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DYN3D Calculations for the V-1000 Test Facility and Comparisons with the Measurements

Ulrich Grundmann* and Siegfried Mittag
Research Centre Rossendorf, Institute of Safety Research,
P.O.Box 510119,D-01314 Dresden, Germany

In the framework of the EU project VALCO, measurements at the V-1000 test facility of the Russian Research Centre "Kurtschatov Institute" are used for the validation of three-dimensional neutronic calculations. Experimental results of steady states and kinetic experiments are available for comparisons with calculations. Respective DYN3D calculations have been performed by using the cross section libraries generated with the codes HELIOS, CASMO and WIMS.

Results obtained by the DYN3D code are compared with steady-state measurements for two different configurations of the V-1000 facility. Pin-power distributions measured within one fuel assembly are compared to the results of the pin power reconstruction implemented in DYN3D.

Two kinetic experiments performed in the V-1000 facility were simulated by the DYN3D code. Comparisons of the calculated results with the measurements at the in-core detector positions are given. The calculated fast flux of the nodes, situated near to the ionisation chambers of the two reactimeters, is compared with the detector signal. The results of the relative detector rates coincide with the measurements. The dynamical reactivities are obtained from the core-averaged flux by inverse point kinetics. It is compared with reactivity curves, provided by the two reactimeters.

KEYWORDS: Three-dimensional neutron kinetics, steady states, kinetic experiments, code validation, VVER-reactors, reactivity.

1. Introduction

Experiments were performed at the full-scale zero power critical facilitlity V-1000 of the Russian Research Centre "Kurtschatov Institute" for the investigation of neutron physical parameters of the VVER-1000 core. Measurements of two steady states and two transients were provided for the validation of three-dimensional neutron kinetic codes in the frame of the EU project VALCO [1]. The results obtained with the DYN3D code [2] are compared with the measurements. Different libraries of two group constants generated with the cell codes HELIOS[3], CASMO[4] and WIMS[5] were used. The comparisons of the radial power distribution and the power in the fuel assembly 85 for the two steady-states with all control rods out of core and with inserted bank 10 are presented in the section 3.

A single control rod of bank 9 is moved in the core and reverse in the kinetic experiment 1. The results of the calculations with the three libraries are compared with the in-core detectors signals and the

* Corresponding author, Tel. +49 351 260 3037, FAX +49 351 260 2383, E-mail: U.Grundmann@fz-rossendorf.de

signals of two ionization chambers in section 4. The reactivity given by inverse point kinetics from the ionization chambers signals and from the core-averaged flux of the calculation are presented. The reactivities obtained during the insertion of the rod are compared with the rod worth derived from stationary calculations. Similar comparisons were presented in section 4 for the kinetic experiment 2 which was a scram with a delayed motion of one stuck cluster.

2. Description of the V-1000 Facility

The full-scale zero power critical facility V-1000 (ZPCF V-1000) is equipped with 163 fuel assemblies (FA) of the VVER-1000 and with the 61 standard clusters of absorber rods. The assembly lattice pitch is 23.6 cm. A reflector of stainless steel is located around the core to simulate the reflector of the reactors installed in nuclear power stations. The annular gap between the reflector and the reactor tank is filled with moderator and simulates the VVER-1000 downcomer (see Fig. 1). The reflector has several vertical tubes. Most of them were filled with stainless steel rods. Ionization chambers for neutron flux measurements are also inserted into tubes. The gap between the fuel assemblies and the steel reflector is filled with moderator. The gap width is changing around the core. It was measured and the local properties of the reflector were taken into account in the calculations of neutronic properties of the reflector [6]. The experiments were carried out on a core representing the first fuel loading of a three-year fuel cycle of a VVER-1000. The criticality of the core was achieved by the moderator level in the core.

