# LATEST STUDIES RELATED TO THE USE OF BURNUP CREDIT IN FRANCE

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for
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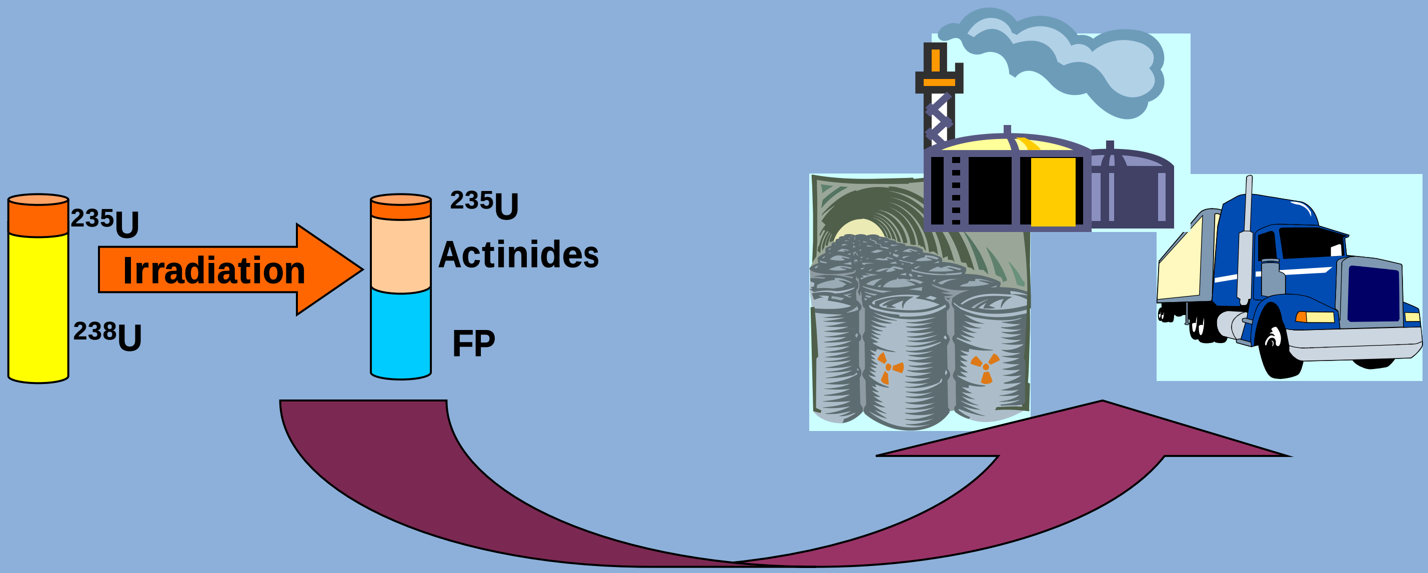


