DLFR

Demonstration Lead-cooled Fast Reactor

S & U Analysis

Sensitivity & Uncertainty Analysis

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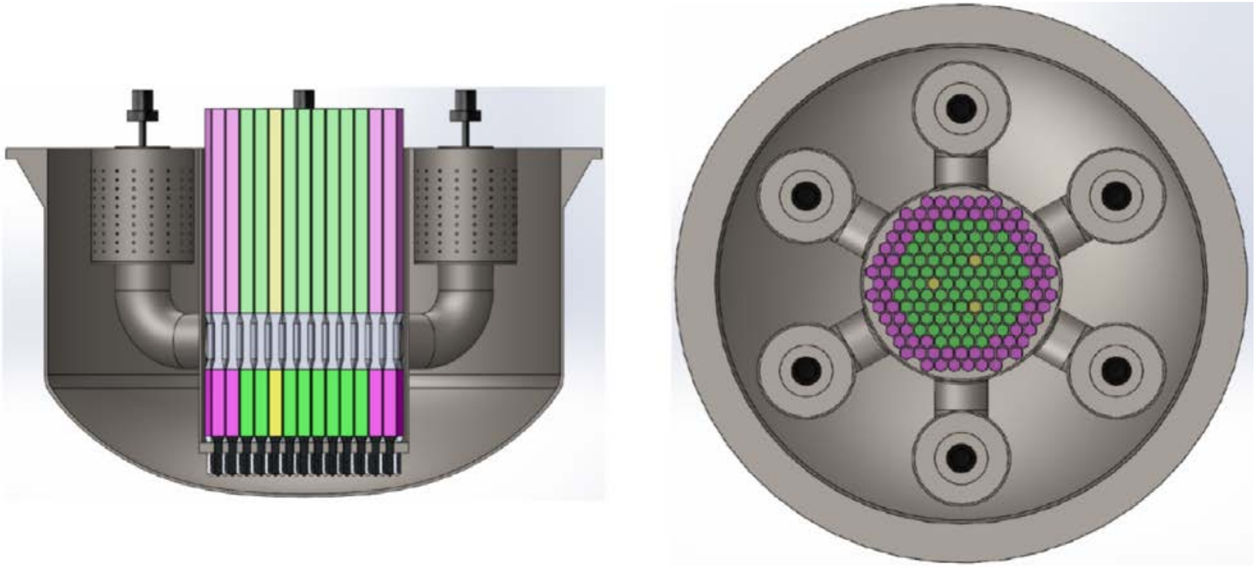
PART 01

Introduction

DLFR By Westinghouse, U.S.

Demonstration Lead-cooled Fast Reactor



DLFR primary system layout, vertical and horizontal cross section
(pre-conceptual, not in scale, DHRS not shown)

Design Parameter

Power rate: 500MWt

Neutron flux: Peak ~ 2×10^{15} n/cm^2

Reactor Type

Lead-cooled

Pool-type

Fast reactor

Objective

Feasibility

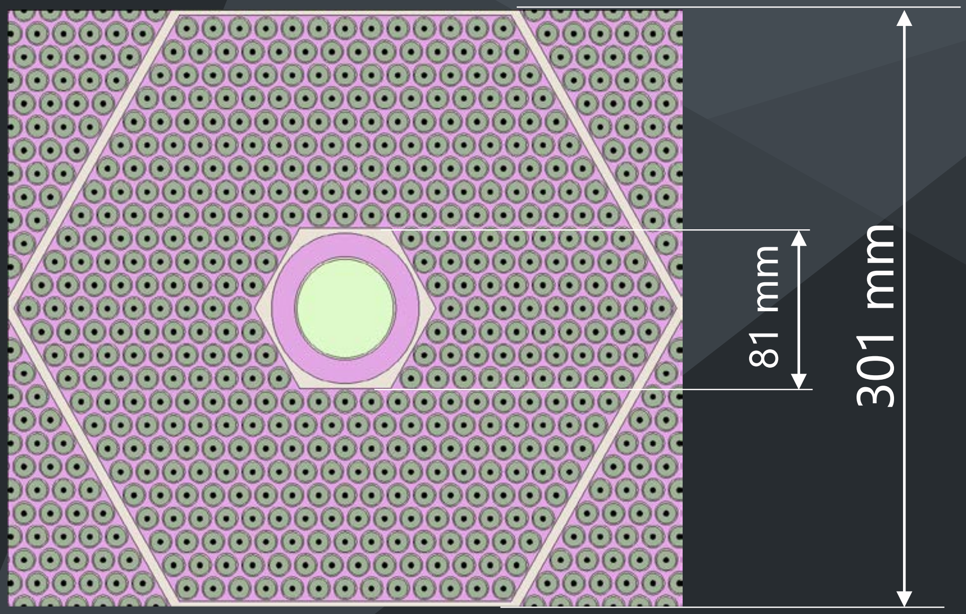
Basic performance

Uprate

PART 02

Modeling

Assembly



Coolant	Pb	
Cladding	Steel	
Hollow	Void	
Fuel		

Boundary: Periodical

Calculation:

Periodical Boundary

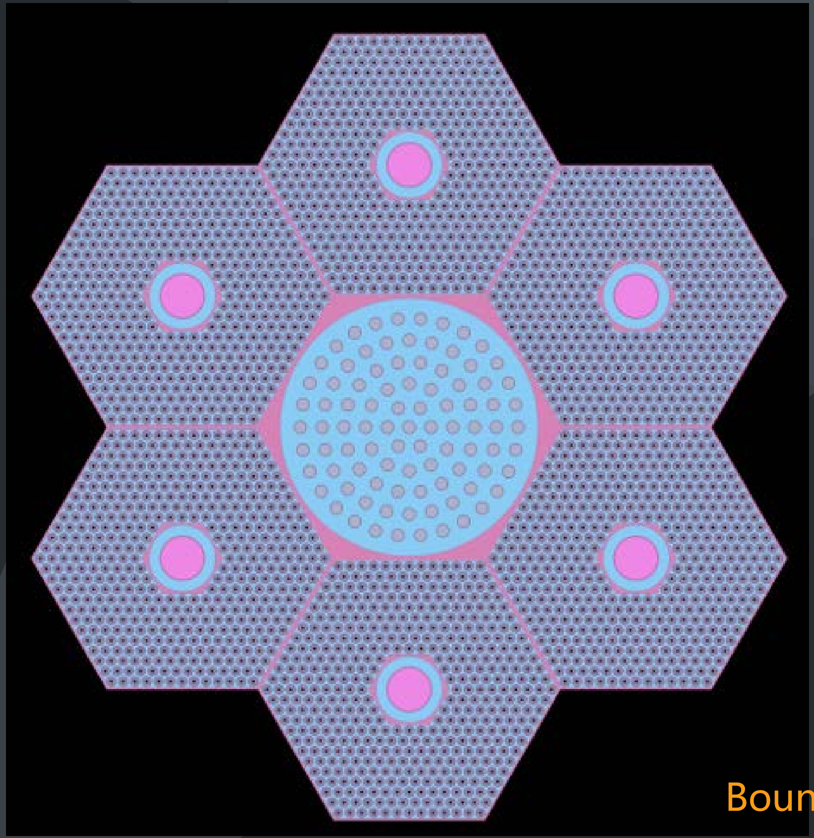
Inner Core Assembly

Fuel	K-inf	Error
BoL	1.26791	0.00246
BoC	1.19807	0.00278
EoC	1.16523	0.00278
EoL	1.10776	0.00316

Outer Core Assembly

Fuel	K-inf	Error
BoL	1.34074	0.00291
BoC	1.28491	0.00289
EoC	1.26066	0.00292
EoL	1.19467	0.00281

Safety Rod



Coolant -Pb
Cladding -Steel
Hollow -Void
Inner Core Fuel
Reflector -YSZ 8% mol
Safety -B_4C

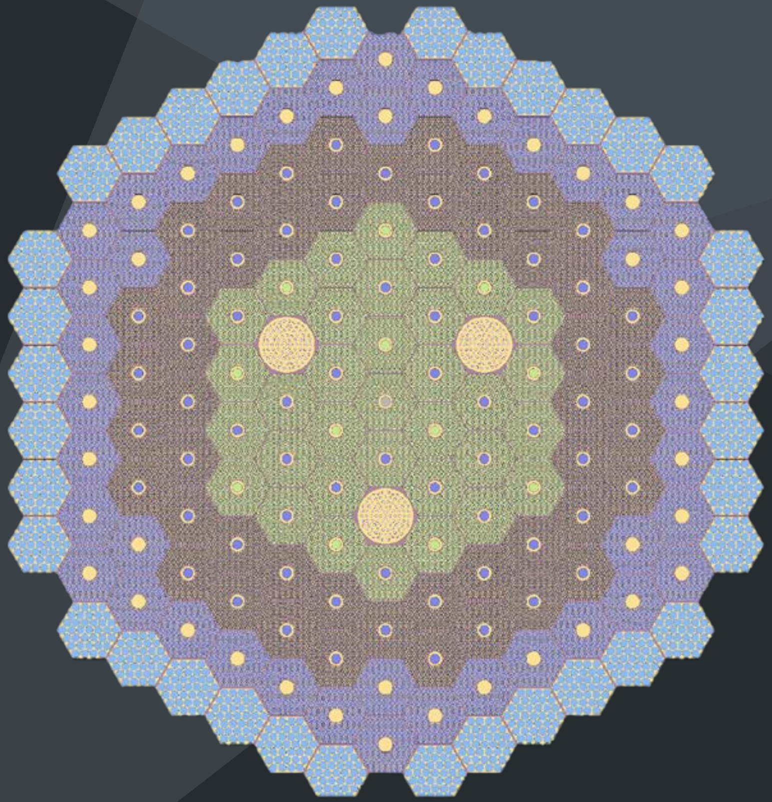
Calculation:

Black Boundary

Safety surrounded by Inner Core Assembly

Fuel	K-inf	Error
BoL	1.02864	0.00361
BoC	0.98266	0.00377
EoC	0.96995	0.00349
EoL	0.94755	0.00392

Core



Coolant	-Pb	Reflector	-YSZ 8% mol
Cladding	-Steel	Shield	-Borated Steel
Inner Fuel		Safety	-B_4C
Outer Fuel		Plenum	

Calculation:

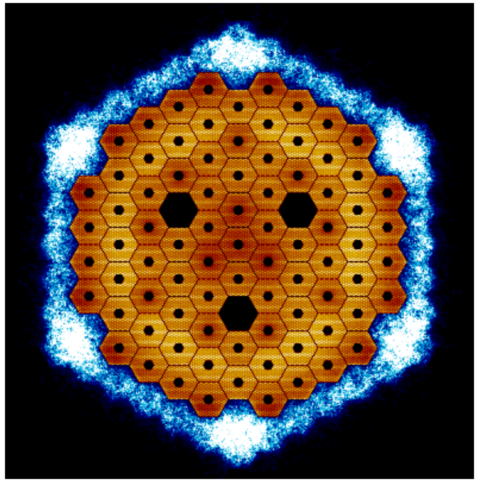
Safety Rod out

K-inf	**1.14634 $\pm$ 0.00285**

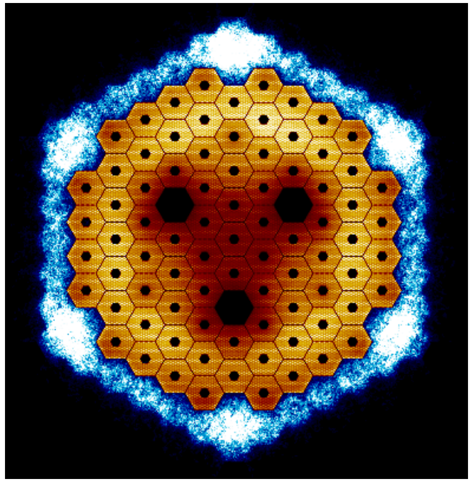
Safety Rod in

K-inf	**1.12353 $\pm$ 0.00326**

Power Distribution:



Safety Rod out



Safety Rod in

PART 03

Calculation

Sensitivity

Definition

$$S_x^R = \frac{\partial R/R}{\partial x/x}$$

$$R = \frac{\langle \Sigma_1, \Psi \rangle}{\langle \Sigma_2, \Psi \rangle}$$

R — Response function
x — A certain perturbed parameter
S_x^R — Sensitivity coefficient of R with respect to x

$$S_x^R = \frac{\partial R/R}{\partial x/x} = \left\langle \frac{\frac{d\Sigma_1}{dx}\Psi x}{\Sigma_1 \Psi} - \frac{\frac{d\Sigma_2}{dx}\Psi x}{\Sigma_2 \Psi} + \frac{\partial R}{\partial \Psi}\frac{\partial \Psi}{\partial x}\frac{x}{R} \right\rangle$$

$\langle\,\rangle$ — Inner product
Ψ — Neutron flux
Σ_1, Σ_2 — Any kind of macroscopic cross section

Sensitivity

Calculation

Direct effect terms

Indirect effect terms

$$S_x^R = \frac{\partial R/R}{\partial x/x} = \left\langle \underbrace{\frac{\frac{d\Sigma_1}{dx}\Psi x}{\Sigma_1 \Psi} - \frac{\frac{d\Sigma_2}{dx}\Psi x}{\Sigma_2 \Psi}}_{\text{Direct effect terms}} + \frac{\partial R}{\partial \Psi}\frac{\partial \Psi}{\partial x}\frac{x}{R} \right\rangle$$

Direct Terms

Describe impact on generalized response

Relatively easy to compute

Indirect Term

Describe impact on flux

Complicated to compute

Method for Indirect Term

- GEAR (Generalized Adjoint Response) method
  based on GPT (Generalized perturbation theory)
  used by TSUNAMI-3D
- Collision-based History method
  based on accepted and rejected events
  used by SERPENT2

Uncertainty

Definition

$$\boxed{\vec{S} = \left(S_{x_1}^k, S_{x_2}^k, \dots, S_{x_n}^k\right)}$$

$$n = Nuclide\sim Reaction\ number \times Energy\ Bin\ number$$
$$15543 = 471 \times 33$$

$$\boxed{\operatorname{cov}(x_i, x_j) = \int \left(x_i - E(x_i)\right)\left(x_j - E(x_j)\right) p(x_1, \dots, x_n) dx_1 \dots dx_n}$$

Sandwich Rule

$$\boxed{r_k^2 = \vec{S} V \vec{S}^T}$$

— V is (relative) covariance matrix

$$V = \begin{bmatrix} r_{x_1}^2 & \operatorname{rcov}(x_1, x_2) & \cdots & \operatorname{rcov}(x_1, x_n) \\ \operatorname{rcov}(x_2, x_1) & r_{x_1}^2 & \cdots & \operatorname{rcov}(x_2, x_n) \\ \vdots & \vdots & \ddots & \vdots \\ \operatorname{rcov}(x_n, x_1) & \operatorname{rcov}(x_n, x_2) & \cdots & \operatorname{rcov}(x_n, x_n) \end{bmatrix}$$

$$\boxed{\operatorname{rcov}(x_i, x_j) = \frac{\operatorname{cov}(x_i, x_j)}{x_i x_j}}$$

$$\boxed{r_{x_i}^2 = \frac{\sigma_{x_i}^2}{x_i^2}}$$

—$r_{x_i}^2$ is relative variance

COMMARA-2.0

Released by BNL & LANL in March 2011

Based on ENDF/B-VII.0

Including 110 Nuclides:

12 Light Nuclei (Coolant & Moderator)
78 Structural Materials & Fission products
20 Actinides

Reaction Channels

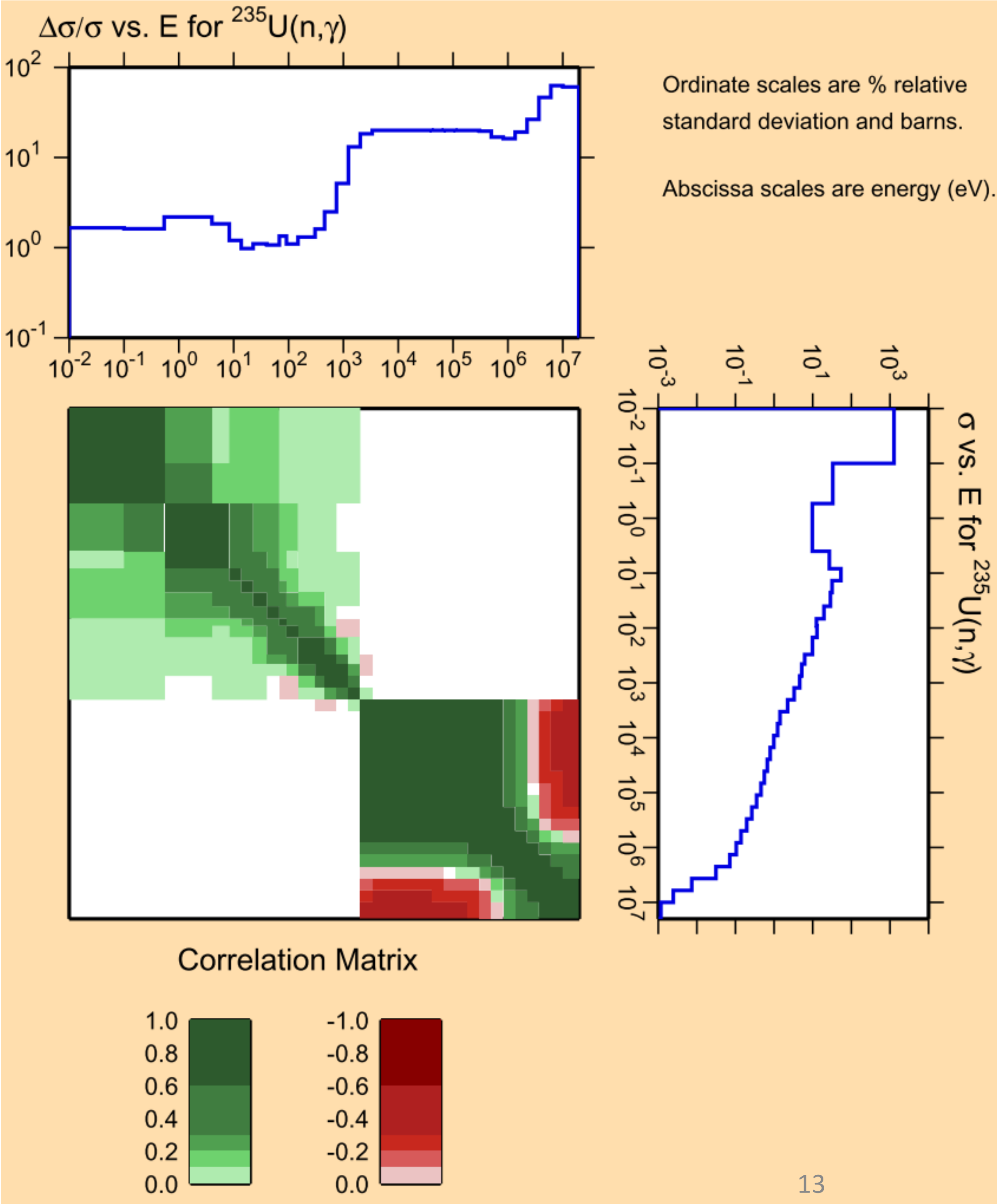
Elastic/Inelastic Scattering $(n,n)/(n,n')$
Capture (n,γ)
Neutron Multiplication (n,xn)
Fission (n,f)、$\bar{\nu}$、χ

Total Files (Nuclide-Reaction)

569

Energy

10^{-5} eV – 19.6 MeV
33 Groups



Covariance Matrix

Calculation

NEA provides COMMARA-2.0 correlation matrices and relative uncertainty:
https://www.oecd-nea.org/science/wpec/sg33/benchmark/results/data.html

$$C = \begin{bmatrix} 1 & \mathrm{cor}(x_1, x_2) & \cdots & \mathrm{cor}(x_1, x_n) \\ \mathrm{cor}(x_2, x_1) & 1 & \cdots & \mathrm{cor}(x_2, x_n) \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{cor}(x_n, x_1) & \mathrm{cor}(x_n, x_2) & \cdots & 1 \end{bmatrix}$$

$$\boxed{r_{x_i} = \frac{\sigma_{x_i}}{x_i}}$$

— r_{x_i} is relative uncertainty

Obtain relative covariance matrix from correlation matrices and relative uncertainty:

$$\boxed{\mathrm{rcov}(x_i, x_j) = r_{x_i} r_{x_j} \mathrm{cor}(x_i, x_j)}$$

$$V = \begin{bmatrix} r_{x_1}^2 & \mathrm{rcov}(x_1, x_2) & \cdots & \mathrm{rcov}(x_1, x_n) \\ \mathrm{rcov}(x_2, x_1) & r_{x_1}^2 & \cdots & \mathrm{rcov}(x_2, x_n) \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{rcov}(x_n, x_1) & \mathrm{rcov}(x_n, x_2) & \cdots & \mathrm{rcov}(x_n, x_n) \end{bmatrix}$$

Relative Uncertainty

Definition

$$U_{total} = r_k^2 = \vec{S}V\vec{S}^T$$
$$= \sum_i S_i V_{ii} S_i + \sum_i \sum_{j \neq i} S_i V_{ij} S_j$$

Sensitivity Index: $$SI_i = \frac{U_i}{U_{total}}$$

The conservative estimate of uncertainty:

$$\widetilde{\boldsymbol{U}_i} = S_i V_{ii} S_i + 2 \times \sum_{j \neq i} S_i V_{ij} S_j$$

Conservative Sensitivity Index: $$\widetilde{SI_i} = \frac{\widetilde{\boldsymbol{U}_i}}{U_{total}}$$

Calculation

Serpent

Output Files

***_res.m** – General Results

***_sens.m** – Sensitivity Data

C++

- Output File Preprocess
- Extract Information
- Generate MATLAB Script

Mixed Programming!

