Reduced Enrichment for FRM II

FRM-II

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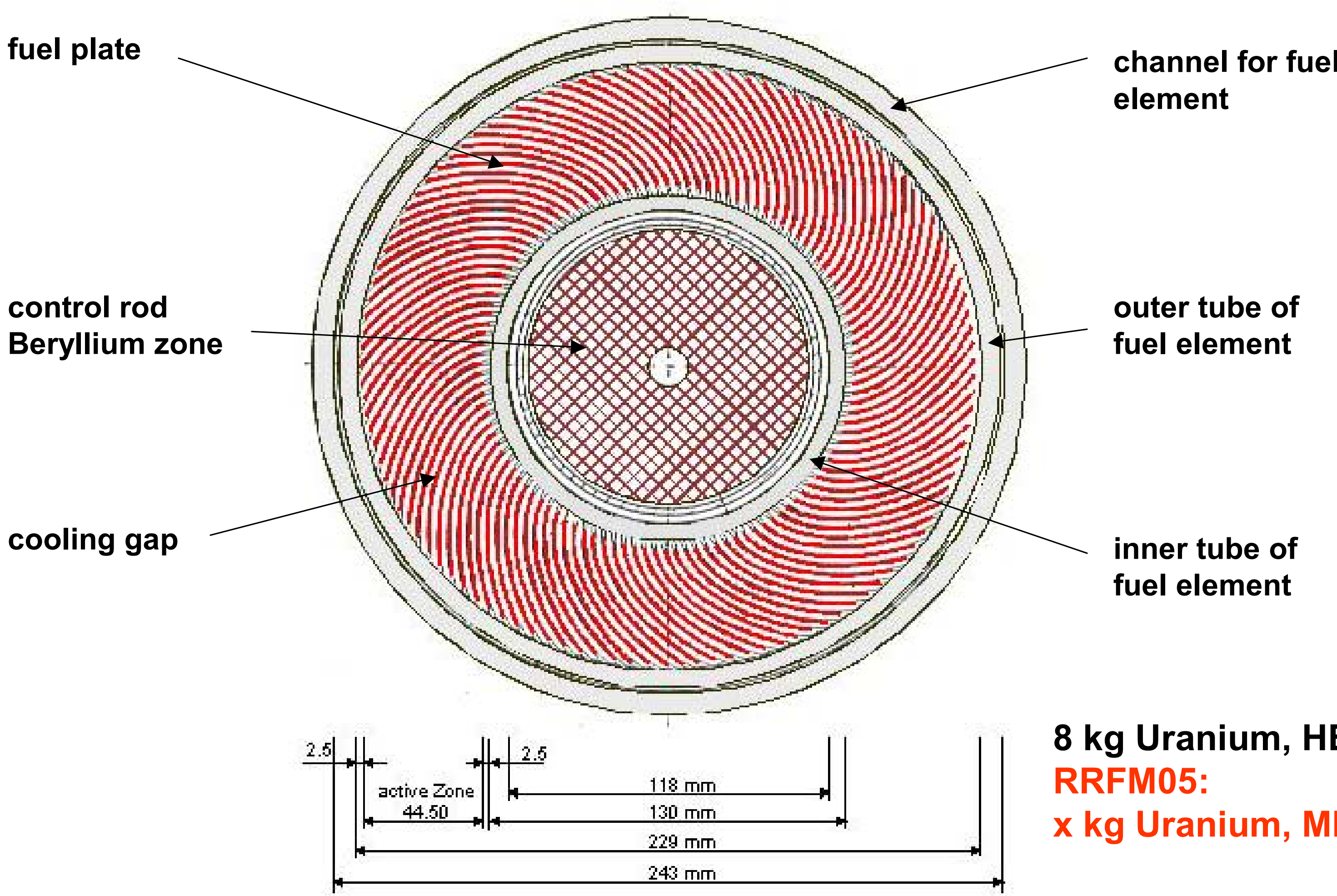
RRFM06

