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Interdisciplinary Research Group
Science, Technology and Security

TECHNISCHE
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# Neutronic Calculations for Conversion of One-Element-Cores from HEU to LEU Using Monolithic UMo Fuel

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# Performance Analysis

Not only maximum flux and cycle length

Performance of a research reactor (beam type) is a function of

- Available beam time per year (cycle length and downtime)
- Number and efficiency of neutron guides and experiments
- Available flux at experiments

Best approach:
Modelling from the source to the experiment
Coupling of instrumentation codes (e.g. MCSTAS, VITESS) to the reactor code?

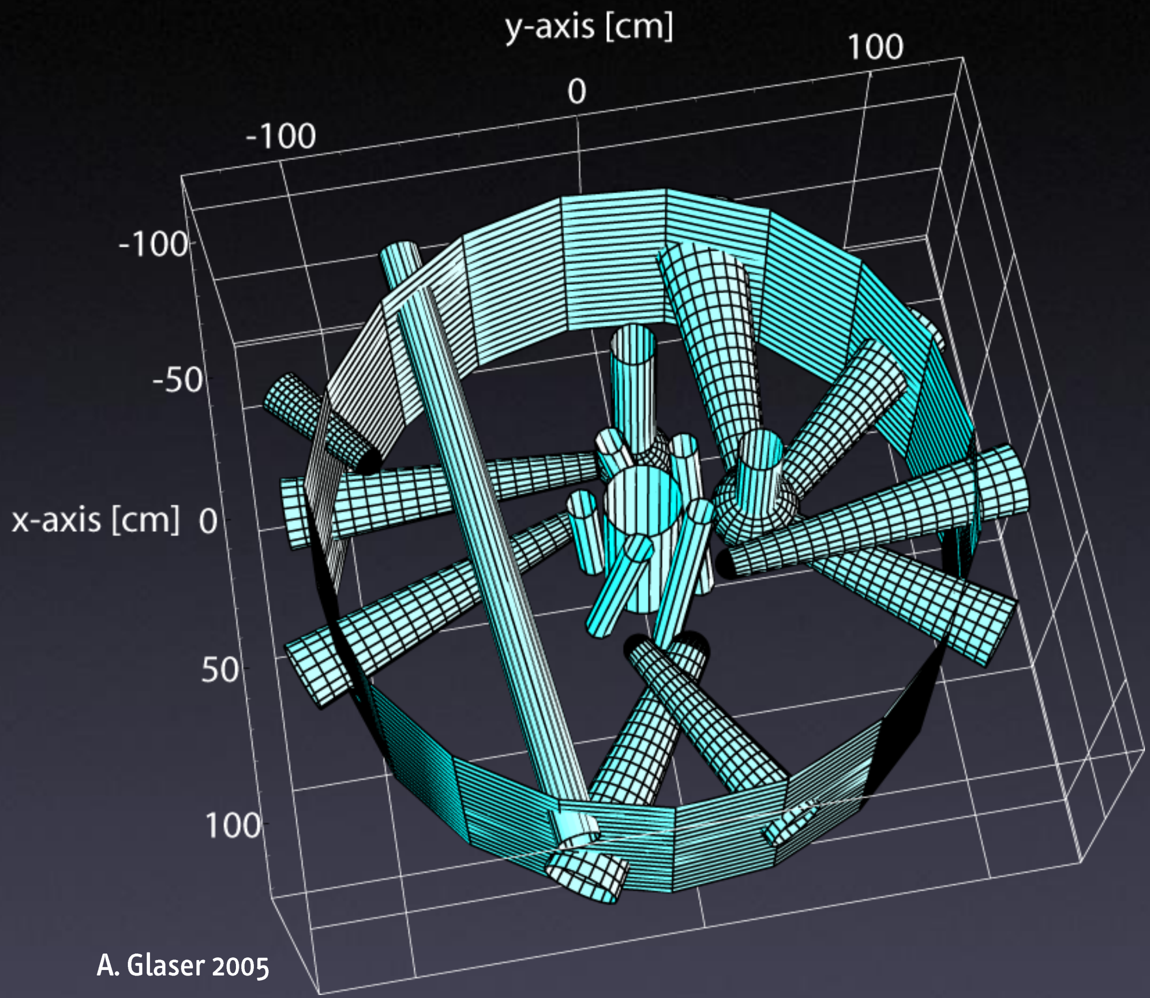
Also for other reactors:
Maybe flux losses can be compensated by improving neutron guides and experiments
(e.g. ILL, Petten et al.) (economic benefits !?)

# FRM-II Principal Conversion Options

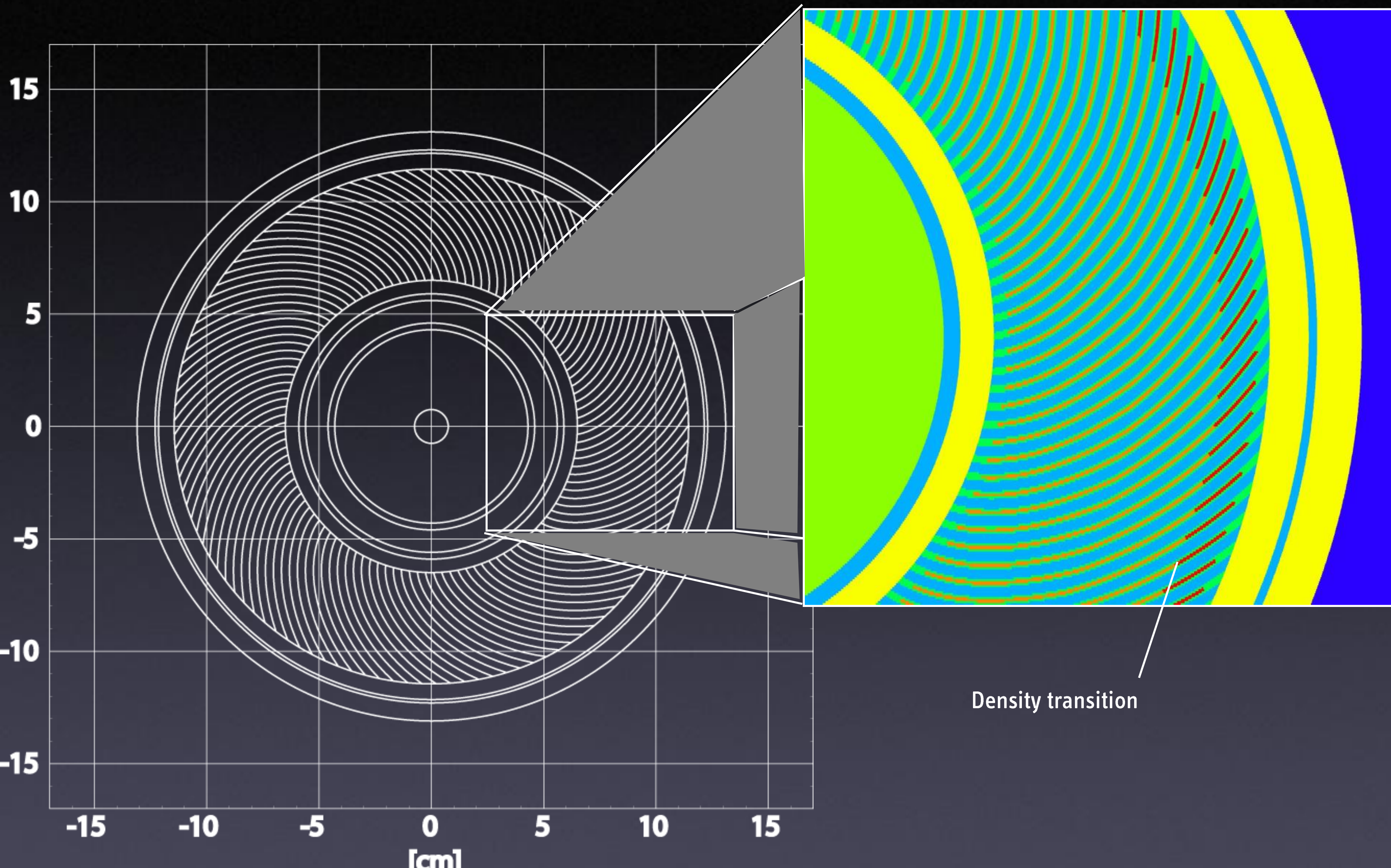
Obligation to convert to at least 50% enrichment or below by end of 2010
(according to scientific-technological possibilities)

| UMo Dispersion | UMo Monolithic |
| --- | --- |
| 8 g/cc | 16 g/cc |
| 50% enrichment | < 33 % enrichment |
| ~8% flux losses | potential for LEU ?! |
| (LEU impossible) | this talk |

