

New Spent Fuel Characterization Proposal:

REGAL – Rod Extremity and Gadolinia AnaLysis

K. Govers, M. Gysemans, M. Verwerft

December, 2009

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Boeretang 200
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New Spent Fuel Characterization Proposal: REGAL – Rod Extremity and Gadolinia AnaLysis

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- Background
- Scope
- Timing

- **ARIANE**
 - 1994 – 2000
 - Radiochemical investigations (pellet average values and limited local values) on medium to high BU UO_2 and MOX fuels (30-60 GWd/tHM), PWR & BWR prototype and commercial reactors
- **MALIBU**
 - 2004 – on-going
 - Radiochemical investigations (pellet average values) on ultra high BU UO_2 and MOX fuels (75 GWd/tHM), PWR & BWR commercial reactors
- **Common objectives**
 - Comprehensive, representative and validated database for
 - Reactivity studies (reactor cores, transport, storage)
 - Source term studies (radioprotection)
 - Minor actinide studies (storage, transmutation)

<i>Programme</i>	ARIANE				MALIBU				
	PWR		BWR		PWR			BWR	
	UO2	MOX	UO2	MOX	UO2	UO2	MOX	UO2	MOX
<i>reactor type</i>	Goesgen		Beznau		Goesgen			Leibstadt	
<i>fuel type</i>	15x15		14x14		15x15			10x10-4	
<i>name</i>	Dodewaard		Dodewaard		Ringhals			Gundremmingen	
<i>assembly design</i>	6x6		6x6		17x17			9x9-1	
<i># samples</i>	3 (4-1)		5 (6-1)		4			1	
<i>enrichment</i>	3		1		2			3	
<i>U235 (w%)</i>	3.4, 4.1		0.2		4.3			3.9	
<i>Pu/(U+Pu) (w%)</i>	5.5 & 6.0		6.4		depleted			depleted	
<i>Pu fiss/Pu (w%)</i>	71		71		7.7			7.7	
<i>Pu fiss (w%)</i>	4.2		4.6		71 (assumed)			71 (assumed)	
<i>Burnup, GWd/tM</i>	5.5		5.5		5.5			5.5	
<i>position</i>	30 to 60		34 to 56		70			60	
	37 to 59		54.4		70			50 to 80	
	m13, p7		b2		f12			e4	
	d3, b6, k7		d5		e14			g3	
	various		next to 2 Gd rods		next to WR			next to W. Channel	
	various		next to 1 WR		next to WR			next to Gd rods	

Some SIMS analysis
(only MOX rods)

Some rod extremity analysis
(no systematics)

Complementary research required for

- Data on long cycle operation
 - ARIANE & MALIBU: annual cycles
 - *Proposal: use of 18 months cycle fuels (TIHANGE 1)*
- Rod extremity effects (criticality, shielding)
 - Limited information available from MALIBU - no systematics
 - *Proposal: to include a series of samples of the first span*
- Gadolinium fuel
 - Absent in ARIANE or MALIBU
 - *Proposal: data on UO₂ rods in optimised fuel assemblies*
 - *Proposal: data on Gado fuel rod*
- Local distribution of fissile isotopes and fission products (fuel performance studies and code validation)
 - Some information available from ARIANE on MOX fuel
 - *Proposal: to include EPMA and SIMS analysis of UO₂ fuel and Gado fuel*

- Same philosophy as ARIANE and MALIBU
 - Detailed fuel description & irradiation conditions
 - Target: Macrocells of 3x3 assemblies