The power distributions of the steady states were measured by the irradiation of experimental short fuel rods – detectors in the central tubes of the fuel assemblies (FA). The middle parts of the short fuel rod-detector were at the elevation 120 cm from the lower end of fuel and between spacing grids. The enrichment of the rod – detectors was equal to the enrichment of fuel rods around the assembly central tube. The power distribution measurements for the core were performed for all fuel assemblies. The powers of single fuel pins of the assembly 85 were measured by dismantling the assembly and detecting the irradiation of the fuel pins. The following steady-states are available for comparisons with calculations:

- State without control rods
- State with fully inserted control rods (CR) of bank 10 in the assemblies 41, 44, 79, 85, 120 and 123 of Fig. 1

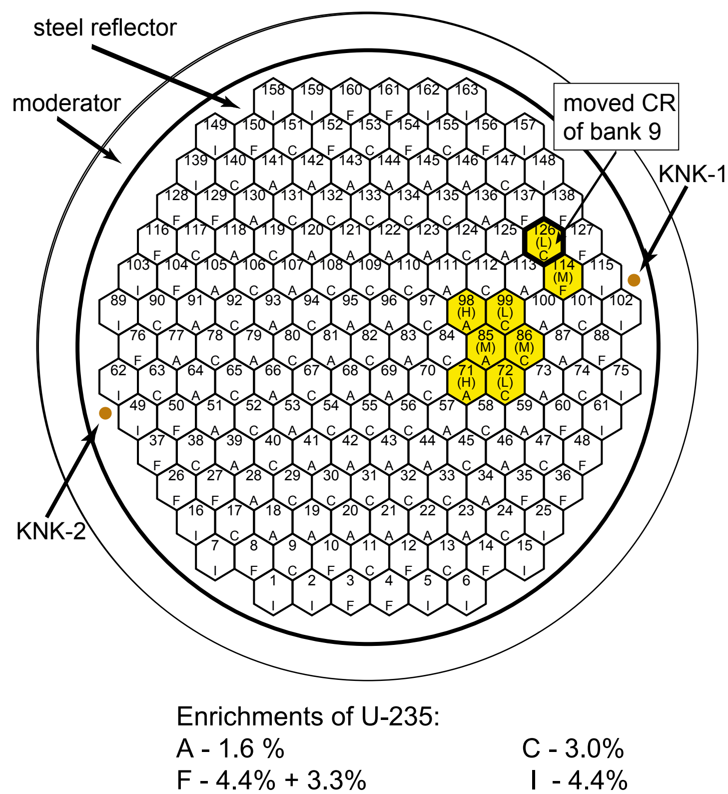

Fig. 1 Assembly numbers with enrichments. Positions of in-core detectors and the single cluster of bank 9.

Concerning the kinetic experiments the neutron flux was measured with the 8 micro fission chambers 71H, 72L, 85M, 86M, 98H, 99L, 114M and 126L denoted by the FA-No. and the axial position where they are situated. They are located in the central tubes of the FAs at the three different axial levels of 265 cm (H), 175 cm (M) and 85 cm (L) (see Fig. 1). The reactivities of the two reactimeters were determined by inverse point kinetics from the signals of the ionisation chambers KNK-1 and KNK-2. The detector rates were normalized at the beginning of the experiments. Measurements of two kinetic experiments were used for the comparisons:

- Motion of a single peripheral control rod cluster of bank 9 (Fig. 1) into the core and reverse (kinetic experiment 1)
- Scram of all control rods except the one cluster of bank 9 (Fig. 1) which was moved delayed with lower speed (kinetic experiment 2)

The core conditions of the different experiments can be seen in Table 1.

Table 1 Conditions of the V-1000 at the measurements

	Critical state CR out of core	Critical state Bank 10 inserted	Intial state kinetic experiment 1	Intial state kinetic experiment 2
boron concentration	1518 ppm	1484 ppm	1528 ppm	1538 ppm
temperature	15.2 °C	15.2 °C	18.6 °C	14.0 °C
moderator level	266.8 cm	253.5 cm	324.0 cm	325.0 cm

3. Steady-State Comparisons

The whole core calculations were performed by DYN3D using different libraries of two group diffusion parameters generated in cell calculations which were performed with the codes HELIOS34], CASMO[4] and WIMS[5]. The fuel assembly discontinuity factors (ADF) used for the reduction of the homogenisation error and the pin power distributions are included in the libraries. In all DYN3D calculations the albedo boundary conditions generated by HELIOS-MARIKO[6] were applied at the outer boundary of the fuel assemblies. Different albedos based on the different reflector conditions around the core were provided.