# Reactor



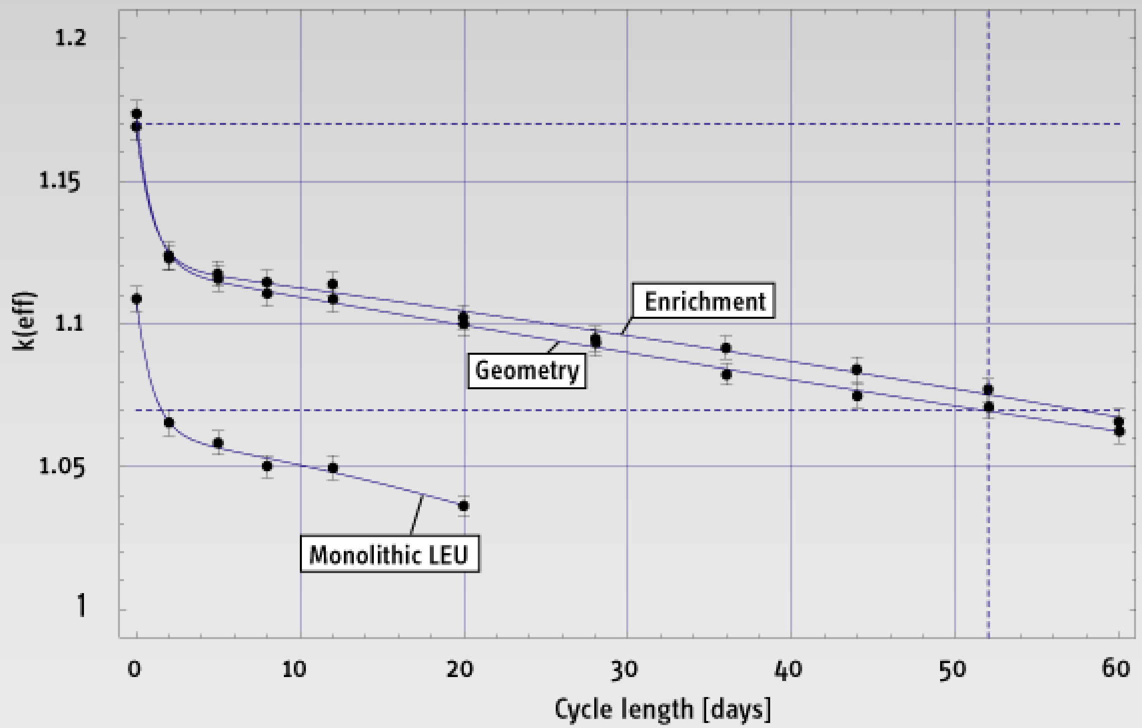
# Fuel Element Model



# Increasing Initial Reactivity

| | Enrichment | Enrichment + Geometry |
|---|---|---|
| Thermal Power | 20 MW | 20 MW |
| Fuelled height of core | 70 cm | 80 cm |
| Required Enrichment | 32-33% | 26-27% |

Elongation of active height




-> $k(eff)_{ini}$ ~ 1.17

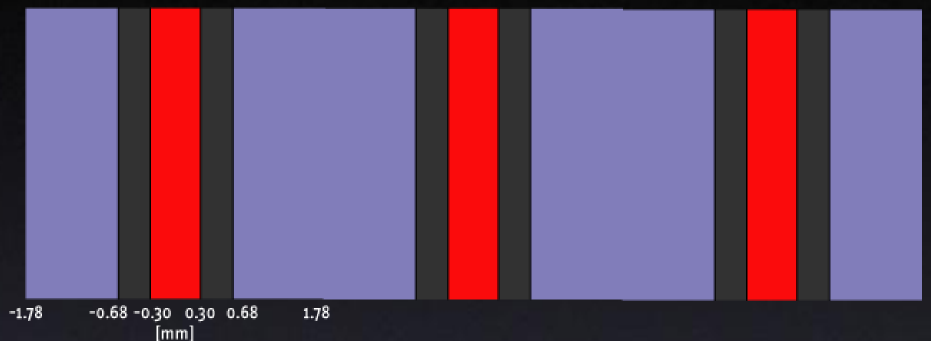
Non-proliferation objective ?

Cycle Length of the FRM-II core for the current HEU design and for monolithic fuel with 16 g/cm3 in the current HEU design geometry.

