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International Conference on Fast Reactors and Related Fuel Cycles:
Safe Technologies and Sustainable Scenarios
FR13

Technical Session 1:
Fast reactor designs: goals and paths of progress

A New Design Option for Achieving Zero Void Effect in Large SFR Cores

Patent application in process

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The authors wish to thank CEA teams involved in SFR core design for their constructive support.

Engineering & Projects Organization

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Contents

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Introduction

- **French R&D on future SFR technology resumed in 2006**
  - **French Act of June 2006 relative to nuclear waste management**
  - **Consistent with GEN-IV guidelines**
  - **Lead by CEA in collaboration with industrial partners EDF and AREVA**

- **As a reactor vendor AREVA continuously maintained its own SFR skills acquired on past realizations and projects (Superphénix, SPX2, EFR), in particular in core design**

- **The following refers to AREVA's own R&D work which has been performed since late 2011.**

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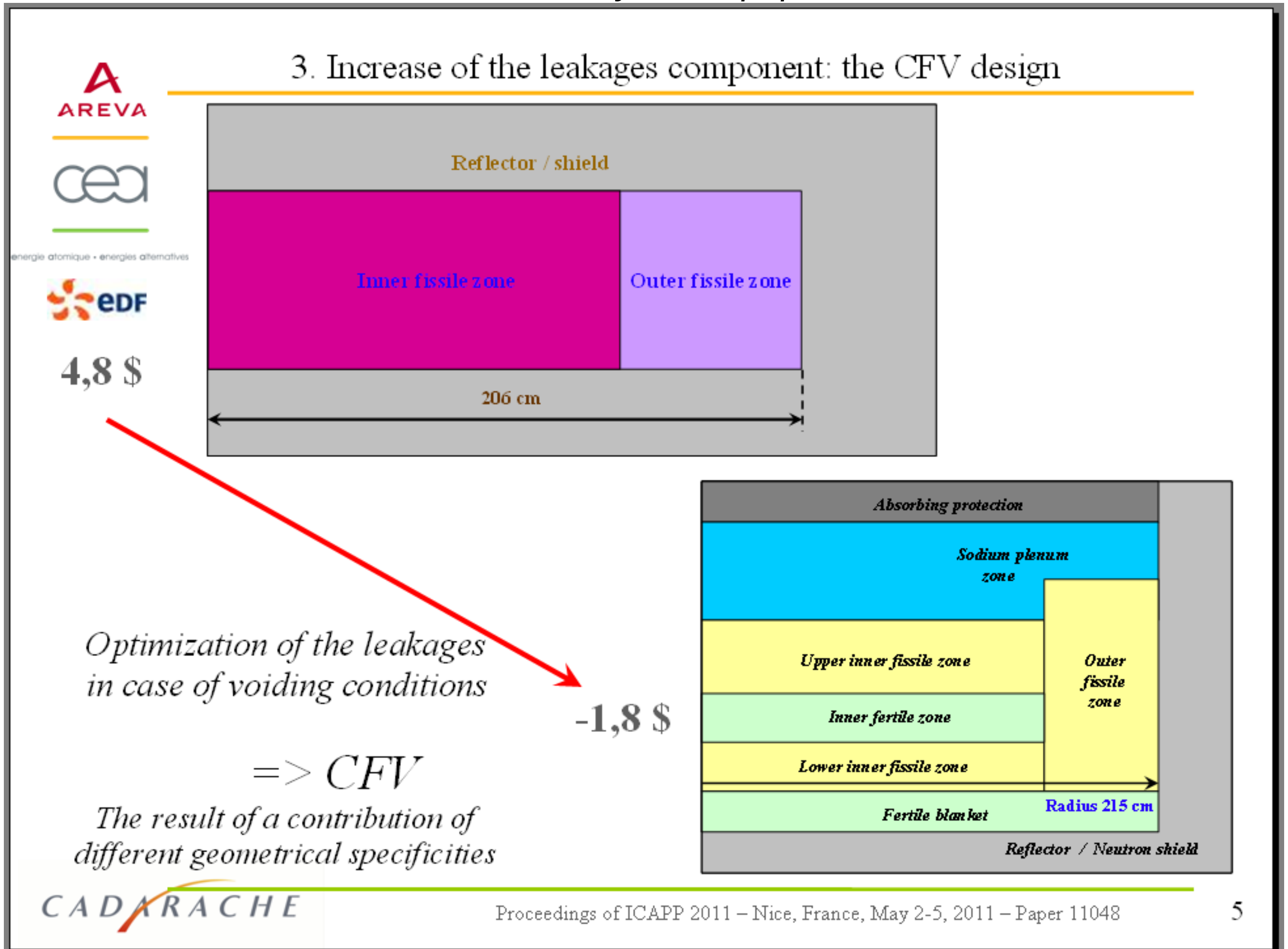
Starting point: CFV Core design from CEA

