UNCERTAINTY DUE TO NUCLEAR DATA FOR AN MTR FUEL ASSEMBLY

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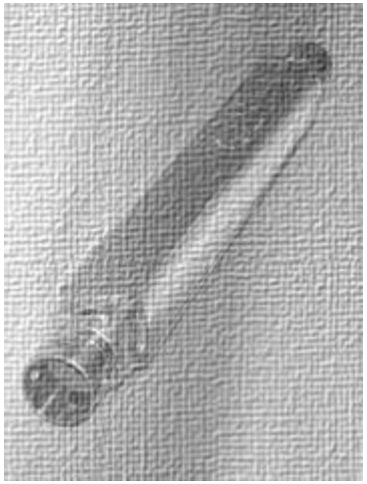
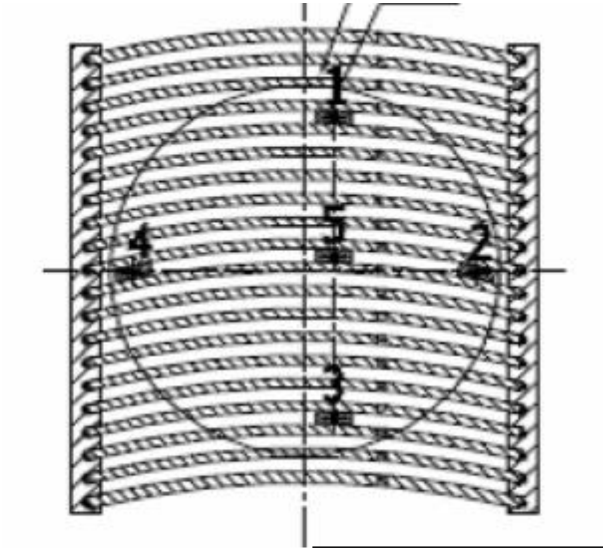
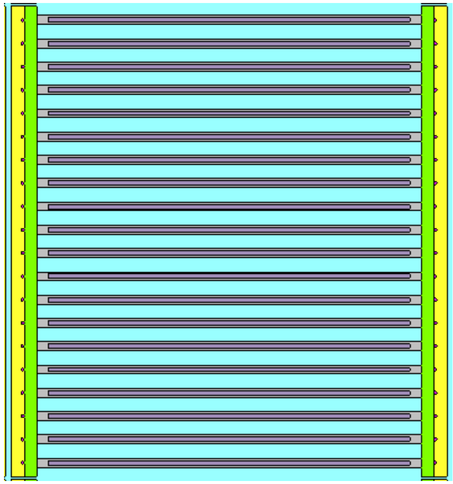
INTRODUCTION

- The HFR reactor is one of the main suppliers of Mo-99 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 work focuses on the uncertainty quantification with the application of the Total Monte-Carlo method, considering as source the uncertainties in nuclear data