# Geometrical Changes I

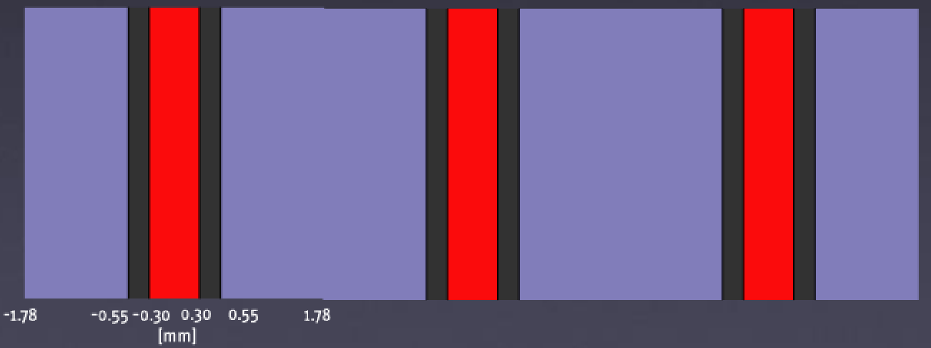
Constant Number of Plates in the core

Current Geometry

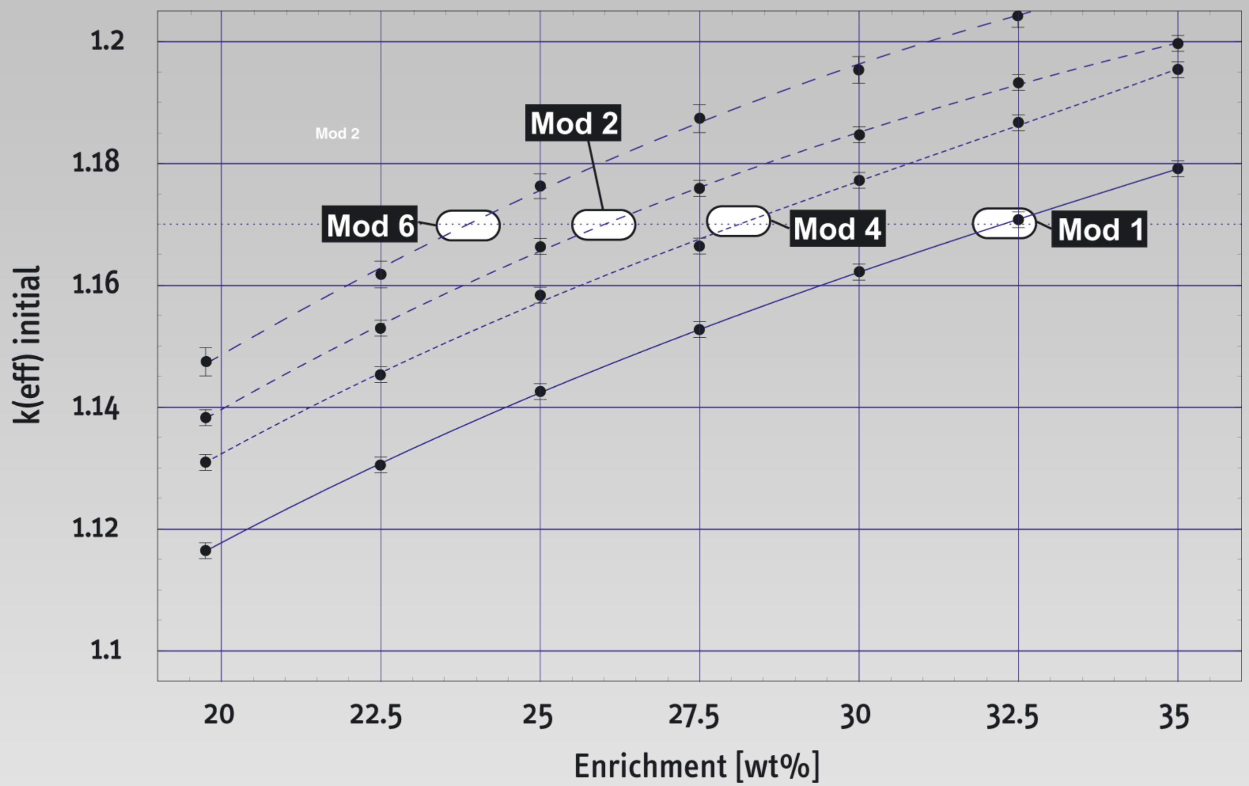



Thinner Cladding
Thicker Meat


Thinner Cladding
Wider cooling channels

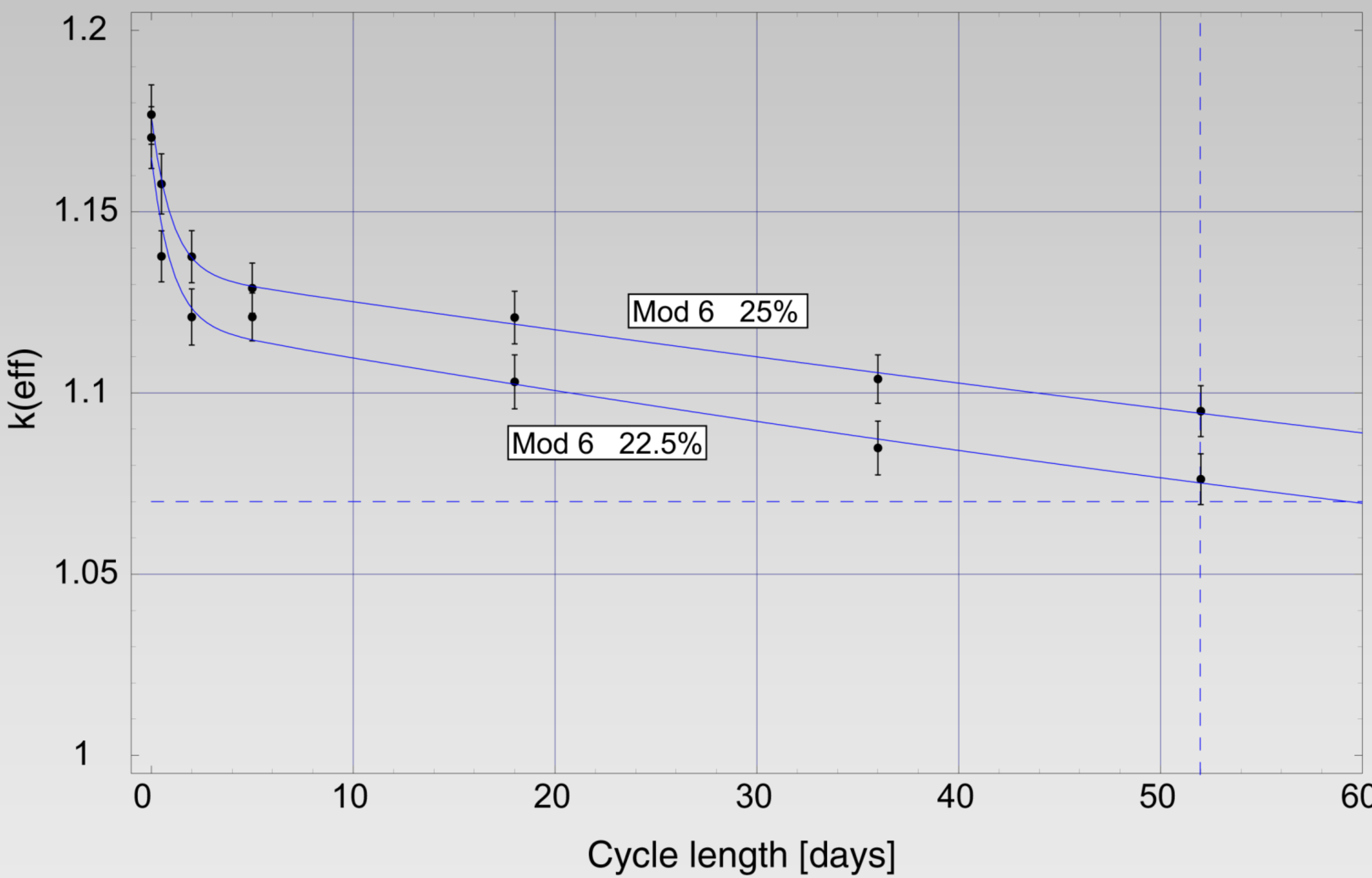


# Compensation by Enrichment




| | Height | Meat | Clad | Cool | Mass | Enrichment | Plnr. |
|---|---|---|---|---|---|---|---|
| Mod. 1 Original | 70 cm | 0.60 mm | 0.38 mm | 2.20 mm | 43.25 kg | 32-33 % | 113 |
| Mod. 2 | 80 cm | 0.60 mm | 0.38 mm | 2.20 mm | 49.42 kg | 26-27 % | 113 |
| Mod. 4 | 70 cm | 0.86 mm | 0.25 mm | 2.20 mm | 61.99 kg | 27-28 % | 113 |
| Mod. 5 | 70 cm | 0.60 mm | 0.25 mm | 2.46 mm | 43.25 kg | 27-28 % | 113 |
| Mod. 6 | 80 cm | 0.86 mm | 0.25 mm | 2.20 mm | 70.84 kg | 24-25 % | 113 |

# Cycle Length for Mod 6




Mod 6:
Height: 80 cm
Meat: 0.86 mm
Clad: 0.25 mm

# Improved strategy (striving for global optimization)

Parameter Space Studies:
simultaneous variations of
$x_i$ : active height, meat cladding and cooling channel thickness

to get $k(eff)_{ini}$ $(x_i)$ and $\Phi(x_i)$ for LEU fuel

having in mind:
- sufficient initial reactivity, optimum flux,
- keeping constraints like (cycle length, power peaking, heat flux ...)

The parameter study was an intermediate step towards solving the full optimization problem:

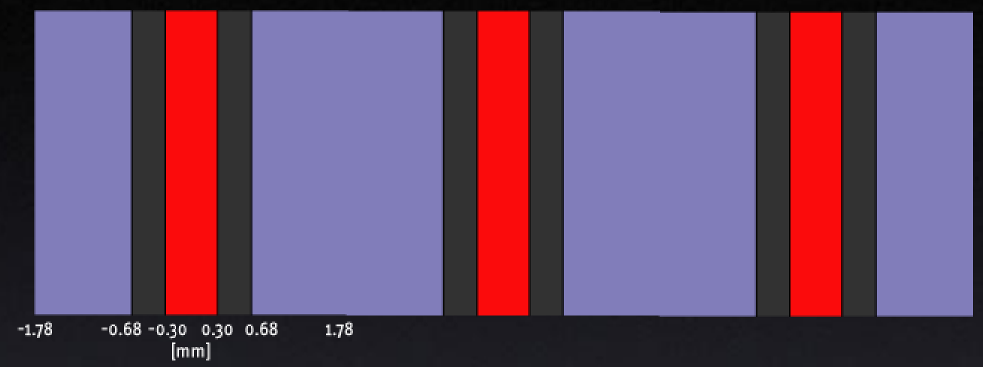
- maximizing reactor performance
- minimizing enrichment (hopefully LEU or near LEU)
- keeping operational constraints

First steps to establish a global optimization routine.
Approach of first investigating a wide range of parameters and then constraining the results

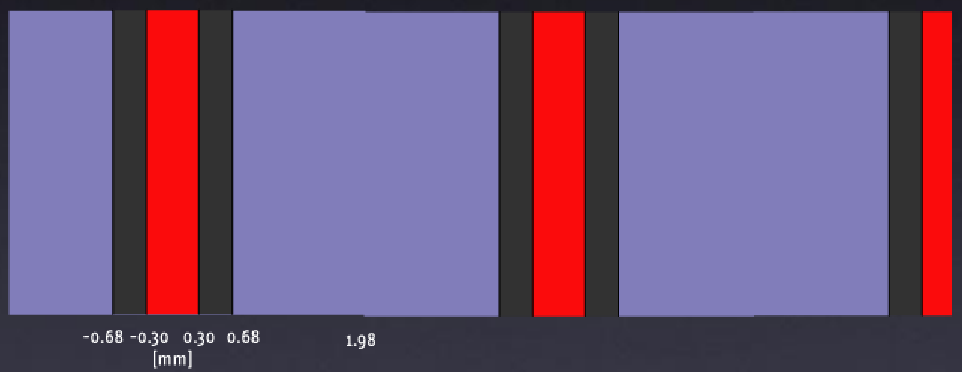
# Geometrical Changes II

Varied number of fuel plates

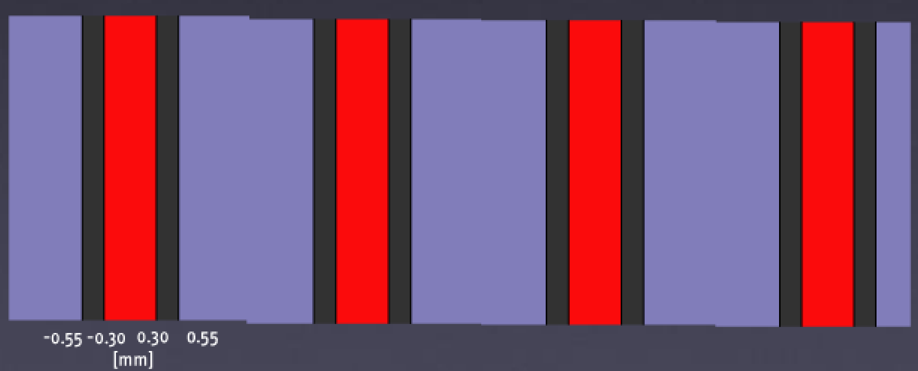
Current Geometry




Wider cooling channels
Less plates

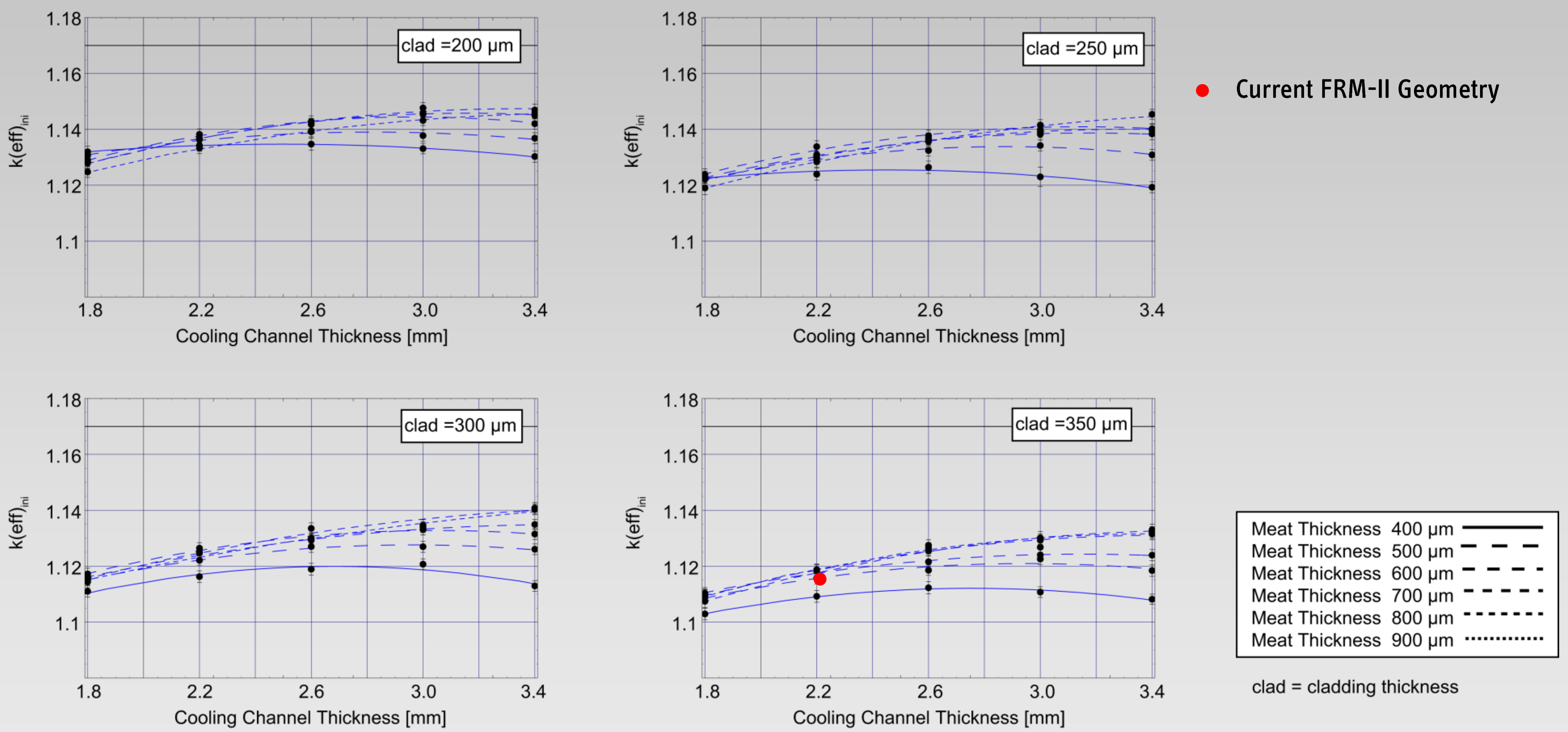



Thinner cooling channels
Thinner clad
More Plates



# Systematic Study to increase k(eff) initial

## Variation of cooling channel, cladding and meat thickness (19.75% enriched, 70 cm )




Optimum cooling channel thickness between 2.6 and 3.4 mm

The more cooling channel thickness the more sensitive is k(eff) on the meat thickness