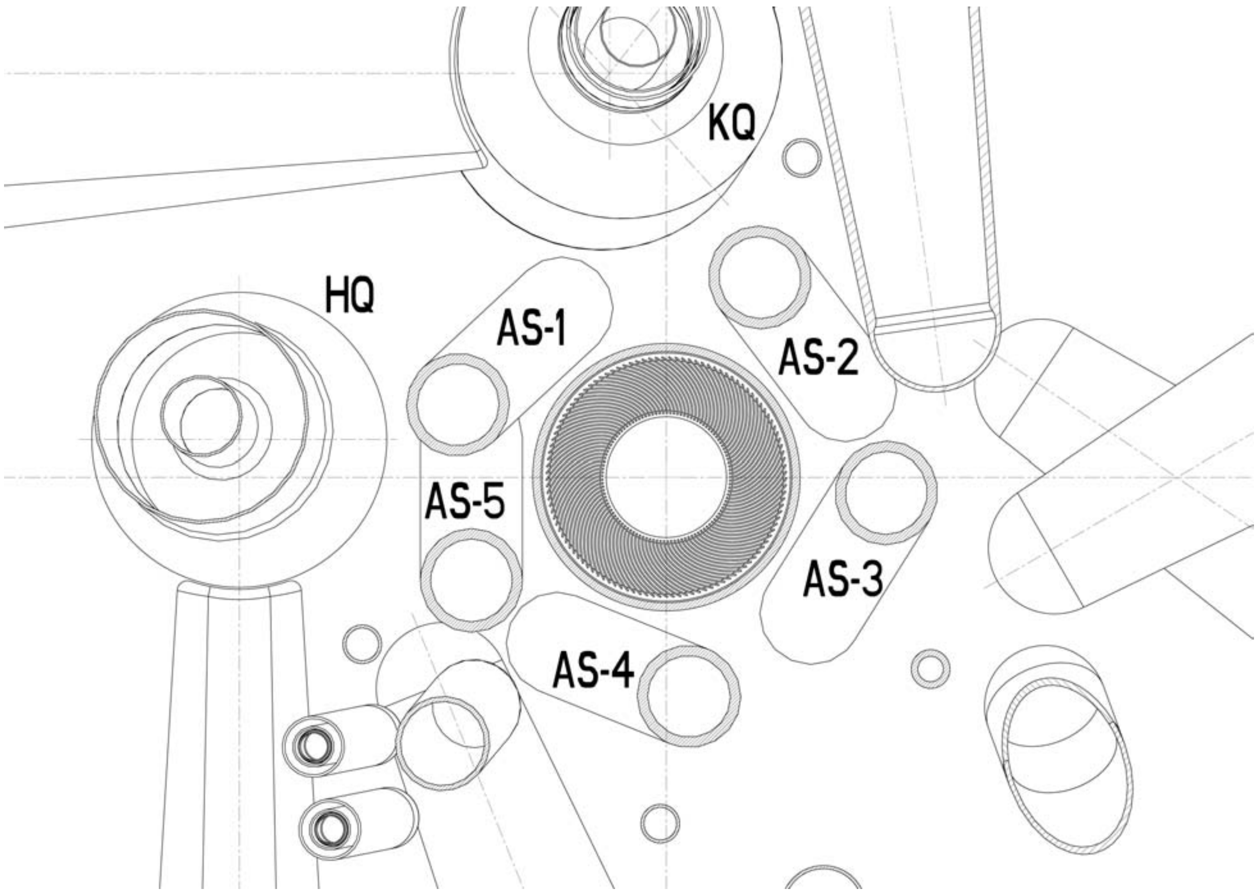
30 April – 3 May 2006, Sofia

single fuel element design – FRM II



8 kg Uranium, HEU)!
RRFM05:
x kg Uranium, MEU?

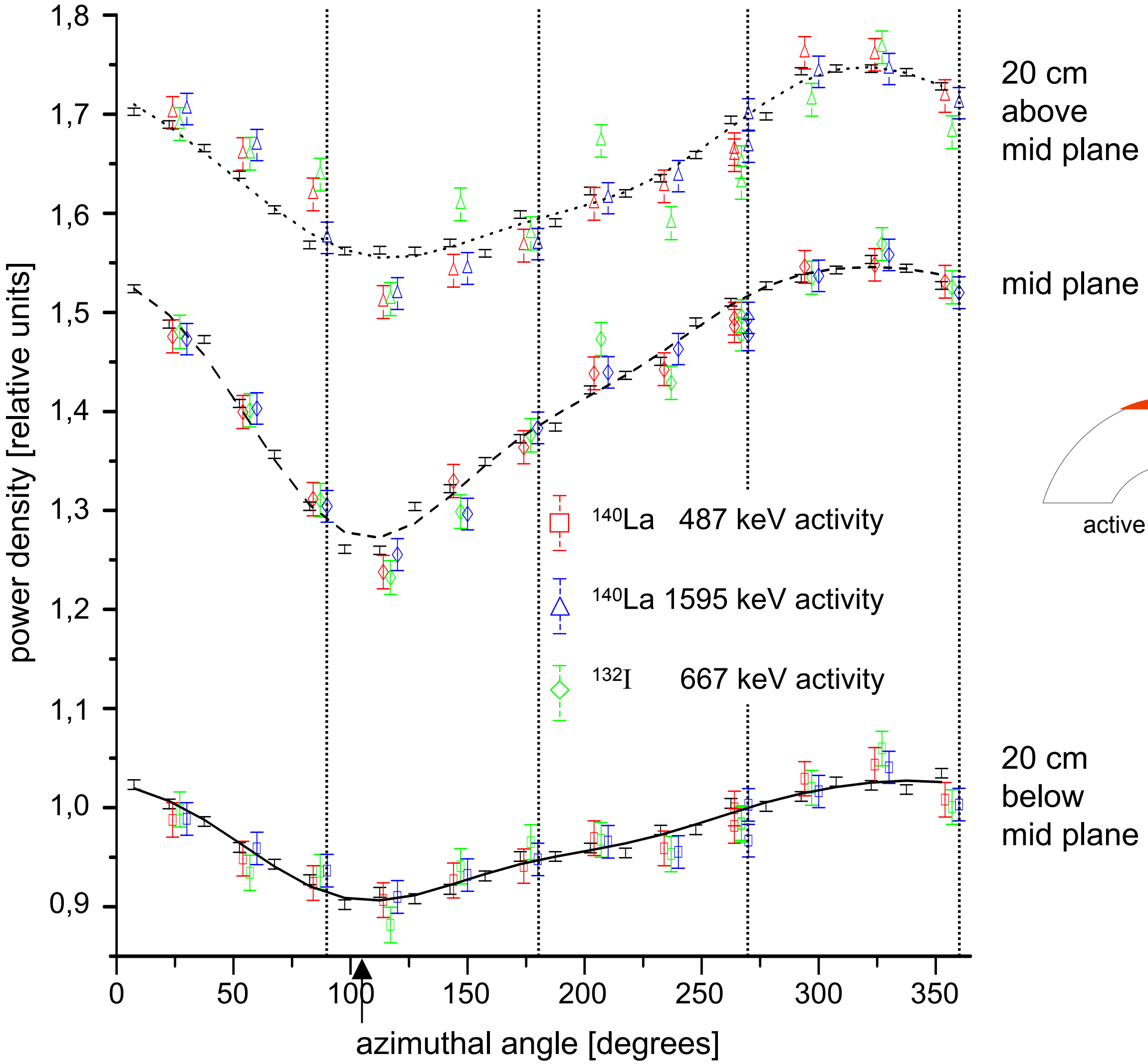
Horizontal cut through FRM II /core midplane