X	X	X
X	Analysed assembly	X
X	X	X

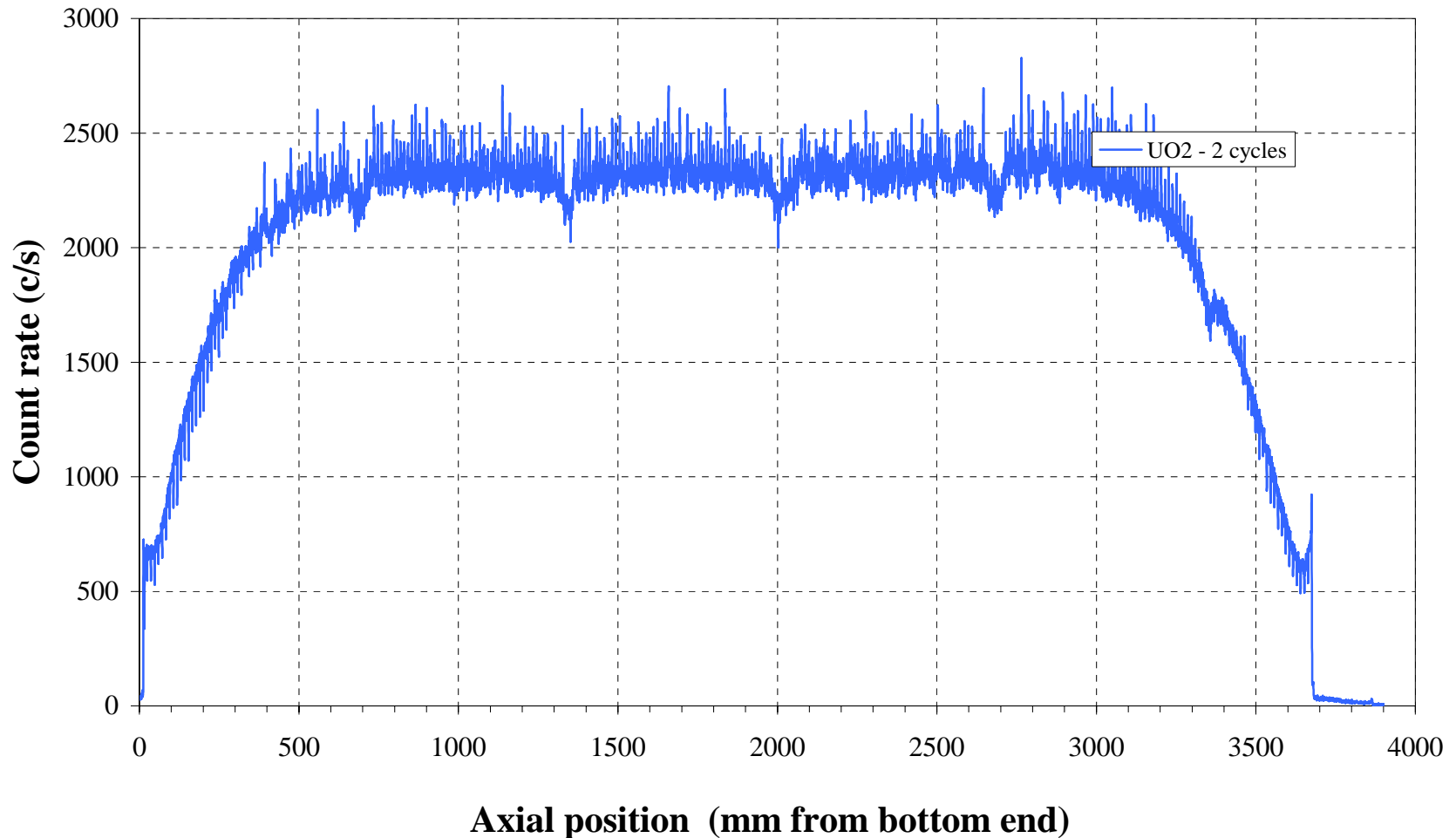
- Assembly & sample power history
- Experimental part
 - Cross-check between laboratories
 - Include distribution profiles

<i>Programme</i>	ARIANE	MALIBU	Present High duty fuel	Present Gd fuel
<i>Reactor type</i>	PWR	PWR	PWR	PWR
<i>Cycle length (months)</i>	12	12	18	18
<i>Assembly</i>	15x15 No Gd	15x15 No Gd	15x15 With Gd*	15x15 With Gd
<i>Fuel</i>	UO ₂	UO ₂	UO ₂	UO ₂
<i>Enrichment U²³⁵</i>	3.5%	4.3%	4.25%	2% U²³⁵,
<i>Gd</i>				10% Gd
<i>Burnup (GWd/tM)</i>	30, 50 & 60	50 & 70	52 GWd/t	15 GWd/t
<i>N cycles</i>	3, 5	4	2	1

