Italian National Agency for New Technologies,
Energy and Sustainable Economic Development

The current ALFRED core design

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Outline

- ✓ The ALFRED project
- ✓ The ALFRED core design
- ✓ Characterization of the core design
- ✓ Power and temperature distribution
- ✓ Conclusion

The ALFRED Project

The next generation of nuclear reactors focuses on GCRs or LMRs. Among the LMRs the most promising are the sodium-cooled reactors and lead/lead alloy-cooled reactors like those following the Advanced Lead-cooled Fast Reactor European Demonstrator - ALFRED.

ALFRED design was initially conceived in the ‘Lead-cooled European Advanced Demonstration Reactor’ – LEADER project under the 7th EURATOM Framework Program (FP7).

Since the conclusion of the LEADER project, the ALFRED design is being carried on by the Fostering ALFRED Construction – FALCON – International Consortium, signed by ENEA, Ansaldo Nucleare, RATEN-ICN Romania.

A new strategy for ALFRED

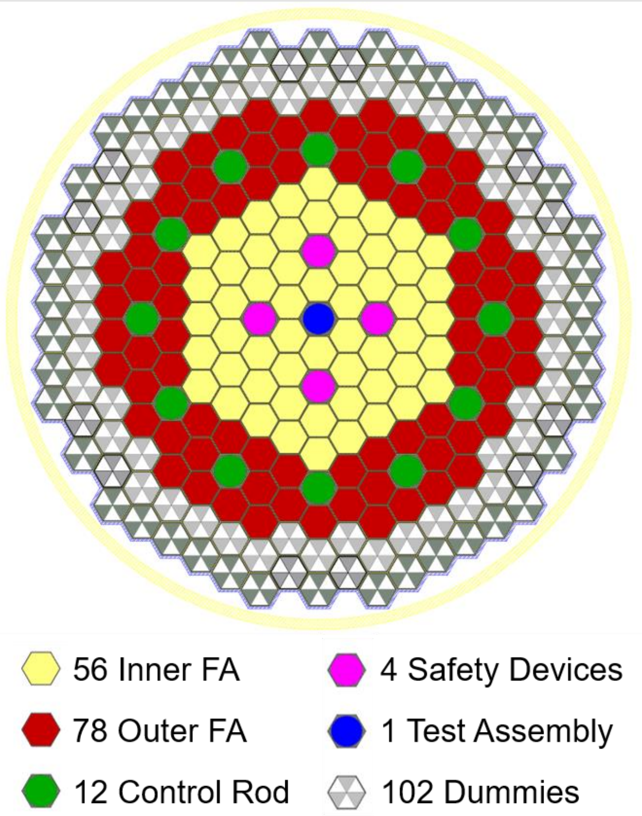
Due to the innovative nature of the demonstrator, ALFRED was conceived since the beginning for operating with wide margins for a broader flexibility in different conditions, representative of nominal and off-nominal situations anticipated for future reactors.

Being the first LFR, the operation of ALFRED has been segmented in phases with increasing power and temperature. Each phase will be used to qualify the following phase under neutron irradiation at representative conditions (achieved in a special in-core position).

	Commissioning	Phase 1	Phase 2	Phase 3
Core power [MW]	≈ 0	100	200	**300**
Core inlet temperature [°C]	390	390	400	**400**
Core outlet temperature [°C]	390	430	480	**520**
Cladding hot-spot temperature [°C]	≈ 390	< 450	< 550	**< 600**