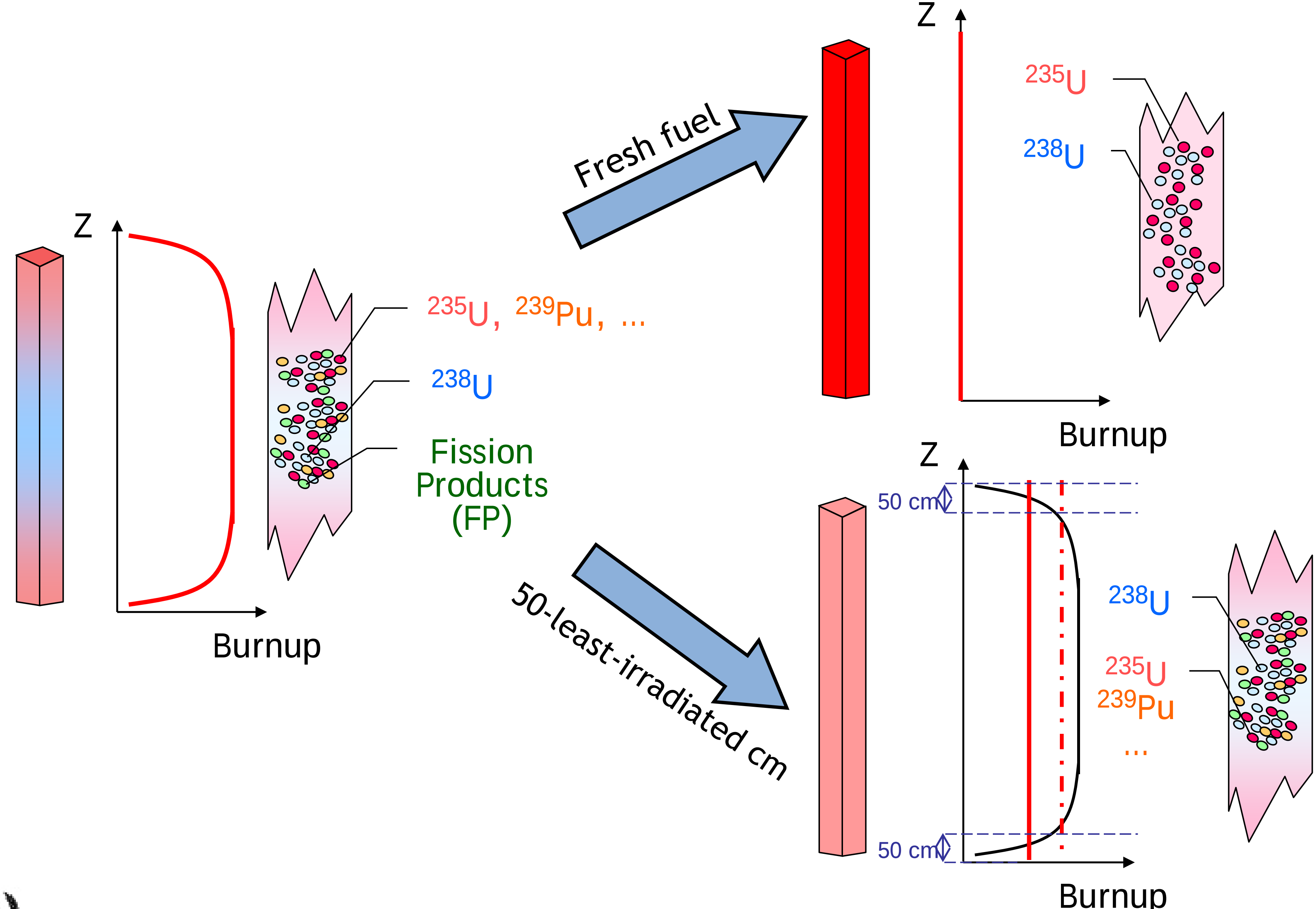

**International Workshop on Advances in Applications of Burnup Credit for Spent Fuel Storage, Transport, Reprocessing, and Disposition**

**27-30 October 2009 - Cordoba, Spain**

# OVERVIEW

1. **Burnup Credit context in France**
2. **Process to take Burnup Credit into account in criticality calculation with CRISTAL package**
3. **PWR fuels studies**
   - Determination of an axial burnup profile for UOX fuel
   - Determination of correction factors for isotopic composition of UOX fuel
   - Determination of a bounding isotopic MOX composition
4. **BWR UOX fuels studies**
5. **Burnup Credit gain estimation**
6. **Conclusion and prospects**