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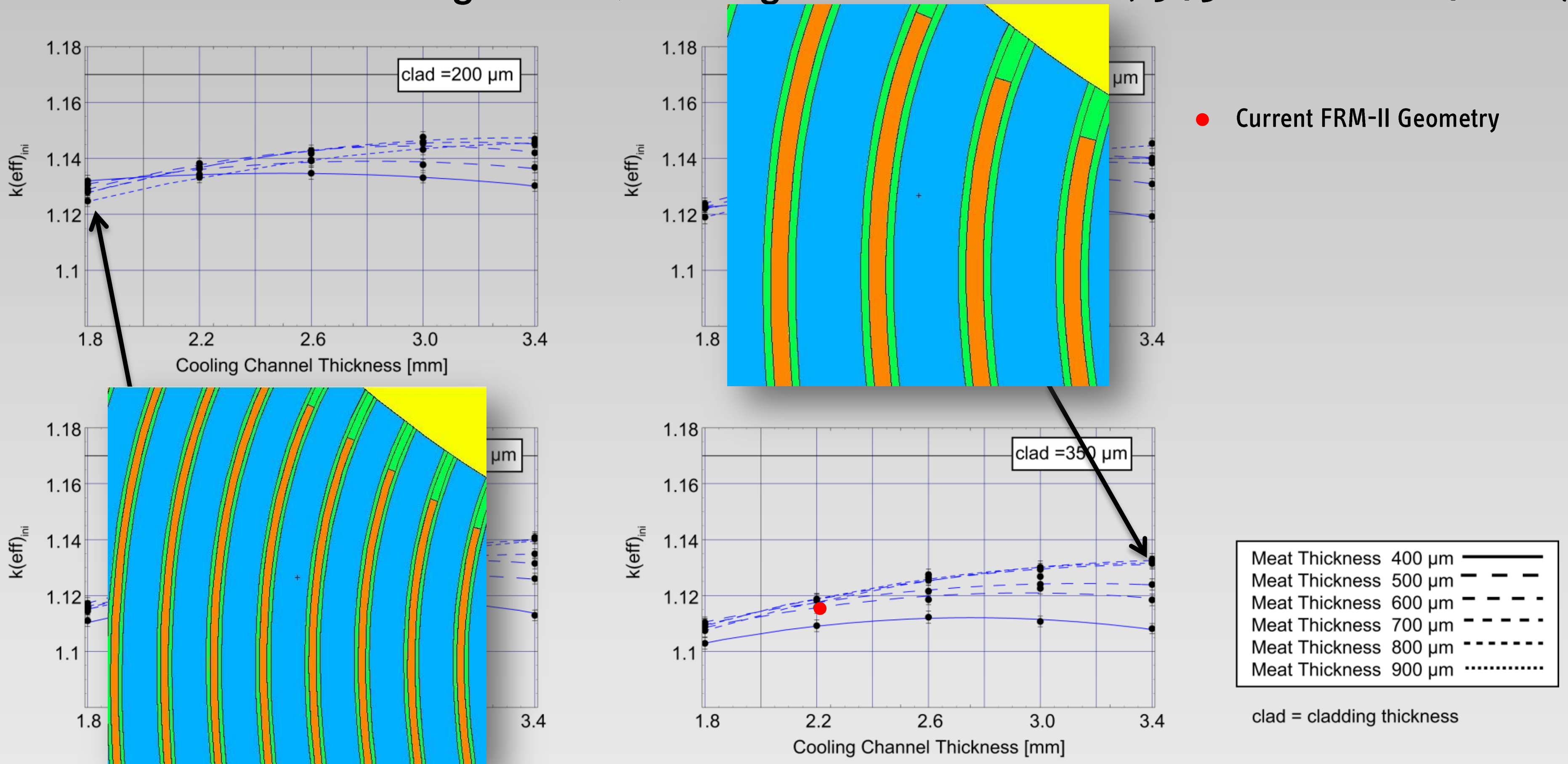


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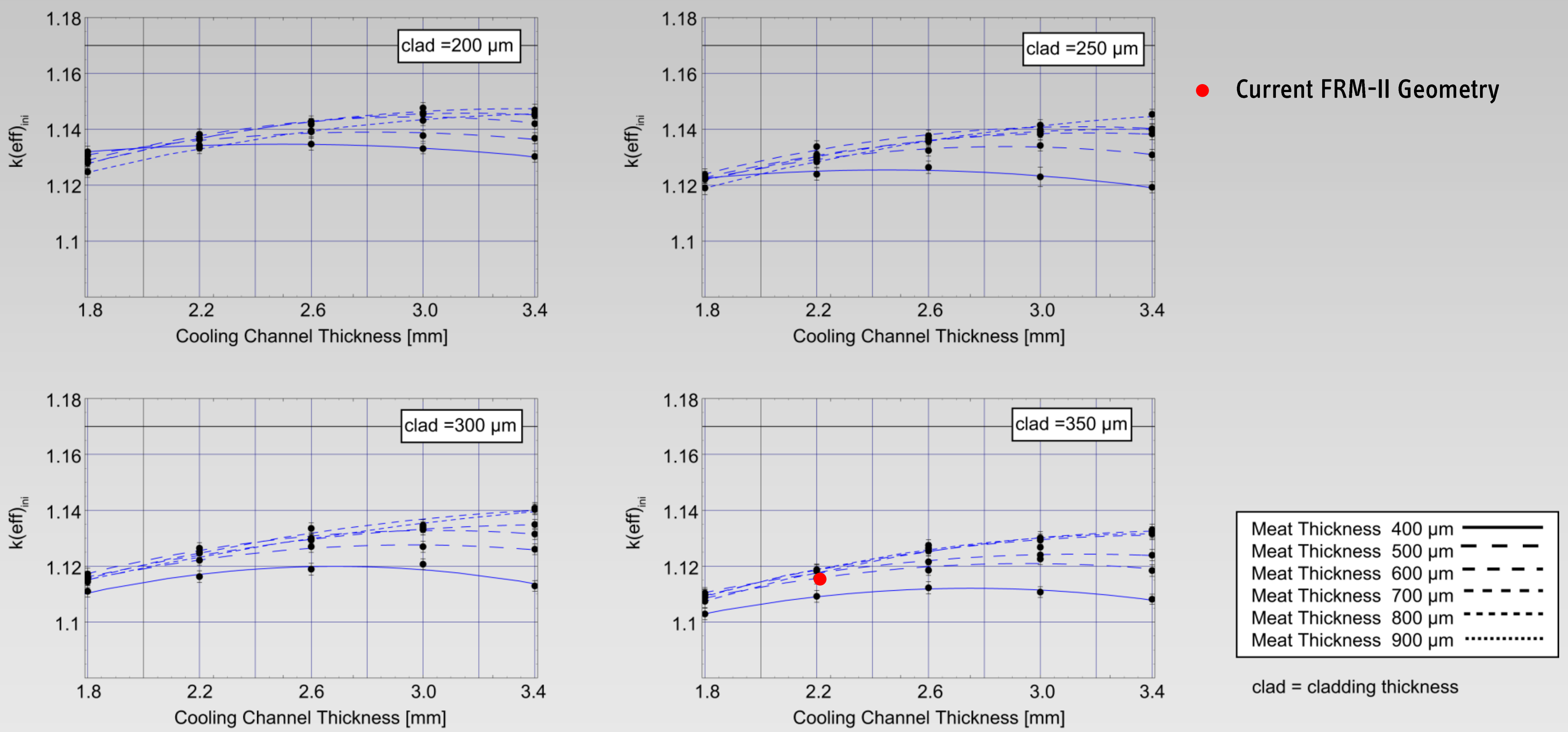


