Adjusting the valve boundary condition in Olkiluoto 1 load rejection test calculated using TRAB-3D

Authors Malla Seppälä

Confidentiality Public

Report's title	
Adjusting valve boundary condition in Olkiluoto 1 load rejection test calculated using TRAB-3D	
Customer, contact person, address -	Order reference -
Project name TRICOT / SAFIR2010	Project number/Short name 13228
Author(s) Malla Seppälä	Pages 13/21
Keywords TRAB-3D, load rejection test	Report identification code VTT-R-08574-07

Summary

At VTT, one of the programs used for transient calculations is 3D coupled neutronics/thermal hydraulics code TRAB-3D. It is validated against international benchmarks and measured data from a load rejection test performed on Olkiluoto 1 nuclear reactor in 1998. The original calculation on the load rejection test was based on measurement data with 0.2 s sample interval. In 2001, new data with 0.02 sample interval was received from TVO.

The objective of this study was to determine whether the accuracy of the load rejection test calculation could be improved by imposing new valve boundary conditions in accordance with the measurement data received in 2001. The boundary condition was varied and results compared to the original calculations and measured data.

It was discovered that the importance of the new measurement data is minor. Changes on the boundary condition needed to be substantial in order to increase the accuracy of the calculation and even than the impact could be seen only for a couple of seconds at the beginning of the calculation.

Confidentiality	Public

Espoo 09.10.2007

Malla Seppälä	Antti Daavittila	Timo Vanttola
Trainee Research Scientist	Team Leader	Technology manager

VTT's contact address

P.O. Box 1000, FI-02044 VTT, Finland

Distribution (customer and VTT)

Fortum: M. Antila, R. Teräsvirta
TVO: M. Solala, K. Ranta-Puska
STUK: R. Sairanen, R. Mattila
TKK: P. Aarnio
LUT: R. Kyrki-Rajamäki
VTT: A. Daavittila, T. Vanttola, A. Hämäläinen, H. Räty, E. Syrjälahti, M. Anttila, E-K. Puska, V. Suolanen, S. Tähtinen

Contents

1 Introduction 4

2 Models and solving methods in TRAB-3D 5

2.1 Neutronics 5
2.2 Thermal Hydraulics 6

3 Load rejection test 7

3.1 Test description 7
3.2 Calculation using TRAB-3D 8

4 New calculations 9

5 Results 10

6 Conclusions 12

References 13

1 Introduction

During the designing process of a nuclear power plant many kinds of safety calculations are made to ensure the durability of the plant and to discover any defects left unnoticed. One category of calculations is transient calculations in which severe transient scenarios are studied in order to determine whether the response of the reactor is in accordance with regulations. At the Technical Research Center of Finland (VTT) three dimensional transient calculations are performed using two programs, TRAB-3D and HEXTRAN, depending on the geometry of the fuel assembly. Both programs have been developed at VTT. An important part of developing a transient code that models nuclear reactors is the validation of the program using international benchmarks or data from experiments carried out on domestic nuclear reactors.

The objective of this study is to examine one of the validation calculations performed on TRAB-3D, a load rejection test performed on the Olkiluoto 1 reactor in Finland in 1998, and to determine whether the calculation could be enhanced using new, more detailed measurement data received from TVO in 2001. The original calculation was based on data with 0.2 s sample interval. In the new data the sample interval is 0.02 s. The focus of the new calculation is on a valve opening-closing mismatch that occurs during the first few seconds of the test initiating a disturbance in the system pressure. The mismatch is modeled in TRAB-3D with a boundary condition in the input. First the exact mismatch values from the data are put to use in the boundary condition and the results are assessed in respect to the original calculation to evaluate the importance of the new data. Second the mismatch is adjusted to maximize the accuracy of calculated pressure in respect of measured pressure during the first second of the calculation. Last the accuracy of calculated pressure is maximized during first three seconds of the calculation. The latter two calculations are performed to determine the sensibility of the calculation regarding the mismatch.

2 Models and solving methods in TRAB-3D

In a nuclear reactor core the coupling of neutronics, heat transfer and thermal hydraulics is very strongly present. It is therefore of vital important to describe this phenomenon in the dynamic codes in order to gain a feasible model of the core. At VTT coupled three dimensional transient codes have been developed, validated and used since the mid eighties.

TRAB-3D [1, 2] is a stand-alone BWR dynamics code, whose core model is based on the 3D hexagonal core model in HEXTRAN [3], and circuit and system models are adopted from one-dimensional code TRAB [4]. TRAB-3D can be applied to transient and accident analyses of boiling (BWR) and pressurized water (PWR) reactors with rectangular fuel bundle geometry. The code has been validated against international benchmarks and actual measured data from real plant transients and it is in active use at VTT.

2.1 Neutronics

In TRAB-3D neutronics are modeled with two-group diffusion equations which are solved by nodal expansion method in x-y-z-geometry. The nodal expansion is based on the steady-state solution method for hexagonal core model in the HEXBU-3D simulator. The basic principle of the solving method is the decoupling of the diffusion equations, which is accomplished by separating the equations using two spatial modes. The characteristic solutions of the spatial modes construct the two group fluxes. There are two types of characteristic solutions, asymptotic and transient. The fundamental, asymptotic mode is a well-behaving function within a node and it can be approximated using polynomial functions, whereas the transient mode has a large buckling in LWR cores and therefore needs to be approximated by exponential functions. The interaction of adjacent nodes is handled through continuity conditions at the interfaces. The dynamic equations include six groups of delayed neutrons. [5]

A two-level iteration scheme is used to solve the nodal equations. In the inner iteration only one unknown, the average fundamental mode, is determined. The nodal flux shapes are enhanced in the outer iteration by recalculating the coupling coefficients. Cross-sections are calculated using polynomial fittings to coolant temperature, density and soluble boron density. Homogenized cross sections are created with the CASMO-4 cell burnup code. [1]

2.2 Thermal Hydraulics

The thermal hydraulics model and its solution method are adopted from the one-dimensional transient code TRAB. Flow channels are parallel and they are connected freely to one or several fuel assemblies. The principal equations represent the conservation of the masses of water and steam, respectively, total enthalpy and total momentum. Additional equations for disequilibrium of evaporation and condensation, slip and one- and two-phase friction can also be utilized. Mass distribution through flow channels is determined from the pressure balance in the core. The phase velocities are determined using slip ratio or the drift-flux formalism. Properties of water and steam are calculated locally as rational functions of pressure and enthalpy.

During the thermal hydraulic iteration one-dimensional heat transfer is calculated for an average fuel rod in each fuel assembly. Fuel rod and cladding are discretised with several radial mesh points and the calculations are performed at equidistant axial elevations. Heat conduction is solved according to Fourier’s law with temperature dependent thermal properties of fuel pellet, gas gap and fuel cladding and with different heat transfer coefficients for different hydraulic regimes.

TRAB-3D includes a 1D model for BWR’s thermal hydraulics inside the pressure vessel, as well as models for pumps, steam lines, and control systems. The circuit components of TRAB-3D are shown in Figure 1. When TRAB-3D is used for PWR transient calculations, it is coupled with a 1D thermal hydraulic system code SMABRE for the hydraulic circuit. [1]

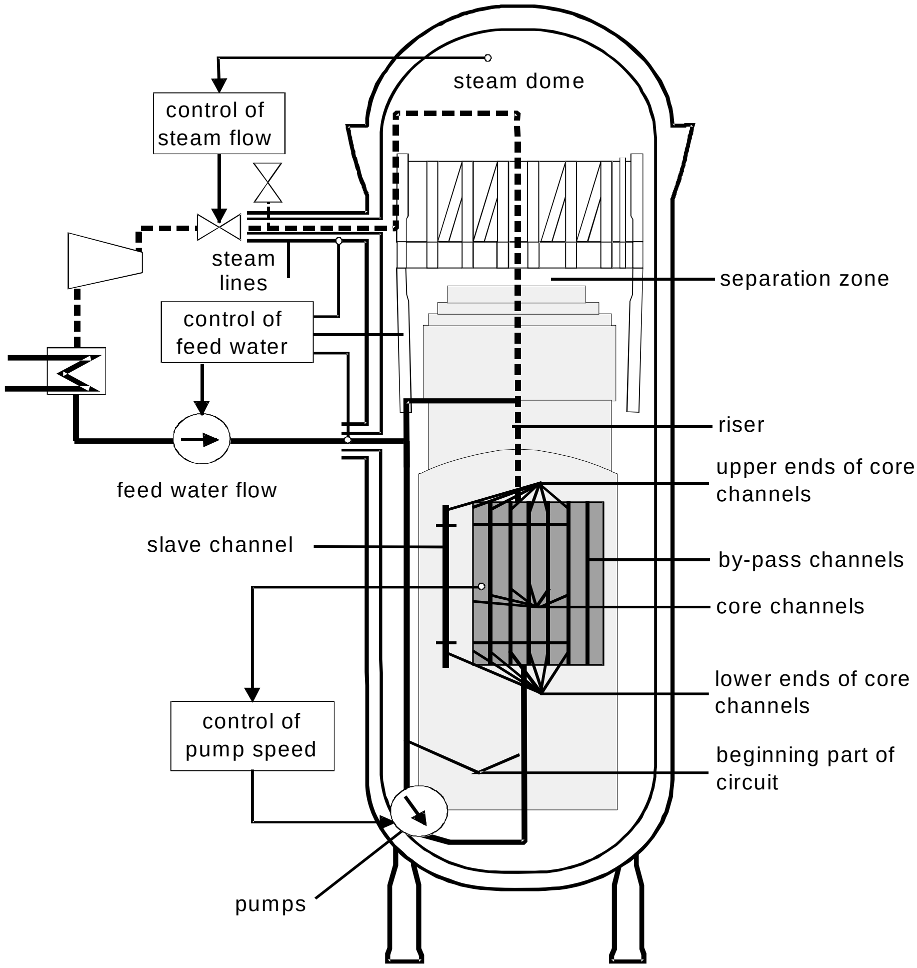


Figure 1. TRAB-3D BWR pressure vessel model. [1]

3 Load rejection test

3.1 Test description

The load rejection test was performed on Olkiluoto1-reactor on June 16th 1998 during the start-up testing after its modernization and power uprating. The purpose of the test was to show that the plant can endure a shift from full 2500MW operation power to a 30% power level in case of external load rejection. In this situation the plant is supposed to feed an in-house load and dump excess steam to the condensers. These actions were carried out through a partial scram, in which one scram rod group was inserted hydraulically in a few seconds and another slowly electrically taking 260 seconds, and by slowing the main circulation pump to minimum speed. The plant functioned as expected. [1]

The test offers excellent material for testing of 3D codes, because the transient is asymmetric in the core and there are measurements from local power range monitors available on several axial and radial locations in the core as well as measurement values of bundle flows for several bundles.

At the initial stage of the test the plant was on 2500 MW operation power, the turbine valves were open and the dump valves closed. At the beginning turbine valves close and dump valves open. At the same time a partial scam takes place, as one rod group is inserted hydraulically and another slowly. Feed water pumps operate both under automatic control and under manual control by the operators. The plant stabilized on a 30% house turbine operation power level. [6]

3.2 Calculation using TRAB-3D

Several modifications were initially done on TRAB-3D in order to calculate the load rejection test. The first full core model on TRAB-3D was constructed, since the partial scram was not half-core symmetric. The thermal hydraulic model was altered to take into account the impact of the partial length Atrium fuel rods on the flow geometry. A simple detector model was coded approximating local power range monitors (LPRM) with averaging the thermal flux of the four nodes adjacent to the detector. Average power range monitor (APRM) values are calculated from 28 LPRM values. As the main object of the calculation was to evaluate the capability of TRAB-3D to model 3D core phenomena, no modifications were made on coolant circuit model or controller models. The values of the feed water flow were set as transient boundary conditions because of the manual operator actions during the test and due to the absence of feed water controller in the present TRAB-3D input for TVO reactors. Feed water enthalpy and pump speed were also used as boundary conditions. [7]

In the initial test measurement data the closing of the turbine valves and the opening of the dump valves appeared simultaneous. After some test calculations, a 0.05 s mismatch in the closing and opening of the valves was chosen due to the relatively long sample interval 0.2 s, and the total time taken in opening and closing the valves was fixed to 0.15 s. These values were also set as boundary conditions for the calculation. The load rejection test was calculated for 400 seconds with TRAB-3D. Agreement with measured 3D time-dependent LPRM data was good. [1, 8]

4 New calculations

In 2001 new, more specific measurement data of the load rejection with a 0.02 s sample interval was received. The objective of this study is to determine whether the accuracy of the calculation of the load rejection test could be improved by imposing more detailed boundary conditions for the turbine and dump valves in the beginning of the calculation. In addition, the sensitivity of the calculation in respect of the opening and closing of valves was evaluated and thereby the significance of the new data.

In the current TRAB-3D input opening and closing of valves is modeled by one variable, which represents the fraction of openness of all the turbine and dump valves. This is because in the present calculation the four steam lines are lumped as one. Therefore, if no mismatch was related to the closing of the turbine valves and the opening of the dump valves, the value of the valve variable, A2VAL1, would stay one through the first few seconds of the calculation. In the initial calculations the mismatch was modeled by a plateau between the beginning of the closing of the turbine valves and the end of the opening of the dump valves, shown in Figure 3. The constant value of the valve variable on the plateau was determined by varying it and comparing the calculated pressure to measured system pressure.

For the new calculation, the fraction of openness of the valves in the measurement data was plotted to determine more detailed boundary conditions, see Figure 2. In the new, exact boundary conditions mismatch is modeled the same way as in the original calculation, by a plateau. The value of the valve variable on the plateau was determined by comparing calculated and measured pressures.

In order to evaluate the sensitivity of the calculation and to find out the optimal mismatch values, the calculation was performed with varying valve boundary condition values. The mismatch and time taken in opening and closing the valves was varied freely, without paying any attention to the values gained from measurement data. The accuracy of the calculated system pressure was chosen as criterion for the quality of the boundary condition. At first only the first second of the calculation was considered when comparing the pressures and later first three seconds were taken into account.

Closer inspection of the new data revealed that the starting point of the calculation needed to be readjusted in respect to the measured data to allow comparison. The zero-time of the calculation was set to the beginning of the valve opening/closing and the calculation started 0.1 seconds before it. In the initial calculation, the zero-time of the calculation corresponded to 58.2 s in the measured data. It was corrected to 58.28 s in accordance with the new data.

5 Results

The valve boundary condition is modelled in tabulated form in the input. The values of the variable, A2VAL1, used in the calculations are shown in Table 1 and they are graphed in Figure 3.

Table 1. Valve boundary condition values.

Original calculation	Time (s)	0.1	0.15	0.25	0.3
	A2VAL1	1.0	0.6667	0.6667	1.0
Exact boundary conditions	Time (s)	0.1	0.11	0.13	0.14
	A2VAL1	1.0	0.5	0.5	1.0
1s-fitted boundary conditions	Time (s)	0.21	0.34	0.4	0.57
	A2VAL1	1.0	0.74	0.74	1.0
3s-fitted boundary conditions	Time (s)	0.2	0.3	0.8	1.1
	A2VAL1	1.0	0.87	0.87	1.0

Figures of the most interesting variables, pressure, main circulation flow, steam flow out of steam line and feed water flow are presented in Figures 4-7 for the first ten seconds of the calculation for the different boundary conditions. Measured data and data from original calculation are also graphed in the same figures to allow comparison. In addition, results from a local power range monitors (LPRM16) located near a hydraulic scram rod group at four heights axially are shown in Figure 9 and results from an average power range monitor (APRM1) based on 28 LPRM measurements in Figure 8. Relative LPRM values are scaled with an arbitrary initial value to allow visualization of four axial values in the same figure.

Examining system pressure in Figure 4 shows that the exact mismatch determined from measured data is too rapid to create the rise in pressure observed in the measured pressure in the beginning of the test. During the first four seconds, the calculation performed using the exact boundary condition is less accurate than the original calculations. For the calculation in which pressure was optimized for the first second of the calculation, the calculated pressure is, as expected, quite consistent with measured pressure for the first second and therefore more accurate than the pressure in the original calculation. In the 3s optimized calculation calculated pressure follows the measured pressure well for almost three seconds. However, after four seconds all the calculated pressures converge and no deviation can bee seen between the original calculation and new calculations.

Steam flow out of steam line in Figure 5 shows differences between the calculations for the first three seconds of the transient but little improvement can be seen in its accuracy. In the other variables, the new calculations show little variation from the original calculation.

A longer 300 s calculation was performed using the last valve boundary condition, in which pressure was optimized for three seconds. Figures of the results are shown at the end of this report.

6 Conclusions

The objective of this study was to apply new, more detailed boundary conditions to the transient calculation of the load rejection test performed in 1998 on Olkiluoto 1 nuclear reactor. The exact boundary conditions for the valve variable were determined from the new measurement data and they were used in the calculation. In addition, the sensitivity of the calculation in respect of the valve boundary condition was evaluated by trying to adjust calculated pressure to measured pressure by varying the boundary condition freely. At first, only the first second of the calculation was considered and second, first three seconds were taken into account. The results are compared to the measured data as well as the original calculation.

The results are shown in the figures at the end of this report. Using the exact boundary conditions the mismatch appears to be too rapid in order to create the rise in pressure observed in the beginning of the test. Therefore, the new, exact boundary conditions do not enhance accuracy but rather impair it at the beginning of the calculation. Overall, this has little impact on the calculation as a whole. The calculations in which pressure was optimized for one and three seconds, are somewhat more accurate than the original calculation at the beginning, but their influence lasts no more than a couple of second. The impact of the new boundary conditions is very little on other variables apart from pressure and steam flow out of steam line.

As a conclusion, it can be summarized that the boundary conditions on the valve variable are not critical concerning the load rejection test calculation. Some enhancements can be attained during the first few seconds of the calculation, but in order to do so the values of the valve variable must be changed substantially from the one gained from measured data. Even when doing so, no effect is seen after four seconds.

In the future, improvements on the calculation of the load rejection test could be attained for example by adding a feed water controller model to the input. In the present calculations height of water level is fairly accurate until 100 seconds. After that, however, the absence of the controller model shows evidently.

References

[1] A. Daavittila, A. Hämäläinen & H. Räty, *Transient and Fuel Performance Analysis with VTT's Coupled Code System*, Mathematics and Computation, Reactor Physics and Nuclear and Biological Applications, Avignon, France, September 12-15, 2005

[2] Daavittila, A., Kaloinen, E., Kyrki-Rajamäki, R. & Räty, H. *Validation of TRAB-3D against Real BWR Plant Transients.* In: International Meeting on "Best-Estimate" Methods in Nuclear Installation Safety Analysis (BE-2000). Washington, D.C., USA, 12-16 November, 2000 [CD-ROM]. La Grange Park: American Nuclear Society, 2000. File Log40~54.pdf. ISBN 0-89448-658-6

[3] Kyrki-Rajamäki, R.**,** *HEXTRAN: VVER Reactor Dynamics Code for Three-Dimensional Transients,* In: Proceedings of the first Symposium of AER, Řež near Prague, 23-28 September 1991. Budapest: KFKI Atomic Energy Research Institute, 1991. Pp. 474-481.

[4] Rajamäki, M., *TRAB, a transient analysis program for BWR, Part 1. Principles*. Helsinki 1980. Technical Research Centre of Finland, Nuclear Engineering Laboratory, Report 45. 101 p + app. 9 p.