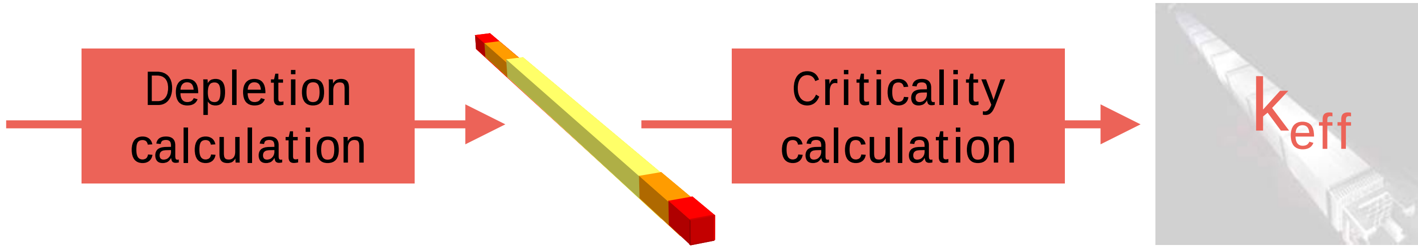
# Burnup Credit context in France

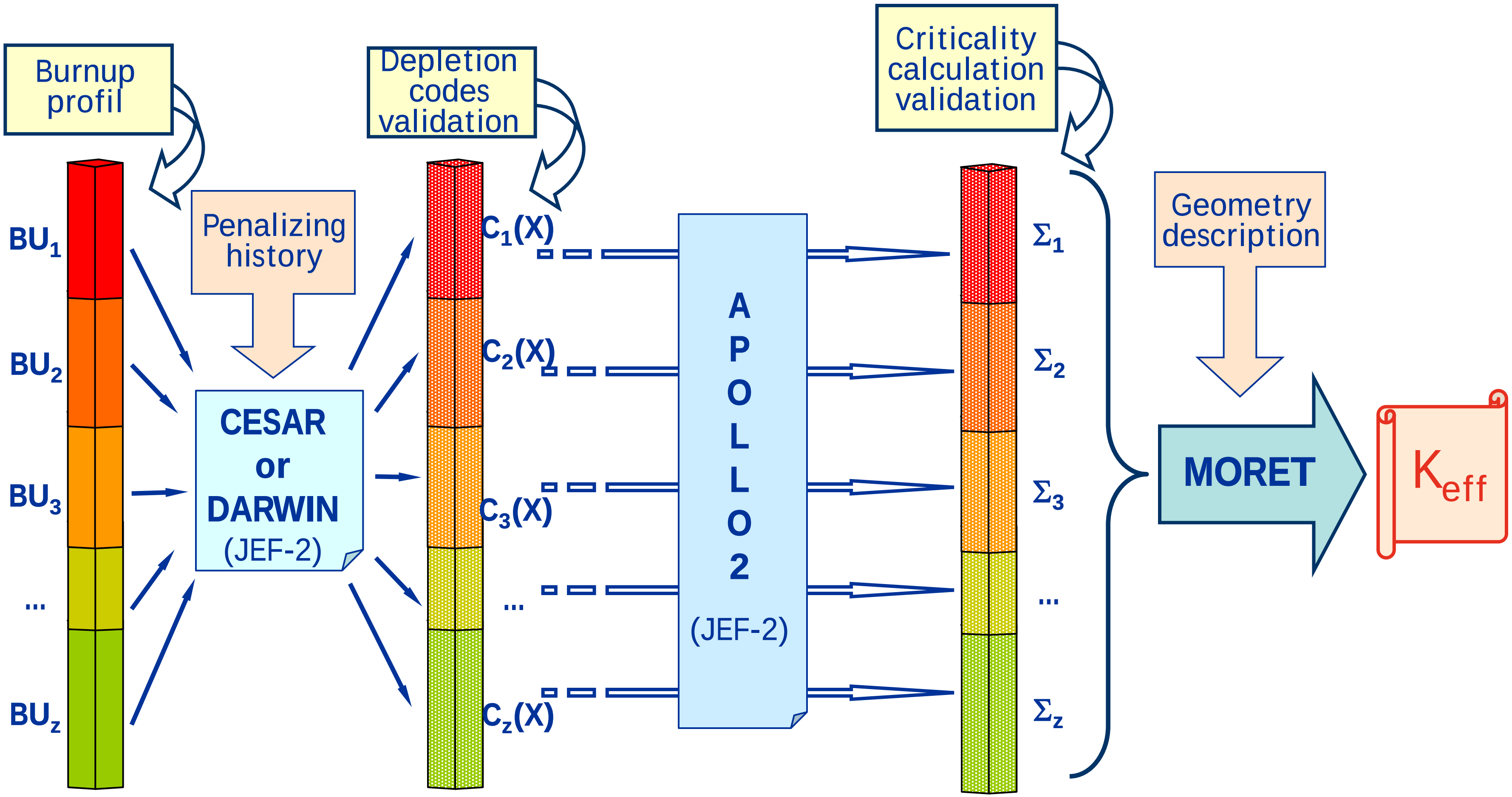


**UOX fuel initial enrichment ↗**
**Storage needs for spent fuel ↗**

➡ Need for less penalizing method to implement Burnup Credit (take into account fission products and a bounding axial burnup profile)

**Creation of a working group composed of AREVA, EDF, CEA, ANDRA and IRSN**



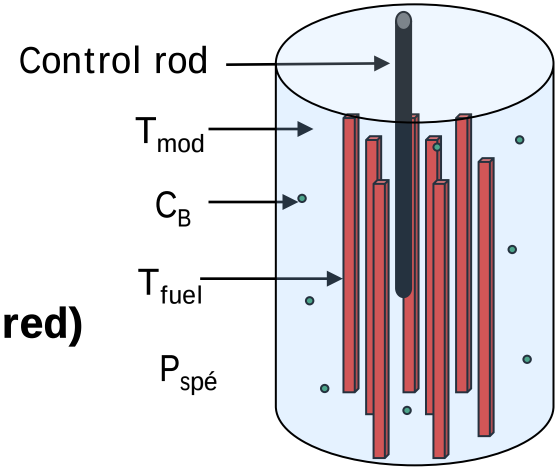

Burnup profil
Depletion codes validation
Criticality calculation validation
BU$_1$
BU$_2$
BU$_3$
...
BU$_z$
Penalizing history
CESAR or DARWIN (JEF-2)
C$_1$(X)
C$_2$(X)
C$_3$(X)
...
C$_z$(X)
A P O L L O 2 (JEF-2)
$\Sigma_1$
$\Sigma_2$
$\Sigma_3$
...
$\Sigma_z$
Geometry description
MORET
K$_{eff}$

## Conclusions from early studies about PWR UOX fuels:

**It is conservative to consider for the depletion calculations:**

- **Presence of the control rods**
- **Maximum boron concentration**
- **Maximum moderator temperature**
- **Maximum fuel temperature**
- **Maximum specific power (when no cooling time is considered)**
- **Minimum cooling time justified by operators (<50 years)**

