UNCERTAINTY IN REACTIVITY DUE TO NUCLEAR DATA FOR AN MTR CORE

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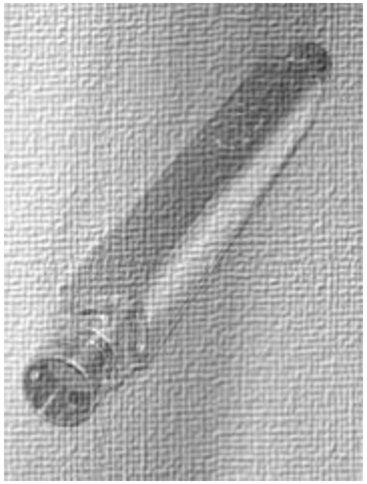
INTRODUCTION

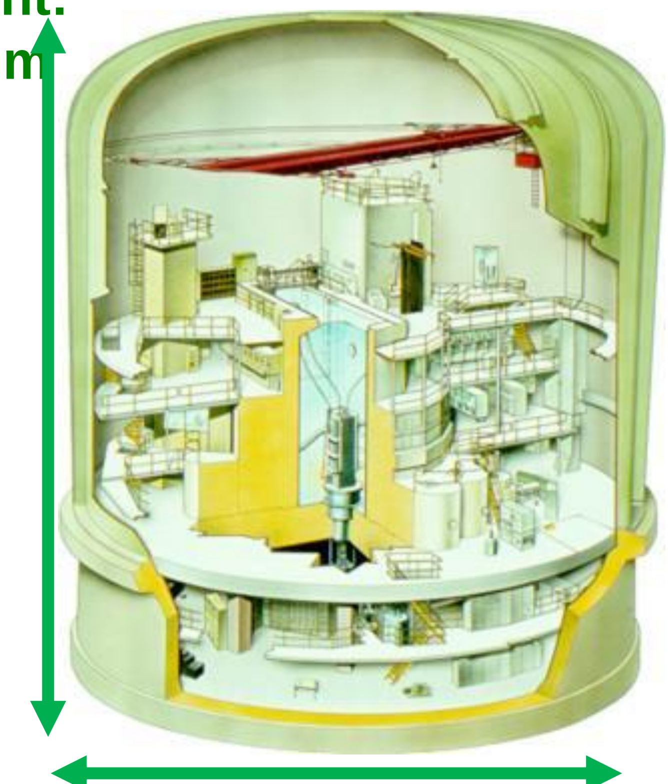
- The HFR reactor is one of the main suppliers of ^{99}Mo and other medical isotopes
- We continuously strive to improve our services, which entails in having reliable/predictable irradiation conditions and to maximize the uptime, by increasing the cycle length or number of cycles per year
- Reducing the current safety margins is therefore an important issue, while still guaranteeing safety for the diverse postulated accident
- To justify increase in cycle length uncertainties on reactivity are required to allow the decrease of the design margins in a controlled manner
- Our ongoing work focuses on the uncertainty quantification with the application of the Total Monte-Carlo method, considering as source the uncertainties in nuclear data



NRG PETTEN (THE NETHERLANDS)

THE HIGH FLUX REACTOR (HFR)

