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Lessons learnt from
OECD/NEA Phase II-C through Phase II-E Benchmarks

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Overview

- **Introduction: Some words about OECD/NEA Benchmarks Phase II-C through II-E**
- **Phase II-C: Description and Results**
- **Phase II-E: Description and Results**
- **Conclusion for different configurations**

Introduction

Phase II-C: Impact of the asymmetry of axial burnup profiles of spent PWR UO_2 fuel assemblies on the end effect was studied.

Results:

- End effect increases with increasing asymmetry and
- is significantly dependent on "local asymmetry" of the profiles.
- Asymmetry decreases with increasing average burnup,
- but end effect increases with increasing average burnup at given asymmetry.

Phase II-D: Effect of control rod (CR) insertion during irradiation of PWR UO_2 fuel assemblies on the spent fuel composition.

Results: Due to spectrum hardening,

- **CR insertion results in a change of the spent nuclear fuel (SNF) isotopic inventory:**
  At given initial enrichment and given burnup, SNF which was exposed to CR insertion during irradiation has a higher reactivity than SNF which has not been exposed to CR insertion.

Phase II-E: Combination of asymmetry effect and CR insertion effect

Phase II-C

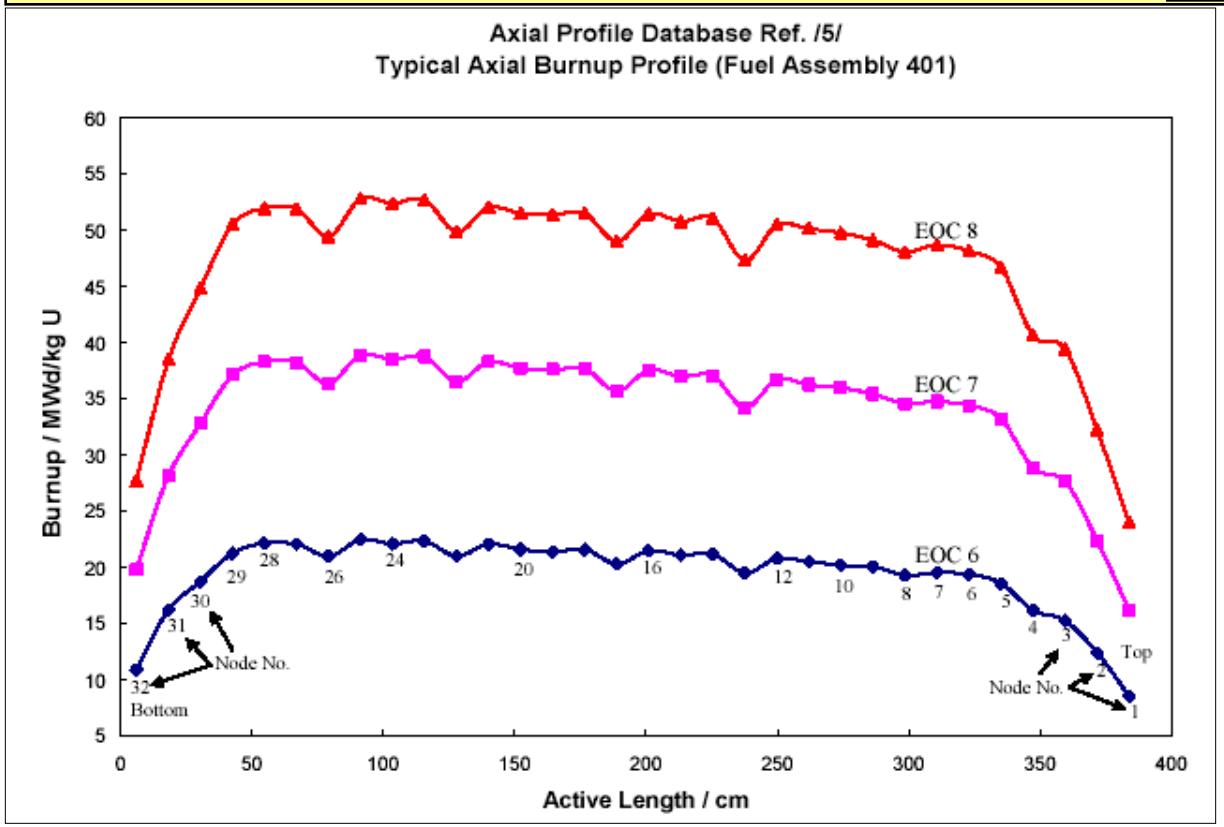
Objective

Objective: Impact of the asymmetry of axial profiles on

- **end effect**
- **axial fission density distribution**

Definition of the end effect:

$\Delta k = k_{eff}\,(\text{shape}) - k_{eff}\,(\text{uniform})$



Fission density in zone i:
Number of fissions by unit volume in zone i normalized to one fission by unit volume in the whole system

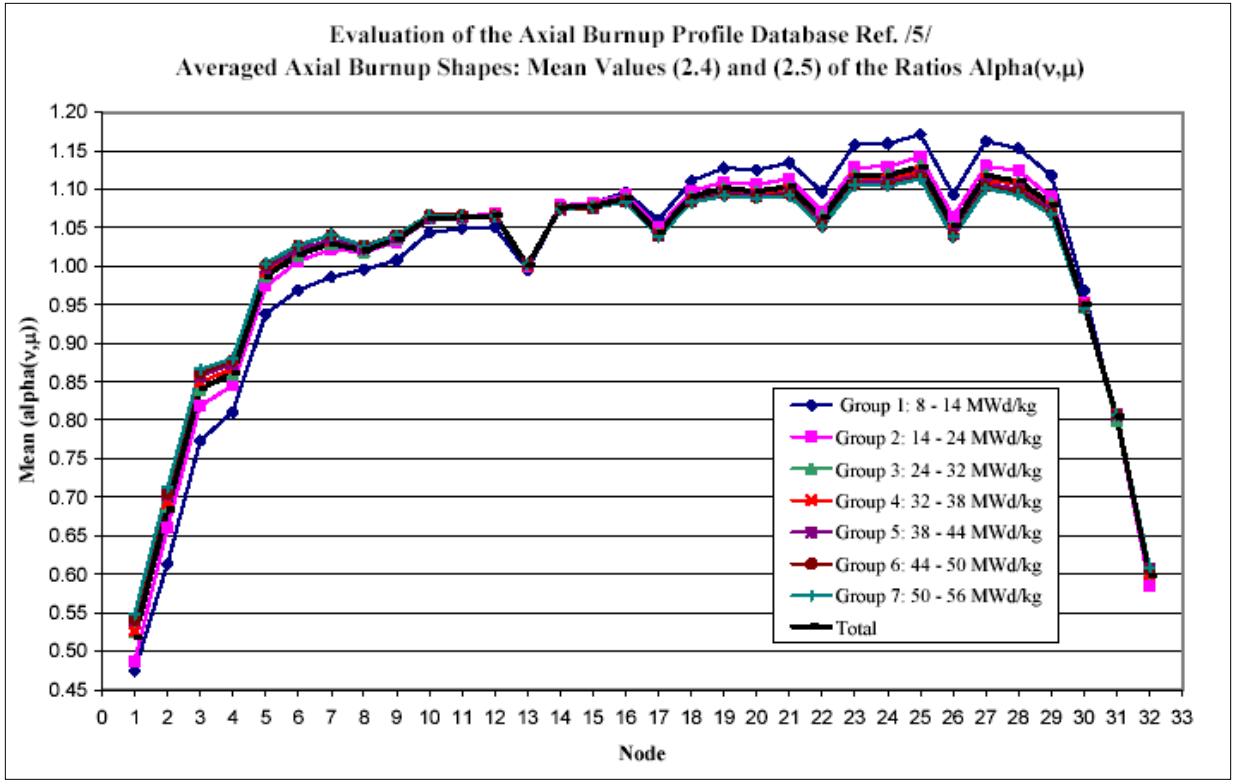
$$\rho_i = \frac{\frac{\int_{V_i} \Sigma_f(\vec{r},E)\Phi(\vec{r},E)\,d\vec{r}\,dE}{V_i}}{\sum_i \left(\frac{\int_{V_i} \Sigma_f(\vec{r},E)\Phi(\vec{r},E)\,d\vec{r}\,dE}{V_i} \right)}$$

V_i:= Volume of zone i
Φ:= Scalar flux
Σ_f:= Macroscopic fission cross section

Phase II-C

Evaluation of a database of 850 axial profiles

- **Normalized shapes for 7 burnup groups and the total sample**
- **Observation: Tendency of decreasing asymmetry with increasing average burnup**



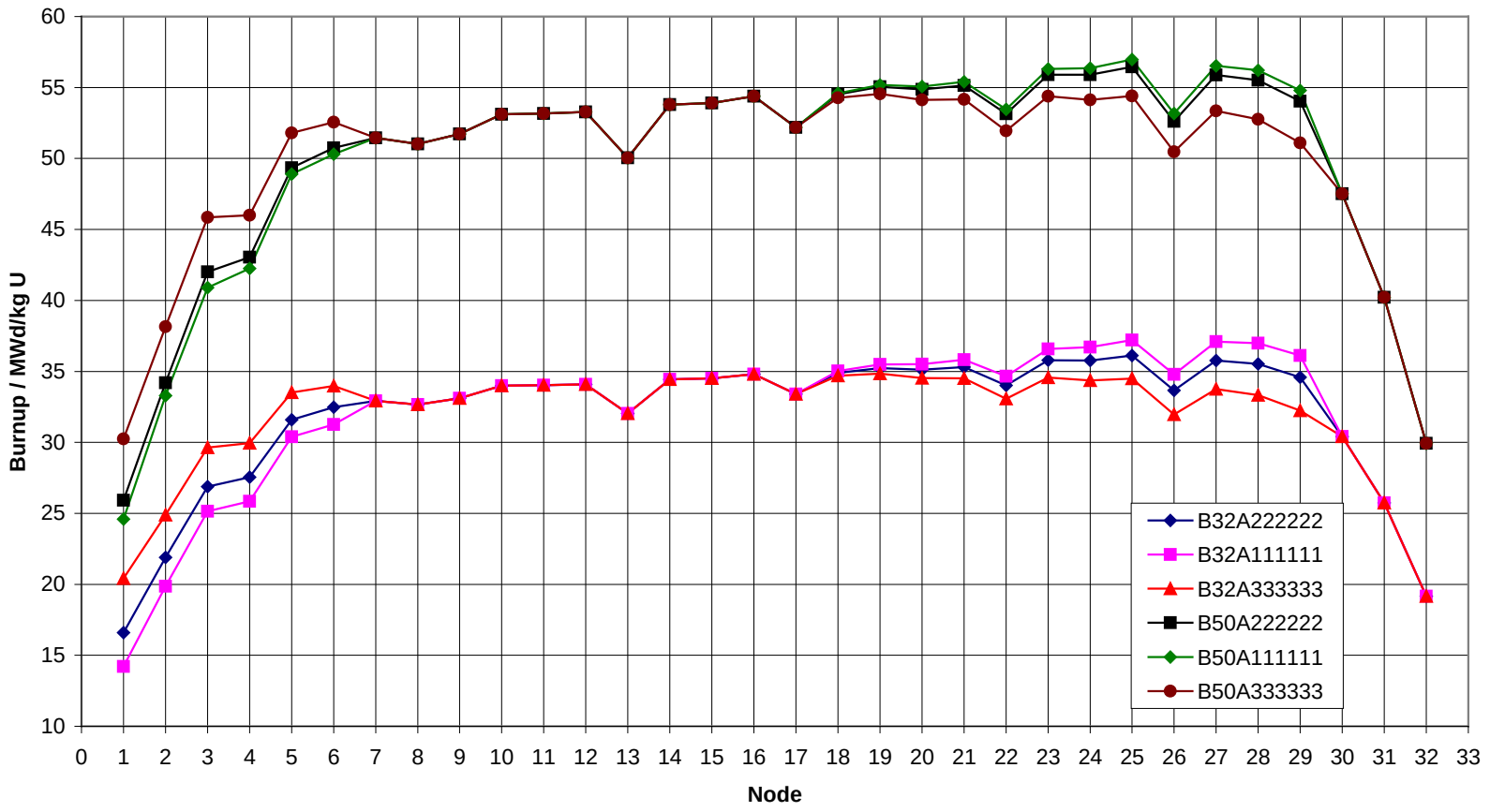
Description of the asymmetry of axial burnup profiles:

Top End Parameter Sκ → S6

$$S\kappa(\mu) \equiv \Sigma_{1,\kappa}(\mu) = \frac{1}{n}\sum_{\nu=1}^{\kappa} \alpha_{\nu\mu}$$

Phase II-C

Evaluation of a database of 850 axial profiles



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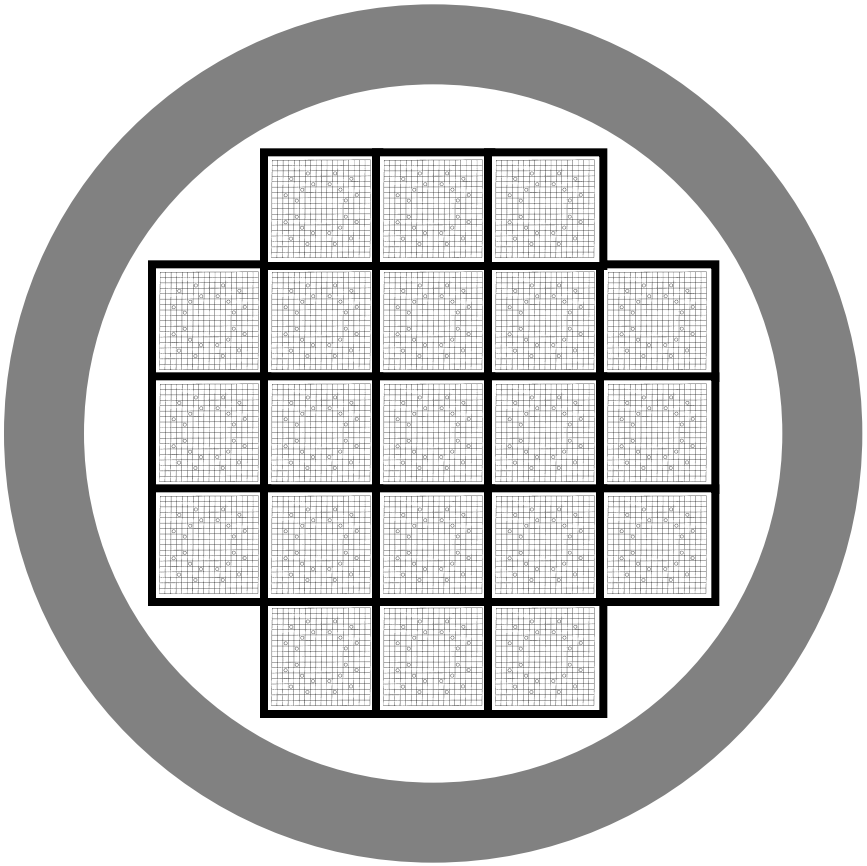
Phase II-C

Description of the cask configuration

Transport cask configuration on the analogy of Phase II-B Benchmark:

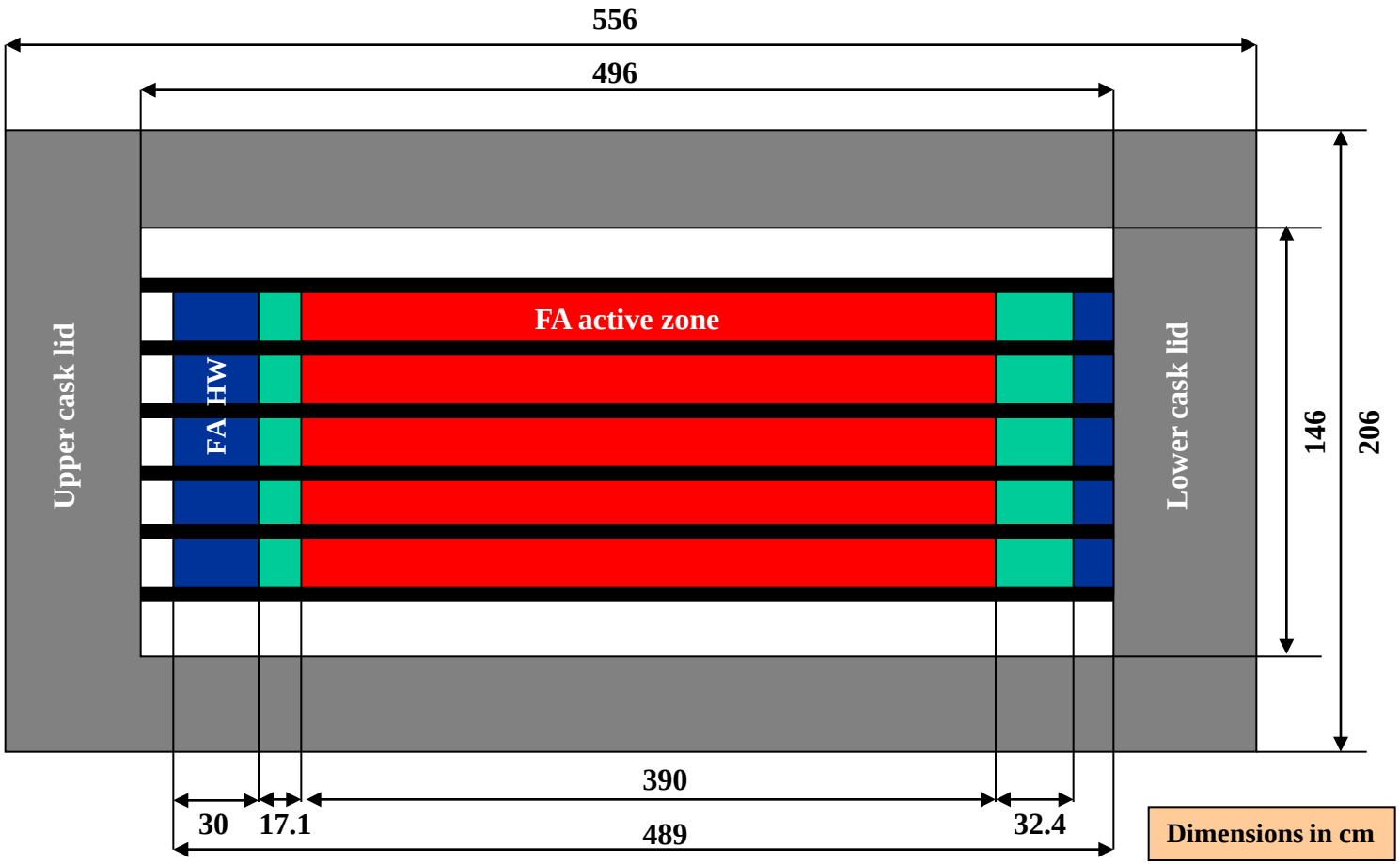
- **21 fuel assembly positions in a 5*5 array (without corner positions)**
- **Fuel assemblies centrally positioned within the basket regions**
- **Cask completely flooded with water.**



Phase II-C

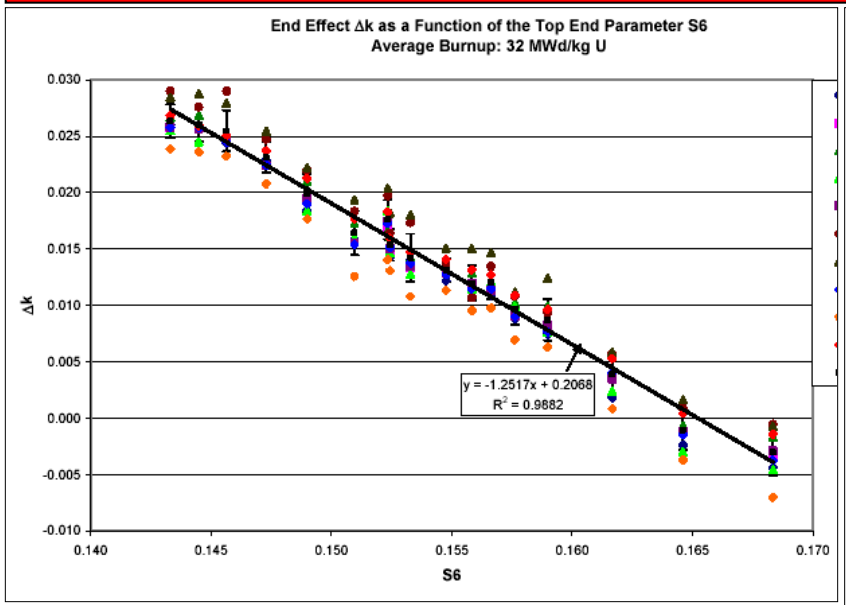
Description of the cask configuration

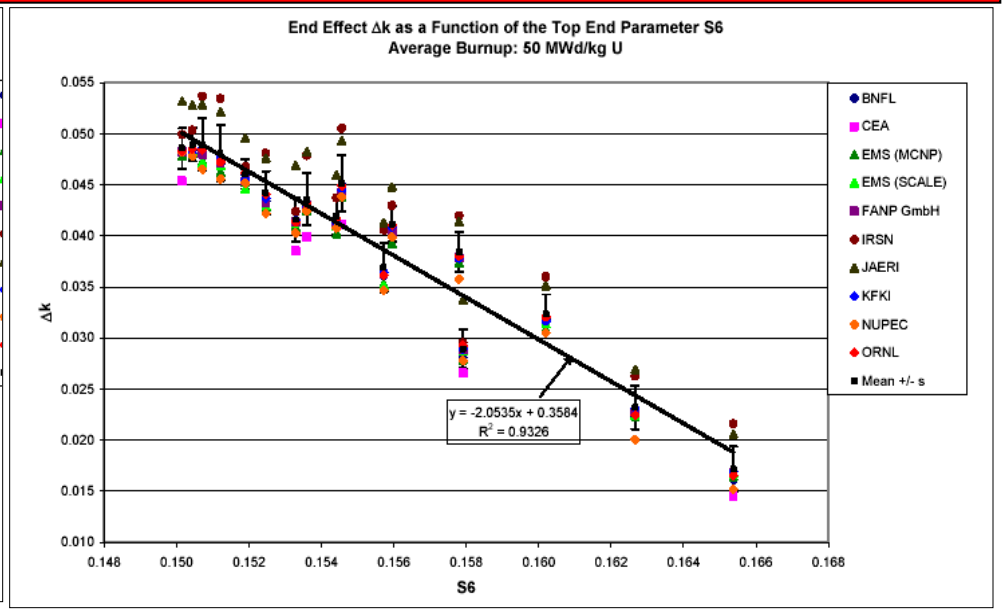
Cask shell:
- **Inner cavity: 496 cm**
- **Outside: 556 cm**
- **Material: Stainless Steel**