Excerpts from CEA presentation: P. Sciora et al., Low void effect core design applied on 2400 MWth SFR reactor, ICAPP 2011, Nice, France, 2-5 May 2011, paper 11048.



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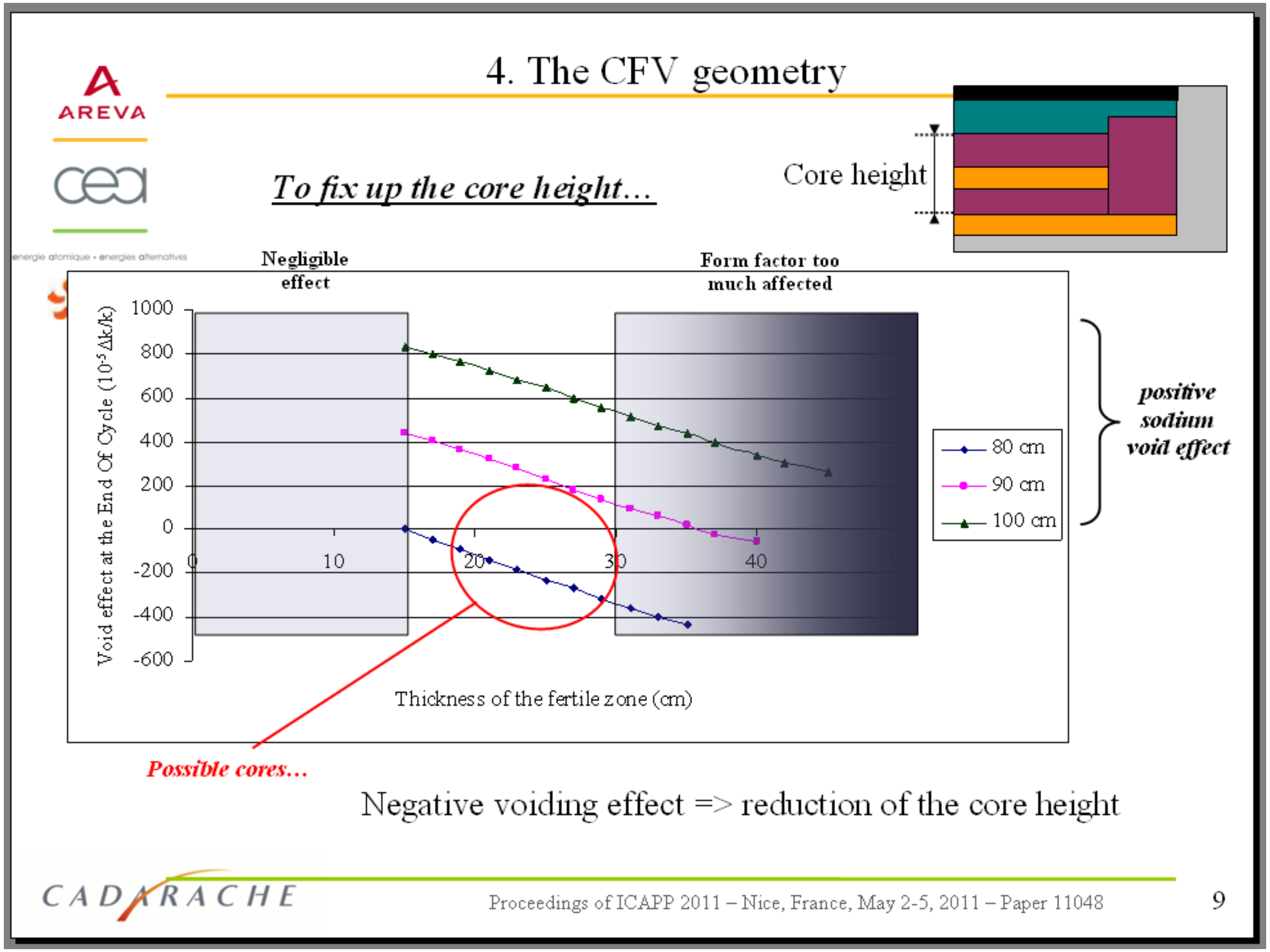