The powers in the central tubes obtained by the nodal flux reconstruction in the assemblies and the pin powers of the cell calculation at the axial positions of detectors were compared with the measured results. Table 2 shows the eigenvalues and the RMS-values of deviations of the DYN3D-results with the different libraries of group constants. Figure 2 and 3 show the deviations of the DYN3D/HELIOS results from the measurements.

Table 2 Eigenvalue k_{eff} and average deviations from measured values for the two steady states.

	CR out of core		Bank 10 inserted	
	k_{eff}	RMS(%)	k_{eff}	RMS(%)
HELIOS	1.00880	3.1	1.01172	4.2
CASMO	1.00841	5.9	1.01132	6.2
WIMS	1.01348	4.6	1.01692	5.0

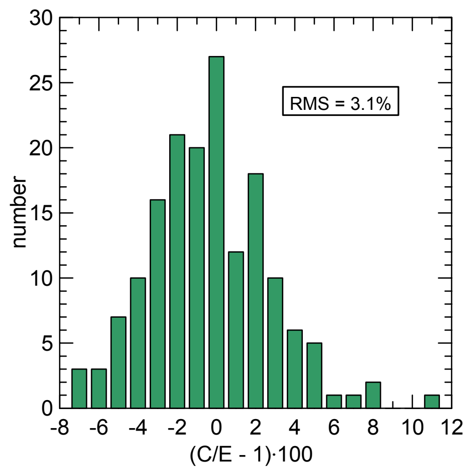

Fig. 2 C/E comparison for state with CR out.

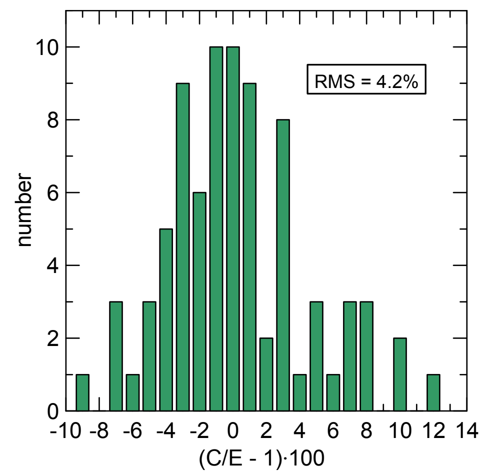

Fig. 3 C/E comparison for state with inserted CR.