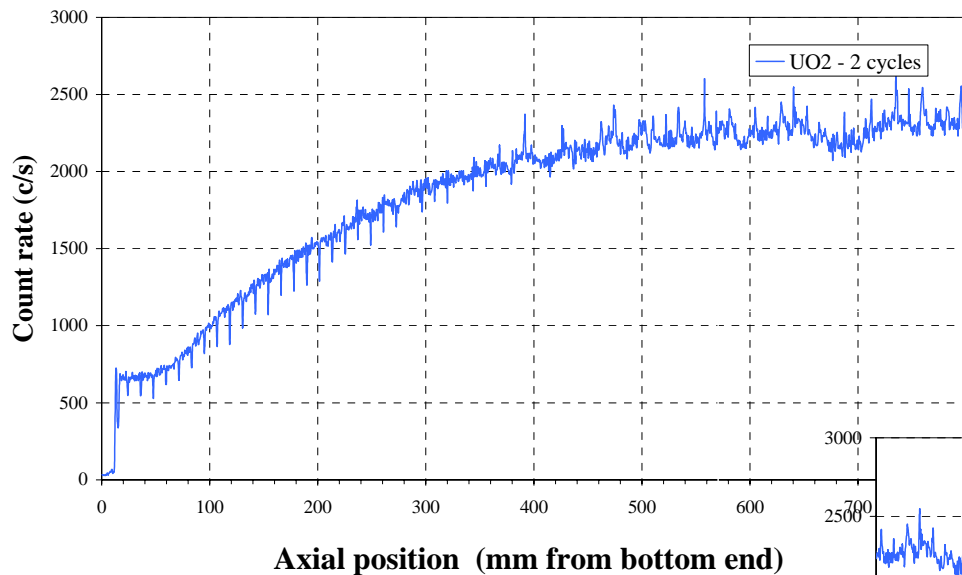
**Representative of today's
PWR operating conditions**

Gamma activity scan – High duty rod

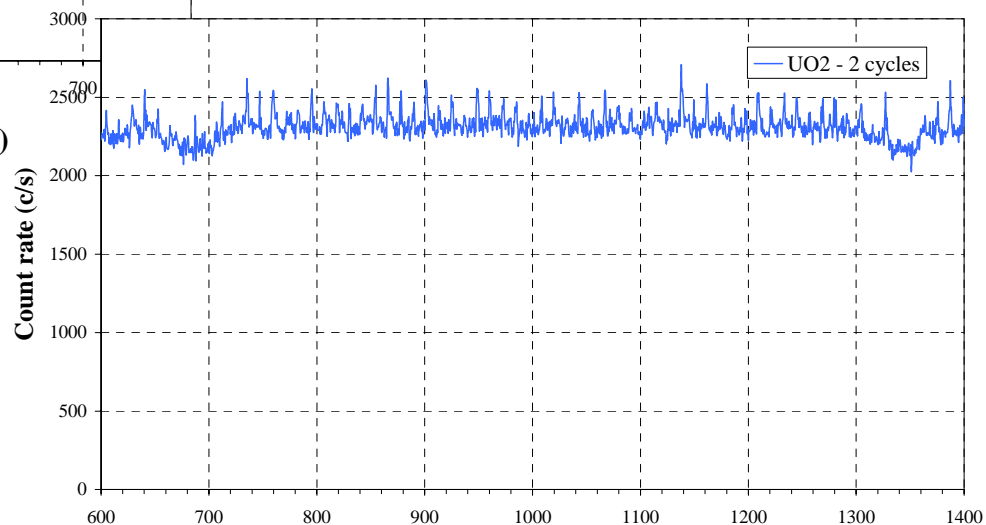
UO₂ - 2 cycles



UO₂ - 2 cycles - 1st span



UO₂ - 2 cycles - 2nd span



Axial position (mm from bottom end)