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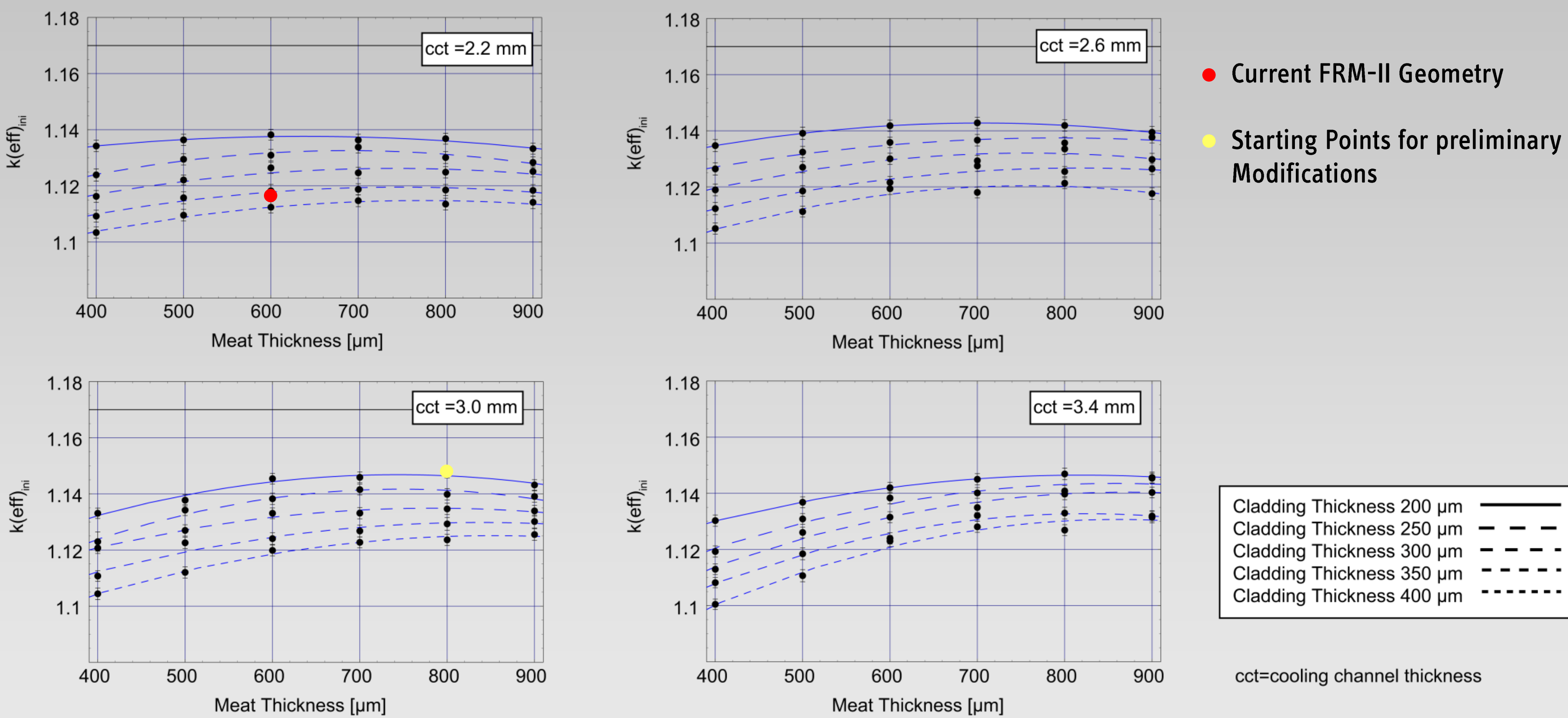



Optimum meat thickness between 0.7 and 0.9 mm

# Lessons from k(eff) study

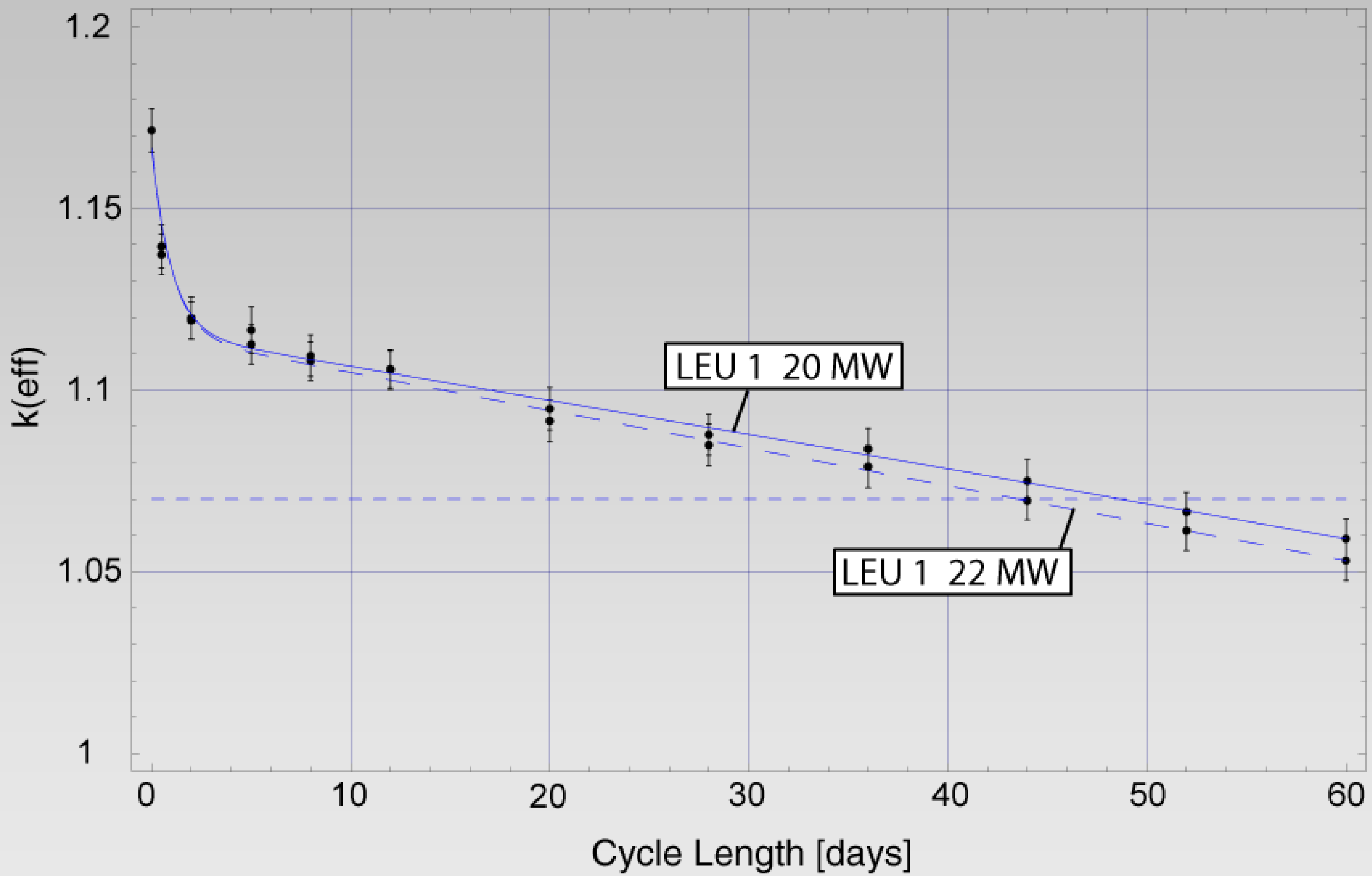
- Thicker cooling channels with an optimum between ~2.6-3.4 mm
- Thin cladding as thin as possible (~<0.25mm)
- Thick meat (~0.7-0.9 mm)
- Reduced number of plates in the core

# Two more preliminary modifications based on LEU

| | HEU Design | LEU 1 | | LEU 2 | |
|---|---|---|---|---|---|
| Enrichment | 93.0% | 19.75% | | 19.75% | |
| Active Height | 70 cm | 80cm | | 84 cm | |
| Meat | 0.60 mm | 0.80 mm | | 0.80 mm | |
| Cooling Channel | 2.20 mm | 3.0 mm | | 3.0 mm | |
| Cladding | 0.38 mm | 0.2 mm | | 0.25 | |
| Power | 20 MW | 20 MW | 22 MW | 22 MW | 22 MW |
| Flux loss max | reference | -15.4% | -7.0% | -16.2% | -7.9% |
| Flux loss CNS | reference | -13.7% | -5.1% | -14.7% | -6.2% |
| Heat Flux | 182 $W/cm^2$ | 188 $W/cm^2$ | 207 $W/cm^2$ | 183 $W/cm^2$ | 202 $W/cm^2$ |

Unusual thin cladding with 0.2 mm in LEU 1 to investigate potential of very thin cladding.
A candidate for this kind could be Zr-clad plates.
Need to evaluate the minimum thickness for cladding . Of course, this might be interesting for Al-cladding as well.

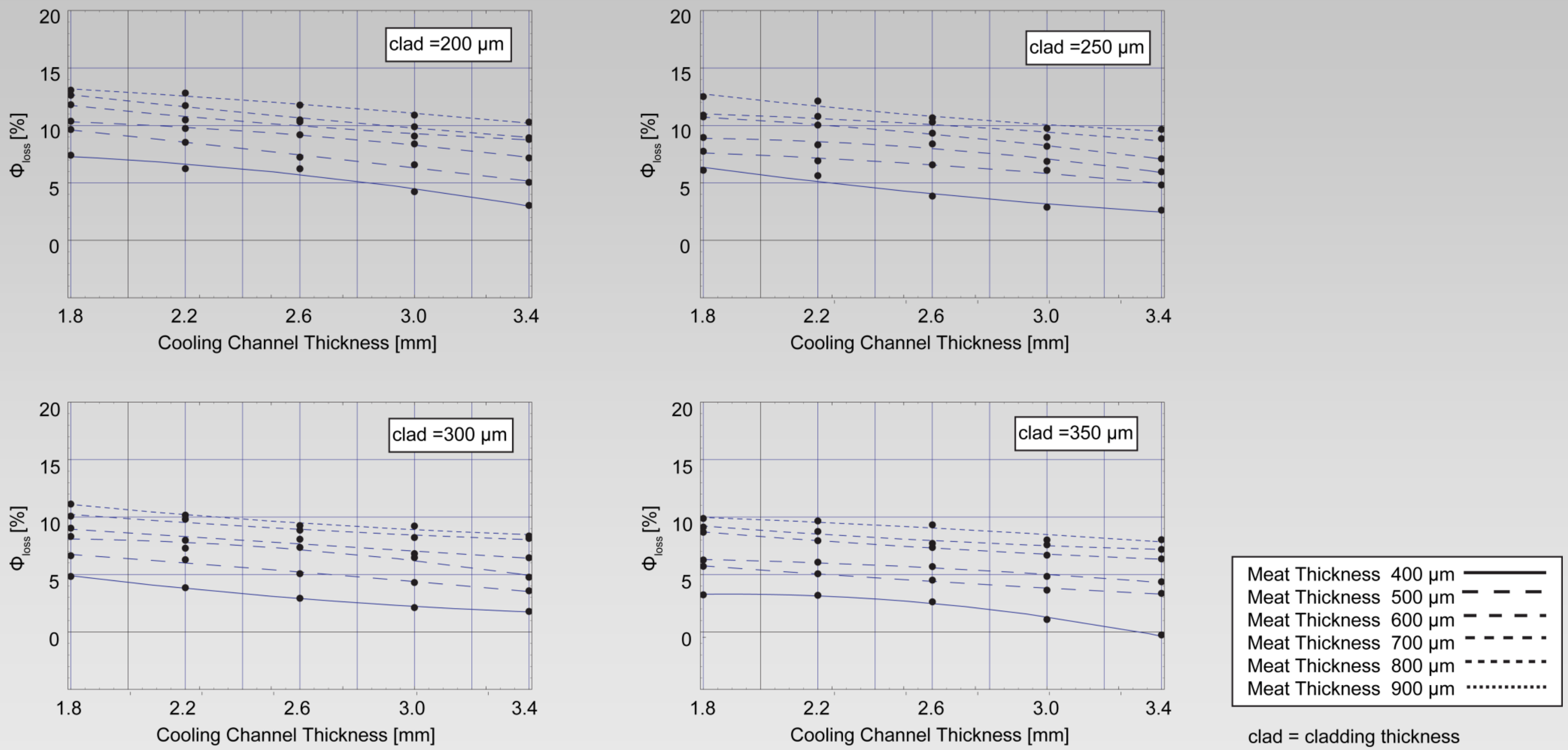
# Cycle Length LEU 1




LEU 1 20 MW additional decrease in flux performance of 1-2%
LEU 2 22 MW additional decrease in flux performance of 4-5%