MATLAB

- Arrange Covariance Matrix
- Calculate Uncertainty
- Plot Distribution Graph

Results

Sensitivity & Uncertainty Distribution

- Nuclide-Reaction List
- Uncertainty Value
- Stairs Graph

C++

- Read Serpent Output File
- Generate Nuclide-Reaction Index
- Match Sensitivity with Covariance

Generate MATLAB Scripts to :

Arrange Covariance Matrix
Calculate Uncertainty
Sort Data
Plot Stairs Graph
……

Interface

MATLAB Engine
Dynamic-link Library

Index Files
Temporary Files
MATLAB Scripts

MATLAB

- Read Covariance Matrix
- Calculate Uncertainty
- Sort Data by Importance
- Plot Stairs Graph

Generate Temporary Files to :

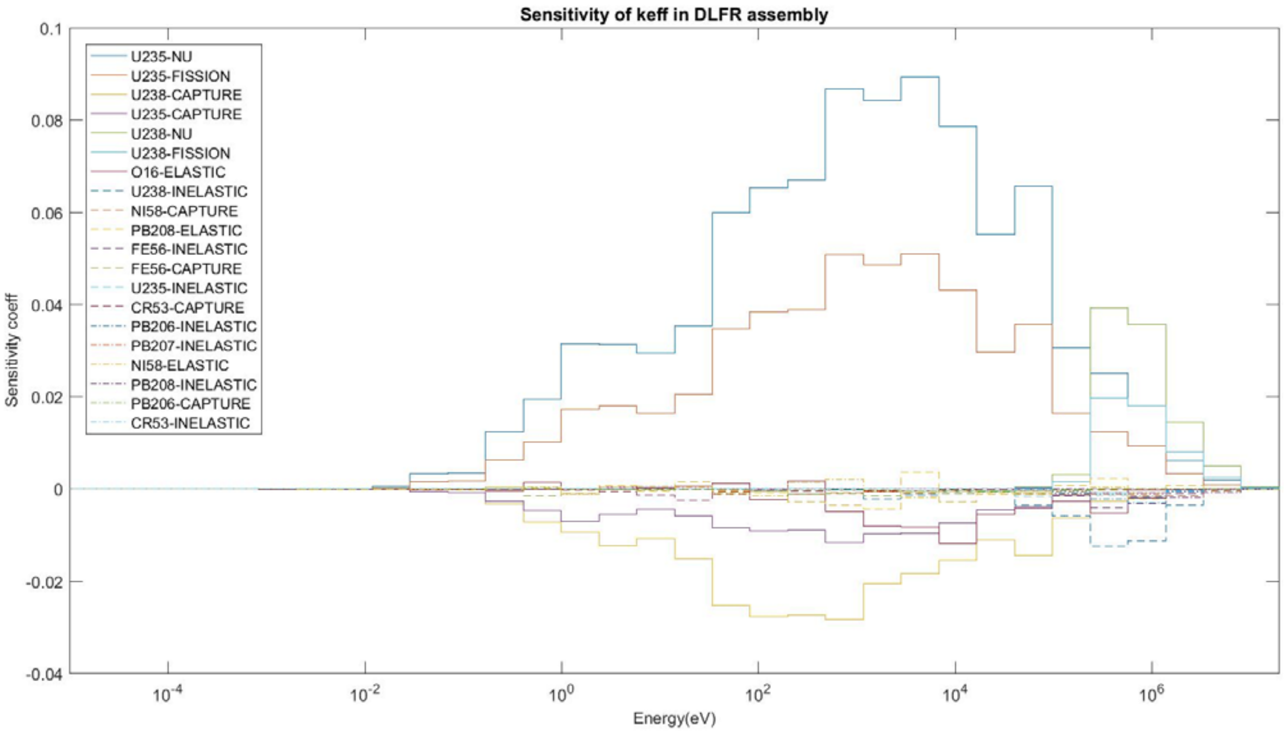
Match Data by Name-Value
Extract Calculation Results
Transfer Data
……

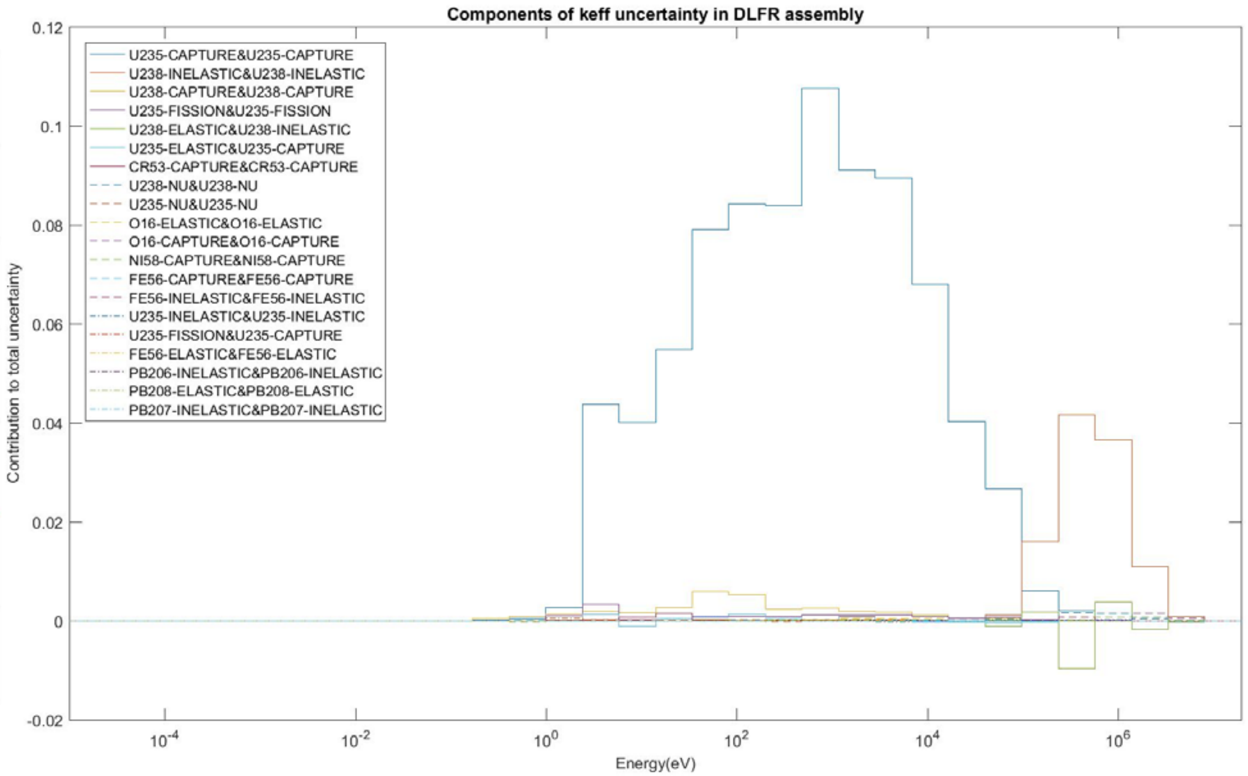
PART 3.1

Fuel Assembly

Distribution of S/U Corresponding to the Most Important 20 Parameters

Inner Core Fuel Assembly at Beginning of Life





BoL inner Assembly Uncertainty Analysis:

K_{eff} Standard Deviation: 0.019226

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	82.1235
$^{238}U - \sigma_{n,n'}$	10.8820
$^{238}U - \sigma_{n,\gamma}$	3.2416
$^{235}U - \sigma_{f}$	1.4514
$^{238}U - (\sigma_{n,n}\,,\ \sigma_{n,n'})$	-0.7076

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.56768	-0.107003
$^{238}U - \sigma_{n,n'}$	0.17516	-0.041029
$^{238}U - \sigma_{n,\gamma}$	0.05615	-0.257976
$^{235}U - \sigma_{f}$	0.02490	0.506052
$^{53}Cr - \sigma_{n,\gamma}$	0.00684	0.007763

BoL outer Assembly Uncertainty Analysis:

K_{eff} Standard Deviation: 0.019821

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	86.7332
$^{238}U - \sigma_{n,n'}$	7.0166
$^{238}U - \sigma_{n,\gamma}$	2.4011
$^{235}U - \sigma_{f}$	1.2345
$^{238}U - (\sigma_{n,n}\,,\ \sigma_{n,n'})$	0.4458

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.64995	-0.110411
$^{238}U - \sigma_{n,n'}$	0.122642	-0.041853
$^{238}U - \sigma_{n,\gamma}$	0.041575	-0.232542
$^{235}U - \sigma_{f}$	0.021593	0.488544
$^{53}Cr - \sigma_{n,\gamma}$	0.005432	0.007141

BoC inner Assembly Uncertainty Analysis: K_{eff} Standard Deviation: 0.015357

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	65.8074
$^{238}U - \sigma_{n,n'}$	19.0909
$^{238}U - \sigma_{n,\gamma}$	5.1079
$^{235}U - \sigma_{f}$	1.7412
$^{56}Fe - \sigma_{n,n}$	1.7377

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.25340	-0.078050
$^{238}U - \sigma_{n,n'}$	0.33066	-0.051604
$^{238}U - \sigma_{n,\gamma}$	0.08877	-0.256832
$^{235}U - \sigma_{f}$	0.02919	0.431738
$^{56}Fe - \sigma_{n,n}$	0.02974	-0.023070

BoC outer Assembly Uncertainty Analysis: K_{eff} Standard Deviation: 0.016577

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	86.7332
$^{238}U - \sigma_{n,n'}$	7.0166
$^{238}U - \sigma_{n,\gamma}$	2.4011
$^{235}U - \sigma_{f}$	1.2345
$^{238}U - (\sigma_{n,n}\,,\ \sigma_{n,n'})$	0.4458

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.513810	-0.090276
$^{238}U - \sigma_{n,n'}$	0.204594	-0.044881
$^{238}U - \sigma_{n,\gamma}$	0.062313	-0.235775
$^{235}U - \sigma_{f}$	0.027417	0.454963
$^{16}O - \sigma_{n,n}$	0.011894	-0.067184

EoC inner Assembly Uncertainty Analysis:

K_{eff} Standard Deviation: 0.014014

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	54.7410
$^{238}U - \sigma_{n,n'}$	27.9248
$^{238}U - \sigma_{n,\gamma}$	5.8622
$^{235}U - \sigma_{f}$	1.8119
$^{16}O - \sigma_{n,n}$	1.5251

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.04262	-0.065688
$^{238}U - \sigma_{n,n'}$	0.48038	-0.050797
$^{238}U - \sigma_{n,\gamma}$	0.10185	-0.250996
$^{235}U - \sigma_{f}$	0.02997	0.397506
$^{16}O - \sigma_{n,n}$	0.02818	-0.087629

EoC outer Assembly Uncertainty Analysis:

K_{eff} Standard Deviation: 0.015726

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	76.2761
$^{238}U - \sigma_{n,n'}$	12.9362
$^{238}U - \sigma_{n,\gamma}$	4.0763
$^{235}U - \sigma_{f}$	1.6353
$^{238}U - (\sigma_{n,n}\,,\ \sigma_{n,n'})$	0.9269

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.451030	-0.084109
$^{238}U - \sigma_{n,n'}$	0.226971	-0.044512
$^{238}U - \sigma_{n,\gamma}$	0.070649	-0.236758
$^{235}U - \sigma_{f}$	0.027646	0.433899
$^{53}Cr - \sigma_{n,\gamma}$	0.010715	-0.007833