} Spectrum hardening

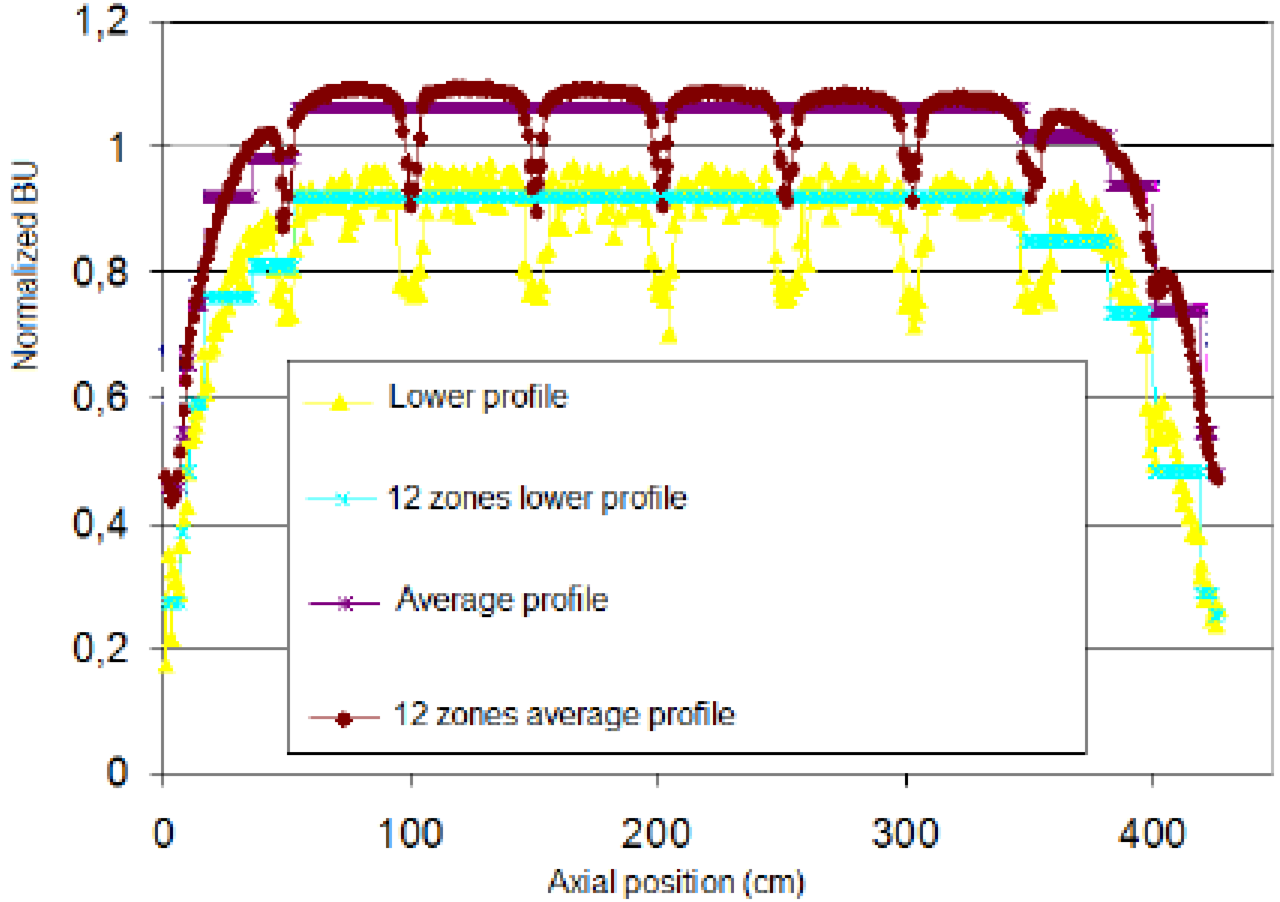



## Latest studies about PWR fuels concerns:

- **Determination of an axial burnup profile for UOX fuel**
- **Determination of correction factors for isotopic composition of UOX fuel**
- **Determination of a bounding isotopic MOX composition**

**Axial burnup measurements from hundreds of French UOX assemblies with**

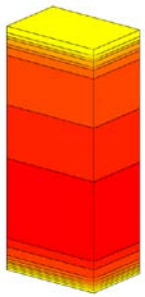
- U235/U (% w) ~ 3.1%
- Average burnup ranging between 30 - 40 GWd/t



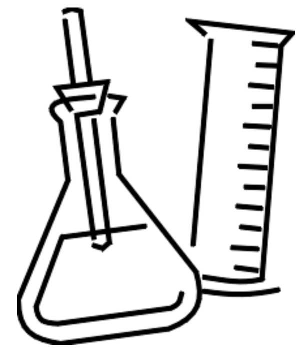

*Cf. "Recommended Bounding Axial Burnup Profiles In BUC Applications From Actual Burnup Measurement of French PWR Assemblies" presented by C. Riffard*