The ALFRED core design – Core layout

Core map



Sub-Assemblies

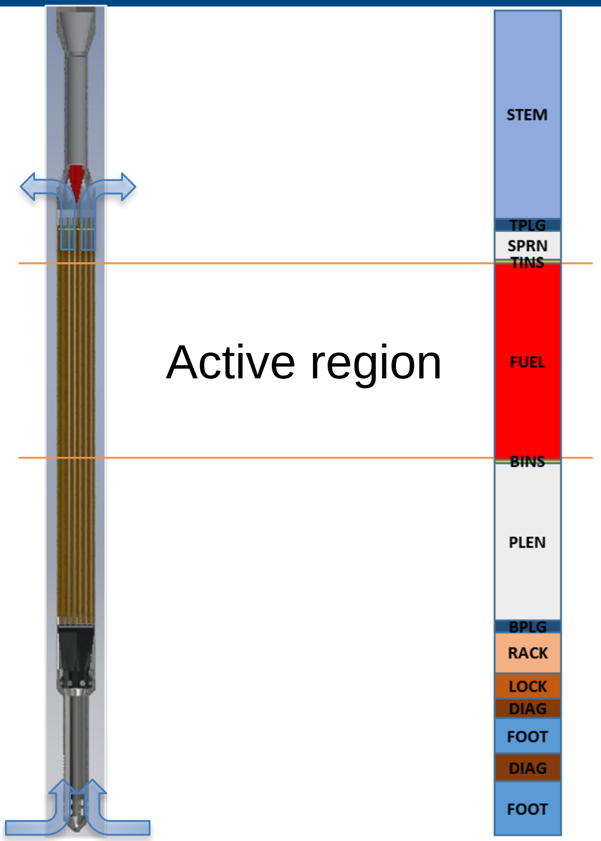
- The adopted core configuration is made of wrapped hexagonal Sub-Assemblies (S/As).
- Each S/A has the same external shape with same size.
- The triangular pitch among the S/As is 167 mm.

The ALFRED core design – Fuel Assembly

Vertical layout

- The active height is short (81 cm) in order to enhance leakage to reduce coolant density effects.
- The axial scheme reflects the structure of the Fuel Assembly (FA), of the bundle within it and of the pins comprising the latter.

Cross-section

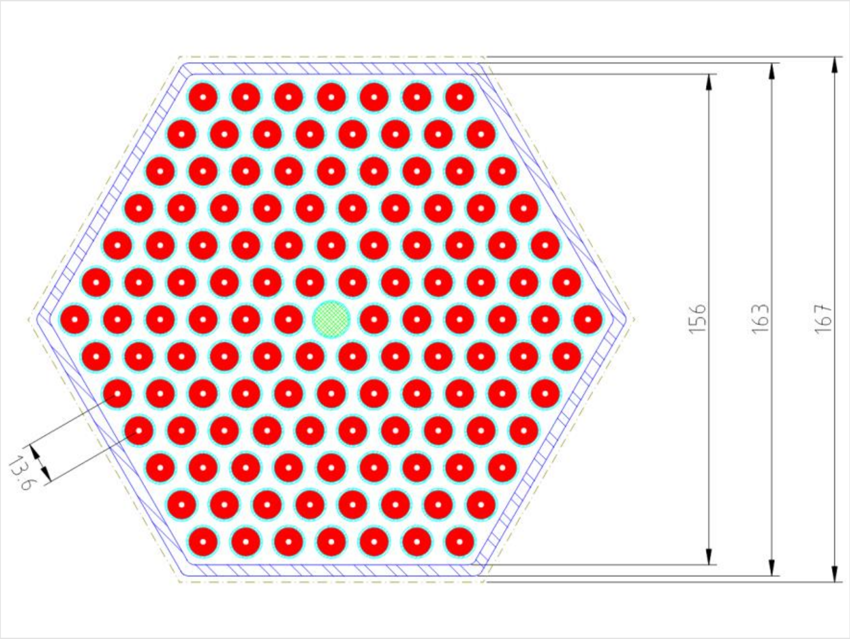


The ALFRED core design – Fuel Assembly

Horizontal layout

- Each FA comprises 126 fuel pins and 1 dummy pin (for instrumentation).
- The two types of FAs only differ for the fuel enrichment:
  - 20.5 wt.% $PuO_{1.97}/(U,Pu)O_{1.97}$ in inner zone;
  - 26.2 wt.% $PuO_{1.97}/(U,Pu)O_{1.97}$ in outer zone.
- The pitch-over-diameter ratio is 1.295 in order to improve natural circulation.

Cross-section

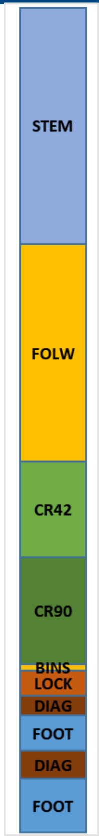


The ALFRED core design – Control Rod

Vertical layout

- The absorber length is segmented in two axial zones:
  - the lower one for reactor shutdown ("CR90"), with B_4C enriched with 90 at.% ^{10}B;
  - the top one ("CR42") for reactor control, with B_4C enriched with 42 at.% ^{10}B.
- Above the absorber there is a reflector follower for neutron economy.