Phase II-C

Results for the end effect





The relationship between the end effects at 32 MWd/kg U and 50 MWd/kg U is found to be:

$$\Delta k(B50) \approx r_{B32} \cdot f + \delta k$$

and

$$\Delta k(B32) \approx (r_{B50} - \delta k) \cdot \frac{1}{f}$$

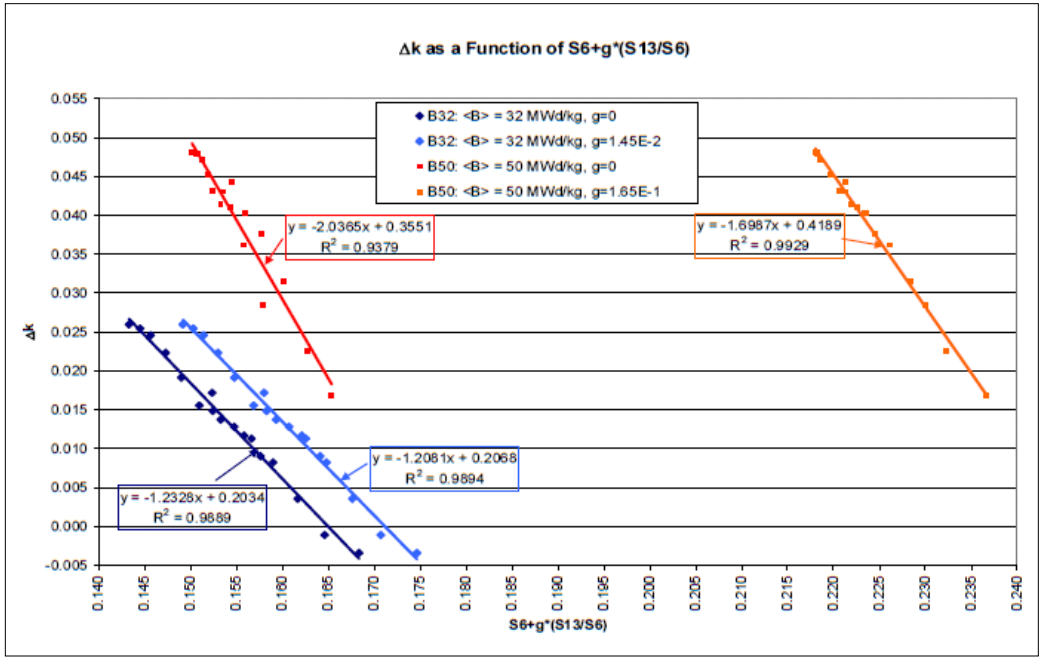
with

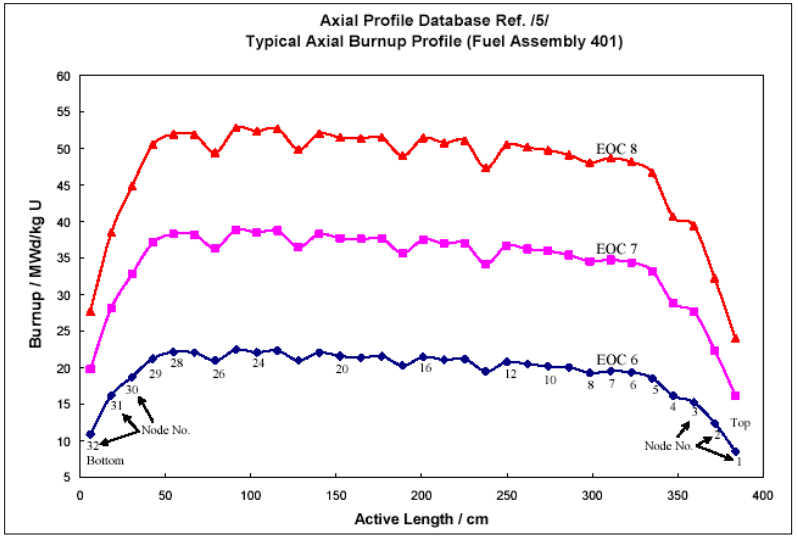
$$f = \frac{50\ \text{MWd/kg U}}{32\ \text{MWd/kg U}}$$

$$\delta k = 0.02$$

Phase II-C

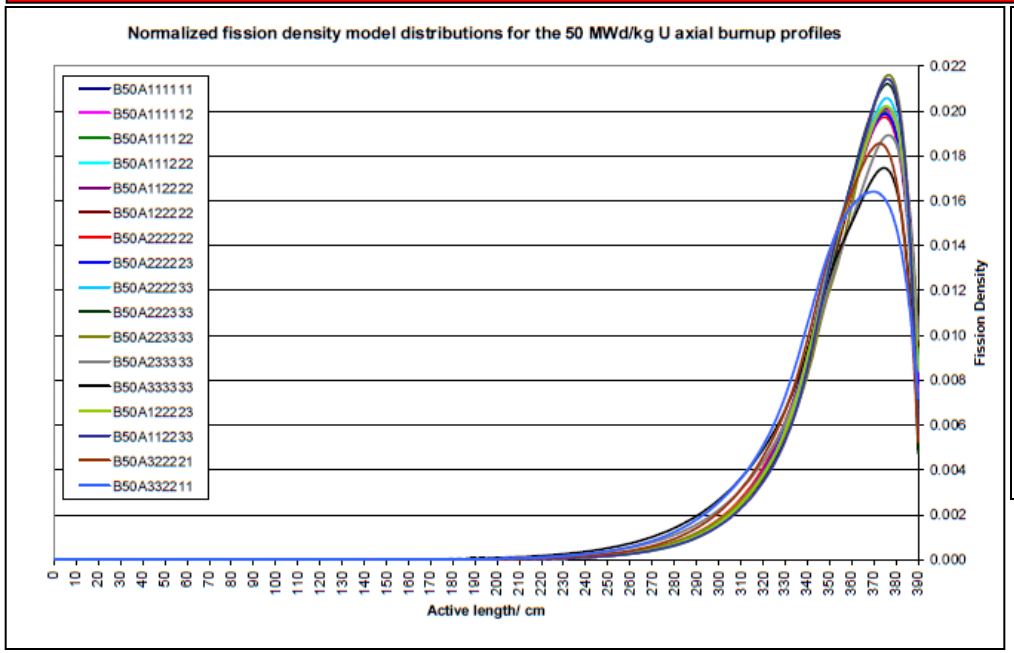
Results for the end effect: Impact of local asymmetry

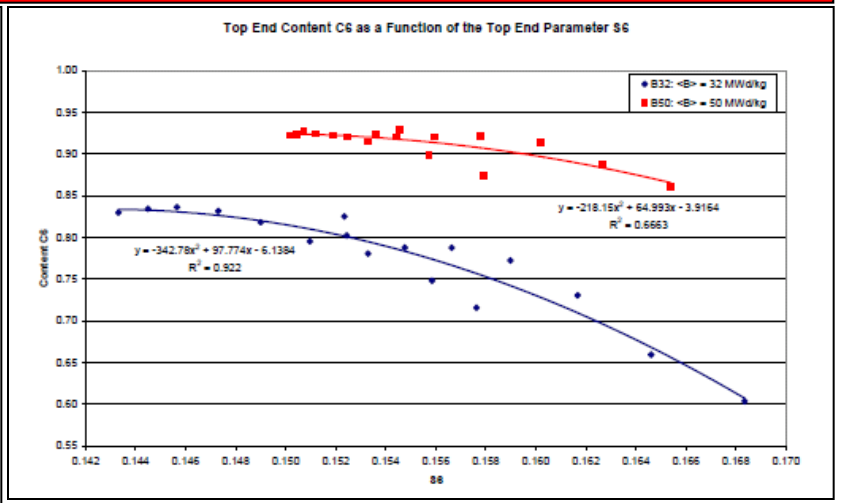




Phase II-C

Results for the fission densities



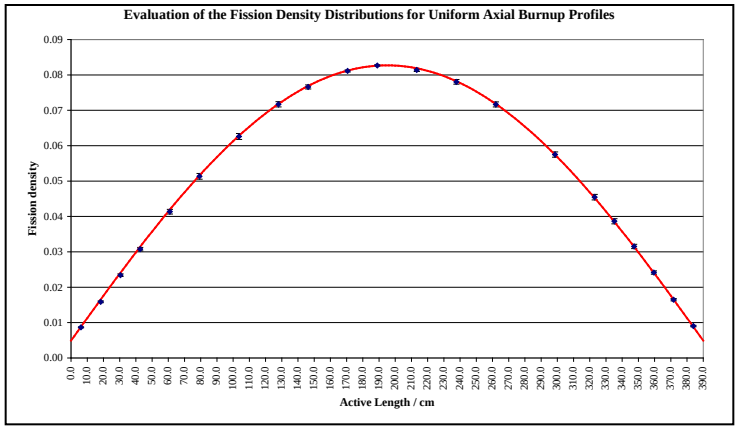


$$C\kappa = \frac{1}{I}\int_{z_\kappa}^{L} f(z)\,dz$$

with

$$z_\kappa = L\cdot\left(1-\frac{\kappa}{n}\right),\ \kappa \le n;\ n = 32.$$

$$I = \int_{0}^{L} f(z)\ dz$$



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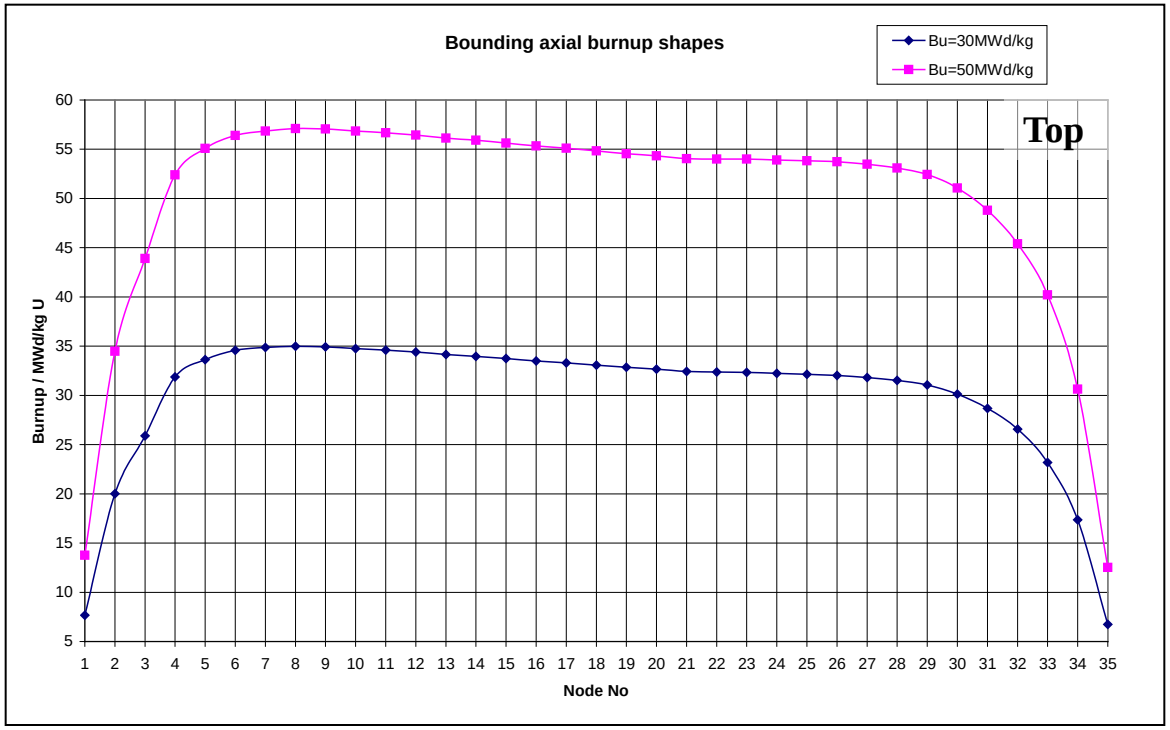
Phase II-E

- **For a given asymmetry, i.e. for a given axial burnup profile the end effect is studied for <u>different CR insertion depths</u> ranging from 0 cm (no insertion) to full insertion.**
- **Since the asymmetry of the axial profiles and the end effect are dependent on the average burnup of the profiles (cf. Phase II-C) <u>two axial profiles</u> are chosen, one related to an average burnup of 30 MWd/kg U, the other related to an average burnup of 50 MWd/kg U.**
- **To be representative and bounding the axial burnup profiles chosen are generated as <u>bounding</u> profiles from a database of <u>real</u> axial burnup profiles**

