

Research reactor simulator

USER MANUAL

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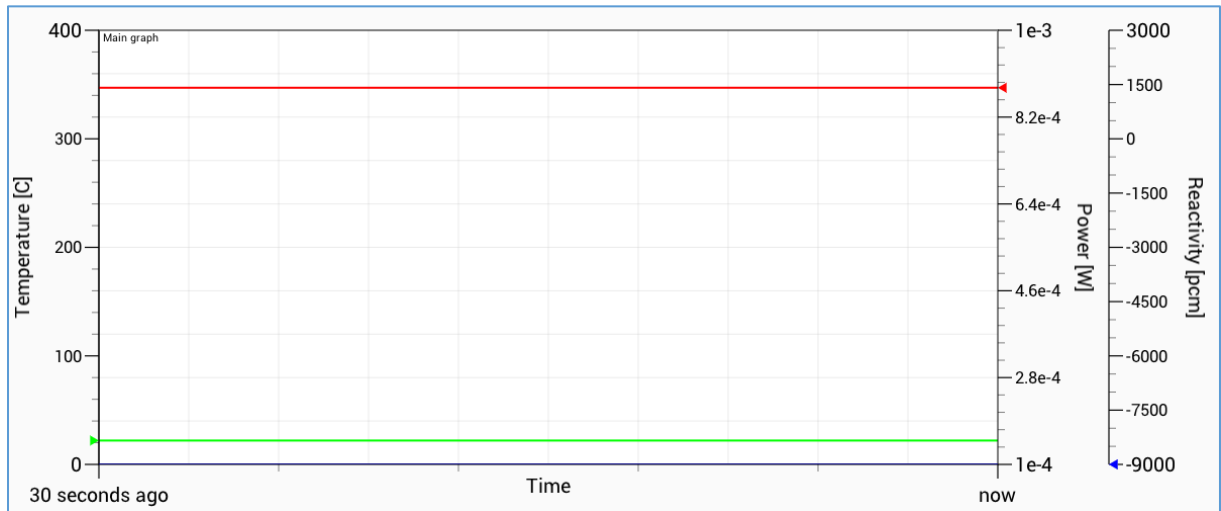
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1. General composition

The program is vertically separated into three parts:

1.1. Main graph



The main graph is composed of 3 vertical linear axes and one horizontal linear axis.

The three vertical axes from left to right display the following values:

- **Temperature** – green line
This plot displays reactor fuel temperature in **°C**. By default, this axis goes from 0°C to 400°C. These values can be changed under **Graph controls**.
- **Power** – red line
This plot displays reactor power (thermal) in **watts**. Reactor power is auto scaled and therefore, limits for this plot cannot be changed. Exponential notation is used for short display of otherwise extremely big or extremely small values.
- **Actual reactivity and inserted reactivity** – blue and grey lines
This axis is shared by two values. The blue line, reactivity, is equal to the inserted reactivity minus temperature defects and Xenon poisoning effects, while the grey line, inserted reactivity is equal to the reactivity inserted by the control rods, without the effects of temperature and Xenon poisoning. By default, this axis goes from the lowest possible inserted reactivity (*excess reactivity - total rod worth*) to the highest possible reactivity (*excess reactivity*). These limits can be changed under **Graph controls**. Units for both of these axes are **pcm**.

Coloured triangles on each of the 3 vertical axes display current values.