EoL inner Assembly Uncertainty Analysis:

K_{eff} Standard Deviation: 0.012044

Parameter Pair	Contribution to Total Uncertainty (%)
$^{238}U - \sigma_{n,n'}$	38.9070
$^{235}U - \sigma_{n,\gamma}$	33.2131
$^{238}U - \sigma_{n,\gamma}$	7.3113
$^{238}U - (\sigma_{n,n}\, , \, \sigma_{n,n'})$	3.9664
$^{16}O - \sigma_{n,n}$	2.7469

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{238}U - \sigma_{n,n'}$	0.68714	-0.059305
$^{235}U - \sigma_{n,\gamma}$	0.63359	-0.044578
$^{238}U - \sigma_{n,\gamma}$	0.12726	-0.238941
$^{16}O - \sigma_{n,n}$	0.05135	0.100010
$^{238}U - \sigma_{n,n}$	0.04130	-0.005715

EoL outer Assembly Uncertainty Analysis:

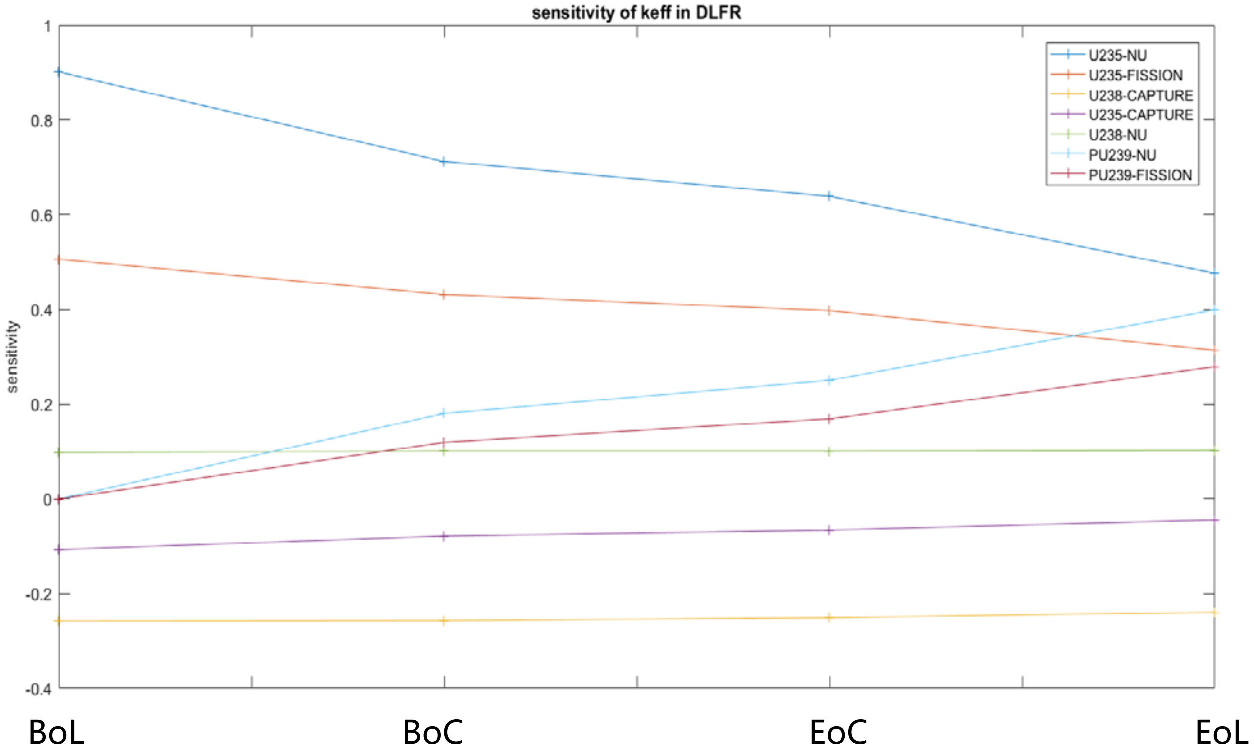
K_{eff} Standard Deviation: 0.013416

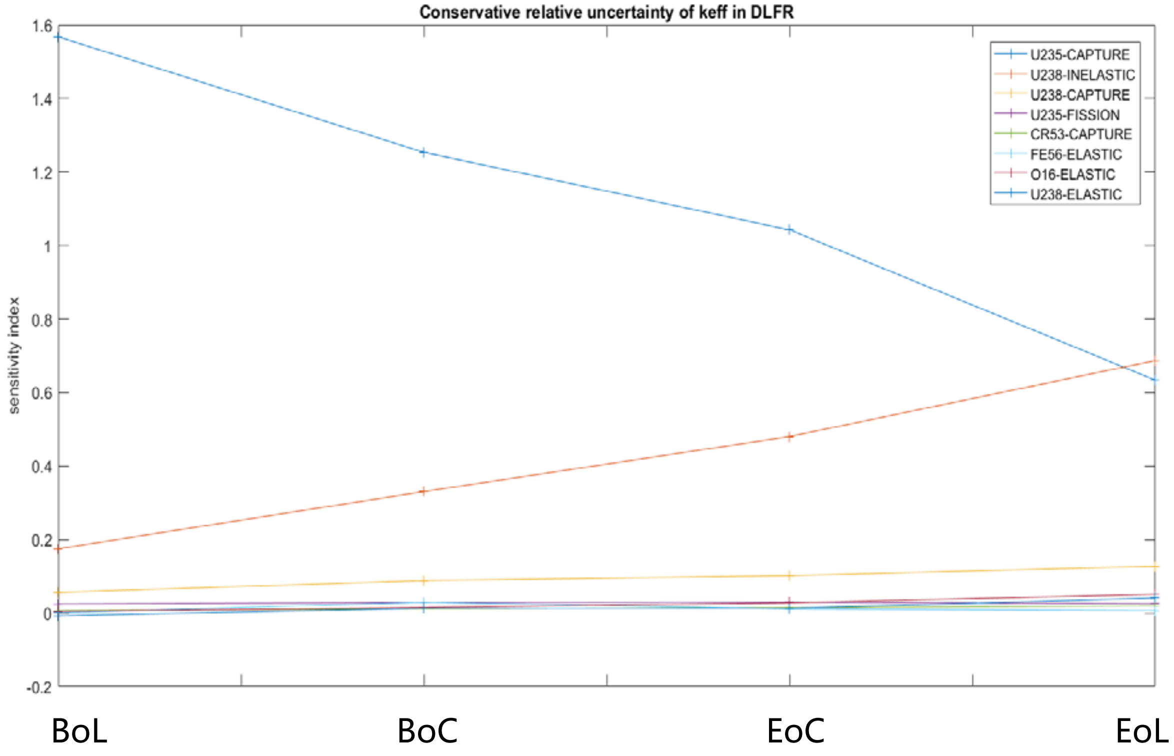
Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	62.8492
$^{238}U - \sigma_{n,n'}$	21.0056
$^{238}U - \sigma_{n,\gamma}$	5.5305
$^{235}U - \sigma_{f}$	1.8597
$^{16}O - \sigma_{n,n}$	1.0447

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.201250	-0.066350
$^{238}U - \sigma_{n,n'}$	0.360621	-0.047198
$^{238}U - \sigma_{n,\gamma}$	0.095879	-0.234376
$^{235}U - \sigma_{f}$	0.031221	0.392085
$^{16}O - \sigma_{n,n}$	0.018994	-0.070047