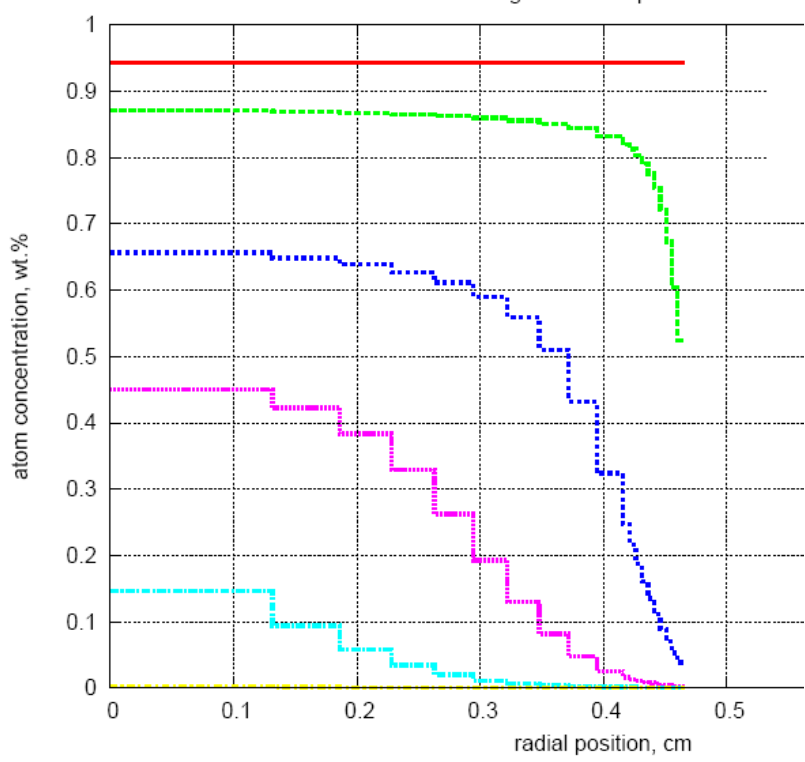
<i>Programme</i>	ARIANE	MALIBU	Present High duty fuel	Present Gd fuel
<i>Reactor type</i>	PWR	PWR	PWR	PWR
<i>Cycle length (months)</i>	12	12	18	18
<i>Assembly</i>	15x15 No Gd	15x15 No Gd	15x15 With Gd*	15x15 With Gd
<i>Fuel Enrichment U^{235} Gd</i>	UO ₂ 3.5%	UO ₂ 4.3%	UO ₂ 4.25%	UO ₂ 2% U^{235}, 10% Gd
<i>Burnup (GWd/tM)</i>	30, 50 & 60	50 & 70	52 GWd/t	15 GWd/t
<i>N cycles</i>	3, 5	4	2	1

