AER Benchmark Specification Sheet

1. Test ID: AER-DYN-005 (Draft 2)

2. Short Description:

This test concerns a double ended break of the main steam header in a VVER-440 plant. The core is at the end of its first cycle in hot shutdown conditions. One group of control rods is stuck out of the core. The cooling of the primary circuit results in recriticality and a rise to power, which is terminated by highly borated water from the high pressure safety injection system. The initial subcriticality of the core in the beginning of the transient is given. Otherwise, own best estimate nuclear data are to be used. The main geometrical parameters of the plant and the characteristics of control and safety systems to be considered are given. Otherwise, own input data decks developed for a VVER-440 plant and for the applied codes can be used.

3. Submitted by: S. Kliem, Forschungszentrum Rossendorf, Institute of Safety Research (Germany)
Date: 17.03.2000

4. Reviewed by: (name)
Date:

5. Accepted by: (name)
Date:

6. Objective:

The objective is to calculate the behaviour of the core during a recriticality event using coupled codes, which combine a three-dimensional neutron kinetics code for the core with a thermal hydraulics system code. This test is also intended to be an exercise in the use of own nuclear data libraries, thus demonstrating differences that can arise, when actual plant analyses are performed with different codes and libraries.

7. Rationale for Test Setup:

This benchmark is the first one for testing the performance of coupled codes. In a steam leak, there is a strong interaction between core behaviour and the thermal hydraulics of the primary and secondary circuits. A number of features in this test are chosen to reduce the problem size and to eliminate extra complications. A symmetric leak is assumed in the main steam header. Hence, all loops behave in a rather similar manner, except for differences caused by the pressurizer in one loop. This allows 60-degree symmetry to be used in core calculations. Coolant flow calculations are kept simple, when all reactor coolant pumps remain in operation. Also, mixing in the reactor pressure vessel is not important in this test.

8. Input:

The reference plant for the definition of this benchmark is a VVER-440/213. The definition is based on the assumption that all possible participants of the benchmark have input data decks for the VVER-440 which have been developed according to the needs of their own thermohydraulic system/neutron kinetic core models. Therefore information about all details necessary for the creation of a new input data deck is not provided. The main geometrical parameters are given to adjust the existing input data decks.

a: Geometry of the primary circuit

Tab. 1: Hot Leg Geometry

Elevation (z) [m]	Length (x) [m]	Diameter (d) [m]
0.0	0.0	0.496
0.0	1.2	0.496
-1.40	5.28	0.496
-1.40	13.52	0.496
-0.45	14.47	0.496
-0.25	14.67	0.800
2.38	17.30	0.800
2.73	17.65	0.550
3.53	18.45	0.496

Tab.: 2 Cold Leg Geometry

Elevation (z) [m]	Length (x) [m]	Diameter (d) [m]
3.53	0.0	0.496
2.73	0.80	0.550
2.38	1.15	0.800
-0.48	4.01	0.800
-0.60	4.13	0.496
-2.92	6.45	0.496
-2.92	15.76	0.496
-1.15	17.53	0.496
-1.15	18.43	0.496
-1.40	18.68	0.496
-1.40	26.28	0.496

The beginning of the hot leg is set to the elevation 0.0m. All elevations provided in the tables 1-3 and 5, 6 are related to this reference point. For checking the geometry of the primary circuit, the most relevant data of the hot leg together with the steamgenerator (SG) inlet collector are presented in Tab. 1 and of the SG outlet collector together with the cold leg in Tab. 2. It should be kept in mind, that the geometry data in Tab. 1 and 2 are only some key data for tuning the data sets. Details of the geometry are not provided. The 5536 U-tubes have a inner diameter of 13.2mm, an outer diameter of 16.0mm and an averaged length of 9.02m. They are distributed on the collectors from elevation z=0.14m to z=1.96m. The reactor pressure vessel (RPV) elevations are shown in Tab. 3. Tab. 4 contains the water volumes of the main parts of the RPV. The pressurizer is connected to one loop by two surge lines of a diameter of 0.21m and a length of 25.37m., each. The connecting point of the surge lines to the hot leg is at x=7.37m (according to Tab. 1). The surge lines can be modeled by one two fold line. The lowest elevation of the pressurizer is -1.15m and the highest is 8.85m. The diameter is 2.40m, the whole volume 44.0m^3. The volume control

Tab. 3: RPV Elevations

Elevation z [m]	
-9.86	lowest RPV elevation
-6.02	beginning of the unheated core part
-5.38	lower fuel boundary
-2.94	upper fuel boundary
-2.46	end of the unheated core part
3.56	highest RPV elevation

Tab. 4: RPV Volumes

Object	Volume [m^3]
Downcomer	18.8
Lower plenum	23.1
Core region	12.7
Upper plenum including vessel head	40.9

system is connected to all six cold leg at x= 8.45m (according to Tab. 2). The High Pressure Injection System (HPIS) consists of three trains. Each train is symmetrically connected to two cold legs at x=21.66m (according to Tab. 2).

b: Geometry of the secondary circuit

The SG has an inner diameter of 3.21m (the corresponding elevations are z=-0.025m and z=3.185m). On the top it is connected to the main steam line (MSL). The connecting lines between SG and MSL can be omitted. The elevations and lengths of the MSL are shown in Tab. 5. The main steam header (MSH) is a pipe with a diameter of 0.425m and a length of 83.40m (Tab. 6). It is directly connected to the MSL (without any small connecting pipes) at x=51.25m (according to Tab. 5). The modeled MSL should be distributed symmetrically on both ends of the MSH to guarantee the symmetry of the leak. The MSH isolation valve is not modeled.