Sensitivity and Uncertainty Contributed to Total in Different Periods

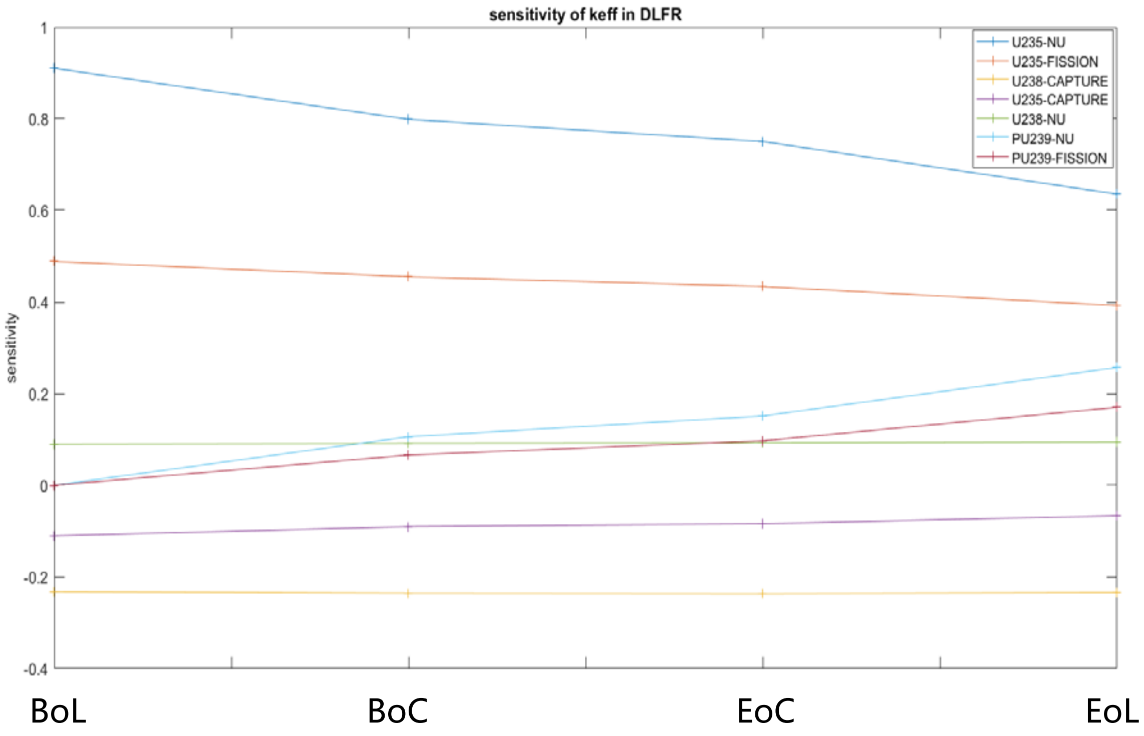
Inner Core Fuel Assembly

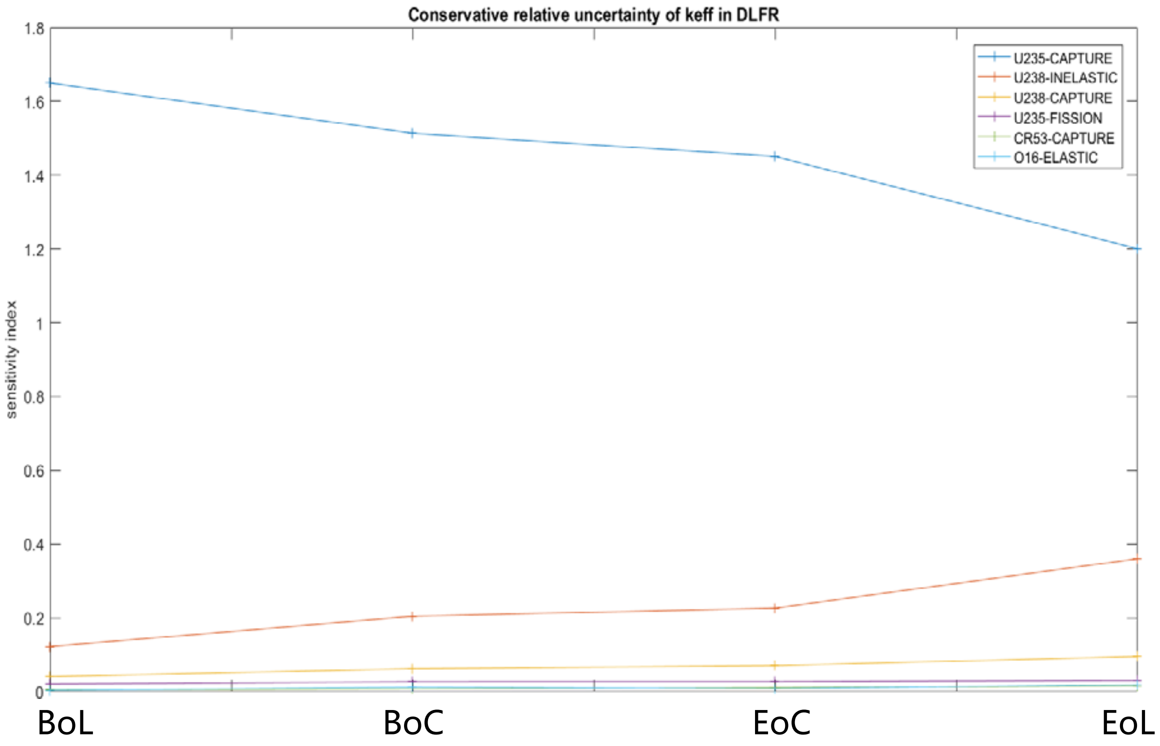




Sensitivity and Uncertainty Contributed to Total in Different Periods

Outer Core Fuel Assembly



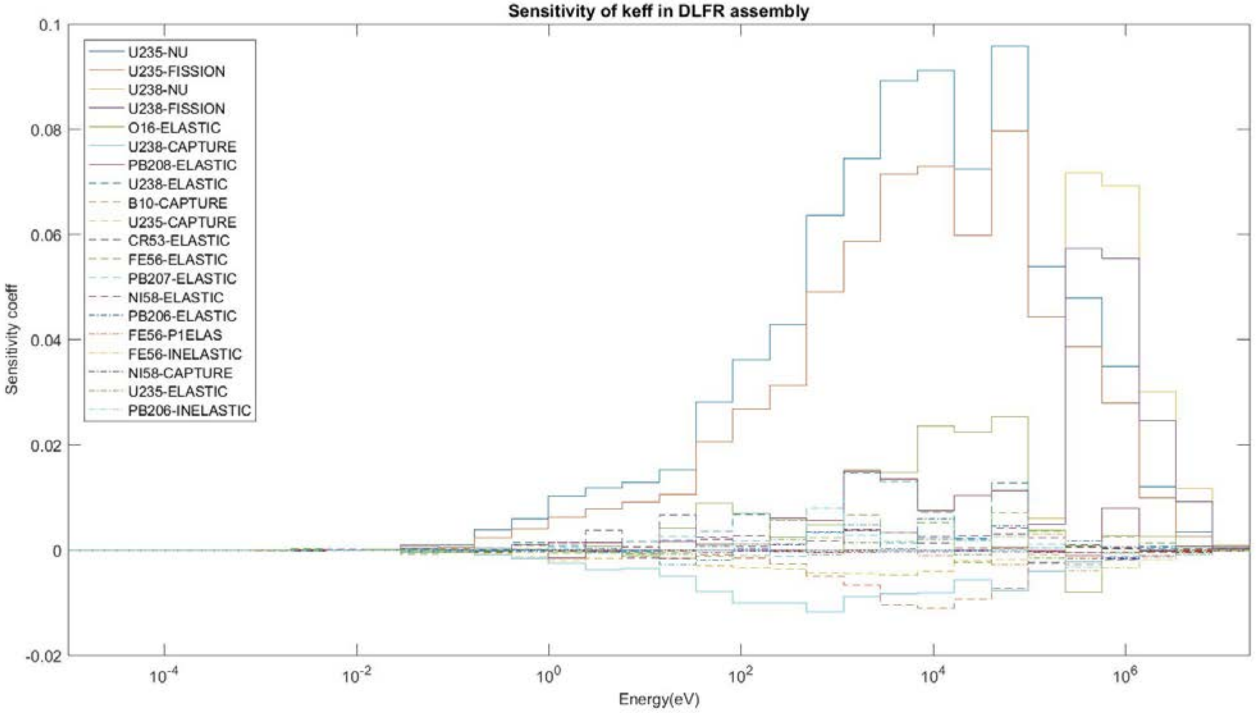


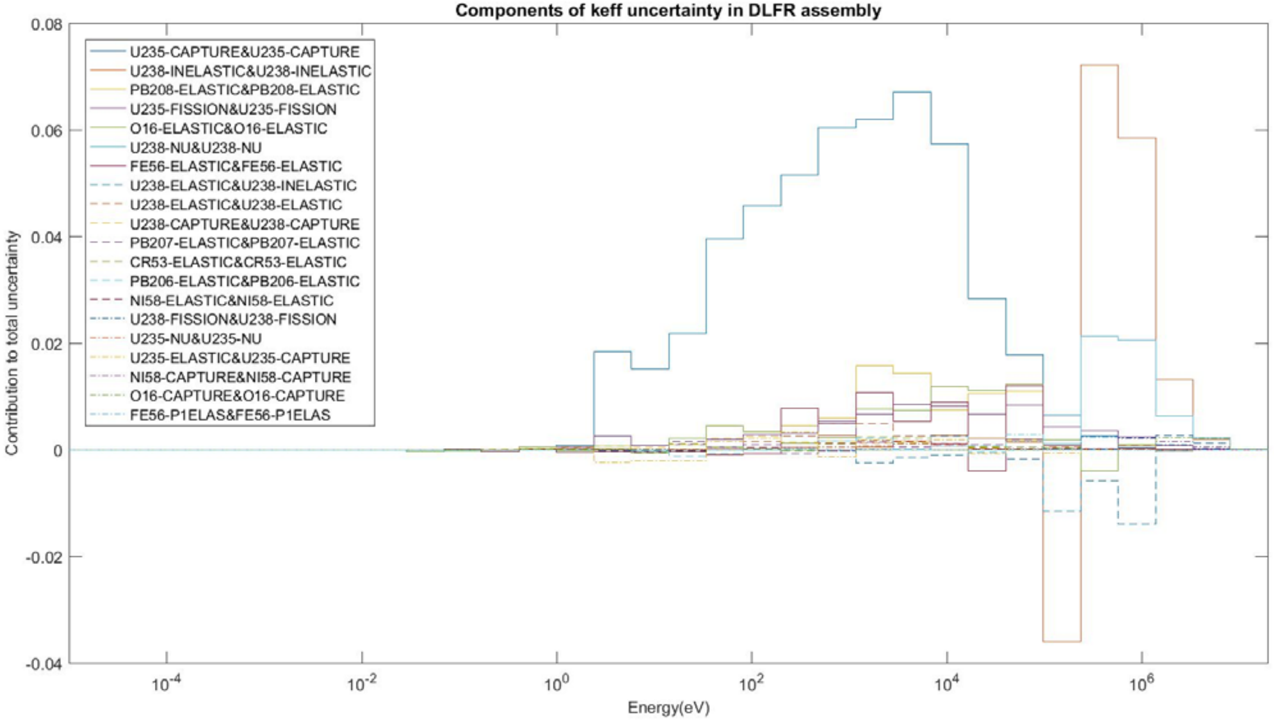
PART 3.2

Safety Rod

Distribution of S/U Corresponding to the Most Important 20 Parameters

Safety Rod surrounded by Inner Core Fuel Assembly at Beginning of Life





Safety Rod surrounded by BoL inner Assembly:

K_{eff} Standard Deviation: 0.009983

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	49.6019
$^{238}U - \sigma_{n,n'}$	12.1277
$^{208}Pb - \sigma_{n,n}$	7.0904
$^{235}U - \sigma_{f}$	6.8442
$^{16}O - \sigma_{n,n}$	6.2960

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	0.94729	-0.041557
$^{208}Pb - \sigma_{n,n}$	0.12561	0.081090
$^{235}U - \sigma_{f}$	0.12502	0.635583
$^{16}O - \sigma_{n,n}$	0.11627	0.129220
$^{238}U - \sigma_{n,n'}$	0.09061	-0.102597

Safety Rod surrounded by BoC inner Assembly:

K_{eff} Standard Deviation: 0.010595

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	20.9232
$^{56}Fe - \sigma_{n,n}$	19.4188
$^{238}U - \sigma_{n,n'}$	14.8347
$^{238}U - (\sigma_{n,n}\,,\ \sigma_{n,n'})$	9.8891
$^{16}O - \sigma_{n,n}$	6.8959

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	0.405438	-0.028904
$^{56}Fe - \sigma_{n,n}$	0.340385	0.057541
$^{238}U - \sigma_{n,n'}$	0.298071	-0.006460
$^{238}U - \sigma_{n,n}$	0.155563	0.074835
$^{16}O - \sigma_{n,n}$	0.129392	0.142088

Safety Rod surrounded by EoC inner Assembly:

K_{eff} Standard Deviation: 0.009616

Parameter Pair	Contribution to Total Uncertainty (%)
$^{238}U - \sigma_{n,n'}$	27.4812
$^{235}U - \sigma_{n,\gamma}$	16.2871
$^{56}Fe - \sigma_{n,n}$	15.8962
$^{238}U - (\sigma_{n,n}\,,\ \sigma_{n,n'})$	7.1493
$^{238}U - \bar{\nu}$	5.9046

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{238}U - \sigma_{n,n'}$	0.44838	-0.006568
$^{235}U - \sigma_{n,\gamma}$	0.31823	-0.023141
$^{56}Fe - \sigma_{n,n}$	0.28609	0.049147
$^{238}U - \sigma_{n,n}$	0.11081	0.075307
$^{238}U - \bar{\nu}$	0.09529	0.194659

Safety Rod surrounded by EoL inner Assembly:

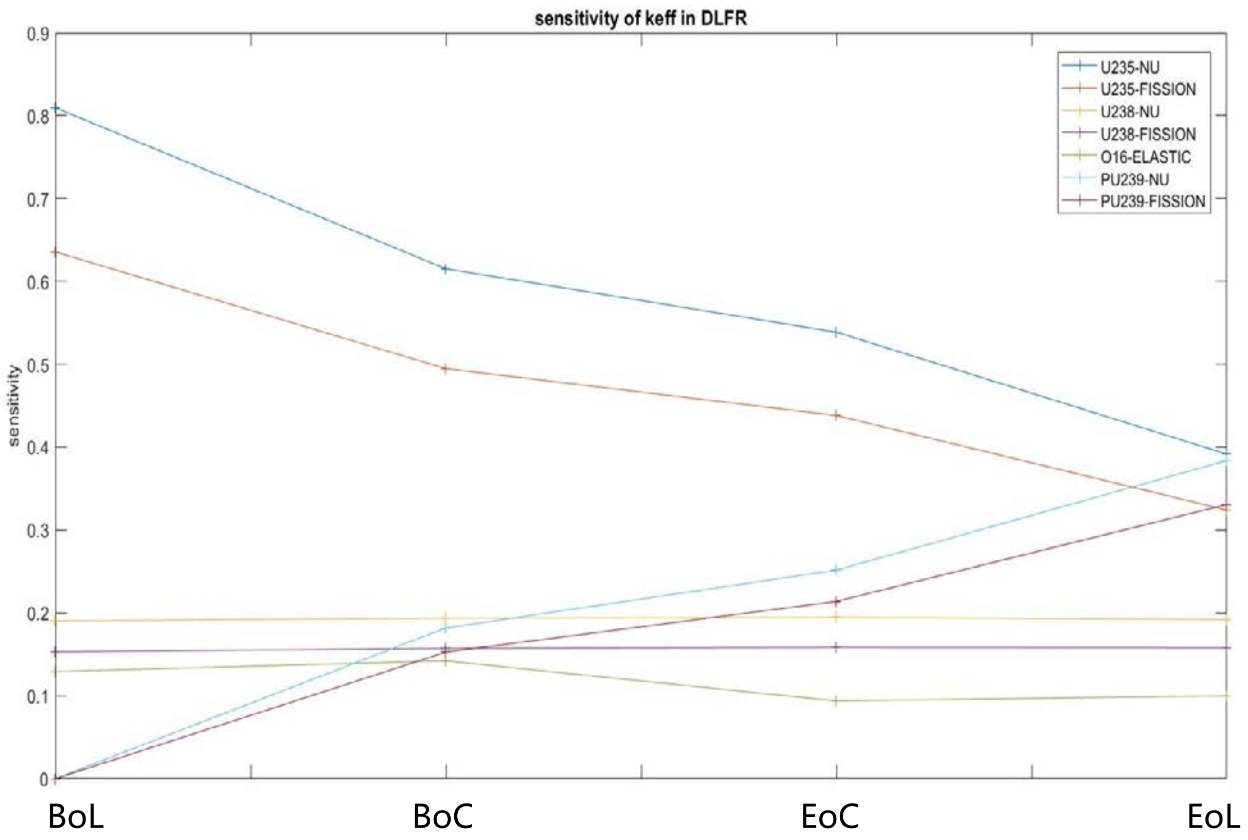
K_{eff} Standard Deviation: 0.008373

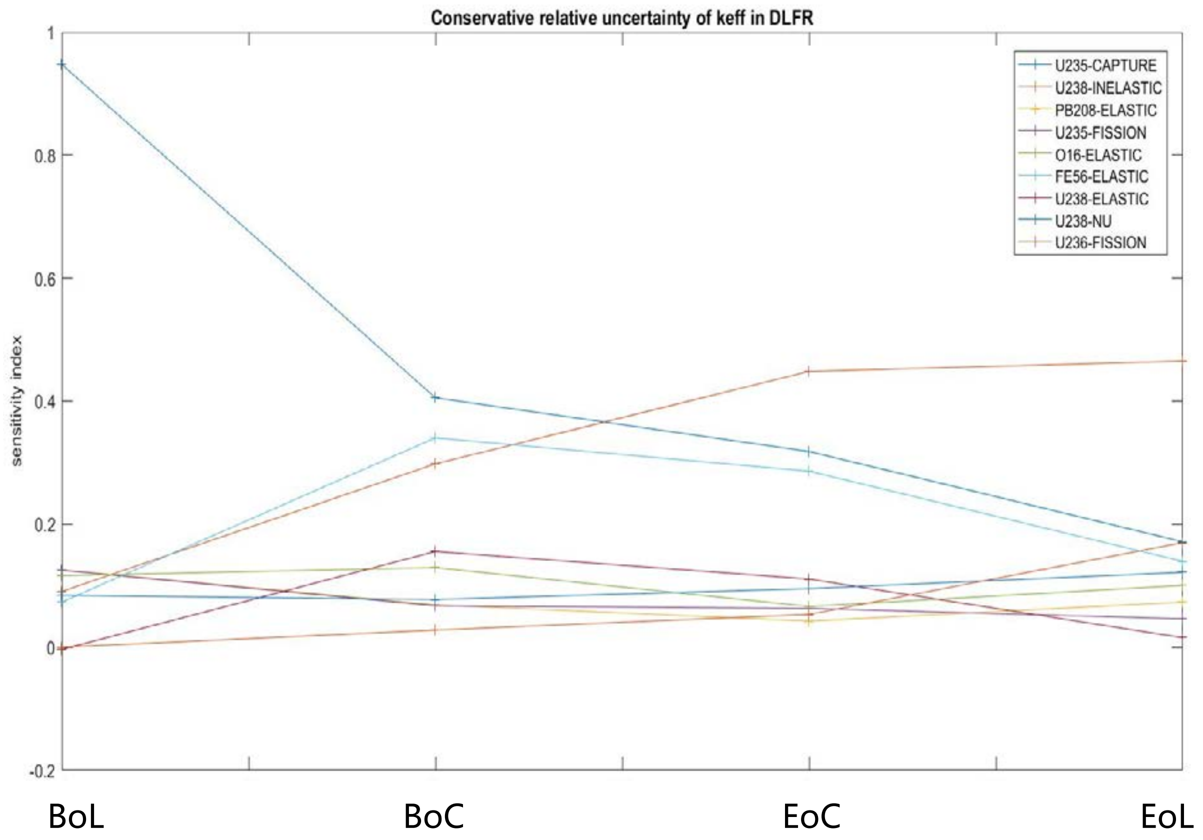
Parameter Pair	Contribution to Total Uncertainty (%)
$^{238}U - \sigma_{n,n'}$	34.8277
$^{236}U - \sigma_f$	9.9612
$^{235}U - \sigma_{n,\gamma}$	8.8226
$^{56}Fe - \sigma_{n,n}$	8.7255
$^{238}U - \bar{\nu}$	7.5280

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{238}U - \sigma_{n,n'}$	0.465302	-0.017072
$^{235}U - \sigma_{n,\gamma}$	0.171462	-0.015318
$^{236}U - \sigma_f$	0.170007	0.010268
$^{56}Fe - \sigma_{n,n}$	0.139694	0.028763
$^{238}U - \bar{\nu}$	0.121730	0.191956

Sensitivity and Uncertainty Contributed to Total in Different Periods

Safety Rod



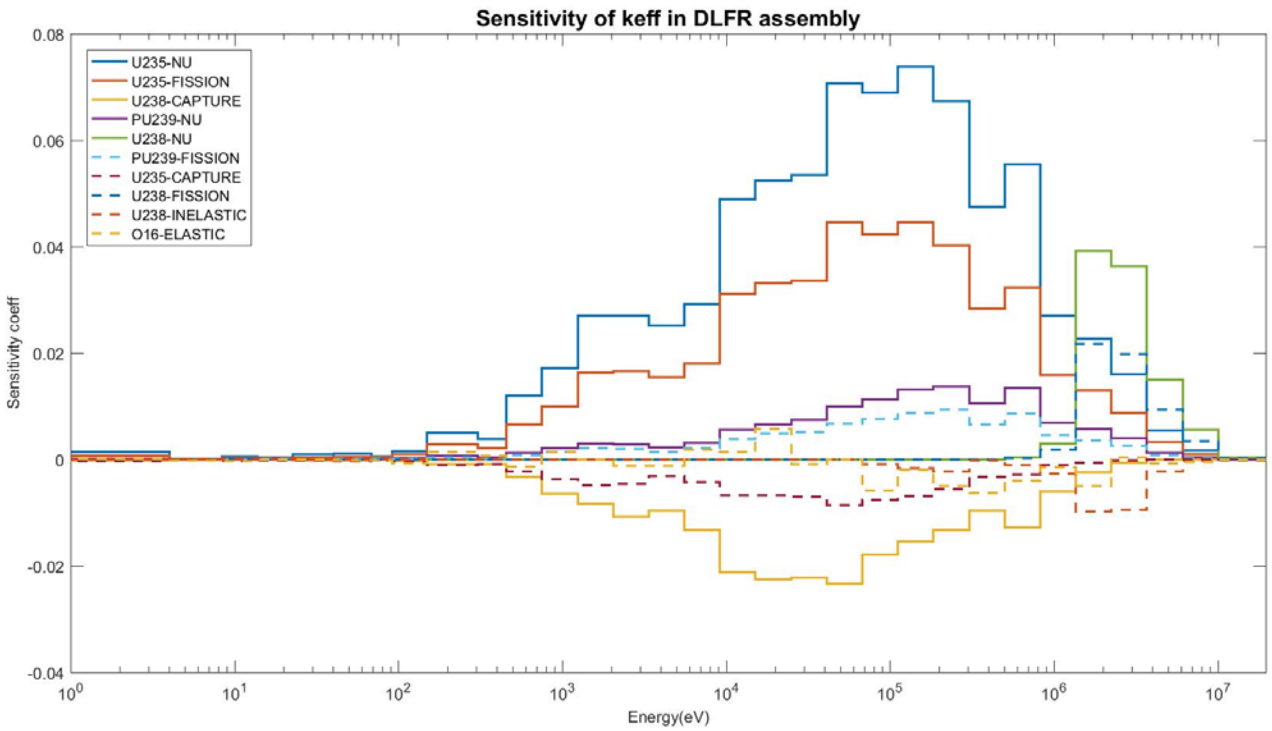


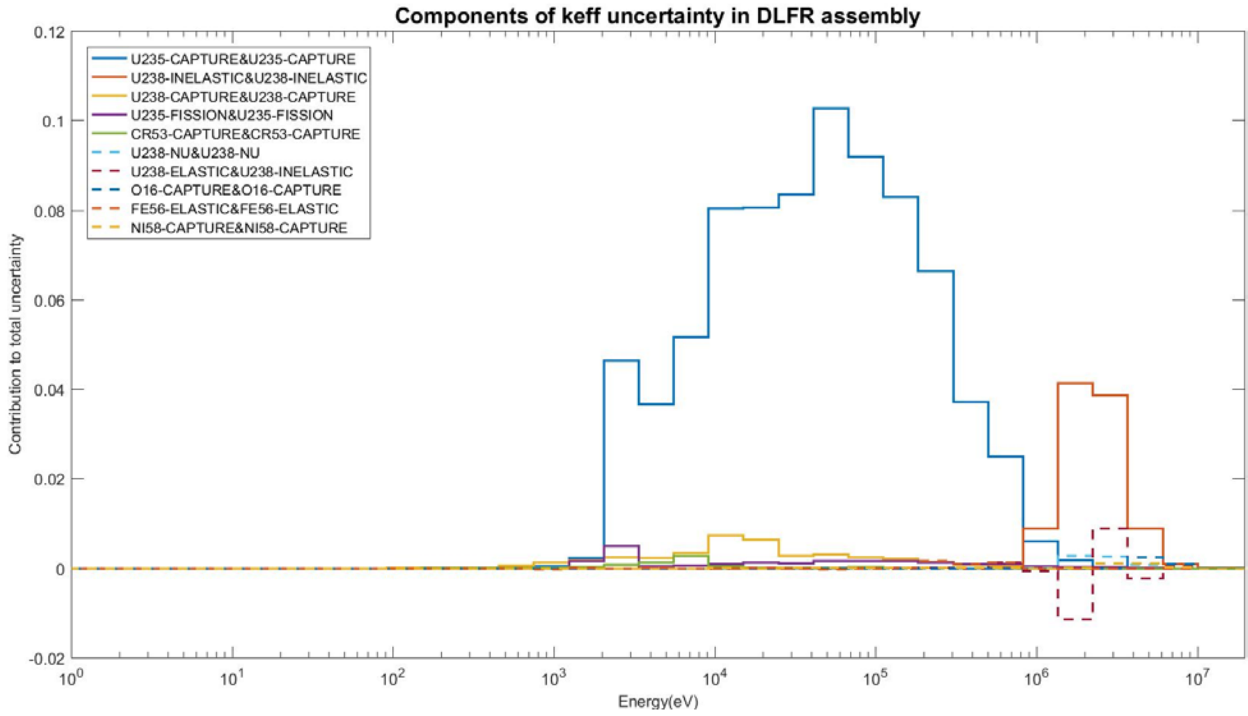
PART 3.3

2D Whole Core

Distribution of S/U Corresponding to the Most Important 20 Parameters

2D Whole Core with Safety Rod out at Beginning of Life





2D Whole Core with Safety Rod out at BoL:

K_{eff} Standard Deviation: 0.018312

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	85.7526
$^{238}U - \sigma_{n,n'}$	6.7353
$^{238}U - \sigma_{n,\gamma}$	2.8558
$^{235}U - \sigma_f$	1.5954
$^{53}Cr - \sigma_{n,\gamma}$	0.4204

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.63256	-0.105167
$^{238}U - \sigma_{n,n'}$	0.11449	-0.030883
$^{238}U - \sigma_{n,\gamma}$	0.04961	-0.232031
$^{235}U - \sigma_f$	0.02768	0.516727
$^{53}Cr - \sigma_{n,\gamma}$	0.00738	-0.008322

2D Whole Core with Safety Rod in at BoL:

K_{eff} Standard Deviation: 0.017555

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	86.3874
$^{238}U - \sigma_{n,n'}$	6.0158
$^{238}U - \sigma_{n,\gamma}$	2.7750
$^{235}U - \sigma_f$	1.7115
$^{235}U - (\sigma_{n,n}, \sigma_{n,\gamma})$	0.5316

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.650370	-0.102008
$^{238}U - \sigma_{n,n'}$	0.100996	-0.026569
$^{238}U - \sigma_{n,\gamma}$	0.048149	-0.220782
$^{235}U - \sigma_f$	0.029751	0.517308
$^{238}U - \bar{\nu}$	0.007436	-0.099255

2D Whole Core with Safety Rod out at BoC:

K_{eff} Standard Deviation: 0.014663

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	74.8630
$^{238}U - \sigma_{n,n'}$	14.9642
$^{238}U - \sigma_{n,\gamma}$	4.3700
$^{235}U - \sigma_{f}$	1.9593
$^{238}U - (\sigma_{n,n}\,,\ \sigma_{n,n'})$	-0.6863

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.42781	-0.080677
$^{238}U - \sigma_{n,n'}$	0.23889	-0.040280
$^{238}U - \sigma_{n,\gamma}$	0.07618	-0.228616
$^{235}U - \sigma_{f}$	0.03363	0.457535
$^{53}Cr - \sigma_{n,\gamma}$	0.01167	-0.008219

2D Whole Core with Safety Rod in at BoC:

K_{eff} Standard Deviation: 0.014649

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	79.6184
$^{238}U - \sigma_{n,n'}$	9.9974
$^{238}U - \sigma_{n,\gamma}$	4.0479
$^{235}U - \sigma_{f}$	2.0654
$^{53}Cr - \sigma_{n,\gamma}$	0.6980

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.517920	-0.082469
$^{238}U - \sigma_{n,n'}$	0.159858	-0.030205
$^{238}U - \sigma_{n,\gamma}$	0.070529	-0.220632
$^{235}U - \sigma_{f}$	0.035196	0.464817
$^{53}Cr - \sigma_{n,\gamma}$	0.012284	-0.008725

2D Whole Core with Safety Rod out at EoC:

K_{eff} Standard Deviation: 0.013733

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	68.2625
$^{238}U - \sigma_{n,n'}$	16.6753
$^{238}U - \sigma_{n,\gamma}$	4.9563
$^{235}U - \sigma_{f}$	2.0403
$^{238}U - (\sigma_{n,n}\,,\ \sigma_{n,n'})$	1.9791

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.30141	-0.072598
$^{238}U - \sigma_{n,n'}$	0.29936	-0.038201
$^{238}U - \sigma_{n,\gamma}$	0.08626	-0.226594
$^{235}U - \sigma_{f}$	0.03467	0.432950
$^{238}U - \sigma_{n,n}$	0.02027	0.020273

2D Whole Core with Safety Rod in at EoC:

K_{eff} Standard Deviation: 0.013612

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	73.7283
$^{238}U - \sigma_{n,n'}$	14.8969
$^{238}U - \sigma_{n,\gamma}$	4.5753
$^{235}U - \sigma_{f}$	2.1267
$^{238}U - (\sigma_{n,n}\,,\ \sigma_{n,n'})$	-1.0337

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.405050	-0.074914
$^{238}U - \sigma_{n,n'}$	0.234099	-0.031540
$^{238}U - \sigma_{n,\gamma}$	0.079765	-0.217126
$^{235}U - \sigma_{f}$	0.036291	0.438973
$^{53}Cr - \sigma_{n,\gamma}$	0.014358	-0.008940

2D Whole Core with Safety Rod out at EoL:

K_{eff} Standard Deviation: 0.011337

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	52.9760
$^{238}U - \sigma_{n,n'}$	27.7183
$^{238}U - \sigma_{n,\gamma}$	6.7575
$^{235}U - \sigma_{f}$	2.2284
$^{239}Pu - \sigma_{n,\gamma}$	1.3614

Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.00330	-0.054048
$^{238}U - \sigma_{n,n'}$	0.45294	-0.040884
$^{238}U - \sigma_{n,\gamma}$	0.11805	-0.218333
$^{235}U - \sigma_{f}$	0.03726	0.365957
$^{16}O - \sigma_{n,n}$	0.02460	-0.066129

2D Whole Core with Safety Rod in at EoL:

K_{eff} Standard Deviation: 0.011652

Parameter Pair	Contribution to Total Uncertainty (%)
$^{235}U - \sigma_{n,\gamma}$	54.1477
$^{238}U - \sigma_{n,n'}$	26.4607
$^{238}U - \sigma_{n,\gamma}$	6.2537
$^{235}U - \sigma_{f}$	2.2348
$^{238}U - \bar{\nu}$	1.1135

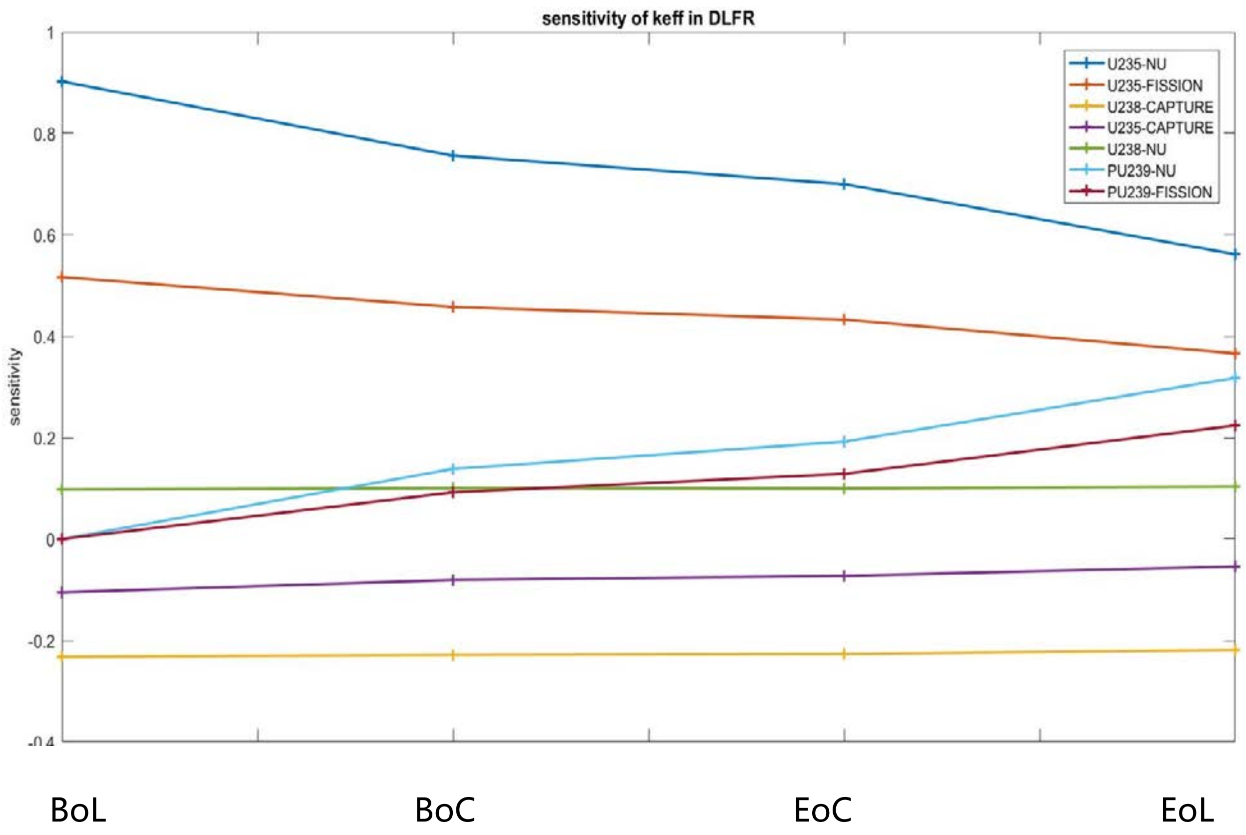
Parameter	Conservatively Estimated Relative Uncertainty	Sensitivity
$^{235}U - \sigma_{n,\gamma}$	1.033740	-0.056374
$^{238}U - \sigma_{n,n'}$	0.448968	-0.040219
$^{238}U - \sigma_{n,\gamma}$	0.109147	-0.216051
$^{235}U - \sigma_{f}$	0.037422	0.377496
$^{53}Cr - \sigma_{n,\gamma}$	0.019183	-0.008523