HFR FUEL ASSEMBLY

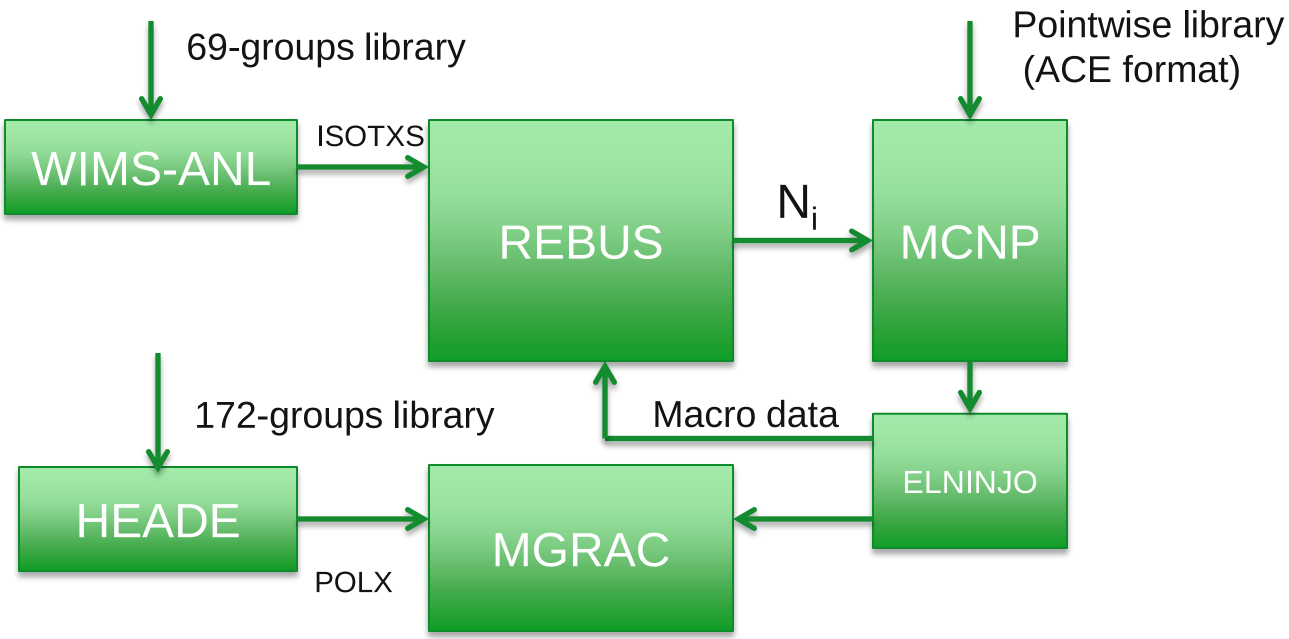




Parameter	
Fuel type	LEU / U_3Si_2-Al
Fuel meat density	4.8 g/cm^3
^{235}U content	550 g
Nr. of fuel plates	20
Cladding thickness	0.38 mm
Cd wires	40x Ø = 0.5 mm
Rating	1.25MW

HFR CORE DESIGN SOFTWARE

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

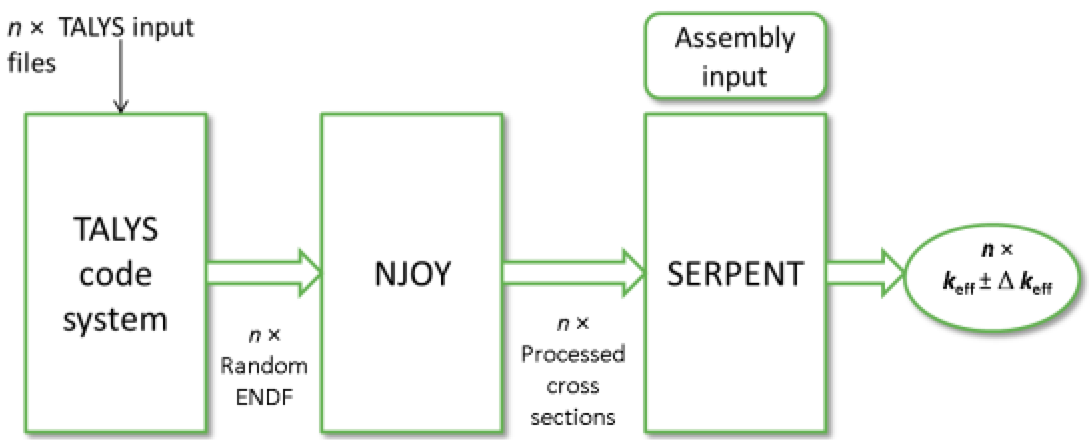


METHODOLOGY

- Single fuel element modelled in MCNP and SERPENT (2.1.27)
- 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 $^{235,238}U$, $^{111-114}Cd$, ^{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