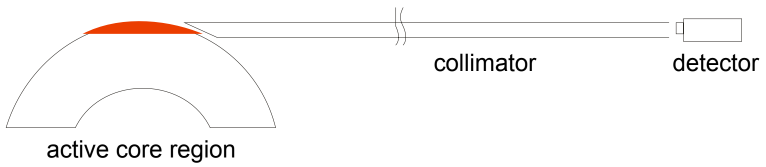
shut down rods move very close to central core tube if dropped

other user installations are also relatively close = optimized position

Anisotropic power density in FRM-II fuel element

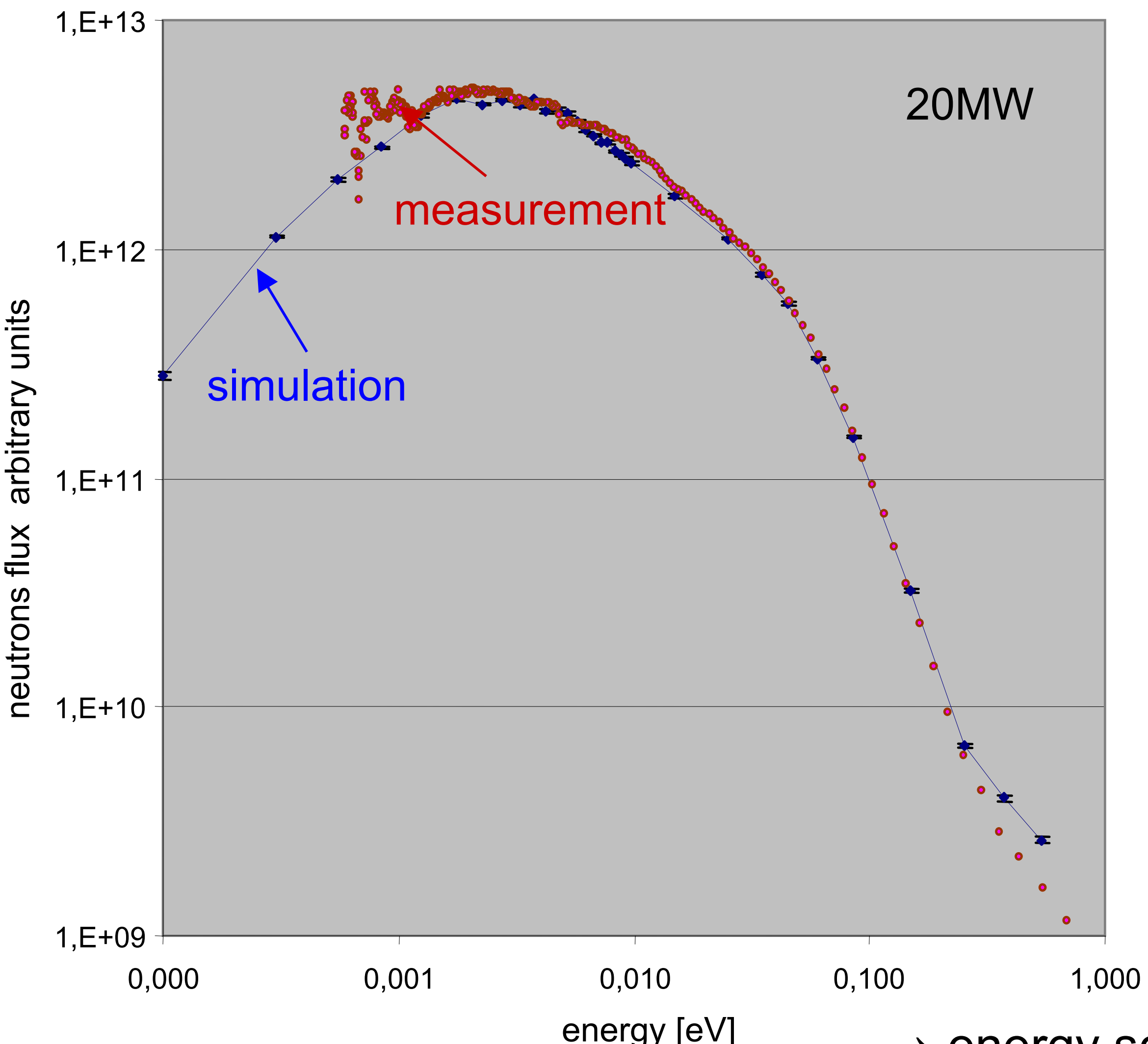


Measurement set up



Comparison of power densities at different heights in the fuel element after two days at about 50 kW thermal power, recalculated and measured by fission product activities some days after operation. Densities are measured and calculated at an outer segment (thickness 13 mm) as function of the azimuthal angle.
A dip in the power density (arrow) is clearly visible near to the azimuthal position of the cold source (center at 98°).

Spectrum of cold source



measurement and simulation with direct view to surface of cold source CNS, at about 20m distance

rather good agreement with simulation:

- fill level = 12 cm,
- empty displacer,
- density cold D_2=93% (due to bubbling)

→ energy scale over 4 decades !