Tab. 5: Main Steam Line

Elevation (z) [m]	Length (x) [m]	Diameter (d) [m]
3.185	0.00	0.425
3.185	9.80	0.425
5.385	12.00	0.425
5.385	26.80	0.425
11.485	32.90	0.425
11.485	66.33	0.425
2.785	75.03	0.425
2.785	83.13	0.425

Tab. 6: Main Steam Header

Elevation (z) [m]	Length (x) [m]	Diameter (d) [m]
11.485	0.00	0.425
12.985	1.50	0.425
12.985	81.90	0.425
11.485	83.40	0.425

c: Leak

The leak is postulated as a double ended break in the middle of the main steam header. The leak opens within 0.1s. It is recommended to use a critical discharge model for the simulation of the leak mass flow rate. The maximum leak mass flow rate of one half of the leak which can be reached is about 600kg/s. If there are great deviations the participants should adjust their models.

d: Reactor core geometry and material parameters

A 60^o symmetry sector with three different fuel enrichments is used (Fig. 1). As follows from Tab. 3 the active core length is 2.44m. The unheated parts below and above the active core have the same hydraulic parameter like the core. The main fuel parameters are given in Tab. 7. All types of fuel assemblies have the same heat transfer characteristics. 97.5 % of the total power are released uniformly in fuel pellet, the other 2.5% directly in the coolant of the respective fuel assembly due to γ-radiation. The gas gap heat transfer coefficient is to be kept constant during the whole transient: 3000 W/ (m^2*K). Radial thermal conductivities and thermal capacities of fuel pellet and cladding are described with best data of each participant. Axial transfer of heat is neglected in fuel pellet and cladding.

Each participant should use own best estimate nuclear cross section and other neutronic related data.

Tab. 7: Main Fuel Parameters

Fuel assembly pitch	14.7cm
Number of heated pins per assembly	126
Fuel pellet inner diameter	0.14cm
Fuel pellet outer diameter	0.76cm
Cladding inner diameter	0.78cm
Cladding outer diameter	0.92cm
Free flow cross section per fuel assembly	89.0cm^2
Equivalent hydraulic diameter	0.86cm
Fuel density	10.4 g/cm^3

e: Heat structure modeling

The following components have to be included in the heat structure modeling: the RPV, the primary coolant pipes, the heat exchanger tubes and the pressurizer with the surge lines.

f: Characteristics of considered control and safety systems

In this section the characteristics and setpoints of control and safety systems to be considered in the calculation are given. Only systems and signals which are mentioned explicitly have to be taken into account. All others should be neglected. The pressurizer has four group of heaters. The power and the activation pressure are shown in Tab. 8. It is recommended to model the reaching of full heater power after switching-on by a low pass filter with a time constant of 5s. When the collapsed level in the pressurizer measured from the bottom of the pressurizer drops below 2.56m, the heaters are automatically switched-off, also through the same low pass filter.

Tab. 8: Pressurizer Heater Groups

	Power [kW]	**Activation Pressure [MPa], measured in the PRZ**
Group 1	180	12.0
Group 2	180	11.9
Group 3	540	11.8
Group 4	540	11.5

The volume control system is activated when the pressurizer collapsed level drops by 6cm from the nominal level and is deactivated when the level exceeds the nominal level by the same value. The mass flow rate increases within 0.6s from zero to maximum in the case of activation and decreases from maximum to zero within the same time when the system is deactivated. The maximum mass flow rate is 2.96kg/s per loop. The supplied water has the same boron concentration like the reactor coolant and enters the reactor coolant system with a temperature of 200^{o}C.

The HPIS is activated when the following two signals are fulfilled: The upper plenum pressure, measured in the RPV at the elevation of the hot leg outlet nozzle, is equal or less than 10.7MPa and the pressurizer collapsed level drops below 3.26m. The water from the HPIS has a boron concentration of 40g/kg and a temperature of 55°C. The mass flow rate of one train depends at a linear rate from the pressure at the connection point and is defined in Tab. 9.

The feedwater system has to be modeled in the following manner: The feedwater and steam flow in the initial state should be adjusted to the decay heat generation in the core. During the transient only one feedwater pump is available. The time characteristic of the feedwater mass flow rate is shown in Tab. 10. The pump is controlled by the SG collapsed level. When the level in at least one SG decreases by 7.5cm the pump is activated and will feed water from the feedwater tank. When the collapsed level exceeds the nominal level value by 7.5cm the pump is deactivated and the feedwater mass flow rate decreases according to the same time characteristics. The feedwater temperature is 164°C. The overall feedwater mass flow rate is the summation of the feedwater mass flow rate according to the initial conditions and the feedwater mass flow rate from Tab. 10.