Cross-section

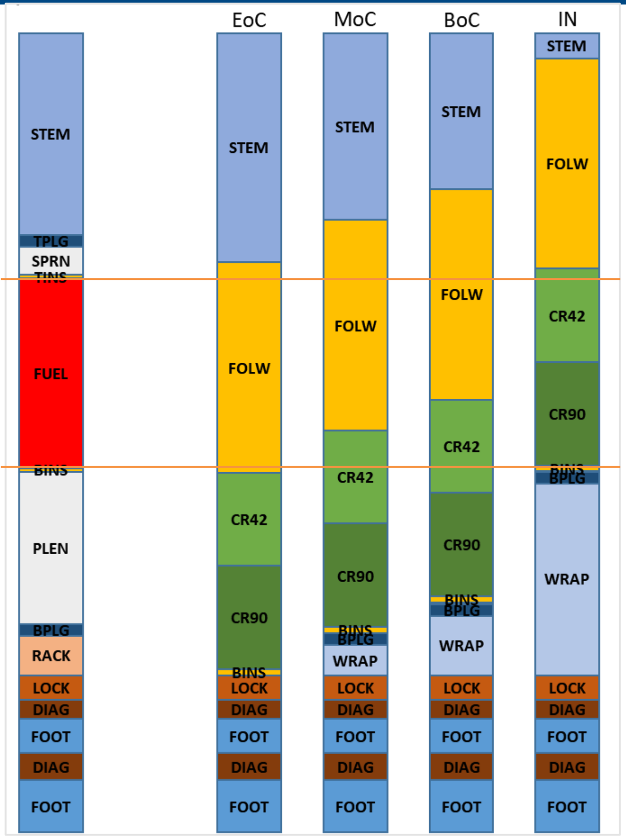


The ALFRED core design – Control Rod

Operating principle

- For reactor control, only a portion of the upper column enters the active region from the bottom.
  - at Beginning of Cycle (BoC) the absorber is in by 26.5 cm;
  - at End of Cycle (EoC) the absorber is out by 4 cm.
- For reactor shutdown, both absorber columns overlap symmetrically with the active region.

Cross-section

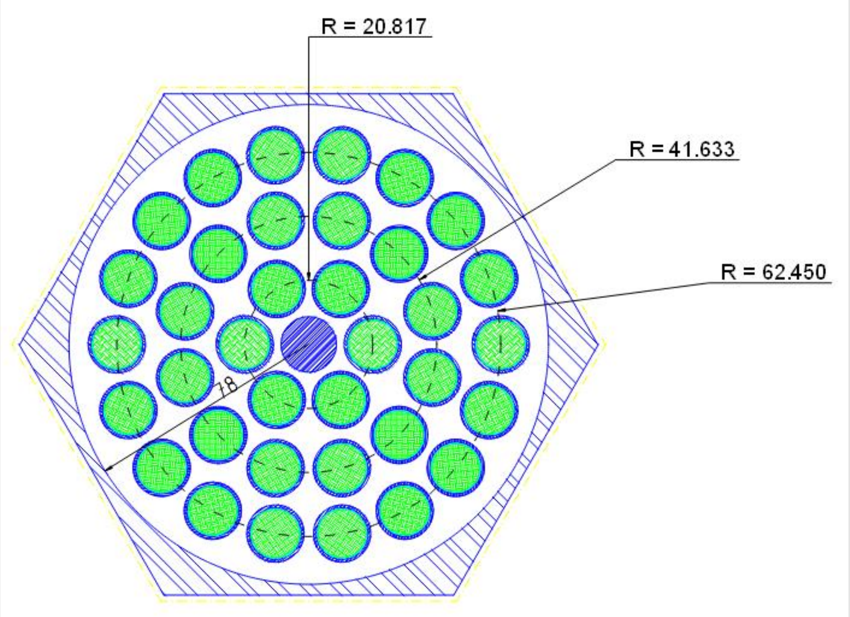


The ALFRED core design – Control Rod

Horizontal layout

- Each Control Rod (CR) comprises 36 absorber pins and 1 dummy pin (structural).
- On the inside the wrapper is cylindrical to facilitate the centering of the bundle.