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4
5
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7
8
9
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11
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13
14

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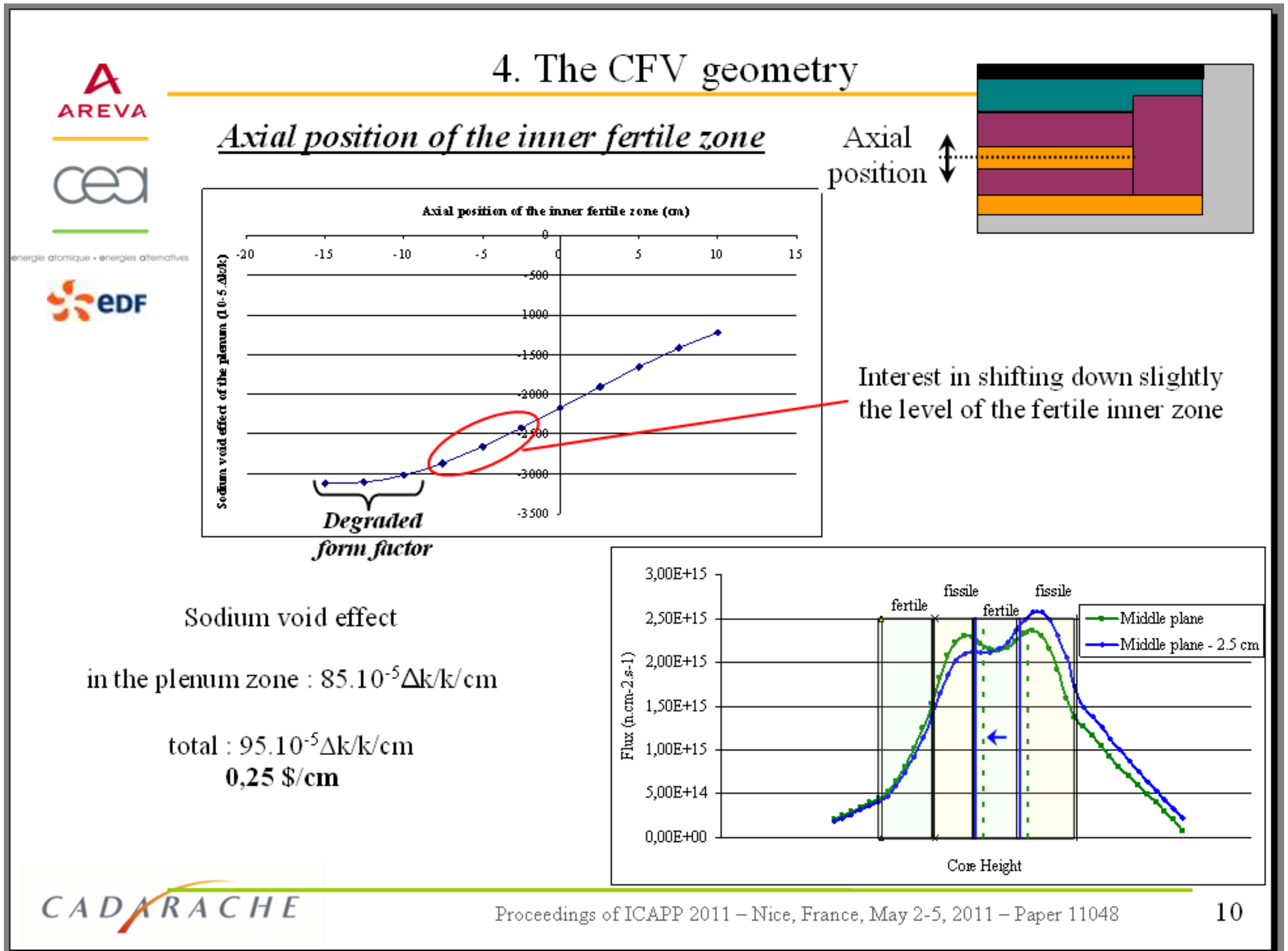