[5] Kaloinen, E. & Kyrki-Rajamäki, R., *TRAB-3D, a new code for three-dimensional reactor dynamics.* CD-ROM Proceedings of ICONE-5, 5th International Conference on Nuclear Engineering. "Nuclear Advances through Global Cooperation". May 26-30 1997, Nice, France. Paper ICONE5-2197.

[6] Hanski, O., *OL1 – koe 859, kuormanpudotuskoe, tulosraportti*. TVO:n muistio S03-KK-M-60/98. 17.6.1998. (in Finnish).

[7] Räty, H., *TRAB-3D-Ohjelman Validointi Olkiluoto1 Kuormanpudotuskokeen 16.6.1998 Avulla*, VTT Energy, Programme Document, ENE-PR-14/01.

[8] Daavittila, A, Räty, H., Reactor physics and dynamics (READY): Validation of TRAB-3D. In: Kyrki-Rajamäki, Riitta & Puska, Eija-Karita (eds.) *FINNUS The Finnish Research Programme on Nuclear Power Plant Safety 1999-2002. Final Report*. Espoo: Technical Research Centre of Finland. Pp. 127 - 133. (VTT Research Notes 2164). ISBN 951-38-6085-X, 951-38-6086-8.

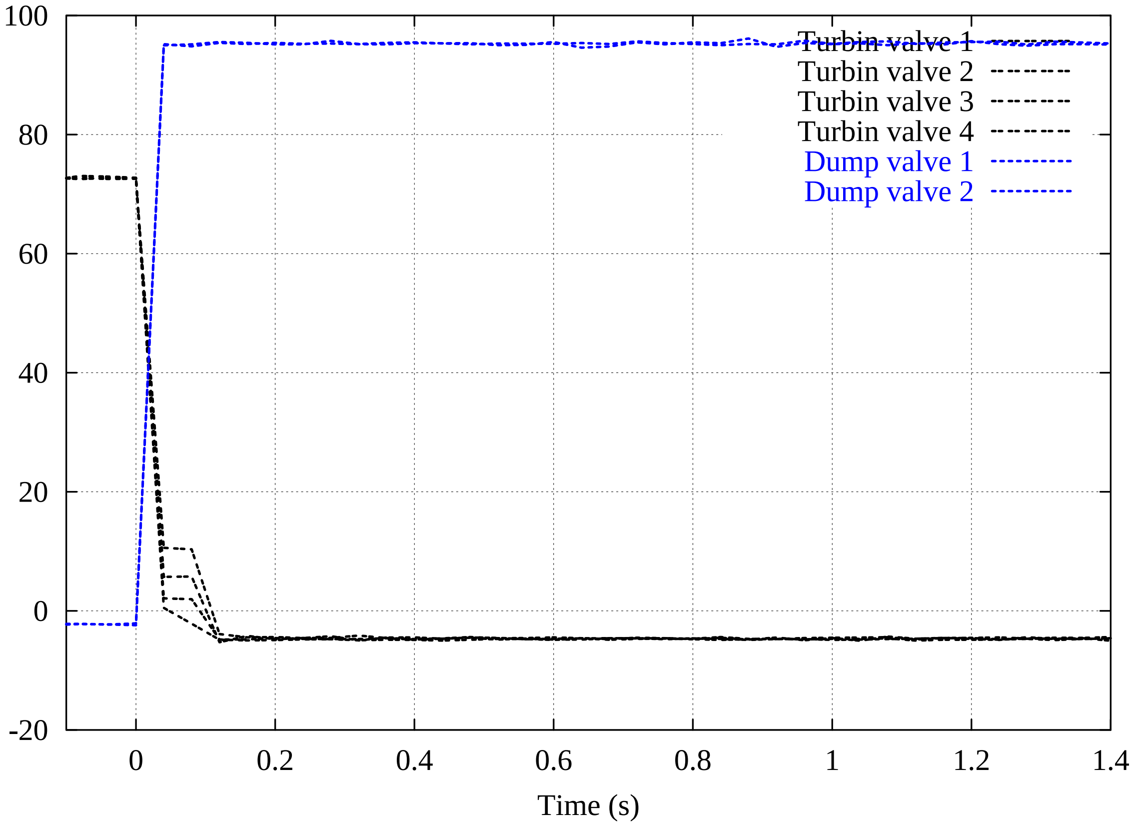


Figure 2. Measured data of turbine and dump valves.

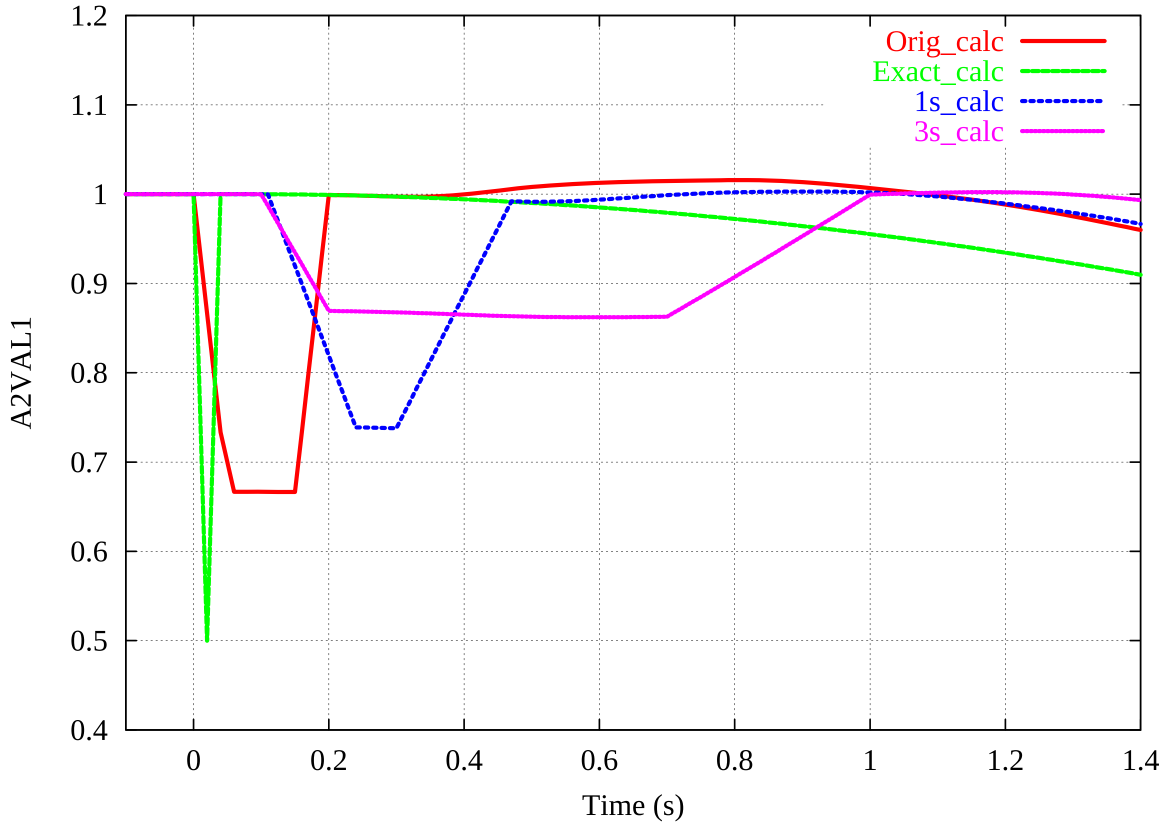


Figure 3. Valve boundary condition in the original and new calculations.

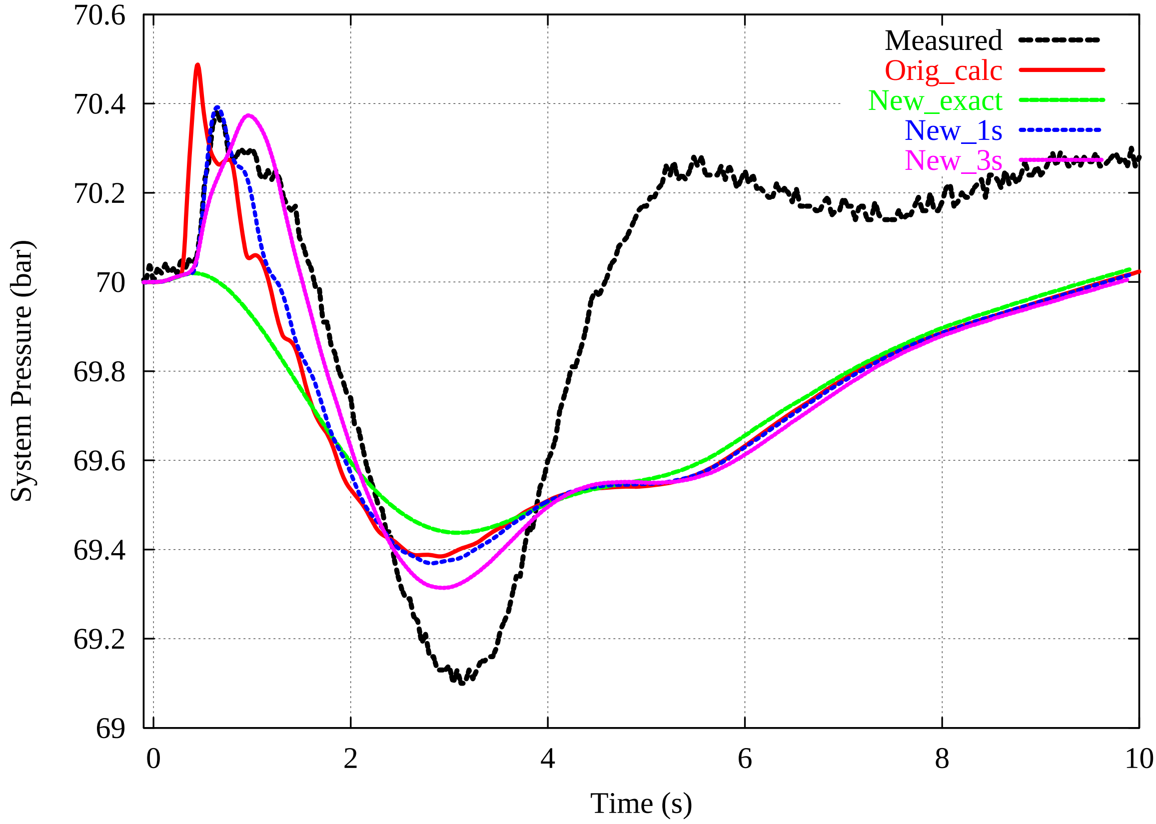


Figure 4. Measured and calculated system pressure.

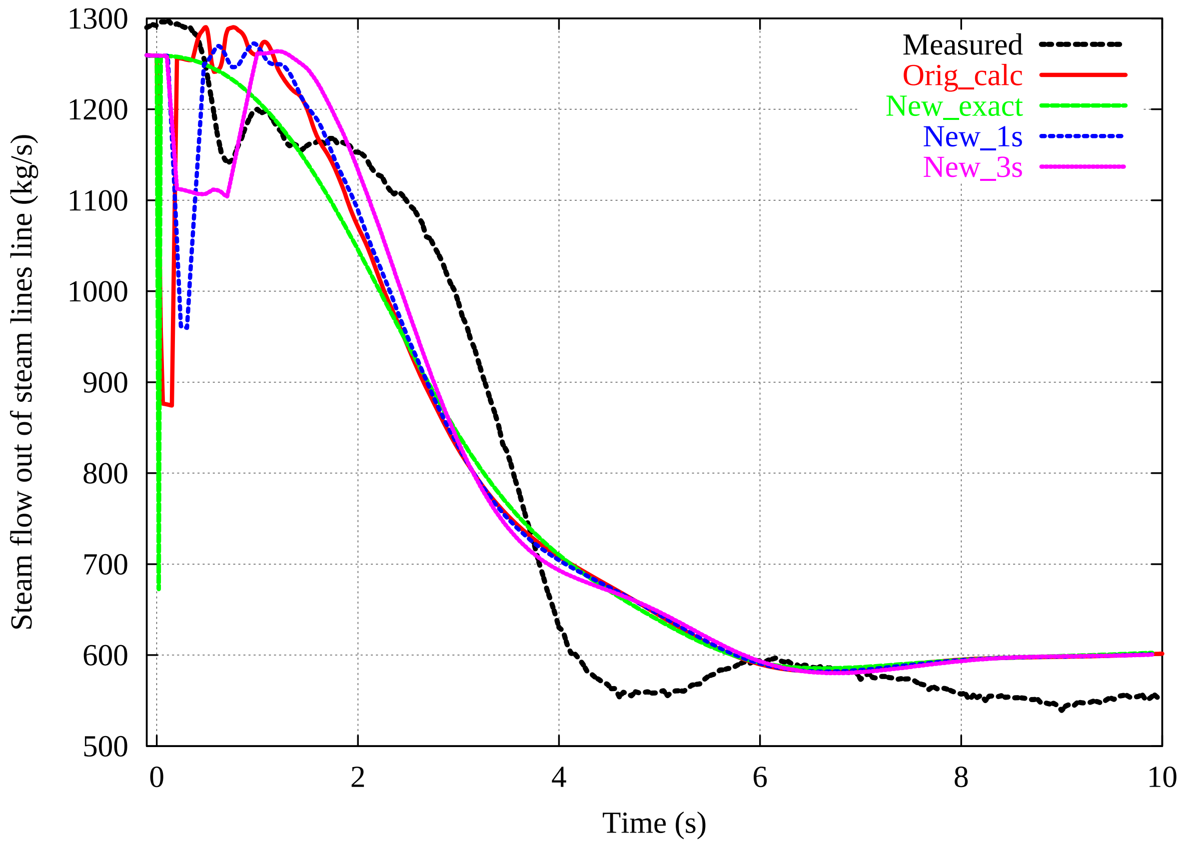


Figure 5. Measured and calculated steam flow out of steam line 1.

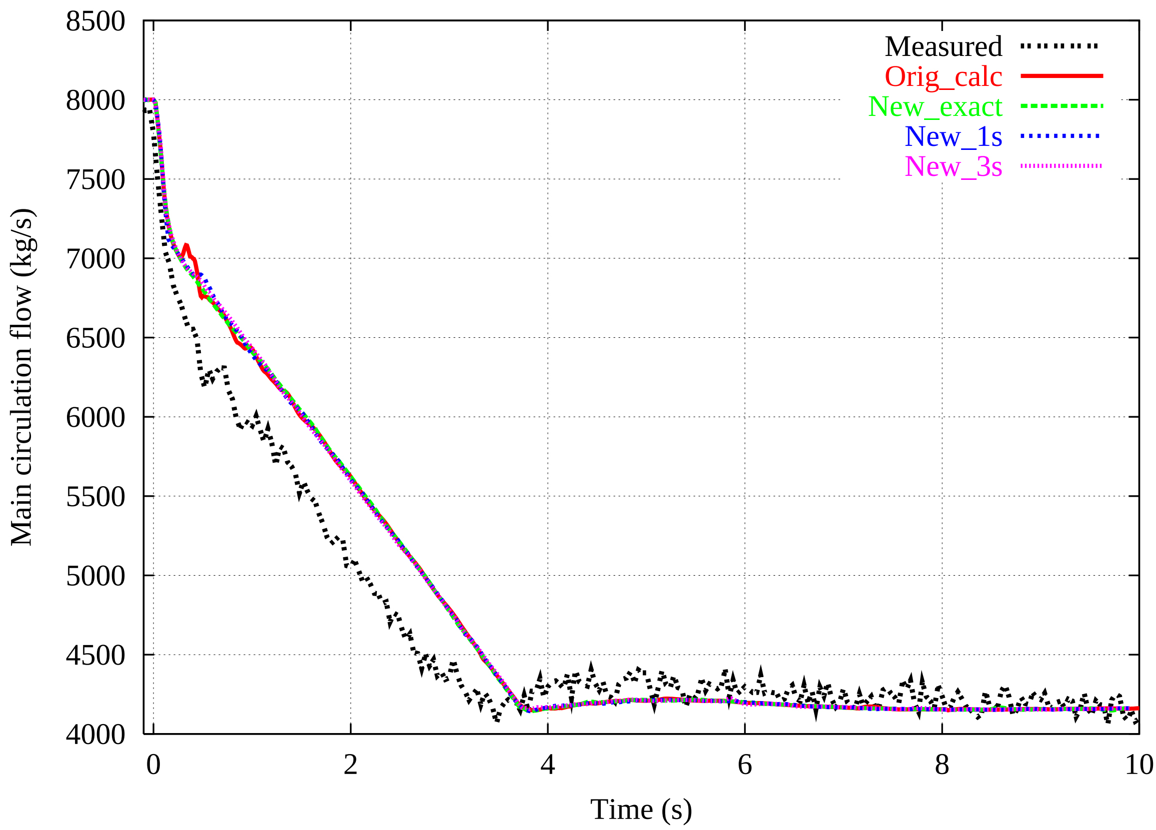


Figure 6. Measured and calculated main circulation flow.

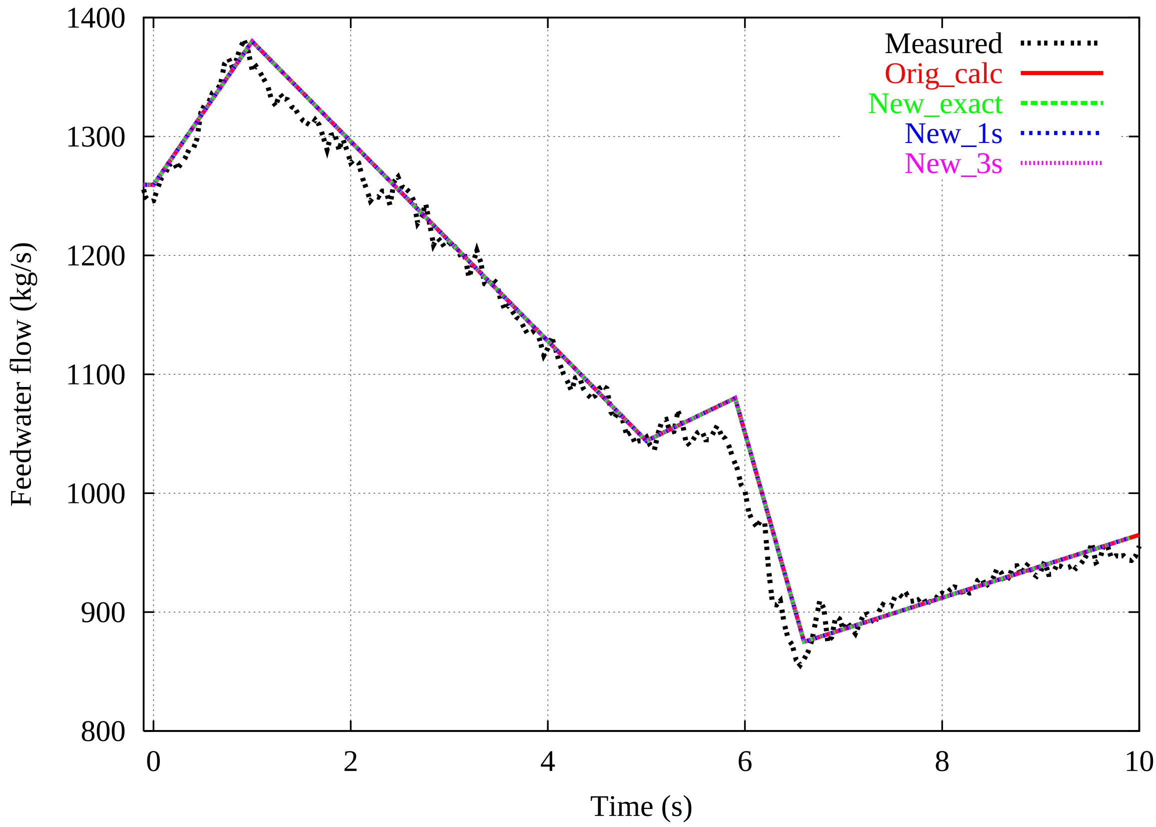


Figure 7. Measured and calculated feedwater flow. Boundary condition.

