

# IMPLEMENTATION OF INVOLUTES IN SERPENT

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Serpent User Group Meeting  
October 28<sup>th</sup> 2020  
TUM

# CORE DESIGN

- Coupled calculations
- Codes have to deal with constraint conditions
  - Very compact core
  - Complex geometry
  - High flux gradients
  - Tight cooling channels
  - High aspect ratio
- Steady state & transient study
- “Ready for licensing”

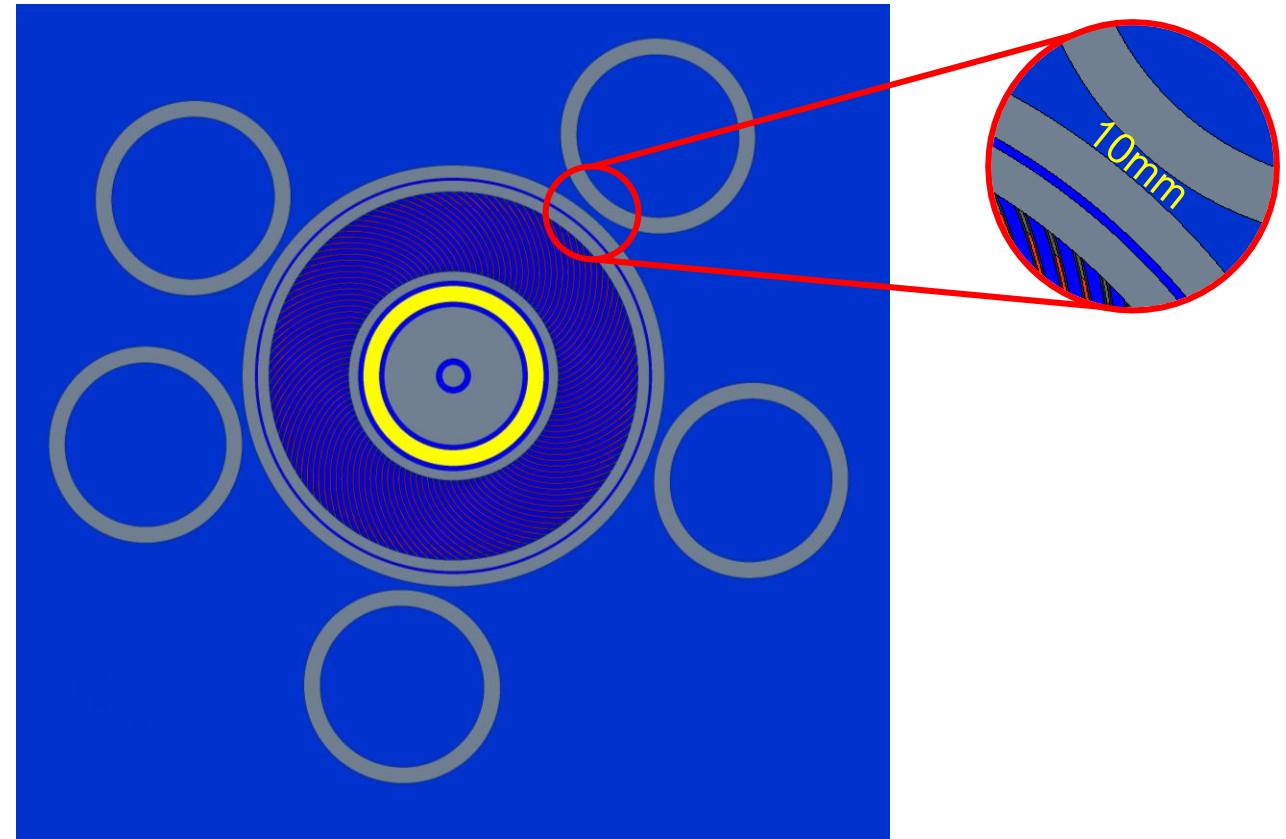
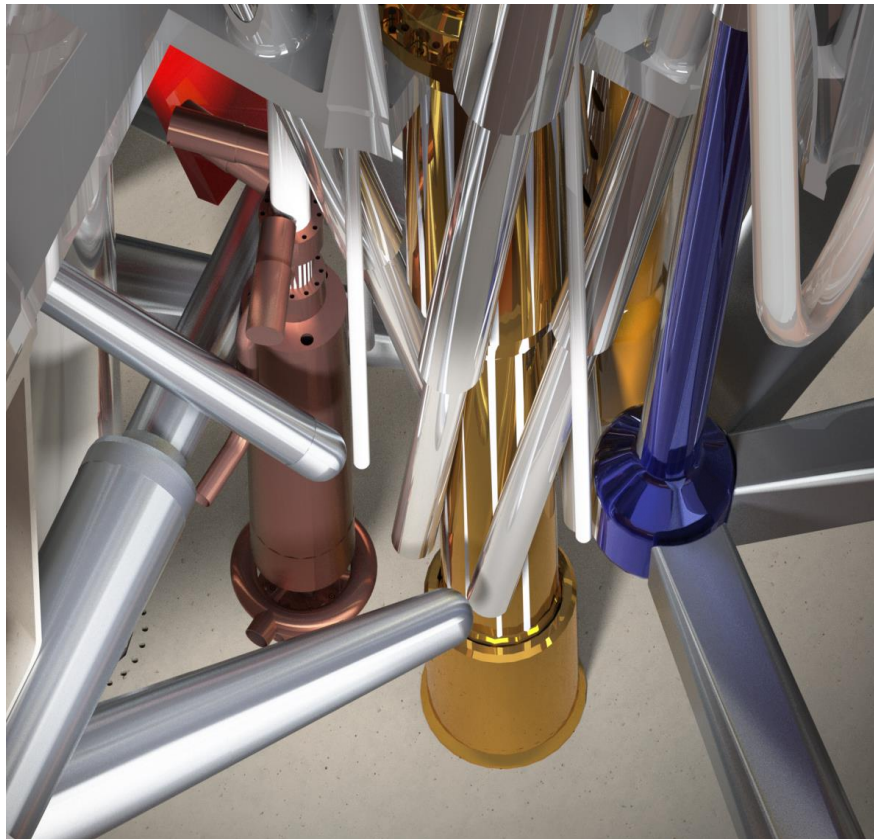
TUM is looking for a compatible core with the lowest enrichment, as technically and economically feasible, with the condition of only marginal losses of scientific performance

```

FRMII_komplett_5.1.s2: "F... X
SERPENT 2
Input
2606 cell c0303_01 0303 3 1302 # SR-Mantel (Alu)
2607 cell c0303_02 0303 void #c0303_01
2608 # <- Vakuum im SR
2609 # ***
2610 # --- durch Wasserabschirmung
2611 cell u0003 00 fill 0003 -1303 1311
2612 cell c0003_01 0003 3 1302 # SR-Mantel (Alu)
2613 cell c0003_02 0003 void #c0303_01
2614 # <- Vakuum im SR
2615 # ***
2616
2617 # --- SR-4: Strahlrohr an der KQ zur Experimentierhalle
2618 # --- Innerhalb Moderatortank
2619 cell u0214 02 fill 0214 1401 -1403 -1402 1404 330 1430
2620 cell c0214_01 0214 void 1405 -1407 -1406 1408 1111 # Vakuum im Rohr
2621 cell c0214_02 0214 3 #c0214_01
2622 # <- Alu-Rohr
2623 # ***
2624 # durch Moderatortank
2625 cell u0304 03 fill 0304 -1461 1430
2626 cell c0304_01 0304 void 1405 -1407 -1406 1408 -1450 # Vakuum im Rohr (innerer Teil (-1450))
2627 cell c0304_02 0304 void 1450 -1462 # Vakuum im Rohr (auesserer Teil (1450))
2628 cell c0304_03 0304 2 (-1451:1453:1452:-1454) -1460 1422 # D2O
2629 cell c0304_04 0304 3 1460 # erstes tally Segment
2630 cell c0304_05 0304 3 -1460 1462 1450 # Alu aussen
2631 cell c0304_06 0304 3 #c0304_01 #c0304_02 #c0304_03 #c0304_04 #c0304_05
2632 # ***
2633 # --- durch Wasserabschirmung
2634 cell u0004 00 fill 0004 -1461 1430
2635 cell c0004_01 0004 void 1405 -1407 -1406 1408 -1450 # Vakuum im Rohr (innerer Teil (-1450))
2636 cell c0004_02 0004 void 1450 -1462 # Vakuum im Rohr (auesserer Teil (1450))
2637 cell c0004_03 0004 2 (-1451:1453:1452:-1454) -1460 1422 # D2O
2638 cell c0004_04 0004 3 1460 # erstes tally Segment
2639 cell c0004_05 0004 3 -1460 1462 1450 # Alu aussen
2640 cell c0004_06 0004 3 #c0004_01 #c0004_02 #c0004_03 #c0004_04 #c0004_05
2641 # ***
2642 # ***
2643
2644 # --- SR-5: Thermisches Strahlrohr zur Experimentierhalle
2645 # --- Innerhalb Moderatortank
2646 cell u0215 02 fill 0215 -1503 (-1501:1511)
2647 cell c0215_01 0215 3 1500 -1511 # SR-Nase
2648 cell c0215_02 0215 3 1502 1511 # SR-Mantel
2649 cell c0215_03 0215 void #c0215_01 #c0215_02
2650 # <- Vakuum im Rohr
2651 # ***
2652 # --- durch Moderatortank
2653 cell u0305 03 fill 0305 1511 (-567:-1503)
2654 # --- Strahlrohr innen
2655 cell u030501 0305 fill 030501 -1503 1511
2656 cell c030501_01 030501 3 1502 1511 # SR-Mantel
2657 cell c030501_02 030501 void #c030501_01
2658 # <- Vakuum im Rohr
2659 # --- Flanschrohr
2660 cell u030502 0305 fill 030502 1511 -567 1503
2661 cell c030502_01 030502 3 -567 595 # Flanschrohr
2662 cell c030502_02 030502 2 -595 # SW in Flanschrohr
2663 # ***
2664 # --- durch Wasserabschirmung
2665 cell u0005 00 fill 0005 1511 (-567:-1503)
    
```



