Exercises in Reactor Kinetics and Dynamics (SH2705)

Transient Exercises with the Generic Nordic BWR reactor APROS 6 model

Table of Contents

1. Introduction

This document provides a step-by-step guide on how to run transient cases on the Generic Nordic BWR APROS 6 model. The cases described here are:

1. Running pressure transient (with scram (multiple delays)/without scram);
2. Running steam line break transient;
3. Running feed water line break tansient;
4. Running feed water pump trip transient;
5. Running feed water enthalpy decrease transient;
6. Running reactor power decrease transient;
7. Running manual reactor scram transient.

The data logging has been defined to store output to the “EX_output.dat” file. The nomenclature for the output columns is given at the end of the document. When running the simulations, do not over write the original .apros file or the original “Initial condition 0”! If you want to export the model or save new initial conditions, choose different names!

If you get convergence errors, decrease the Maximum time step and increase the Minimum number of iterations (see Figure 1).

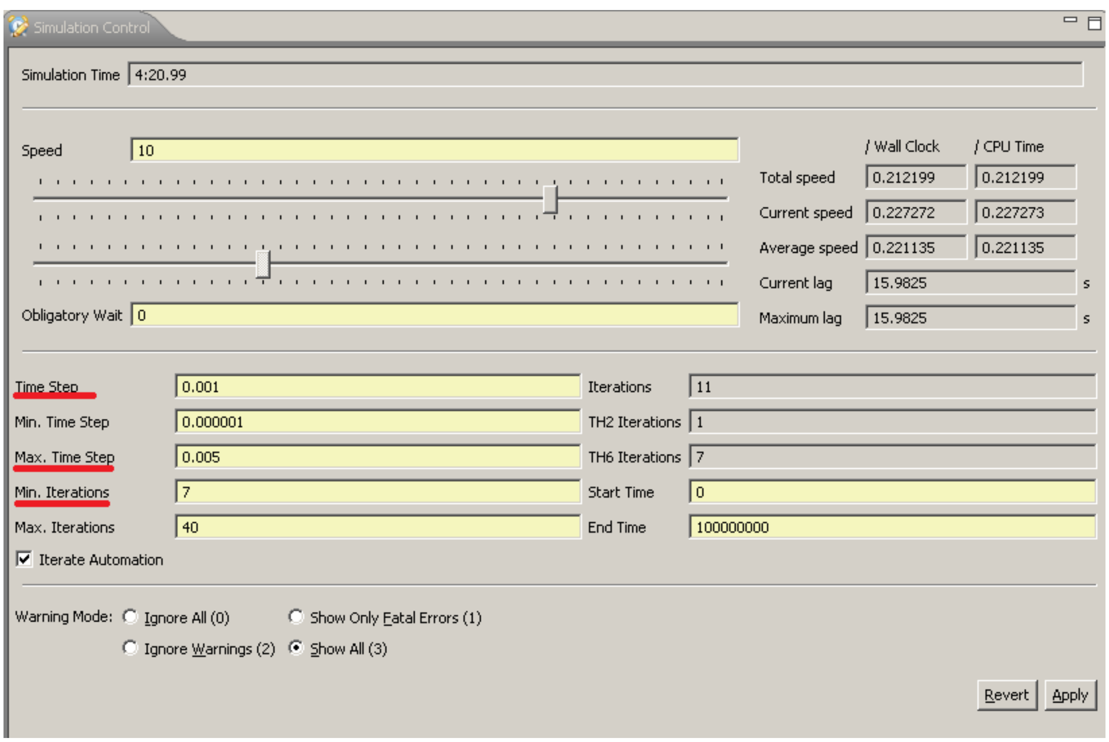

Figure 1. Setting the Time Step, Max. Time Step and Min. number of Iterations

Do the exercises in the given step-by-step order and answer the questions. Remember, when reporting plotted data plot only the parameters relevant for the transient. Do not plot and report everything!

2. Running a pressure transient

This exercise demonstrates a typical BWR plant response in a minor accident scenario caused by closure of the main steam isolation valves at full power. The valves are assumed to close by an inadvertent activation of the plant protection signal 516-A (main steam line rupture supervisory protection chain). Reactor scram due to 516-A is prevented (case i) or allowed with multiple delay values (case ii).

1. Describe briefly what you expect to happen in the accident scenario.

2. Define trends with interesting parameters to follow during the accident. You can add more logged variables by editing the “Database name for IO” table in “DBN_EX” (Configuration, non-visual->IO and Communication->DB_NAMES). Add your variables of choice to the end of the table (see Figure 2). More parameters can be added to the GUI charts by holding Ctrl and DND the monitors from the process diagram.

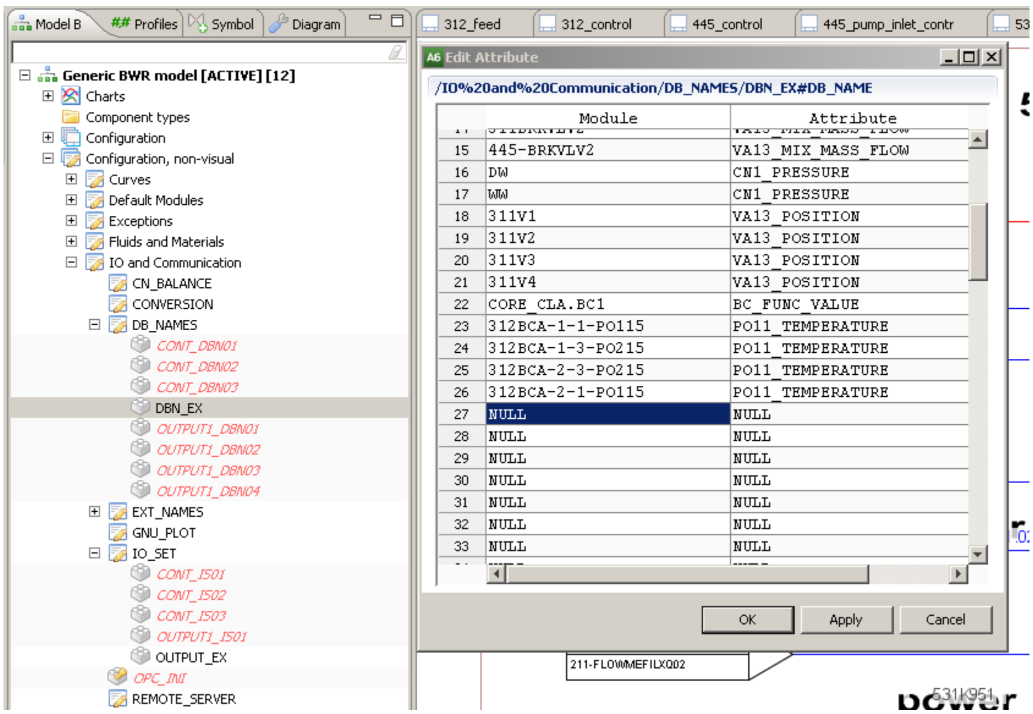

Figure 2. Adding variables to be logged to the output file

3. Enable diagram monitors by selecting “Operables 1”, “Simulated 1”, “Not in simulation”, “Module names”, “Binary signal coloring” and “Analog signal values” from “Profiles” -> “All”.