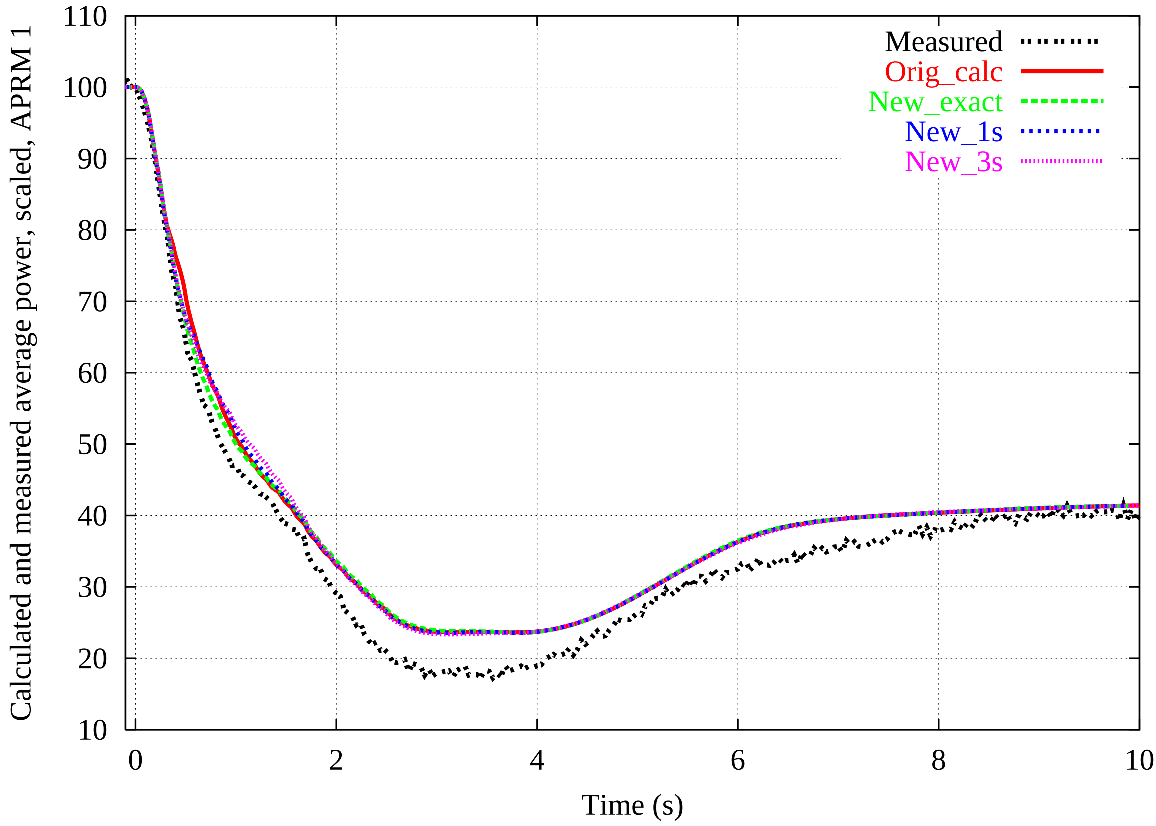


Figure 8. Calculated and measured average power, APRM 1.

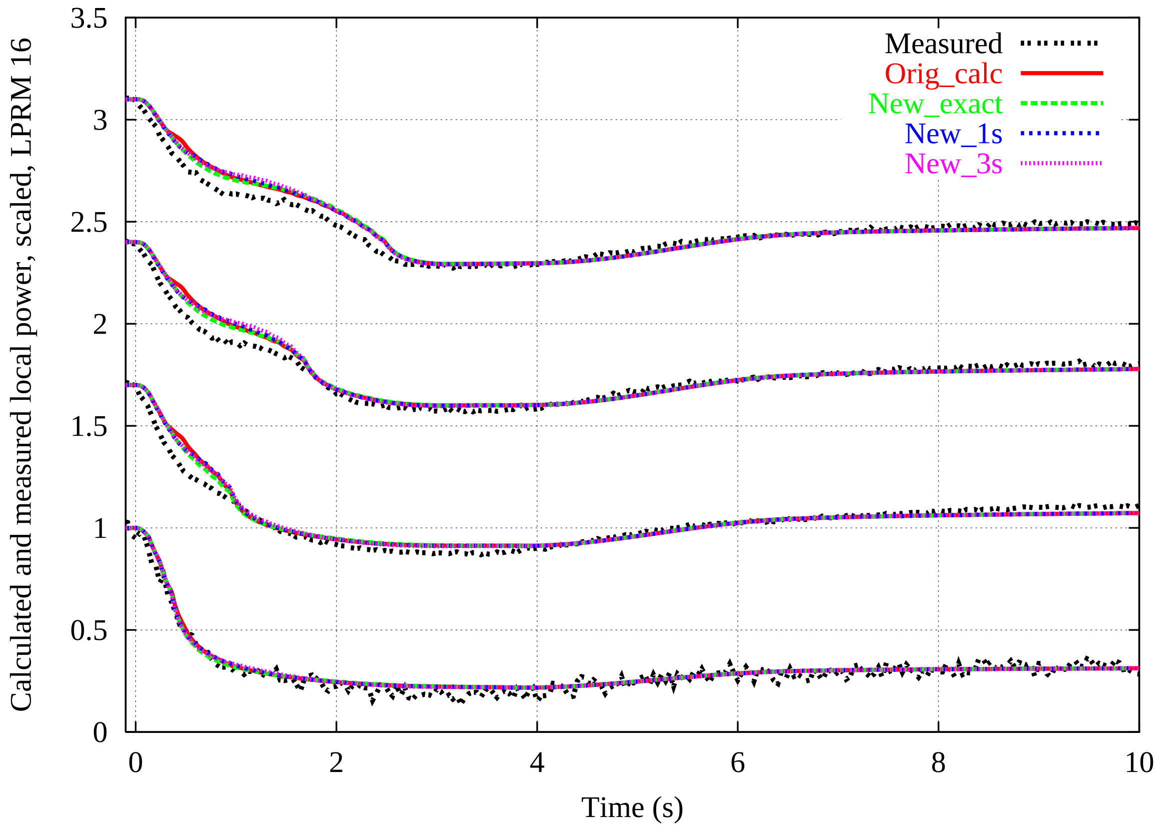
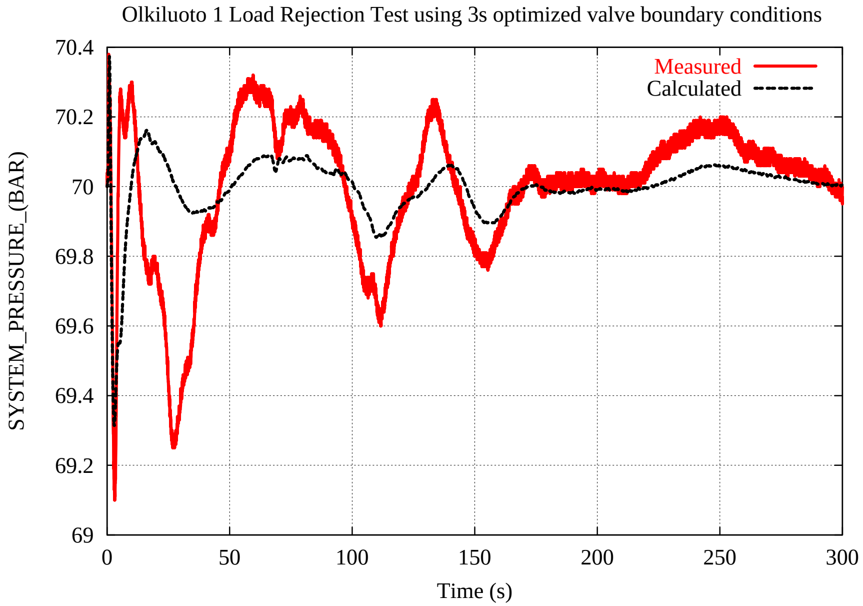
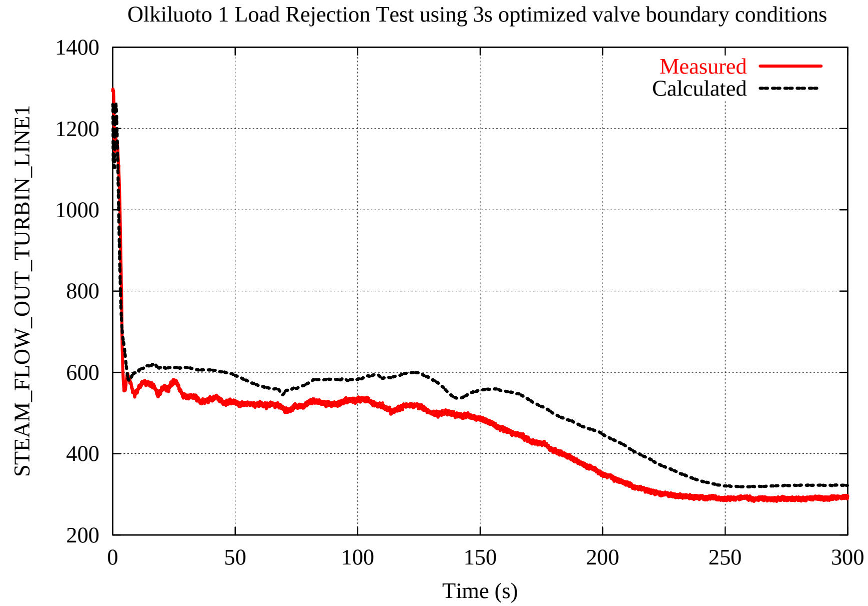
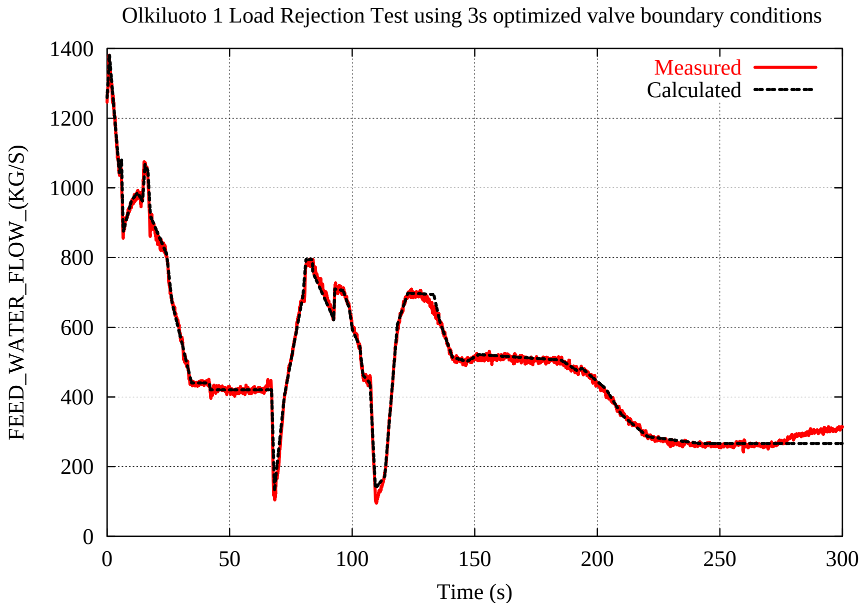
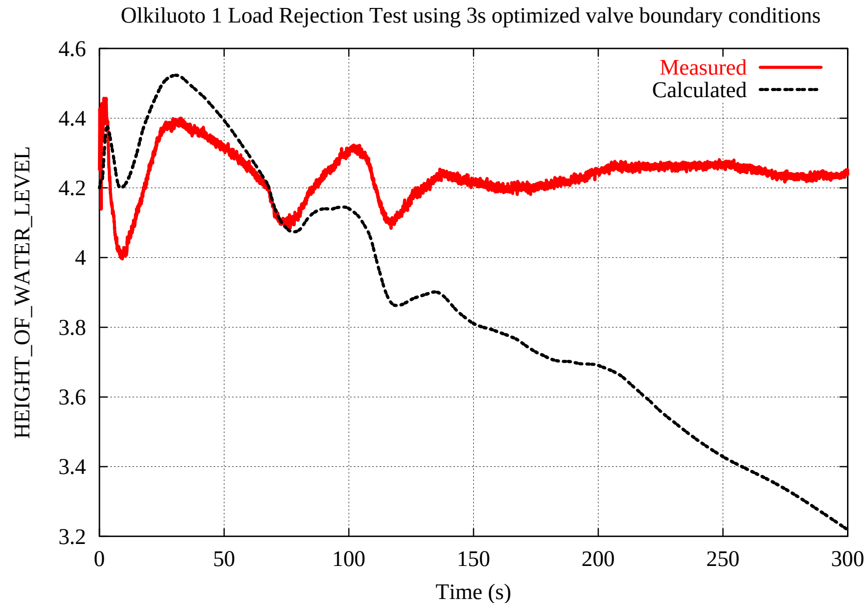


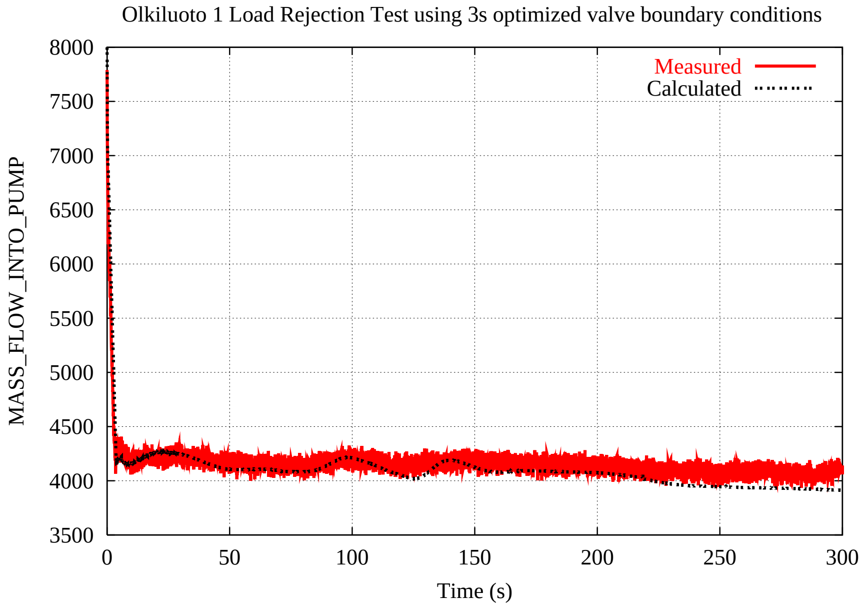
Figure 9. Calculated and measured local power, LPRM 16.

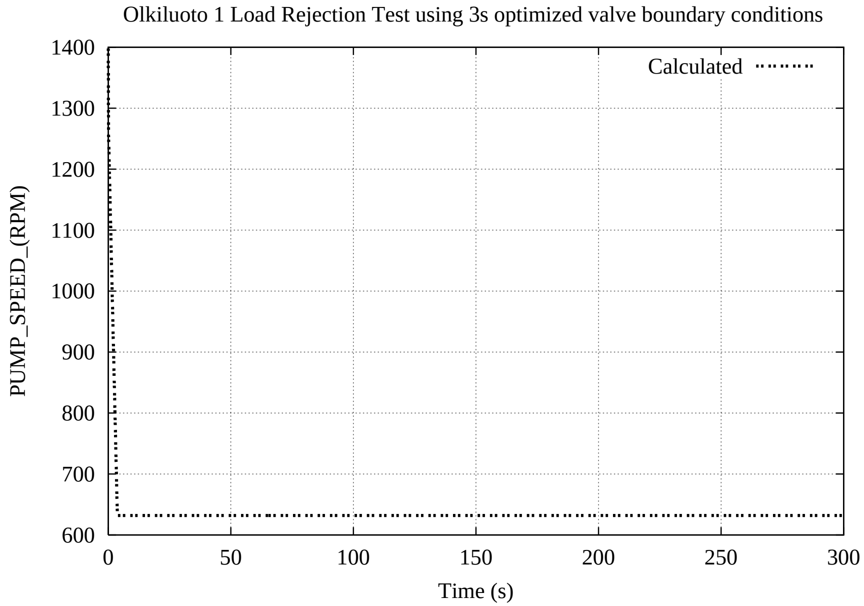

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Measured
Calculated
SYSTEM_PRESSURE_(BAR)
70.4
70.2
70
69.8
69.6
69.4
69.2
69
0
50
100
150
200
250
300
Time (s)

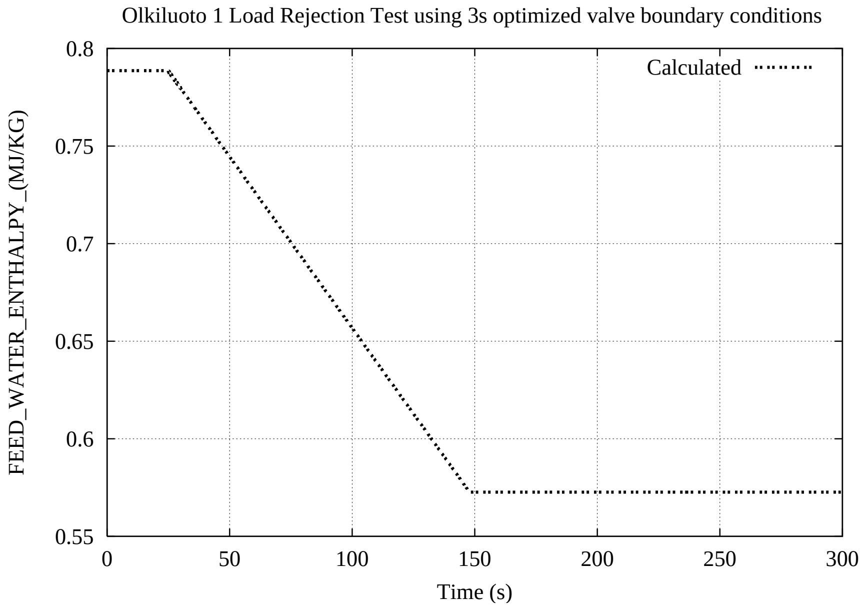

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Measured
Calculated
STEAM_FLOW_OUT_TURBIN_LINE1
1400
1200
1000
800
600
400
200
0
50
100
150
200
250
300
Time (s)