# NO SPACE LEFT



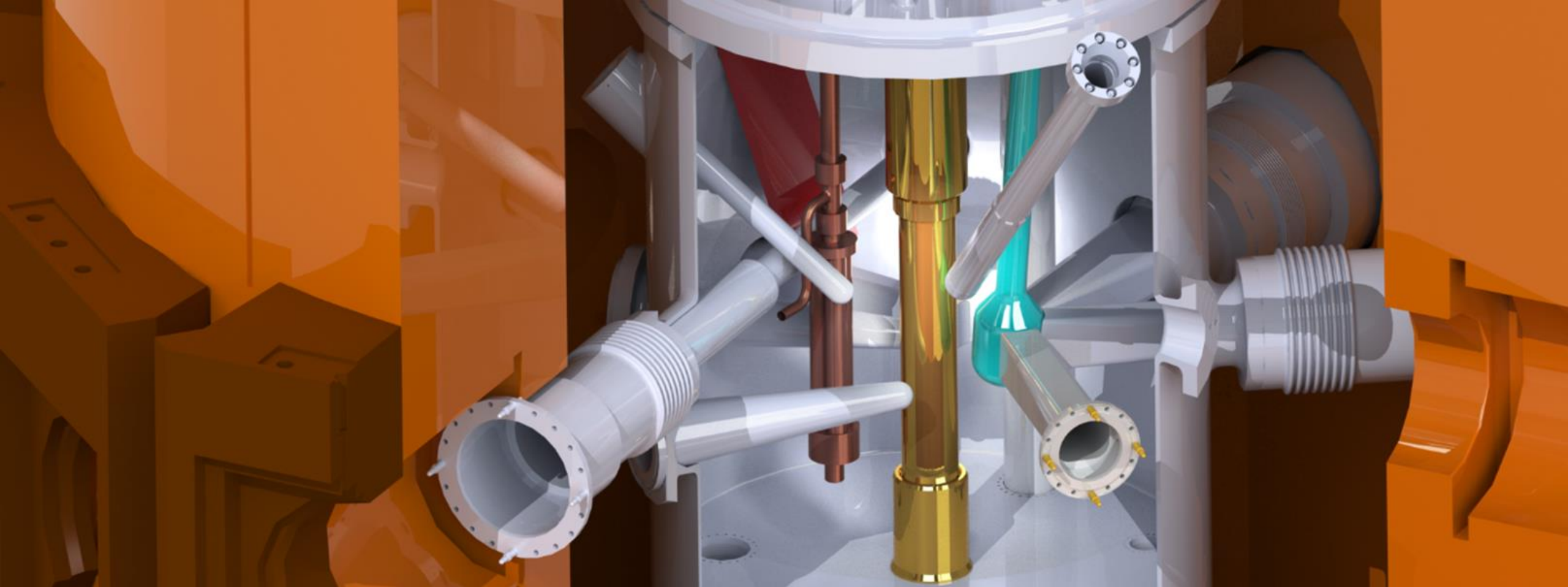
# POSSIBLE PARAMETERS

- Three fuel candidates:  $U_3Si_2$ , disperse and monolithic U-Mo
- Meat & cladding thickness
- Molybdenum content
- Number of plates
- Density jump and/or burnable poison

Fuel element

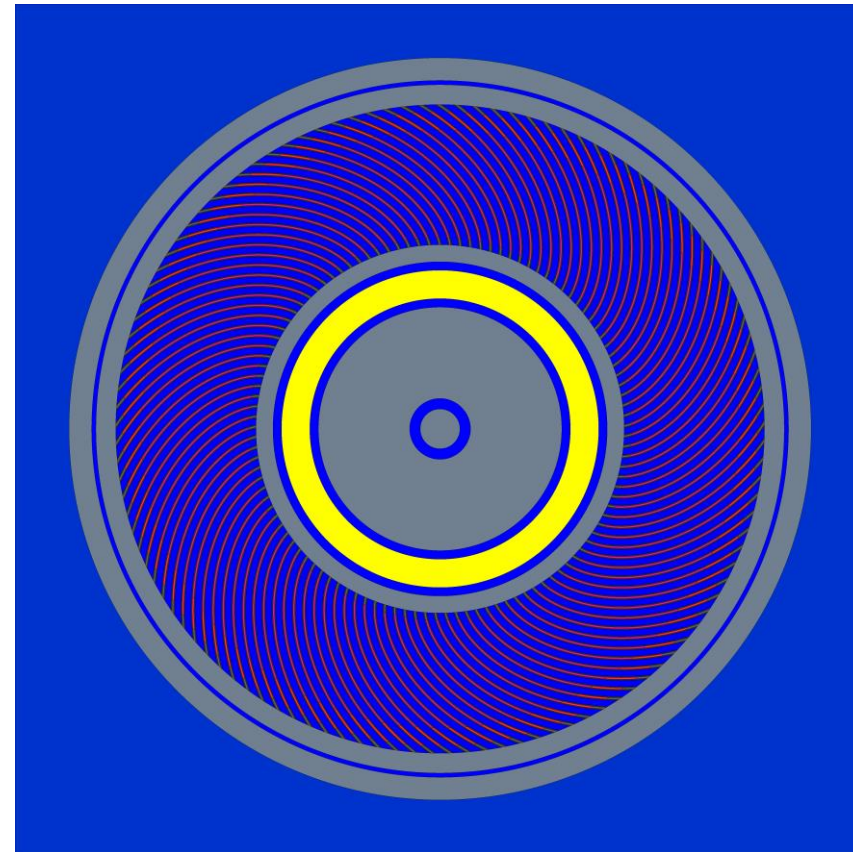
- Central channel tube: diameter and material
- Control rod tube: diameter and material