Conversion program FRM II

Aim:

50% or below (MEU)

Necessity:

increase of uranium density in fuel layer of plates

Task:

Search for new high density fuel type (RERTR):

- calculations with new fuel (UMo dispersive and monolithic)
- test irradiations of MEU full size plates (UMo dispersive)
- alternative fuels, alternative investigations and support development

Irradiation program FRM II, actual status

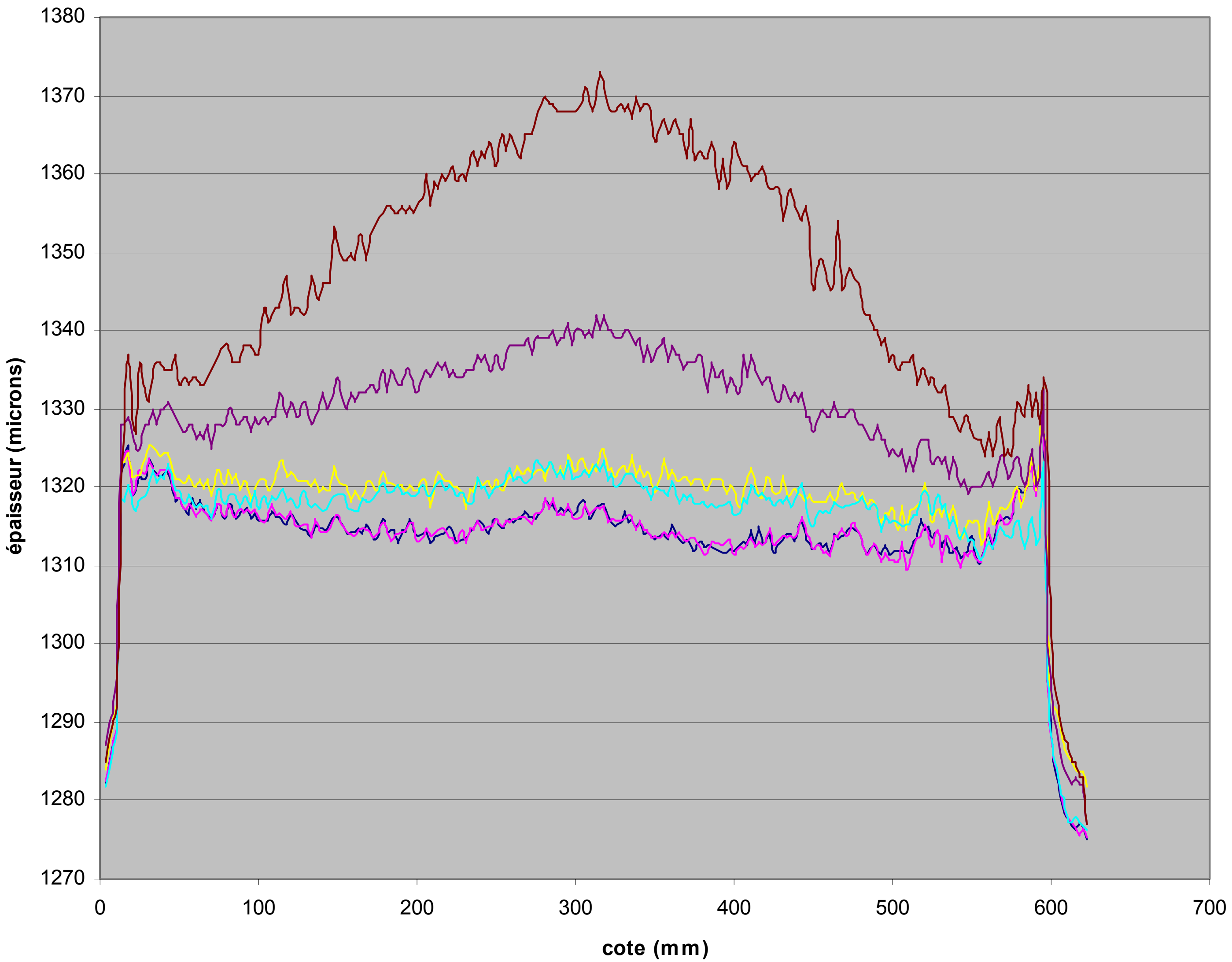
six full size plates (fuel area 60*6cm^2) with UMo fuel fabricated by CERCA, (all 50% enrichment)

- same fuel powder for all 6 plates
  - UMo, 8%wt. Mo
  - ground powder
- densities
  - 8 g/cm^3
  - 8 g/cm^3, but 2% Si added in fuel matrix
  - 7 g/cm^3 = fall back option in irradiation program
- conditions
  - up to 300 W/cm^2, rather constant

Irradiation in IRIS device, FRM II, actual status (new)

- irradiations started June 2005
- four cycles achieved
  - maximum of 1.9-2.1 10^{21}/cc reached in meat (3.4-3.8 10^{21}/cc in fuel)
  - no abnormal swelling for either plate so far
- final target
  - cover fission densities (FD) up to 2.3 10^{21} cm^{-3} in meat
  - one extra cycle needed, June 2006
  - γ-scans for experimental fission density evaluation (up to now only calculated – CEA) done now after cycle 4
  - PIEs, report 2007

Swelling of plate 8501, 2% Si added, longitudinal traces after different irradiation cycles



fuel length:
60 cm

swelling nearly symmetrical in height

precalc. FD in meat (fuel):
2.1 (3.8) 10^{21} /cc

max. swelling:
62µm or 12.5%

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FRM II reduced enrichment design / the frame

fixed constraints:

- same power of 20MW
- same geometry, element dimensions as for current U_3Si_2 fuel
- same cycle length requested as with U_3Si_2 fuel

practical contraints:

- flatten power density (PD) distribution =
  flatten fission density distribution (= time integrated PD)
- mass of fissionable uranium in fuel element should not be too high,
  relative burn up must not be below 10%, better above 15%