Tab. 9: HPIS Mass Flow Rate for One Train

Pressure [MPa]	Mass flow rate [kg/s]
0.1	31.7
13.16	0.0

Tab. 10: Feedwater Mass Flow Rate

Time [s]	Mass Flow Rate [kg/s]
0.0	0.0
5.0	1.0
10.0	10.0
15.0	30.0
20.0	60.0
23.5	100.0
28.5	150.0
32.25	187.5

g: Initial conditions

Burn-up

Because the benchmark calculation will be performed for the end of the first fuel cycle (EOC) conditions, a burn-up calculation for the first loading of the VVER-440 core is required. This calculation should be made at a power level of 1375MW until the critical boron concentration reaches the value zero. During the burn-up calculation all control rod groups are fully with-drawn. Their position will not changed. The burn-up distribution obtained at the end of this calculation should be used in the transient calculation.

Initial neutronic conditions

At the beginning of the transient the Xe in the fuel assemblies is assumed already to have de-cayed. All control rod groups are inserted in the core, expect the control rod group K4, which is assumed to stuck at fully withdrawn position. No boron acid is in the coolant. The thermal power level is 10MW. This level corresponds to the decay heat. The nuclear power level due to spontanous fission in the subcritical core is 1W. The initial subcriticality of this state is -1534pcm. This value may be achieved by adjusting the control rod efficiency. Other neutronic data will not be given to perform a realistic exercise.

Initial thermohydraulic conditions

The following thermohydraulic input data are given:

Primary circuit

Upper plenum pressure:	12.14 MPa
Core inlet temperature: (This value is given only for information, the real value is determined by the secondary side pressure)	approximately 260°C
Core mass flow rate (including 3% bypass): (The core mass flow rate without the 3% bypass is entirely available for fuel cooling.)	8718kg/s
Pressurizer collapsed level (measured from the bottom):	5.97m

Secondary circuit

Pressure at SG outlet:	4.65MPa
Temperature:	Saturation temperature
SG collapsed level (measured from the bottom):	2.08m
SG water inventory (for information only):	approximately 37000kg

h: Scenario of the transient calculation

The initiating event is a double ended break in the middle of the main steam header. The beginning of the leak opening refers to the time t=0s. The symmetric leak causes a depressurization of all steamgenerators. For this reason, the feedwater of the one available feedwater pump will be distributed evenly over all SG. The leak causes an overcooling of the primary circuit and the pressure decreases. The pressure and volume control systems are in operation and immediately will be switched on to correct the system pressure and the pressurizer level. The HPIS will be activated with a delay time of 180s after reaching the corresponding actuation points. The calculation should be continued until the highly-borated water from the HPIS enters the core and terminates the power excursion. It is recommended to perform the calculation until at least 400s after the leak opening. The main coolant pumps remains in operation during the whole transient.

9. Hardware and Software Requirements:

For the calcuation of this benchmark, an average work station is necessary. On such a computer, the computation time is about two hours.

10. Output:

a: Requested Results

1. Results of tuning, maximum etc. ("Key parameter")

- Subcriticality of the initial state before tuning [pcm]
- Time of reaching recriticality [s]
- Time of maximum fission power [s]

- Maximum fission power [MW]
- K_{eff} at isothermal core inlet temperature 240 ^oC
- K_{eff} at isothermal core inlet temperature 220 ^oC
- K_{eff} at isothermal core inlet temperature 200 ^oC

The other core conditions for the three stationary K_{eff} calculations are to be taken from the specification (burn-up, initial neutronic conditions, relevant initial thermohydraulics conditions).

2. Spatial nuclear power distribution (" Power distribution")

Two-dimensional assembly-wise power distributions are to be given. Each distribution is normalized to unity over the total core volume including the absorber parts of inserted control assemblies. The values of the assembly powers are to be provided according to the numbering used in fig. 1(rowwise from left to right and from bottom to top).

The power distributions are to be given at following times:

- t=0.0s, initial state
- time of reaching recriticality
- time of maximum fission power

3. Time function of the core power ("Core power ")

- Total core power [MW] (FPOW)

4. Time functions of some other global parameters ("Global time functions")

- Total power transferred to coolant [MW] (THPOW)
- Reactivity [pcm] (REAC)
- Upper plenum pressure, measured at the hot leg outlet elevation [MPa] (PUP)
- Pressure at pressurizer top [MPa] (PPRZ)
- Pressurizer collapsed level measured from the pressurizer bottom [m] (CLPRZ
- Pressure drop over the core, including unheated parts [kPa] (DPCOR)
- Core mass flow rate without bypass [kg/s] (MFCOR)
- Bypass mass flow rate [kg/s] (MFBYP)
- Averaged core inlet coolant temperature [^oC] (TIN)
- Averaged core outlet coolant temperature [^oC] (TOUT)
- Maximum fuel pellet centerline temperature [^oC] (TFMAX)
- Averaged fuel temperature in the core [^oC] (TFAVE)

(The fuel temperature should be averaged over all nodes of the active core including the absorber parts of inserted control assemblies.)