Reactor



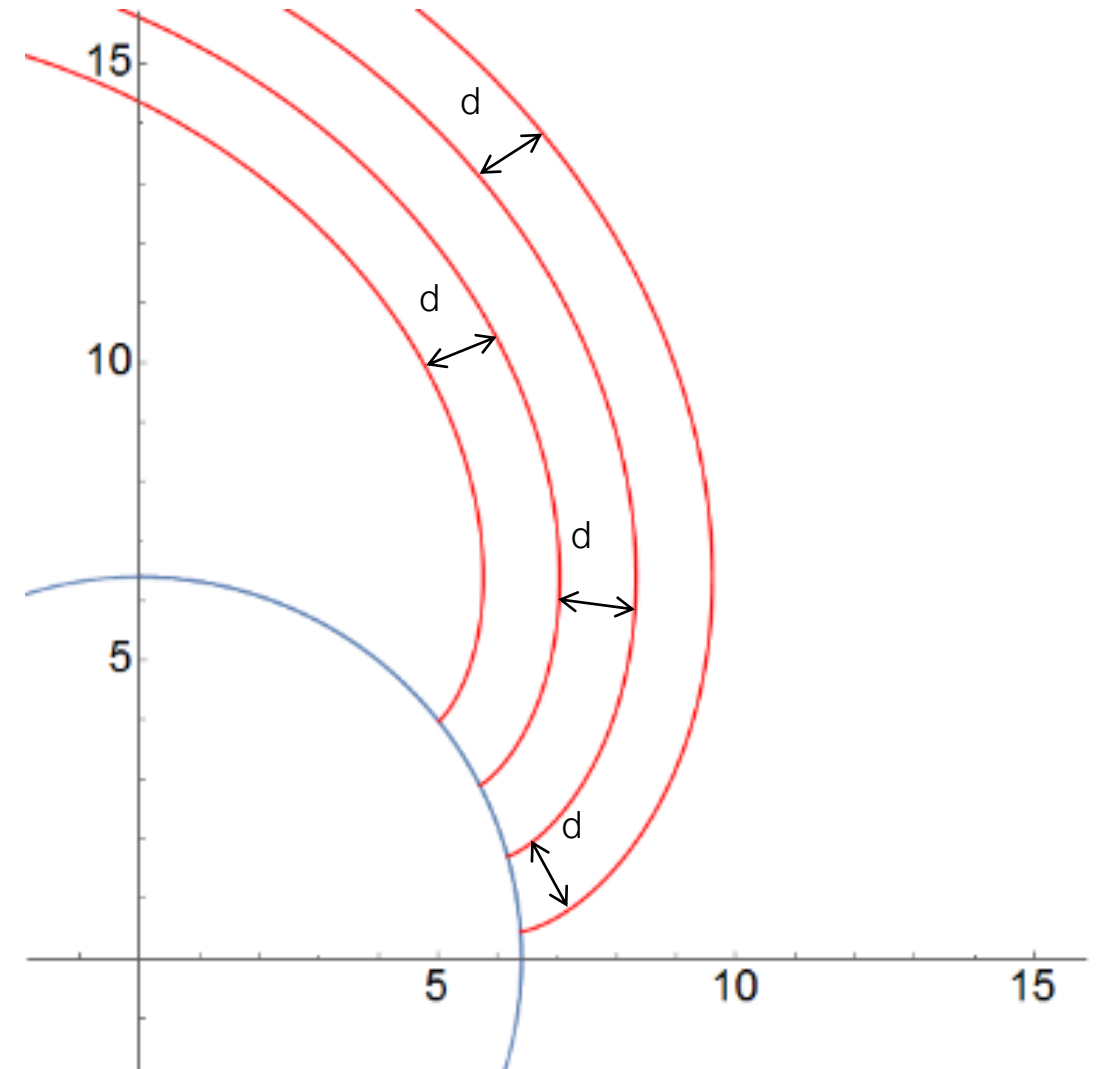
INVOLUTES

# CURRENT FUEL ELEMENT



## WHY INVOLUTES?

Constant cooling channel thickness solves the challenging cooling of high-flux-neutron-reactor FRM II





# MATHEMATICAL BACKGROUND

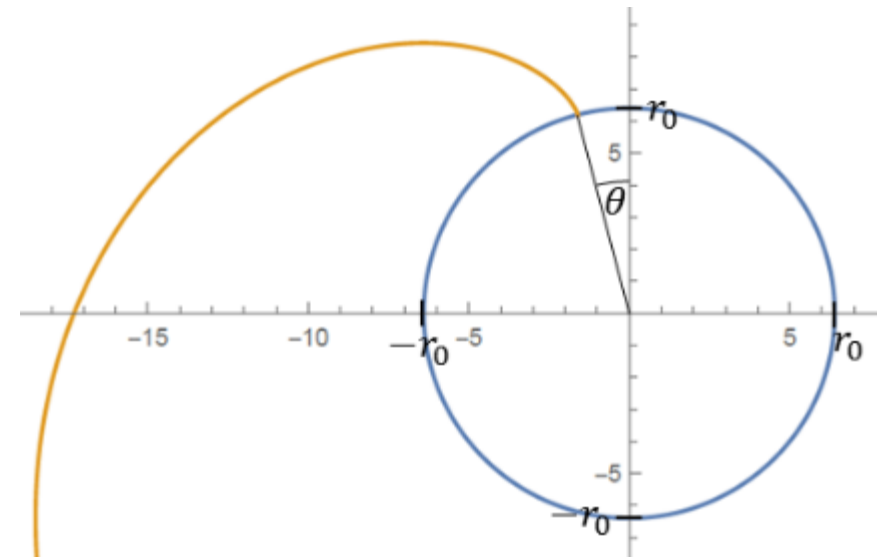
$$\begin{pmatrix} x(r_0, \theta, \varphi) \\ y(r_0, \theta, \varphi) \end{pmatrix} = r_0 \begin{pmatrix} \varphi \cdot \cos(\varphi + \theta) - \sin(\varphi + \theta) \\ \cos(\varphi + \theta) + \varphi \cdot \sin(\varphi + \theta) \end{pmatrix}$$

Defining Parameter:

$$r_0 \in [0, \infty[$$

$$\theta \in [0, 2\pi]$$

Parameter:  $\varphi \in [0, \infty[$





# DEFINITION OF SURFACE-TYPES

## Surface-type (Parameters)

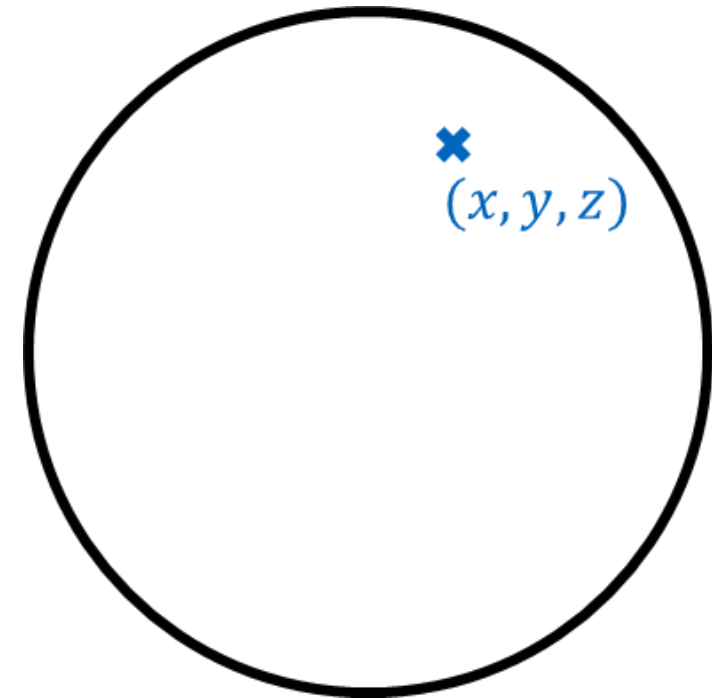
1. Testing if point  $(x, y, z)$  is inside or outside (left or right) the surface
2. Calculating the shortest distance to the surface from point  $(x, y, z)$  in direction  $(u, v, w)$