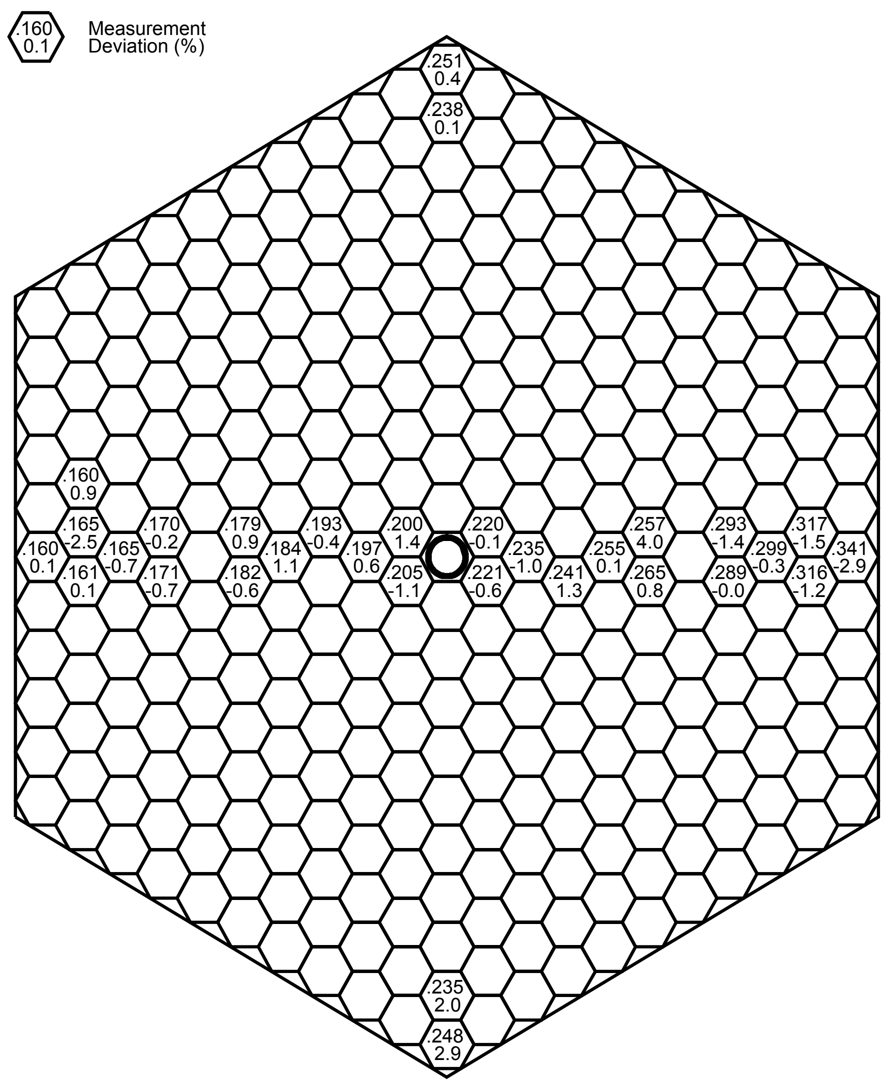

Fig. 4 FA 85 without CR: Measured pin powers and deviations of calculation

Pin power measurements in assembly 85 enabled the validation of the pin power recovery method implemented in DYN3D. Fig. 5 and Fig. 6 show the measured results and the deviations of DYN3D/HELIOS calculation for the two states. It can be seen that the deviations increase in the case of inserted control rod cluster in assembly 85.