- Total leak mass flow rate [kg/s] (MFDEB)
- Pressure in both ends of the MSH [MPa] (PMSH1) (PMSH2)

5. Local time functions of the loop with the pressurizer ("Loop 1 time functions")

- Primary coolant temperature at SG inlet collector [^oC] (TSGIN)
- Primary coolant temperature at SG outlet collector[^oC] (TSGOU)

- Collapsed level in SG secondary side [m] (CLSG)
- Mixture level in SG secondary side [m] (MLSG)
- Steam pressure at SG outlet [MPa] (PSG)
- Steam mass flow rate at SG outlet [kg/s] (MFSG)
- Total power transferred to secondary side in the U-tubes [MW] (POWSG)
- Power transferred to secondary side in the U-tubes part 1 [MW] (UT1)
- Power transferred to secondary side in the U-tubes part 2 [MW] (UT2)
- Power transferred to secondary side in the U-tubes part 3 [MW] (UT3)
- Power transferred to secondary side in the U-tubes part 4 [MW] (UT4)
- Power transferred to secondary side in the U-tubes part 5 [MW] (UT5)

6. Local time functions averaged over all other modeled loops ("Loop 2 time functions")

- Primary coolant temperature at SG inlet collector [^{o}C] (TSGIN)
- Primary coolant temperature at SG outlet collector[^{o}C] (TSGOU)
- Collapsed level in SG secondary side [m] (CLSG)
- Mixture level in SG secondary side [m] (MLSG)
- Steam pressure at SG outlet [MPa] (PSG)
- Steam mass flow rate at SG outlet [kg/s] (MFSG)
- Total power transferred to secondary side in the U-tubes [MW] (POWSG)
- Power transferred to secondary side in the U-tubes part 1 [MW] (UT1)
- Power transferred to secondary side in the U-tubes part 2 [MW] (UT2)
- Power transferred to secondary side in the U-tubes part 3 [MW] (UT3)
- Power transferred to secondary side in the U-tubes part 4 [MW] (UT4)
- Power transferred to secondary side in the U-tubes part 5 [MW] (UT5)

7. Selected pressure/steam moisture time functions ("Add. time functions")

In this section, the moisture of the steam (mass water quality) and the pressure at the following locations on the secondary side of the loop with the pressurizer are requested:

- Moisture in the last (uppermost) node of the SG [-] (M1)
- Pressure in the last (uppermost) node of the SG [MPa] (P1)
- Moisture in the first node of the MSL [-] (M2)
- Pressure in the first node of the MSL [MPa] (P2)
- Moisture in the last node of the MSL [-] (M3)
- Pressure in the last node of the MSL [MPa] (P3)
- Moisture in the first node of the MSH [-] (M4)
- Pressure in the first node of the MSH [MPa] (P4)
- Moisture in the last node before the leak of the MSH [-] (M5)
- Pressure in the last node before the leak of the MSH [MPa] (P5)

b: Files, Format

Each type of the described output data should be preceded by the given keyword, and each power distribution additionally by the time for the distribution. The time functions of the subsections 3 - 7 should be presented with a time resolution of at least 2s. It is recommended, to use a finer output for the core power during the power peak. The functions UT1-UT5 require the presentation of the power transferred to the secondary side in one fifth of the U-tubes (division over the height) beginning with the lowest part. Therefore they are requested optionally, only if the nodalization of the SG allows such type of presentation.

The data arrays of all time functions should contain the time (in s) and the values of the requested quantities (in the given order) for successive time points. The first point t=0.0s corresponds to the leak opening. Each data array with time functions should contain a heading line with the keyword ”TIME” in the first column and the abbreviations for the provided quantities given above in the other columns.

All output should be given in one file.

11. References

[1] S. Danilin, M. Lizorkin, V. Pekhterev: "Solution of the Fifth AER Benchmark with Code Package ATHLET/BIPR8KN", Proc. 8th Symposium of AER, pp. 405-420, KFKI Atomic Energy Research Institute, Budapest (1998)

[2] A. Hämäläinen, R. Kyrki-Rajamäki: "The Fifth AER Dynamic Benchmark Calculation with HEXTRAN/SMABRE", Proc. 8th Symposium of AER, pp. 369- 385, KFKI Atomic Energy Research Institute, Budapest (1998)

[3] J. Hadek, R. Meca: "Results of the Fifth 3-Dimensional Dynamic AER Benchmark Problem Calculations", Proc. 8th Symposium of AER, pp. 389-403, KFKI Atomic Energy Research Institute, Budapest (1998)

[4] S. Kliem: "Solution of the Fifth Dynamic AER Benchmark Using the Coupled Code DYN3D/ATHLET", Proc. 8th Symposium of AER, pp. 357-367, KFKI Atomic Energy Research Institute, Budapest (1998)

[5] S. Kliem: "Comparison of the Results of the Fifth Dynamic AER Benchmark - A Benchmark for Coupled Thermohydraulic System/3D Hexagonal Neutron Kinetic Core Models", Proc. 8th Symposium of AER, pp. 429-469, KFKI Atomic Energy Research Institute, Budapest (1998)

12. Recommended Solution:

There is no unique reference solution to this test. It is a pure comparison of solutions by different codes and data libraries.