# Influence on Flux Losses at Position of Maximum Flux

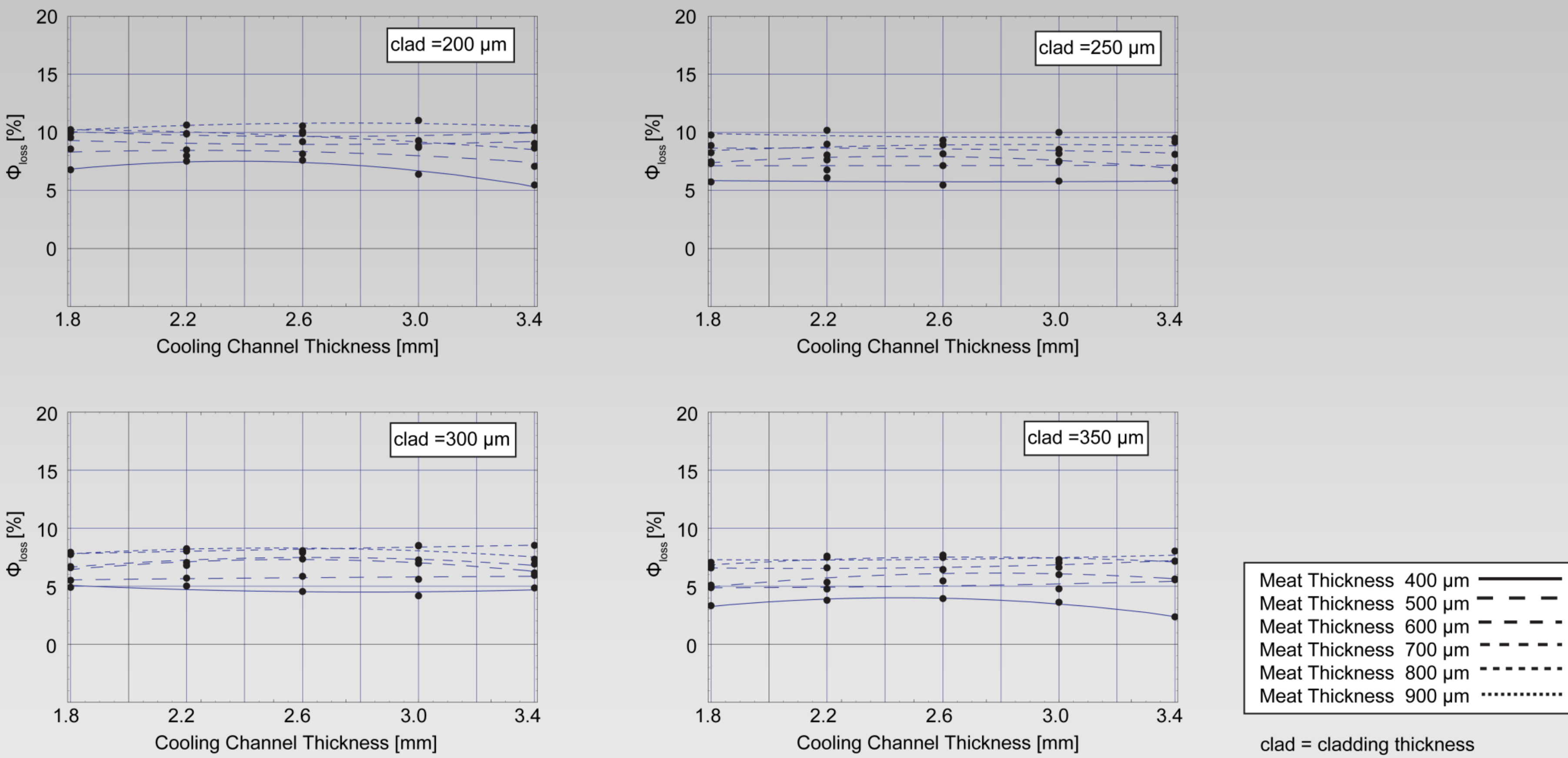
Variation of cooling channel, cladding and meat thickness (19.75% enriched, 70 cm)




Increasing cooling channel thickness reduces flux loss
Reducing cladding thickness increases flux losses
Increasing meat thickness increases flux losses

# Influence on Flux Losses at Position of Cold Neutron Source

Variation of cooling channel, cladding and meat thickness (19.75% enriched, 70 cm)

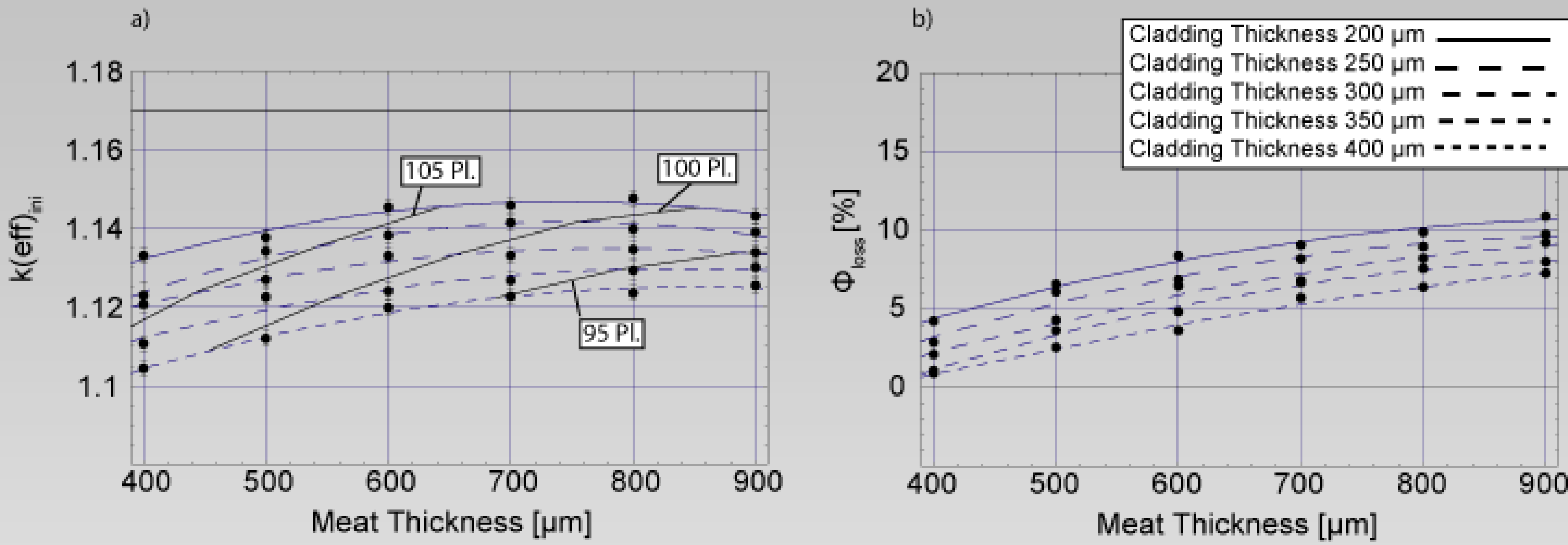



Increasing cooling channel thickness has nearly no influence on flux losses

Reducing cladding thickness increases flux losses

Increasing meat thickness increases flux losses (but less than at max position)