4. Enable data logging by typing “io open OUTPUT_EX” to the APROS console. The output data should now be exported to “EX_output.dat”. Data logging can be stopped by typing “io close OUTPUT_EX” to the console.

5. Open the chart window with the main parameters and run steady state for 10 s.

6. Prepare for the scenario by preventing signals 516-A, 516-I and 516-M to cause reactor scram. To do so go to the "516_ss_v" diagram and exclude the n/m selector component 516SS12CH1 from simulation (see Figure 3).

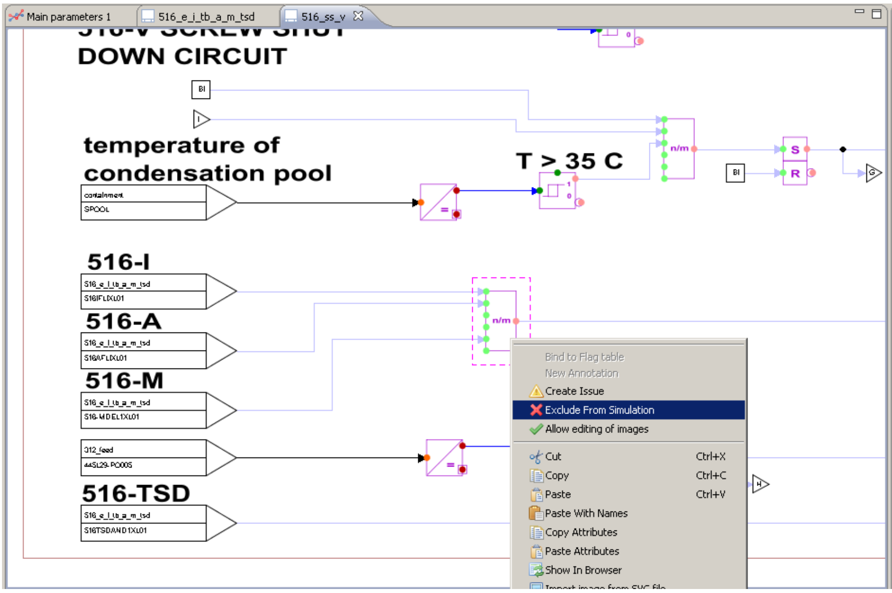

Figure 3. Excluding the n/m selector component in diagram "516_ss_v" from simulation

7. Go to "516_e_i_tb_a_m_tsd" diagram and activate manually 516-A isolation by changing the binary signal 516A1SIGN from false to true (see Figure 4).

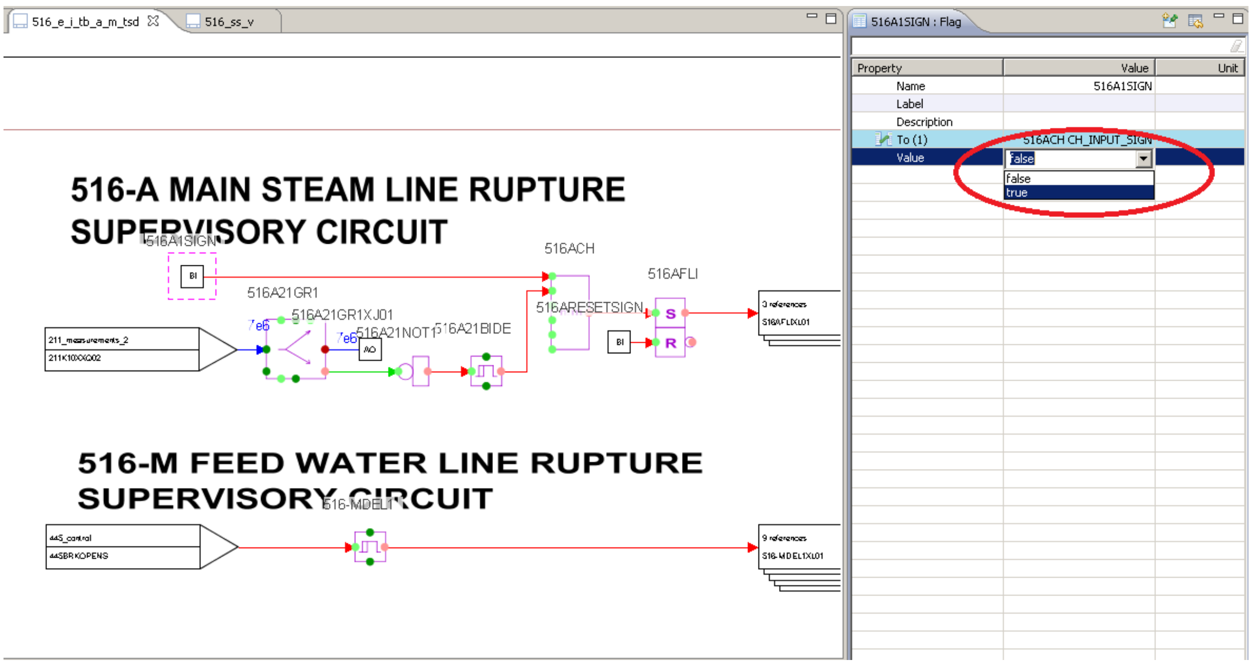

Figure 4. Manually activating the 516-A signal

8. Before starting the transient calculation change the Maximum time step and the Simulation time step from 0.1 to 0.001 s.

9. Increase also the number of minimum iterations to e.g. 7.

10. Continue running the simulation for several tenths of seconds. You can monitor the progress on the GUI charts. You can adjust the Scroll Increment in Chart properties to see better (right click-> Properties).

11. The transient phase of the scenario is fast. In order to see what happened, zoom in the Chart window around the time where the transient starts, or plot and look at the output data. Look at the trend curves and monitors and check if the expectations on the plant response in step 1 are correct.