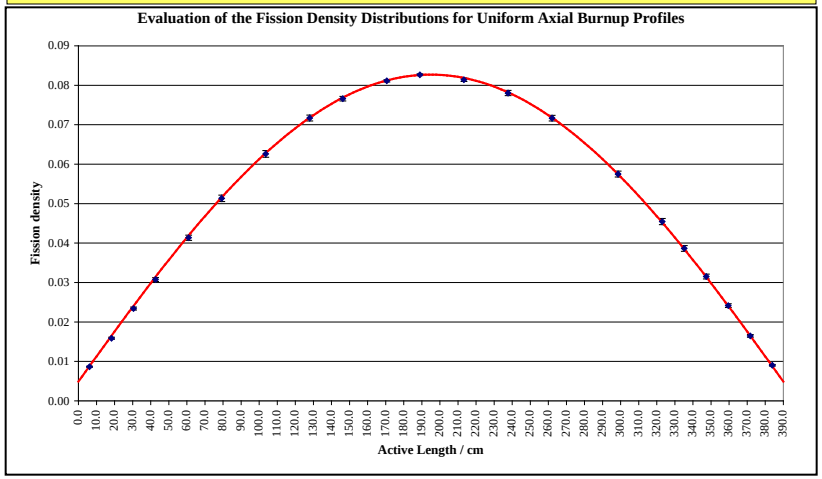


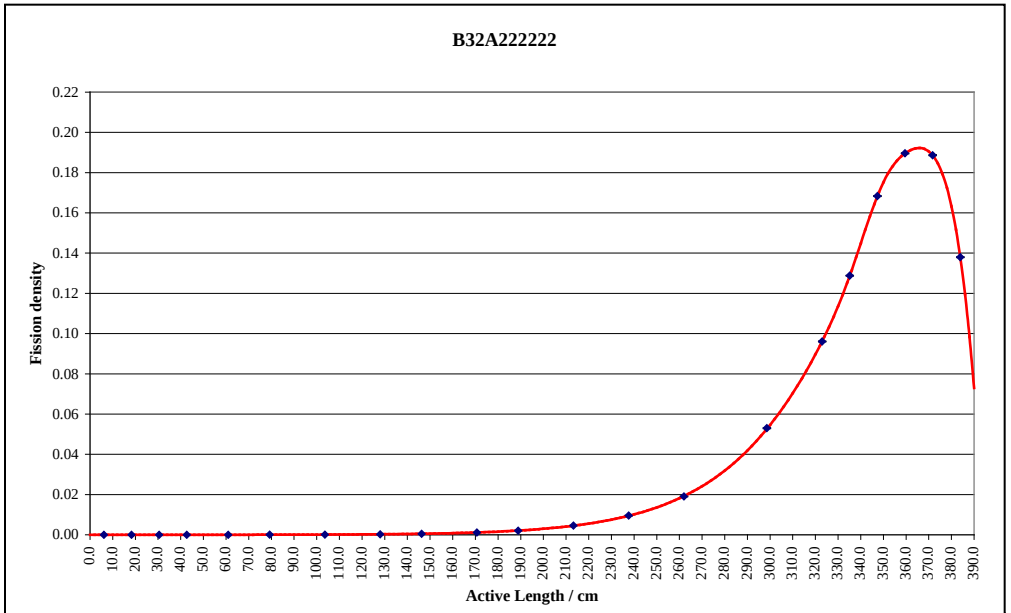
Phase II-E: ? Results to be expected

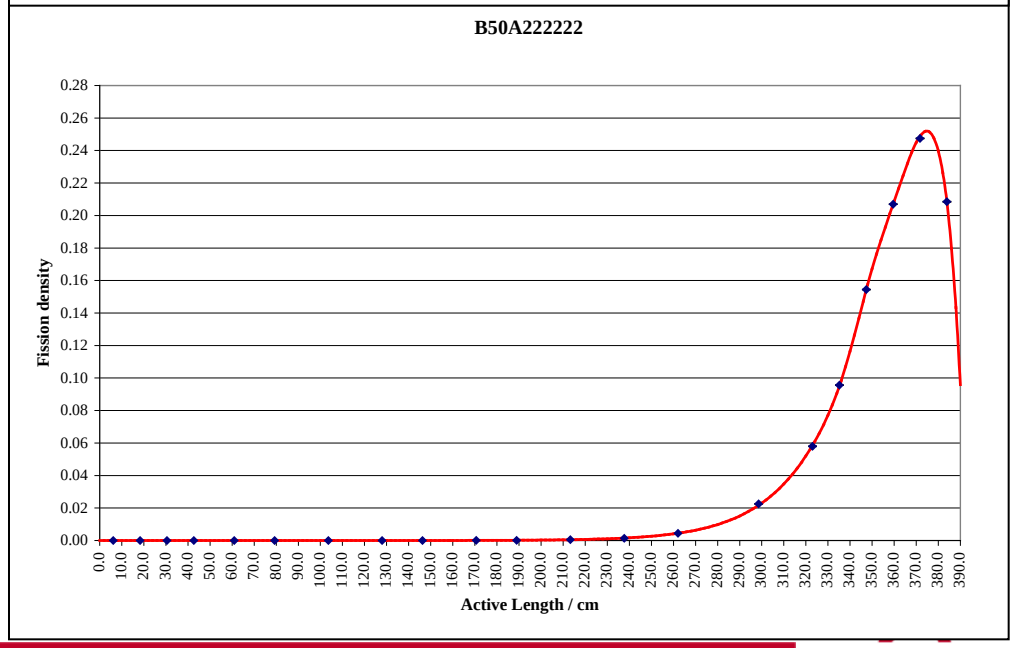
↑

Phase II-C and Phase II-D

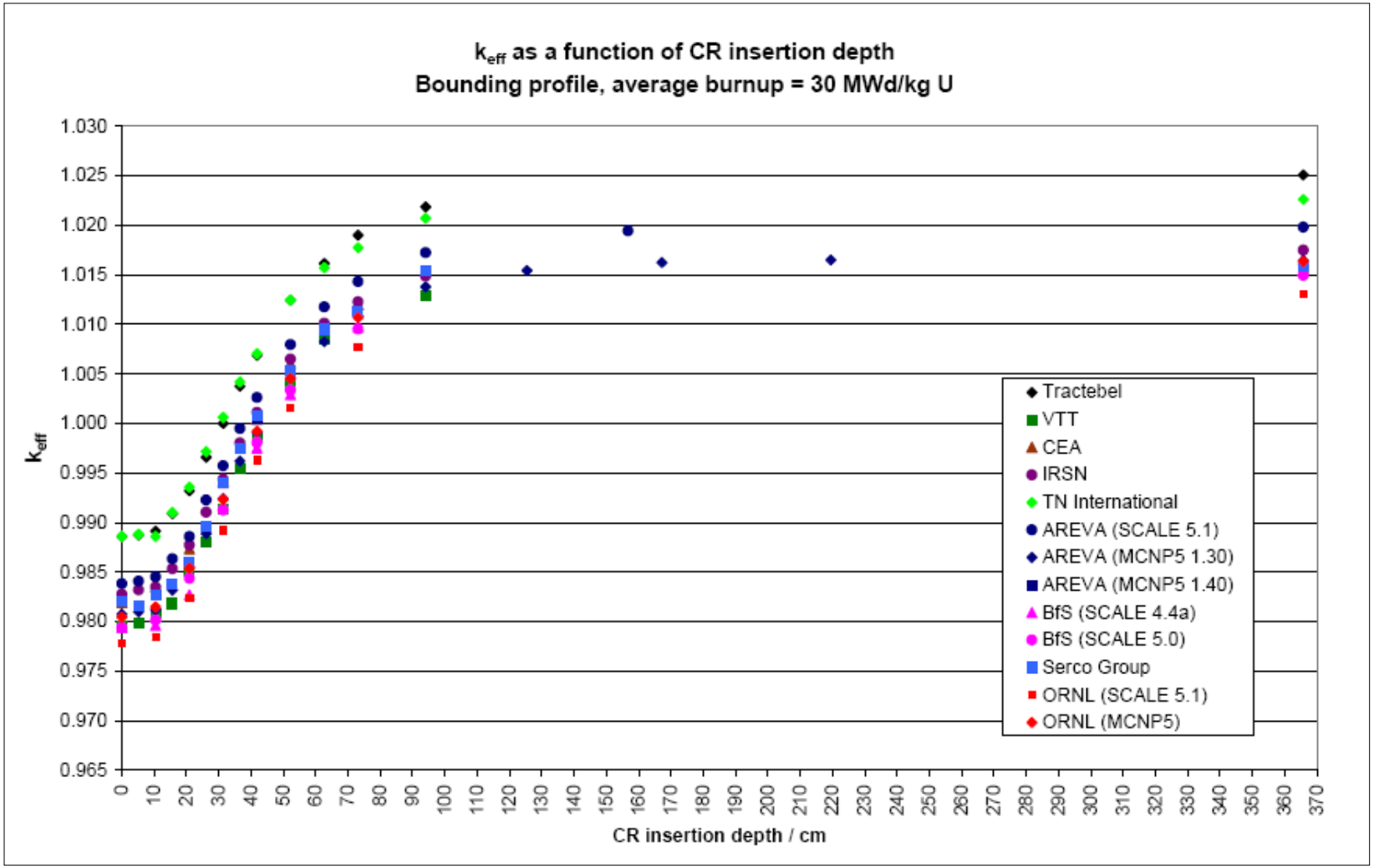
End effect $\Delta k = k_{Profile} - k_{uniform}$