Cross-section

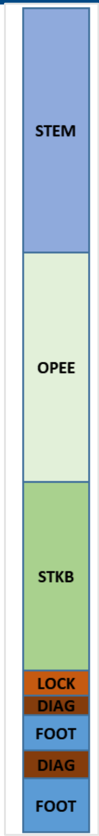


The ALFRED core design – Safety Device

Vertical layout

- The device is made of two axial regions:
  - a lower section containing the absorber and
  - an upper section to host the absorber in operation.

Cross-section

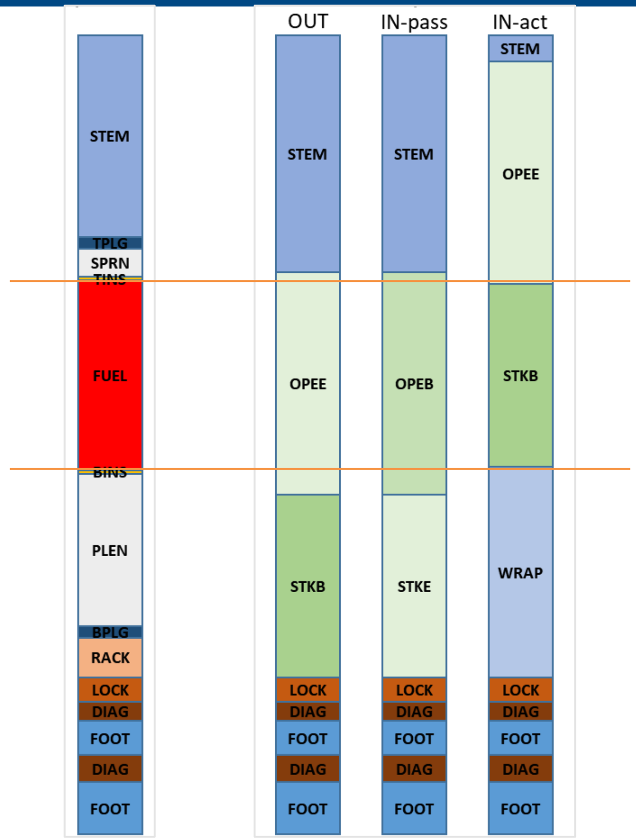


The ALFRED core design – Safety Device

Operating principle

- The device is able to operate both on demand (active) and spontaneously (passive):
  - when actively commanded, the whole device translates vertically up to have the absorber facing the core;
  - when passively actuated, the absorber is moved from the lower section to the upper one.

Cross-section

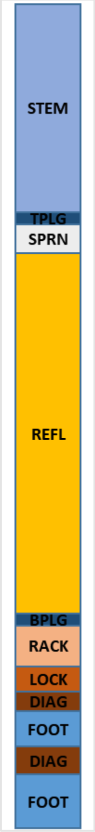


The ALFRED core design – Dummy Assembly

Vertical layout

- The dummy assembly has the same layout of the FA, with the only difference that all internal regions in the pin (but the top spring) are replaced by yttria-stabilized zirconia pellets.

Cross-section

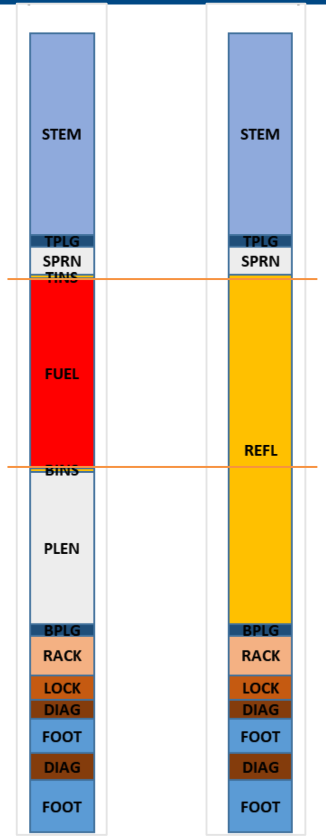


The ALFRED core design – Dummy Assembly

Operating principle

- The reflecting/shielding region is meant to reflect leaking neutrons back to the core and to provide protection to the inner vessel against neutron damage.