12. Plot and save the graphs of what you think are the most interesting variables (preferably from the generated output data).

13. Reopen the model (File->Import->Apros 6->Model->"Generic BWR model_EX.apros").

14. Run the transient again, now without preventing the scram signal from 516-A (without excluding the n/m selector component 516SS12CH1 from simulation).

15. Plot and save the graphs again.

16. How do the results change?

17. There is a 300 ms delay for 516-SS signal in net "354_reactor_scram" (see Figure 5). Try setting this to e.g. 100 ms or 500 ms and repeat the simulation case without preventing the scram signal from 516-A once more. Start from reopening the model.
18. Again plot the data of interest.

19. How do the results change?

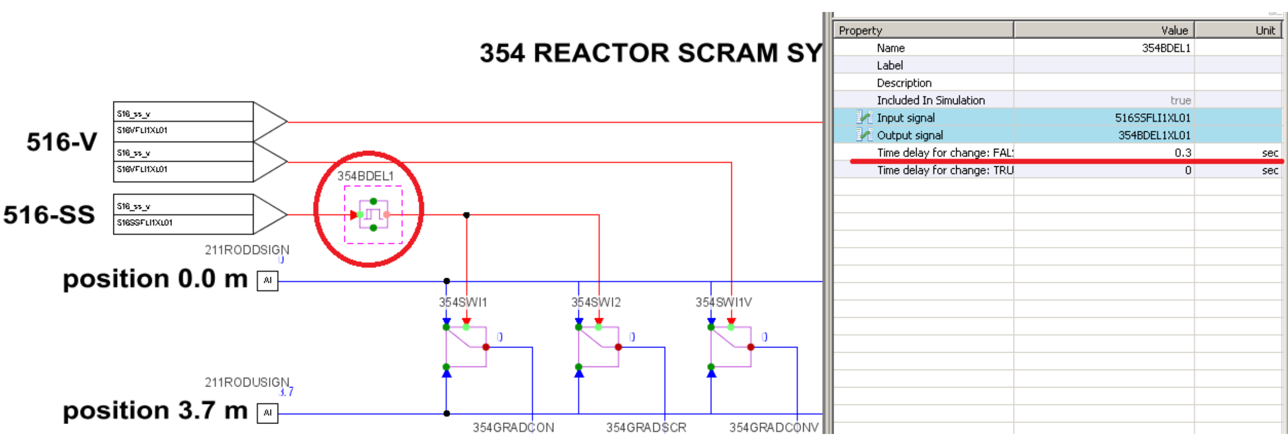

Figure 5. Adjusting the delay for the 516-SS signal

3. Running Steam line break accident

In this exercise a 200 % guillotine break in one steam line is simulated.

1. Describe briefly what you expect to happen in the accident scenario.

2. Import the "Generic BWR model_EX.apros" file.

3. Define trends with interesting parameters to follow during the accident. You can add more logged variables by editing the “Database name for IO” table in “DBN_EX” (Configuration, non-visual->IO and Communication->DB_NAMES). Add your variables of choice to the end of the table (see Figure 2). More parameters can be added to the GUI charts by holding Ctrl and DND the monitors from the process diagram.

4. Enable diagram monitors by selecting “Operables 1”, “Simulated 1”, “Not in simulation”, “Module names”, “Binary signal coloring” and “Analog signal values” from “Profiles” -> “All”.

5. Enable data logging by typing “io open OUTPUT_EX” to the APROS console. The output data should now be exported to “EX_output.dat”. Data logging can be stopped by typing “io close OUTPUT_EX” to the console.

6. Run steady-state for a while (several tenths of seconds).

7. A ready-made break location is modeled in net “311_ste”. Break valves from both the reactor side and the turbine side are connected to the containment drywell. An auxiliary valve in the steam line is closed simultaneously as the break valves open (see Figure 6).

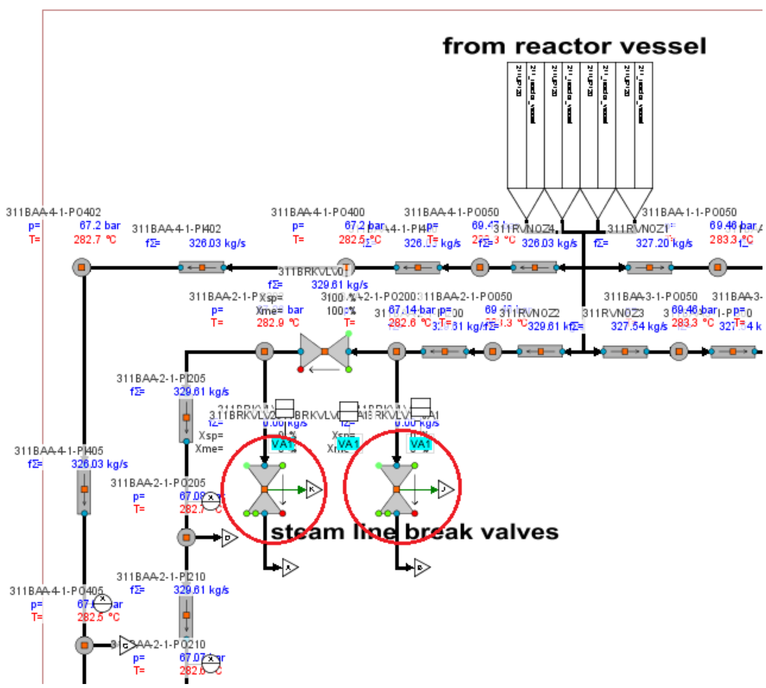

Figure 6. Steam line break valves in the “311_ste” diagram

8. Jump from one break valve to net “311_control” diagram. The break valves are opened and the auxiliary valves are closed when signal 311BREAKOPENS is changed from F->T (see Figure 7).

