Recommended bounding axial profiles in BUC applications from actual Burnup measurements in French PWR assemblies

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BUC Methodology

The recent BUC methodology developped by CEA in collaboration with AREVA-NC is accounting for:

- Actinides + 15 Fission Products (stable and non-gazeous)
- Conservative hypothesis for the depletion calculation
- Qualification Reports for spent fuel inventory calculation and reactivity worth of BUC nuclides : Isotopic Correction Factors (cf. II, 2.5)
- Bounding axial burnup profile of spent fuel assemblies

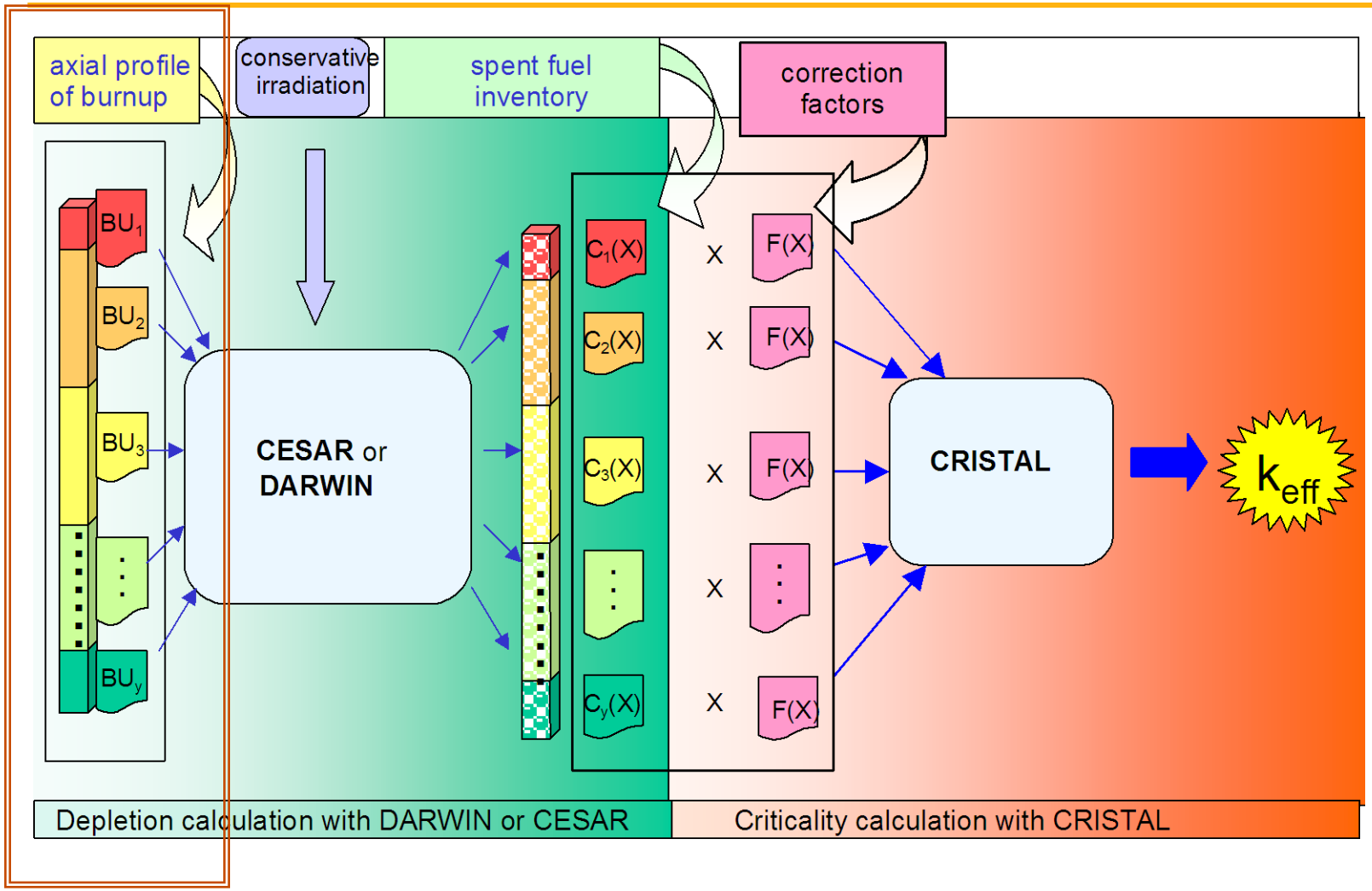
Main references : ICNC'95, FJSS'98, PHYSOR2002, TMC2005, ICNC'07