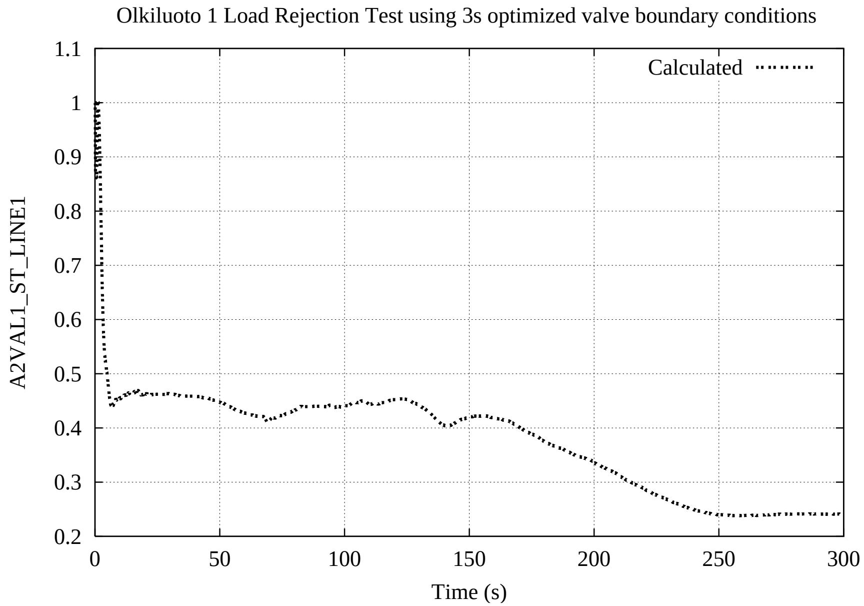

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Measured
Calculated
FEED_WATER_FLOW_(KG/S)
1400
1200
1000
800
600
400
200
0
0
50
100
150
200
250
300
Time (s)

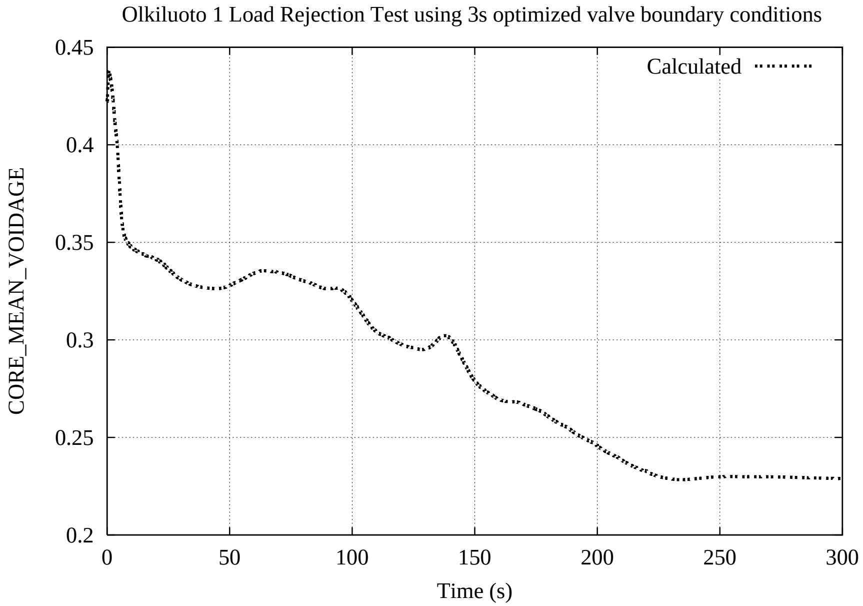

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Measured
Calculated
HEIGHT_OF_WATER_LEVEL
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
0
50
100
150
200
250
300
Time (s)

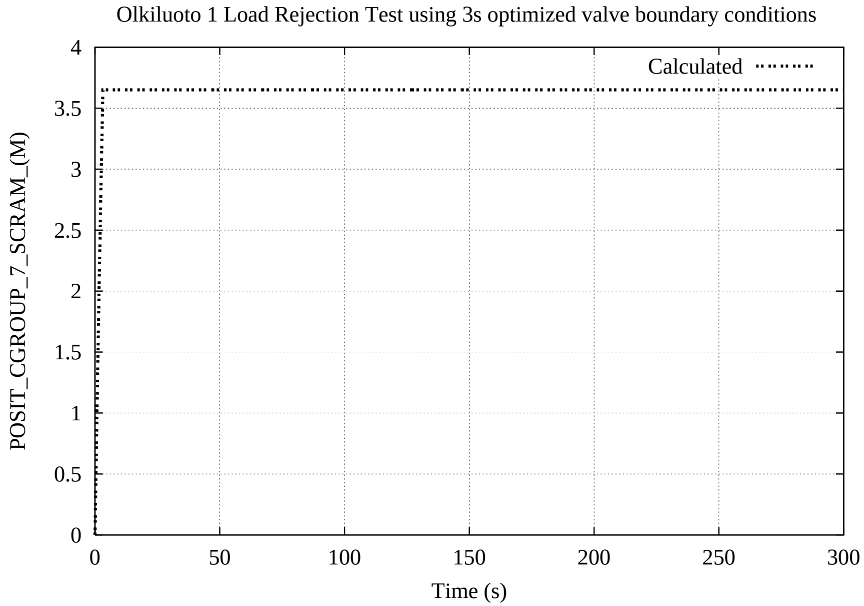

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
MASS_FLOW_INTO_PUMP
Measured
Calculated
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
0
50
100
150
200
250
300
Time (s)

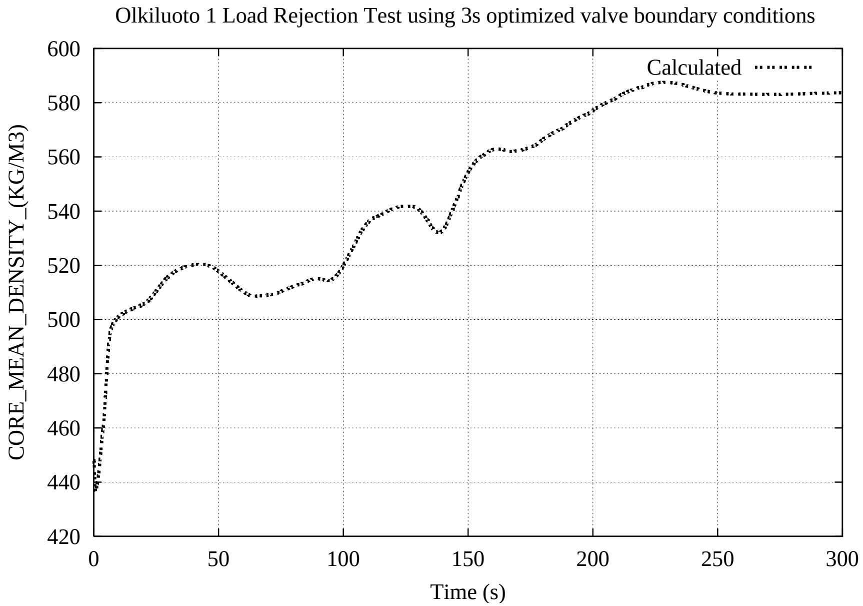

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
PUMP_SPEED_(RPM)
Calculated
1400
1300
1200
1100
1000
900
800
700
600
0
50
100
150
200
250
300
Time (s)

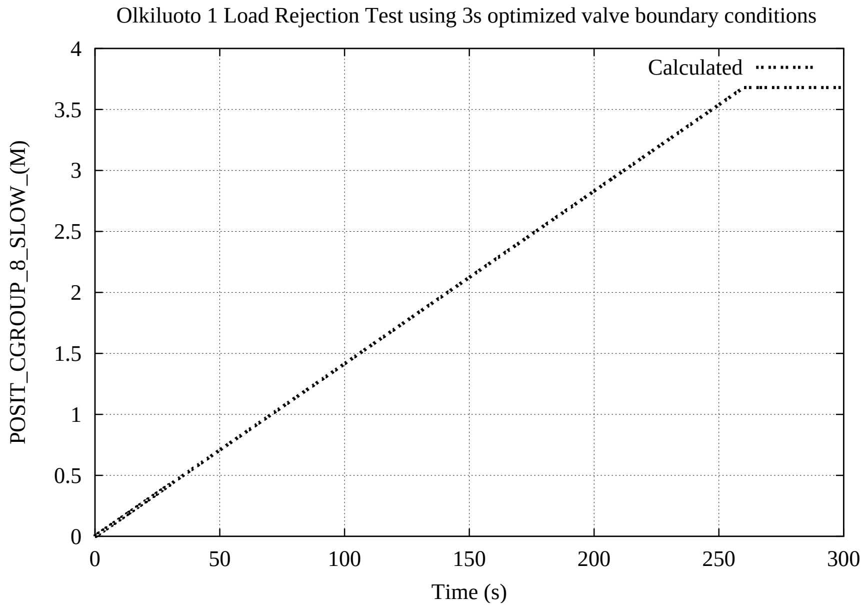

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
FEED_WATER_ENTHALPY_(MJ/KG)
Calculated
0.8
0.75
0.7
0.65
0.6
0.55
0
50
100
150
200
250
300
Time (s)

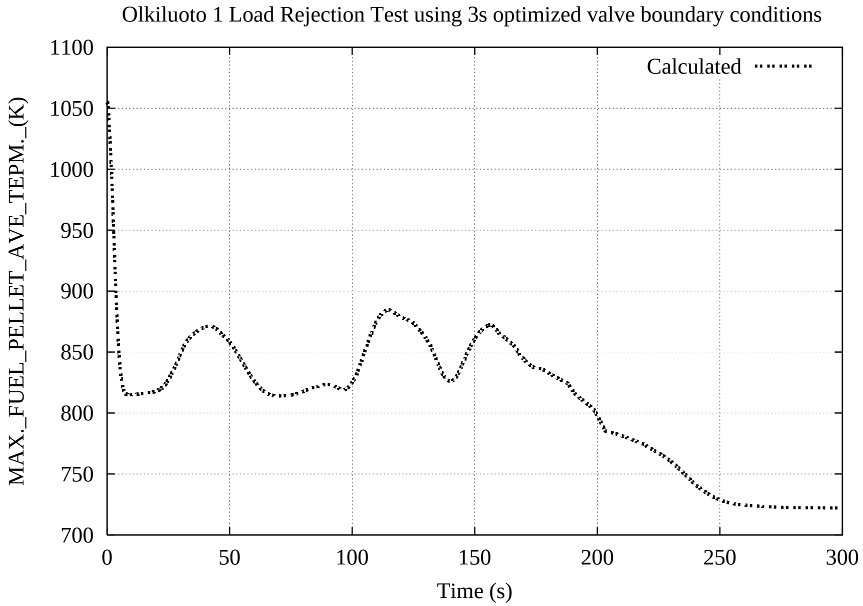

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
A2VAL1_ST_LINE1
Calculated
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
50
100
150
200
250
300
Time (s)

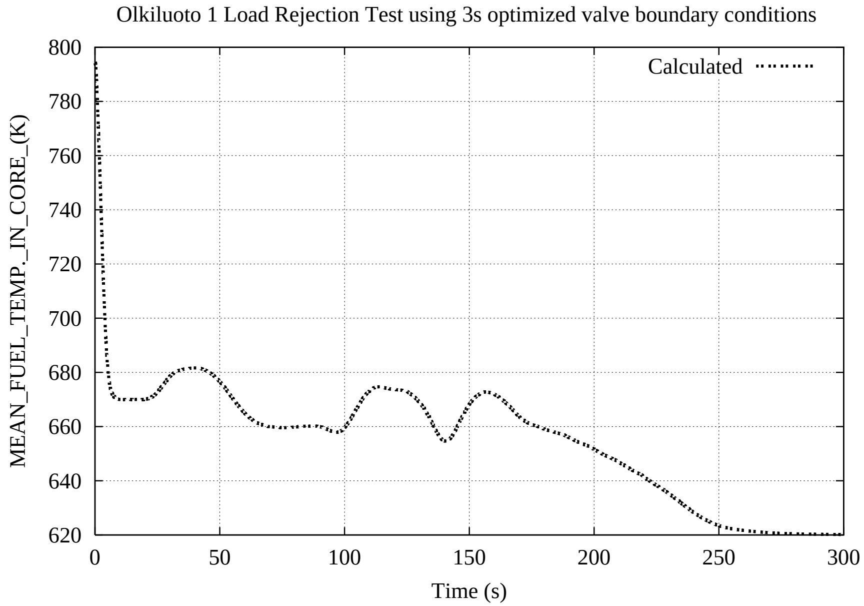

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
CORE_MEAN_VOIDAGE
Time (s)
Calculated
0.45
0.4
0.35
0.3
0.25
0.2
0
50
100
150
200
250
300

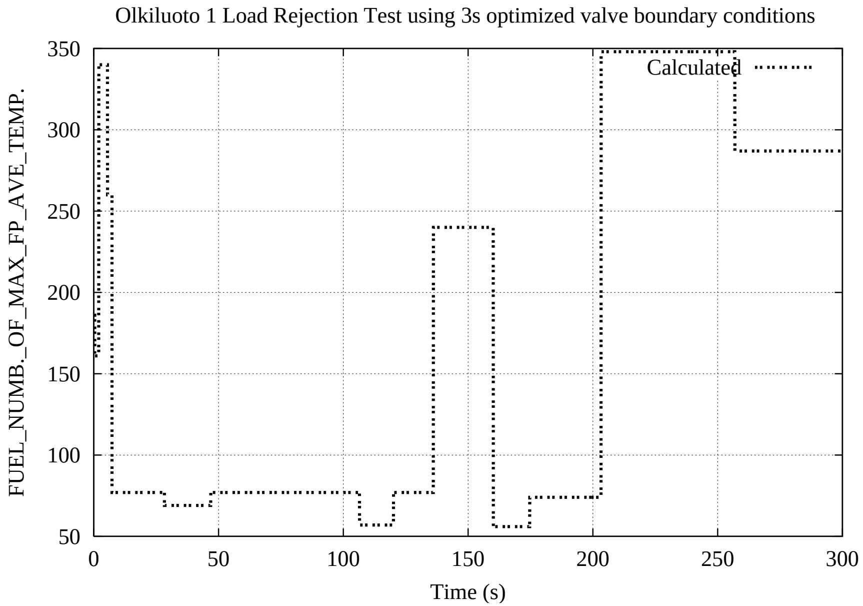

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
POSIT_CGROUP_7_SCRAM_(M)
Time (s)
Calculated
4
3.5
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300

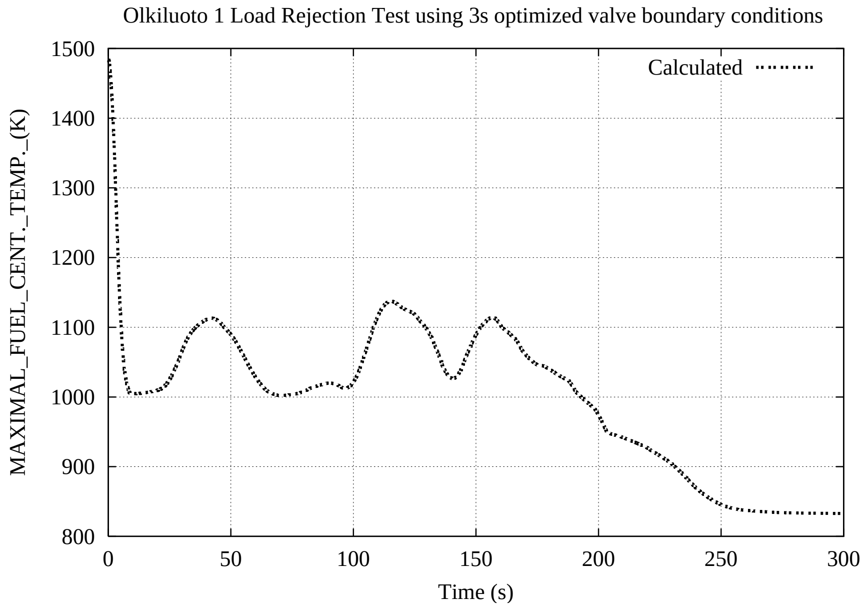

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
CORE_MEAN_DENSITY_(KG/M3)
Time (s)
Calculated
600
580
560
540
520
500
480
460
440
420
0
50
100
150
200
250
300

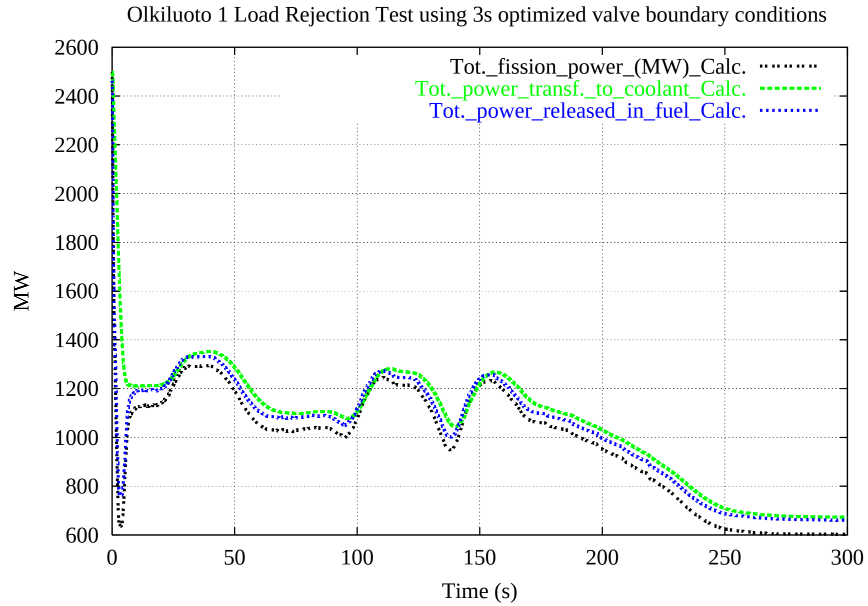

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
POSIT_CGROUP_8_SLOW_(M)
Time (s)
Calculated
4
3.5
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300

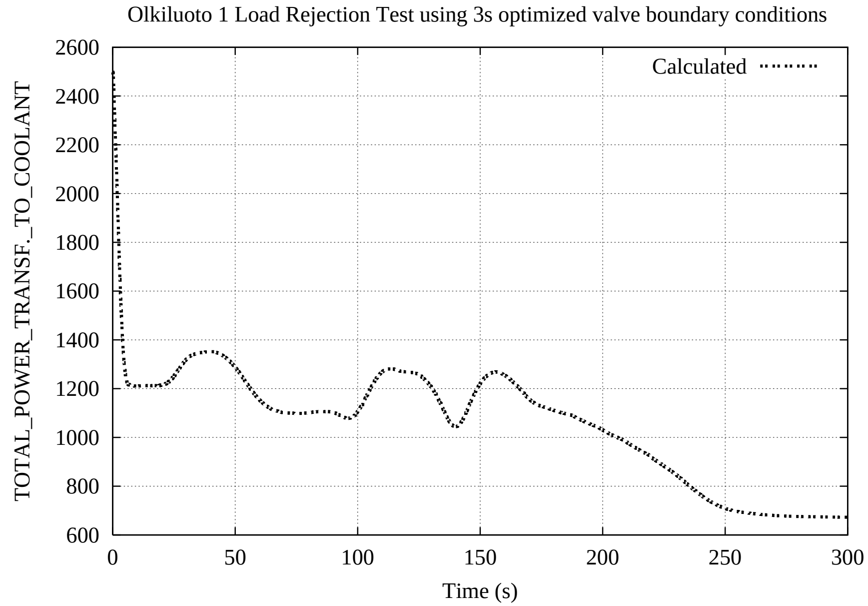

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
MAX._FUEL_PELLET_AVE_TEPM._(K)
Time (s)
Calculated
1100
1050
1000
950
900
850
800
750
700
0
50
100
150
200
250
300