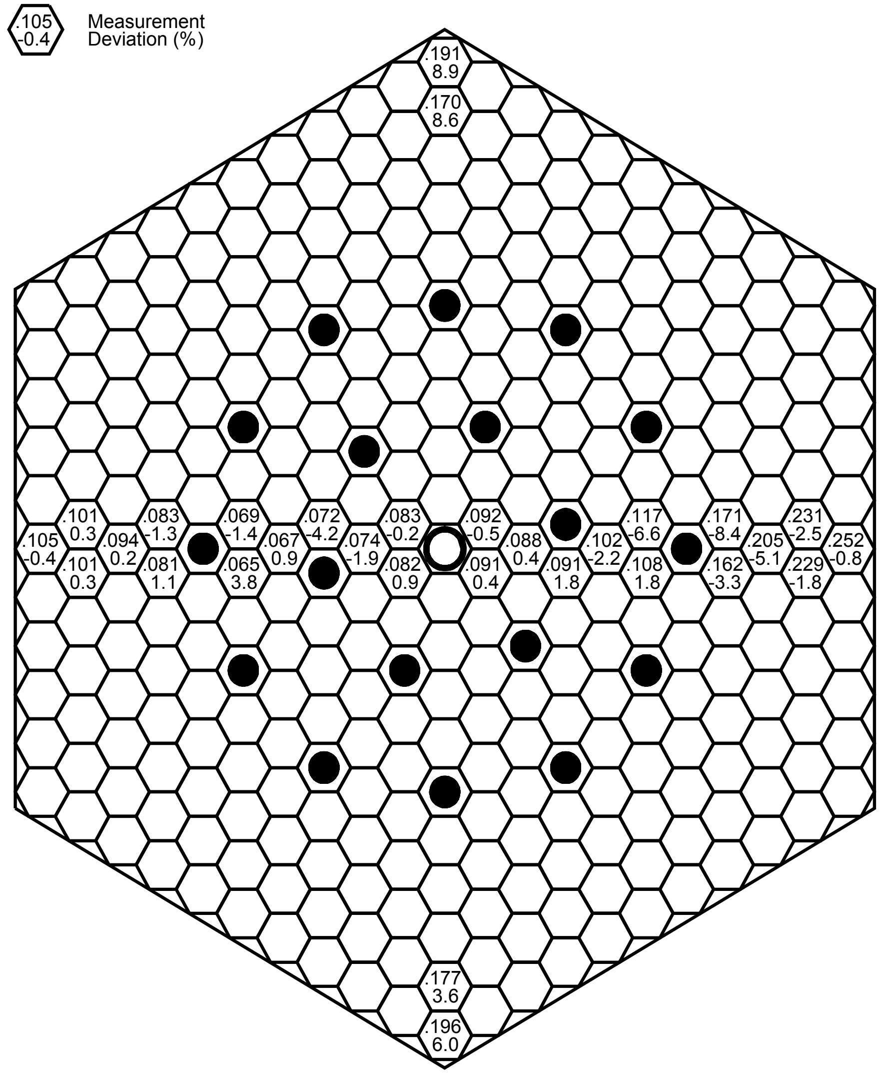

Fig. 5 FA 85 with inserted CR: Measured pin powers and deviations of calculation

Table 4 $ß_{eff}$ and reactivities (kin. experiment 1)

	$ß_{eff}$	Inv. kinetics (pcm)	rod worth (pcm)
measurement	6.50E-3	-65.0	
HELIOS	7.11E-3	-67.5	-67.4
CASMO	7.10E-3	-65.1	-65.3
WIMS	7.33E-3	-66.9	-67.2

Table 3 CR positions (kin. exp. 1)

time (s)	Position (cm)
0.0	324.0
21.8	324.0
95.5	0.0
798.1	0.0
831.0	324.0
1760.0	324.0

4. Kinetic Experiments

4.1 Kinetic Experiment 1 – Motion of a Single Rod

The single cluster of bank 9 in FA 126 was moved into the core and back to its original position. Table 3 shows the control rod positions. The calculations were performed with the two-group constants produced by HELIOS, CASMO and WIMS. Different effective constants of delayed neutrons were obtained for the three libraries (see Table 4). The reactor was overcritical before the experiment with a reactivity of 0.0385 ß (25 pcm) given from the reactimeters. It was taken into account in the calculation by a prompt jump at the beginning of calculation. Fig. 6 shows the comparisons for the two in-core detectors 71H and 126L. The flux reconstruction was applied for the calculation of the detector rate in FA 126, because the detector becomes surrounded by the cluster pins when the control rod reached its axial position. The averaged fast fluxes in the assemblies 102, 115 and 49, 62 were used for comparison with the signals of the ionization chambers KNK-1 and KNK-2 (Fig. 7). The dynamical reactivity was calculated by invers point kinetics from the time behaviour of the of the averaged neutron fluxes. It is compared with the output of the two reactimeters given by inverse point kinetics from the signals of KNK-1 and KNK-2 (Fig. 8). Taking into account the initial overcriticality, the asymptotic reactivities of the state with inserted cluster agree with the rod worth within 0.4%. (Table 4). The calculated reactivities obtained with the three different libraries agree with the experimental value within 3.8%.