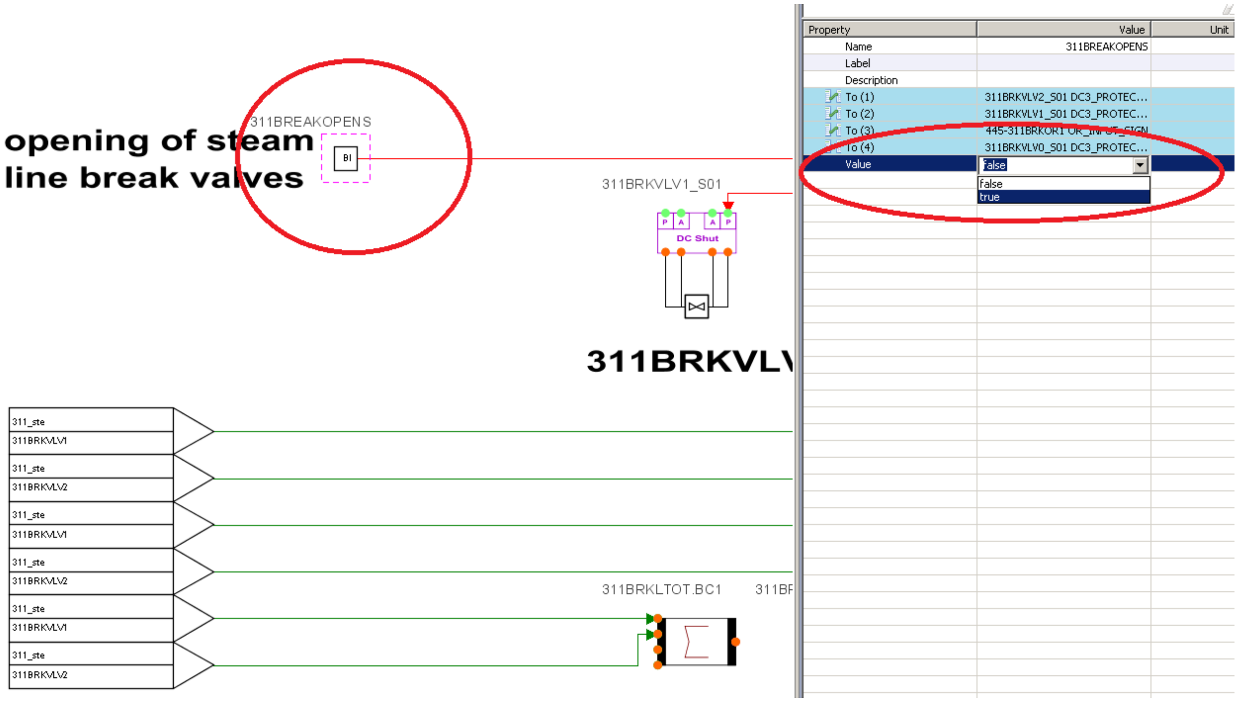

Figure 7. Opening the steam line break valves by activating the "311BREAKOPENS" signal

9. Before starting the transient calculation change the Maximum time step and the Simulation time step from 0.1 to 0.001 s.

10. Increase also the number of minimum iterations to e.g. 7.

11. You can monitor the progress by opening a GUI chart window. You can adjust the Scroll Increment in Chart properties to see better (right click-> Properties).

12. Run simulation for several tenths of seconds (or more).

13. Plot and save the graphs of what you think are the most interesting variables (preferably from the generated output data).

14. What is happening?

4. Feed water line break

In this exercise a feed water line break is simulated.

1. Describe briefly what you expect to happen in the accident scenario.

2. Import the "Generic BWR model_EX.apros" file.

3. Define trends with interesting parameters to follow during the accident. You can add more logged variables by editing the "Database name for IO" table in "DBN_EX" (Configuration, non-visual->IO and Communication->DB_NAMES). Add your variables of choice to the end of the table (see Figure 2). More parameters can be added to the GUI charts by holding Ctrl and DND the monitors from the process diagram.

4. Enable diagram monitors by selecting “Operables 1”, “Simulated 1”, “Not in simulation”, “Module names”, “Binary signal coloring” and “Analog signal values” from “Profiles” -> “All”.

5. Enable data logging by typing “io open OUTPUT_EX” to the APROS console. The output data should now be exported to “EX_output.dat”. Data logging can be stopped by typing “io close OUTPUT_EX” to the console.

6. Run steady-state for a while.

7. Before starting the transient calculation change the Maximum time step and the Simulation time step from 0.1 to 0.001 s.

8. Increase also the number of minimum iterations to e.g. 7.

9. A ready-made break location is modeled in net “312_feed”. The break valve is located in the feed water line outside of the containment (see Figure 8).