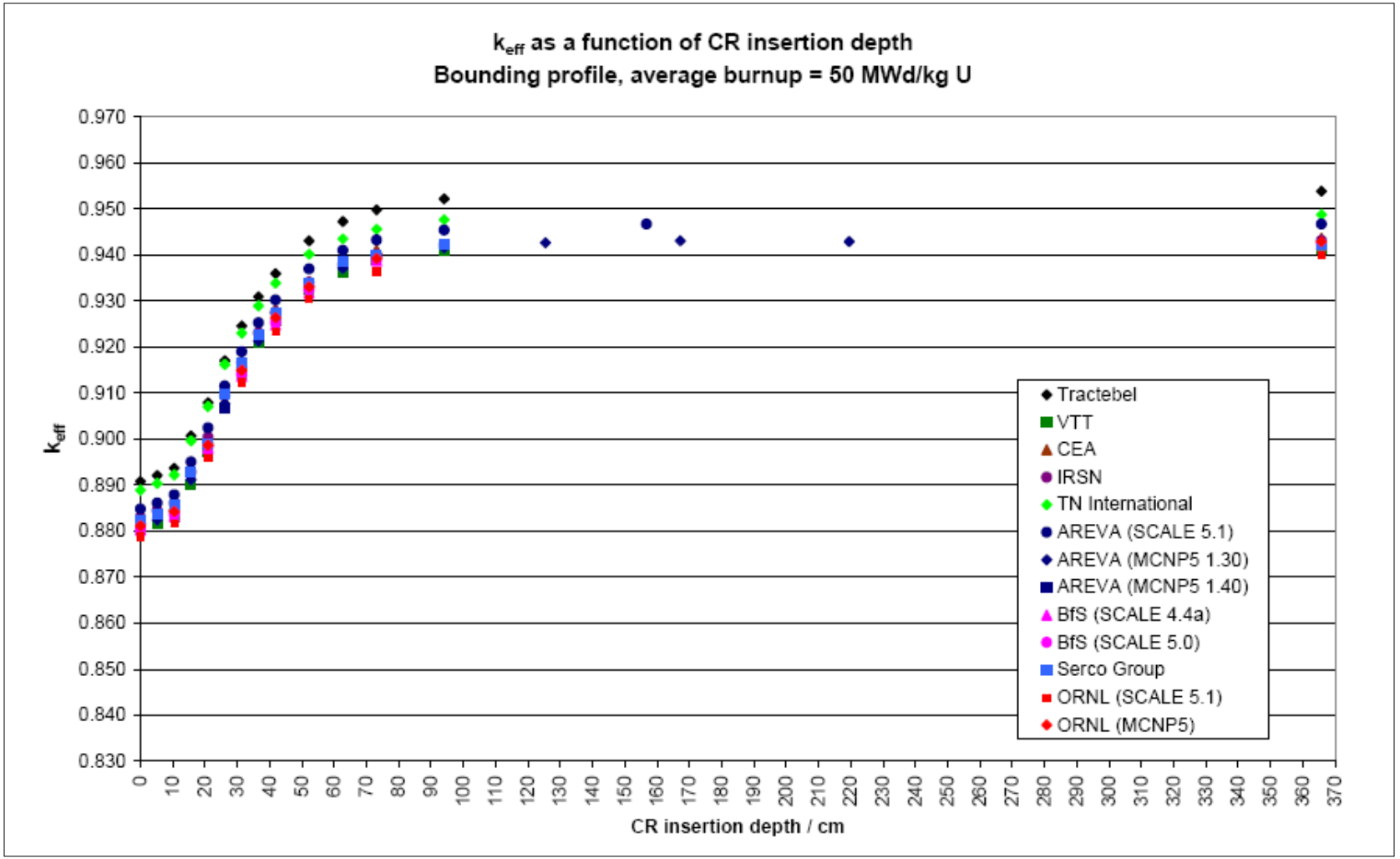




Phase II-E: Results



Phase II-E: Results



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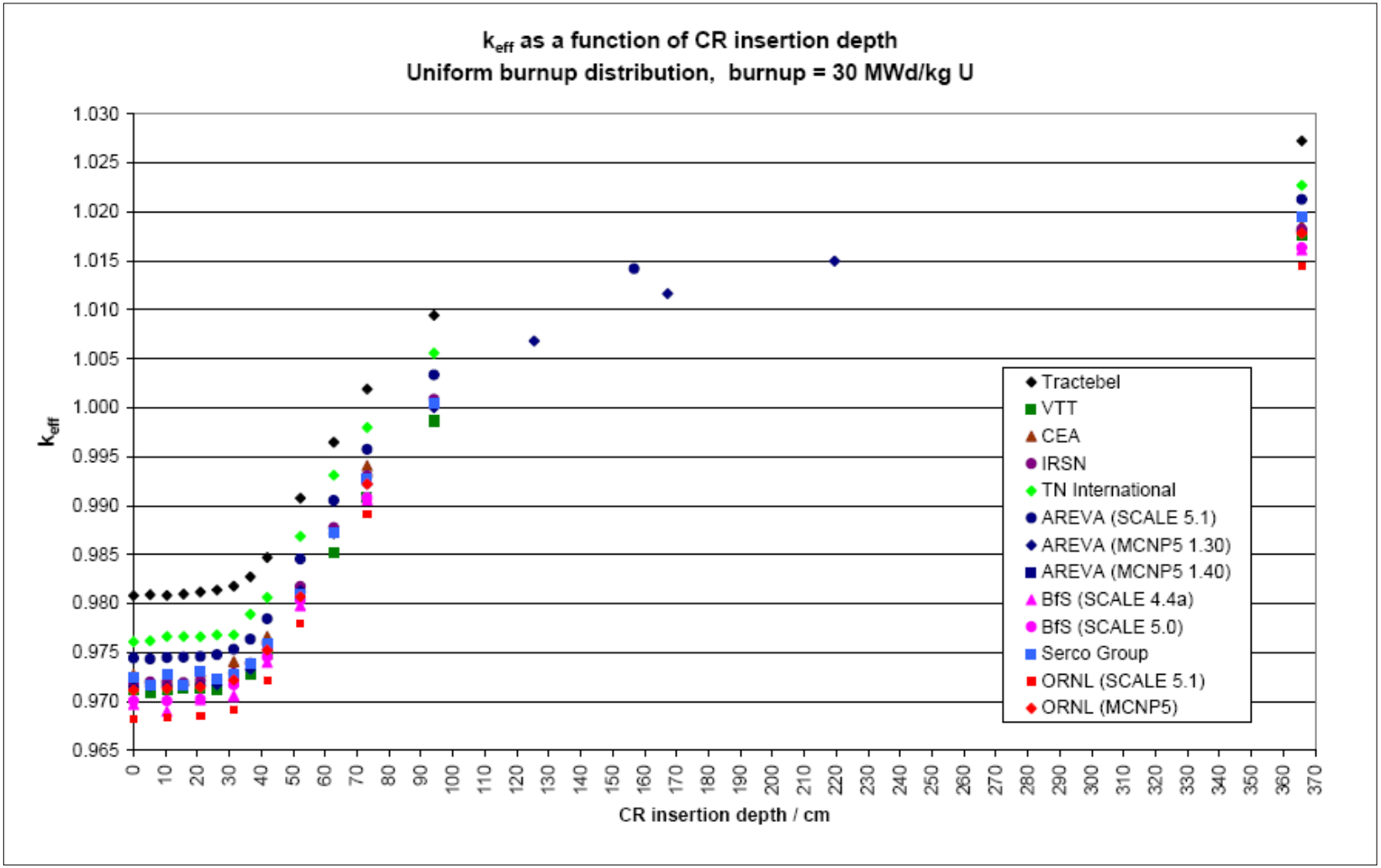

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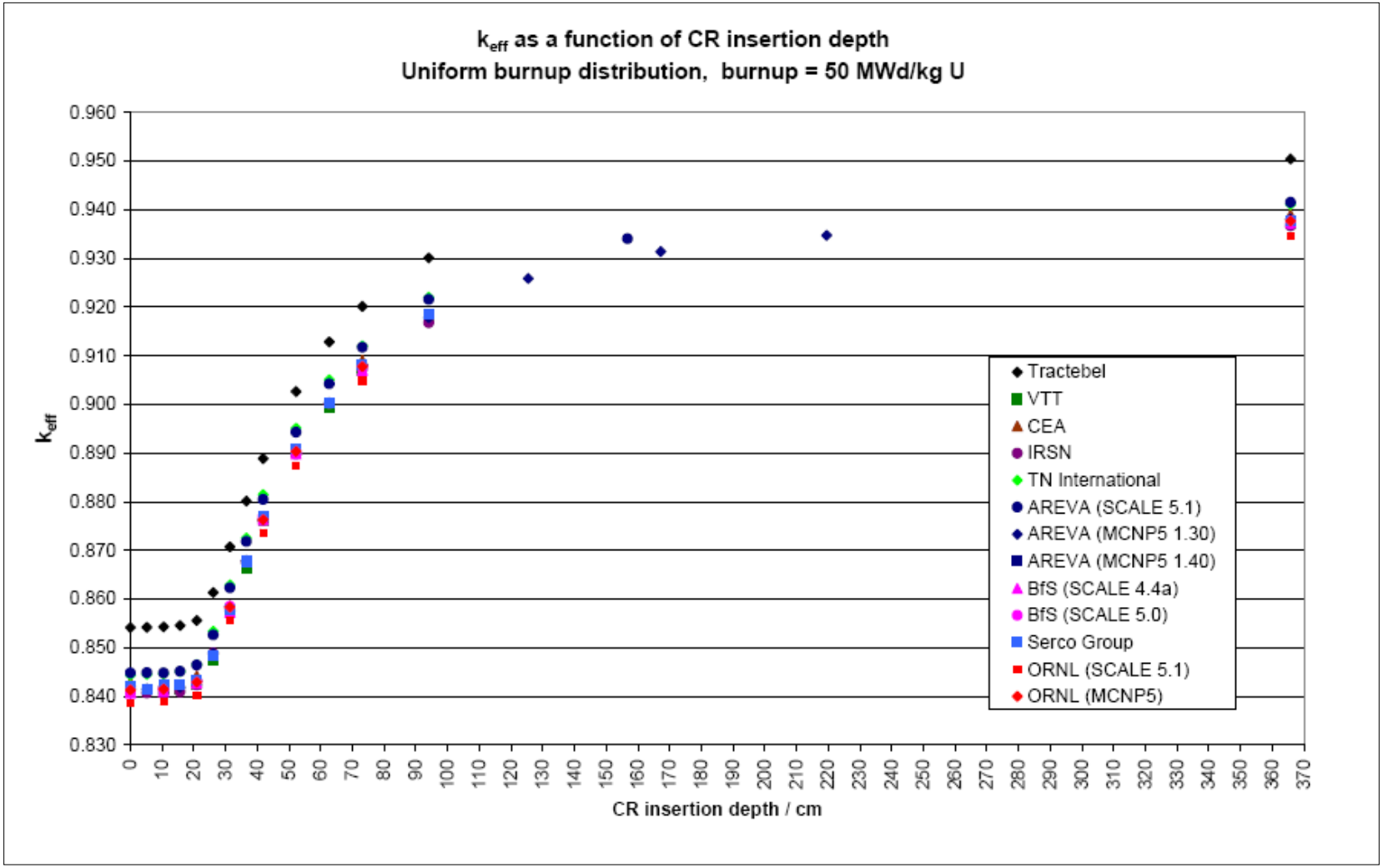

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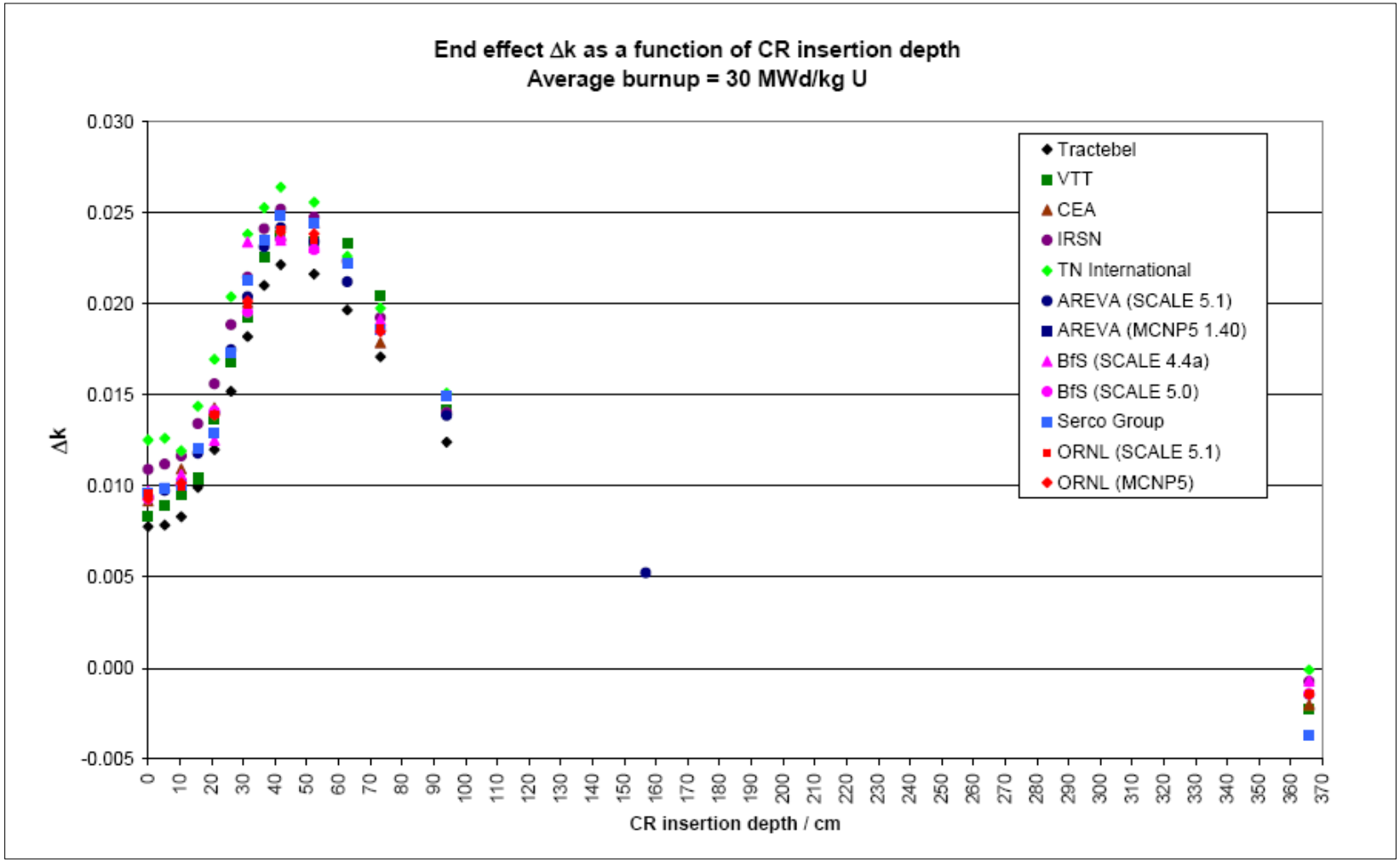