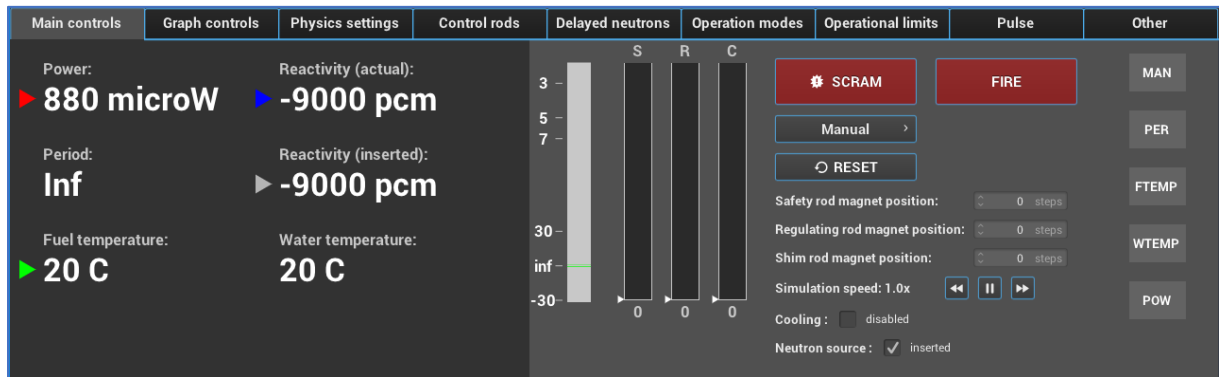
The single horizontal axis represents time, in **seconds**. The right end of the graph represents the current status, while the left end is X seconds ago. X can be changed by changing the "Display time" setting (more under **Graph controls**).

The graph background is divided into a 10 by 10 grid for better visibility.

1.2. Tab area

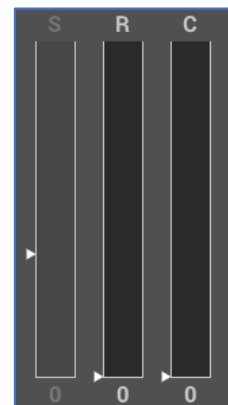
The tab area is used to change all of the simulator settings and also to display exact values of several reactor properties. It serves mainly as a control panel, composed of nine different categories:

1.2.1. Main controls



The main controls tab serves as a central display area for current reactor power, inserted reactivity, period, fuel temperature, water level, water temperature, and actual reactivity. These values are displayed in the left dark grey area of the tab.

Next from left to right is the control rod position display. Displaying safety (S), regulating (R) and shim (C) rod positions as the dark grey bar on a bright background. Rod magnet positions are also displayed – indicated by a white triangle on the left side of each rod. The number on the bottom side of all three control rods is the exact position of the control rod in steps. When a control rod is disabled or detached from its magnet, the colour scheme of the rod changes to a colour scheme with lower contrast, shown in the image to the right.



Several buttons and textboxes that are common to reactor operation are also placed on this tab:

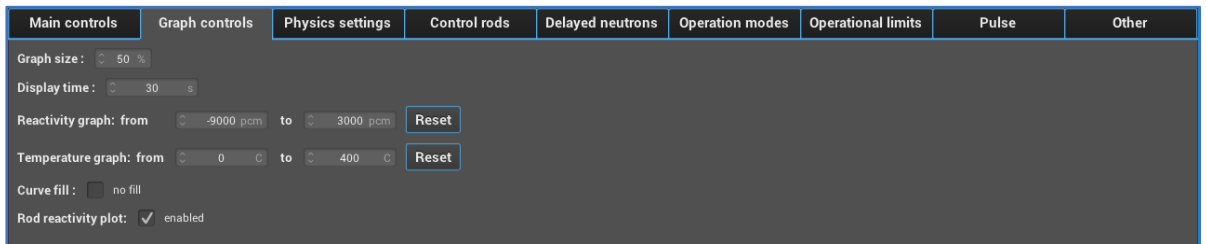
- **SCRAM** button
The SCRAM button scrams the reactor (manual SCRAM).
- **FIRE** button
The FIRE button fires the regulating rod at a fixed speed to the position of the regulating rod magnet.
- **Operation modes** dropdown list
In the operation mode dropdown list, the user can select the behaviour of the regulating rod. More about operation modes under *Concepts*.
- **RESET** button
The RESET button resets the reactor after a SCRAM. Doing this enables all disabled control rods.
- **Safety, regulating and shim rod position** textboxes
Entering a value in this checkbox moves the corresponding control rod to the desired position.
- **Simulation speed** buttons
A label preceding the buttons displays the current simulation speed as a factor of real time speed (factor x 1 second = the number of seconds that the simulation advances for each second in real time). The three buttons with icons, following this label, are used to control the speed of the simulation.
Clicking on the left button (double left arrow icon) slows down the simulation.
The middle button (pause or play icon) pauses or resumes the simulation.
The right button (double right arrow icon) speeds up the simulation.
More about simulation speed under *Concepts*.
- **Cooling** checkbox
Toggling this checkbox enabled or disables the primary water cooling system.
- **Neutron source** checkbox
Toggling this checkbox withdraws or inserts the neutron source.