10. The break valve is opened when signal 445BRKOPENS in the “445_control” diagram is changed from F->T (see Figure 9).

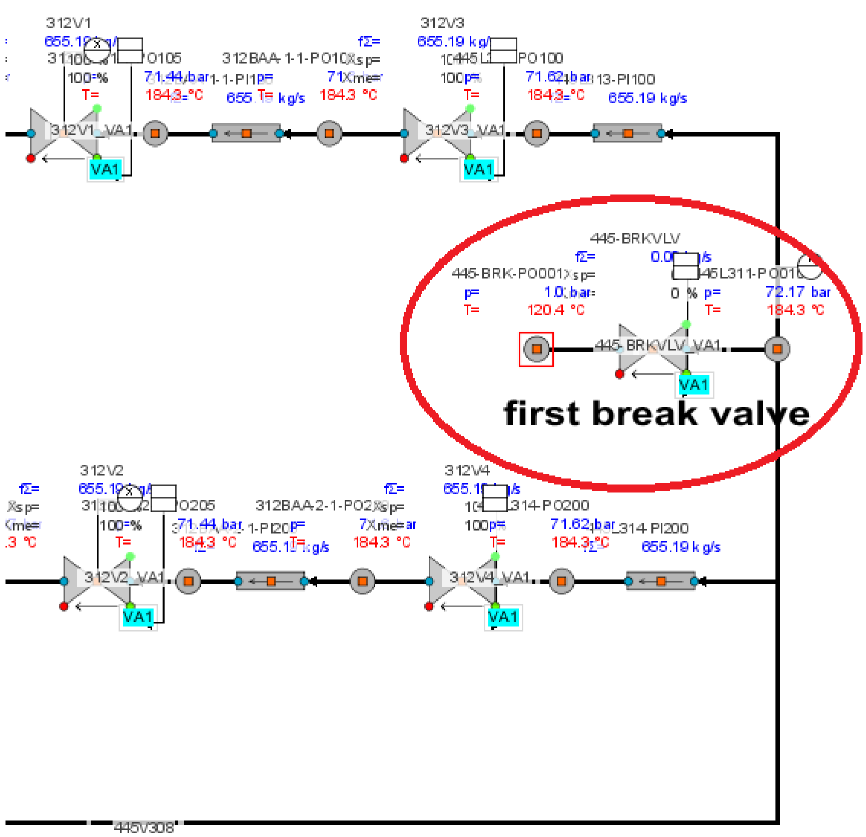

Figure 8. Location of feed water break valve outside the containment

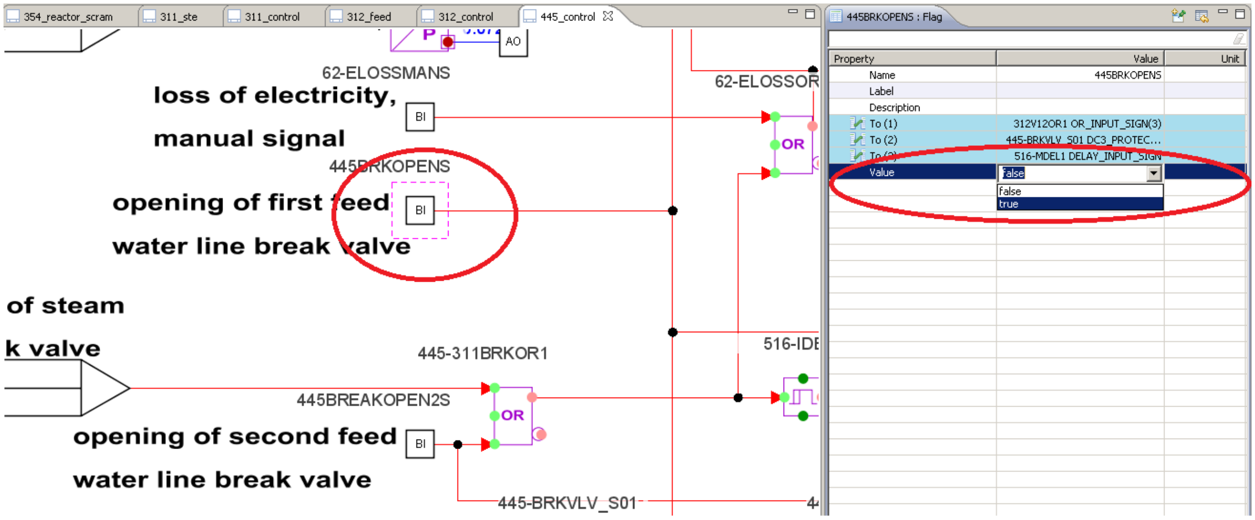

Figure 9. Opening the first feed water line break valve by activating the “445BRKOPENS” signal

11. You can monitor the progress by opening a chart window. You can adjust the Scroll Increment in Chart properties to see better (right click-> Properties).

12. Run simulation for several tenths of seconds (or more). You can increase the simulation speed by changing the simulation time step to 10 ms after 20 s of transient simulation.

13. Plot and save the graphs of what you think are the most interesting variables (preferably from the generated output data).

14. What is happening?

15. Optional: You can repeat the transient by opening the feed water break valve in the containment (see) by activating the signal “445BREAKOPEN2S”.

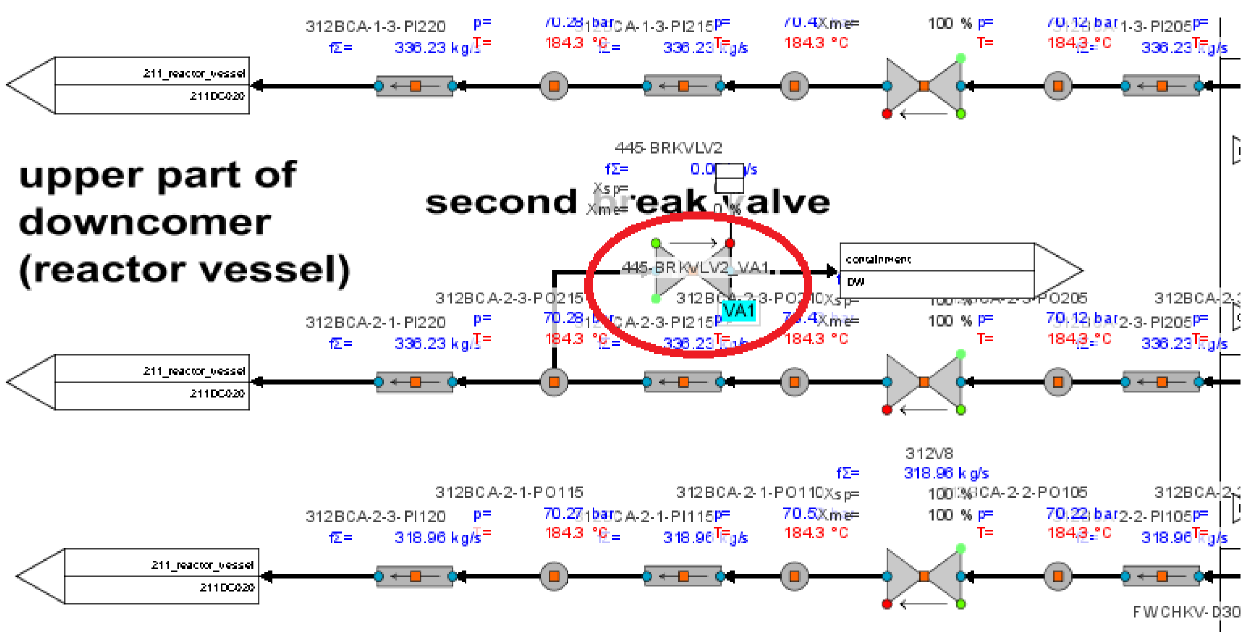

Figure 10. Location of feed water break valve inside the containment

5. Feed water pump trip

This exercise demonstrates how to trip a feed water pump

1. Describe briefly what you expect to happen in the accident scenario.

2. Import the "Generic BWR model_EX.apros" file.

3. Define trends with interesting parameters to follow during the accident. You can add more logged variables by editing the "Database name for IO" table in "DBN_EX" (Configuration, non-visual->IO and Communication->DB_NAMES). Add your variables of choice to the end of the table (see Figure 2). More parameters can be added to the GUI charts by holding Ctrl and DND the monitors from the process diagram.

4. Enable diagram monitors by selecting "Operables 1", "Simulated 1", "Not in simulation", "Module names", "Binary signal coloring" and "Analog signal values" from "Profiles" -> "All".

5. Enable data logging by typing "io open OUTPUT_EX" to the APROS console. The output data should now be exported to "EX_output.dat". Data logging can be stopped by typing "io close OUTPUT_EX" to the console.

6. Run steady-state for a while.

7. Make a new input signal (Setpoint Binary) for OR-gate "445STPOR1" in the "445_control" diagram (see). This can be used to trigger feed water pump trip. The signal also changes the boundary conditions in the feed water inlet (enthalpy and pressure).