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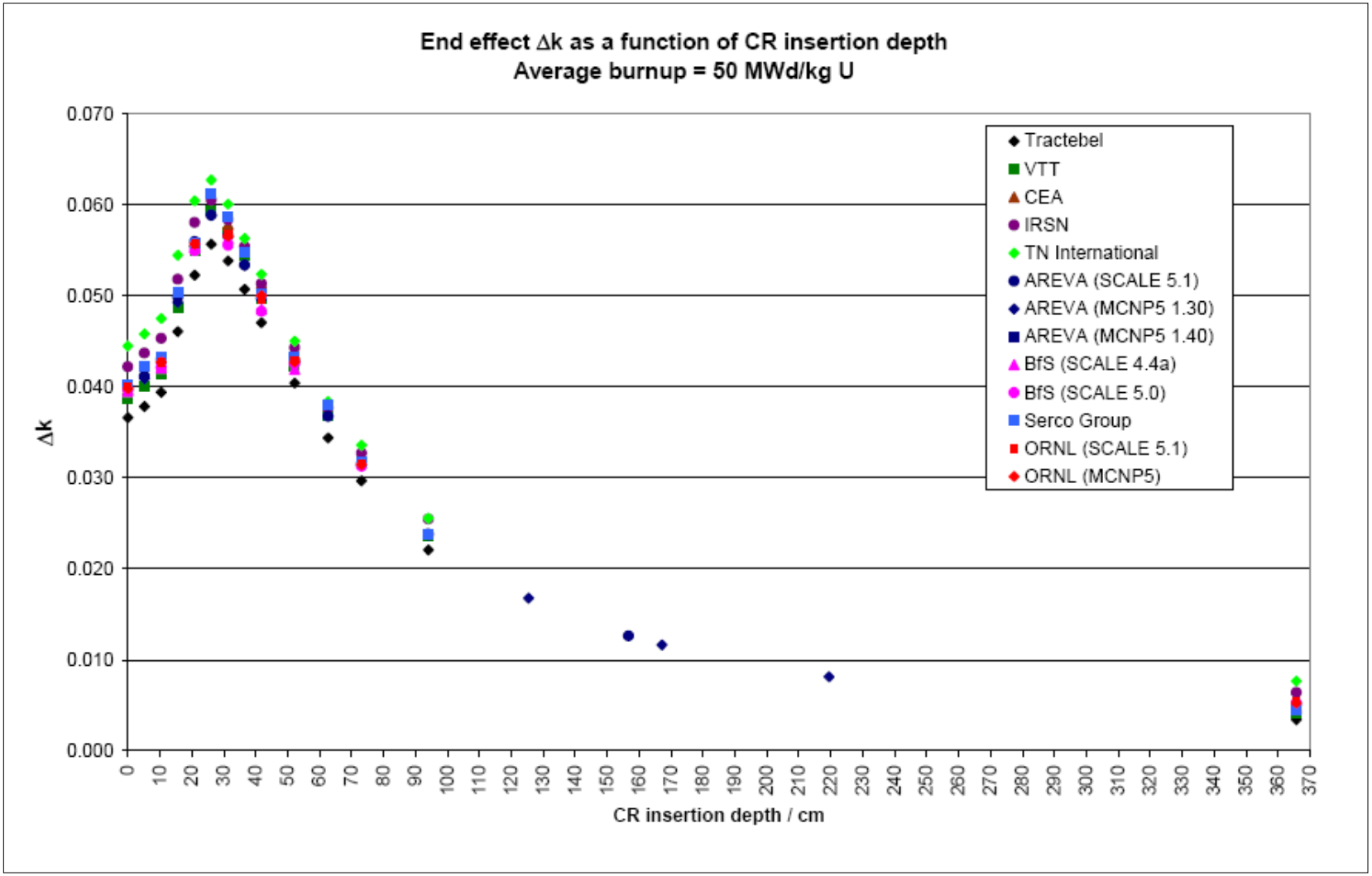
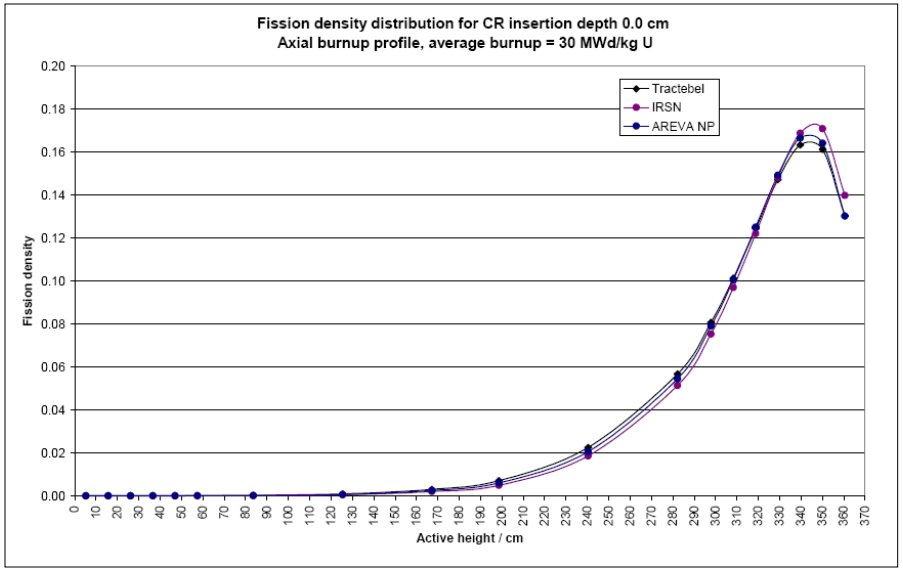
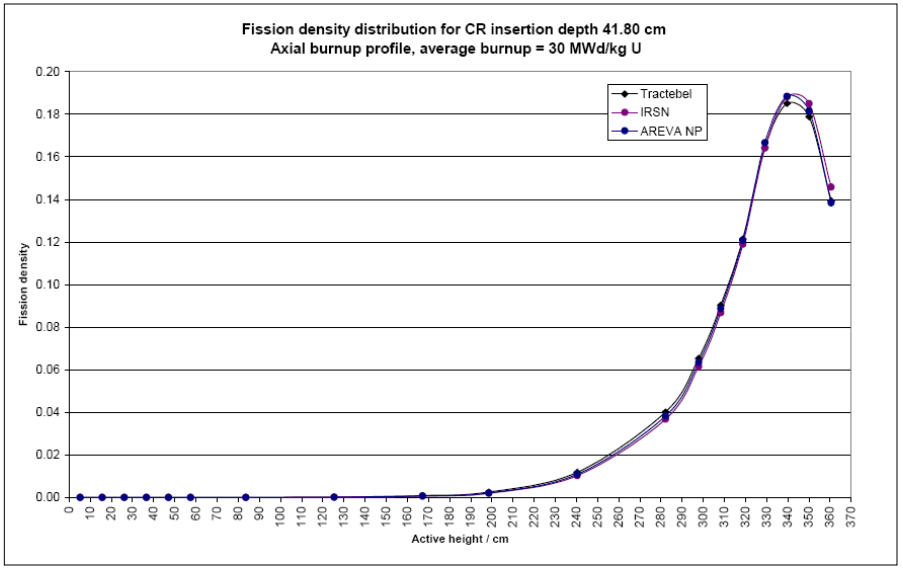
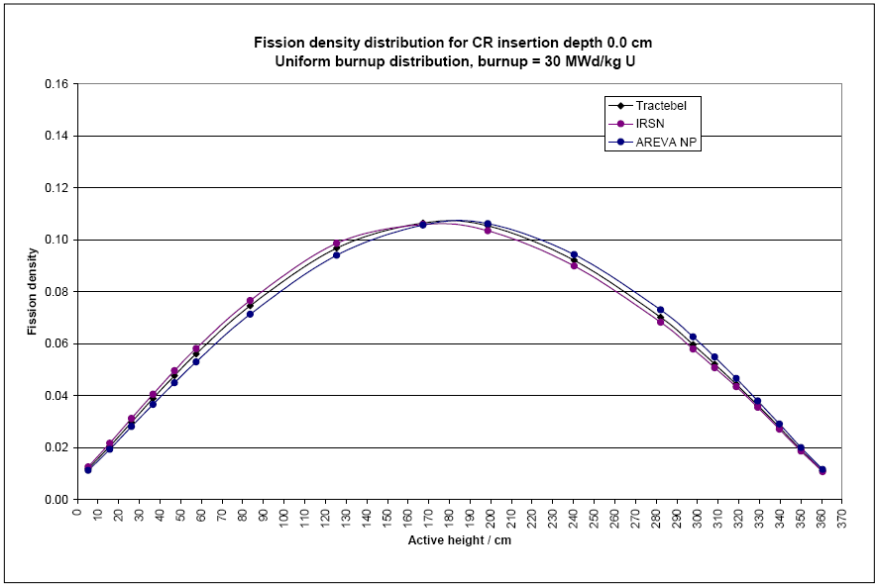
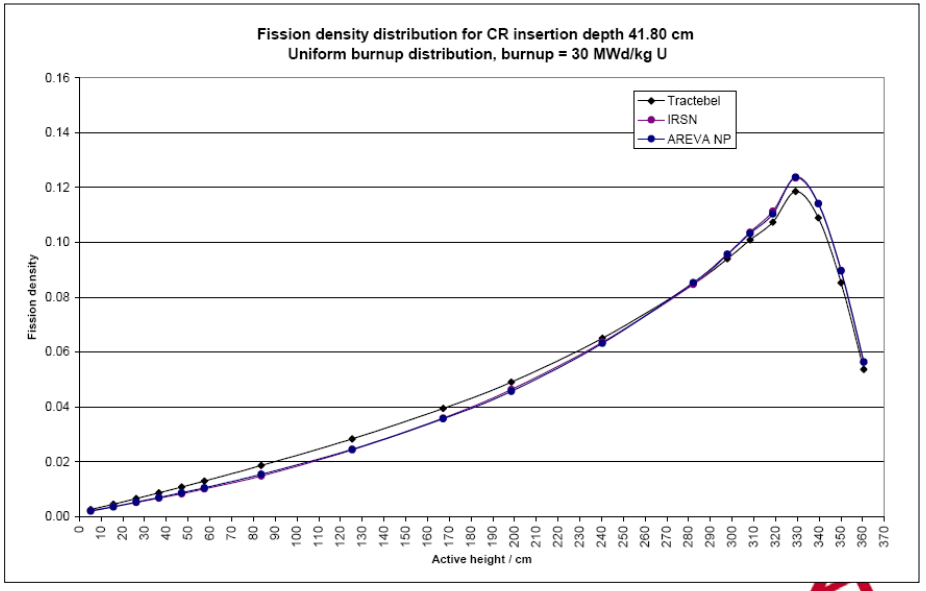


Phase II-E: Results









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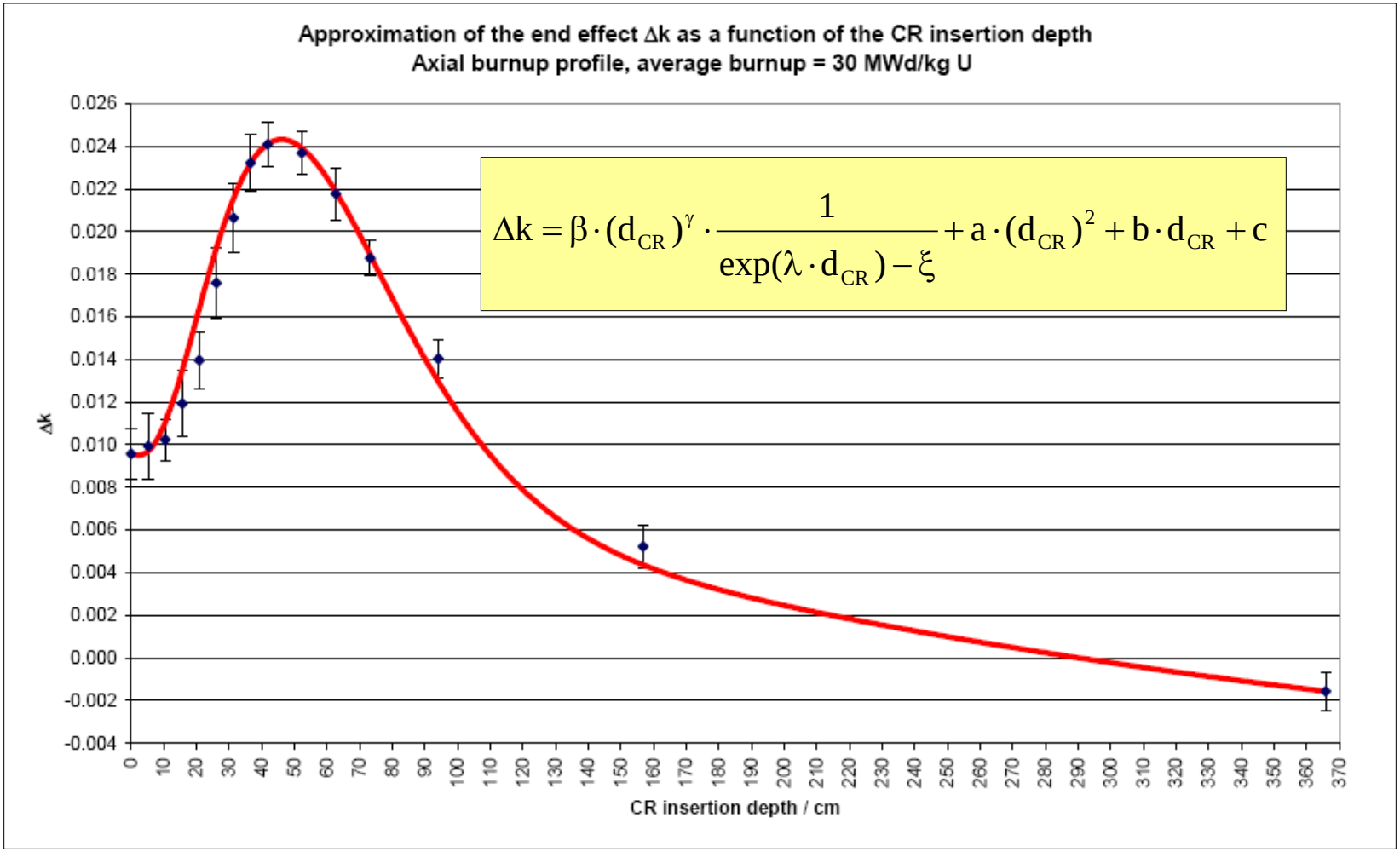