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## Example: Sphere

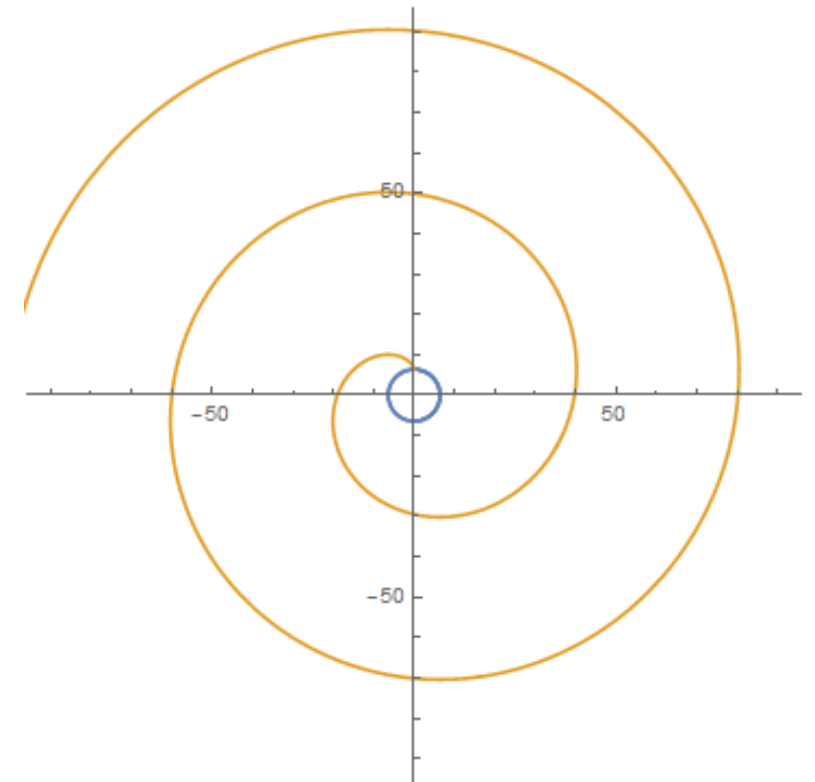


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## Involute



## DEFINITION AS MACROBODY

In x-y-plane defined by parameters:

$r_0$ : involute radius

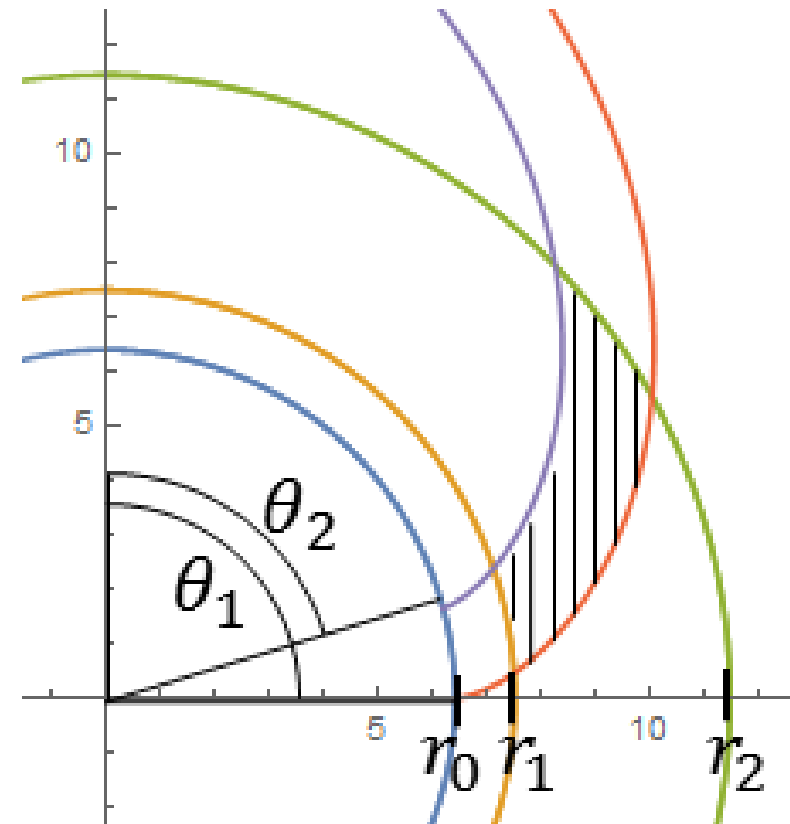
$\theta_1$ : starting angle of first involute

$\theta_2$ : starting angle of second involute

$r_1$ : radius of inner cylinder

$r_2$ : radius of outer cylinder

Body infinite extended in z-direction





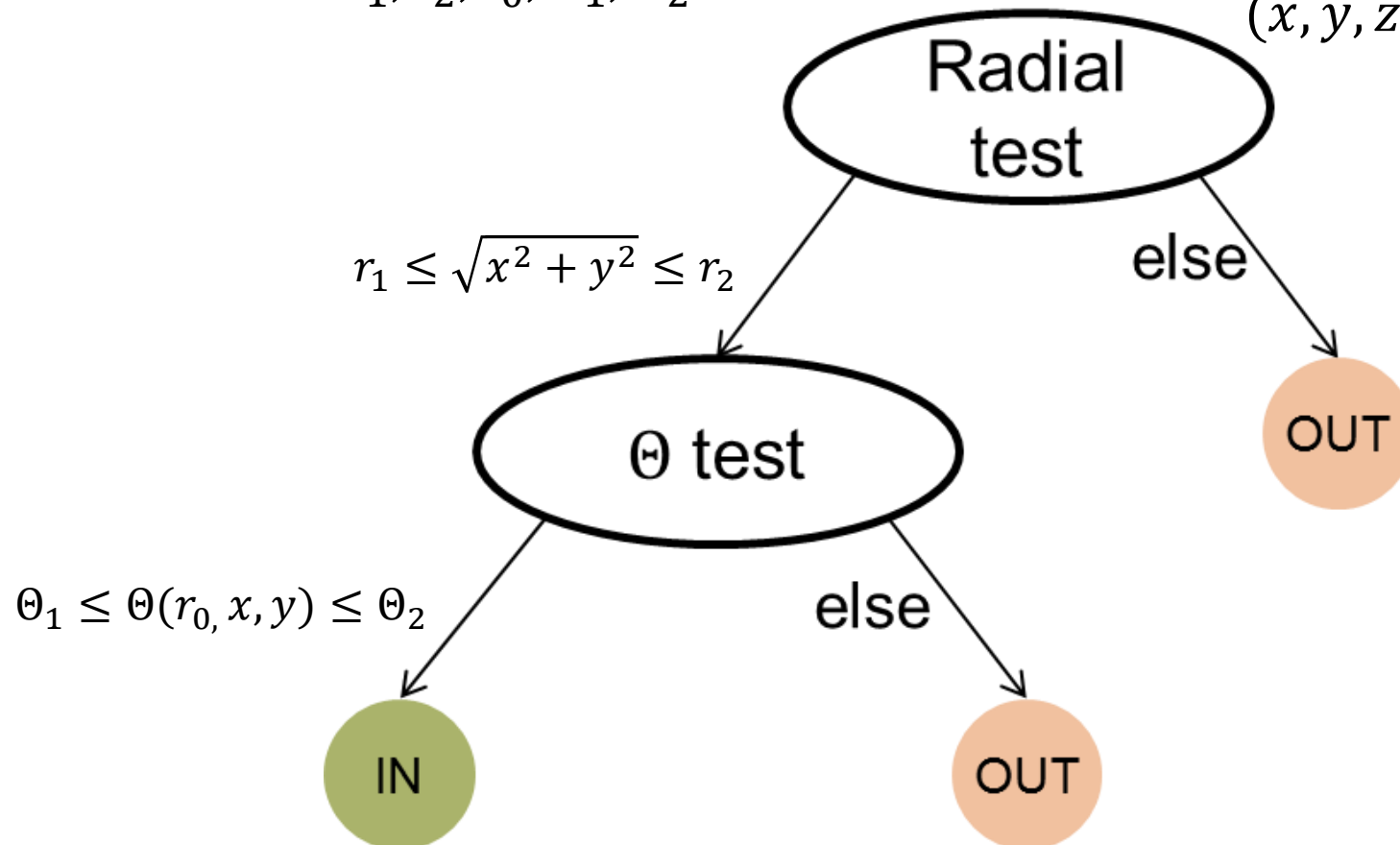
# TEST FOR “INSIDE” AND “OUTSIDE”