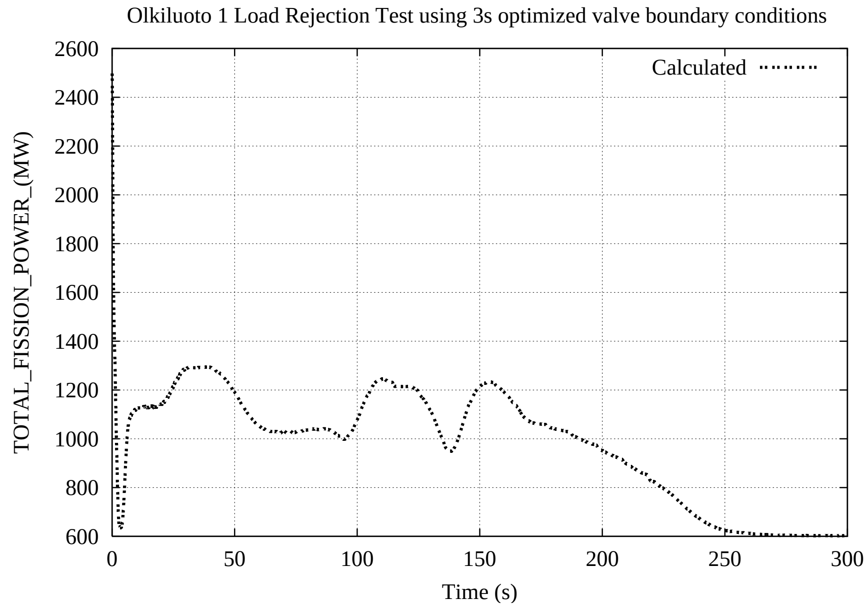

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
MEAN_FUEL_TEMP._IN_CORE_(K)
Time (s)
Calculated
800
780
760
740
720
700
680
660
640
620
0
50
100
150
200
250
300

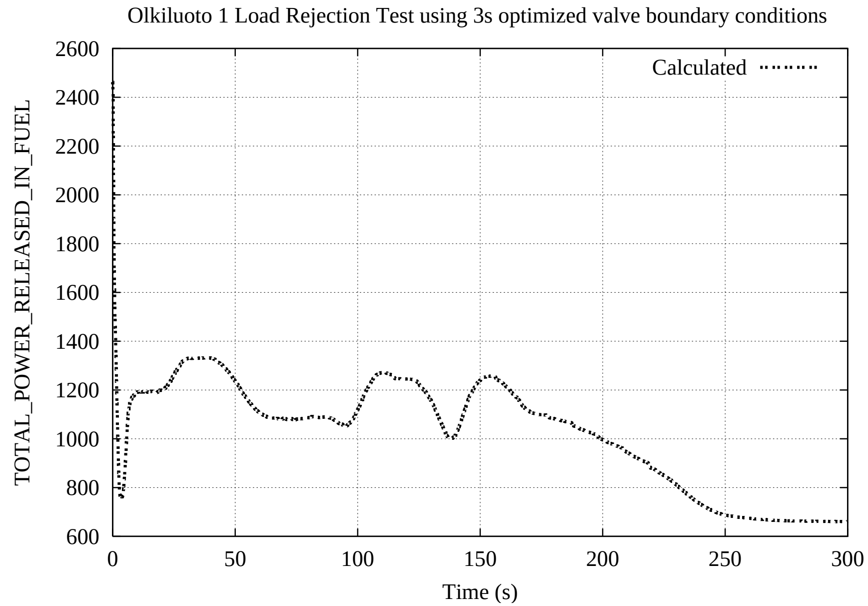

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
FUEL_NUMB._OF_MAX_FP_AVE_TEMP.
Time (s)
Calculated
350
300
250
200
150
100
50
0
50
100
150
200
250
300

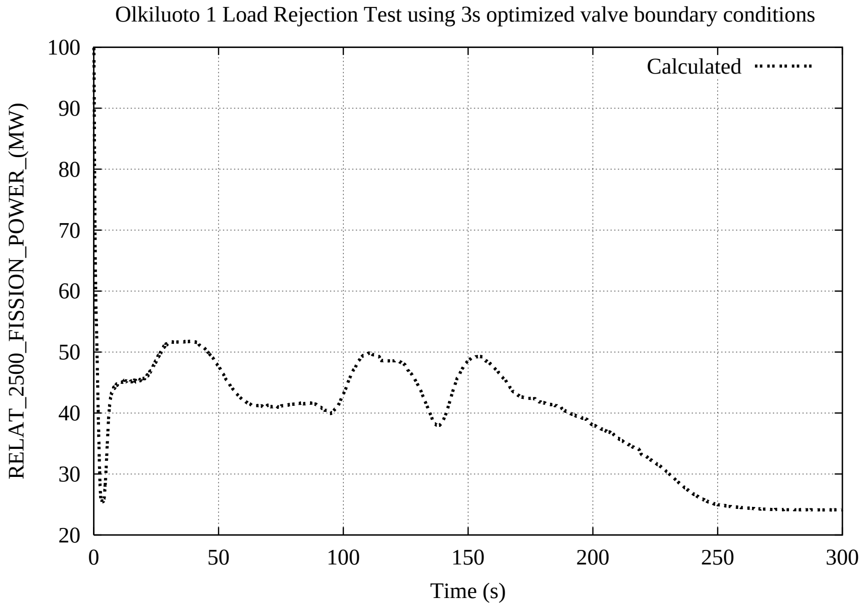

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
MAXIMAL_FUEL_CENT._TEMP._(K)
Time (s)
Calculated
1500
1400
1300
1200
1100
1000
900
800
0
50
100
150
200
250
300


Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
MW
Time (s)
Tot._fission_power_(MW)_Calc.
Tot._power_transf._to_coolant_Calc.
Tot._power_released_in_fuel_Calc.
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
0
50
100
150
200
250
300

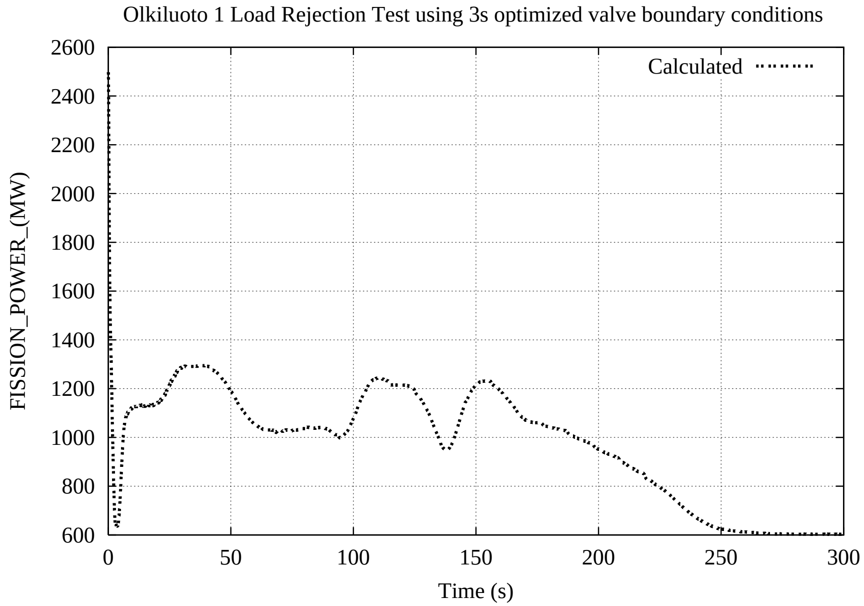

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
TOTAL_POWER_TRANSF._TO_COOLANT
Time (s)
Calculated
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
0
50
100
150
200
250
300


Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
TOTAL_FISSION_POWER_(MW)
Time (s)
Calculated
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
0
50
100
150
200
250
300

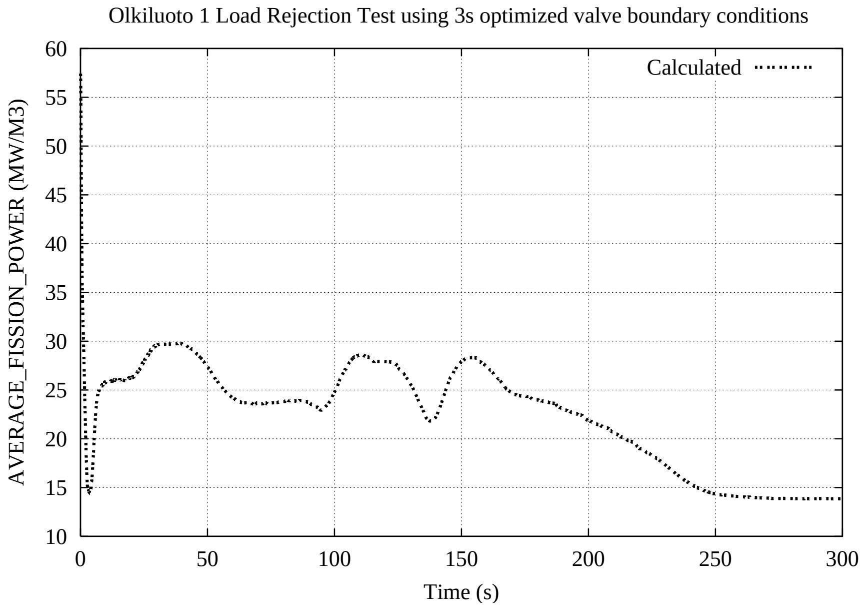

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
TOTAL_POWER_RELEASED_IN_FUEL
Time (s)
Calculated
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
0
50
100
150
200
250
300



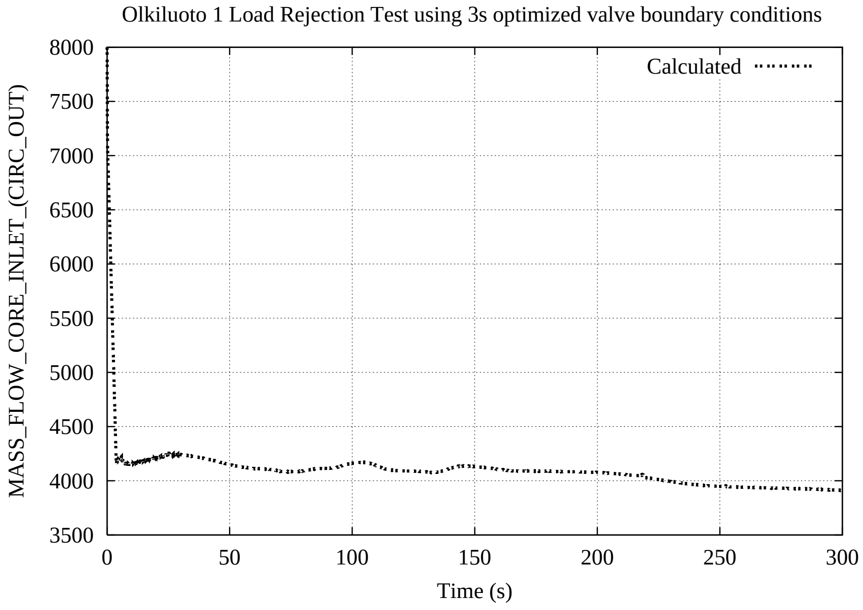
Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
RELAT_2500_FISSION_POWER_(MW)
Time (s)

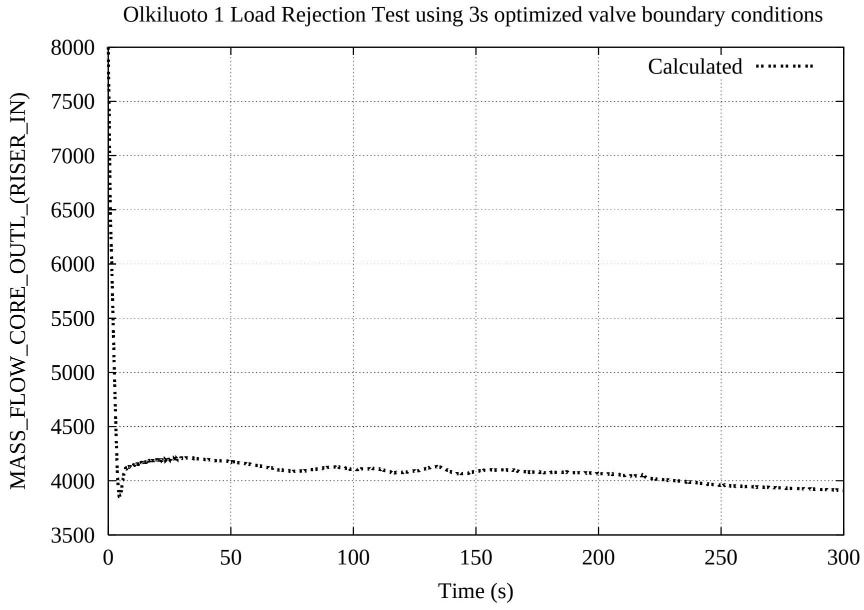


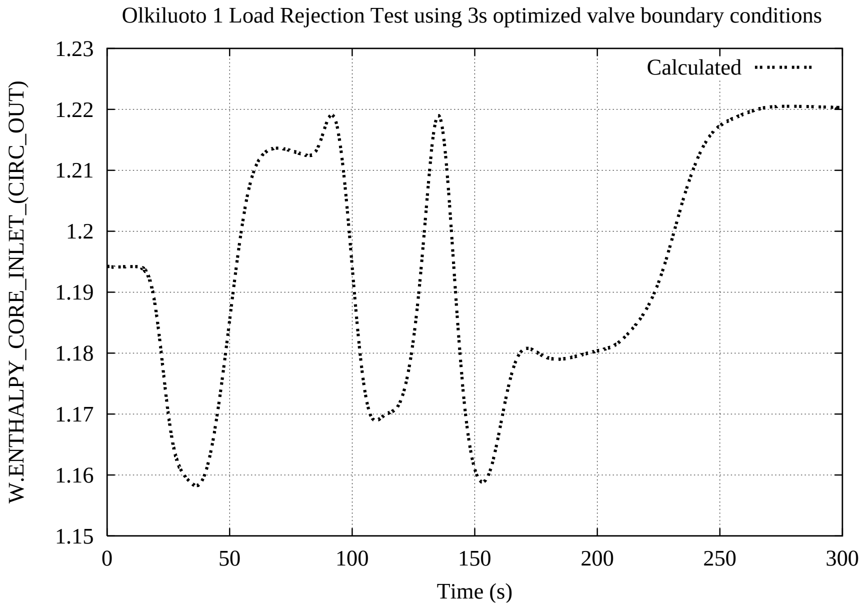
Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
FISSION_POWER_(MW)
Time (s)

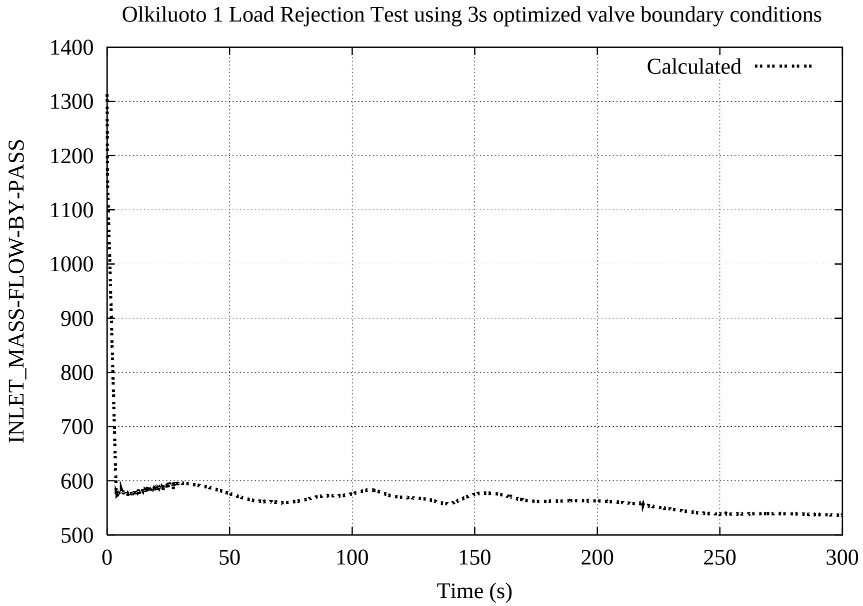


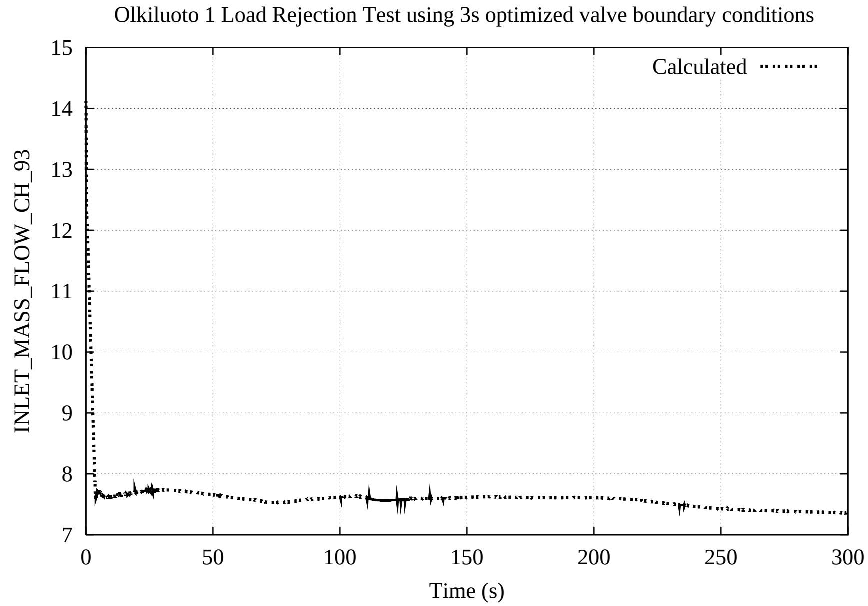
Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
AVERAGE_FISSION_POWER (MW/M3)
Time (s)

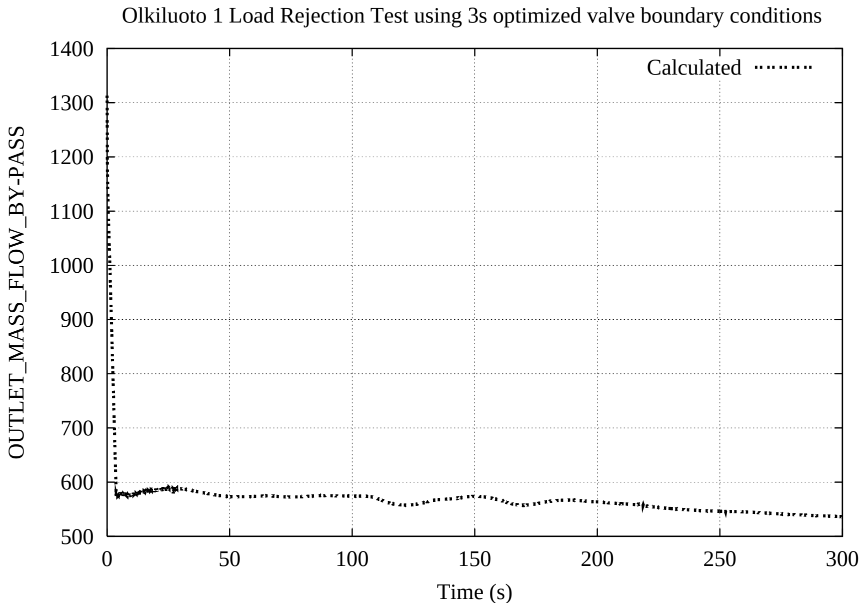

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
MASS_FLOW_CORE_INLET_(CIRC_OUT)
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
0
50
100
150
200
250
300
Time (s)