**To refine capabilities of today's
neutronic codes with regard to Gd
depletion in PWR conditions**

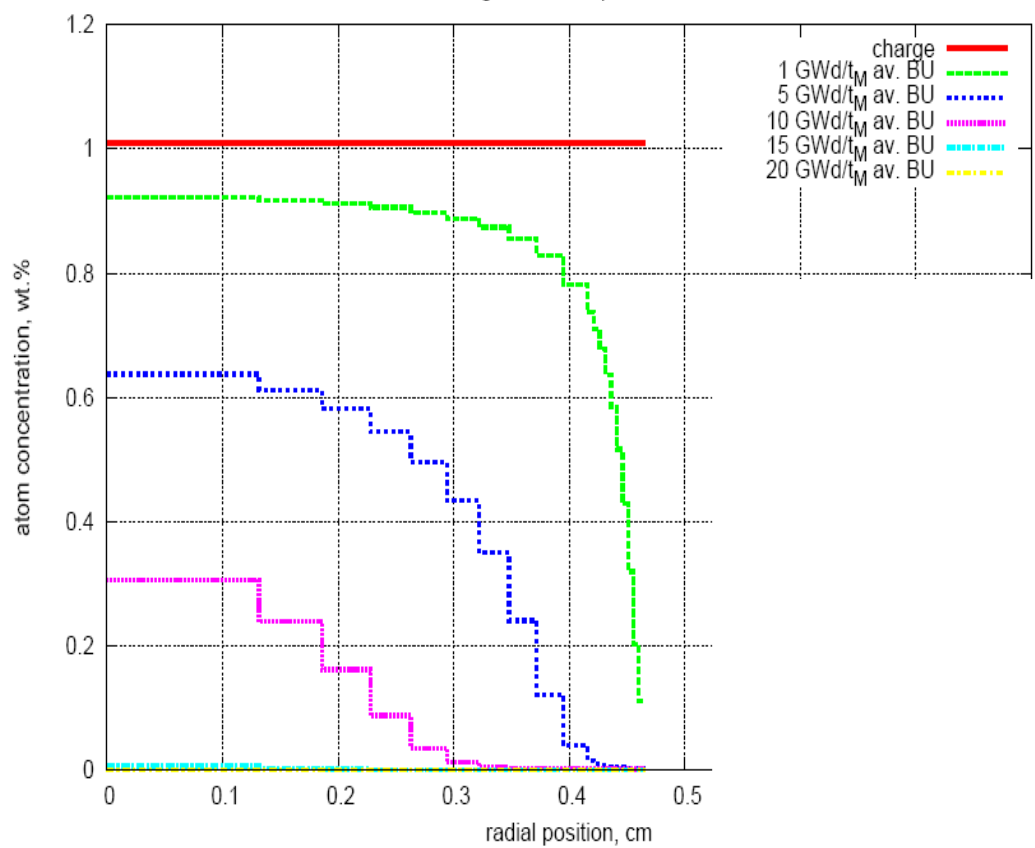
1-cycle Gd rod – Gd depletion profiles



gd155 radial profile

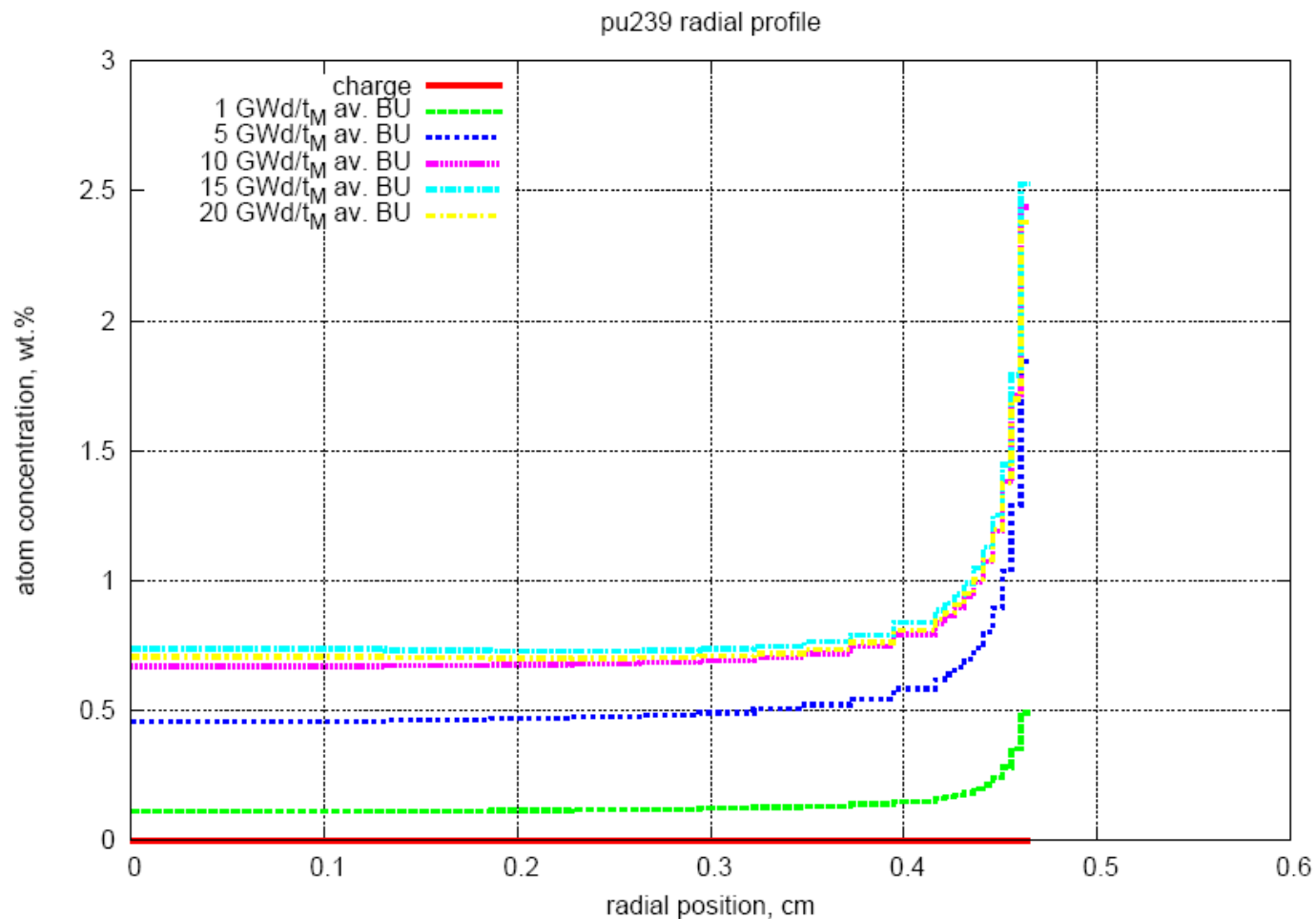


gd157 radial profile