13. Summary of Available Solutions:

Results are available from the following organizations:

Tab 11: Participants of the calculations

Organization	Code	Reference
RRC Kurchatov Institute Moscow (Russia)	BIPR8/ATHLET	[1]
VTT Energy Espoo (Finland)	HEXTRAN/SMABRE	[2]
Nuclear Research Institute Rez (Czech Republic)	DYN3D/ATHLET	[3]

KFKI AEKI Budapest (Hungary)	KIKO3D/ATHLET	[5]
Forschungszentrum Rossendorf (Germany)	DYN3D/ATHLET	[4]

In this section, an overview of the main results of the benchmark is given.

All codes predicted the recriticality of the core due to overcooling, but at different times (Tab. 12). The corresponding recriticality temperatures were determined by stationary K_{eff}-calculations (Fig. 2). For these calculations all boundary conditions were given, so that differences in the results are caused only by the different nuclear libraries used in the calculations. It can be seen, that the recriticality temperature of the core belongs to an interval from 228.2°C (DYN3D/ ATHLET) to 218.3°C (BIPR8/ATHLET). These differences in the nuclear data also cause the deviations in the predicted recriticality time.

Tab. 12: Comparison of Key Parameters

	DYN3D/ ATHLET	**BIPR8/ ATHLET**	**HEXTRAN/ SMABRE**	**DYN3D/ ATHLET (REZ)**	**KIKO3D/ ATHLET**
Recriticality Time [s]	48.8	80.4	66.0	56.9	58.2
Recriticality Temperature [°C]	228.2	218.3	221.2	225.1	222.0
Time of max. Core Power [s]	232	233	237	233	226
max. Core Power [MW]	686	547	534	658	586
Integrated Leak Mass at 400s [t]	169	148	155	165	149
Time of HPIS Activation [s]	230	230	236	231	225
Integrated Mass injected by HPIS at 400s [kg]	2191	1767	2874	2421	3399
Boron concentration at 400s [ppm]	95.5	68.1	129.5	109.5	149.1

The main steam header pressure (Fig. 3) shows qualitatively the same behaviour in all calculations. Differences are to be seen at the moment of leak opening. Three calculations (DYN3D/ATHLET, BIPR8/ATHLET and KIKO3D/ATHLET) show a sharp pressure decrease immediately after leak opening. In the DYN3D/ATHLET (Rez) and HEXTRAN/SMABRE calculations such a jump cannot be observed, the pressure decreases rather slowly without any jumps (Fig. 3a). Further, it seems, that the leak opening in the BIPR8/ATHLET calculation is delayed by 2s. A similar behaviour of the integrated leak mass (Fig. 4) is observed by all codes.

Within the first 60s the thermohydraulic quantities in the primary circuit behave very similar in all calculations. Later on, the influence of the re-established power generation in the core after recriticality can be seen. The minimum pressure reached during the overcooling depends on the time of recriticality. In the later phase of the transient (after t=230s) the pressure is dominated by the beginning HPI (Fig. 5).

Fig. 6 shows the core power. The time of significant power increase varies from 62s (DYN3D/ATHLET) to 123s (BIPR8/ATHLET). This is the result of different rates of reactivity insertion into the core, which is due to differences in the temperature coefficient of reactivity and also to some differences in the rate of core inlet temperature decrease. An initial power peak can be seen in the results of only two codes (DYN3D/ATHLET and DYN3D/ATHLET (Rez)). There are two reasons for this variation. First, a higher rate of reactivity insertion during the rise of power tends to increase the initial power peak. A second effect comes from the neutron flux level at the time of reaching recriticality. If the initial flux level is lower, there is some additional time to insert more reactivity before Doppler feedback becomes effective. The initial fission power was normalized to 1 W. In some codes such as DYN3D an initially critical reactor is made subcritical in the beginning of the calculation. This causes the neutron flux to decrease significantly before criticality is reached. In some other codes the neutron source from spontaneous fissions can be modeled. With a constant neutron source the neutron flux will increase already before criticality is reached, due to the steadily improving subcritical multiplication. The significance of the initial power peak is low due to the relatively small total energy it produces. No initial peak is observed in the maximum fuel temperature, only a rapid jump.