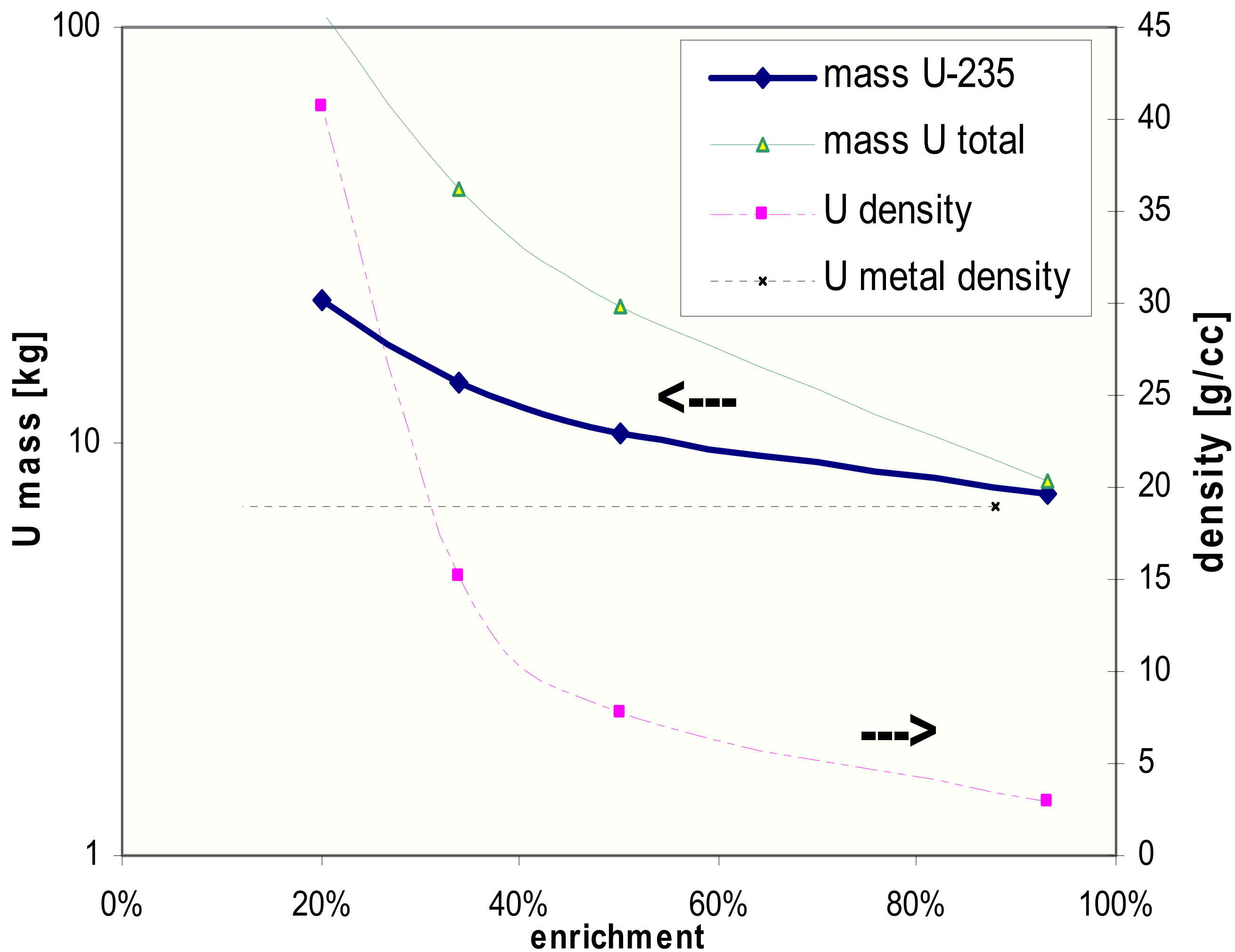
calculations:

- change of fuel composition in variabel time steps
- change of inner reflector composition with time steps
- change of control rod position with time steps
- inclusion of experimental installations,
  = change of neutronics balance (perturbed flux) included

First results for FRM II with ***UMo monolithic fuel***

former task:

find out required enrichment of UMo fuel to achieve current cycle length

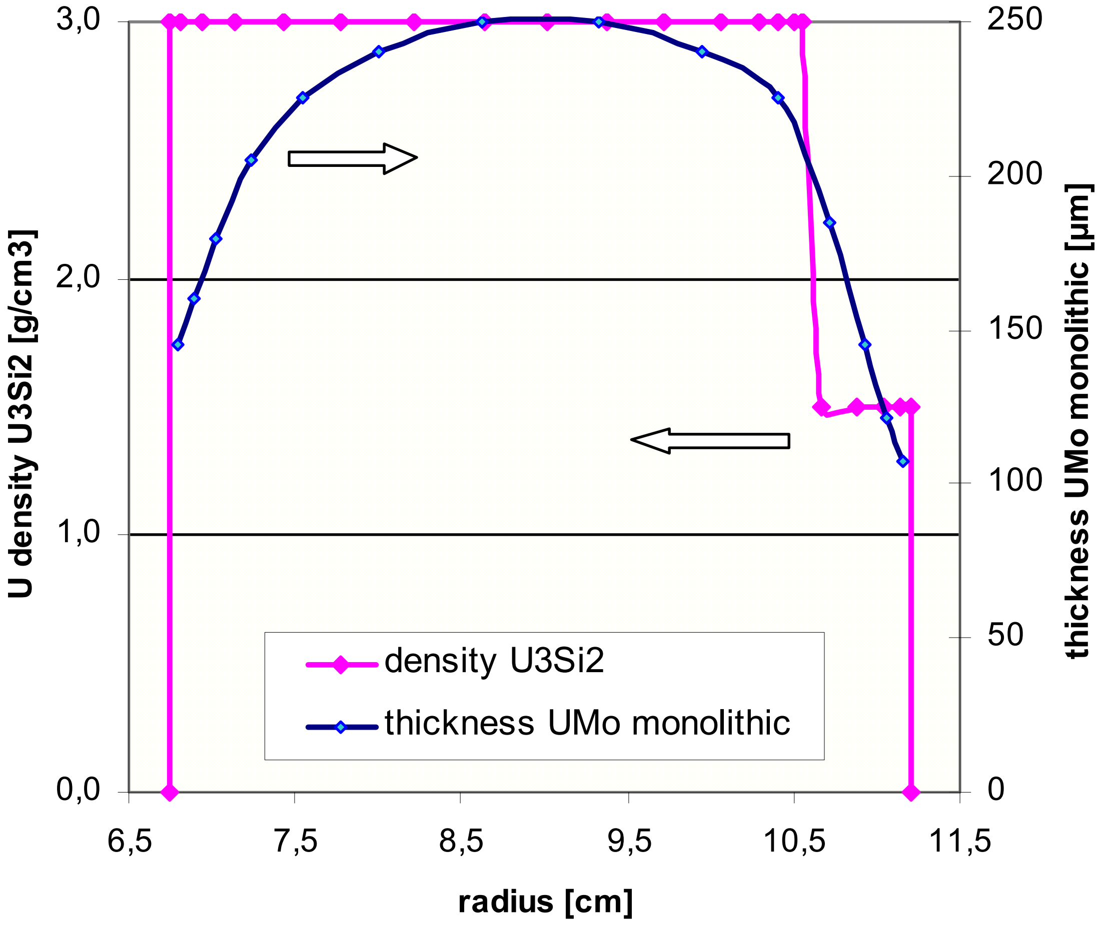


same geometry,
fuel plate as currently,
grading full/half density (thickness)

Result with monolithic UMo - MEU (50%)

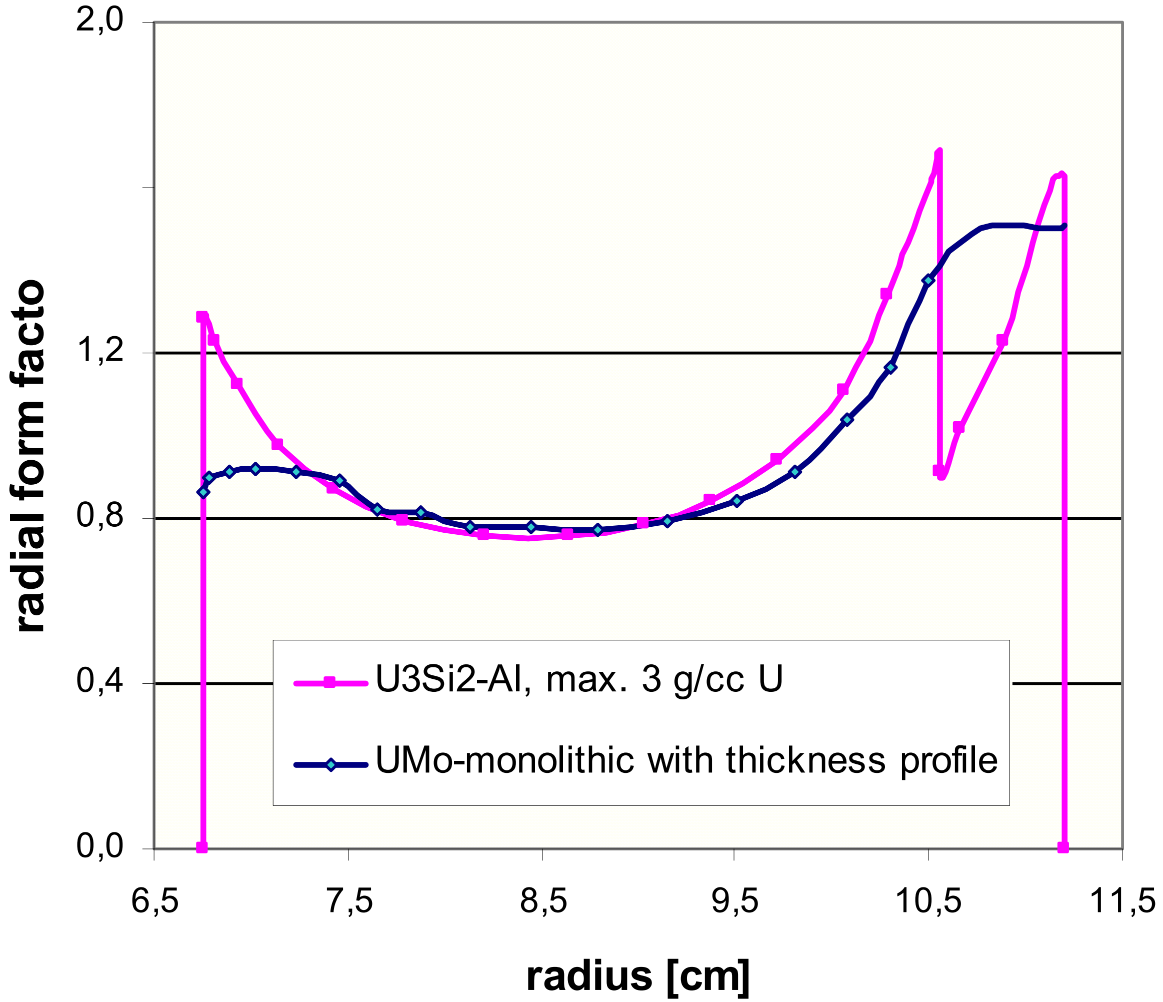
parameter of thickness variation leads to an optimized radial profile:

- ‚Turkish hat' (thickness rather flat inside and fall off at the sides
- maximal thickness (center) 250µm