Calculations with SCALE 5.1 (Triton / t-depl5, using the 238groupndf5 library)
 -10% Gd-enriched rod, 2% U²³⁵; -1 cell calculation; -20 radial zones.

1-cycle Gd rod – Pu profile



Calculations with SCALE 5.1 (Triton / t-depl5, using the 238groupndf5 library)

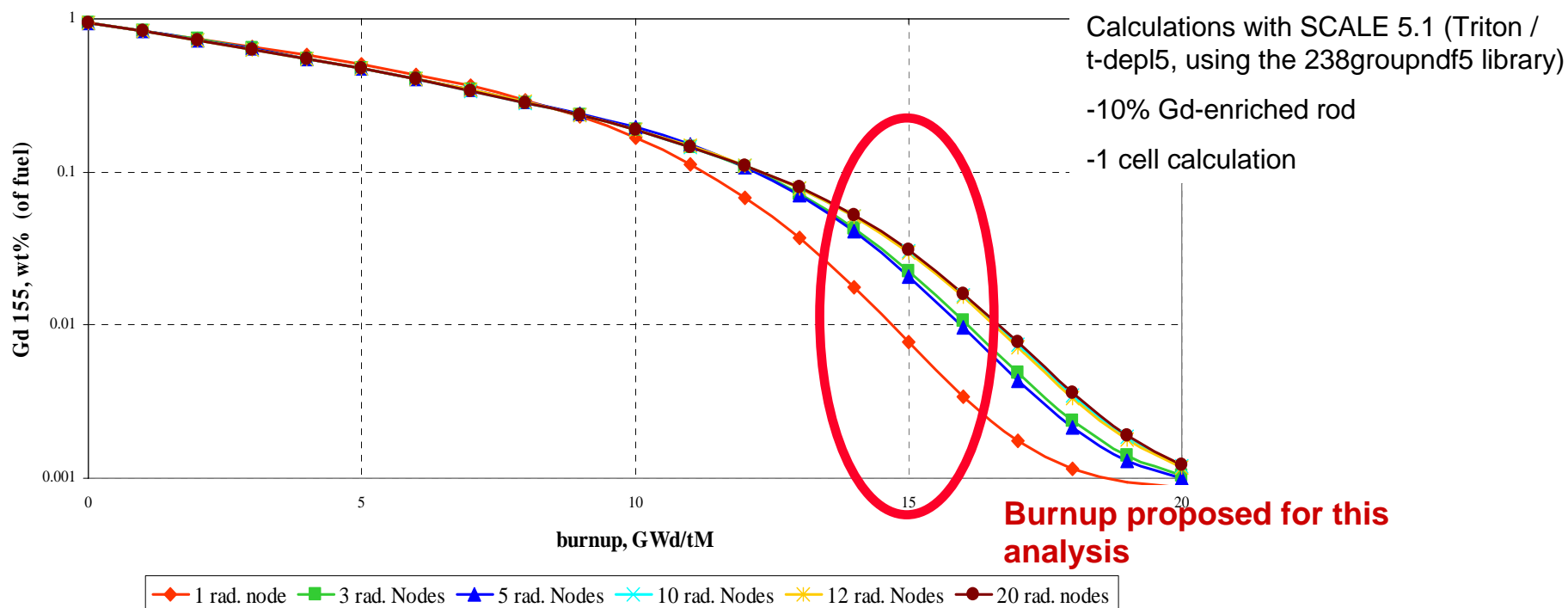
-10% Gd-enriched rod, 2% U²³⁵;

