# UNCERTAINTY IN REACTIVITY DUE TO NUCLEAR DATA FOR AN MTR CORE

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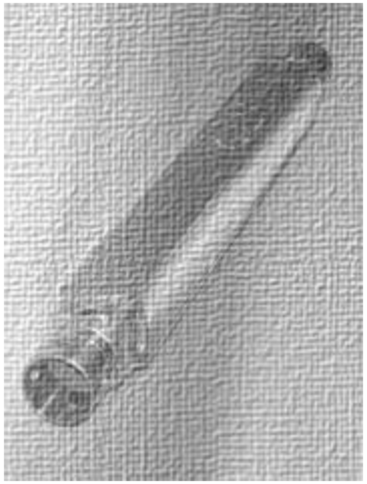
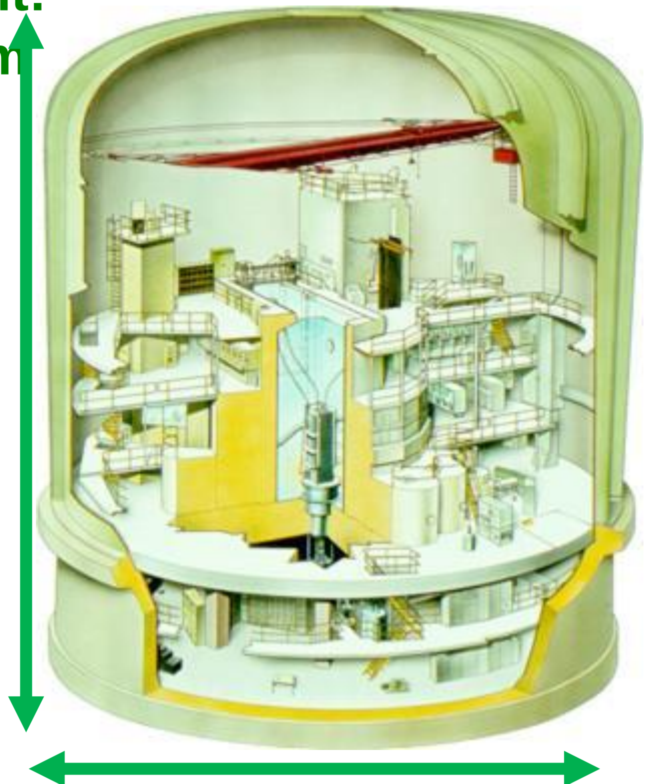
# INTRODUCTION

- 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)