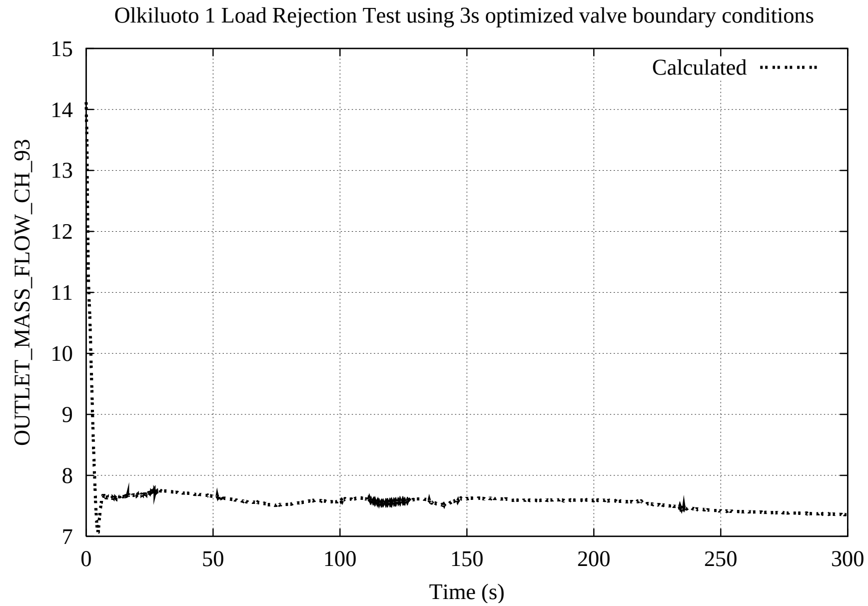

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
MASS_FLOW_CORE_OUTL_(RISER_IN)
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
0
50
100
150
200
250
300
Time (s)

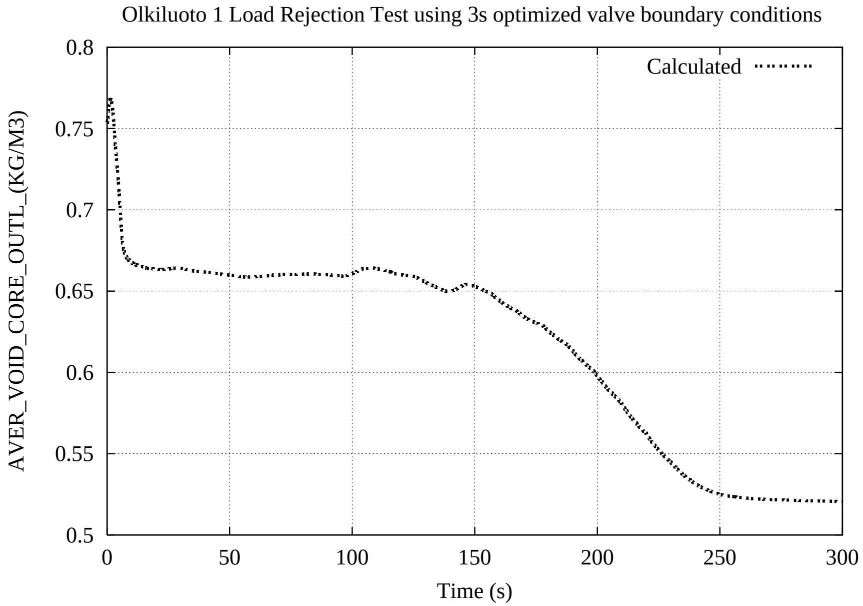

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
W.ENTHALPY_CORE_INLET_(CIRC_OUT)
1.23
1.22
1.21
1.2
1.19
1.18
1.17
1.16
1.15
0
50
100
150
200
250
300
Time (s)

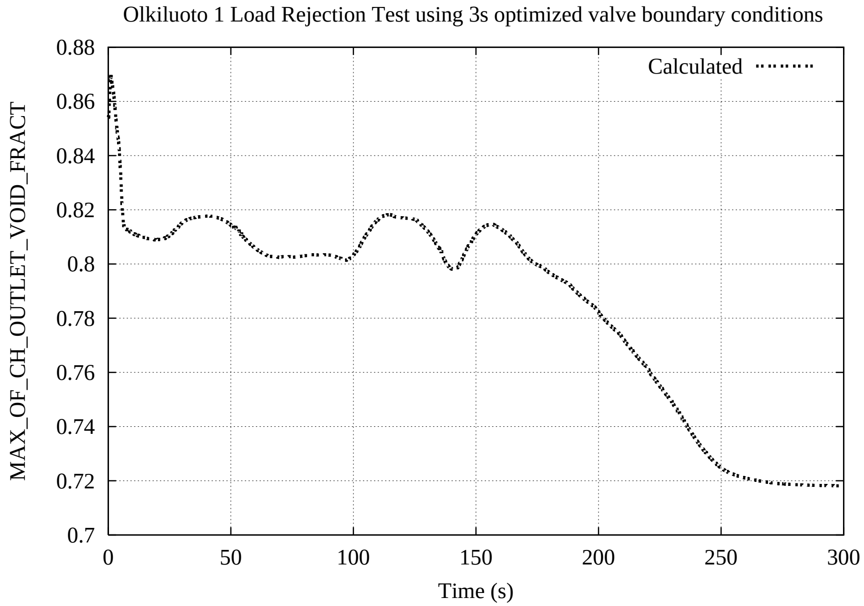

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
INLET_MASS-FLOW-BY-PASS
Time (s)
1400
1300
1200
1100
1000
900
800
700
600
500
0
50
100
150
200
250
300

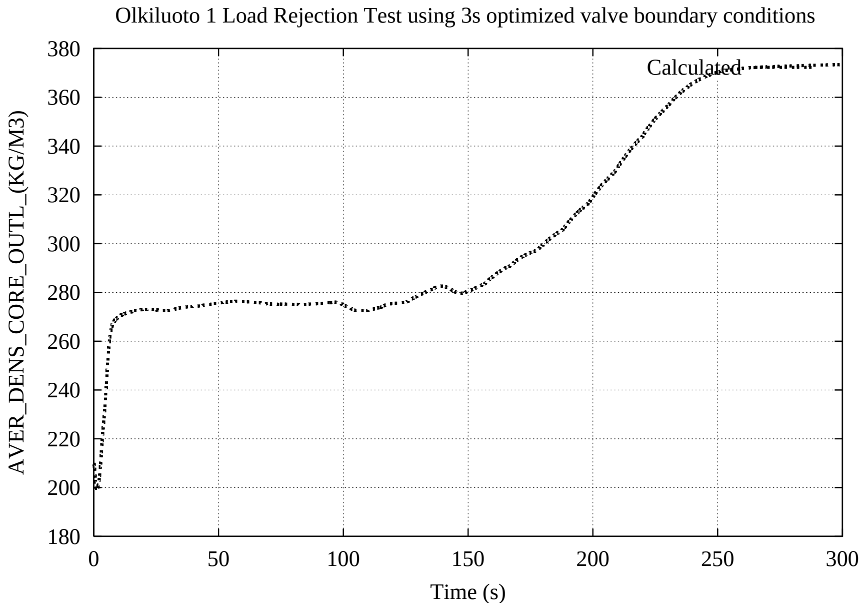

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
INLET_MASS_FLOW_CH_93
Time (s)
15
14
13
12
11
10
9
8
7
0
50
100
150
200
250
300

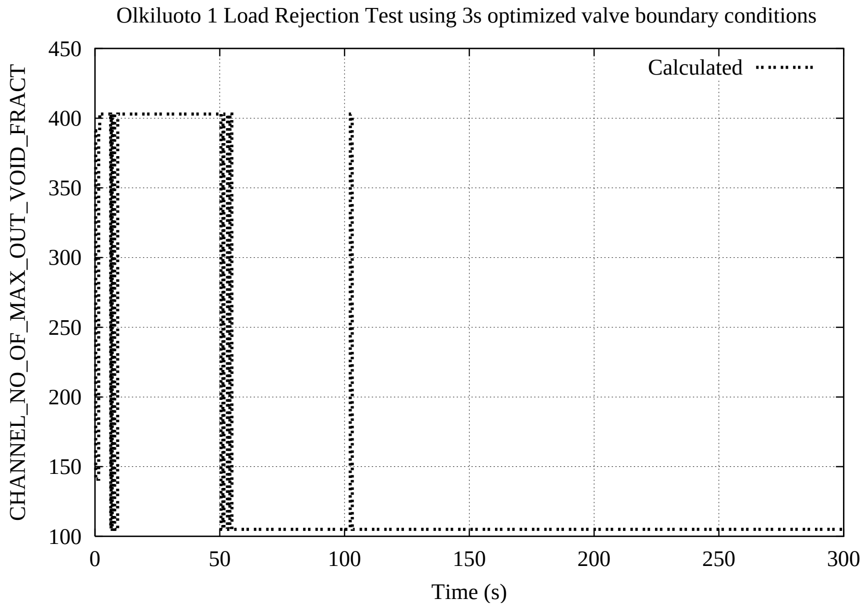

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
OUTLET_MASS_FLOW_BY-PASS
Time (s)
1400
1300
1200
1100
1000
900
800
700
600
500
0
50
100
150
200
250
300

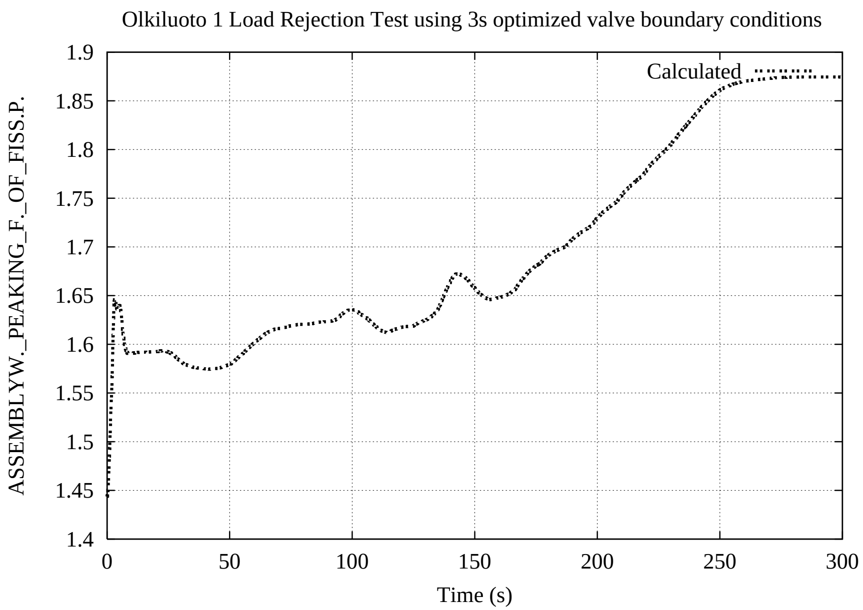

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
OUTLET_MASS_FLOW_CH_93
Time (s)
15
14
13
12
11
10
9
8
7
0
50
100
150
200
250
300

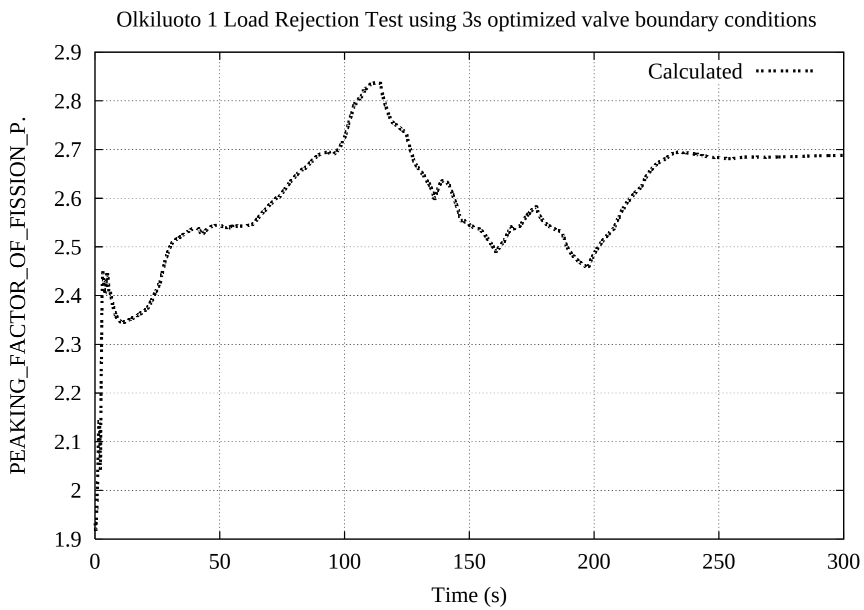

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
AVER_VOID_CORE_OUTL_(KG/M3)
Time (s)
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0
50
100
150
200
250
300

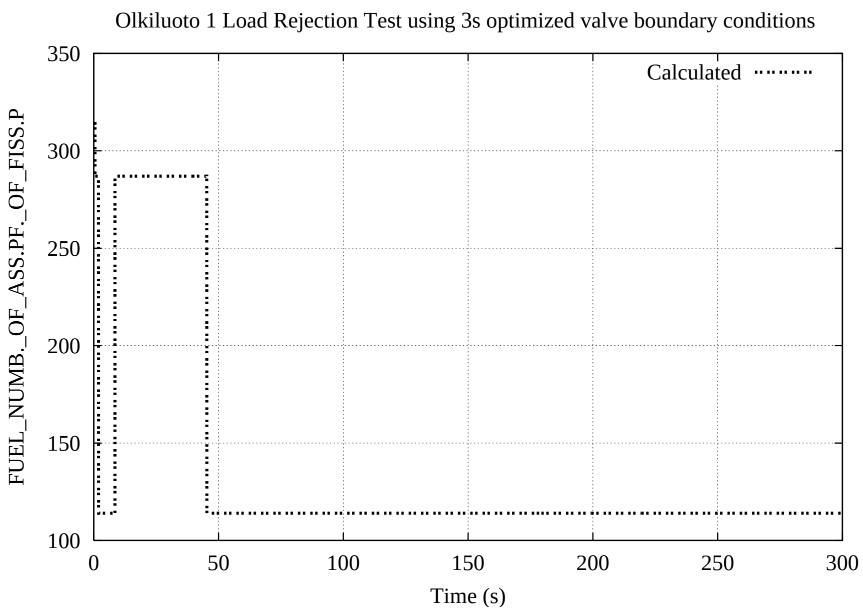

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
MAX_OF_CH_OUTLET_VOID_FRACT
Time (s)
0.88
0.86
0.84
0.82
0.8
0.78
0.76
0.74
0.72
0.7
0
50
100
150
200
250
300

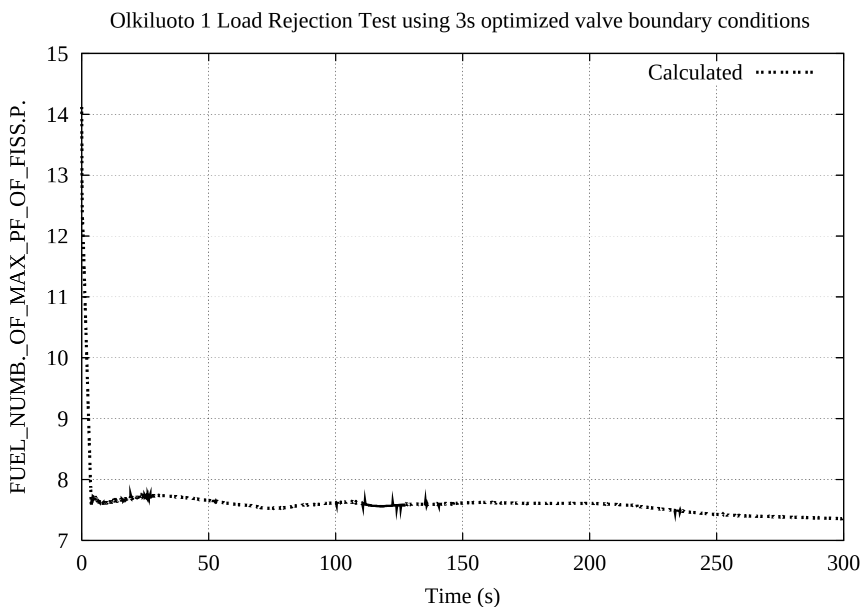

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
AVER_DENS_CORE_OUTL_(KG/M3)
Time (s)
380
360
340
320
300
280
260
240
220
200
180
0
50
100
150
200
250
300

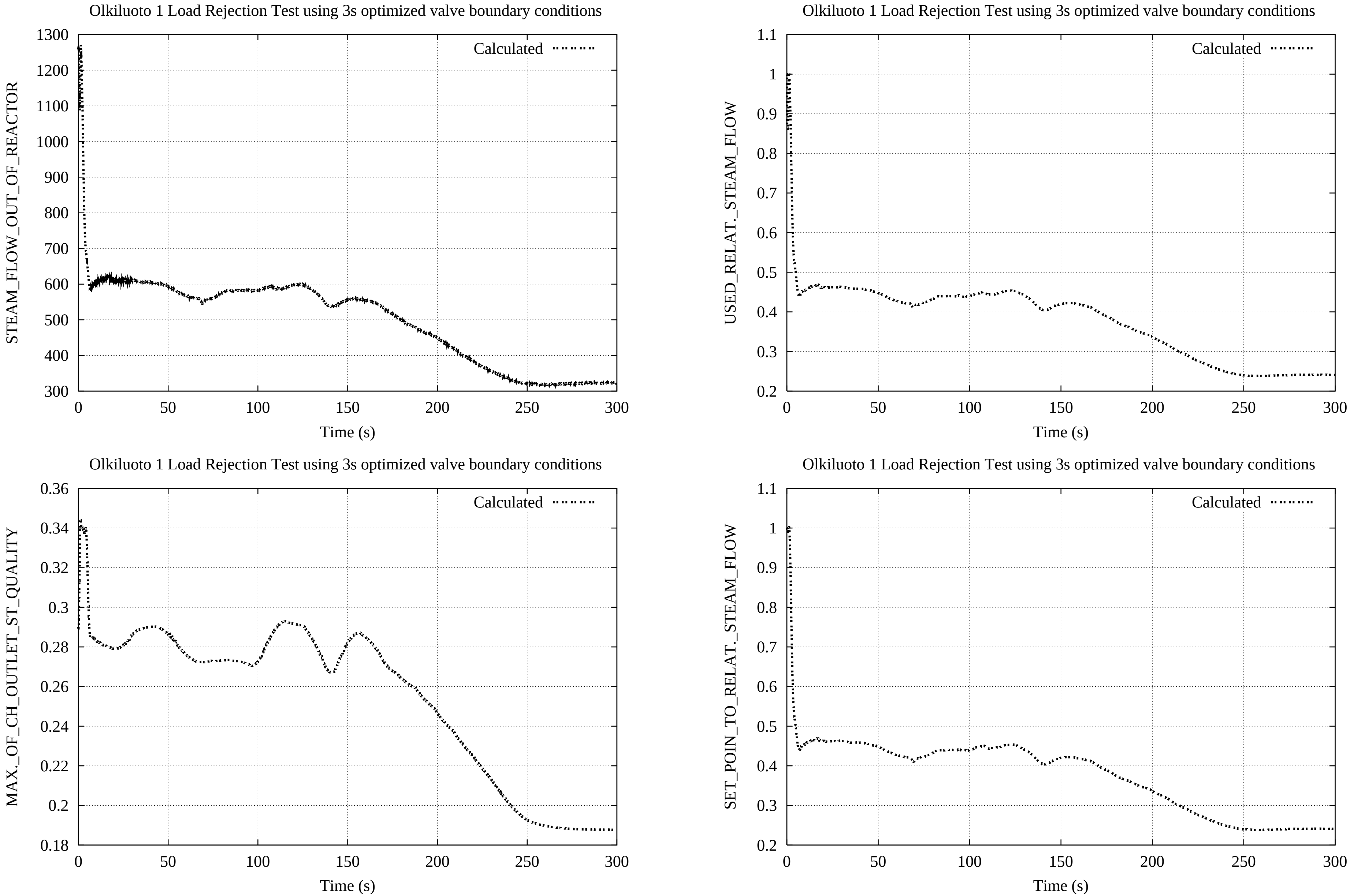

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
CHANNEL_NO_OF_MAX_OUT_VOID_FRACT
Time (s)
450
400
350
300
250
200
150
100
0
50
100
150
200
250
300

