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Burnup credit implementation for transport/storage casks of irradiated PWR UO_2 fuel assemblies

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Looking to the future PATRAM 2010

LOGISTICS

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TNI's burnup credit practice - Overview

Type of cask	Package approval for:	
	Nr of fuel elements	Max initial enr. ($^{235}U/U_{total}$)
TN® 13/2	11	3.31 wt. %

1984 Fresh fuel assumption

1987 Actinides only BUC — TN® 13/2 — (12) 3.2 GWd/t_U — 3.55 wt.% — Qualitative checking

1993 Actinides only BUC — TN® 13/2 — (12) 12 GWd/t_U — 4 wt.% — Quantitative measurement

2000 Actinides + FP BUC, Bounding axial profiles — TN® casks under application — ? GWd/t_U — 5wt. % — Quantitative measurement or Reactor record data + Qualitative checking

TNI's actinides only BUC

Very pessimistic assumptions

- **Only 8 major actinides**

  ^{235}U, ^{236}U, ^{238}U, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu

- **Irradiation History**
  - Specific power 40 W/g
  - 1 irradiation cycle
  - No cooling time

TNI's actinides only BUC
- Calculation scheme

Depletion Code

DARWIN (APOLLO2)

FUEL INVENTORY

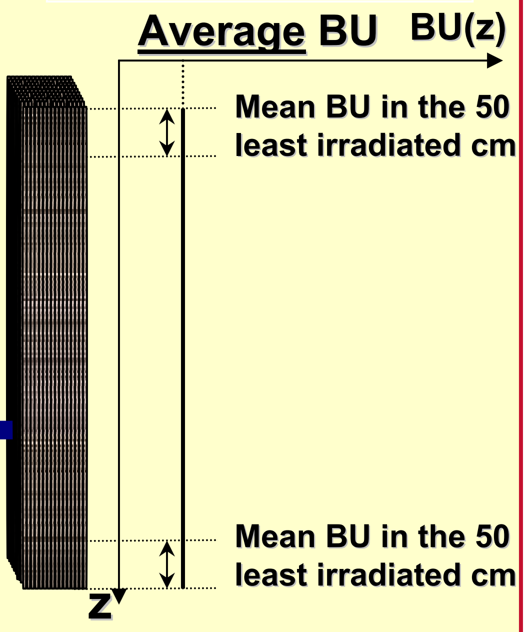
CRISTAL V1 Package

JEF2 → *CEA93* → *APOLLO2 Cell Calculation 1D* → *MORET4 Monte-Carlo Method 3D*

DARWIN (APOLLO2) → APOLLO2 Cell Calculation 1D

K_{eff}

AXIAL BURNUP PROFILE



Axial burnup profile → MORET4 Monte-Carlo Method 3D

TNI's new BUC methodology

- The new BUC methodology implemented in TNI is based on Actinides + Fission products (FP) and
  - Conservative irradiation data for depletion calculations
  - Use of bounding axial profiles evaluated from reactor record data or measurements
  - Validation of the depletion code
  - Validation of the criticality code

TNI's new BUC methodology

- **9 Actinides and 6 Fission Products (FP) are taken into account**

☞ **^{235}U, ^{236}U, ^{238}U, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am**
+ ^{149}Sm, ^{103}Rh, ^{133}Cs, ^{152}Sm, ^{143}Nd, ^{155}Gd,

Nota : OECD recommandations 15 FP (stable and non-gazeous) :
^{149}Sm, ^{103}Rh, ^{133}Cs, ^{152}Sm, ^{143}Nd, ^{155}Gd,
^{95}Mo, ^{99}TC, ^{101}Ru, ^{109}Ag, ^{145}Nd, ^{147}Sm, ^{150}Sm, ^{151}Sm, ^{153}Eu

↳ ***6 PF*** *: 50% anti-reactivity of all FP*

↳ ***15 PF*** *: 80% to 90% anti-reactivity of all FP*

TNI's new BUC methodology
- Calculation scheme

Depletion Code

DARWIN (APOLLO2)