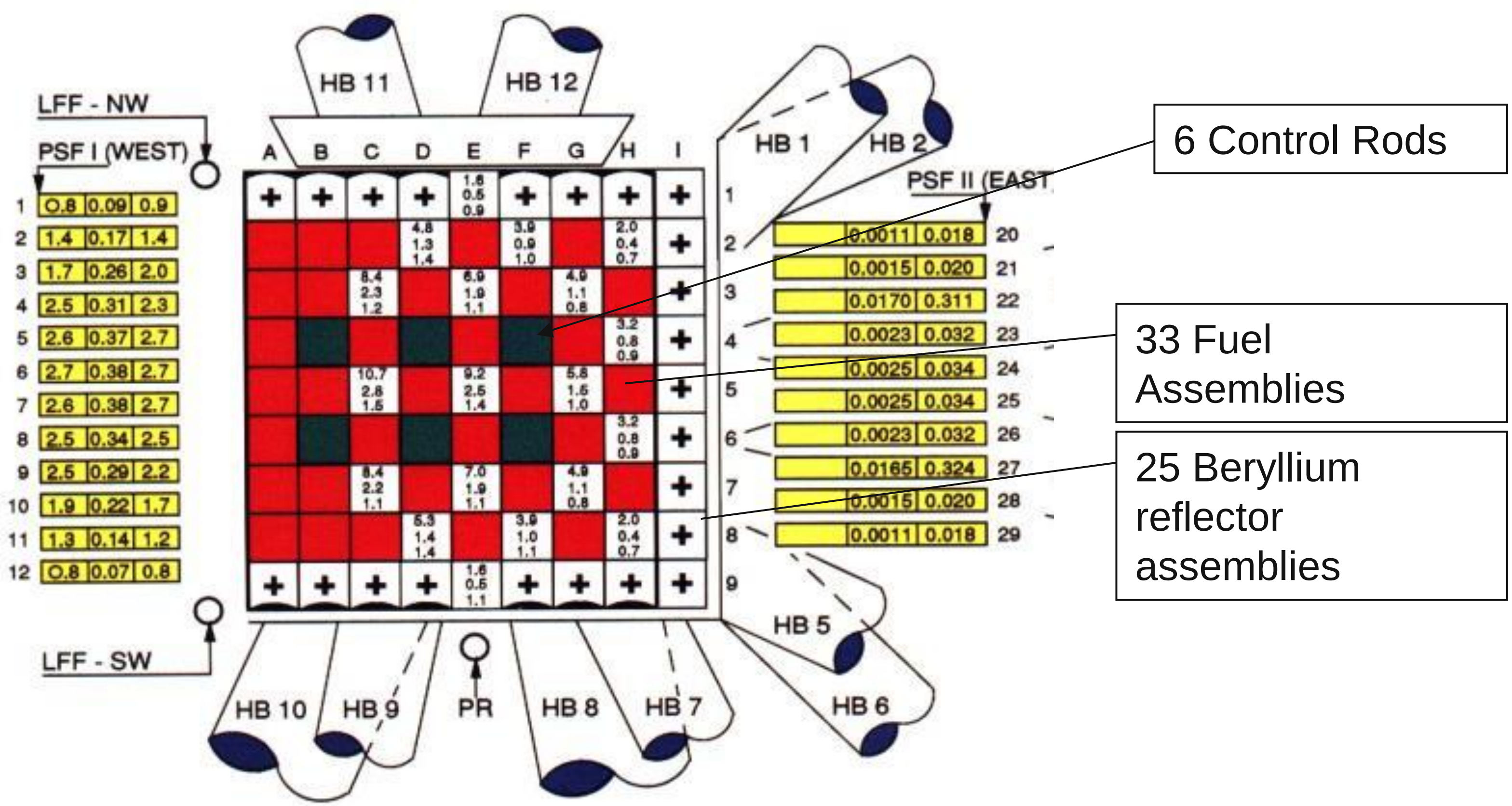

# THE HIGH FLUX REACTOR (HFR)



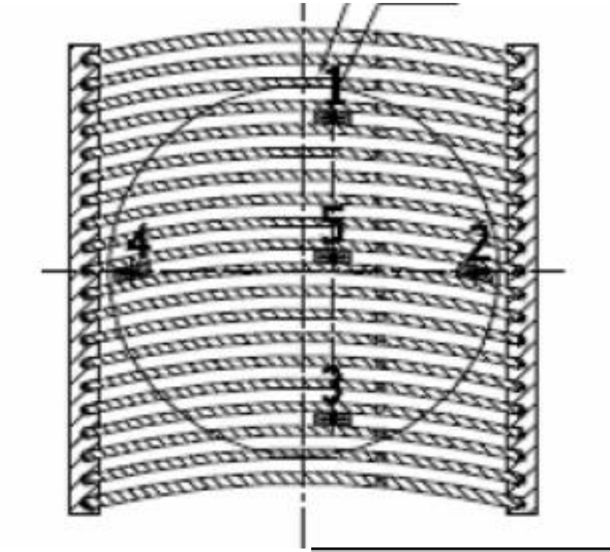

## The HFR is used for:

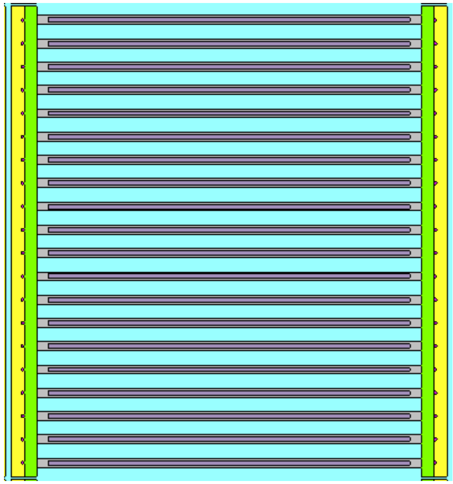
- Nuclear Research & Development
  - Qualification of fuels
  - Irradiation damage in materials
- Production of isotopes
  - For medical applications; diagnostics, therapy and palliative treatment
  - For industrial applications