Height: 23.5 m

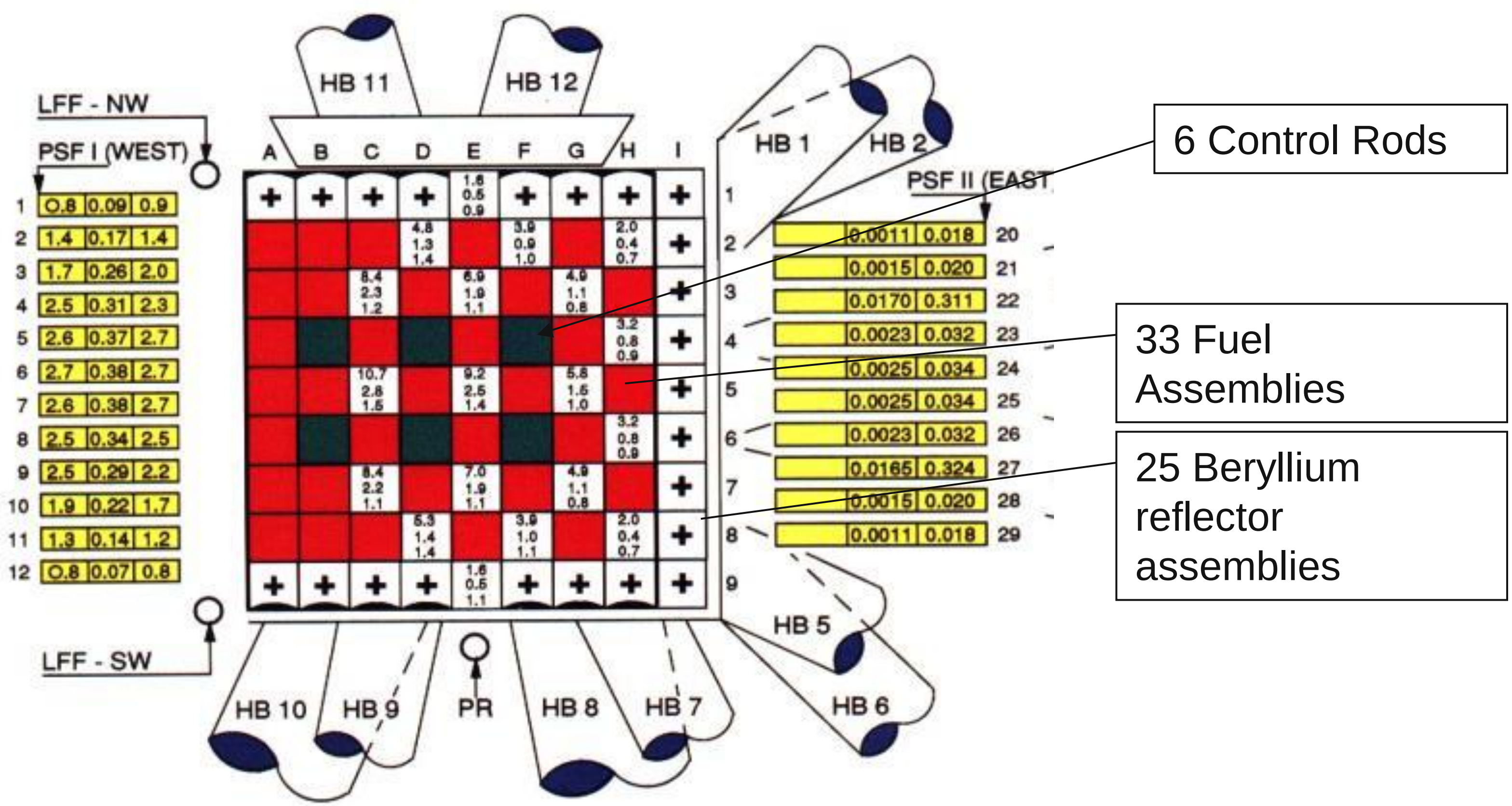


Diameter: 25 m

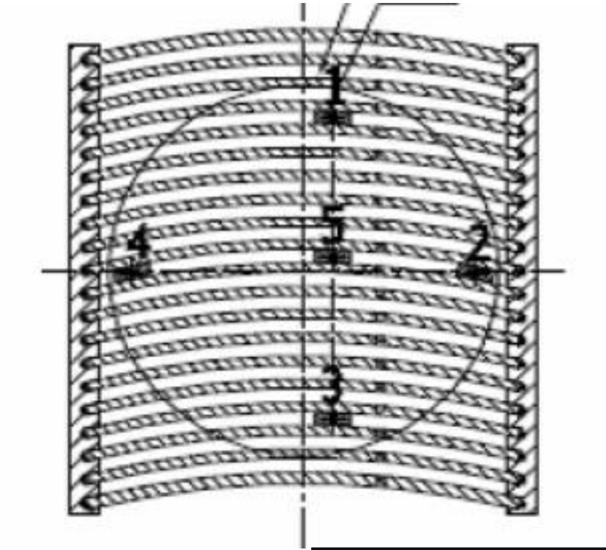
The HFR is used for:

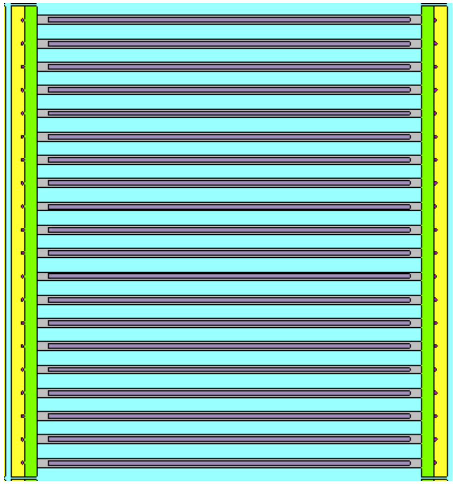
- Nuclear Research & Development
  - Qualification of fuels
  - Irradiation damage in materials
- Production of isotopes
  - For medical applications; diagnostics, therapy and palliative treatment
  - For industrial applications

HIGH FLUX REACTOR CORE



HFR FUEL ASSEMBLY

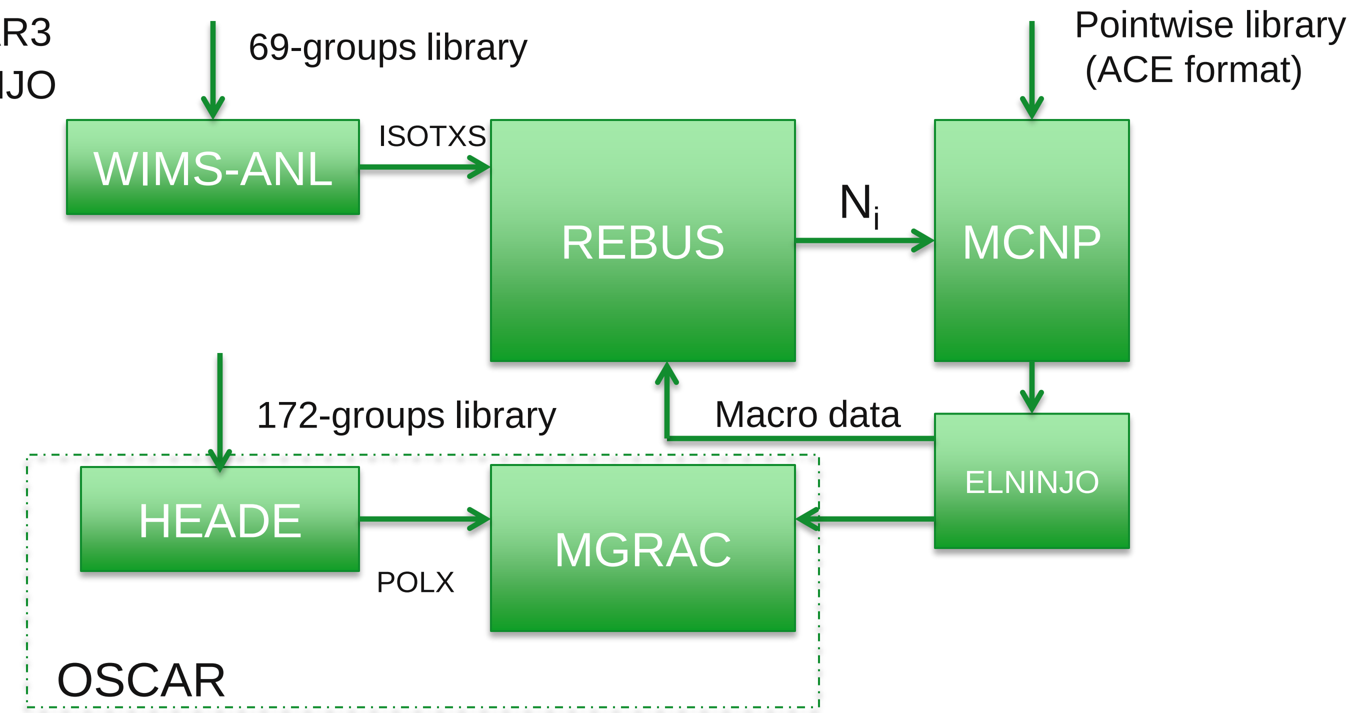




Parameter	
Fuel type	LEU / U_3Si_2-Al
Fuel meat density	4.8 g/cm^3
^{235}U content	550 g
Nr. of fuel plates	20
Cladding thickness	0.38 mm
Cd wires	40x Ø = 0.5 mm
Rating	1.25MW

HFR CORE DESIGN SOFTWARE

- The following codes are used for core design/analysis:
  - MCNP
  - REBUS 1.45
  - WIMS-ANL
  - OSCAR3
  - ELNINJO

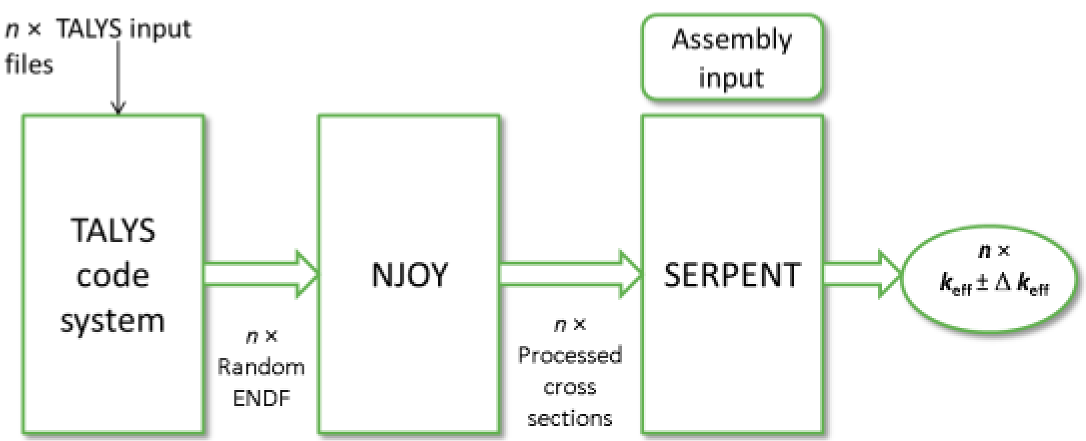


METHODOLOGY

- Single fuel element modelled in MCNP and SERPENT (2.1.29)
- Reflective boundaries in x-y plane
- 20 plates and 40 Cd-wires modelled
- 180°-symmetry assumed in SERPENT model
- In axial direction fuel plates divided in 8 sections (burnup zones)
- Each Cd wire divided in 5 radial burn-up zones and 8 axial zones
- Total of 480 BU zones, and 42 BU steps
- Propagation of uncertainties for variation in nuclear data for $^{235,238}U$, $^{111\text{-}114}Cd$, ^{27}Al, ^{239}Pu, and thermal scattering of ^{1}H in H_2O, separately using Total Monte-Carlo method

TOTAL MONTE-CARLO METHOD

- Total Monte-Carlo (TMC) method developed in 2008 at NRG is a statistical method proposed for uncertainty quantification as result of uncertainties in nuclear data
- Perform same type of calculation large number of times, and randomly varying each time input parameters sampled within pre-determined intervals
- Total Monte-Carlo (TMC) method applied using Monte-Carlo codes (SERPENT and MCNP)
- Basic XSDIR file based on JEFF3.1.1 data
- XSDIR complemented with random data (~ 600 runs) for all important isotopes . Random data files either from TENDL library or based on ENDF/B-VII.1 covariance data.
- Propagation of nuclear data uncertainties for ^{235,238}U, $^{111\text{-}114}$Cd, ^{27}Al, ^{239}Pu, and thermal scattering of ^{1}H in H_2O, one at a time