FUEL INVENTORY

CRISTAL V1 Package

JEF2

CEA93

APOLLO2
Cell Calculation

MORET4
Monte-Carlo Method

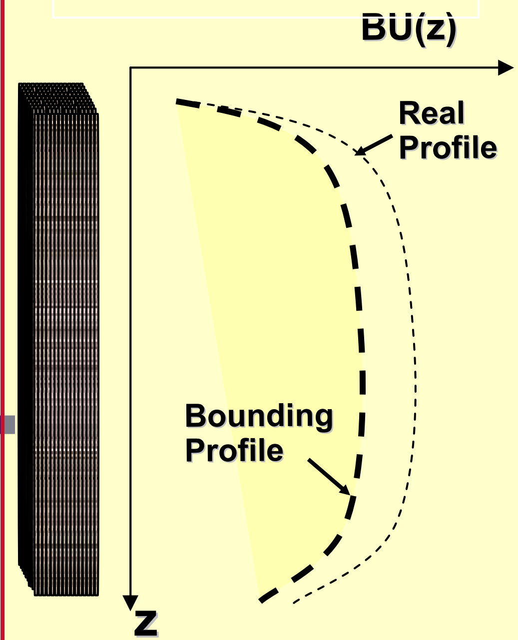
K_{eff}

Correction factors

or

Penalty terms

AXIAL BURNUP PROFILE



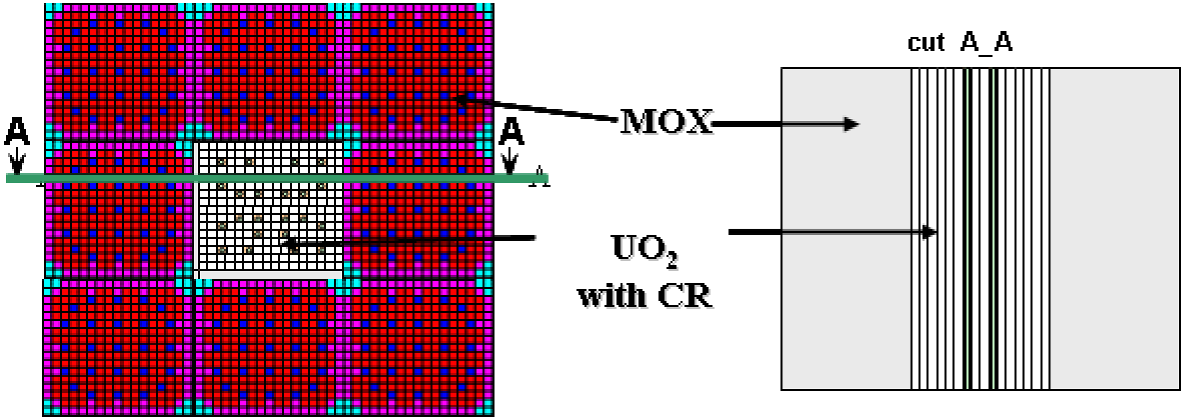
TNI's new BUC methodology – Fuel inventory

▶ **Conservative irradiation data for depletion calculations**

Parameters	Comment	Reference
Specific power	30-50 W/g ⇒ Low effect on reactivity ⇒ realistic P_{spec}	*« Current studies related to the Use of burnup credit in France »* ICNC2003
Fuel temperature	550°- 650°C ⇒ Low effect on reactivity ⇒ realistic T	
Moderator temperature	Conservative value: at the outlet of the core	
Natural boron concentration in the moderator	800 ppm Conservative value: constant average boron concentration	*Phenomena and parameters important to burnup credit"* ORNL IAEA 10-14 July 2000
Irradiation history	1 cycle: conservative value	

TNI's new BUC methodology
- Fuel inventory

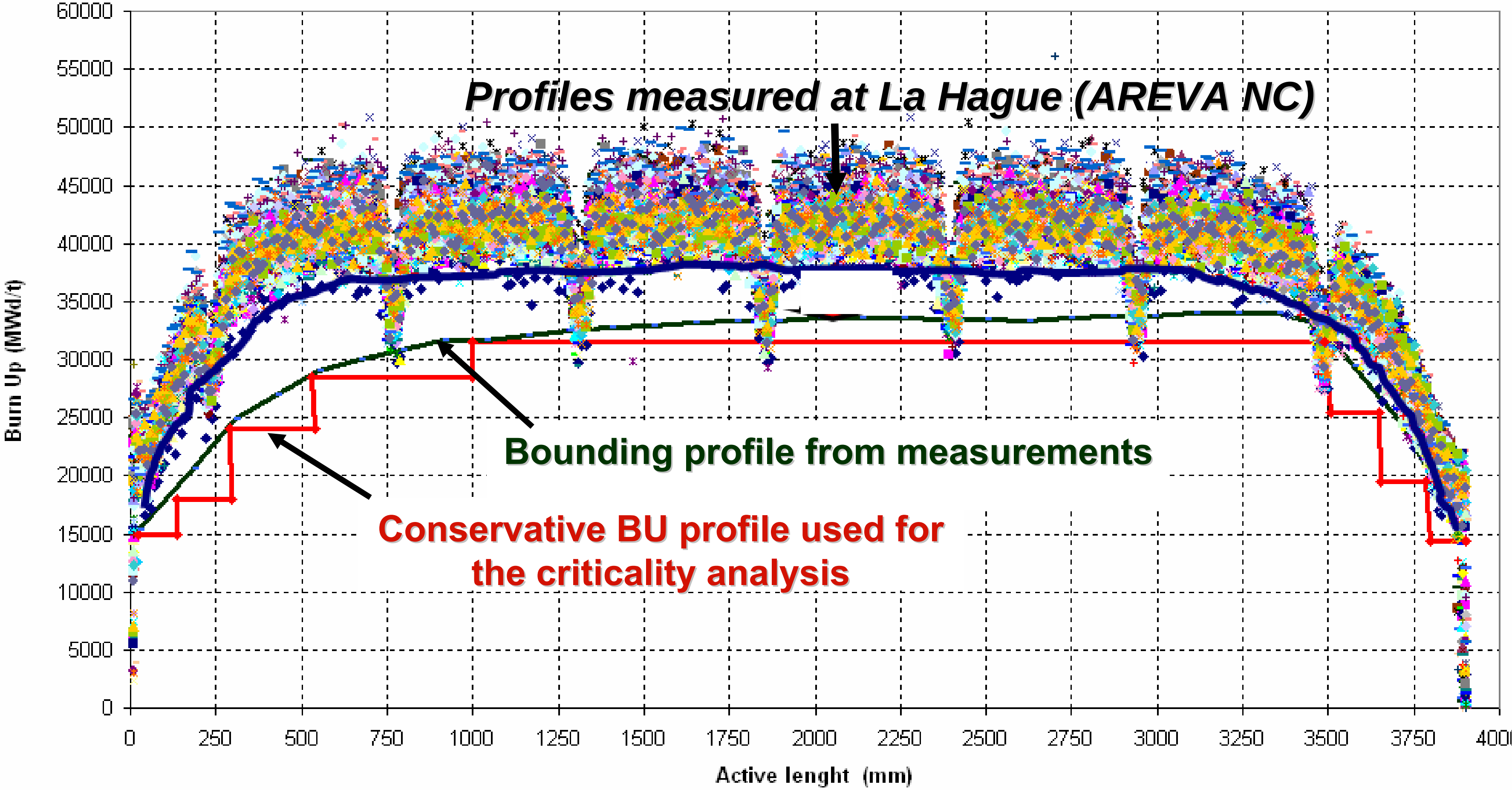
Parameters	Assumptions	Comment
Location of the fuel assemblies within the core	UOX assembly surrounded by 8 MOX assemblies during the entire irradiation	Conservative
Control rods (B_4C or AIC)	Total insertion of the CRs during the entire irradiation	Conservative
Cooling time of fuel assemblies	2 years	Conservative