# HIGH FLUX REACTOR CORE



# HFR FUEL ASSEMBLY

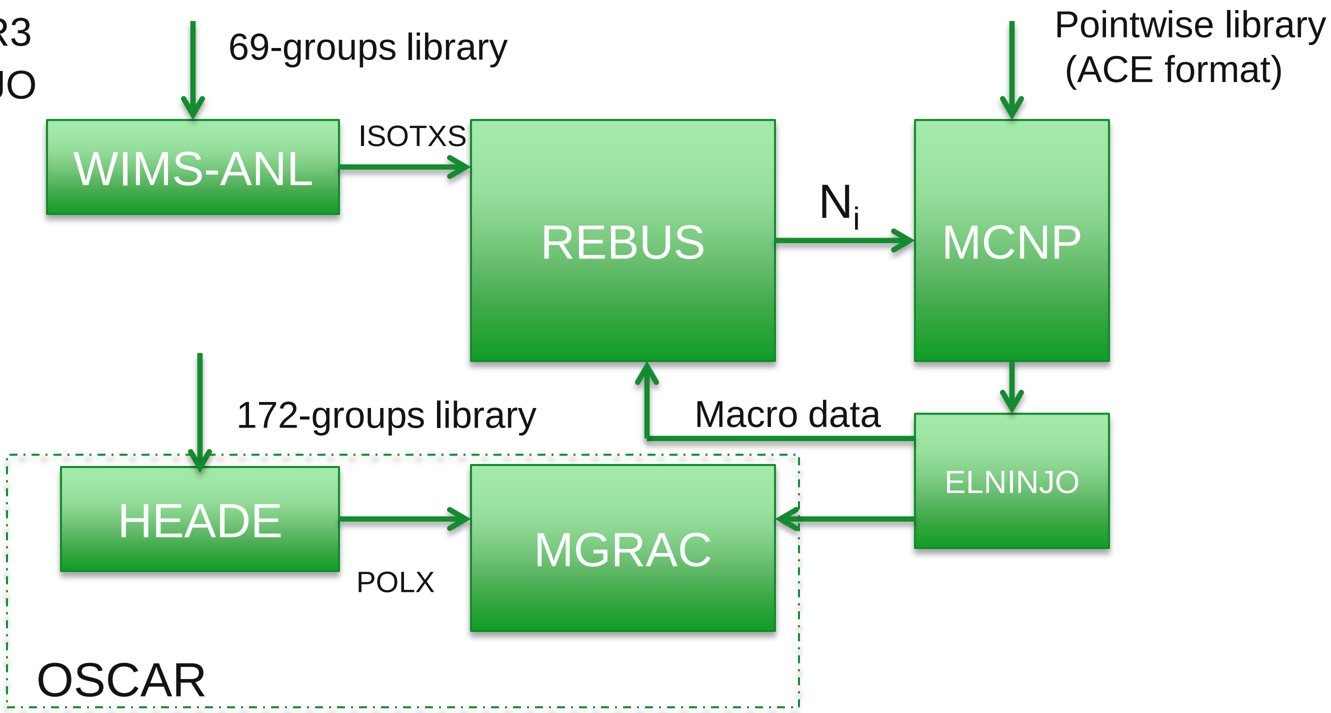


| Parameter | |
|---|---|
| Fuel type | LEU / $U_3Si_2$-Al |
| Fuel meat density | 4.8 g/cm$^3$ |
| $^{235}$U content | 550 g |
| Nr. of fuel plates | 20 |
| Cladding thickness | 0.38 mm |
| Cd wires | 40x Ø = 0.5 mm |
| Rating | 1.25MW |