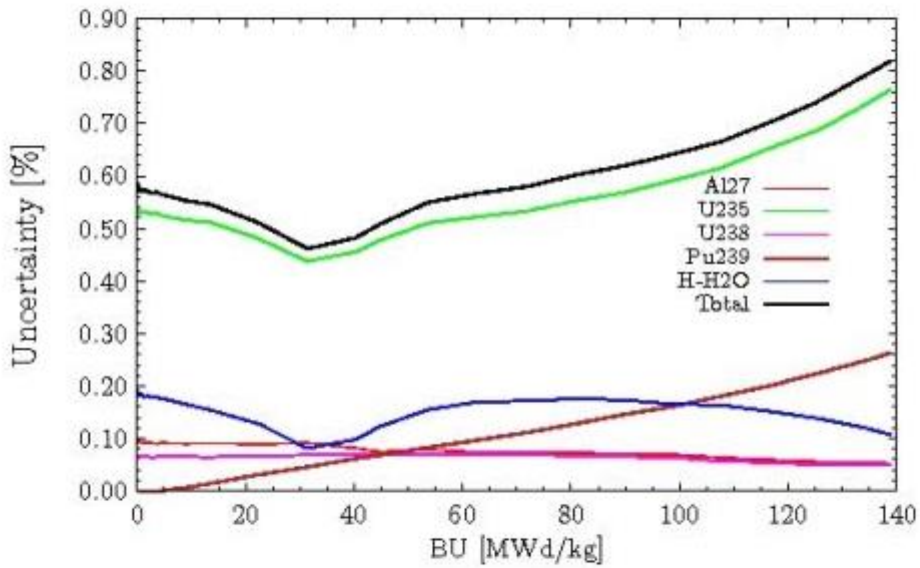
UNCERTAINTY IN K_{eff} - BOL

[in pcm]

	MCNP		SERPENT-2	
	No Cd-wires	Cd-wires	No Cd-wires	Cd-wires
^{235}U	512	542	506	539
^{238}U	65	66	63	65
^{27}Al	92	97	89	94
H in H_2O	76	196	77	193
^{111}Cd	--	<σ	--	--
^{112}Cd	--	<σ	--	--
^{113}Cd	--	14	--	11
^{114}Cd	--	<σ	--	--
Total	**530**	**588**	**523**	**584**

- Two models at BOL conditions considered in MCNP and SERPENT
- Partial relative uncertainties for each isotope
- Total uncertainty obtained by combination of partials (uncorrelated)
- Statistical uncertainty in total value: 25 pcm (1σ)
- Good agreement between the two codes

UNCERTAINTY IN K_{eff} – BURNUP



TENDL-2012 data

- Burn-up performed for SERPENT-2 model with Cd-wires
- Total uncertainty obtained by combining partial contributions (uncorrelated) of $^{235,238}U$, ^{27}Al, ^{239}Pu, and ^{1}H in H_2O
- ^{235}U contributes the most over the whole burn-up range
- Total uncertainty increases towards EOL (585 pcm → 820 pcm)
- Minimum uncertainty at 30 MWd/kg (460 pcm)

