# SENSITIVITY STUDIES OF ALLEGRO GFR DEMONSTRATOR

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## 1. Introduction

Reactor ALLEGRO is experimental demonstrator of Gas-cooled Fast Reactor (GFR) technology. GFR is one of the Generation IV innovative concepts and GFR represents high temperature, fast spectrum system with closed fuel cycle. Helium is used like coolant medium. The main goal is to combine advantages of fast spectrum and high operation temperature. ALLEGRO will be the 75 $MW_{th}$ demo reactor and its realization represents a necessary milestone in developing a large industrial power reactor (GFR2400). [1][2]

## 2. Reference ALLEGRO MOX model specification

For the purpose of the studies, three-dimensional hexagonal ALLEGRO model was developed using SCALE/KENO VI. computational tool [3]. Model consists of active core, reactivity control system both axial and radial reflector and shielding. Active core contains *81* fuel subassemblies arranged in *5* concentric rings. Active part of fuel subassembly is formed by hexagonal array of *169* cylindrical MOX fuel pins covered with AIM1 cladding enclosed. Plutonium volume fraction in fuel reaches *25.5 %*. Active core height is *86.58cm*. Reactivity control system consists of *6* control safety devices (CSD) and *4* diverse safety devices (DSD) with the same material composition and structure. Each CSD/DSD contains array of *54* absorber pins. High enriched boron carbide $B_4C$ is used as absorber material. In addition, active core features *6* dummy positions tend to be used for experimental purposes. These experimental positions with dummy assemblies are composed from AIM1 wrapper filled with helium. In radial direction, ALLEGRO core is surrounded by *3* rings of AIM1 reflector and *3* rings of shielding assemblies. Reflector and shielding subassemblies are made from appropriate homogeneous material enclosed in AIM1 wrapper. Reflector and shielding layers are placed in both axial direction of active core. Total model height is *303.03 cm*. Radial cross section of fuel rod, control rod and whole core are shown in the Fig.1, Fig.2 and Fig.4. [2]

## 3. Sensitivity studies

The reference core mentioned above was developed by research group at Institute of Nuclear and Physical Engineering (INPE). Design is based on ESNII+ALLEGRO core specification [2] with some geometrical improvements. Industrial partner VUJE also participates at ALLEGRO project in Slovakia. Based on local experience, model developed by group at VUJE differs from the model created at INPE. To evaluate the impact of these geometrical differences and changes on system reactivity and behaviour is essential for further analysis and studies of ALLEGRO core and also for next cooperation between INPE and VUJE research groups.

Sensitivity study of the geometrical improvements and differences is the main subject of the paper. Each change in geometry has been incorporated into the model individually and KENO VI calculation was provided and $k_{eff}$value for each model was determined . Values were compared to reference model $k_{eff}$in order to evaluate the difference in system reactivity.

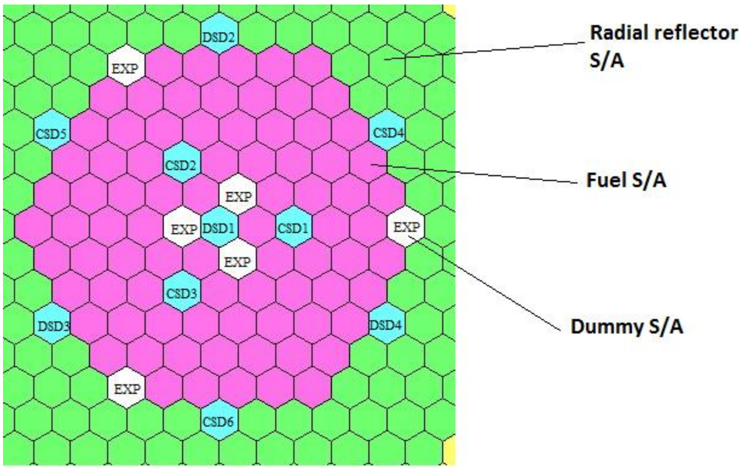

Fig.1: *a) Active core with CSD and DSD positions*

### Reference case and homogenization effect

At first, reference model calculation was provided for both “All up” and “All down” control rods positions. At position “All up”, lower edge of every control rod is at parking position on the upper edge of fuel part. Position “All down” means all control rods are fully inserted in the active core, and their lower edges are situated at the bottom edge of the fuel part. Heterogeneous ALLEGRO core model described in section 2 was chosen as reference case. Parameters of KENO VI calculations were set to 5000 generations of 30000 neutrons each. ENDF/B-VII.0 continuous nuclear data libraries were used in all calculations. Results are shown in Table 1.