Involute with Parameters

$$r_1, r_2, r_0, \Theta_1, \Theta_2$$

Arbitrary Point

$$(x, y, z)$$

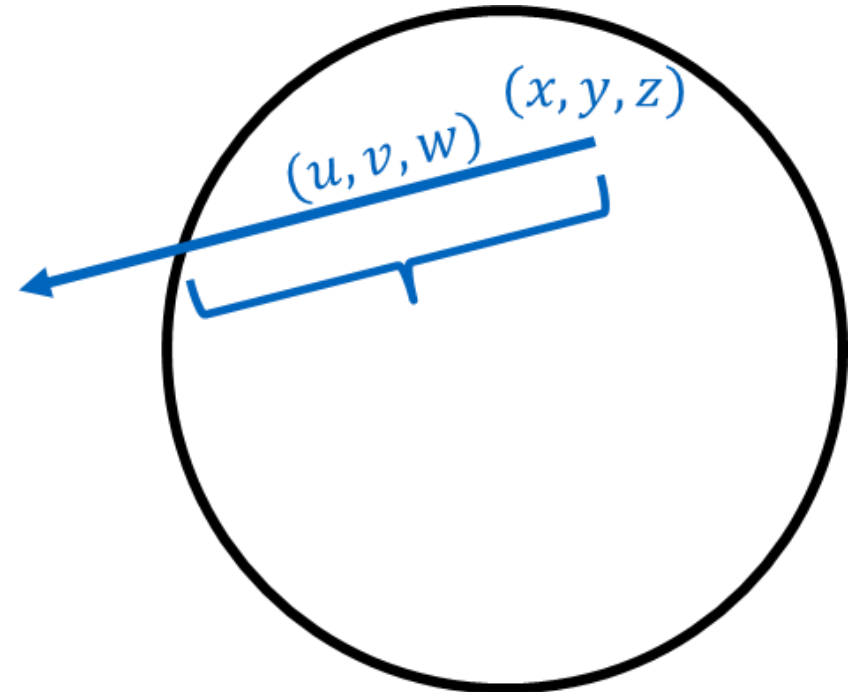


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## Example: Sphere

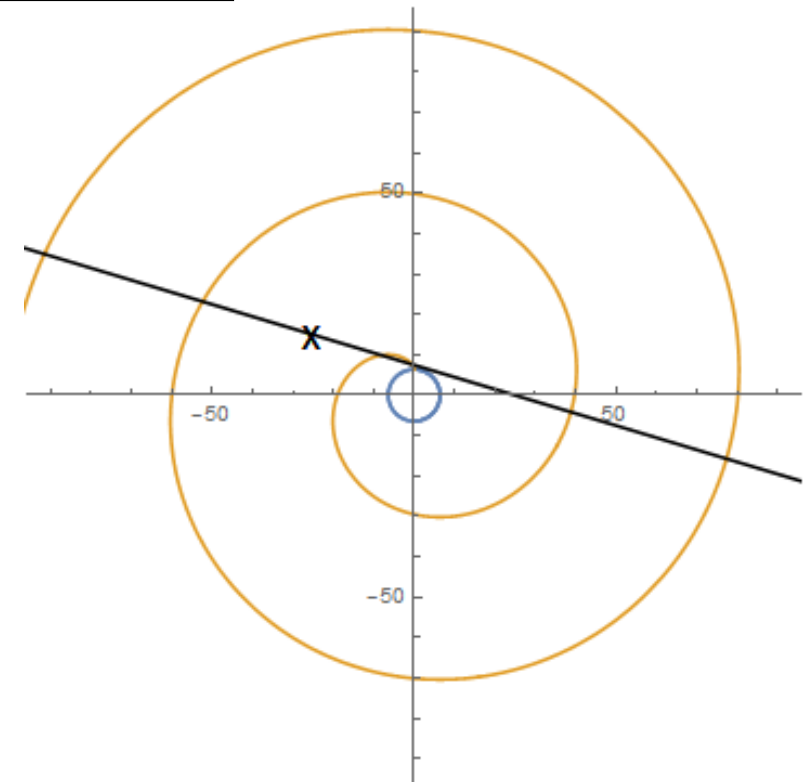


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## Example: Involute



# NEED FOR NUMERICS

Intersection point of an involute with a line is not analytically solvable:

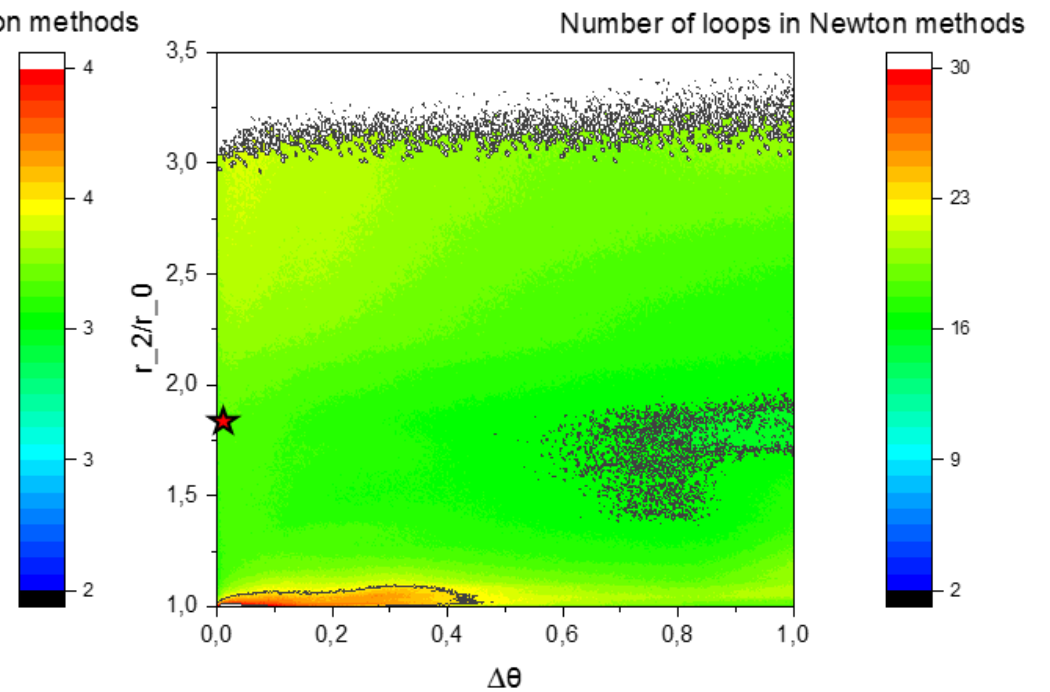
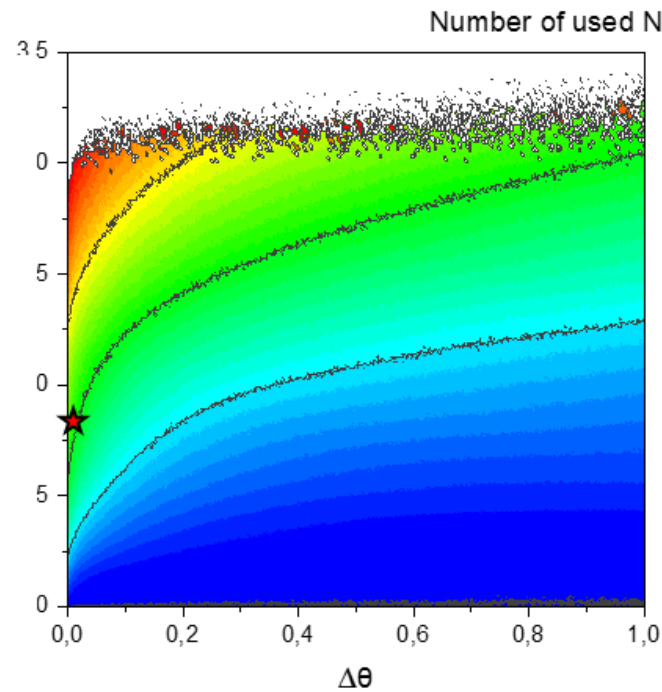
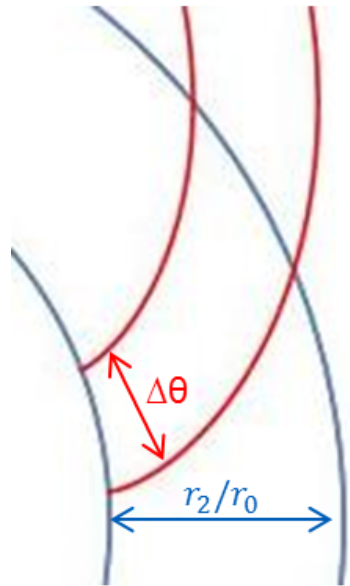
$$f(\varphi) = \{r \cdot [\varphi \cdot \cos(\varphi + \theta) - \sin(\varphi + \theta)] - x_0\} \cdot dy \\ + \{(-r) \cdot [\cos(\varphi + \theta) + \varphi \cdot \sin(\varphi + \theta)] + y_0\} \cdot dx = 0$$