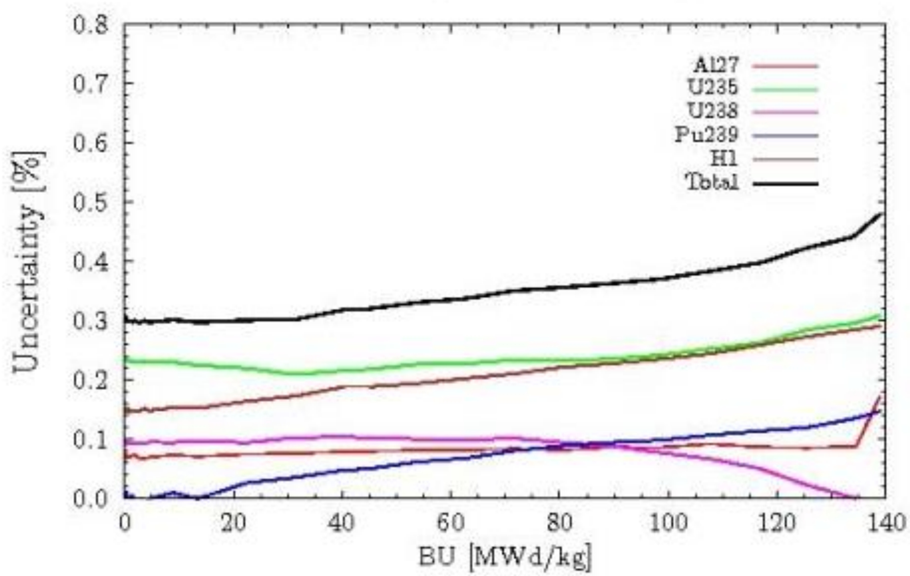
EFFECT OF NUCLEAR DATA LIBRARY

	BOL		MOL		EOL	
	TENDL	*ENDF/B-7.1*	*TENDL*	*ENDF/B-7.1*	*TENDL*	*ENDF/B-7.1*
^{235}U	544	238	533	234	766	308
^{238}U	63	95	69	102	49	<sig
^{27}Al	91	72	74	84	52	88
^{1}H-in-H_2O	193	--	171	--	107	--
^{1}H	--	151	--	210	--	289
^{239}Pu	0	0	111	81	263	147
Total	**588**	**306**	**580**	**351**	**820**	**441**

[pcm]

- Same study performed for ENDF/B-7.1 evaluation
- Random files generated using covariance data
- Random data for ^{1}H missing in TENDL library, and covariance data for ^{1}H-in-H_2O in ENDF/B-7.1
- Total uncertainties differ by as much as a factor of 2 between the two libs

EFFECT OF NUCLEAR DATA LIBRARY (2)



ENDF/B-7.1 data

- Major contributions are from ^{235}U and ^{1}H, over the whole period
- Behavior does not show a local minimum for ^{235}U and ^{1}H contributions, the total uncertainty increases monotonically towards EOL
- Contribution of ^{238}U drops to “zero” at EOL, different behavior than seen for TENDL random data

UNCERTAINTY HFR FULL CORE

- HFR model for cycle **2016-05** (MCNP model)
- Actual fuel and experimental loading considered
- Control Rod settings as measured
- Models for 3 time steps considered (BOC, MOC and EOC)
- Assemblies with different BU values (5-6 cycles)
- Uncertainty in k-eff due to nuclear data (TENDL)
- Partial uncertainties for $^{235,238}U$, ^{239}Pu, ^{27}Al, ^{9}Be, ^{1}H-in-H_2O (TS)

UNCERTAINTY HFR FULL CORE (2)

HFR Core (1605)

	timestep 0 (BOC)		timestep 3 (MOC)		timestep 6 (EOC)	
U235	756	pcm	755	pcm	747	pcm
Al27	164	pcm	164	pcm	161	pcm
U238	70	pcm	63	pcm	64	pcm
H in H2O	142	pcm	131	pcm	122	pcm
Pu239	63	pcm	85	pcm	97	pcm
Be9	126	pcm	106	pcm	104	pcm
Total	**802**	**pcm**	**798**	**pcm**	**789**	**pcm**