The final elements on the main controls tab, located on the right of the tab, are alarm lights. They light up in the event of a scram. The abbreviations on the lights indicate what caused the SCRAM. Lights are vertically arranged in the following order:

- **MAN** (manual)
- **PER** (period)
- **FTEMP** (fuel temperature)
- **WTEMP** (water temperature)
- **POW** (power)

1.2.2. Graph controls

This tab serves as a control area for changing display settings.



For now, six settings are available:

- **Graph size**

The amount of vertical space the main graph takes can be changed here. By default, 50% of the window height is taken by the graph. This value can be set anywhere between 30% and 70%.

- **Display time**

This setting changes the start time (in seconds from current time) from which the main graph is drawn. It can be set anywhere from 0.5 seconds to 7200 seconds.

- **Reactivity graph**

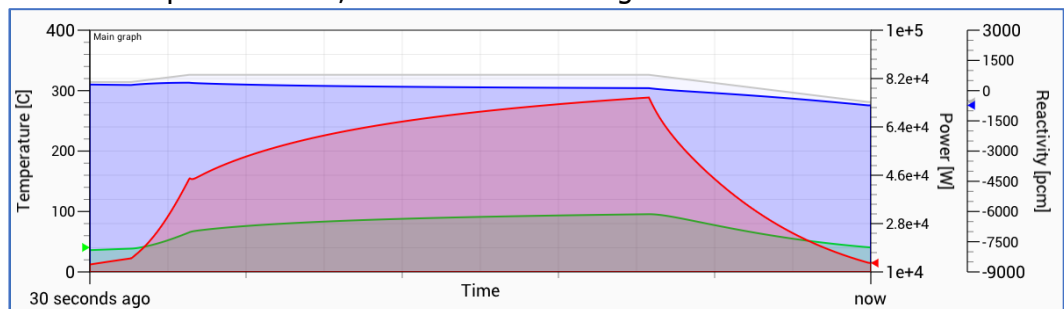
The two number boxes in this line represent the limits of the reactivity axis. Changing these numbers will change the visible range of the reactivity plot. Clicking the "**Reset**" button will reset these values to default.

- **Temperature graph**

The two number boxes in this line represent the limits of the temperature axis. Changing these numbers will change the visible range of the temperature plot. Clicking the "**Reset**" button will reset these values to default.

- **Curve fill**

Clicking this checkbox enables or disables filling the space under all lines with a semi-transparent colour, as shown in the image below.



- **Rod reactivity plot**

This setting enables or disables the grey line (inserted reactivity).

1.2.3. Physics settings

This tab serves as a control area for important physical properties of the reactor and point kinetics.

	Group 1 (slowest)	Group 2	Group 3	Group 4	Group 5	Group 6 (fastest)
Beta():	0.00021	0.001306	0.00119	0.002576	0.000948	0.000232
Lambda():	0.0128	0.0317	0.1205	0.3217	1.403	3.8925
Enabled:	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

Core volume: 5.264681e-05 L

Water volume: 20 m³

Temperature effects: enabled

Fission product effects: disabled

Excess reactivity: 3000 pcm

Water cooling power: 240000 W

Neutron source activity: 100000 Bq

Prompt neutron lifetime: 4e-05 s

Temp. reactivity coef. graph: The graph shows a reactivity coefficient starting at 6 pcm/C at 0°C, peaking at 9 pcm/C at 240°C, and then decreasing with a slope of -0.004 pcm/C².