# HFR CORE DESIGN SOFTWARE

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

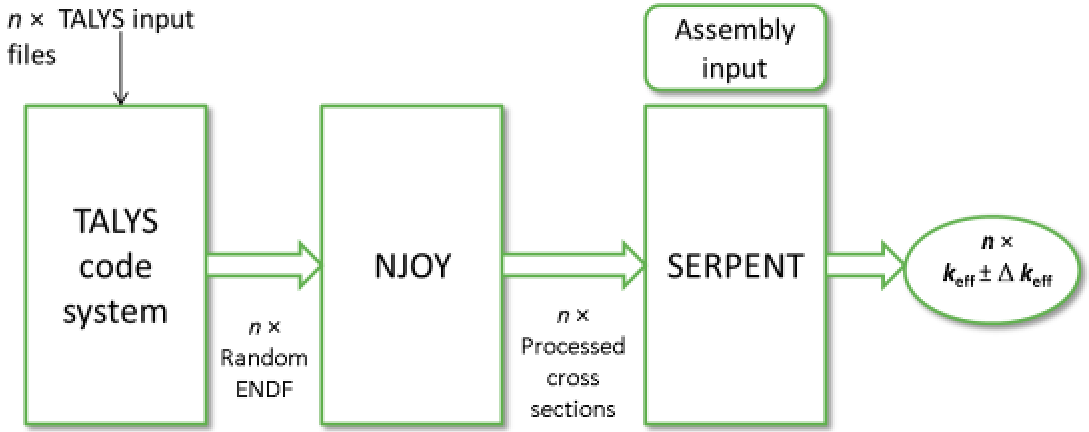


# METHODOLOGY

- 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 $^{235,238}U$, $^{111-114}Cd$, $^{27}Al$, $^{239}Pu$, and thermal scattering of $^{1}H$ in $H_2O$, one at a time



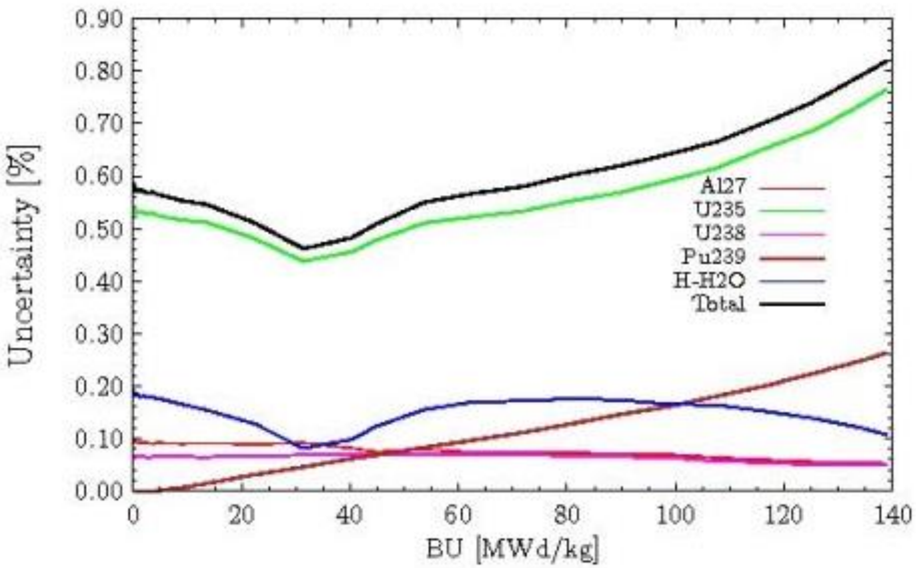

# UNCERTAINTY IN $K_{eff}$ - BOL

[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 |
| $^{111}Cd$ | -- | $<\sigma$ | -- | -- |
| $^{112}Cd$ | -- | $<\sigma$ | -- | -- |
| $^{113}Cd$ | -- | 14 | -- | 11 |
| $^{114}Cd$ | -- | $<\sigma$ | -- | -- |
| **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 (1$\sigma$)
- 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)