First version: Newton's method

Second version: Regular Falsi

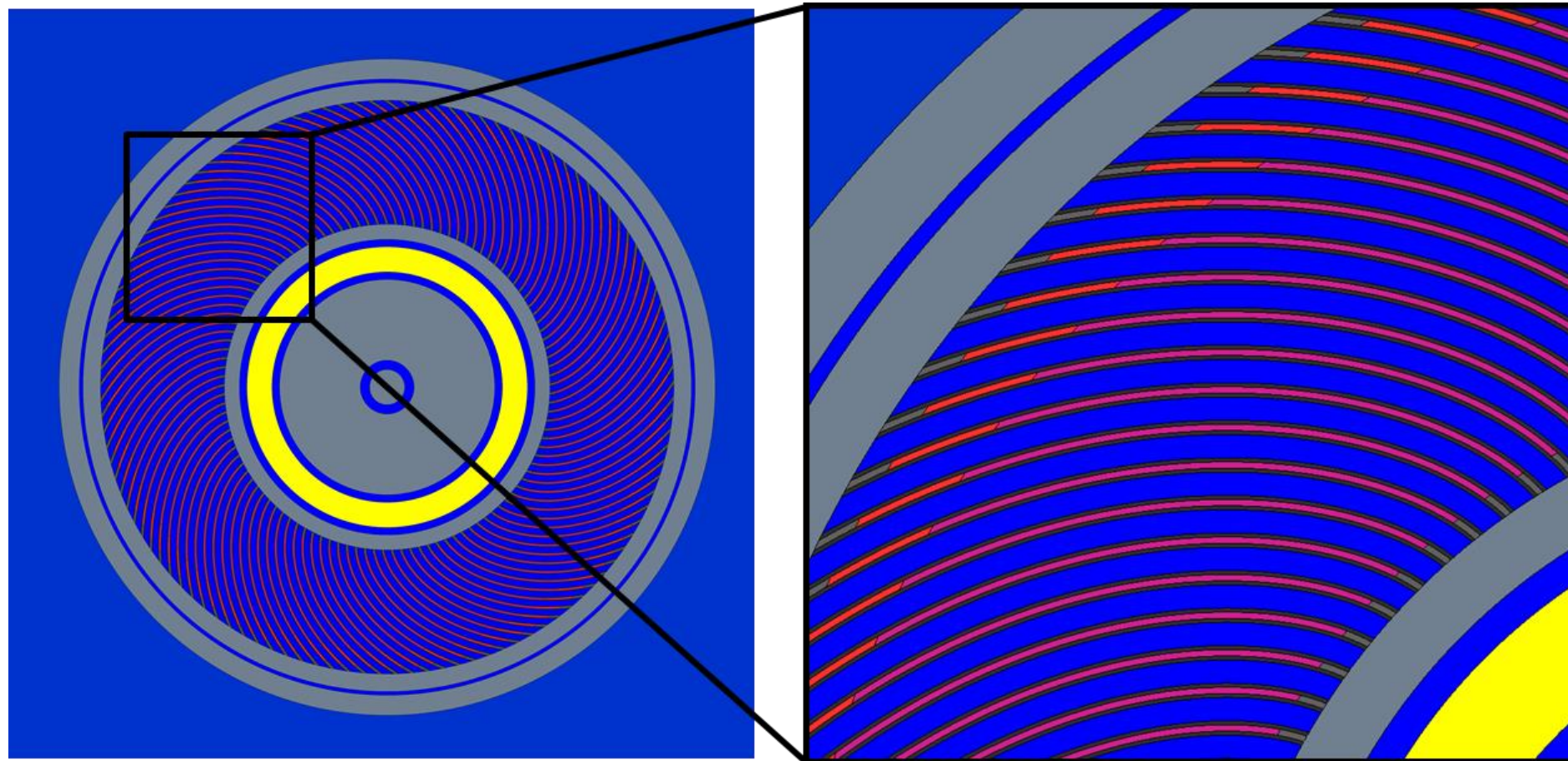


# CONVERGENCE OF NEWTONS METHOD

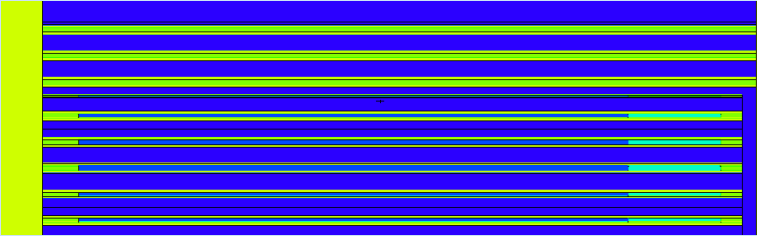
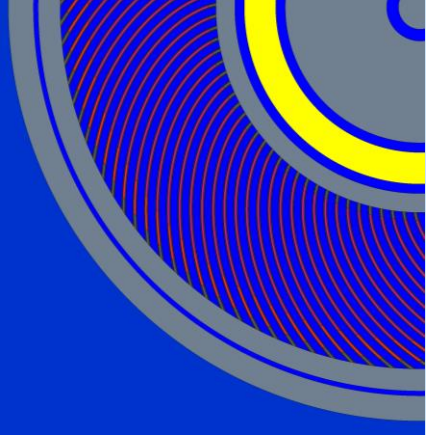
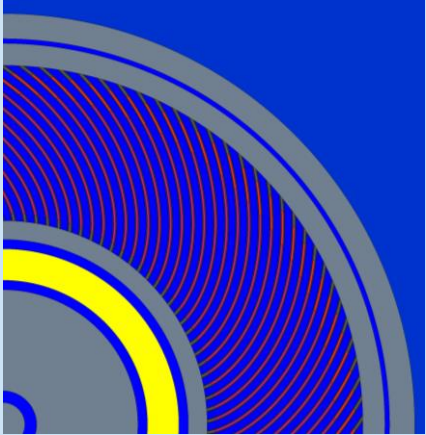