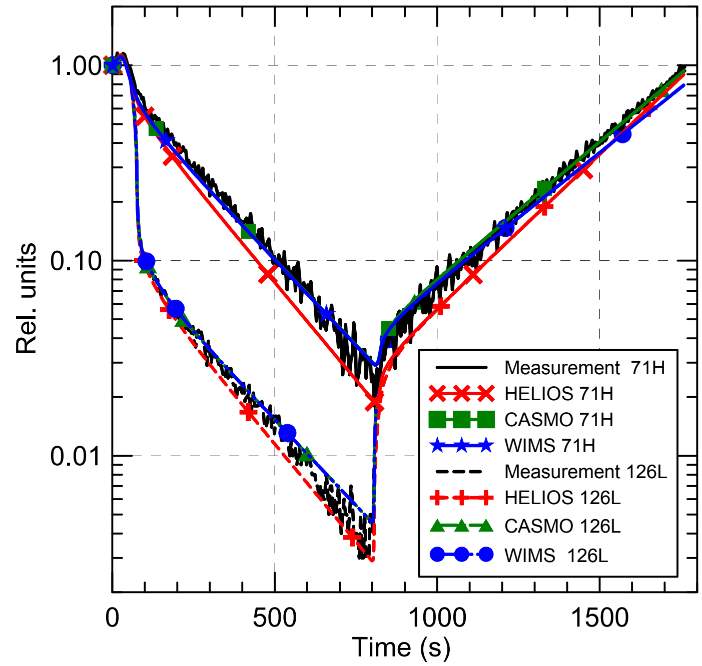

Fig. 6 Comparison of DYN3D results for the detectors 71H and 126L (kin. experiment 1).

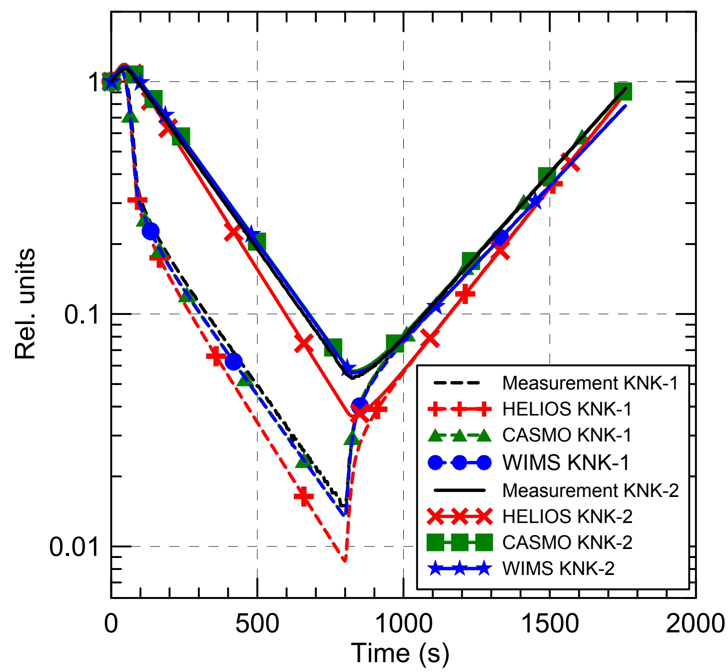

Fig. 7 Comparison of DYN3D results for the outcore detectors (kin. experiment 1).

Table 5 History of position of CR in FA 126 (kin. experiment 2)

time (s)	Position (cm)
0.0	325.0
69.8	325.0
100.7	182.0
281.9	182.0
317.5	0.0
337.0	0.0

4.2 Kinetic Experiment 2 – Scram

Considering the kinetic experiment 2, all control rods were dropped into the core except the rod in FA 126 which was moved delayed (see Table 5). The reactor was overcritical before the experiment with a reactivity of 0.0178 ß (11.5 pcm) given from the reactimeters. Fig. 9 shows the comparisons with the signals of the in-core detectors 71H and 126L, which show larger statistical errors for t > 100s. Fig. 10 depicts the reactivity of the two reactimeters and the calculated behaviour. Beside the fluctuations of the ionization chamber signals for lower amplitudes, the local measurements of the two reactimeters provide different values of reactivity. Comparisons of the calculated behaviour of the flux at the positions of the ionization chambers KNK-1 and KNK-2 have shown an agreement within the measured fluctuations. Considering the calculated dynamical reactivities the results are different from the two reactimeters. The asymptotic values of the dynamical reactivities differ from the calculated rod worth by ~16% (Table 6). The radial flux distribution of the two states without and with inserted CR's is much different and the application of the point kinetics becomes questionable for such transients.