ALLEGRO project ongoing at INPE includes a many various studies using different computational codes. Nowadays, just homogeneous model was developed in deterministic codes, accordingly, to know homogeneous KENO VI model $k_{eff}$ value is useful for the purpose of validation. Reference ALLEGRO MOX model was fully homogenized. Axial structure was maintained for fuel and control rods in terms of homogeneous axial layers of appropriate materials. Values for both “All up” and “All down” cases are given by Table 1.

Tab. 1. *Comparison of heterogeneous and homogeneous model*

| | All up | All down | Total CR worth [*pcm*] |
|---|---|---|---|
| Heterogeneous | 1.01279±0.00019 | 0.89826±0.00019 | 11 453 |
| Homogeneous | 1.00984±0.00019 | 0.89008±0.00019 | 11 976 |

As could be seen in Table 1, homogeneous model $k_{eff}$ valuesare lower than for heterogeneous model. The reason is, self-shielding effect of heavy nuclei is more intensive for homogeneous geometry. The difference is greater in case of “All down” geometry arrangement because of the fact of different neutron spectrum in active core.

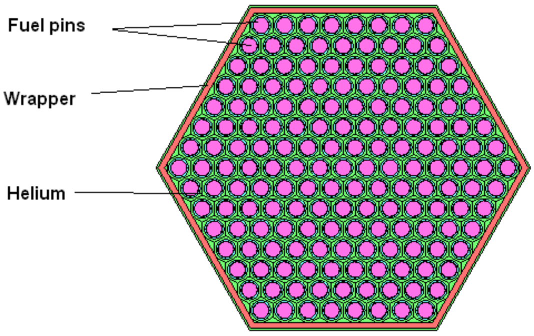

Fig.2: *a) Radial view of fuel subassembly*

**Infinite CR position**

As well as parking (“All up”) CR position, VUJE research group defined also so called infinite control rod position. At this infinite position, the CR lower edge is placed at bottom edge of upper axial reflector layer. Geometry is shown in the Fig.3. In fact, edge of CR is situated *9.06 cm* above fuel part. The impact on system reactivity was investigated for all control rods at infinite position.

Tab. 2. *Comparison of CR parking and infinite position*

| | |
|---|---|
| CR at parking position (reference “All up”) | 1.01279± 0.00019 |
| CR at infinite position | 1.01727± 0.00019 |

Table 2 shows results for CR parking and infinite position. The difference in reactivity is *448 pcm*, which means the effect of infinite CR position is significant .

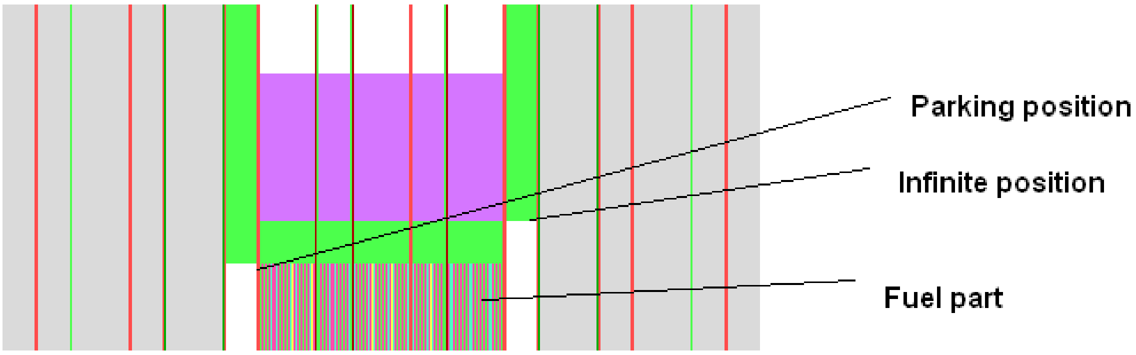

Fig.3: *a) Difference between parking and infinite CR position*

**Inner CR hexagon filling**

In developed reference model, helium is used to fill inner hexagon in control rod subassembly instead of homogeneous rod follower material defined by ESNII+ALLEGRO core specification. However, the rod follower material is homogeneous mixture of helium with small fraction of AIM1, no noticable effect is assumed.