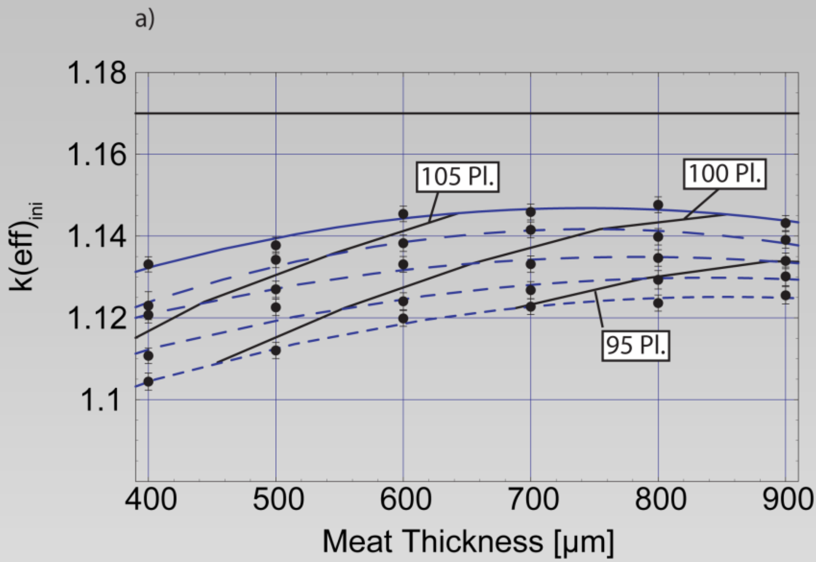
# Flux vs k(eff)$_{ini}$ at Maximum

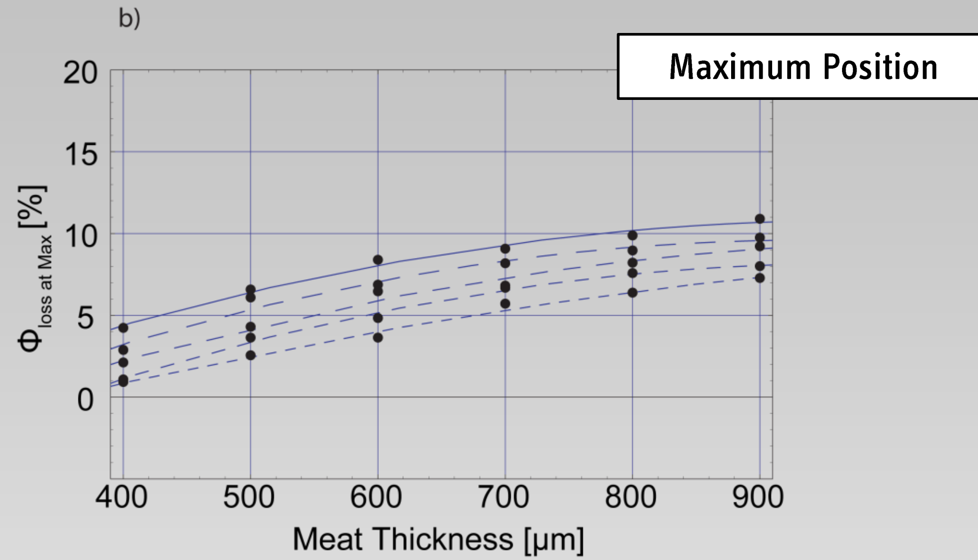


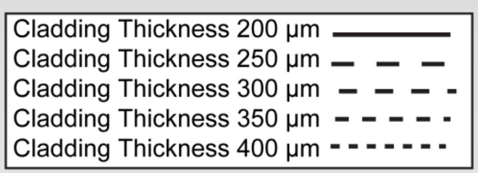

Cooling Channel thickness 3.0 mm, 70 cm height

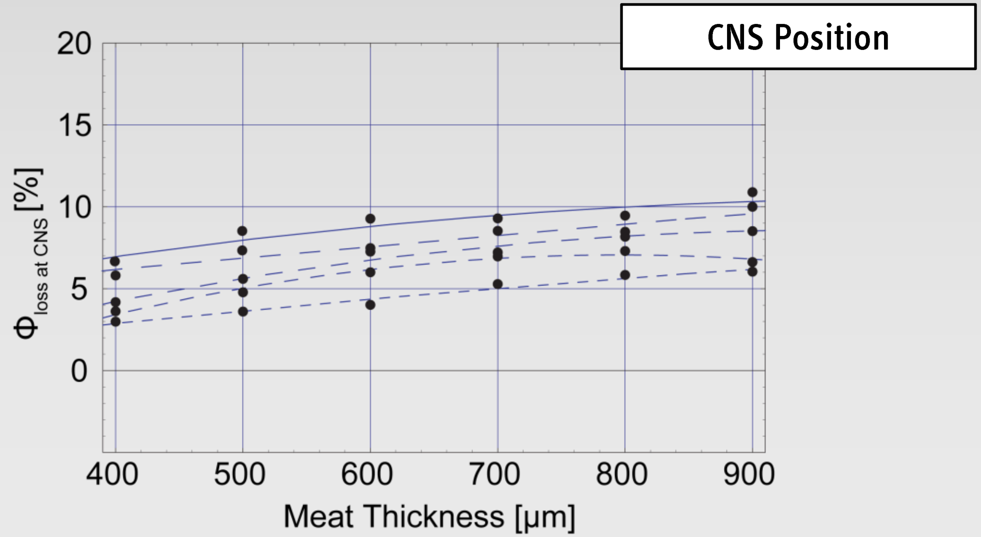
Opposing trends:
Increasing meat thickness to increase k(eff)ini increases also flux losses
Thinner cladding to increase k(eff)ini increases also flux losses
-> Need to find optimum

# Flux vs k(eff)$_{ini}$ at CNS



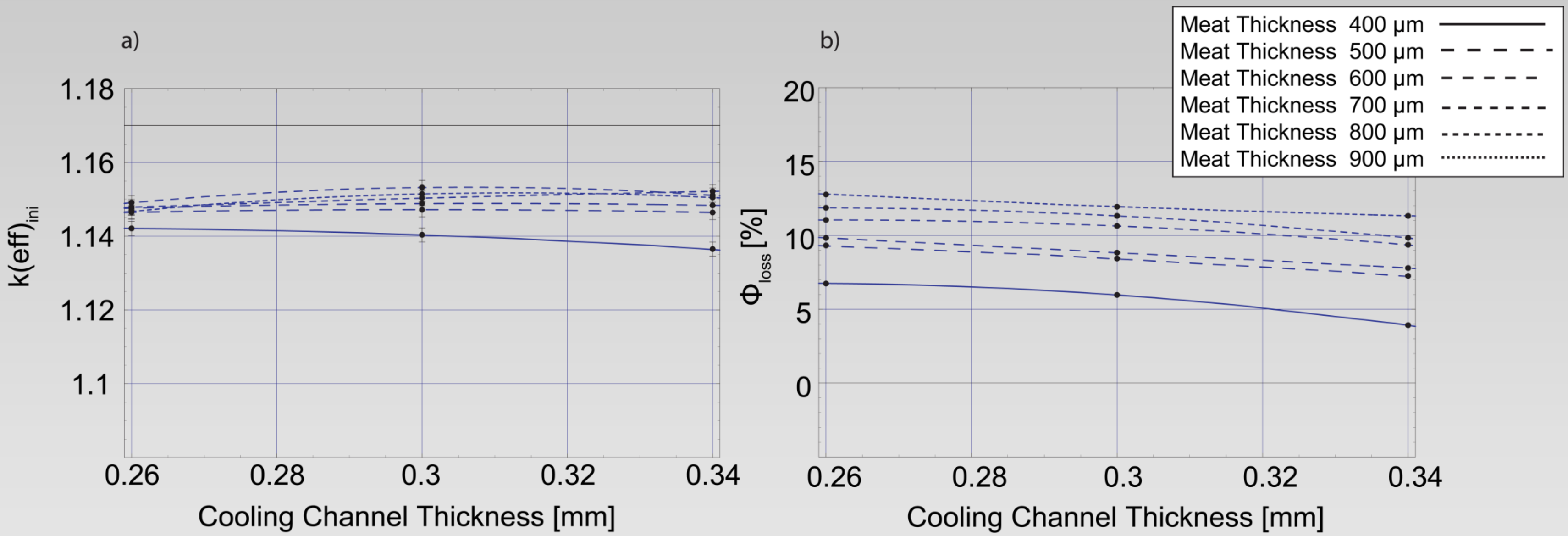




Cooling Channel thickness 3.0 mm

**-> Further Investigation of Flux Profile in Moderator Tank (with installations and axial profile)**

# Zr-Cladding

Very thin Zr-Cladding with 150μm (70 cm height)
Proposed by Argentine Fuel Development Program (E. Pasqualini et al.)



# Improving Power density distribution

Radially shaping of meat (axially?)

Implementation of stepwise/continuous change of meat thickness into automated inputfile generation