... results with thickness variation for monolithic UMo - MEU

- better radial PD distribution with thickness profile



... results with thickness variation for monolithic UMo - MEU

- high fission density peaks (at EOL $6\text{-}7 \cdot 10^{21}$ cm^{-3})
- moderate increase of the fissionable mass U-235 from 7.5 kg (U_3Si_2) up to 9.1 kg

- maximum thermal flux is depressed by 9%
- 66g Pu produced per cycle instead of 10g now
- increased cycle length achievable rather uncomplicated with thicker meat (e.g. 62 FPDs instead of 52 FPDs with 300μm, same profile)
- control and shut down margins very comparable to now without geometry changes

Conclusions:

- first irradiation program for FRM II with UMo disp. fuel nearly finished, results of PIEs to be presented 2007

- thickness variation with monolithic UMo as a very efficient way for power density shaping

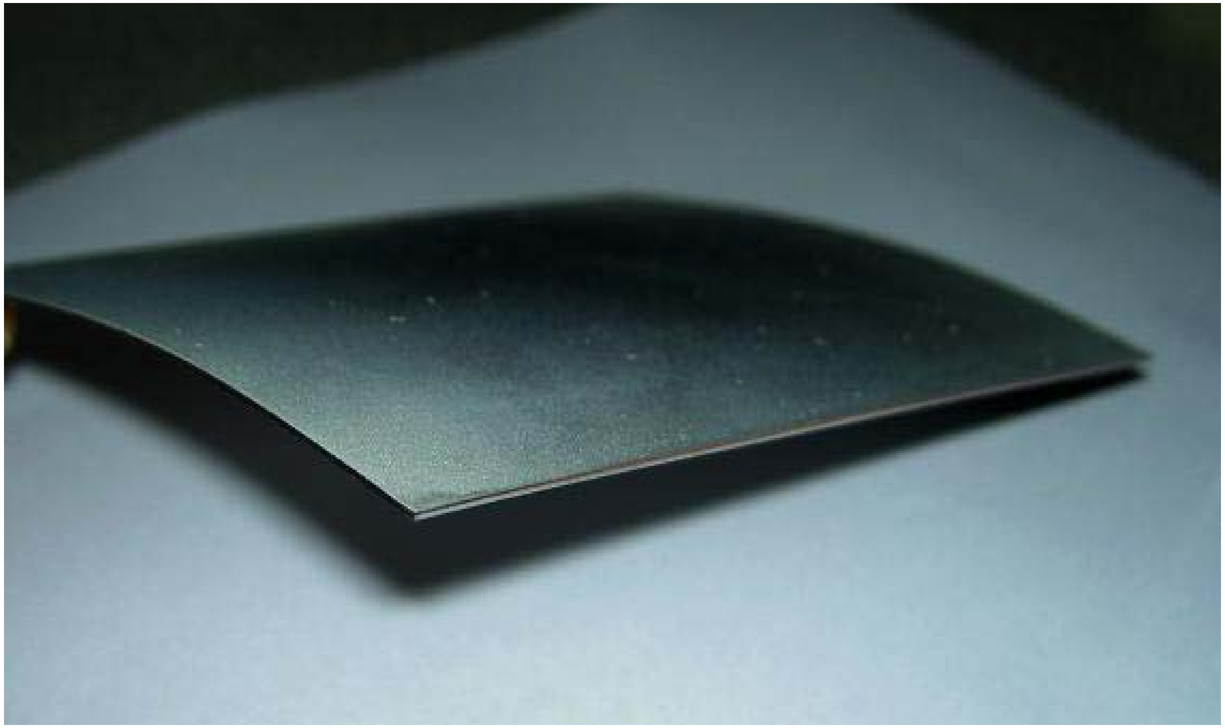
  open items:

  – high fission densities in monolithic fuel,
    at outer edge of FRM II fuel plates always high

  – technical fabrication of monolithic plates

TUMs activity in UMo monolithic plates fabrication

Sputter technics -
thickness variation of
layer adjustable !



FRM II / from design to operation

- core reactor design presented, f.i. 1988 at RERTR, San Diego
- reactor construction started 1996, startup projected 2000/1
- delay in final nuclear permisson till May 2003
- first critical 2.3.2004, full power in August 2004
- first cycle finished 21.10.04
- routine operation by TUM starting april 2005
- meanwhile operating 6. cycle, started 24.3.2006
  without reactor stop so far

FRM-II conditions in comparison to other UMo/disp. full plate irradiations

		IRIS-1	IRIS-2	FUTURE	TUM	
number of plates		3	4	2	4+2	
	powder	ground	atomized	atomized	ground	
	porosity	ca. 12%	1-2%	1-2%	9%	
max. heat flux / W/cm^2		140	240	340	295	
max. clad. temp. / °C		75	100	130	100	
	enrichment	20%	20%	20%	50%	
burn up	reached max.	67%	40%	33%		
	aim				26%	covers 2,3E21
	U total	13,4%	8,0%	6,6%	12,8%	f/cm3
	final status	fine	failed	failed	open	

However
FD of max 2.3 10^{21} cm^{-3} at EOL corresponds to burn up of 64% for LEU fuel

LEU/MEU results for FRM II with U_3Si_2 fuel

- TUM calculations for variation in enrichment 1989, most geometric/material parameters identically, same power of 20MW, same cycle length design, U_3Si_2 fuel (maximum density 4.8 g/cm^3
  - maximum flux value of HEU core 35% above comparable LEU core
  - maximum flux value of HEU core 9% above comparable MEU core (45% enrichment)

- ANL calculations 1995/96, alternative LEU design with U_3Si_2 fuel (maximum density 4.8 g/cm^3)
  - with <u>same fuel element</u> size no conversion possible to LEU
  - reactor power must be 32 MW with <u>increased core</u> dimensions for comparable maximum flux value