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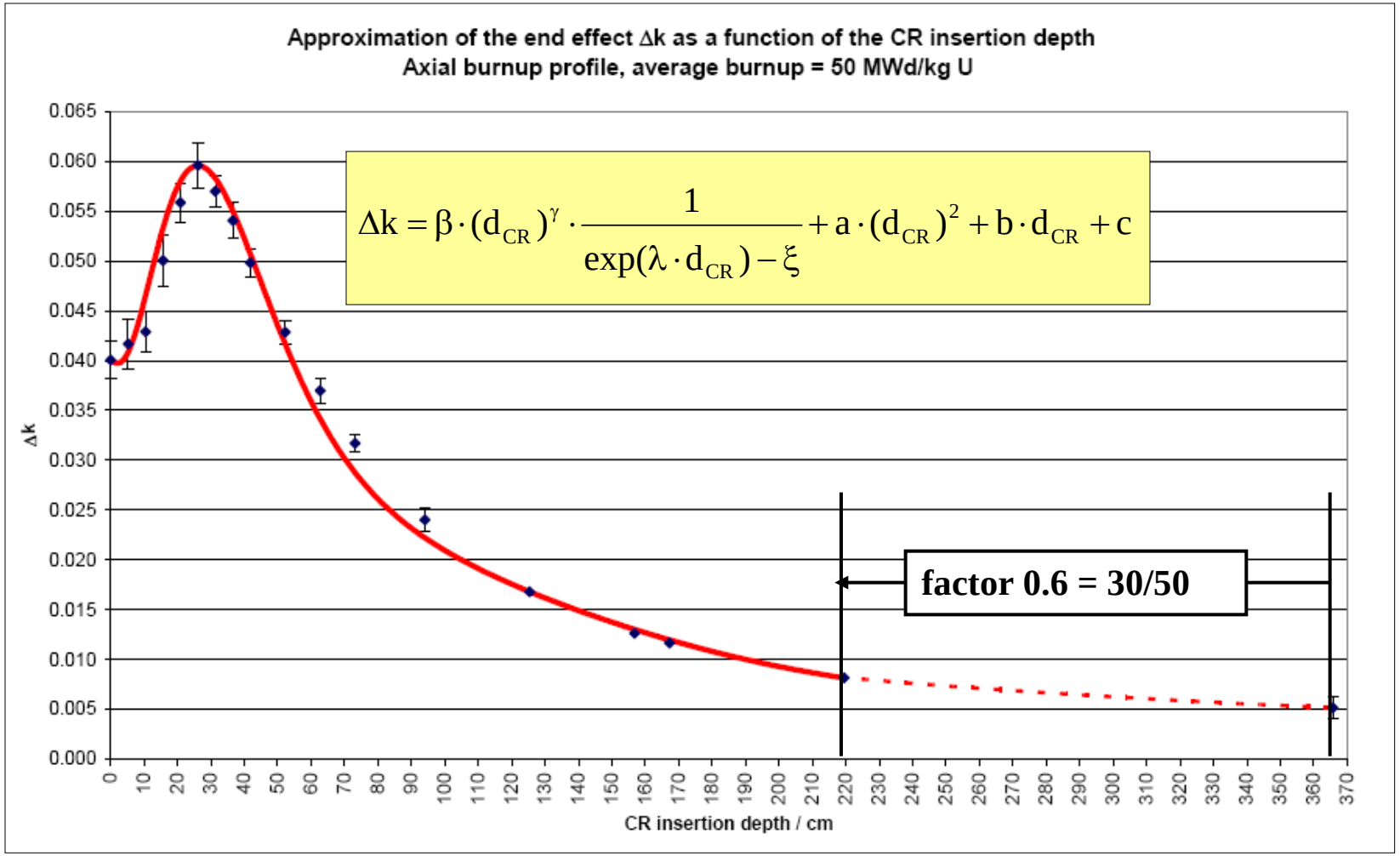
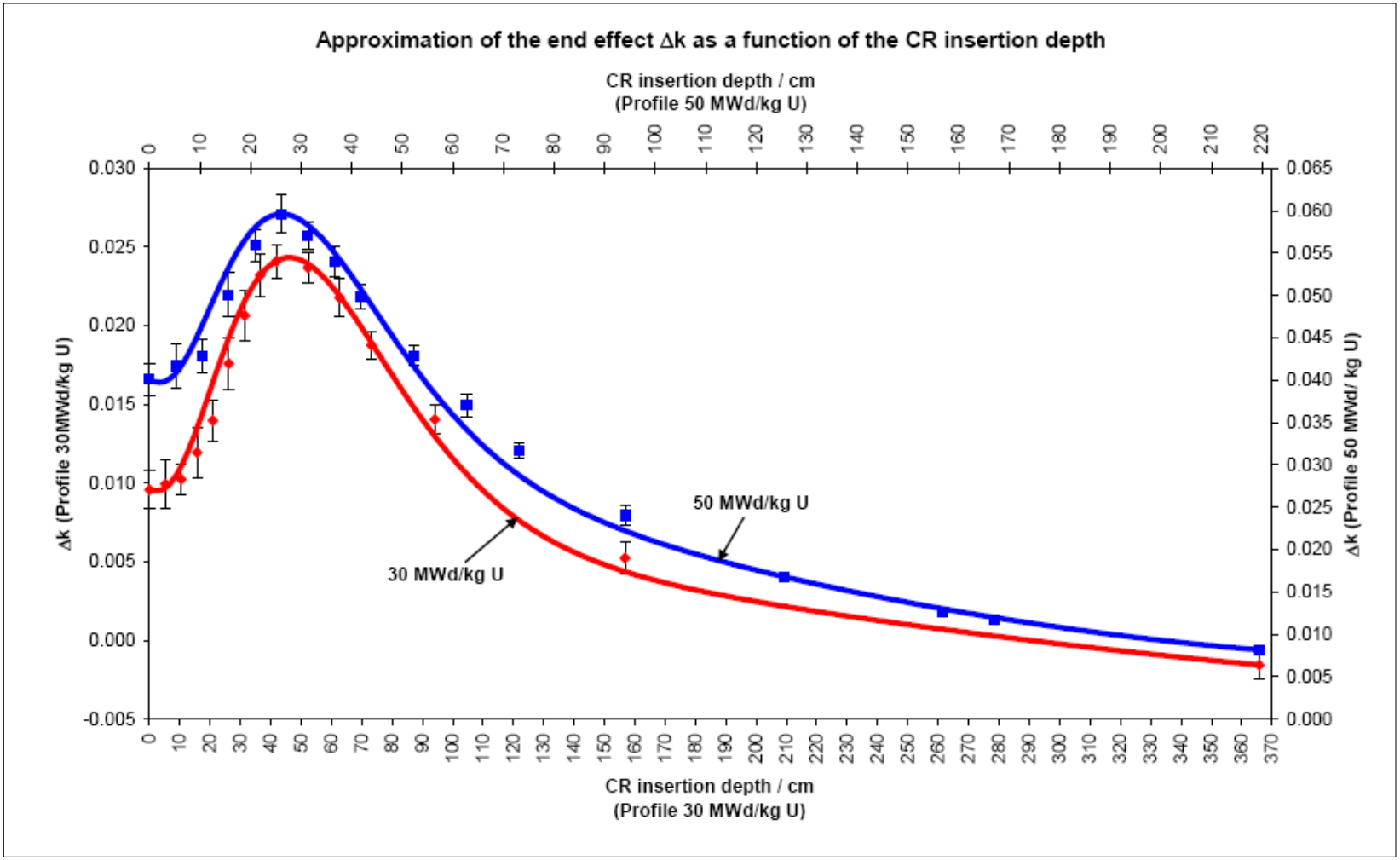
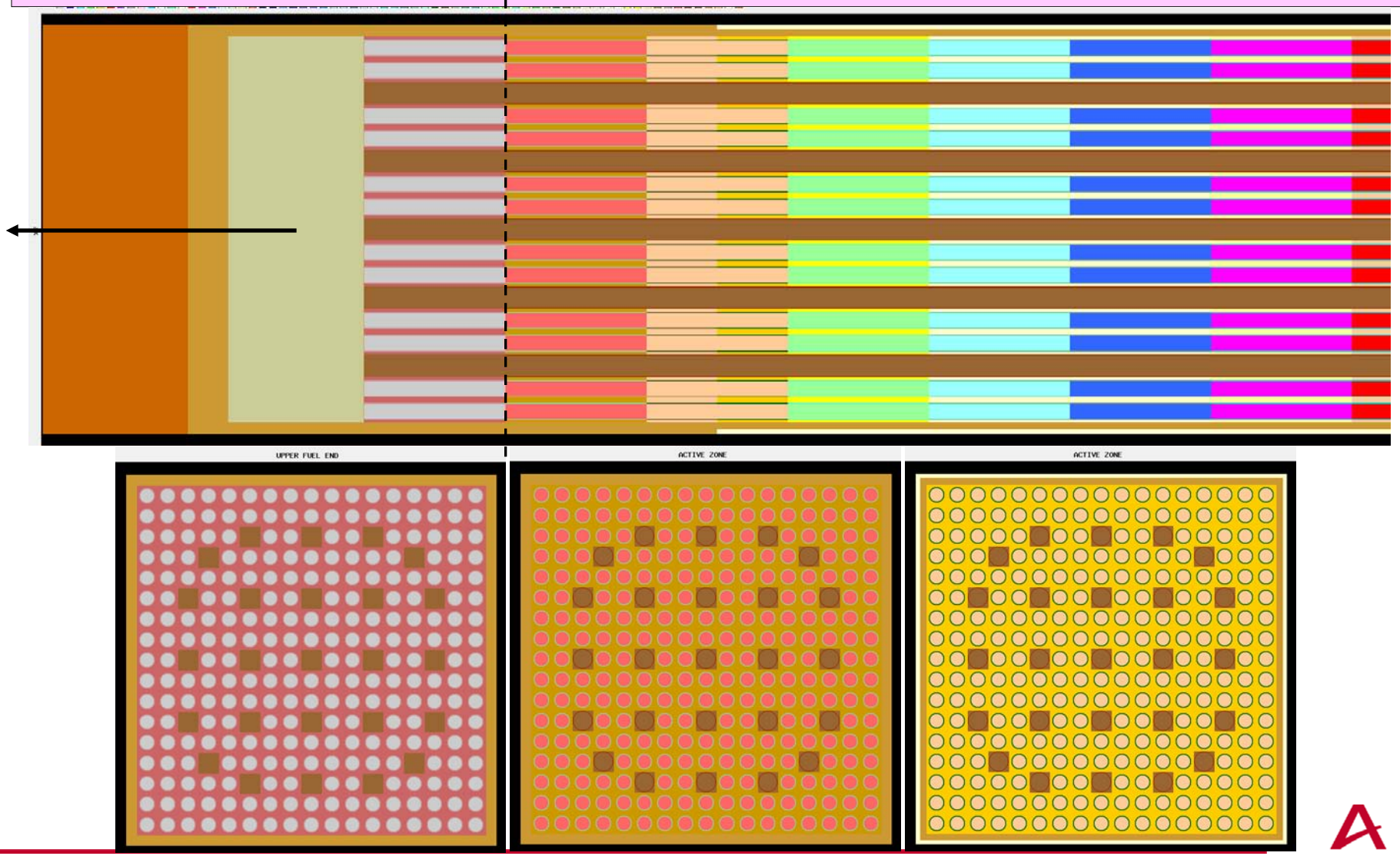