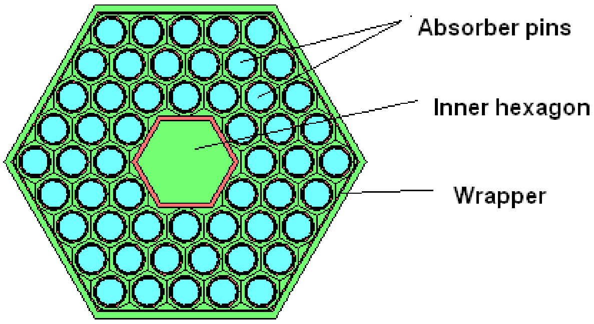

Fig.4: *a) Radial view of control rod subassembly*

Three different CR positions were chosen for the calculations purposes – DSD1 in the middle of the active core, CSD1 close to the central part and CSD6 at outer part of active core. Calculations were provided individually for each position with selected rod fully inserted to active core. Results are given by Table 3.

Tab. 3. *Comparison of CR hexagon inner material*

| | All CR | DSD1 | CSD1 | CSD6 |
|---|---|---|---|---|
| Reference inner material | 0.89826±0.00019 | 0.98701± 0.00019 | 0.98965± 0.00019 | 1.00829± 0.00019 |
| Follower inner material | 0.89818±0.00019 | 0.98698± 0.00019 | 0.98992± 0.00019 | 1.00827± 0.00019 |

As could be seen, the differences between values for reference CR design and CR design with different inner material are for all positions negligible and their values do not exceed statistical uncertainty. It could be considered, the change of inner CR hexagon material has no impact on system reactivity.

### Fuel lattice pitch

Analysis at different fuel temperatures were provided for ALLEGRO core. Seeing that radial thermal expansion is not properly defined, the fuel lattice pitch for reference model was changed from value *0.803* to *0.805 cm*. Since fuel lattice pitch is a critical parameter, the noticable effect on reactivity is expected.

Tab. 4. *Comparison for different fuel lattice pitch*

| | All up | All down |
|---|---|---|
| Reference lattice pitch | 1.01279± 0.00019 | 0.89826± 0.00019 |
| Original lattice pitch | 1.01317± 0.00019 | 0.8978± 0.00019 |

Results are shown in Table 4. Difference for position "All up" is *38 pcm*and for "All down" position *48 pcm*. These values are not so significant as was supposed.

### Helium layer

In the case of placing CR at infinite position, CR upper edge exceeds total height of model. Layer of helium with thickness of *6.04 cm* was added above the whole ALLEGRO core in reference model. The influence of helium presence was investigated for various layer thicknesses. Calculations were provided for layer with half of original thickness, double thickness, with *1 m* thick layer and also for core without helium layer. Helium layer is placed above the shielding, no effect is assumed. Results are given by Table 5.

Tab. 5. *Comparison for different helium layer thickness*

| Layer thickness [cm] | 0 | 3.02 | 6.04 | 12.08 | 100 |
|---|---|---|---|---|---|
| $k_{eff}$ | 1.01337± 0.00019 | 1.01344± 0.00019 | 1.01279± 0.00020 | 1.01324± 0.00019 | 1.01317± 0.00019 |

Differences for various helium layer thickness do not exceed statistical uncertainty, what implies the layer presence above the core has no noticable impact on system reactivity and behaviour.

## 4. Conclusion

Sensitivity studies of ALLEGRO core reference model were provided for various geometrical improvements. The results shown, the most of them has no significant impact on system reactivity. The greater difference in system $k_{eff}$ value appeared just in the case of infinite control rod position. The further analysis are needed to evaluate effect of this improvement on system behaviour. The use of infinite CR position in calculation model should be considered.

## Acknowledgement

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