-1 cell calculation;

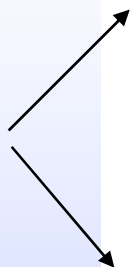
-20 radial zones.

- Gd concentration
 - Strong depletion at pellet periphery
 - Influence of # of zones taken into account:

Gd 155 concentration (pellet cross-section average) vs. burnup



**Sibling
rods**

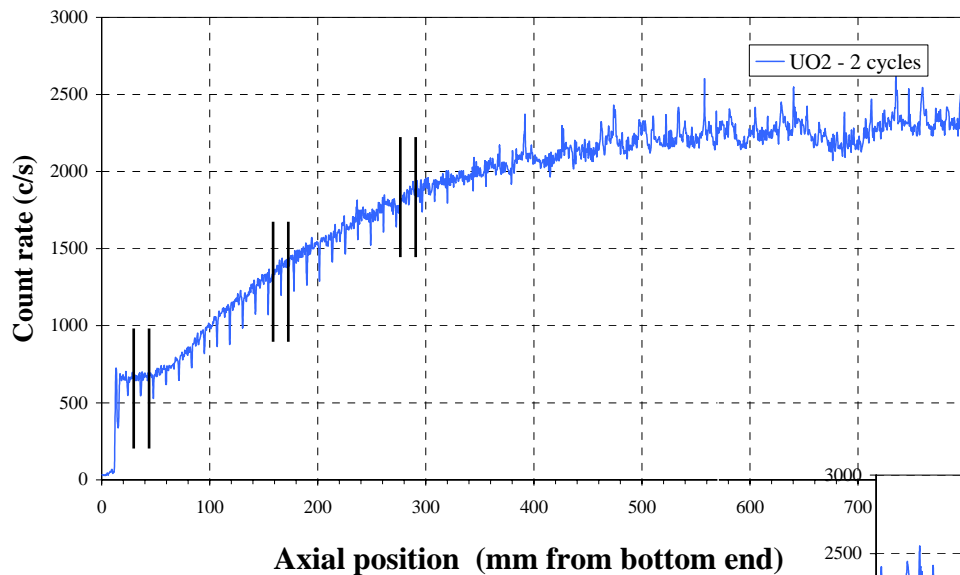


	<i>Radio-chemical analysis</i>	<i>Gadolinium analysis</i>	<i>EPMA</i>	<i>SIMS</i>
UO₂ rod 1 – 1st span	3	-	-	-
UO₂ rod 2 – 1st span	3	-	-	-
UO₂ rod 1 – 2nd span	2	-	1	1
Gado – 2nd span	2	2	1	1