Cross-section



The ALFRED core design – Summary

Parameter	Unit	Value
Thermal power (phase 3)	MW	300
Fuel Assemblies (inner/outer)	--	134 (56 / 78)
Pins per FA (fuel/dummy)	--	127 (126 / 1)
Fissile length	mm	810
Coolant temperature at core inlet/outlet	°C	400 / 520
Inner/outer pellet radius	mm	1.0 / 4.5
Inner/outer cladding radius	mm	4.65 / 5.25
Inner/outer central dummy pin radius	mm	5.5 / 6.0
Pins lattice pitch	mm	13.6
Inner/outer wrapper flat-to-flat	mm	156 / 163
Assemblies lattice pitch	mm	167
Inner/outer inner vessel radius	mm	1475 / 1525

Fuel management strategy

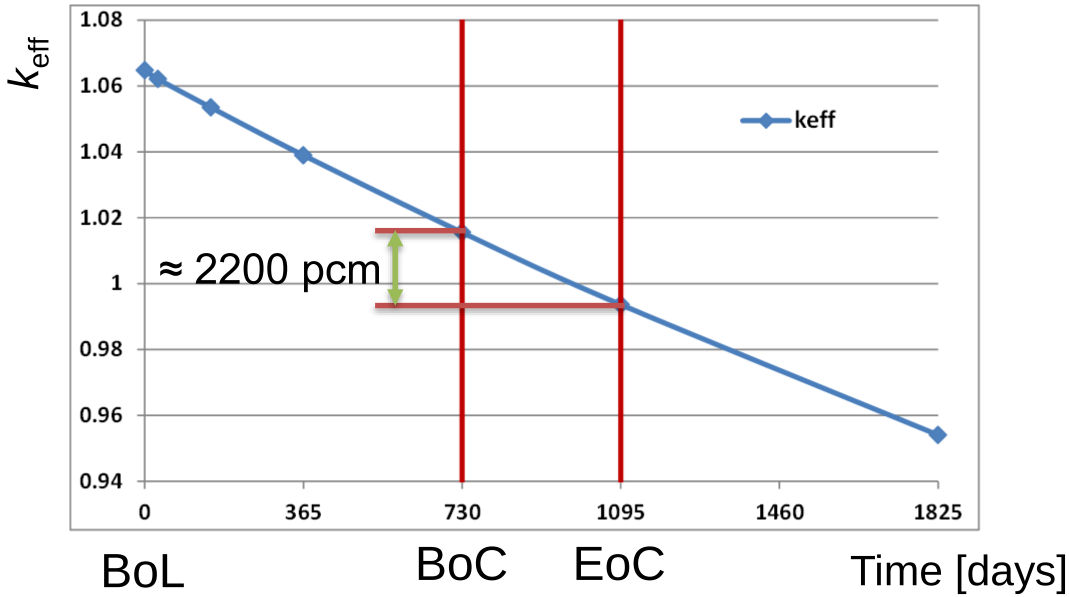
The fuel management strategy is based on a 5 x 1y reloading scheme (5y residence time + 5 batches)

Time after startup [y]	Fuel age before/after refueling [y]				
	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5
0	0	0	0	0	0
1	1 / 0	1 / 1	1 / 1	1 / 1	1 / 1
2	1 / 1	2 / 0	2 / 2	2 / 2	2 / 2
3	2 / 2	1 / 1	3 / 0	3 / 3	3 / 3
4	3 / 3	2 / 2	1 / 1	4 / 0	4 / 4
5	4 / 4	3 / 3	2 / 2	1 / 1	5 / 0

…equilibrium achieved

k_{eff} variation during an irradiation subcycle

Results for CRs inserted halfway between BoC and EoC (sc Middle of Cycle, MoC) and 1-batch approximation:



Status	k_{eff}
BoL	1.06477
BoC	1.01554
EoC	0.99363

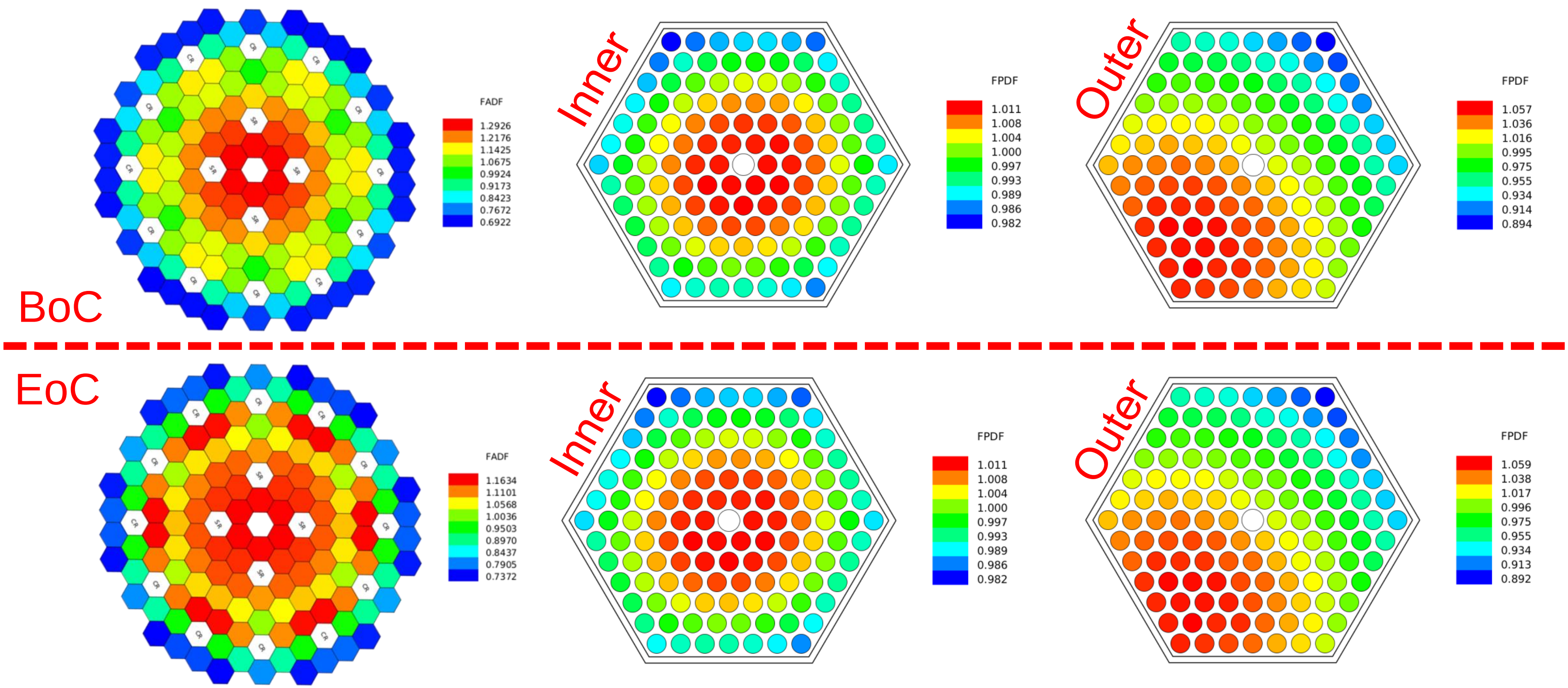
Requirements & worth of CRs and SDs

Results proved that CRs and SDs largely satisfy all requirements:

<table>
<tr><th rowspan="2">Function</th><th rowspan="2">Requirement</th><th>Control</th><th colspan="2">Shutdown</th></tr>
<tr><th>CRs</th><th>CRs</th><th>SDs</th></tr>
<tr><td>Sub-cycle criticality swing [pcm]</td><td>2200</td><td rowspan="2">2900</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Cold-zero-power to Hot-full-power transition [pcm]</td><td>700</td><td rowspan="3">5900</td><td rowspan="3">3900</td></tr>
<tr><td>Maximum reactivity insertion [pcm]</td><td>300</td><td>N/A</td></tr>
<tr><td>Sub-criticality at SCRAM [pcm]</td><td>1000</td><td>N/A</td></tr>
</table>

Core-wise and assembly-wise power distributions

Good power flattening, notably core-wise at pin level (related to the temperature limit of 600 °C on the cladding outer wall)



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