## Validation of depletion codes relies on comparisons between calculated and measured concentration values

**(C-E)/E is the relative error between calculations and measures of each actinide and fission product**



C / E

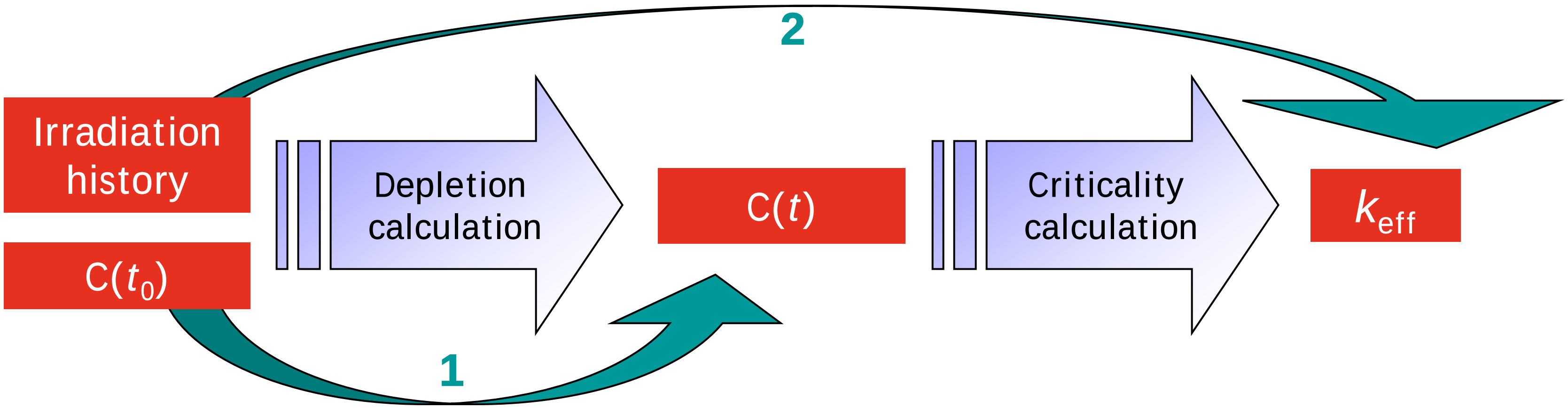


## In a conservative approach, correction factors are needed to :

- Underestimate absorbing isotopes,
- Overestimate fissile isotopes.

# Correction factors for isotopic composition of UOX fuel

**Two sets of correction factors for UOX fuel have been determined:**




**1. Estimation of isotopic correction factors for the depletion calculations: it takes into account the total (C-E)/E uncertainties (uncertainties on chemical assays, determination of the burnup and calculations used in the validation process)**

- **Fissile isotopes are corrected by a factor > 1**
- **Absorbing isotopes are corrected by a factor < 1**
- **Overestimated fissile isotopes and underestimated absorbing isotopes are not corrected.**

} Penalty on the burnup credit gain of this isotopic correction < 2.8%

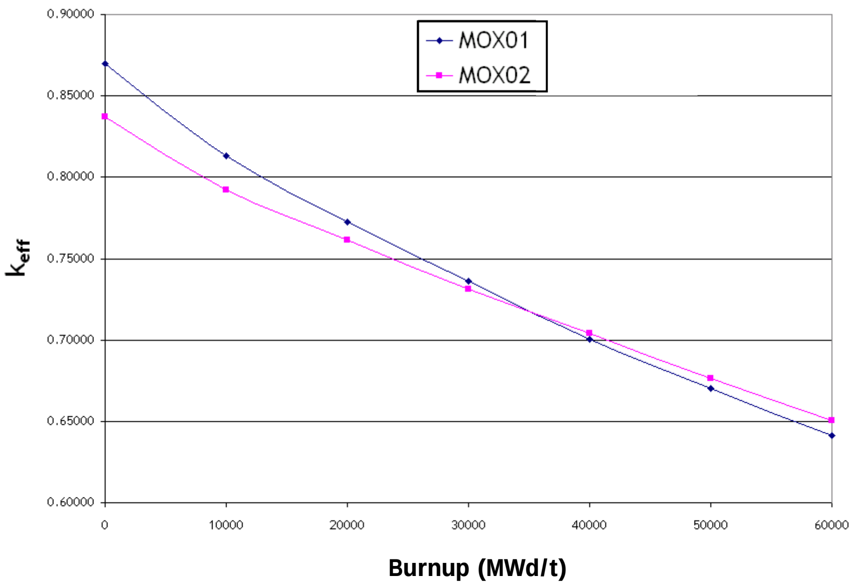
**2. The correction factors are based on the experimental validation of the spent fuel inventory carried out with DARWIN package and on the experimental validation of the reactivity worth carried out with CRISTAL package.**

*Cf. "Correction Factors Derived from French Experiments with the Recent JEFF3.1.1 Library for PWR-UOx BUC Applications" presented by C. Riffard*