Starting point:
CFV Core design from CEA

- **Synthesis of key features of the CFV design**
  - **The CFV design is a sound solution for reducing the sodium void effect**
    - The CFV design is the current reference core for ASTRID Project
    - See paper 242, MS. Chenaud – Status of ASTRID core studies at the end of predesign phase 1, this conference
    - See paper INV-021, DOE-CEA benchmark on SFR Astrid innovative core: neutronic and safety transients simulation, this conference
- **A constraint on core height…**
  - **The principle of an internal fertile slab to axially distort the flux is not enough efficient above 0.8 m fissile height**
  - **Extrapolation to a larger power level means enlarging core diameter**
    - Very flat core with risk of radial instability of flux
    - Potential impact on reactor vessel diameter

R&D orientation = try to remove the constraint on core height

Novelty:
TOPAZ design option from AREVA

1
2
3
4
5
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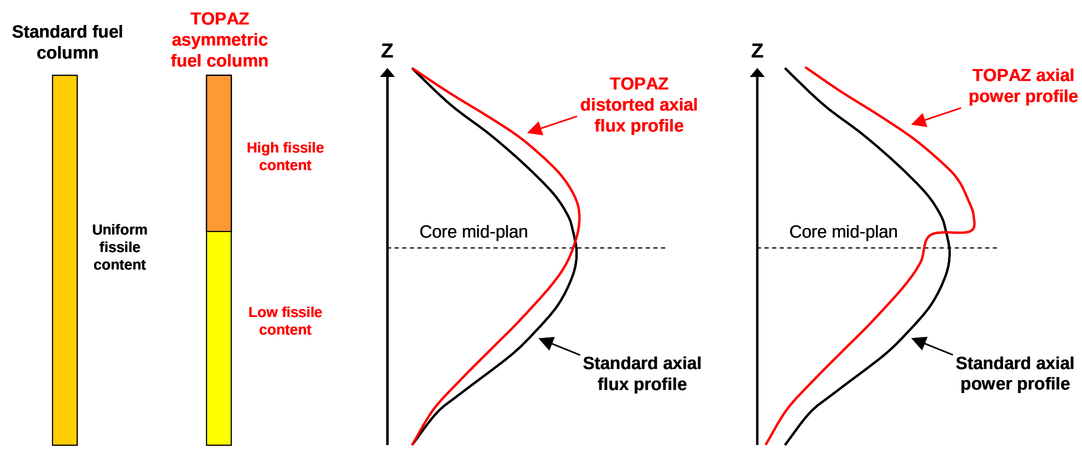
7
8
9
10
11
12
13
14

