750 Bq/s	2 050 Bq/s	3 470 Bq/s	0.138 Bq/s

Design Values for Metal release

	^{137}Cs	^{134}Cs	^{110m}Ag	^{90}Sr
Sensitivity Factor*	5	5	21	13
Release rate (atoms/s)	3.27×10^{13}	9.60×10^{11}	2.27×10^{12}	2.38×10^{9}
Activity released (Bq/s)	23 800 Bq/s	10 300 Bq/s	60 500 Bq/s	1.46 Bq/s

* Sensitivity Factor to allow for uncertainties

Operational Source Term Analyses

P B M R

Expected R/B Values and Coolant Gas Activities

	^{85}Kr	^{88}Kr	^{90}Kr	^{133}Xe	^{131}I
R/B values	2.18×10^{-6}	1.84×10^{-7}	2.29×10^{-8}	2.67×10^{-7}	3.03×10^{-7}
Out of Core Activity (Bq)	6.23×10^{10}	6.33×10^{10}	1.01×10^{10}	2.27×10^{11}	1.18×10^{11}
Coolant Gas Activities	8.23×10^{9}	6.33×10^{10}	1.01×10^{10}	2.27×10^{11}	9.35×10^{5}

Design Values for Noble Gas and Halogen Release

	^{85}Kr	^{88}Kr	^{90}Kr	^{133}Xe	^{131}I
Sensitivity Factor	4	4	4	4	4
Out of Core Activity (Bq)	2.49×10^{11}	2.53×10^{11}	4.04×10^{10}	9.08×10^{11}	4.72×10^{11}
Coolant Gas activities	3.29×10^{10}	2.53×10^{11}	4.04×10^{10}	9.07×10^{11}	3.74×10^{6}

* Sensitivity Factor to allow for uncertainties