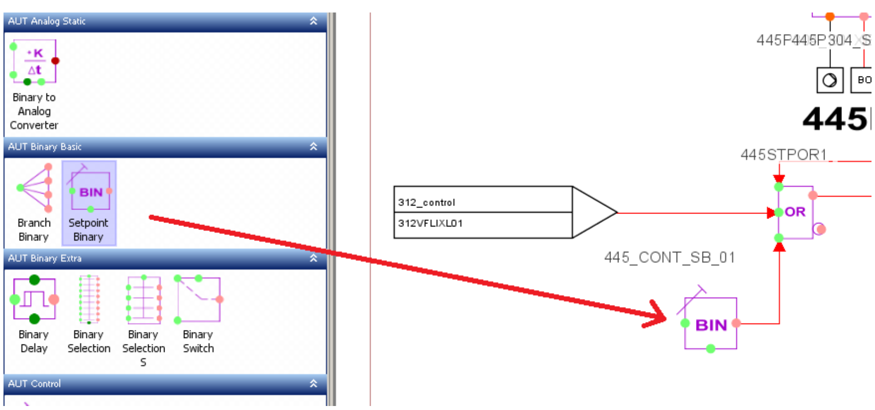

Figure 11. Adding a Setpoint Binary component to the "445_control" diagram

8. Connect the output of the Setpoint Binary signal to the input of the OR gate (by holding Alt).
9. The pumps can be tripped by changing the Logical value attribute to "true" (see Figure 12). The signal arrow should turn green.
10. Continue the simulation after tripping the pumps. To avoid console errors you can increase the minimum number of iterations and decreasing the maximum and simulation time step sizes. You can monitor the progress by opening a chart window. You can adjust the Scroll Increment in Chart properties to see better (right click-> Properties).

11. Plot and save the graphs of what you think are the most interesting variables (preferably from the generated output data).

12. What is happening?

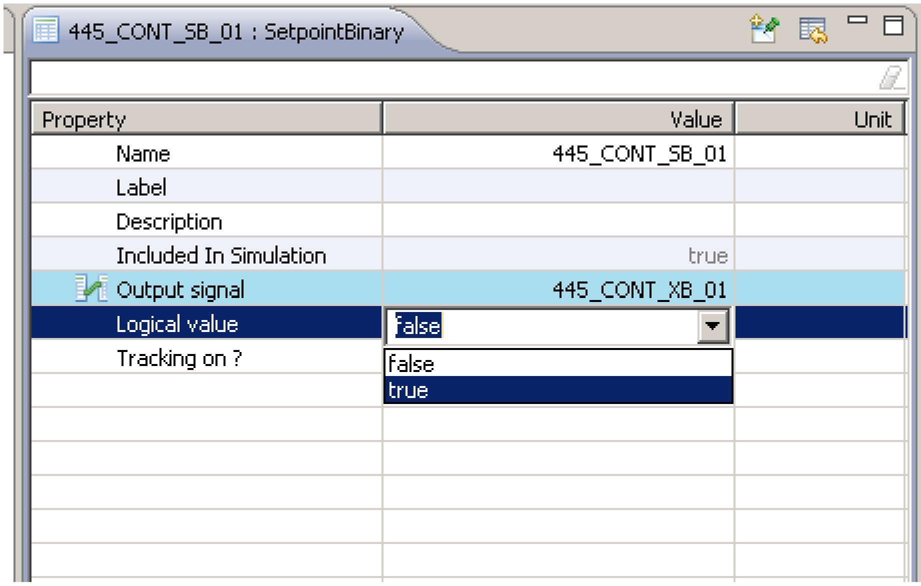

Figure 12. Changing the logical value of the Setpoint Binary component

6. Feed water enthalpy decrease

This exercise demonstrates how to decrease the feed water enthalpy.

1. Describe briefly what you expect to happen in the accident scenario.

2. Import the “Generic BWR model_EX.apros” file.

3. Define trends with interesting parameters to follow during the accident. You can add more logged variables by editing the “Database name for IO” table in “DBN_EX” (Configuration, non-visual->IO and Communication->DB_NAMES). More parameters can be added to charts by holding Ctrl and DND the monitors from the process diagram.

4. Enable diagram monitors by selecting “Operables 1”, “Simulated 1”, “Not in simulation”, “Module names”, “Binary signal coloring” and “Analog signal values” from “Profiles” -> “All”.

5. Enable data logging by typing “io open OUTPUT_EX” to the APROS console. The output data should now be exported to “EX_output.dat”. Data logging can be stopped by typing “io close OUTPUT_EX” to the console.

6. Run steady-state for a while.

7. Add a gradient component between 445LTSWI1 and 445LTBC1 in “445_pump_inlet_control” diagram (see Figure 13).

8. Delete the old signal connection and connect the 445LTSWI1 output to Gradient component input and Gradient component output to 445LTBC1 input (remember Alt).