The sudden power decrease after the beginning of the injection of borated water by the HPIS can be observed in all calculations. The effectiveness of the HPIS depends on the primary circuit pressure. Due to the differences in this pressure, the mass of borated water injected by the HPIS differs in the calculations, too. This can also be seen in the boron concentration at the core inlet at the end of the transient (Tab. 12). Four calculations show a consistency of the primary circuit pressure and the core inlet boron concentration. An analysis of the pressure behaviour in the BIPR8/ATHLET calculation showed, that the mass of injected borated water should be in the range of DYN3D/ATHLET and DYN3D/ATHLET (Rez) calculations. For this reason, the boron concentration should be about the same. However, the provided value is lower.

The behaviour of the core outlet temperature (Fig. 8) is very similar in all calculations. The fast decrease of the core outlet temperature is stopped when the beginning of power generation in the core is reached. The sooner the power rises up, the higher this temperature level is. From that time till the beginning of the HPI the core outlet temperature is approximately constant. The start of the HPI again causes a temperature decrease.

The comparison of the maximum fuel centerline temperature reveals big differences (Fig. 9). The values are between 650°C (BIPR8/ATHLET and HEXTRAN/SMABRE) and more than 1000°C (DYN3D/ATHLET).

Tab. 13: Maximum Values of Heat Transfer in the SGs during Depressurization

	DYN3D/ ATHLET	BIPR8/ ATHLET	HEXTRAN/ SMABRE		KIKO3D/ ATHLET
Heat Transfer in the SG of the Loop with the Pressurizer [MW]	158	134	148	124	132
Averaged Heat Transfer in the other SGs [MW]	109	116	118	106	115

In the definition, it was pointed out, that the break of the main steam header causes a nearly symmetrical temperature perturbation of the core. A small asymmetry is introduced by the connection of the pressurizer to only one loop. During the overcooling of the primary circuit the hot coolant coming down from the pressurizer affects the SG inlet collector temperature. For this reason, differences in the behaviour of the loops were expected. Therefore, results for the loop with the pressurizer and averaged over all remaining loops were compared. Fig. 10 and 11 show the heat transfer from the primary to the secondary side. The maximum values reached during the depressurization of the primary circuit are shown in Tab. 13. A direct comparison of the values of one calculation reveals the expected differences in the behaviour of the loops with and without pressurizer. Two calculations (DYN3D/ATHLET and HEXTRAN/SMABRE), provide much higher values of this difference. This is obviously connected with the higher number of loops modeled in the calculations. The influence of the pressurizer is not distributed over several loops like in a calculation with two 3-fold loops.

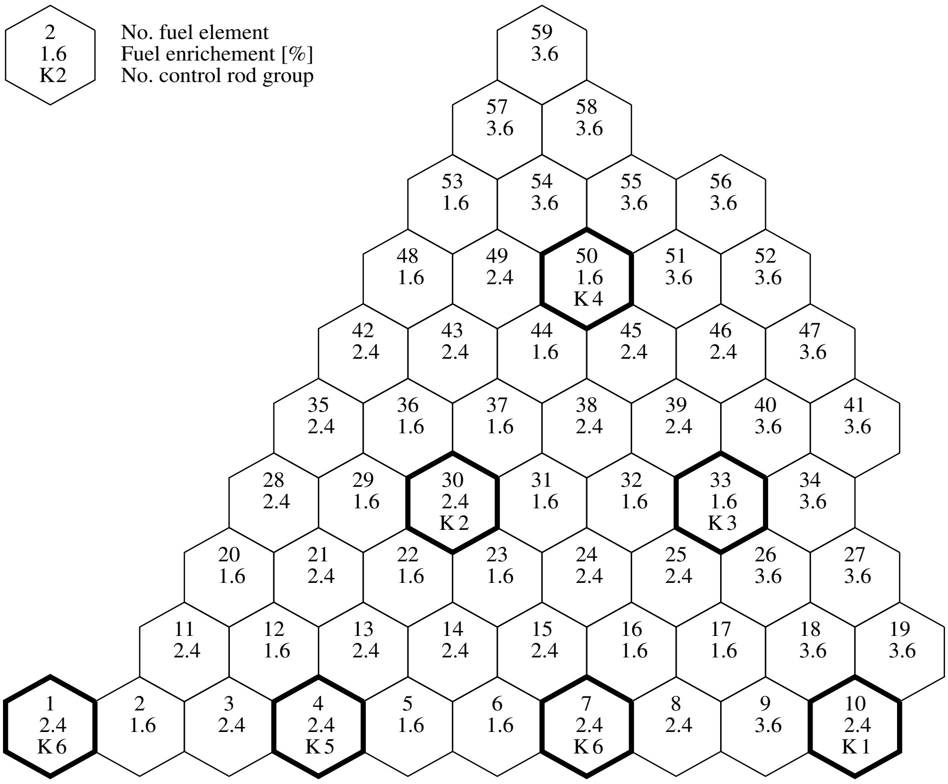

Fig. 1 Horizontal map of the VVER-440 reactor core in 60^{o} core symmetry for this benchmark.