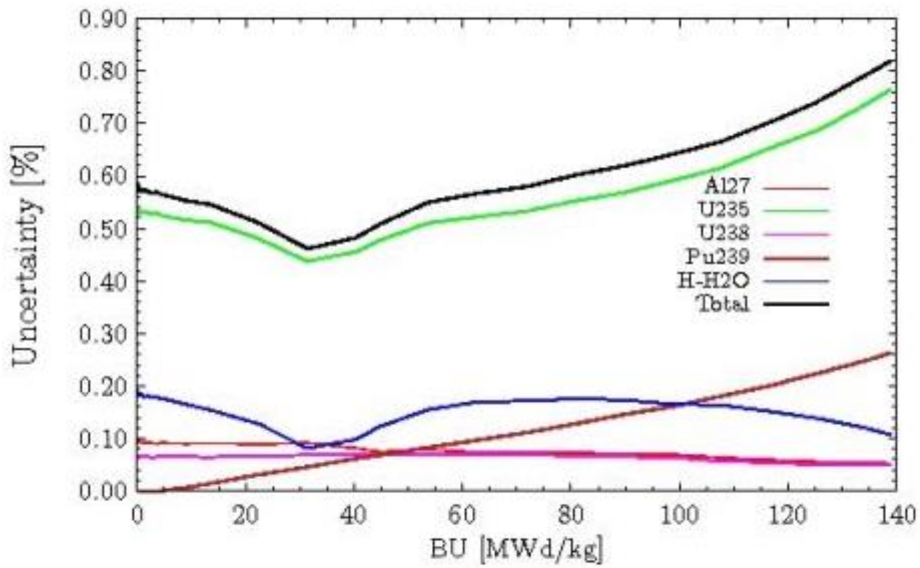
UNCERTAINTY IN K_{eff} - BOL

	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**

[in pcm]

- 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)

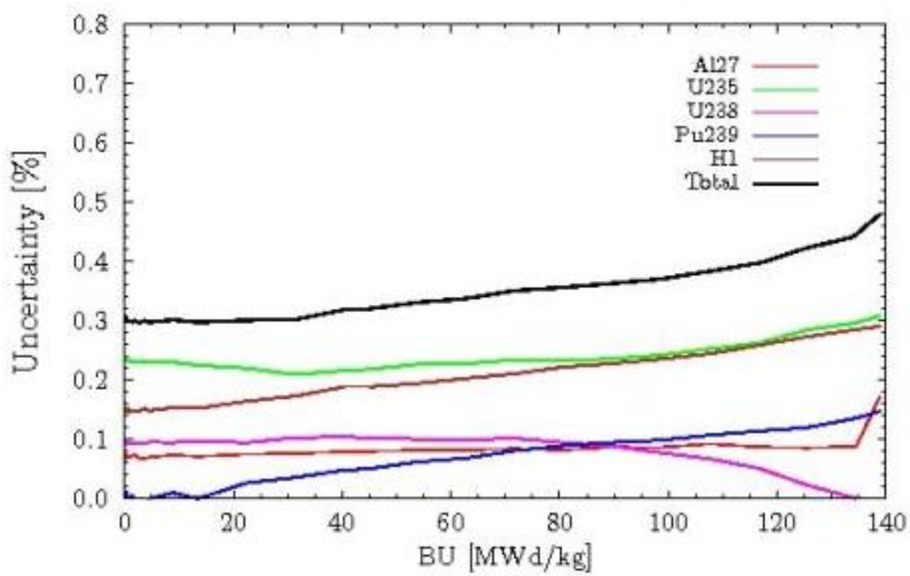
EFFECT OF NUCLEAR DATA LIBRARY

	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$_2$O**	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$_2$O 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

CONCLUSION AND PROSPECTS

- Uncertainty in reactivity as result of variations in nuclear data were calculated for an MTR fuel assembly, using TMC method
- Main isotopes are taken into account: $^{235,238}U$, ^{27}Al, $^{111\text{-}114}Cd$, ^{239}Pu, and ^{1}H (thermal scattering)
- Results at BOL conditions obtained with MCNP and SERPENT are in good agreement. Total uncertainty amounts to 585 pcm (with Cd-wires)
- SERPENT results during fuel burnup (up to 140 MWd/kg) show a burnup-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
- Comparison study between TENDL and ENDF/B-7.1 data showed a substantial difference in the total uncertainty (as much as factor of two). Also shows a different behavior during burnup for some isotopes.
- A follow-up study has started to quantify the uncertainties for a 3D model of the HFR core with a representative core loading