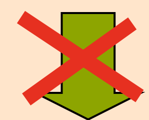
**The conservatism of the inventory of the irradiated PWR MOX fuel depends on the irradiation conditions and the fresh fuel characteristics.**

- **the influence on the conservatism of depletion calculations of the main parameters is studied for a given MOX fuel composition**

| | | |
|---|---|---|
| **Control rods penalty** → | **~ 65%** | **of the total penalty** |
| **Moderator temperature penalty** → | **~ 20%** | |
| **Boron concentration penalty** → | **~ 10%** | |




**A fresh fuel with a conservative isotopic vector of Pu**



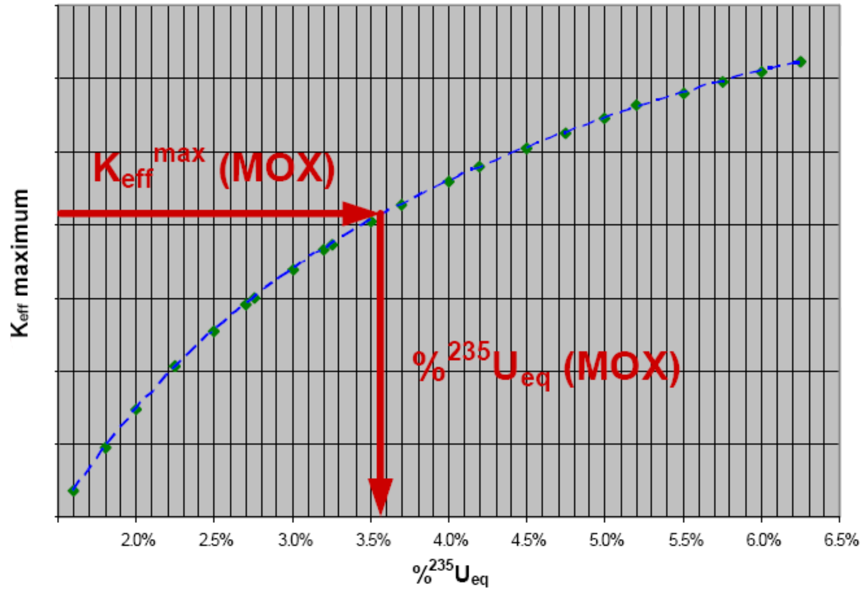
**The most reactive fuel after irradiation for PWR.**

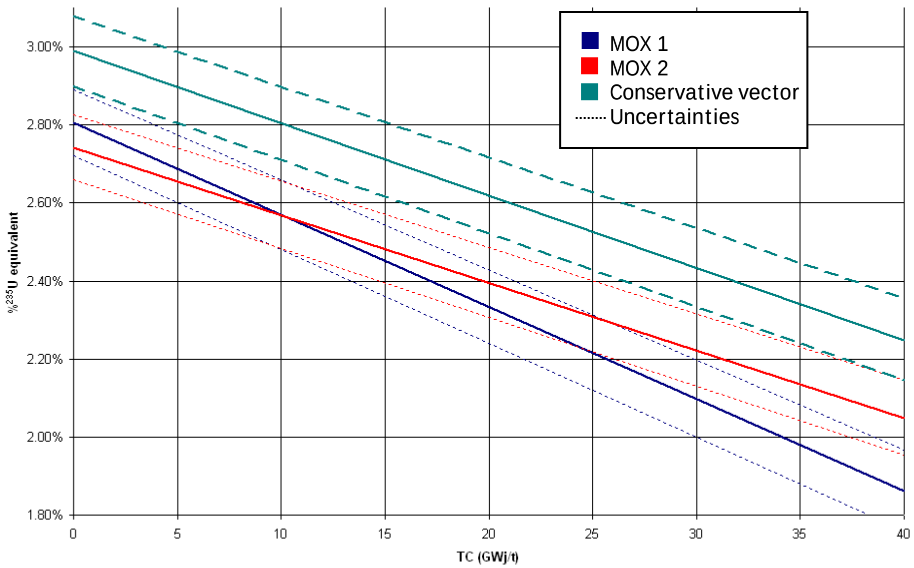
To simplify MOX Burnup implementation, a bounding fresh MOX that remains conservative during depletion should be defined

# 1. Method based on a reactivity equivalence between an UOX enrichment and a MOX fuel composition

This method consists in three steps:

- For each isotope in the MOX composition, a reactivity weight is set to construct a reactivity equivalent equation between MOX and UOX compositions.
  - ↳ an equivalent uranium enrichment ($\%^{235}U_{eq}$) is obtained for each MOX composition
- A correlation equation corresponding with the decay of the reactivity versus irradiation of each MOX composition is determined to take into account MOX fuel irradiation.
- Finally, this method is applied for each MOX fuel composition to select the most reactive composition.