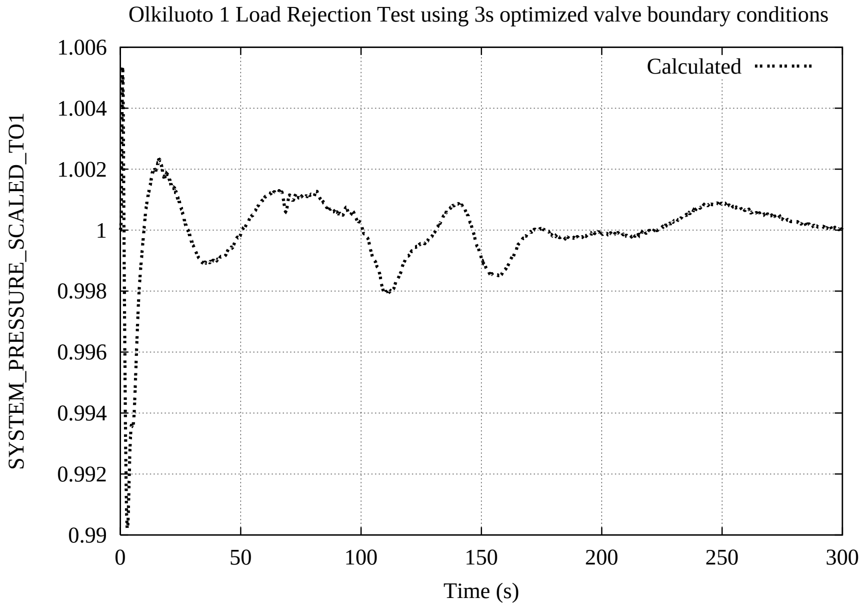

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
ASSEMBLYW._PEAKING_F._OF_FISS.P.
Time (s)

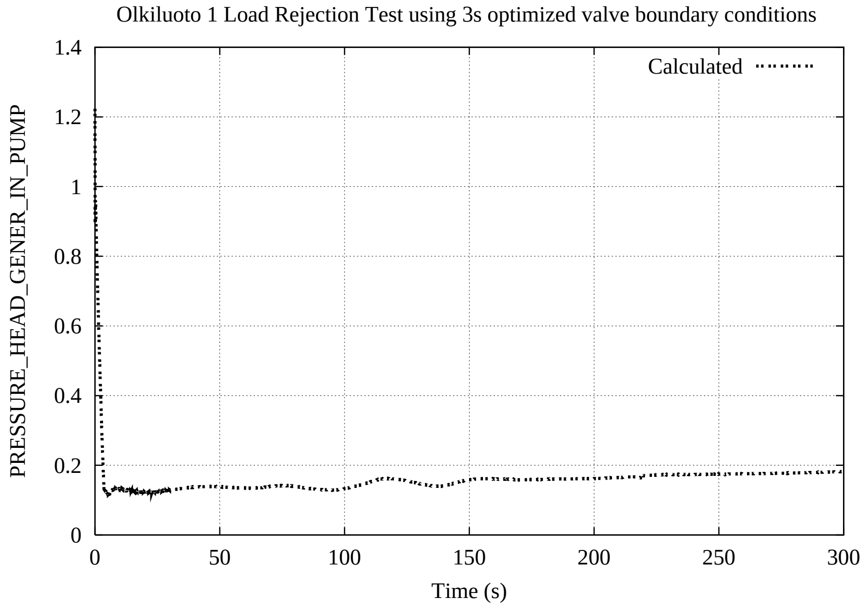

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
PEAKING_FACTOR_OF_FISSION_P.
Time (s)

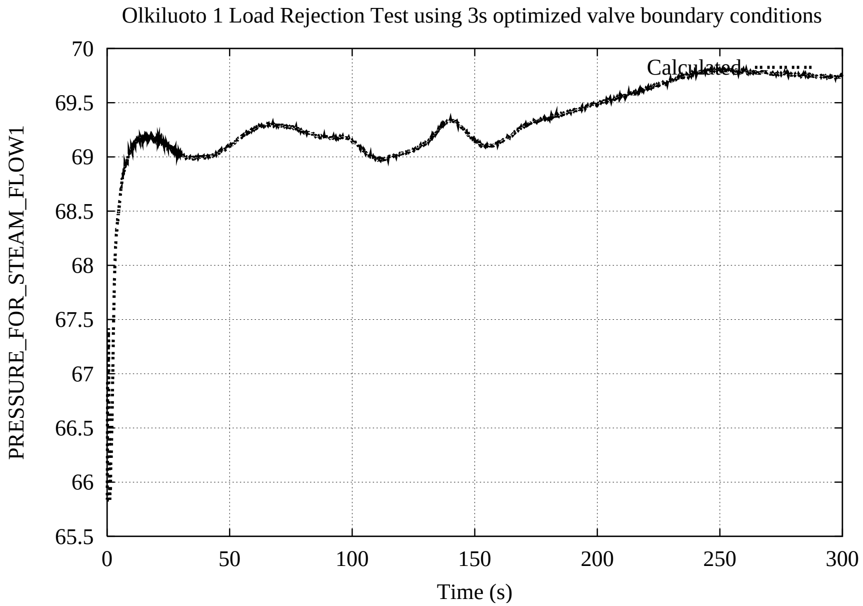

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
FUEL_NUMB._OF_ASS.PF._OF_FISS.P
Time (s)

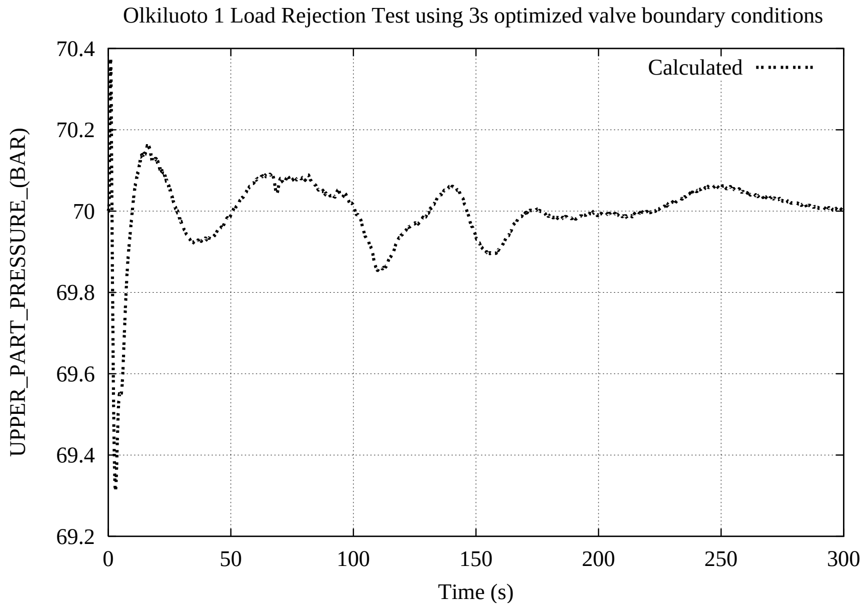

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
FUEL_NUMB._OF_MAX_PF_OF_FISS.P.
Time (s)

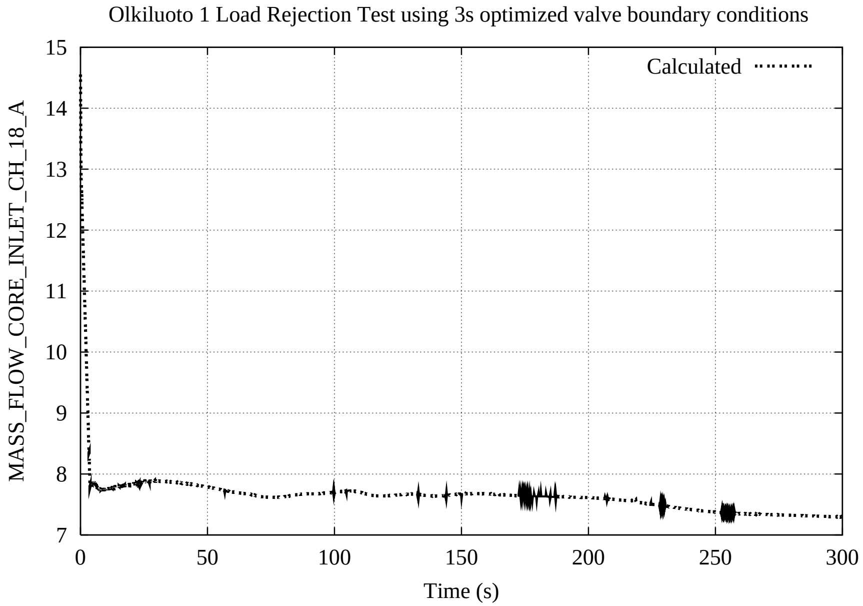

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
STEAM_FLOW_OUT_OF_REACTOR
Calculated
Time (s)
Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
USED_RELAT._STEAM_FLOW
Calculated
Time (s)
Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
MAX._OF_CH_OUTLET_ST_QUALITY
Calculated
Time (s)
Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
SET_POIN_TO_RELAT._STEAM_FLOW
Calculated
Time (s)

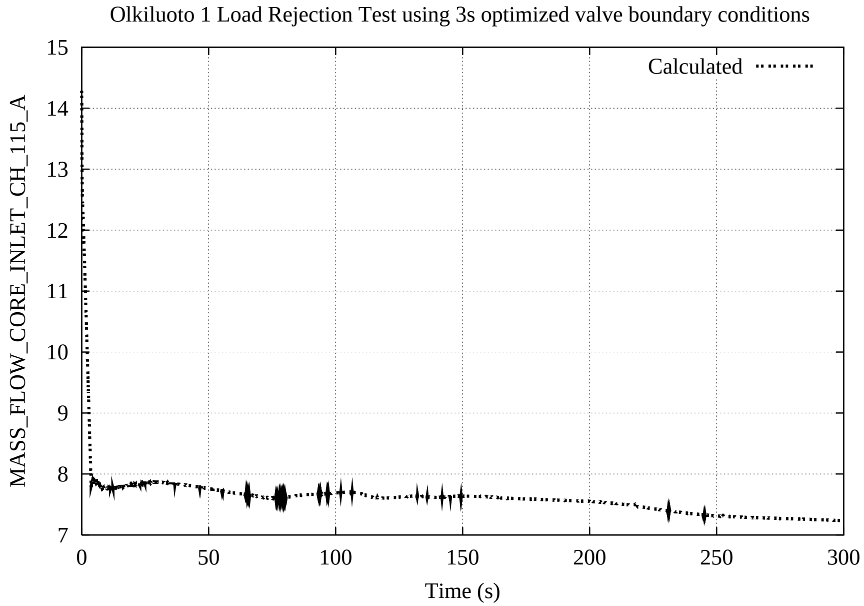

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
SYSTEM_PRESSURE_SCALED_TO1
Time (s)

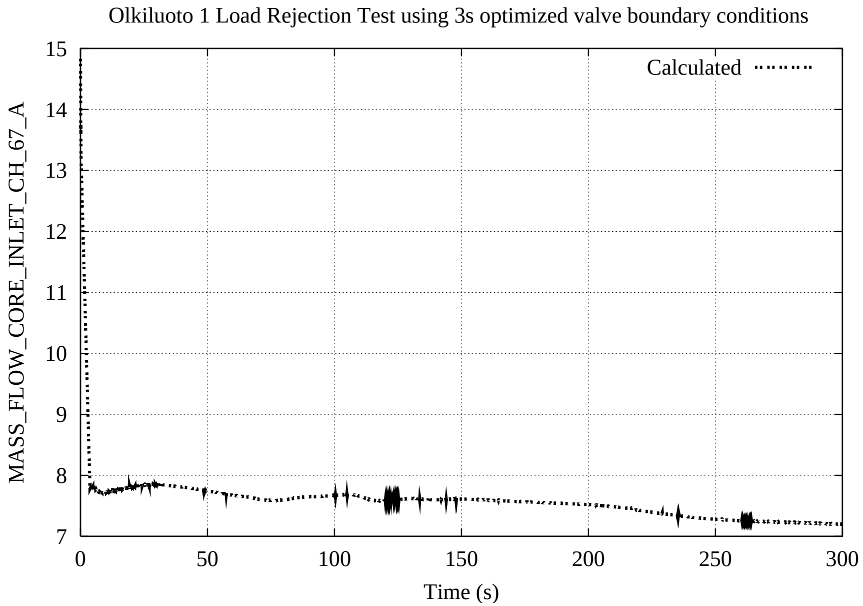

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
PRESSURE_HEAD_GENER_IN_PUMP
Time (s)

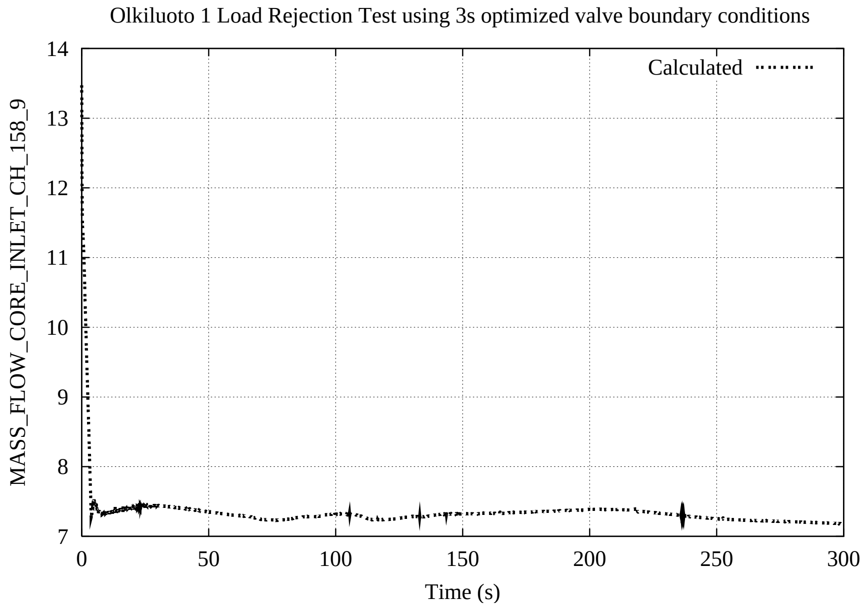

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
PRESSURE_FOR_STEAM_FLOW1
Time (s)


Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
UPPER_PART_PRESSURE_(BAR)
Time (s)

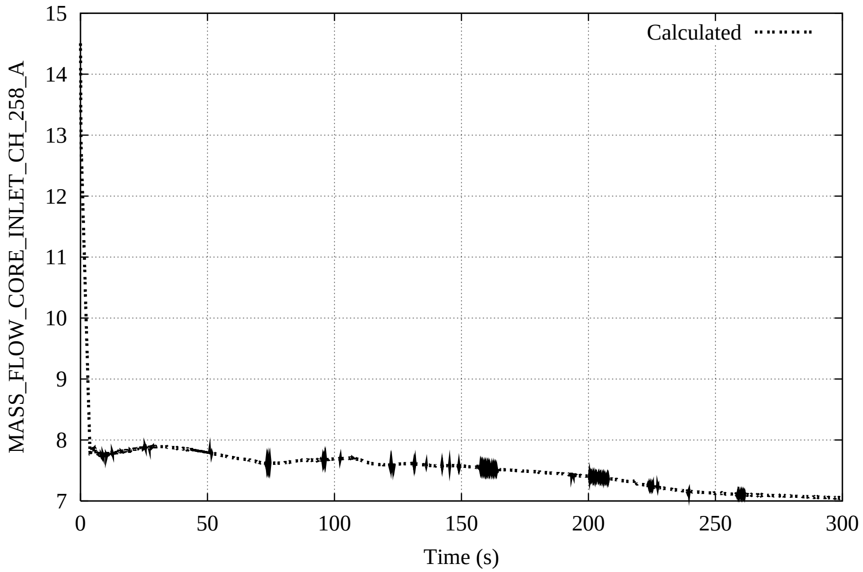

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
MASS_FLOW_CORE_INLET_CH_18_A
Time (s)
15
14
13
12
11
10
9
8
7
0
50
100
150
200
250
300


Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
MASS_FLOW_CORE_INLET_CH_115_A
Time (s)
15
14
13
12
11
10
9
8
7
0
50
100
150
200
250
300

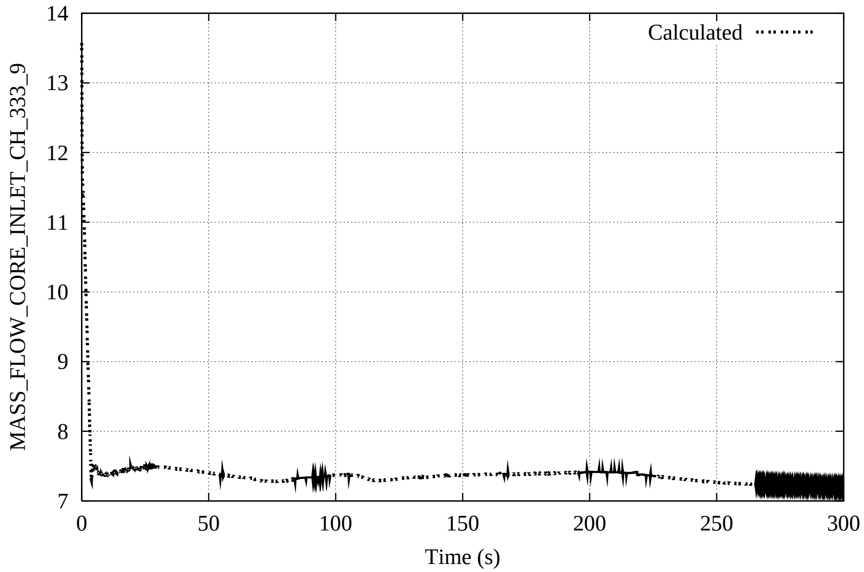

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
MASS_FLOW_CORE_INLET_CH_67_A
Time (s)
15
14
13
12
11
10
9
8
7
0
50
100
150
200
250
300


Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
Calculated
MASS_FLOW_CORE_INLET_CH_158_9
Time (s)
14
13
12
11
10
9
8
7
0
50
100
150
200
250
300