LOGISTICS

TNI's new BUC methodology
- Bounding axial profiles

- Axial profiles evaluated from reactor record data or measurements



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TNI's new BUC methodology - Depletion code validation

- **Validation of the DARWIN depletion code by using isotopic correction factors (CFs) or penalty terms (Δk)**

Two kinds of experiments carried out :

- **P.I.E on PWR spent fuels :**
  - ***Chemical analyses of spent fuel samples (Actinide + FP)***

    → ***Qualification of fuel inventory calculations***

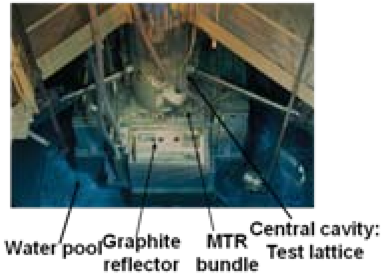
- **Reactivity worth measurements in the Minerve reactor**
  - ***Oscillation of separated FP samples***

    → ***Validation of FP cross section***

  - ***Oscillation of irradiated samples from PWR fuel rod cuts***

    → ***Determination of the total reactivity worth of real irradiated samples***

Minerve core



TNI's new BUC methodology
- Criticality code validation

- **Validation of the criticality code CRISTAL V1 by using French HTC & FP critical experiments**

HTC experiments (HTC rods)

✓ **Objectives : Validation of major actinides cross sections**

✓ **Series of 205 critical experiments**

FP experiments (UOX and/or HTC rods)

✓ **Objectives : Validation of FP cross sections**

Six FP of BUC ⇨ ^{103}Rh, ^{133}Cs, ^{143}Nd, ^{149}Sm, ^{152}Sm, ^{155}Gd

✓ **Series of 145 critical experiments**

Common Interest Program IRSN/COGEMA under disclosure agreement

Application

- Reactivity gain against fresh fuel assumption due to different BUC approaches

Transport cask loaded with 7 PWR 17x17 UO2 FAs, 5 wt. % ^{235}U

Average Burnup (GWd/t_{HM})	Actinides-only	Actinides + 6FPs	Actinides + 15 FPs
10	-2.9 %	-5.5 %	-6.1 %
20	- 6.1 %	-9.1 %	-10.5 %
30	-8.4 %	-12 %	-14 %
40	-10.3 %	-15.2 %	-17.3 %
50	-12.5 %	-17.7 %	-20.2 %

New BUC method based on "Actinides + 6 FPs" used with conservative depletion and criticality calculations gives a reactivity gain of:

- Δk = 5.5 % 10 $GWd/\ t_{HM}$
- Δk = 17.7 % 50 GWd/t_{HM}

Conclusion

- **The advanced BUC method implemented at TN International, based on the consideration of actinides and 6 fission products, allows to extend burnup credit advantages to new transport and storage casks designs**

- **Calculation codes used in the advanced BUC method (DARWIN 2 and CRISTAL V1) are validated to a large experimental program (PIE, MINERVE, HTC and PF experiments) .**

- **Taking profit of the feedback received from investigations on burnup credit, TN International's current and expected future activities for the transport/storage cask design developments are:**
  - **Extension of BUC method for 15 FP**
  - **BUC method for MOX PWR fuel assemblies**
  - **BUC method for UO_2 BWR fuel assemblyies**

Thank you for your attention