Minimum Conservative vector = Max (MOX 1 & MOX 2)

## 2. Method based on plutonium isotopes relative abundance

For each MOX composition, the isotopic vector of Pu is $^{238}Pu_k / ^{239}Pu_k / ^{240}Pu_k / ^{241}Pu_k / ^{242}Pu_k$

$$^{240}Pu = Min(^{240}Pu_k)$$

$$^{241}Pu_{min} = r_1^*{}_{min}\ ^{240}Pu$$
$$^{241}Pu_{max} = r_{1\ max}\ ^{240}Pu$$

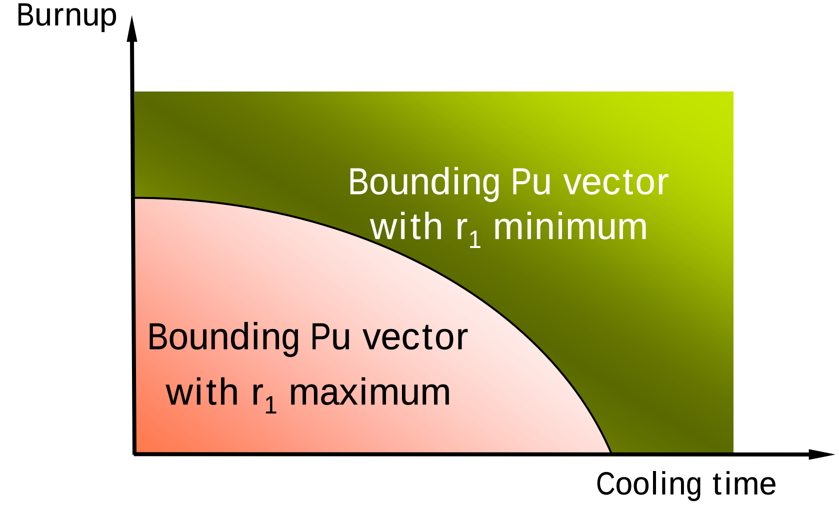
$r_1{}^* = {}^{241}Pu / {}^{240}Pu$

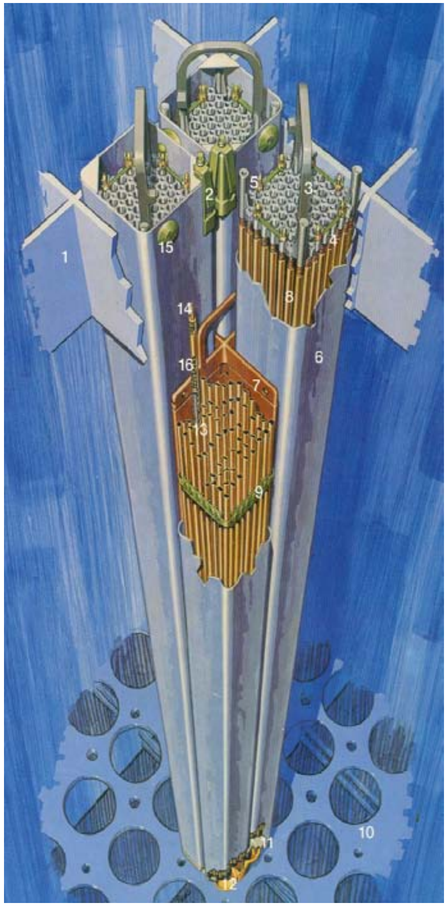
$$^{239}Pu_{min} = 100 - {}^{240}Pu - {}^{241}Pu_{max}$$
$$^{239}Pu_{max} = 100 - {}^{240}Pu - {}^{241}Pu_{min}$$
$$^{238}Pu = {}^{242}Pu = 0$$

2 isotopic vectors

$$F_1 = {}^{239}Pu_{min} \ / \ {}^{240}Pu \ / \ {}^{241}Pu_{max}$$
$$F_2 = {}^{239}Pu_{max} \ / \ {}^{240}Pu \ / \ {}^{241}Pu_{min}$$

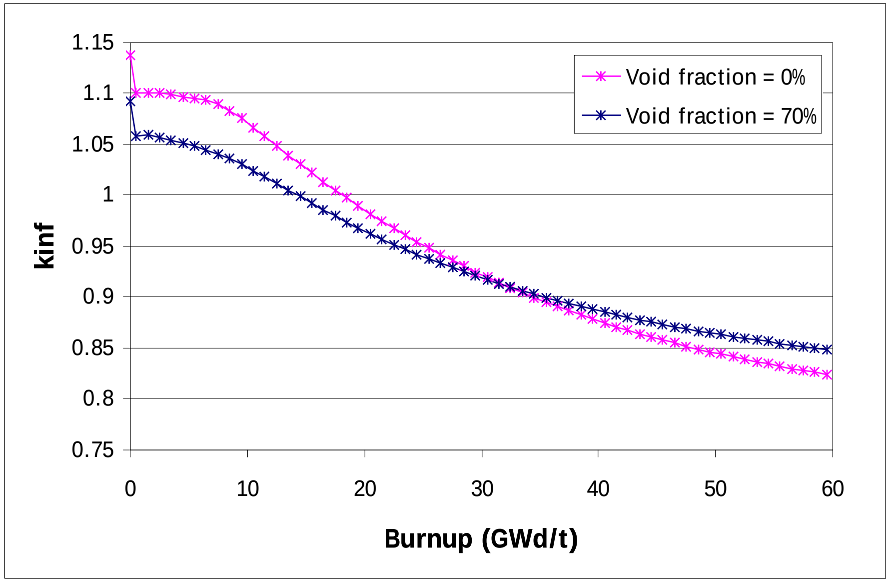
$$\mathbf{Max\ (k_{eff}\ (F_1)\ ;\ k_{eff}\ (F_2))}$$