The previous method using a uniform mean BU gives a non realistic cosines axial flux → not conservative for BU > 30 GWd/t.

Use of burnup profile in criticality-studies necessary because of the "end-effect"

Ref: OECD/NEA Burnup Credit criticality Benchmark Phases II A-B

French PWR UO_2 BUC Calculation Route (DARWIN 2 / CRISTAL V1 / JEF2.2)



Origin of the data

- 200 PWR-UOx fuel assemblies from different NPPs (900 MWe) are considered

  $20 < BU < 50$ GWd/t
- Gamma spectrometry measurement ^{137}Cs in La Hague Reprocessing plant
- Curves of 512 data (1 cm pitch) on 2 opposite faces of each assembly
- Acquisition from the bottom to the top end of each assembly

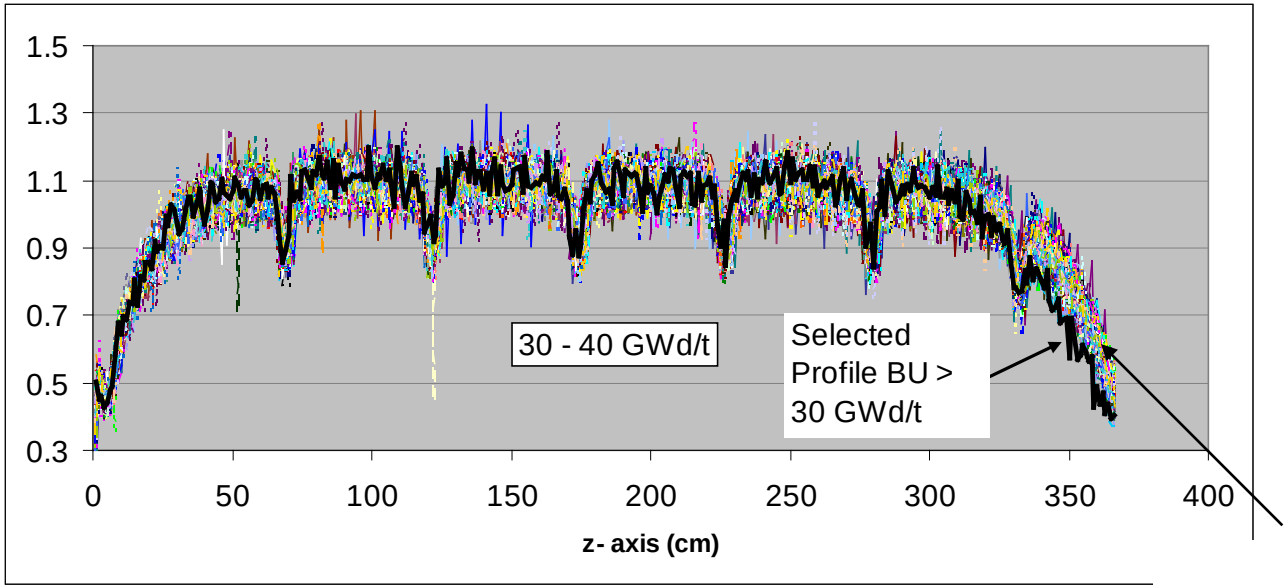
E. Cabrol et al., ICNC'07

Post-treatment

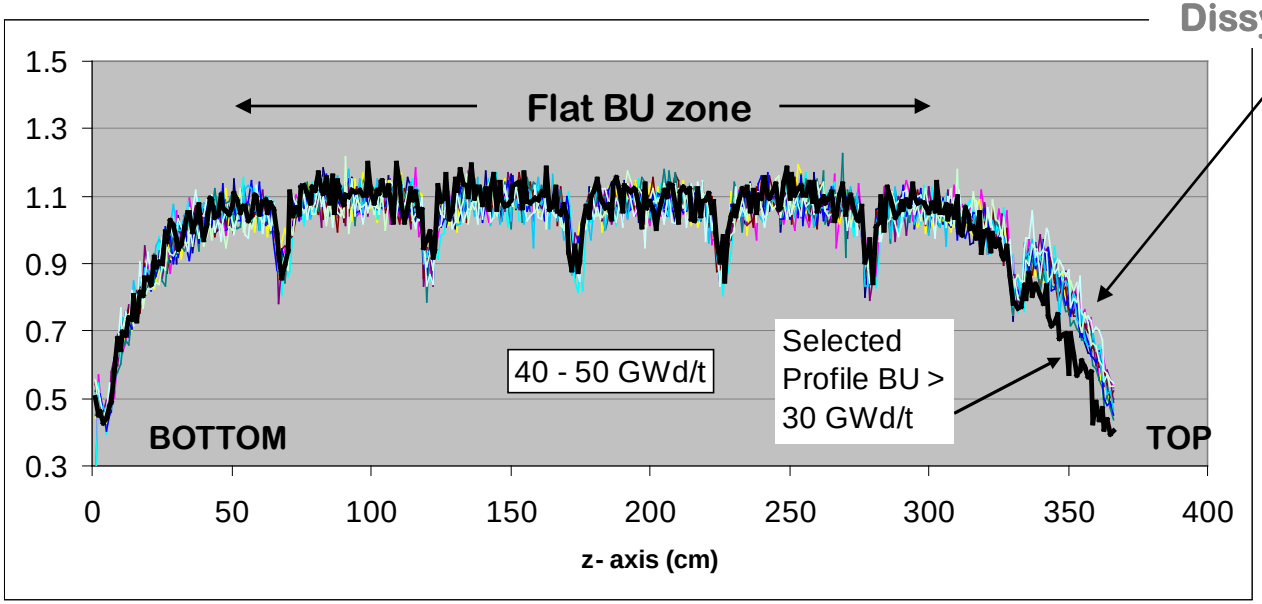
- Threshold + fissile column data selection (366 cm)
- Normalization of the curves to 1.0
- The data are classified in function of the mean BU
  - [20 – 30 GWd/t]
  - [30 – 40 GWd/t]
  - [40 – 50 GWd/t]

Overview of the database (Mean BU > 30 GWd/t)