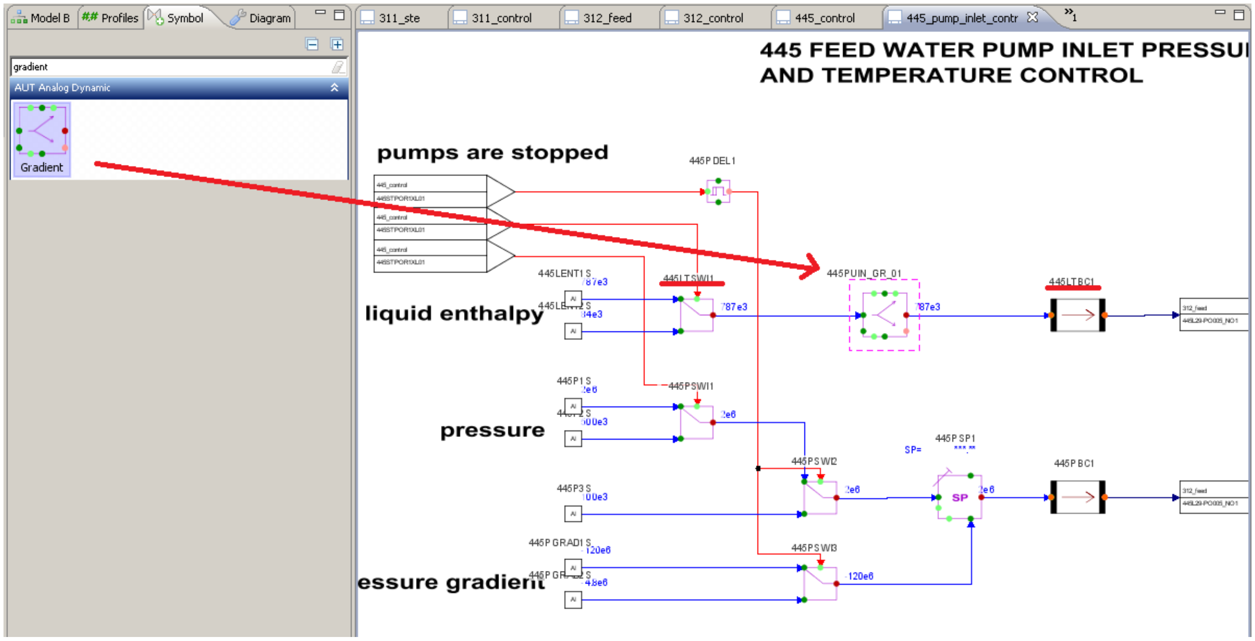

Figure 13. Adding a Gradient component between 445LTSWI1 and 445LTBC1 in “445_pump_inlet_control” diagram

9. Set gradient value for decrease to *x* 1/min. To decrease the enthalpy to *y* kJ/kg, set analog signal 445LENT1S to *y* (see Figure 14 and Figure 15). Choose *x* and *y* values as you like. Remember that enthalpy values are large when setting the gradient! Small gradient values will cause long slow decreases.

10. Continue the simulation. As before you can monitor the progress in the GUI charts.

11. Plot and save the graphs of what you think are the most interesting variables (preferably from the generated output data).

12. What is happening?

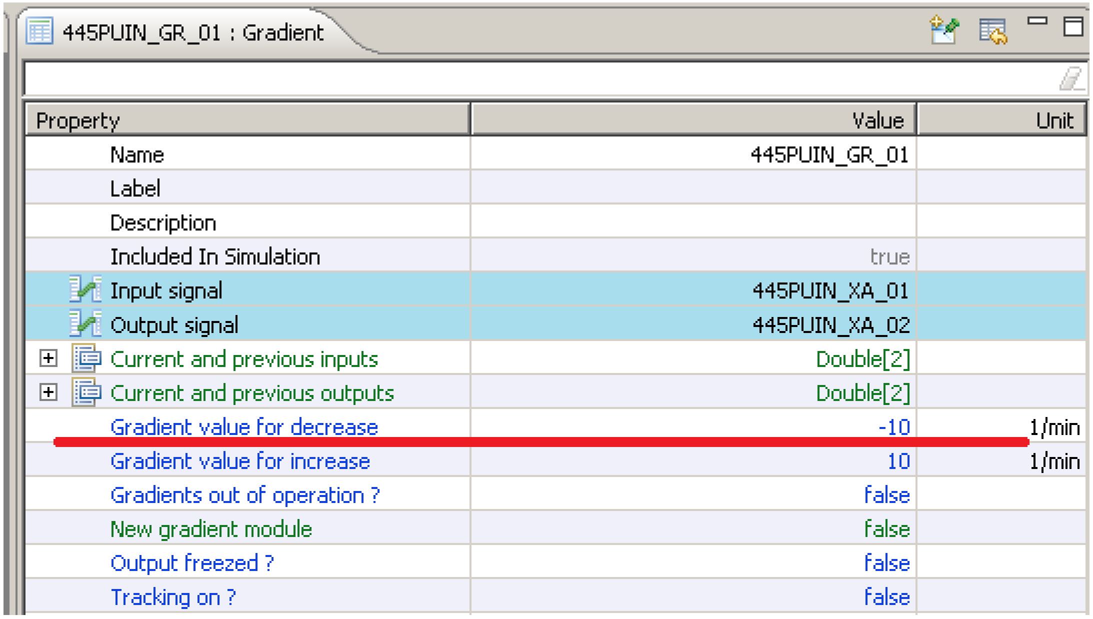

Figure 14. Setting the enthalpy decrease gradient value

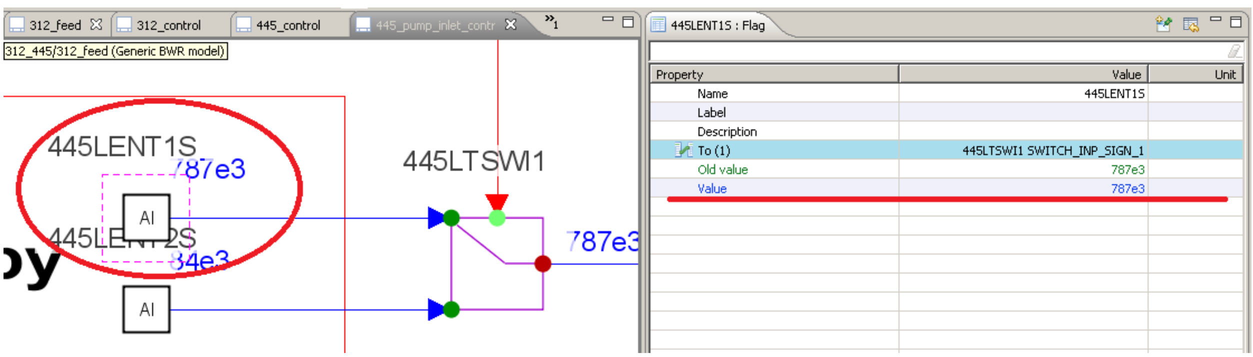

Figure 15. Changing the feed water enthalpy value

7. Reactor power decrease to 90 %

This exercise demonstrates how to adjust reactor power by changing the power setpoint.

1. Describe briefly what you expect to happen in the accident scenario.

2. Import the “Generic BWR model_EX.apros” file.

3. Define trends with interesting parameters to follow during the accident. You can add more logged variables by editing the “Database name for IO” table in “DBN_EX” (Configuration, non-visual->IO and Communication->DB_NAMES). More parameters can be added to charts by holding Ctrl and DND the monitors from the process diagram.

4. Enable diagram monitors by selecting “Operables 1”, “Simulated 1”, “Not in simulation”, “Module names”, “Binary signal coloring” and “Analog signal values” from “Profiles” -> “All”.

5. Enable data logging by typing “io open OUTPUT_EX” to the APROS console. The output data should now be exported to “EX_output.dat”. Data logging can be stopped by typing “io close OUTPUT_EX” to the console.

6. Run steady-state for a while.

7. The simulation should run fine with the standard time step. If not, try adjusting it.

8. Change the “535NFLUXSP” setpoint value in the “535_reactor_power_control” diagram to 0.9 (see Figure 16). Reactor power set point 535NFLUXSP is an input signal for 535 reactor power control system. The rotation speed of the main circulation pumps 313P1-P6 is decreased by the automation to reach the new power set point.