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tasks for UMo dispersive fuel to be exercised in parallel:
fuel irradiation tests and core optimisation

Latest UMo dispersive fuel results / 50% enrichment

required **U density is 8.0 g/cm³** to achieve
'*same cycle length in calculation as for calculation with U_3Si_2 fuel*',
but at current fuel plate dimensions, same grading step (8.0/4.0 g/cm³)

- fissible U-mass 50% higher (10.8 kg, *currently 7.5 kg*)
  total U-mass 250% higher (21,6 kg, *currently 8.1 kg*)
- power density distribution less opportune, higher max. values with UMo
- maximum fission densities higher
- depression of maximum flux value in D_2O-tank of 8%

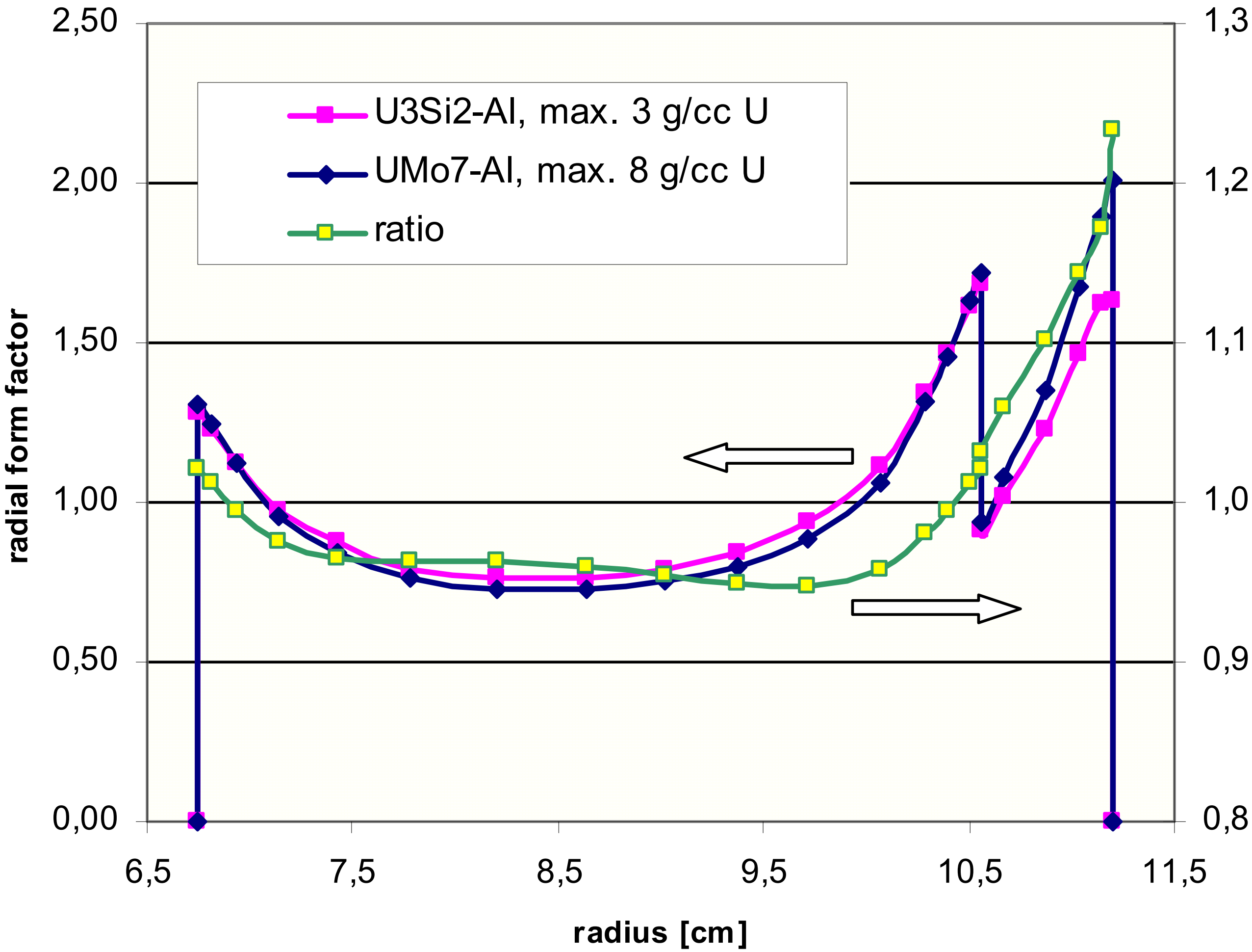
FRM-II core design / reduced enrichment

parameter scope with monolithic fuel:

- high density of UMo monolithic as a way to regain real scope for paramter studies with reduced enriched fuel for FRM II geometry

- change in internal geometry and density variation;
  only few parameters, no density variation as with dispersive fuel
  -> study thickness variation

calculated radial power form factors, FRM II, BOL, comparison: current U_3Si_2 HEU element <-> UMo MEU element



UMo core optimization necessary as:

- max. channel heating higher (see ratio at edge, up to 20%!)
- hot channel now in low U density region

FRM-II with ***UMo monolithic fuel***

results:

- with 34% enrichment the cycle lenght shows up comparable, but ...
- fissible U-mass nearly doubled (about 14 kg, *currently 7.5 kg*)
  total U-mass five times higher (>40 kg, *currently 8.1 kg*)
- power density distribution even less favorable and
- maximum fission densities again higher than in UMo-disp/MEU case
- burn up U-235 after 52 FPD only 9,6%
- 110 g Pu produced per cycle instead of only 10g now
- depression of maximum flux value in D_2O-tank (exploitation of FRM-II) of more than 10%