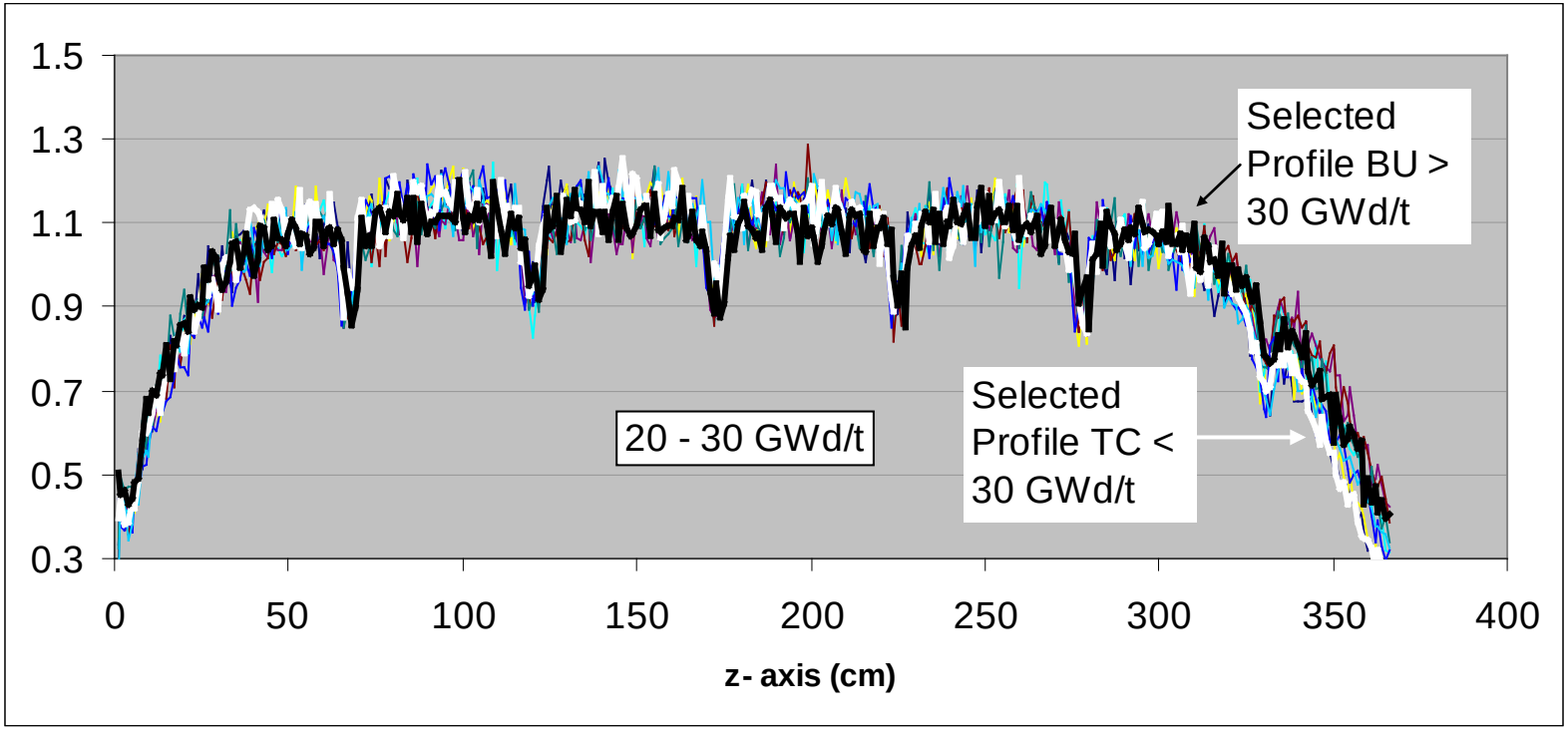
Selection of a bounding profile for FAs with Mean BU > 30 GWd/t