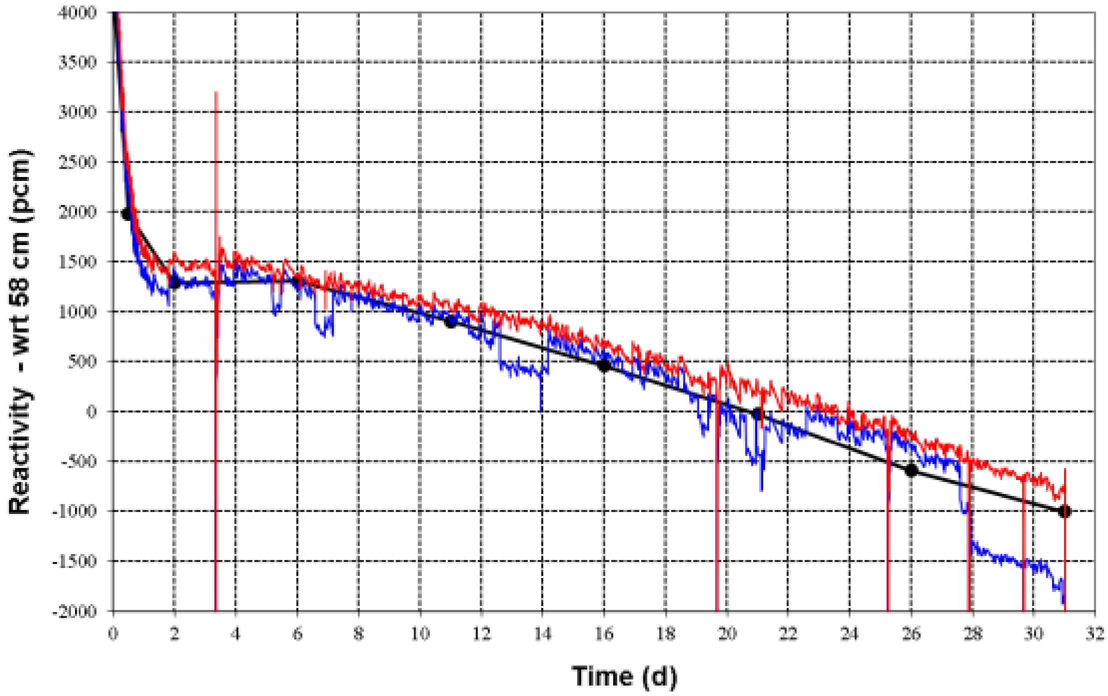
Single Assembly

	BOL	EOL
U235	544	766
Al27	91	52
U238	63	49
H in H2O	193	107
Pu239	0	263
Be9	---	---
Total	**588**	**822**

- Total uncertainties for full core are virtually constant over the cycle (~ 795pcm)
- ^{235}U contribution is the most important, followed by ^{27}Al and ^{1}H-in-H_2O
- Importance of different isotopes differs from single assembly study
- Total uncertainty agrees reasonably well with single assembly value (single assembly model does not taken into account different BU values)

UNCERTAINTY HFR FULL CORE (3)

Core Reactivity – Cycle 201605



- Back line : OSCAR core follow calculations
- Red line: measured core reactivity with respect to a standard CR setting

CONCLUSIONS AND PROSPECTS

- Uncertainty in reactivity as result of variations in nuclear data were calculated for HFR fuel assembly and full core, using TMC method
- Main isotopes taken into account: $^{235,238}U$, ^{27}Al, $^{111-114}Cd$, ^{239}Pu, and ^{1}H (thermal scattering), and ^{9}Be.
- Fuel Assembly:
  - SERPENT results for a single assembly during fuel burnup (up to 140 MWd/kg) show a BU-dependent uncertainty and varies in the range 460-820 pcm
  - ^{235}U is the main source of uncertainty (followed by ^{1}H-in-H_2O), with increasing contribution towards EOL
- Full Core:
  - Study for a full core HFR model show a different behavior, with a time-independent uncertainty during the cycle (795 pcm).
  - The contribution of the different isotopes also differs: ^{235}U is the main contributor followed by ^{27}Al.

THANK YOU !

Any questions ?

HFR IS A 45 MW TANK IN POOL MTR