Phase II-E: Results

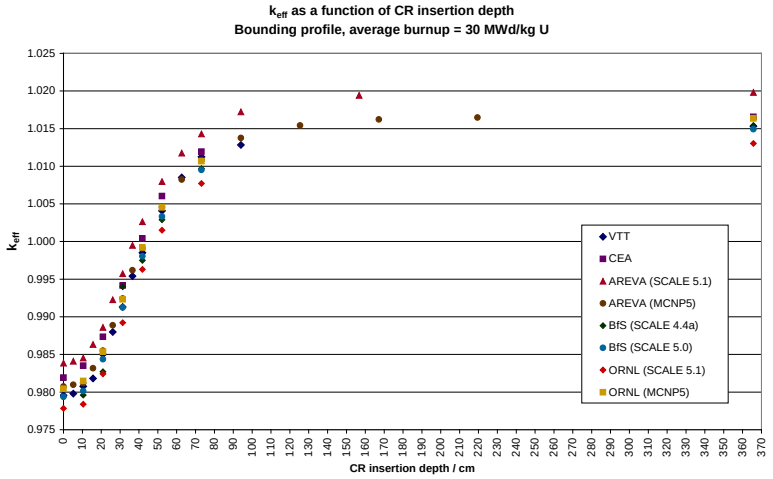


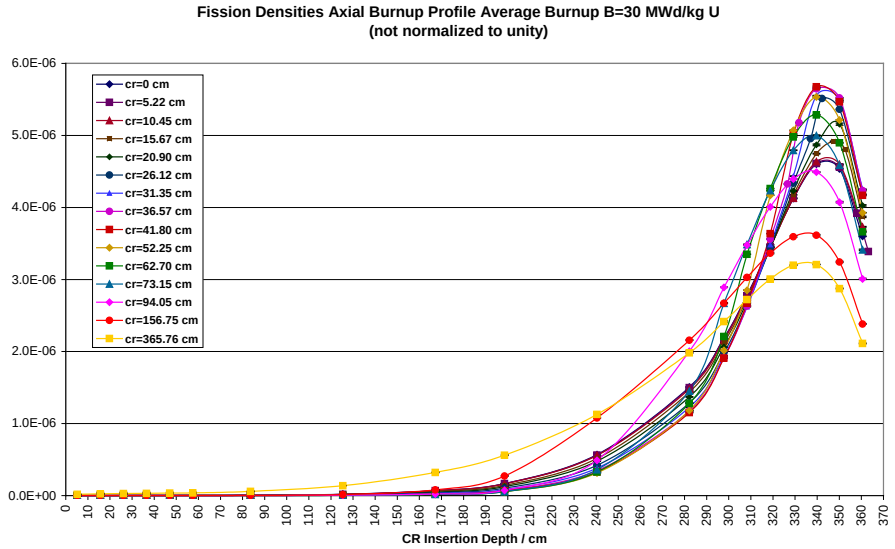
Phase II-C + Phase II-E Results ➔ Conclusions for different configurations ?

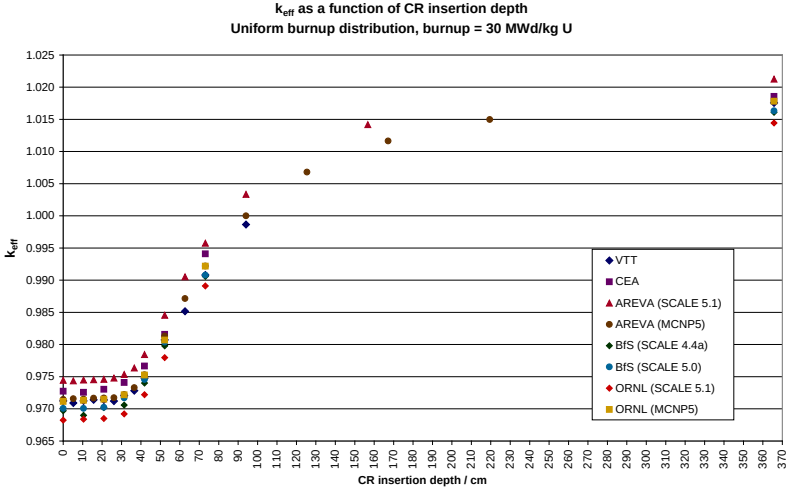
Case of jutting-out of fuel zone

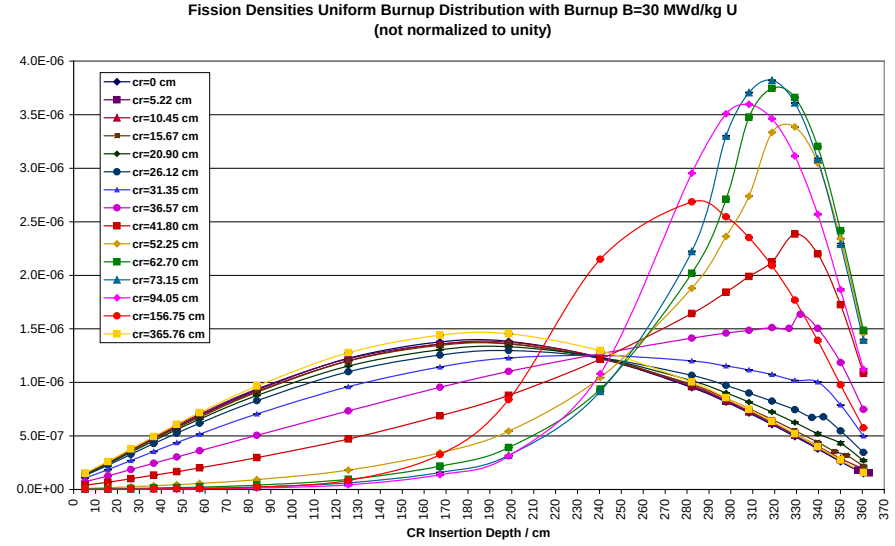


Phase II-C + Phase II-E Results ➔ Conclusions for different configurations ?



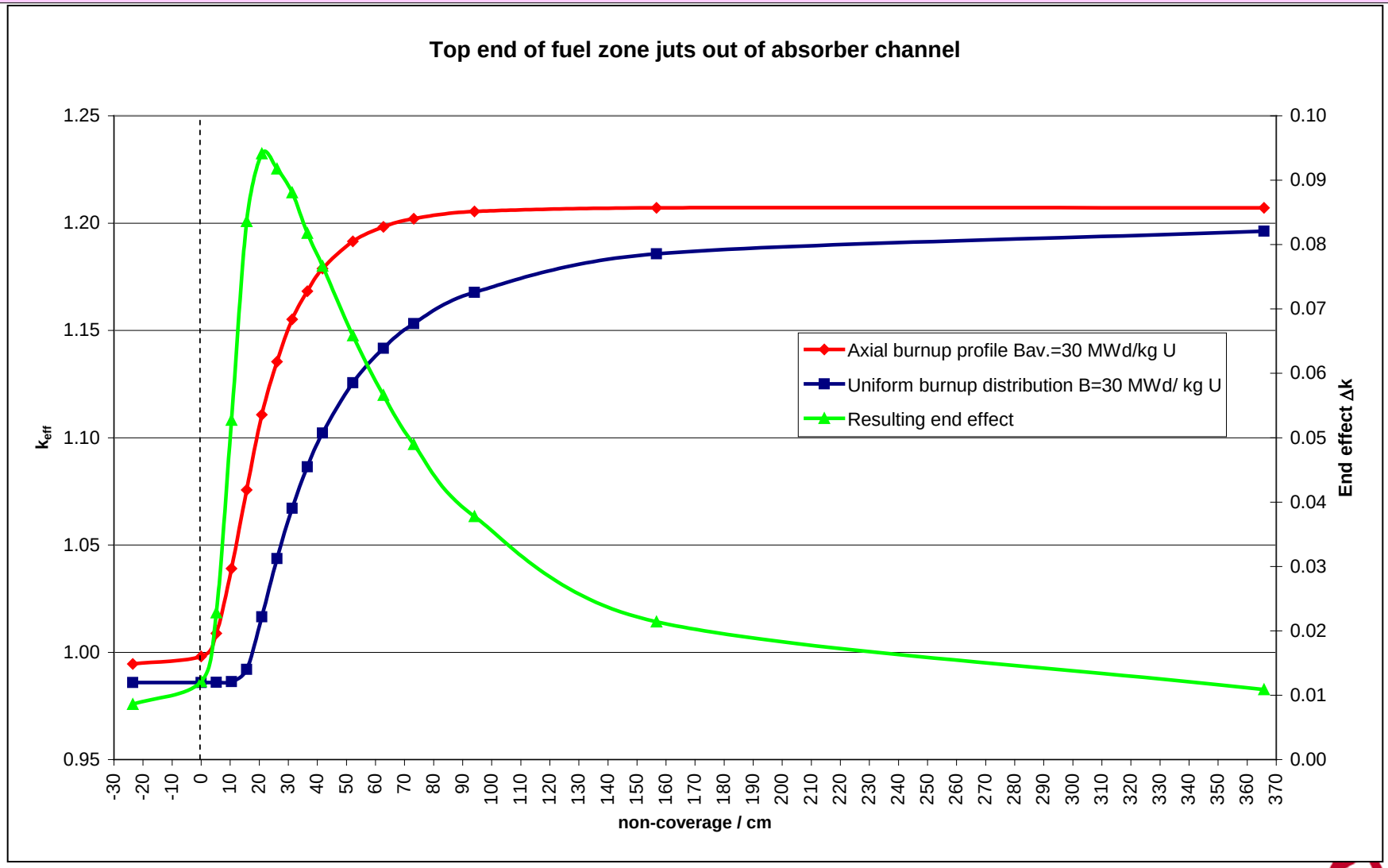




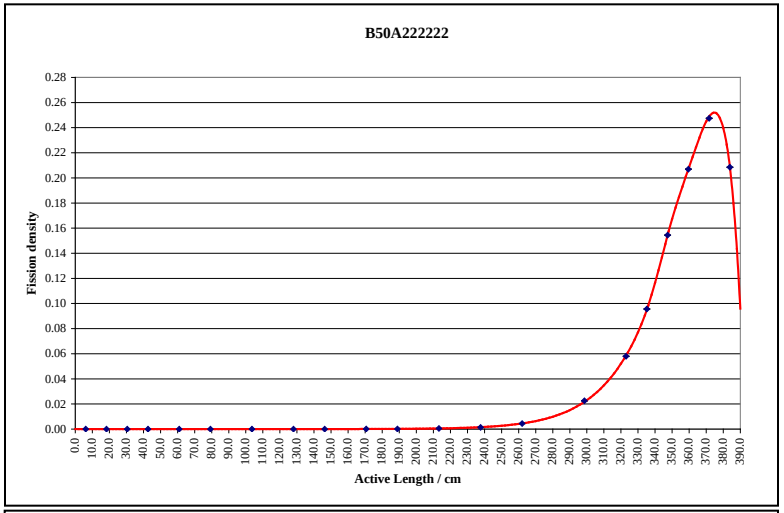


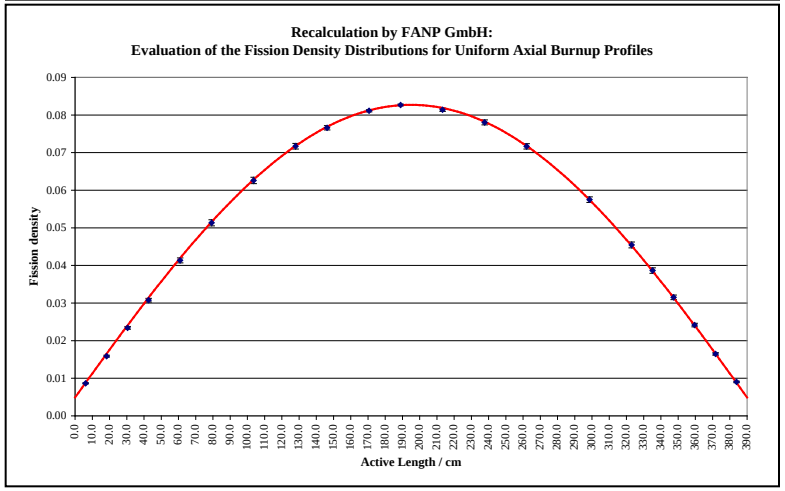
Phase II-C + Phase II-E Results ➔ Conclusions for different configurations

Case of jutting-out of fuel zone



Conclusion





Results of Phase II-C made it possible to predict the behavior of

- **$k_{profile}$, $k_{uniform}$ and**
- **the resulting end effect**
  $\Delta k = k_{profile} - k_{uniform}$

qualitatively for the important cases such as

- **CR insertion**
- **jutting-out of the fuel zone**