Slight Dissymmetry

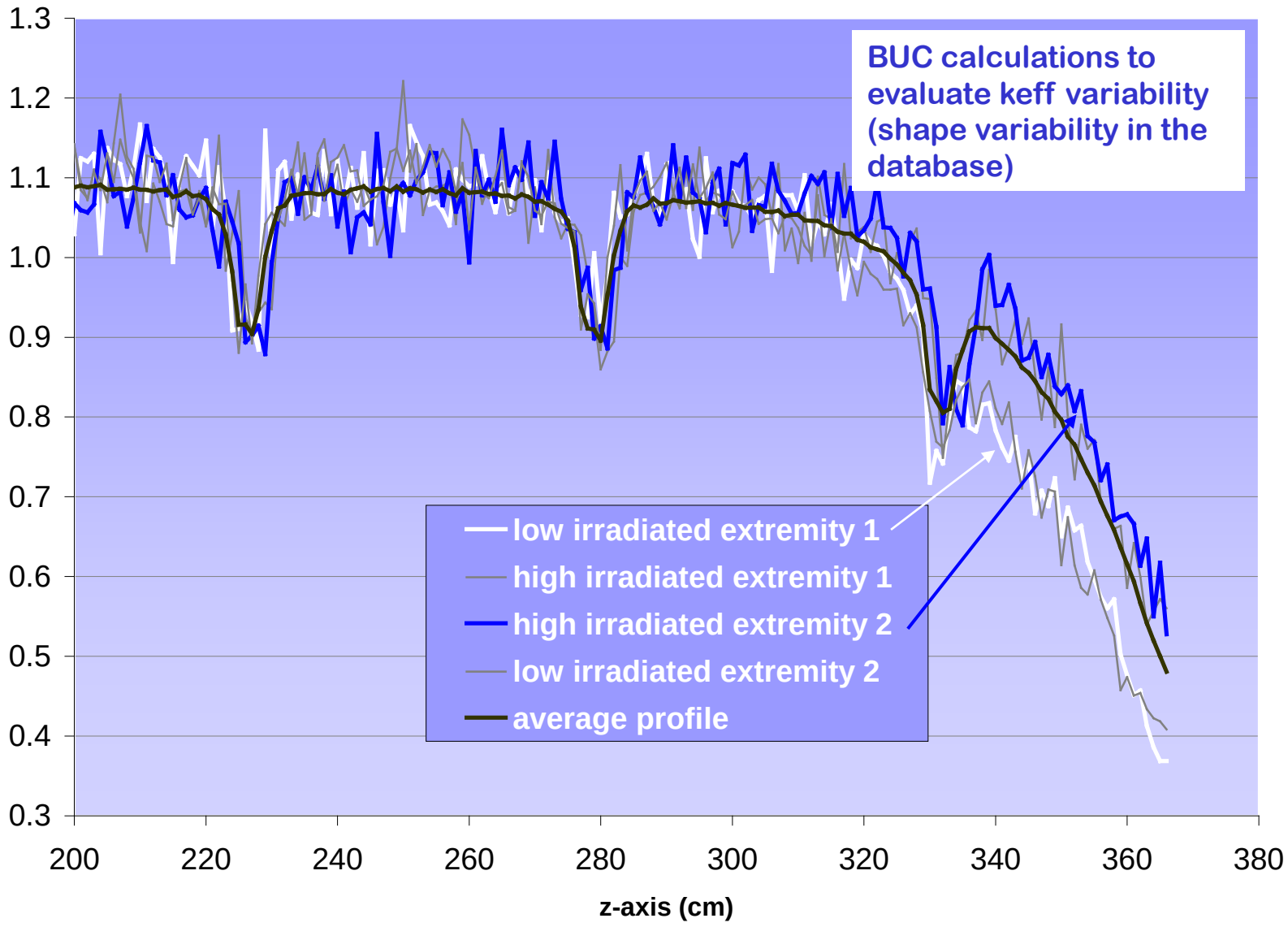


Overview of the database (Mean BU < 30 GWd/t)



Selection of a bounding profile for FAs with Mean BU < 30 GWd/t (More conservative)