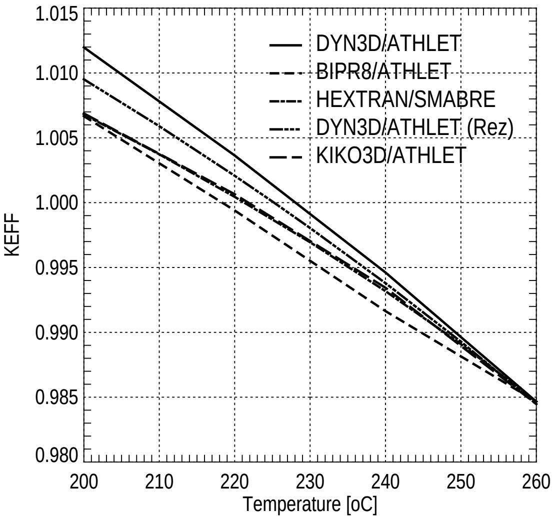

Fig. 2 Keff of stationary calculations with different inlet temperatures

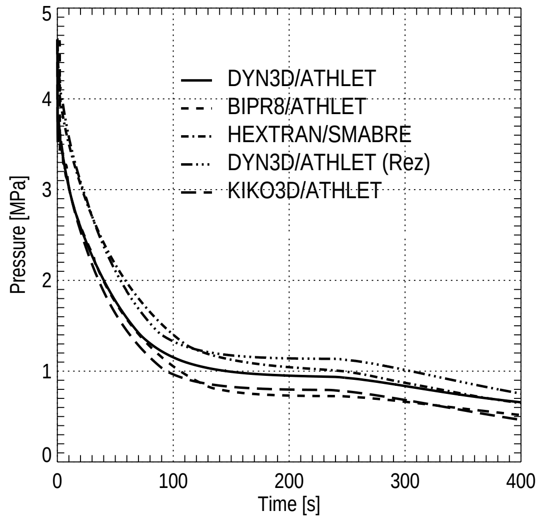

Fig. 3 Main steam header pressure

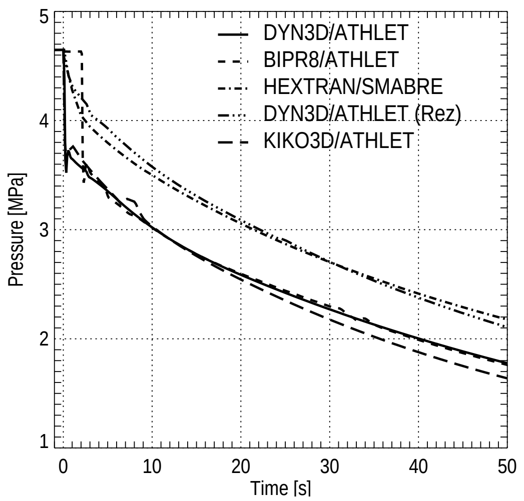

Fig. 3a Main steam header pressure (Zoom)