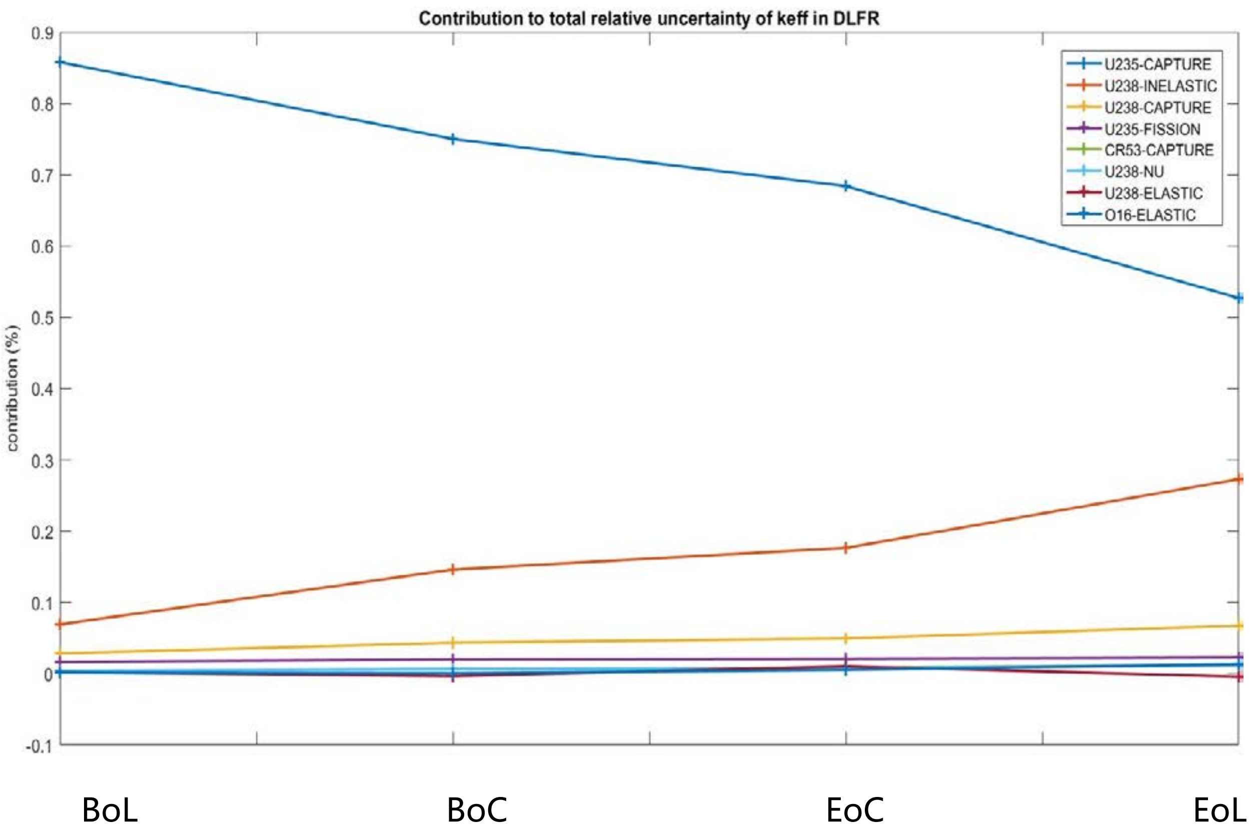
PART 04

Conclusion

Sensitivity and Uncertainty Contributed to Total in Different Periods

2D Whole Core with Safety Rod out



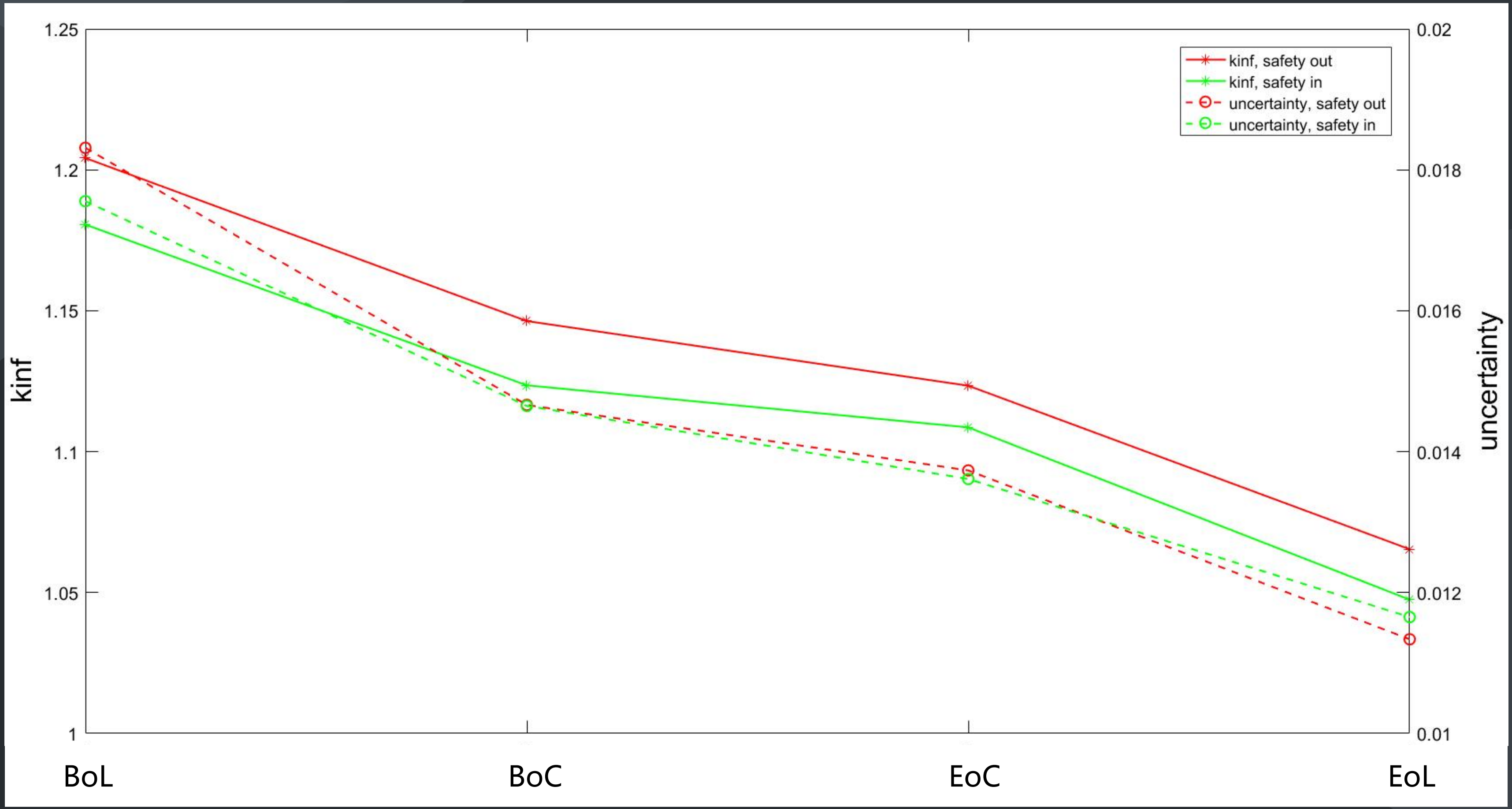


Conclusion

Sensitivity	Uncertainty Contribution
$^{235}U-\bar{\nu}$	$^{235}U-\sigma_{n,\gamma}$
$^{235}U-\sigma_f$	$^{238}U-\sigma_{n,n'}$
$^{238}U-\sigma_{n,\gamma}$	$^{238}U-\sigma_{n,\gamma}$
$^{235}U-\sigma_{n,\gamma}$	$^{235}U-\sigma_f$
$^{238}U-\bar{\nu}$	$^{53}Cr-\sigma_{n,\gamma}$
$^{239}Pu-\bar{\nu}$	$^{238}U-\bar{\nu}$
$^{239}Pu-\sigma_f$	$^{238}U-\sigma_{n,n}$

Period	Relative Uncertainty
BoL	1.83%
BoC	1.47%
EoC	1.37%
EoL	1.13%

k-inf & Uncertainty of 2D Whole Core

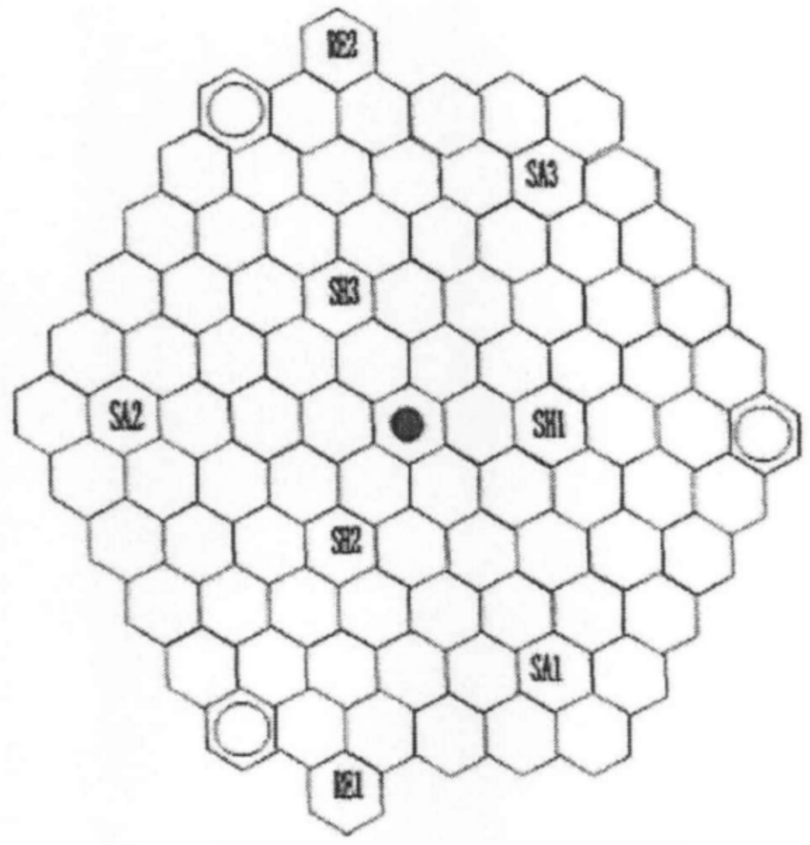


Comparison[1]

Reactor: CEFR (China Experimental Fast Reactor)
Fuel: UO_2 , ^{235}U% = 64.4%
Radius: 30.2 cm
Covariance: Based on Transportation Calculation via ANISN
Code: SUCA1D
(Sensitivity and Uncertainty Code of Analysis, one dimension)

Total Uncertainty	2.65%
Reference Total Uncertainty[2]	1.90%

Number	Parameter Pair	Uncertainty	Contribution to Total (%)
1	$^{235}U - \sigma_f$	1.27%	22.97
2	$^{235}U - \sigma_{n,\gamma}$	2.20%	68.92
3	$^{238}U - \sigma_f$	0.15%	0.32
4	$^{238}U - \sigma_{n,\gamma}$	0.73%	7.59
5	$^{56}Fe - \sigma_{n,\gamma}$	0.12%	0.21



SA Safety Rod
SH Compensation Control Rod
RE Regulation Control Rod
Fuel Assembly
Neutron Source Assembly
Stainless Steel Assembly

CEFR Core in Equilibrium State

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[2]俄罗斯技术报告. CEFR堆芯物理特性计算误差分析
([2] is just mentioned but not cited by [1], reference is not given in [1].)

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END

THANK YOU!

PRESENTED BY LI JIN