First tentative calculations

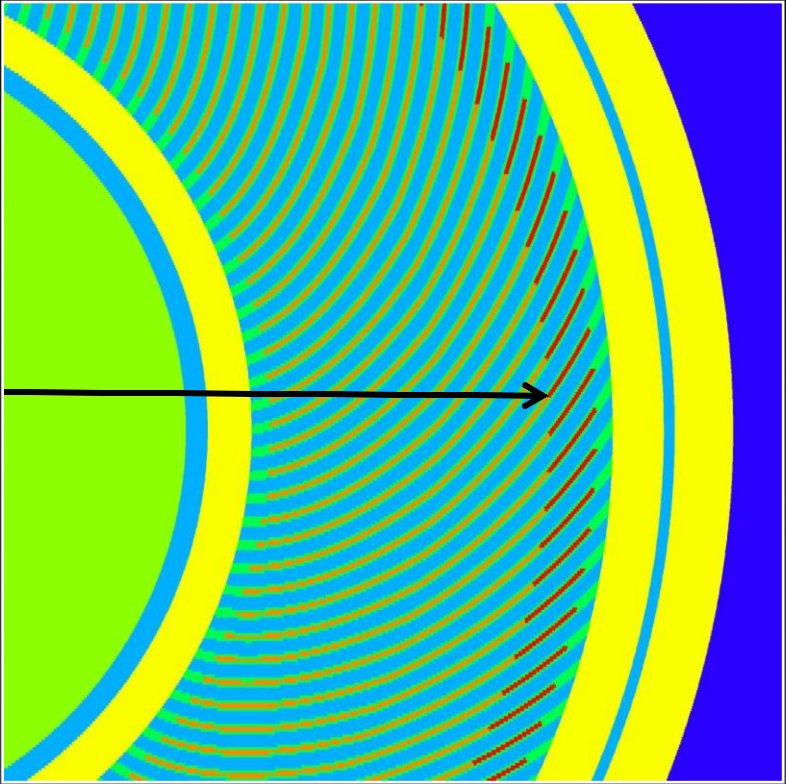
Next step -> finding optimal shape

# First Tentative Calculations
# Changing Transition Radius

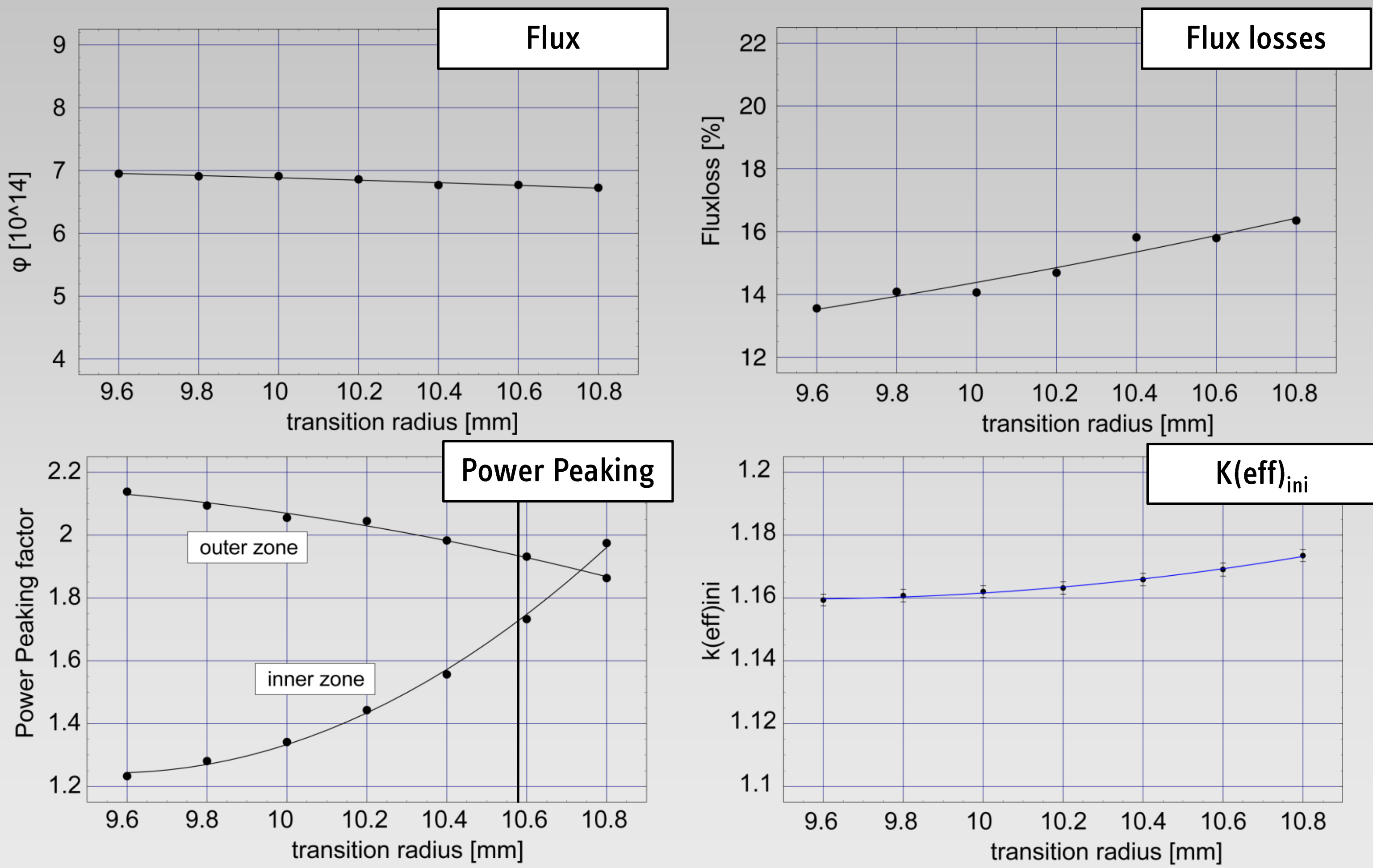
Transition Radius

Current Design: 10.59 cm

Variation: 9.6-10.8 cm

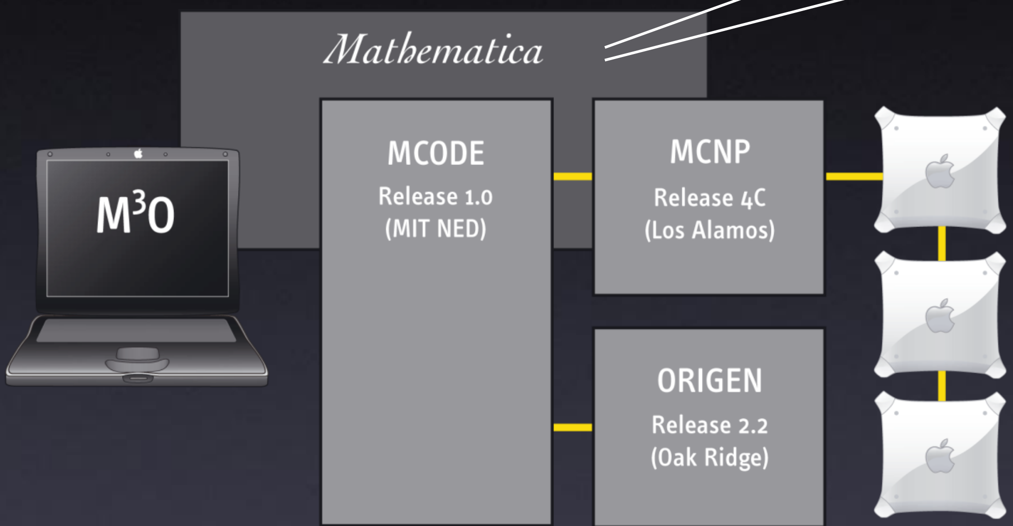


# First Tentative Calculations
# Changing Transition Radius




**Based on LEU1 Modification**

# Computational System




From A. Glaser 2005 or A. Glaser RERTR 2004

Adaptice Cell Structure (ACS) for
Burnup

Automated Inputfile Generation

Automated Outputfile Analysis

File-Handling

Future Work:

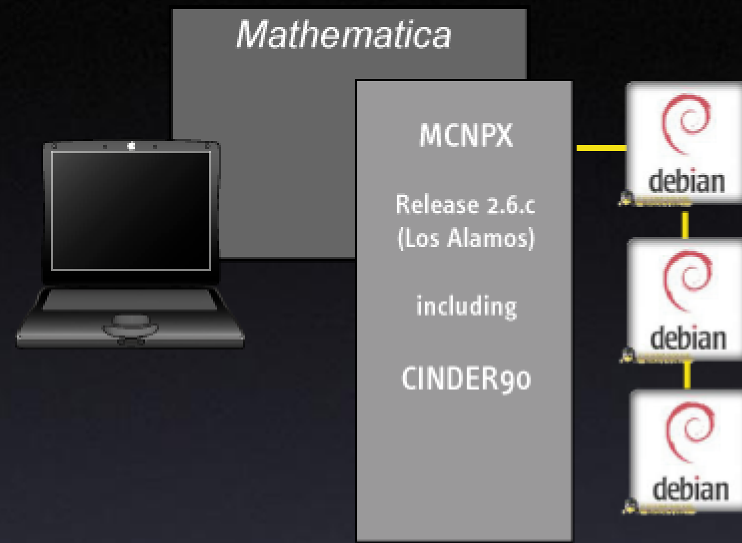
Implementation of optimization algorithm

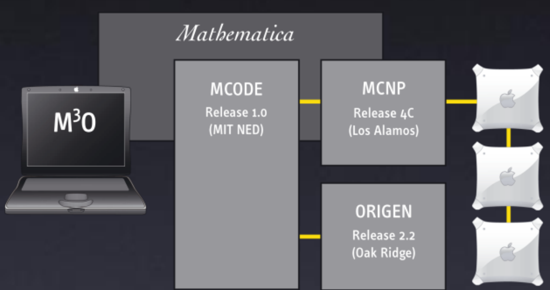
- Global optimization
- Genetic algorithm (?)

-> Need for faster processing of Input decks

# Computational System

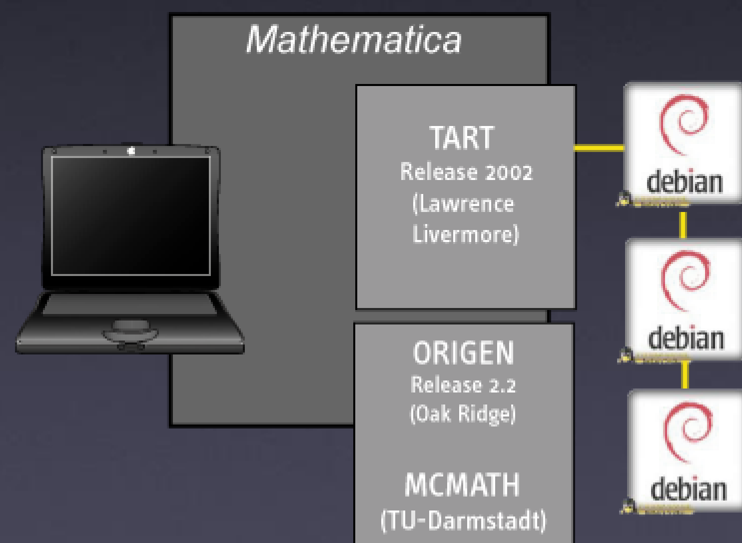
Depletion and neutron transport in one code
Faster KCODE than MCNP4c (multiprocessor)




From A. Glaser 2005 or A. Glaser RERTR 2004

Even Faster KCODE than MCNPX



# Conclusion

For best performing LEU option with UMo monolithic for FRM-II

- cooling channel thickness > 2.2 mm
- increased height  to get adequate cycle length
- marginally increased power to improve flux performance
- find optimal trade off between k(eff) and flux ldepending on variation of meat and cladding thickness

Future Work

- Further steps towards global optimization routine (genetic algorithm?) for high flux one-element research reactors
- Improved reactor model (control rod movement etc.)
- Improved investigation of flux profiles in moderator tank (axial profile) .
- thermohydraulic models and reactivity coefficients
- (Eventually calculations from the source to the experiment by implementing MCSTAS)