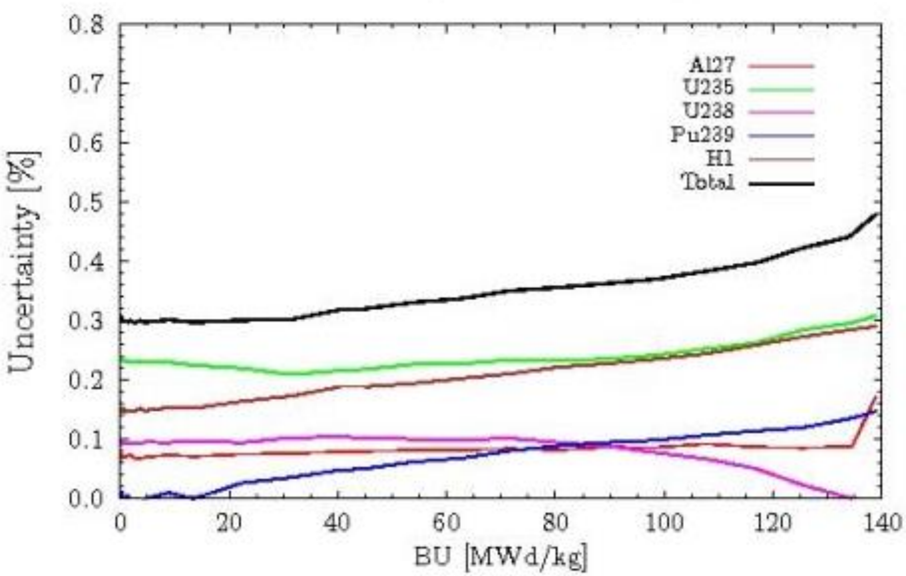
# EFFECT OF NUCLEAR DATA LIBRARY

| | 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** |

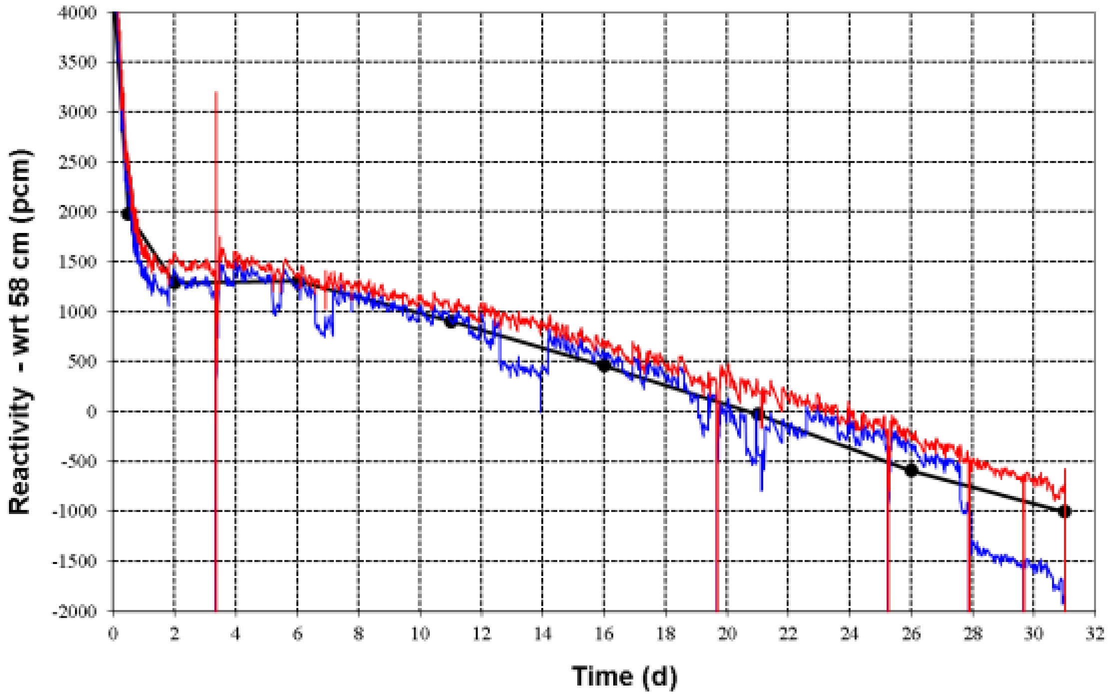
## Single Assembly

| | 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: $^{235,238}U$, $^{27}Al$, $^{111\text{-}114}Cd$, $^{239}Pu$, and $^{1}H$ (thermal scattering), and $^{9}Be$.
- <u>Fuel Assembly</u>:
  - 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
- <u>Full Core</u>:
  - 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