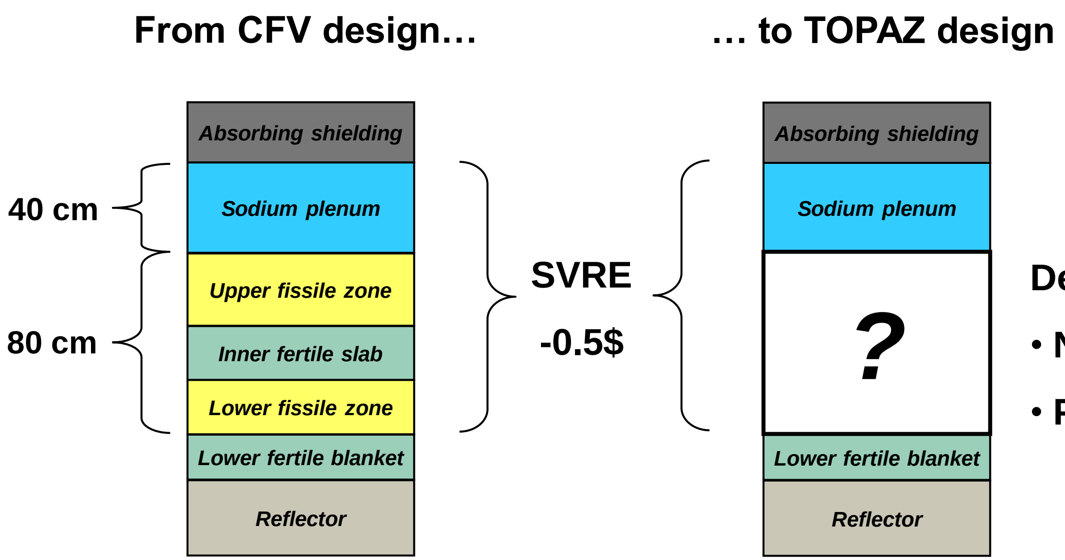
- **Objective**
  - **Improve the CFV concept so as to maintain the negative void worth even in the case of core heights larger than 0.8 m**
  - **Keep the upper sodium plenum and absorber shielding but look for other arrangements of the fuel column…**
- **Identified solution**
  - **Fissile content zoning is known to modify flux shape**
  - **Varying the Pu content as a means to axially distort the flux**



In TOPAZ , fuel zoning is used for axial asymmetric flux distortion

Putting TOPAZ to the test

- **Objective is to verify the effectiveness of the option**
- **Principle of first calculation test**



Details of fuel zoning:

- **Number of axial zones ?**
- **Pu content ?**

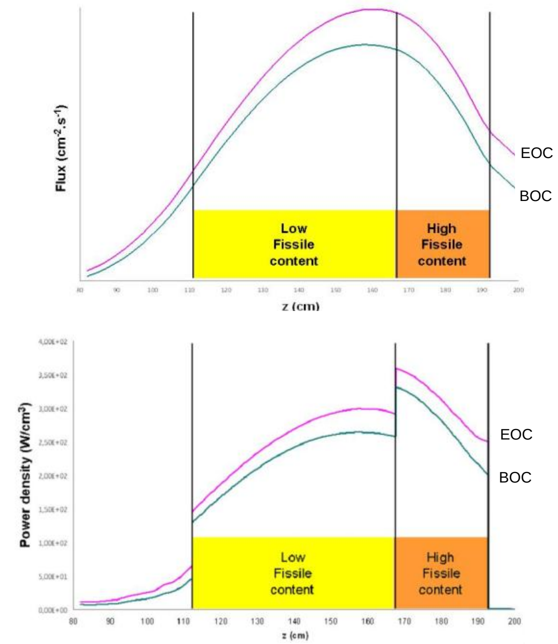
- **Simplified calculation model in 2D RZ geometry**
  - **2D Sn transport solver from ERANOS code system (CEA), + JEFF3.1 data**
  - **Refined axial meshing to properly reflects leakage effects**