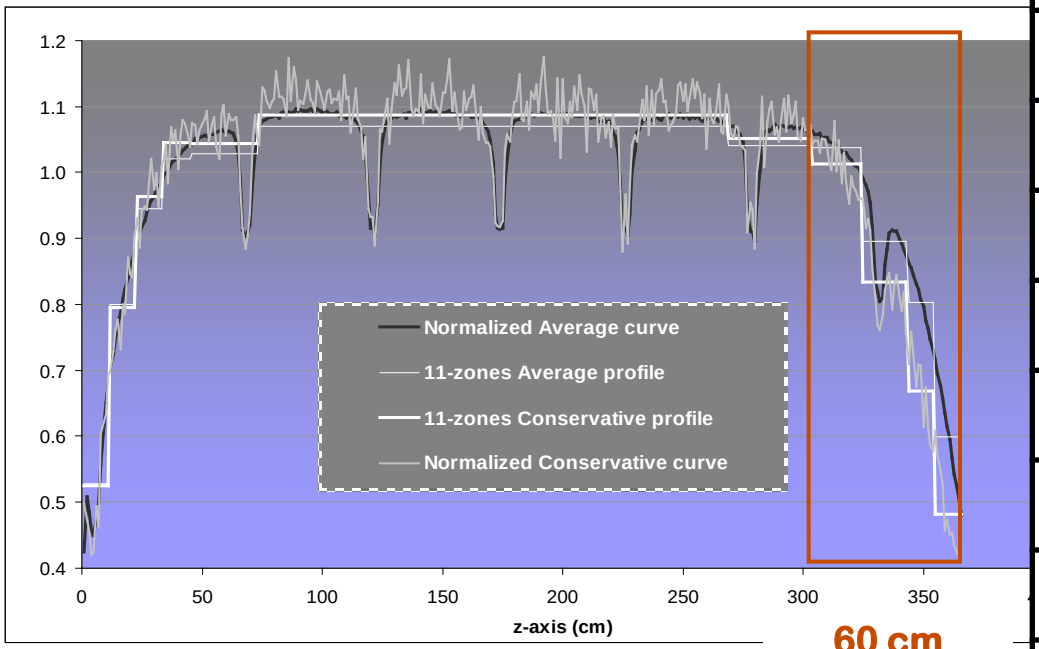
End-effect variability



Axial zoning

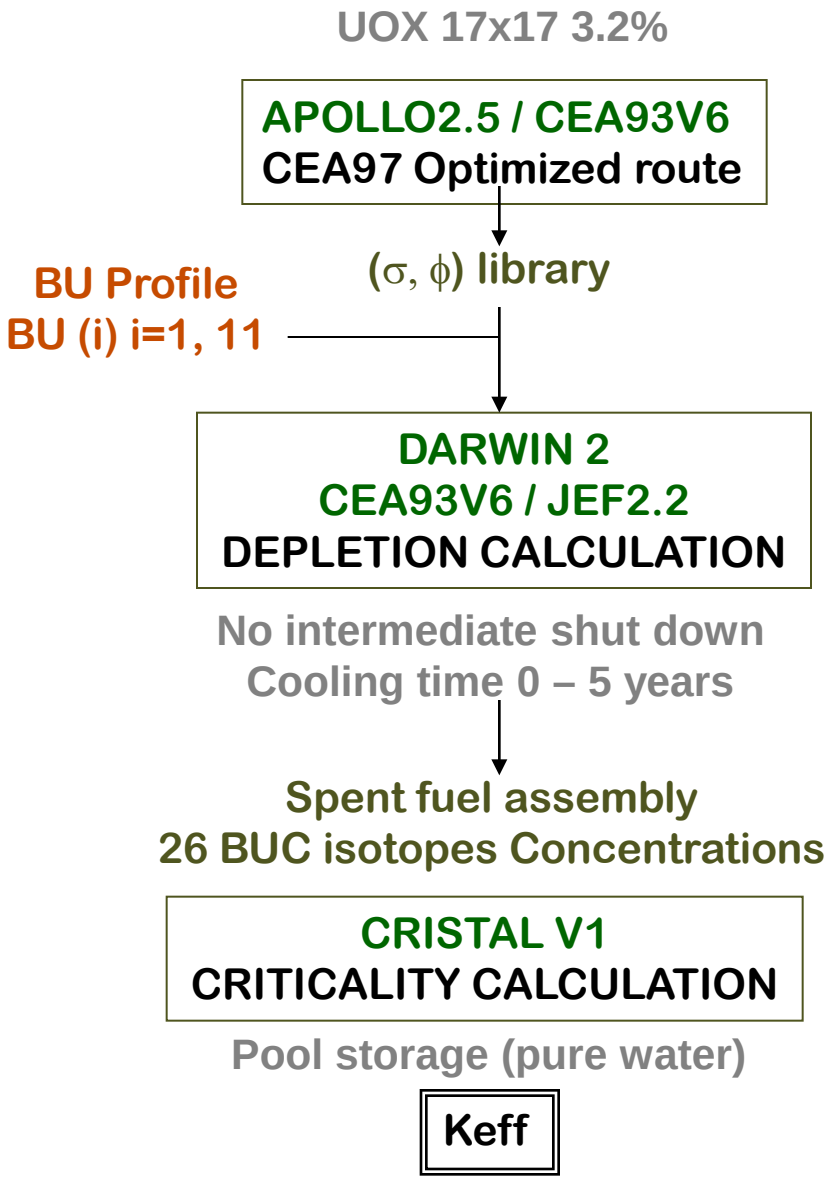
- The modelization of the profiles, i.e. the number of axial zones used for their description, must be optimized to obtain a good time / precision compromise for BUC calculations.