The results obtained with the HELIOS, CASMO and WIMS two-group constants are close together. The relative difference of the calculated reactivities is lower than 3 %

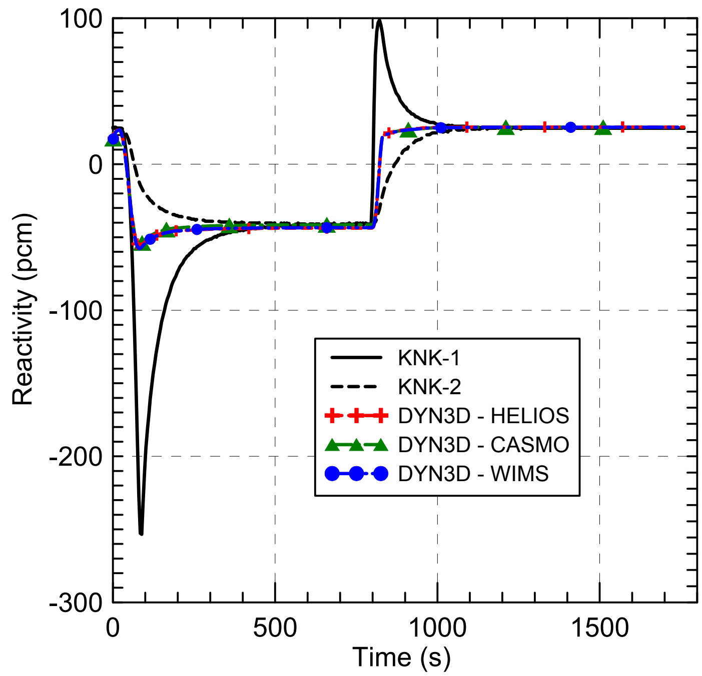

Fig. 8 Comparison of the reactivities (kin. experiment 1).

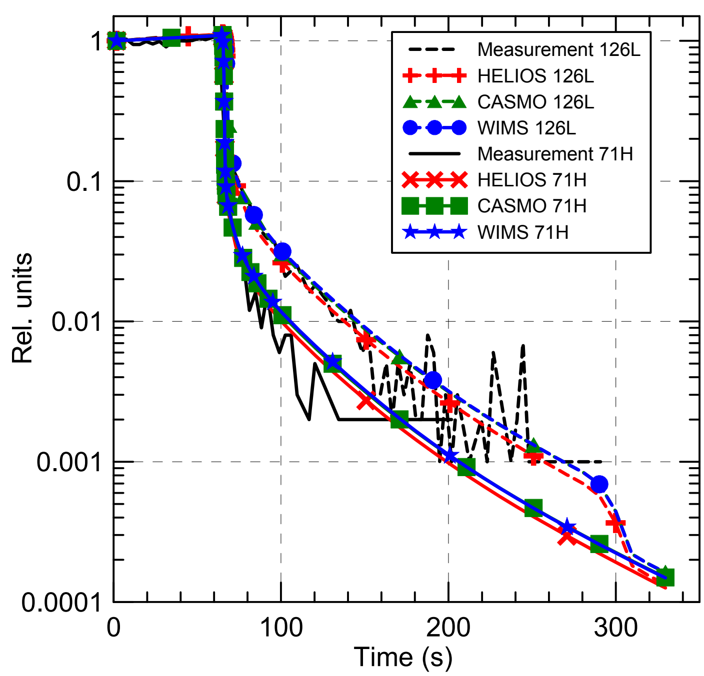

Fig. 9 Comparison of DYN3D results for the detectors 71H and 126L (kin. experiment 2).