Putting TOPAZ to the test

- TOPAZ solution confirmed at 80 cm fissile height

Parameter	80
Average Pu content (%)	19.1
Axial fuel zones in inner core	2
Pu contents* inner core (%)	14.5 22.4 -
Fuel zone heights* inner core (m)	0.55 0.25 -
Axial fuel zones in outer core	1
Pu contents* in outer core (%)	~22 -
Fuel zone heights* outer core (m)	0.80 -
Sodium void worth ($)	-0.9 $

* from bottom to top of the fuel column



- Solutions also found at 90 cm and 100 cm fissile height!
  - 3 zones are required from 90 cm
  - Zoning in outer core becomes necessary as well

1
2
3
4
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6
7
8
9
10
11
12
13
14

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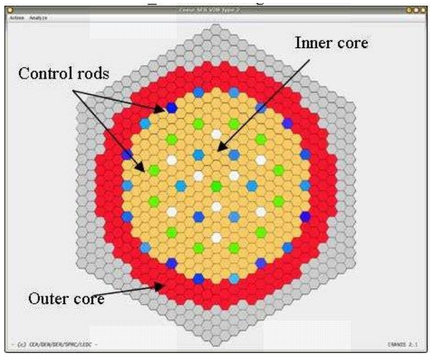
Implementation of TOPAZ on a 3600 MWth core

Sciora P., et al., « A Break-even Oxide Fuel Core for an Innovative SFR »,GLOBAL2009, Paris, France, paper 9528.



Parameter	V2b Reference
Core power (MWth)	3600
Fuel residence time (EFPD)	2050
Core batches	5
Core diameter (m)	4.9
Core fissile height (m)	1
Sodium plenum height (m)	no
Axial fuel zones	1
Average Pu content (%)	15.8
Fuel zones heights* (m)	1
Pu contents* inner core (%)	-
Pu contents* outer core (%)	-
Average burn-up (GWd/t)	99
Peak burn-up (GWd/t)	139
Peak neutron dose (dpa)	148
Internal breeding gain	+0.04
Power density (W/cm^3)	207
Peak Power density (W/cm^3)	294
Peak linear power (W/cm)	420
Sodium void worth ($)	+4.9

- **Reference: SFR V2b core design**
  - **Large power**
  - **Homogneous core with 2 radial zones**
  - **Fully characterized, available calculation files**
- **TOPAZ transformations**
  - **Implement an upper sodium plenum with absorbing upper shielding just above (same as CFV)**
  - **Implement TOPAZ principle in the fuel column, on the basis of results from preliminary 2D calculations**
- **Calculation schemes (ERANOS)**
  - **VARIANT Hex 3D Pn transport code for most of performances**
  - **2D Sn transport code for SVRE**

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Implementation of TOPAZ on a 3600 MWth core

Parameter	V2b Reference	V2b TOPAZ
Core power (MWth)	3600	3600
Fuel residence time (EFPD)	2050	2050
Core batches	5	5
Core diameter (m)	4.9	4.9
Core fissile height (m)	1	1
Sodium plenum height (m)	no	0.4
Axial fuel zones	1	3
Average Pu content (%)	15.8	16
Fuel zones heights* (m)	1	0.80 0.10 0.10
Pu contents* inner core (%)	-	12.3 22.5 28
Pu contents* outer core (%)	-	15.8 23.5 27
Average burn-up (GWd/t)	99	99
Peak burn-up (GWd/t)	139	
Peak neutron dose (dpa)	148	-
Internal breeding gain	+0.04	0.00
Power density (W/cm^3)	207	207
Peak Power density (W/cm^3)	294	350
Peak linear power (W/cm)	420	550
Sodium void worth ($)	+4.9	-0.7**

* from bottom to top of the fuel column

** including sodium plenum

- **Solution found with negative SVRE**
  - **Confirms TOPAZ effectiveness**
- **Best solution consists of:**
  - **3 axial zones in inner core and outer core**
  - **Pu contents in fresh fuel is in the range 12.3% to 28%**
- **Power peaking**
  - **Pronounced in top regions of fresh fuel**
  - **An increase of the number of pins would be probably necessary in case of TOPAZ design**