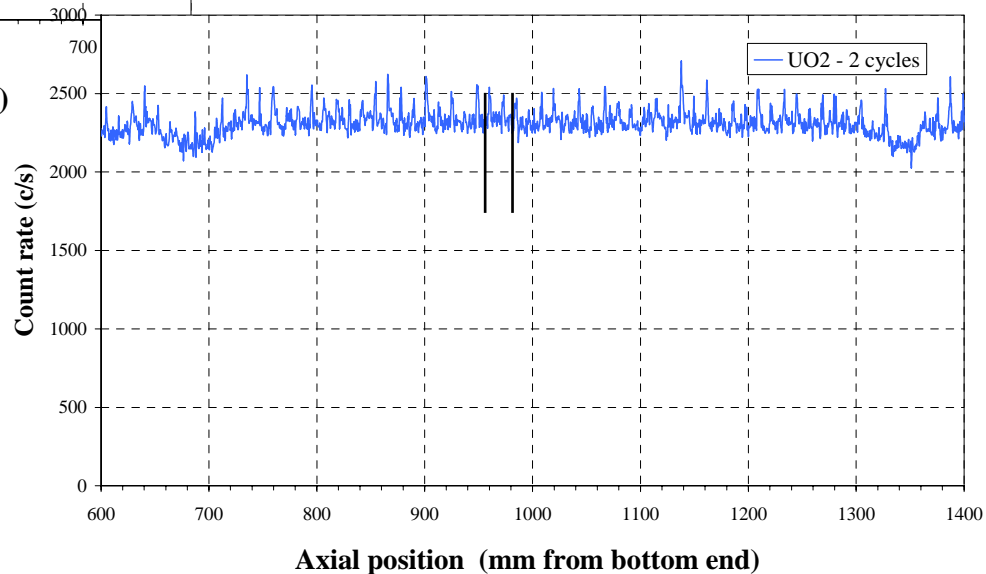
- Actinides:
 - Base
 - ^{234}U , ^{235}U , ^{236}U , ^{238}U
 - ^{238}Pu , ^{239}Pu , ^{240}Pu , ^{241}Pu , ^{242}Pu
 - Minor
 - ^{241}Am , $^{242\text{m}}\text{Am}$, ^{243}Am
 - ^{242}Cm , ^{243}Cm , ^{244}Cm , ^{245}Cm
 - ^{237}Np
- Burnable poison
 - ^{155}Gd , ^{156}Gd , ^{157}Gd , ^{158}Gd
- Fission products
 - Volatiles:
 - ^{134}Cs , ^{137}Cs
 - Lanthanides:
 - ^{144}Ce
 - ^{142}Nd , ^{143}Nd , ^{144}Nd , ^{145}Nd , ^{146}Nd , ^{148}Nd , ^{150}Nd
 - ^{147}Sm , ^{149}Sm , ^{150}Sm , ^{151}Sm , ^{152}Sm
 - ^{153}Eu , ^{154}Eu , ^{155}Eu

- Gd depletion: strong depletion at pellet periphery during 1st cycle
 - Radiochemical analysis
 - Radial distribution profiles
 - EPMA
 - U, Pu, Gd, Nd, Cs, **Xe**
 - SIMS
 - U vector
 - Pu vector
 - Nd vector
 - Gd vector

UO₂ - 2 cycles - 1st span



UO₂ - 2 cycles - 2nd span



- Today
 - Fuel rods from Tihange 1 PWR:
 - 2 sibling UO_2 rods ~52 GWd/tHM
 - 1 Gado fuel rod (10% Gd_2O_3 – 2% ^{235}U)
 - Fuel rods are identified and are available for further analyses
 - First steps in compiling the data book are made
- Tomorrow
 - Collecting *your* expressions interest

- January - June 2010
 - Contract negotiations
- July – December 2010
 - Kick-off meeting
 - Sampling of fuel rods
 - Transport preparation
- January – June 2011
 - Transport
 - Start of analyses
- July 2011 – December 2012
 - Radiochemical analyses
- January 2013 – June 2013
 - Reporting
- December 2013
 - Final meeting

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