A first study based on a GE 8×8 assembly has focused on the void fraction parameter:

- influence of the void fraction during the irradiation of the spent fuel content
- comparison of the results obtained with 2 depletion codes (TRITON and VESTA)




**Maximum void fraction** ⇏ **$k_{eff}$ maximum**

**Good agreement between TRITON and VESTA results**

**The different axial regions of void fraction considered with VESTA 3D calculation do not have much influence between them.**

# Burnup Credit gain estimation

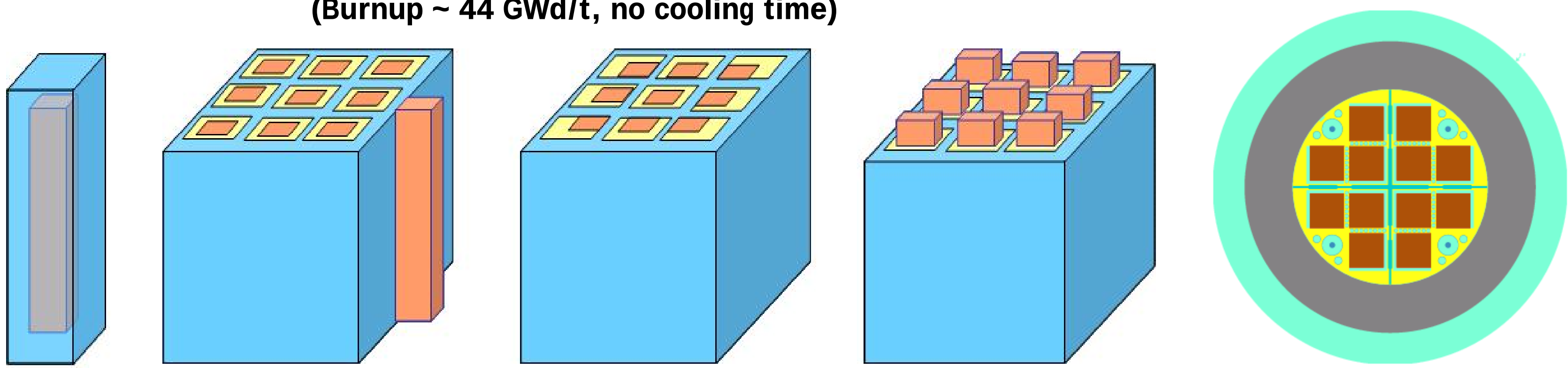
Burnup Credit gain ($\Delta K$) is defined as the difference of reactivity between an irradiated fuel and the same fresh fuel.

PWR

| | ΔK (pcm) | |
|---|---|---|
| | UOX | MOX |
| Assembly surrounded by 20 cm of water | 18300 | 10000 |
| Storage pool (fallen assembly) | 19200 | 10400 |
| Storage pool (of-centered assemblies) | 18300 | 10200 |
| Storage pool (higher standing assemblies) | 16000 | 8800 |
| Transport cask | 19600 | 10900 |

(Burnup ~ 44 GWd/t, no cooling time)

Even with penalizing irradiation conditions, Burnup Credit gains are significant for industrial applications



➡ Burnup Credit gain mainly comes from actinides for UOX fuel (~65%) and from fission products for MOX fuel (~65%).

BWR

➡ For an infinite array of BWR assemblies, $\Delta K$ reach 14000 pcm if standard profile of burnup and void fraction are taken into account.

# Conclusions and Prospects

The state of knowledge of the French working group covers all steps of process to take fuel burnup into account considering fission products and an axial profile for PWR UOX fuel.

↳ new objective: to make use of this knowledge

For PWR MOX fuel, the methods to determine a bounding isotopic MOX composition have to be evaluated to check if Burnup Credit gain is large enough for industrial applications.

Concerning BWR fuel, the French working group knowledge is limited.

Further studies should focus on:

↳ the combined influences of an axial profile of burnup and a void fraction with other profiles

↳ other BWR assembly designs with more heterogeneities

↳ influence of parameters like control blades, neighborhood assemblies, irradiation history.