Table 6: β_{eff} and reactivities (kin. experiment 2)

	β_{eff}	Inv. kinetics (pcm)	rod worth (pcm)
measurement	6.50E-3	-	-
HELIOS	7.11E-3	-4870	-4220
CASMO	7.10E-3	-4770	-4100
WIMS	7.33E-3	-4780	-4150

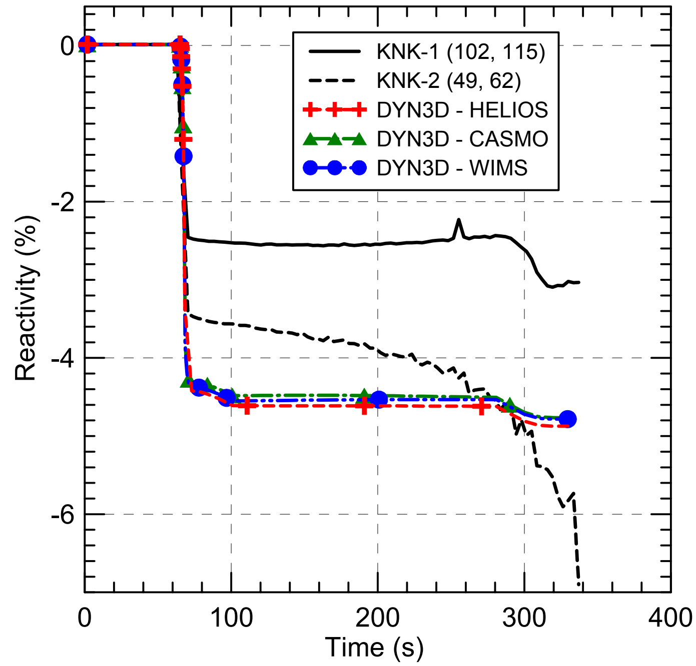

Fig.10 Comparison of the reactivities (kinetic experiment 2).

5. Conclusions

The steady-state comparisons of the measured powers in the central pins with the calculated values based on the HELIOS two-group constants yield RMS deviations of 3.1% and 4.2% for the un-rodded and rodded case, respectively. The pin power distribution in the fuel assembly 85 show deviations < 4% and < 9% for the examples without and with inserted control rod.

Considering the kinetic experiments the results obtained by using the three libraries generated by HELIOS, CASMO and WIMS show a good agreement with the experimental detector rates. In the kinetic experiment 1 with the moved single rod, the results obtained by the CASMO library are closer to the experiment. Regarding the scram with one stuck rod of the kinetic experiment 2 the calculated results are also close to the detector signals. A deviation between the reactivities calculated by inverse point kinetics and the rod worth is observed. It can be explained by the large differences between the initial flux distribution and the distribution of the state with inserted rods. Therefore the behaviour of the flux cannot described by point kinetics. There is no agreement between the two reactimeters for the same reason. The HELIOS library gives the highest value of scram worth, but the difference between the three libraries is lower than 3%.

References

1) V. S. Ionov et al., "Measurements at V-1000 Critical Facility. Kinetics Experiments Description," EU-FP5-Report VALCO/WP3/MEAS(D3)-2, May 2002.
2) U. Grundmann, U. Rohde and S. Mittag, "DYN3D – Three Dimensional Core Model for Steady-State and Transient Analysis of Thermal Reactors," Proceedings of the 2000 ANS International Topical Meeting on Advances in Reactor Physics and Mathematics and Computation into the Next Millennium (PHYSOR 2000), Pittsburgh (USA), May, 7 – 11, 2000.
3) P. T. Petkov, "HELIOS/MARIKO and Diffusion Calculations for the V-1000 and Comparison to Measurements," Minutes of the 2nd Meeting of the EU-FP5-Project VALCO, Budapest, Hungary, September 2002.
4) E. Kaloinen, "VTT Calculations for the V-1000 Facility of the Kurtschatov Institute," EU-FP5-Report VALCO/WP3/VTT-V1000, September 2003.
5) D. Powney, "Input Data for V-1000 Calculations: Macroscopic Cross-Section Library by WIMS," EU-FP5-Report VALCO/WP3/WIMSDAT-1(D5), October 2002.
6) P. T. Petkov, "Calculation of Radial Boundary Conditions for the V-1000 Facility," Minutes of the 3rd Meeting of the EU-FP5-Project VALCO, Garching, Germany, March 2003.