★ = FRM II

# EXACT INVOLUTE GEOMETRY IN SERPENT 2

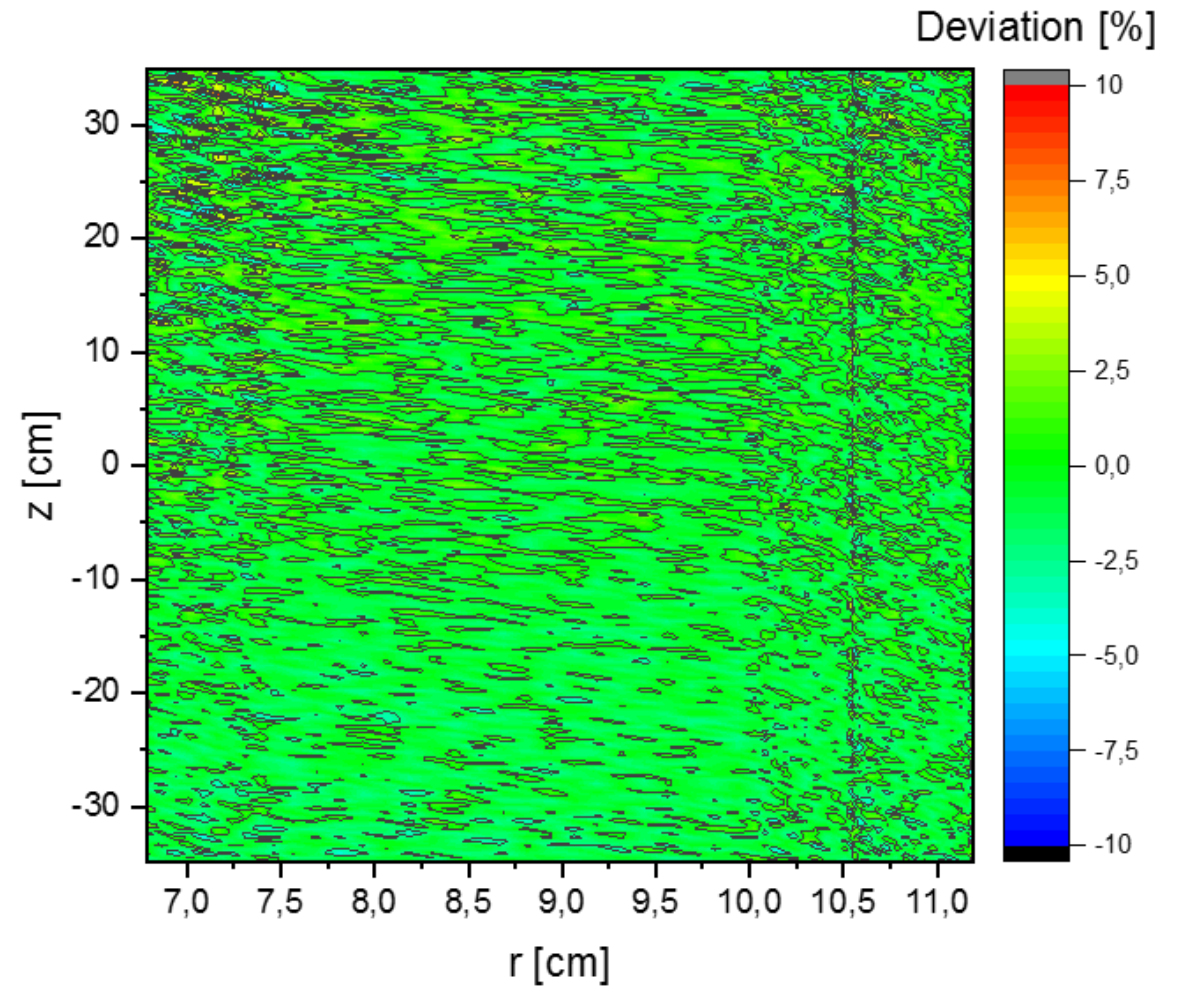
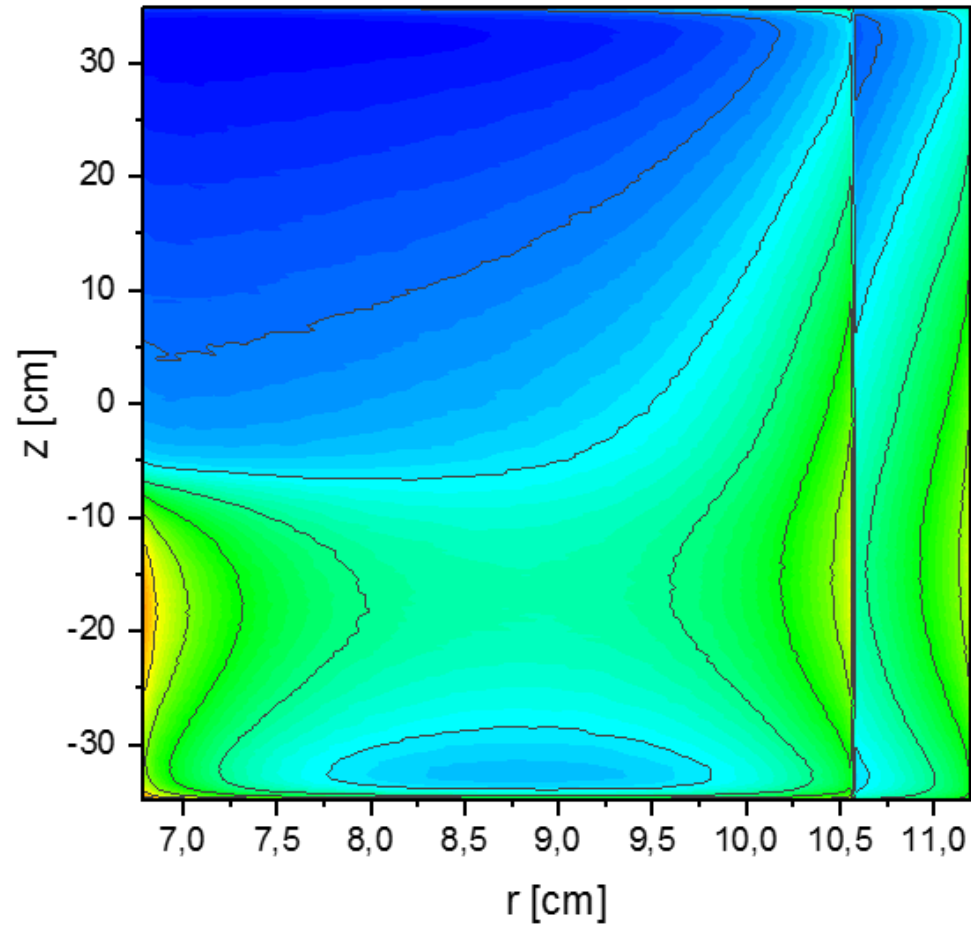