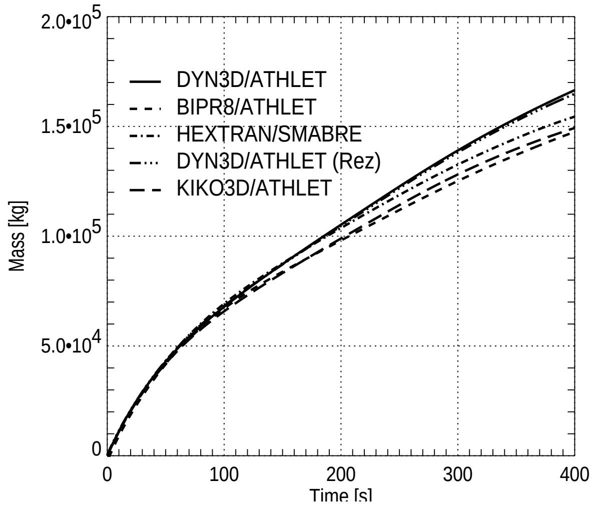

Fig. 4 Integrated leak mass

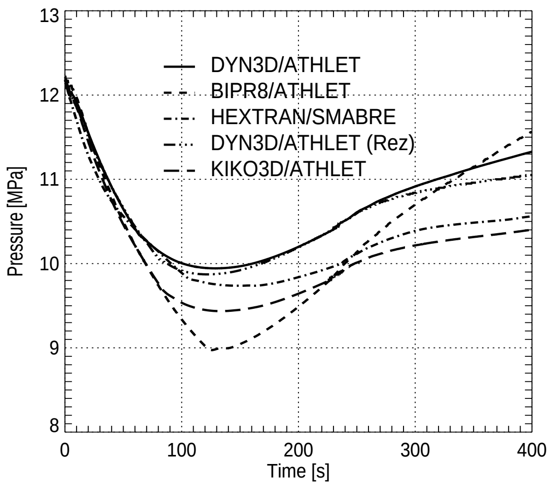

Fig. 5 Upper plenum pressure

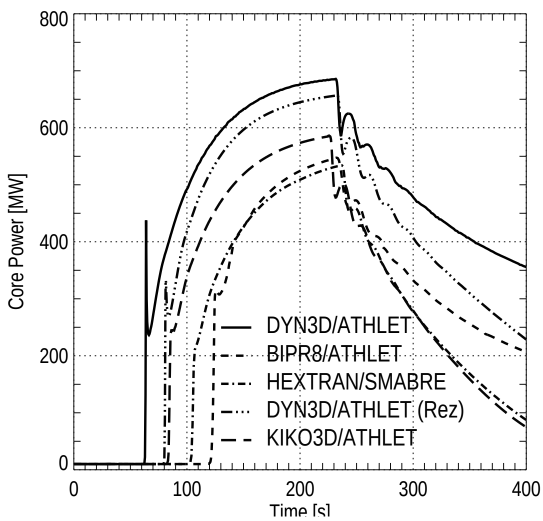

Fig. 6 Total core power

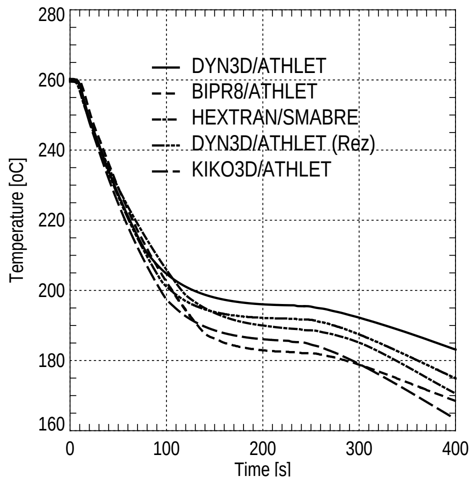

Fig. 7 Core inlet temperature

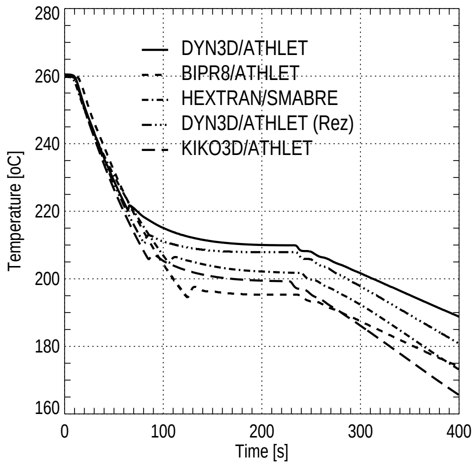

Fig. 8 Core outlet temperature

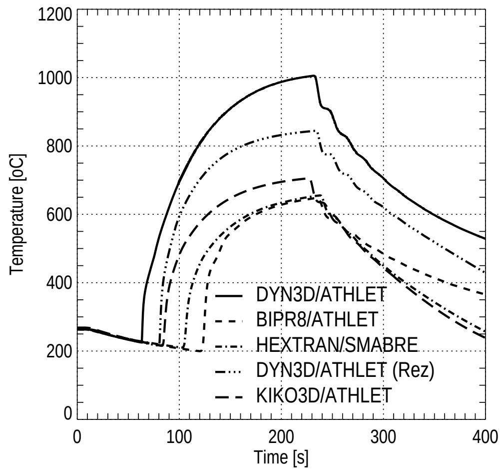

Fig. 9 Maximum fuel centerline temperature

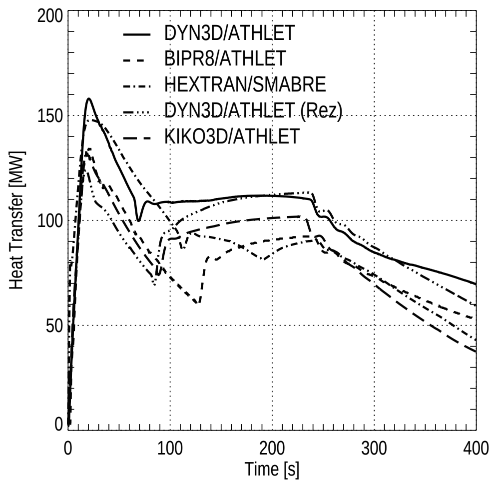

Fig. 10 Heat transfer in the SG of the loop with the pressurizer

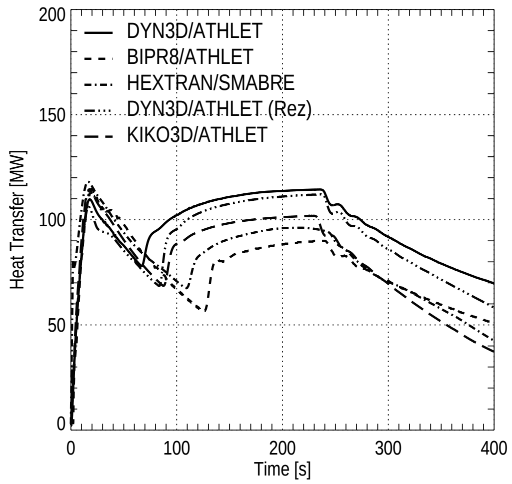

Fig. 11 Averaged heat transfer in the SG of the loops without pressurizer