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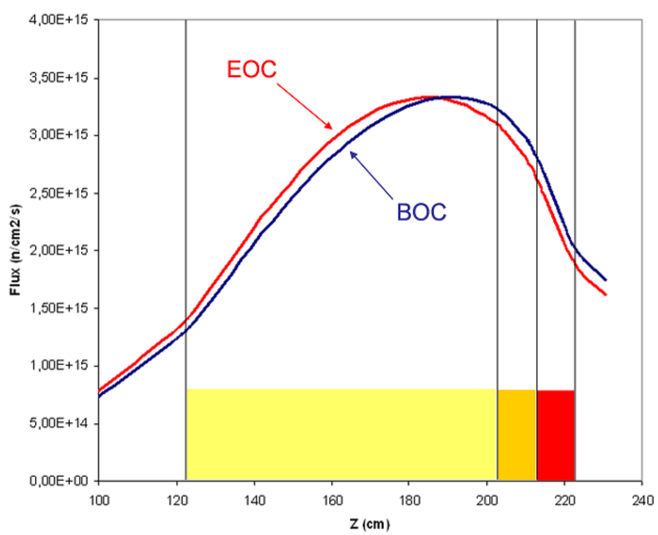
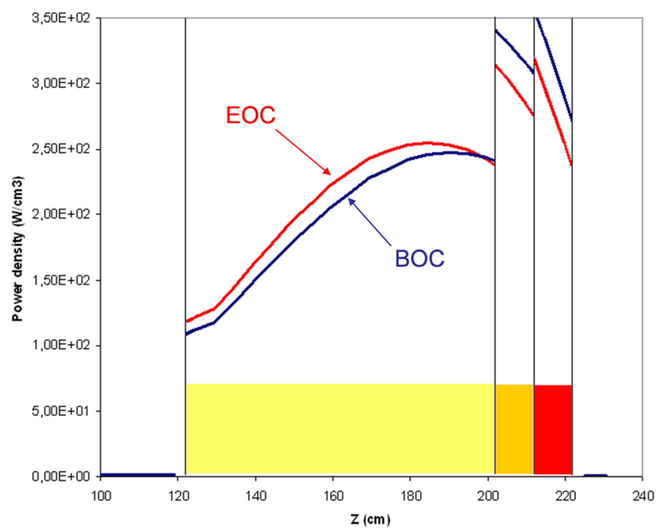
Implementation of TOPAZ on a 3600 MWth core





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Future work

- **Validation of TOPAZ calculations**
  - Currently relies on CEA validation works performed for validating the CFV concept
  - Although involving similar physics phenomena to the CFV, a specific validation programme is necessary (Monte Carlo benchmark)
- **Benefits in case of unprotected transients**
  - A priori, should provide the same advantages as the CFV concept in case of loss of flow or of loss of heat sink, but this should be confirmed
- **Fuel performances**
  - To be verified, particularly because of high linear rates in fresh fuel
  - Impact on fuel manufacturing to be verified
- **Core behaviour in case of fuel melting**
  - Specific behaviour of the TOPAZ fuel column to be evaluated

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Conclusion

- **AREVA has developed the TOPAZ design option as a solution to further minimize the sodium void worth in large SFR cores. The purpose of the TOPAZ option is to amplify the favourable negative component of an upper sodium plenum by means of an asymmetrical axial zoning of Pu content in the fuel column.**
- **Applied on the 3600 MW SFR V2b core design with 1 m fissile height and an upper sodium plenum, the TOPAZ option allows reaching a slightly negative sodium void effect.**
- **The validation of present TOPAZ results relies on current CEA validation works performed for validating the CFV concept. Although involving similar physics phenomena to the CFV, a specific validation programme has to be planned in AREVA in order to fully confirm the gain on sodium void effect with TOPAZ.**
- **In parallel to neutron studies, performances of the TOPAZ design should be now further assessed in regard to fuel behaviour and accidental conditions.**

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Thank you

Questions?