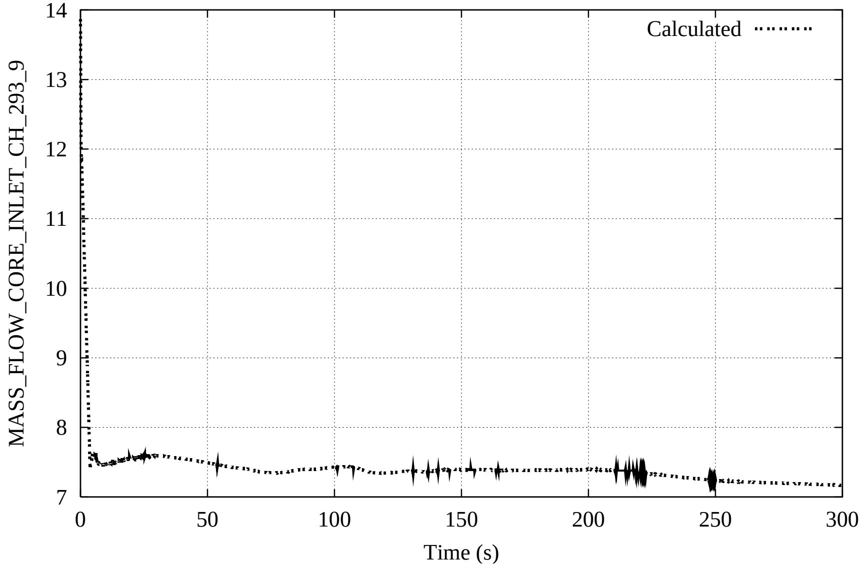
Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions



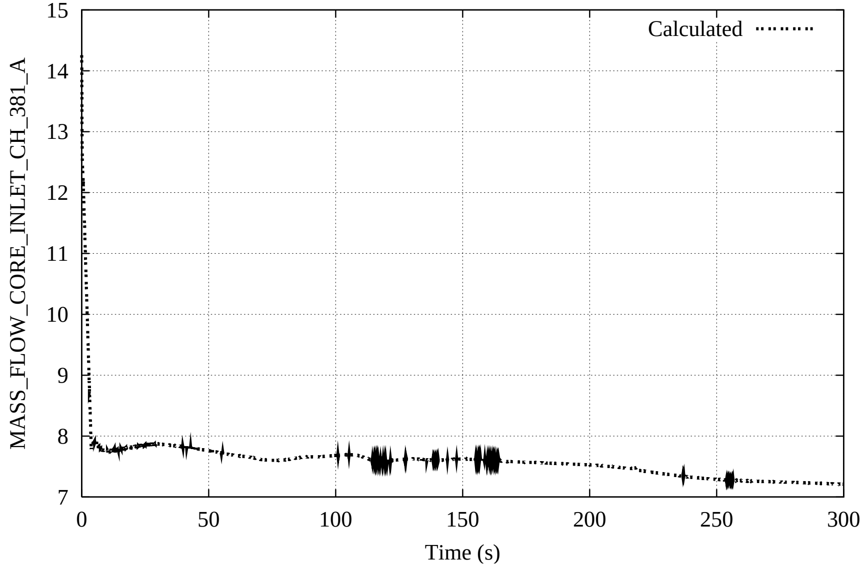
Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions

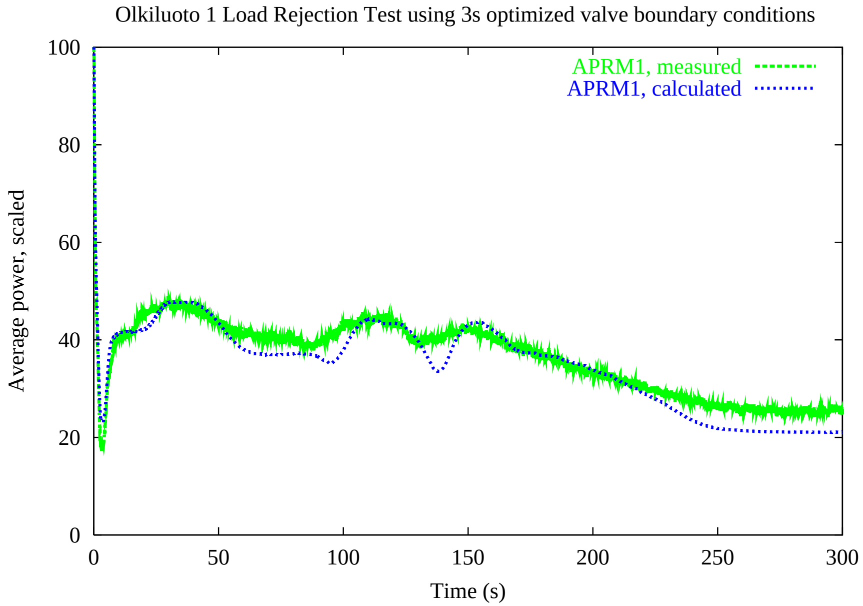


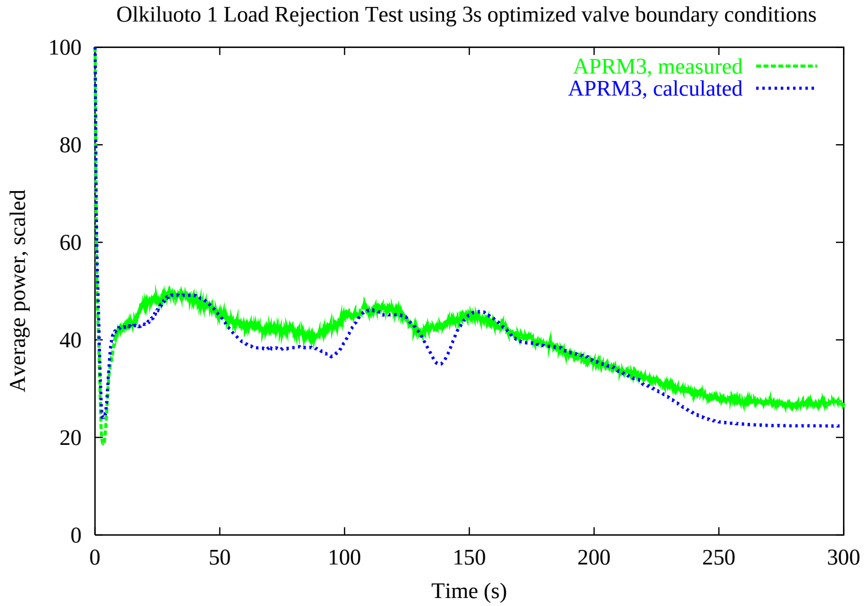
Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions

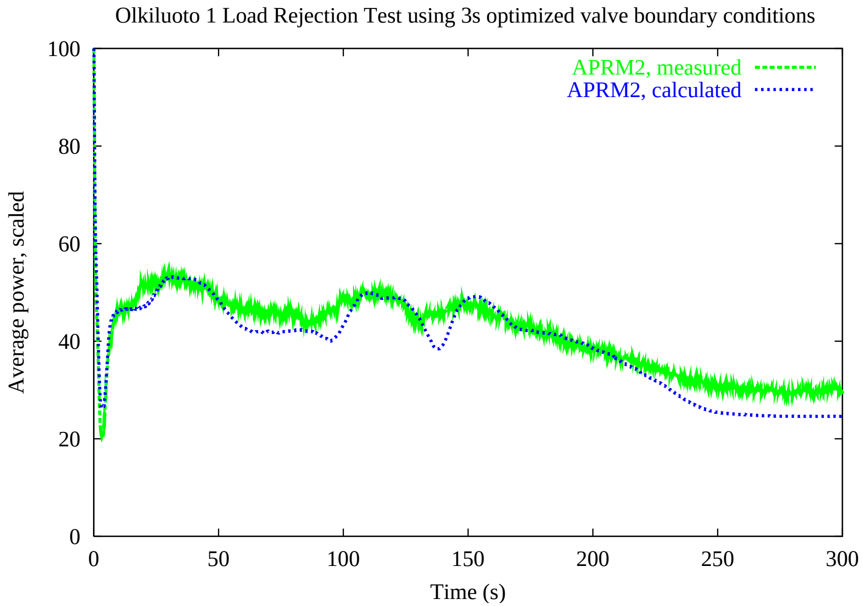


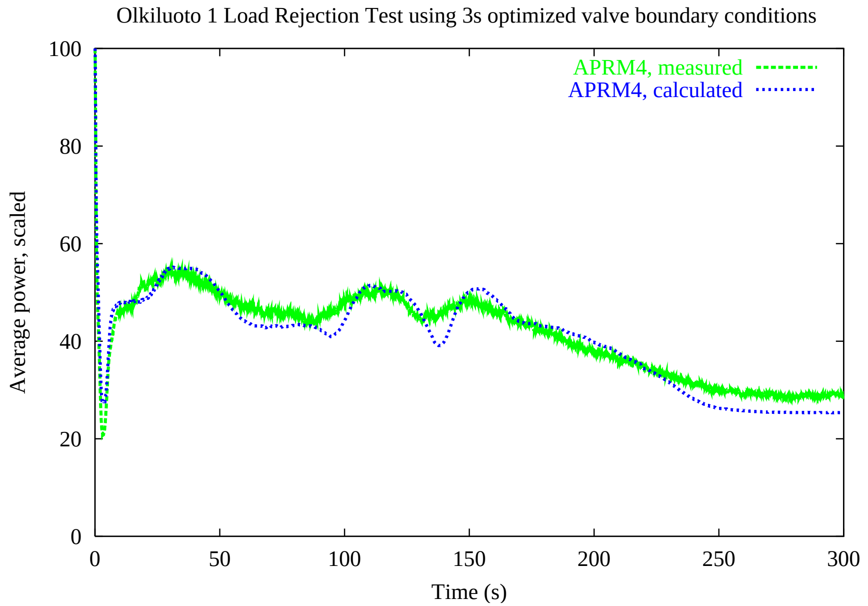
Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions

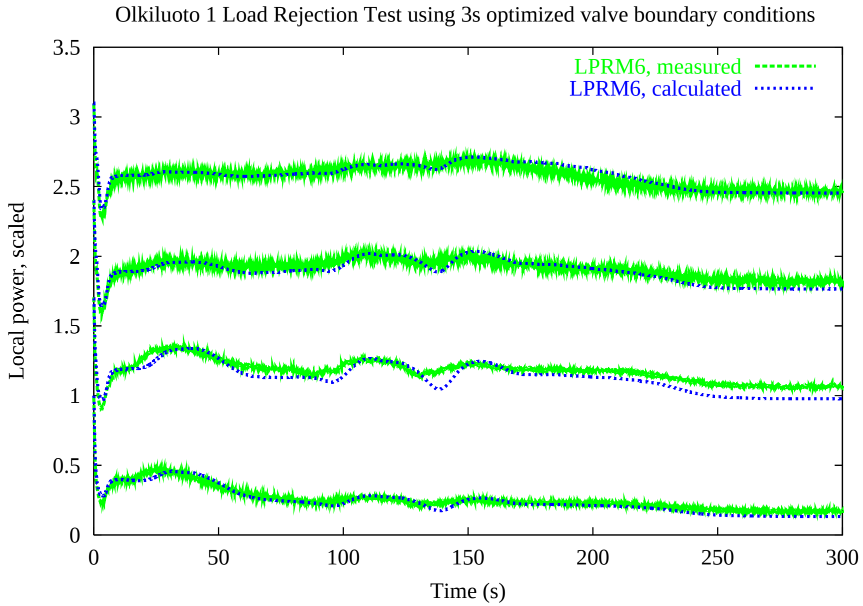


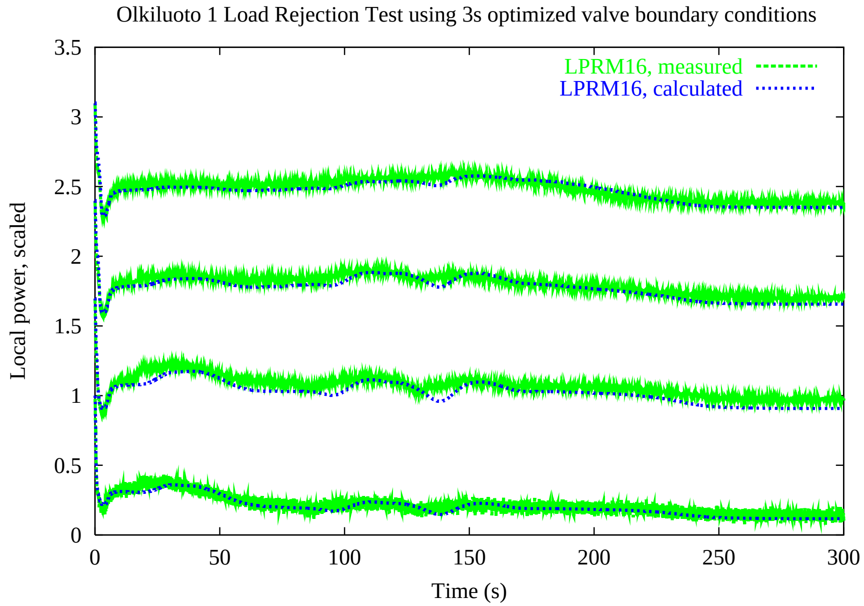

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
APRM1, measured
APRM1, calculated
Average power, scaled
Time (s)
0
20
40
60
80
100
0
50
100
150
200
250
300

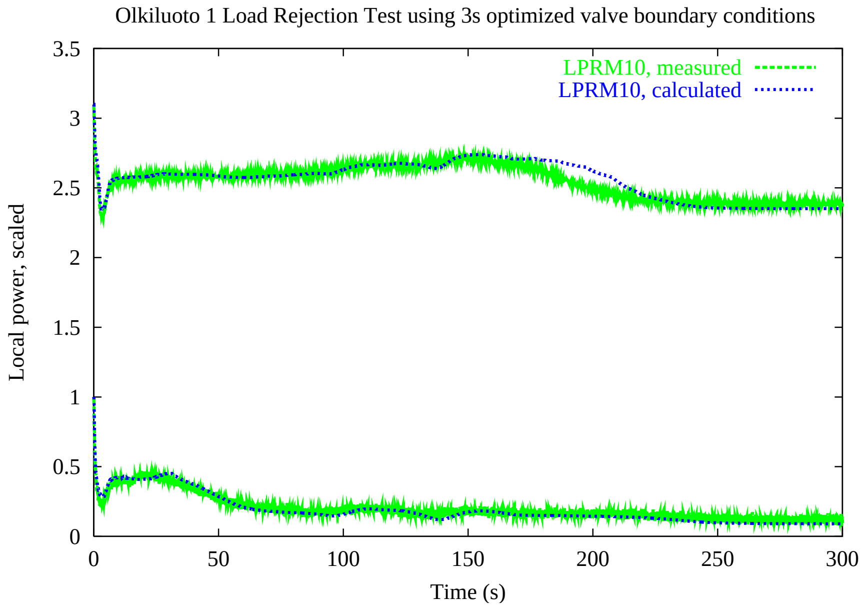

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
APRM3, measured
APRM3, calculated
Average power, scaled
Time (s)
0
20
40
60
80
100
0
50
100
150
200
250
300

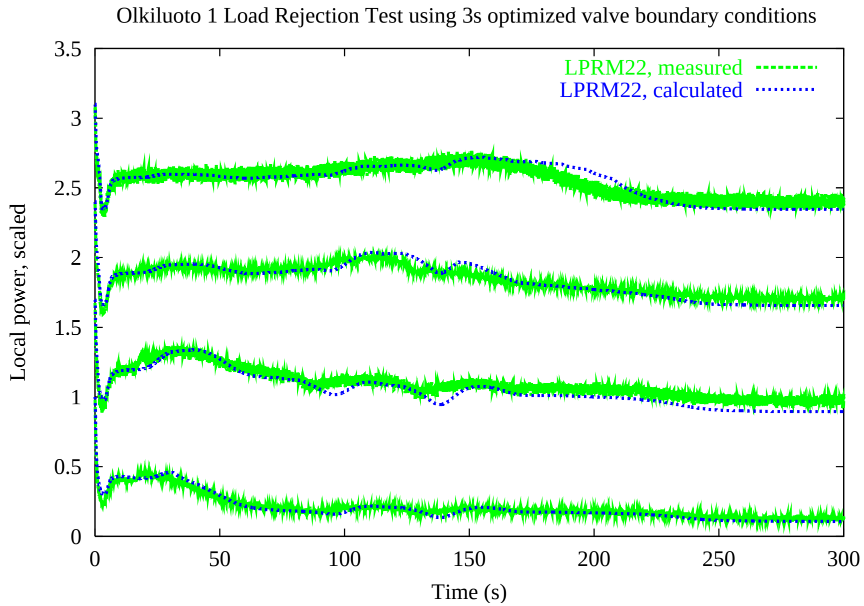

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
APRM2, measured
APRM2, calculated
Average power, scaled
Time (s)
0
20
40
60
80
100
0
50
100
150
200
250
300

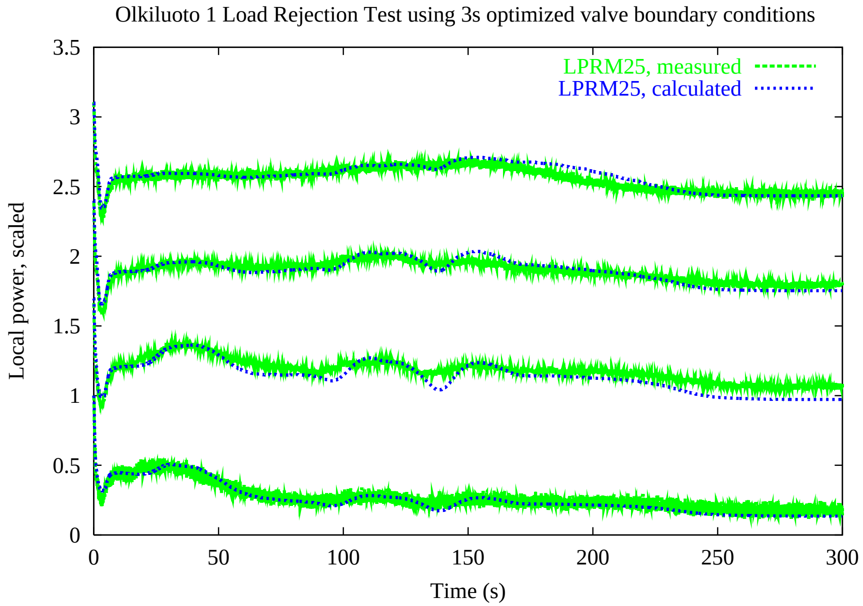

Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
APRM4, measured
APRM4, calculated
Average power, scaled
Time (s)
0
20
40
60
80
100
0
50
100
150
200
250
300


Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
LPRM6, measured
LPRM6, calculated
Local power, scaled
Time (s)


Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
LPRM16, measured
LPRM16, calculated
Local power, scaled
Time (s)


Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
LPRM10, measured
LPRM10, calculated
Local power, scaled
Time (s)


Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
LPRM22, measured
LPRM22, calculated
Local power, scaled
Time (s)


Olkiluoto 1 Load Rejection Test using 3s optimized valve boundary conditions
LPRM25, measured
LPRM25, calculated
Local power, scaled
Time (s)
0
0.5
1
1.5
2
2.5
3
3.5
0
50
100
150
200
250
300