# MULTIPLICATION FACTOR

Substitutional Geometry	Parabola – Ellipse Approximation	Exact involutes
		
	$0,99850 \pm 0.0001$	

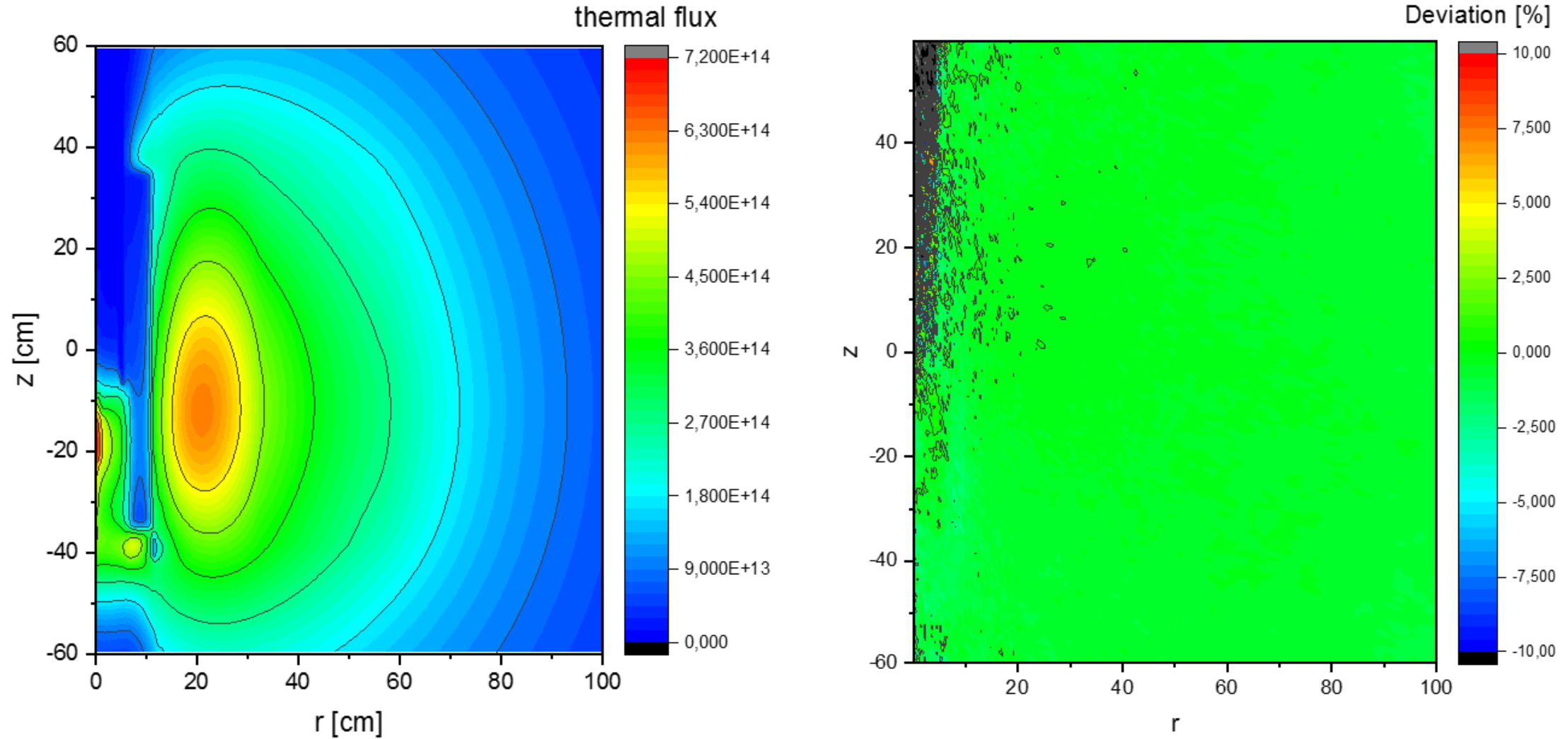


# FISSION RATE

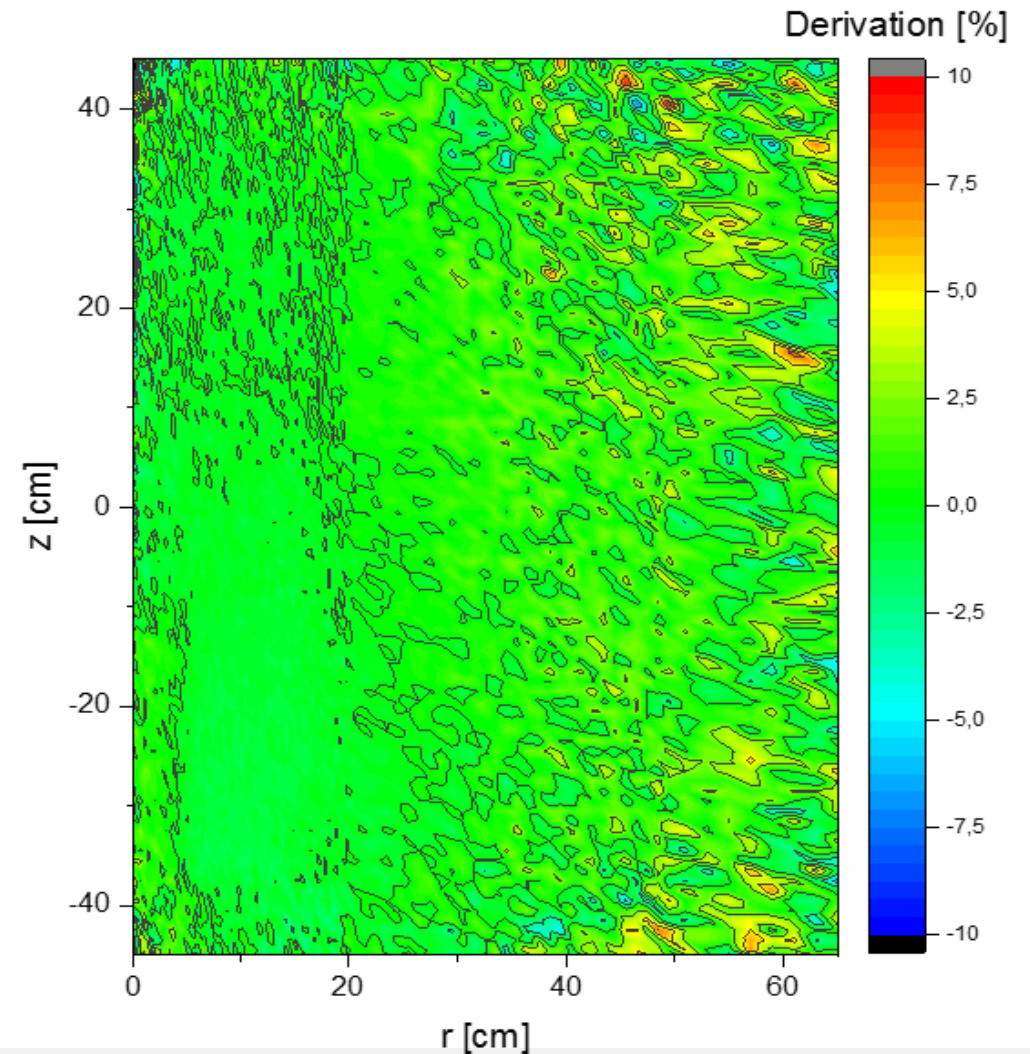
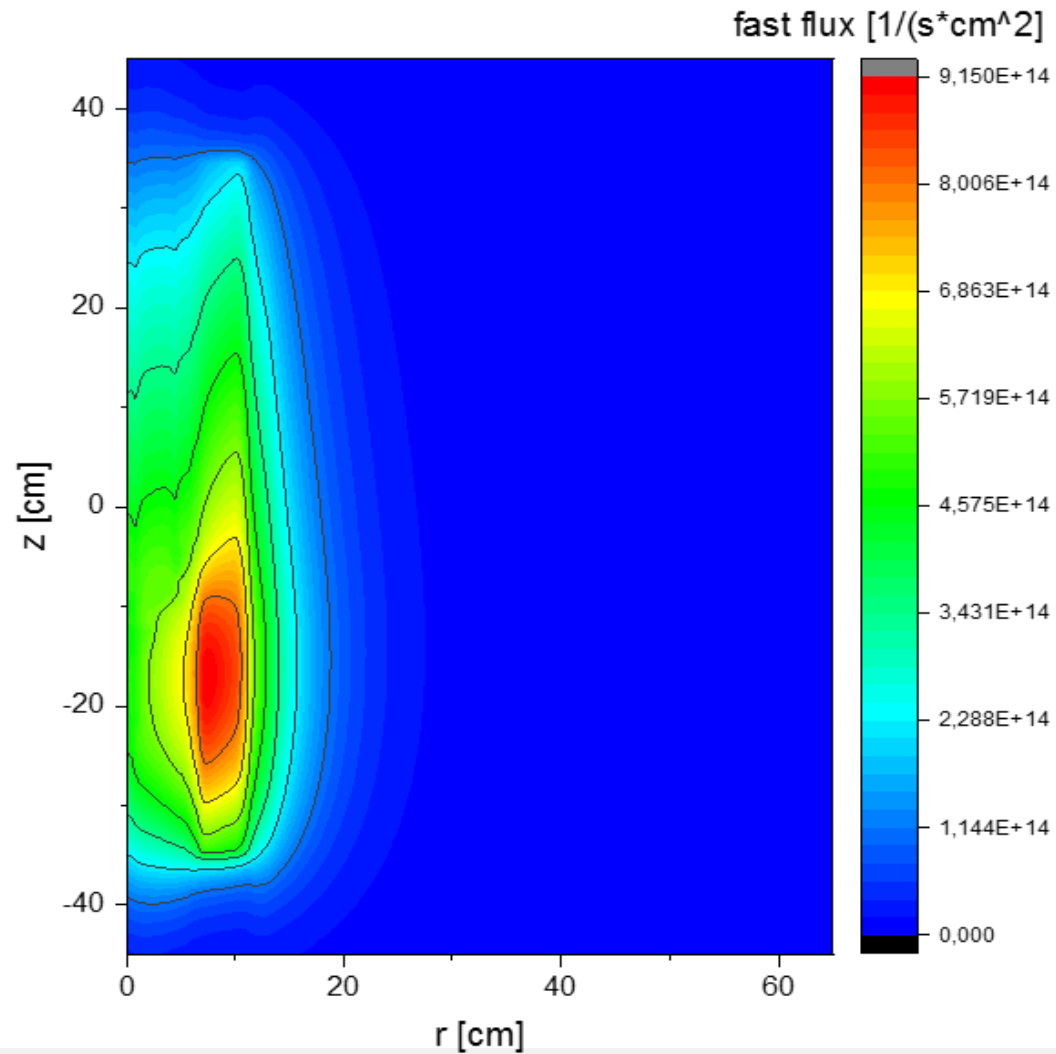




# THERMAL FLUX



# THERMAL FLUX



# ISSUES TO BE SOLVED

- Newtons method works, but:
  - Particles go lost
  - Numerical issues with checkvolumes routine
- Regular Falsi is more stable and faster



THANK YOU