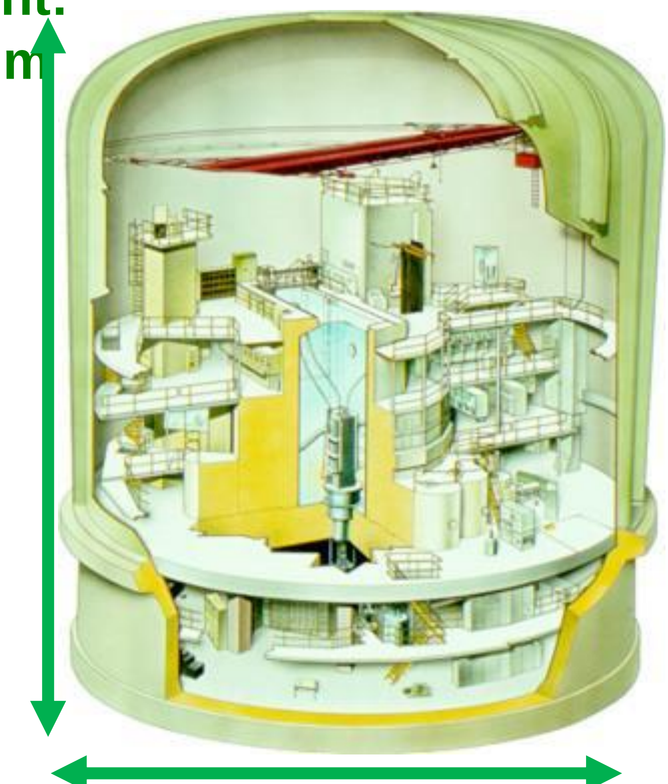
THANK YOU !

Any questions ?

NRG PETTEN

HFR IS A 45 MW TANK IN POOL MTR

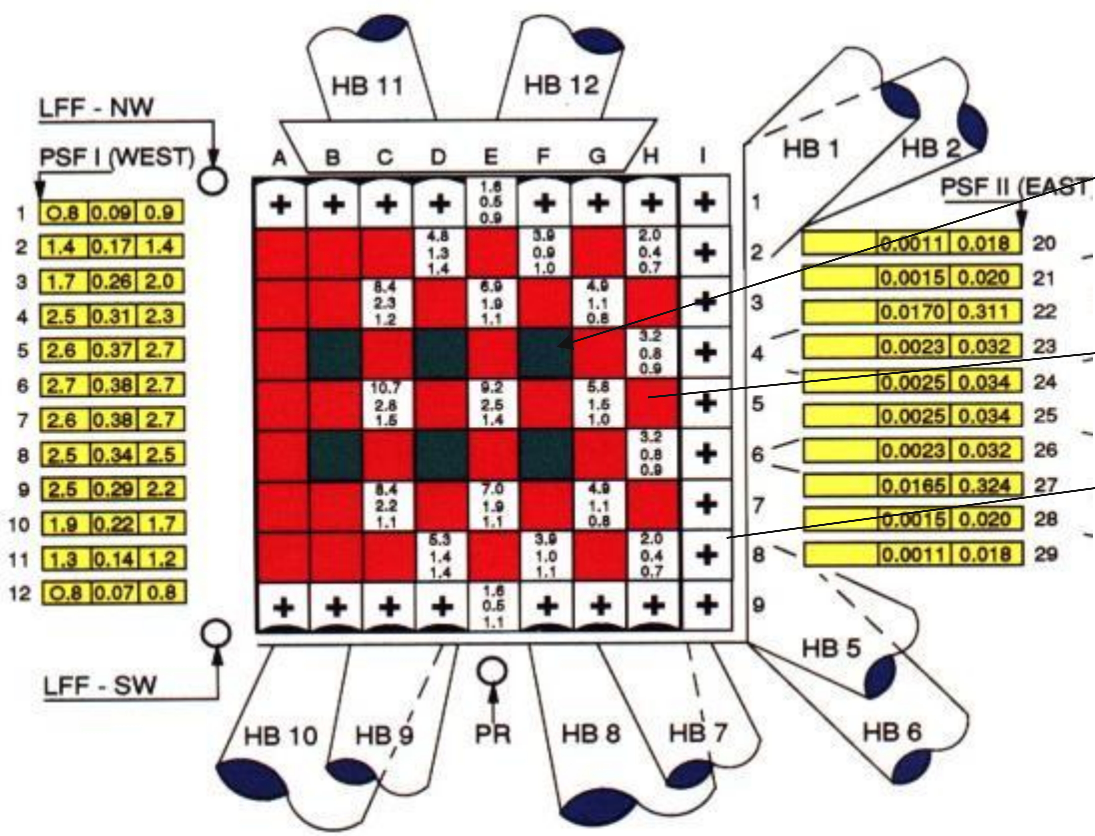
OVERVIEW OF THE HIGH FLUX REACTOR



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



6 Control Rods

33 Fuel Assemblies

25 Beryllium reflector assemblies