9. Continue the simulation.

10. Plot and save the graphs of what you think are the most interesting variables (preferably from the generated output data).

11. What is happening?

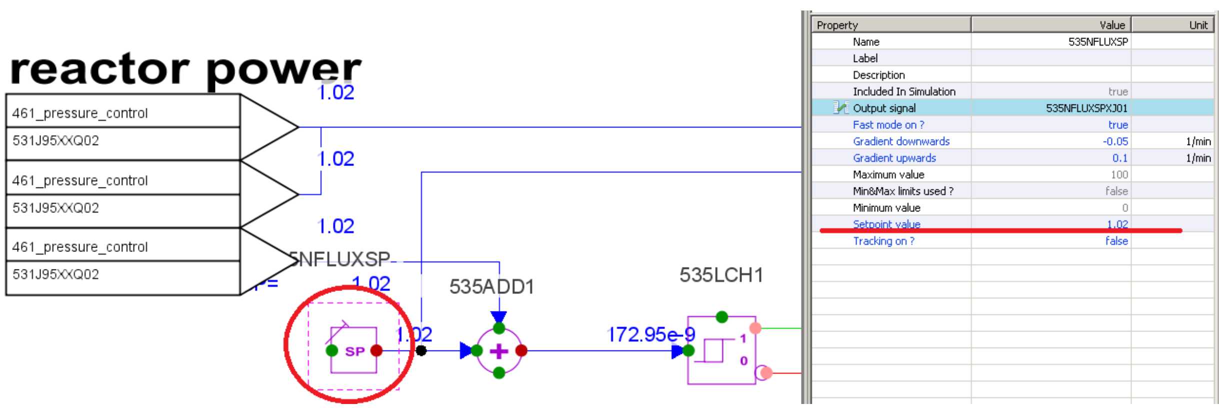

Figure 16. Changing the reactor power setpoint value

8. Manual reactor SCRAM

This exercise demonstrates how to initiate a manual scram of the reactor.

1. Describe briefly what you expect to happen in the accident scenario.

2. Import the “Generic BWR model_EX.apros” file.

3. Define trends with interesting parameters to follow during the accident. You can add more logged variables by editing the “Database name for IO” table in “DBN_EX” (Configuration, non-visual->IO and Communication->DB_NAMES). More parameters can be added to charts by holding Ctrl and DND the monitors from the process diagram.

4. Enable diagram monitors by selecting “Operables 1”, “Simulated 1”, “Not in simulation”, “Module names”, “Binary signal coloring” and “Analog signal values” from “Profiles” -> “All”.

5. Enable data logging by typing “io open OUTPUT_EX” to the APROS console. The output data should now be exported to “EX_output.dat”. Data logging can be stopped by typing “io close OUTPUT_EX” to the console.

6. Run steady-state for a while.

7. Decrease the simulation time step to 5 ms.

8. Change the Manual reactor scram signal “516SS1SIGN” in the “516_ss_v” diagram to “true” (see Figure 17). This leads to normal scram operations of e.g. running down the main circulation pumps and moving the control/scram rods into the core. Turbine trip is triggered automatically 10 s after the scram.

9. Continue the simulation.

10. Plot and save the graphs of what you think are the most interesting variables (preferably from the generated output data).

11. What is happening?

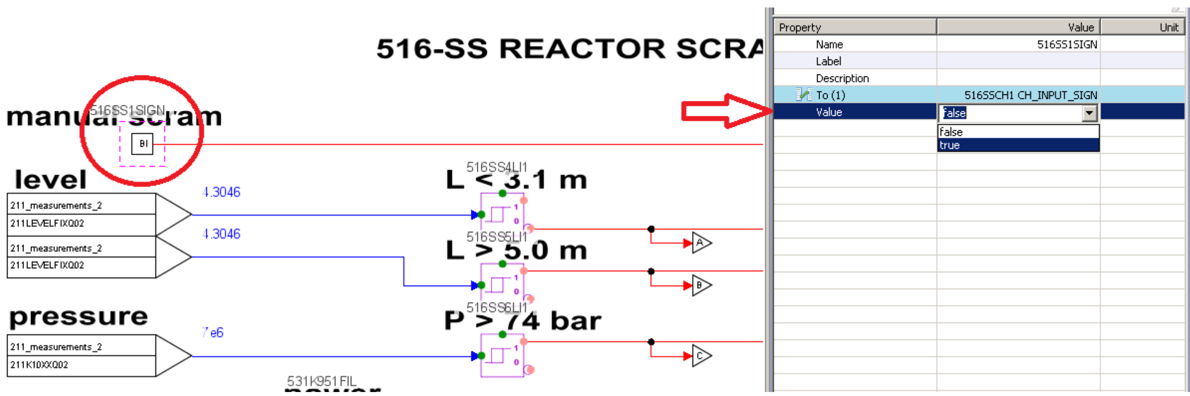

Figure 17. Enabling the reactor scram signal

BWR EX_output.dat column names

Column nr.	Attribute	Unit
1.	Time	s
2.	Reactor relative power	-
3.	Reactor pressure	Pa
4.	Recirculation flow	kg/s
5.	Reactor pressure vessel coarse collapsed level	m
6.	Reactor power to coolant	MW
7.	Feed water flow	kg/s
8.	Steam flow	kg/s
9.	RPV fine level measurement	m
10.	RPV coarse level measurement	m
11.	Relief system flow	kg/s
12.	Core spray flow	kg/s
13.	Aux feed water flow	kg/s
14.	Steam line break valve 1 mass flow	kg/s
15.	Steam line break valve 2 mass flow	kg/s
16.	Feed water line break valve 2 mass flow	kg/s
17.	Containment dry well pressure	bar
18.	Containment wet well pressure	bar
19.	Steam line 1 isolation valve position	-
20.	Steam line 2 isolation valve position	-
21.	Steam line 3 isolation valve position	-
22.	Steam line 4 isolation valve position	-
23.	Maximum cladding temperature	°C
24.	Feed water temperature in line 1	°C
25.	Feed water temperature in line 2	°C
26.	Feed water temperature in line 3	°C
27.	Feed water temperature in line 4	°C
28.	Mixture temperature steam line 1	°C
29.	Mixture temperature steam line 2	°C
30.	Mixture temperature steam line 3	°C
31	Mixture temperature steam line 4	°C
32.	Containment dry well temperature	°C
33.	Containment wet well temperature	°C