BU profile description in 11 zones



60 cm lowest irradiated

Axial z value (cm)	Mean BU ≥ 30 GWj/t	Mean BU < 30 GWj/t
11	0.52	0.49
22	0.79	0.79
33	0.96	0.95
45	1.04	1.07
73	1.05	1.08
H-98	1.089	1.116
H-63	1.05	1.03
H-42	1.01	0.98
H-23	0.83	0.74
H-12	0.66	0.55
H	0.48	0.33


UOX 17x17 3.2%
APOLLO2.5 / CEA93V6
CEA97 Optimized route
(σ, ϕ) library
BU Profile
BU (i) i=1, 11
DARWIN 2
CEA93V6 / JEF2.2
DEPLETION CALCULATION
No intermediate shut down
Cooling time 0 – 5 years
Spent fuel assembly
26 BUC isotopes Concentrations
CRISTAL V1
CRITICALITY CALCULATION
Pool storage (pure water)
Keff

Criticality calculation results

- Calculation results with the standard route (Δkeff/keff)
  - BUC of around 21000 pcm
  - Keff variability 1000 pcm at BU = 30 GWd/t

Type of Profile	BUC (pcm)	Comparison with the average profile $Ln[k_{eff}^{bounding} / k_{eff}^{av}]$(pcm)			
	BU 30 GWd/t, CT 0 y	BU 30 GWd/t		BU 45 GWd/t	
		CT 0 y	CT 5 y	CT 0 y	CT 5 y
Average profile (BU > 30 GWd/t)	-24030	-	-	-	-
Bounding profile BU > 30GWd/t	-23180	+850	+1420	+1930	+2900

'Similar' Burnup profiles for PWR UOx fuels, close to the average one

Type of Profile	End-effect $Ln[k_{eff}^{prof} / k_{eff}^{flat}]$ (pcm)			
	BU 30 GWd/t		BU 45 GWd/t	
	CT 0 y	CT 5 y	CT 0 y	CT 5 y
Average profile (BU > 30 GWd/t)	-920	-780	-550	+30
Bounding profile BU > 30 GWd/t	-70	+640	+1380	+2940

Recommended

- Calculation results with the conservative route (Δkeff/keff)
  - because of the strong conservative options of the APOLLO2 calculation sheme : BUC reduced to 15000 pcm
  - + Variability of the keff reduced < 1000 pcm for all BU

Type of Profile	BUC (pcm)	Comparison with the average profile Δkeff/keff (pcm)			
	BU 30 GWd/t, CT 0 y	BU 30 GWd/t		BU 45 GWd/t	
		CT 0 y	CT 5 y	CT 0 y	CT 5 y
Average profile (FAs BU > 30 GWd/t)	-15150	-	-	-	-
Conservative profile BU > 30GWd/t	-15100	+10	+300	+200	+800
Conservative profile BU < 30 GWd/t		*+500*	*+1250*		

- Use of a Burnup profile for a rigorous taking into account of the reactivity loss of SFAs.
- Bounding axial profile recommended (11 zones)
  - Important experimental French database used
  - Low variability of the end-effect
  - Limited end-effect < 1000 pcm at 30 GWd/t

Axial z value (cm)	Mean BU ≥ 30 GWj/t	Mean BU < 30 GWj/t
11	0.52	0.49
22	0.79	0.79
33	0.96	0.95
45	1.04	1.07
73	1.05	1.08
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