The table with 6 columns and 2 rows is used to set delayed group beta and lambda factors. Lambda factors are in decays per second (**Bq**). Under the table, eight more parameters can be set on the left:

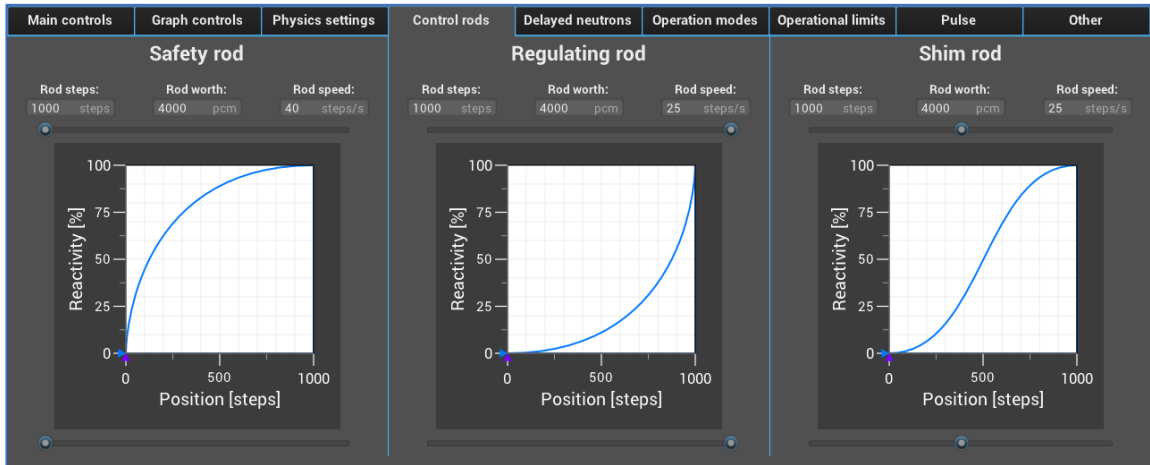
- Core volume**
 The volume of the active core (sum of all fuel element volumes) in **litres (dm³)**. This is used to calculate fuel temperature change in the Fluch-Hans temperature model.
- Water volume**
 The volume of primary water surrounding the reactor core in **cubic meters**. This is used in calculations for heating the water.
- Temperature effects**
 Clicking this enables or disables temperature effects on reactivity. Keep in mind disabling this at high power will SCRAM the reactor due to prompt criticality.
- Fission product effects**
 Clicking this enables or disables Xenon poisoning effects on reactivity. Keep in mind enabling or disabling this at long sustained high power will noticeably lower or increase reactivity.
- Excess reactivity**
 The positive reactivity (in **pcm**) of the core when all control rods are extracted.
- Water cooling power**
 The raw power (in **Watts**) with which the primary water should be cooled.
- Neutron source activity**
 The activity of the neutron source in **decays per second (Bq)**.
- Prompt neutron lifetime**
 The average lifetime of a prompt neutron (in **seconds**).

And four more parameters on the right:

- **Starting coeff.**
The temperature coefficient of reactivity at $T=0^{\circ}\text{C}$ (negative) in $\text{pcm}/^{\circ}\text{C}$.
- **Peak temp.**
The temperature (in $^{\circ}\text{C}$) at which the second data-point is located.
- **Coeff. at peak temp.**
The temperature coefficient of reactivity in $\text{pcm}/^{\circ}\text{C}$ when the temperature is equal to the above setting.
- **Slope after peak temp.**
The slope of the line after this data-point (in $\text{pcm}/^{\circ}\text{C}^2$).

1.2.4. Control rods

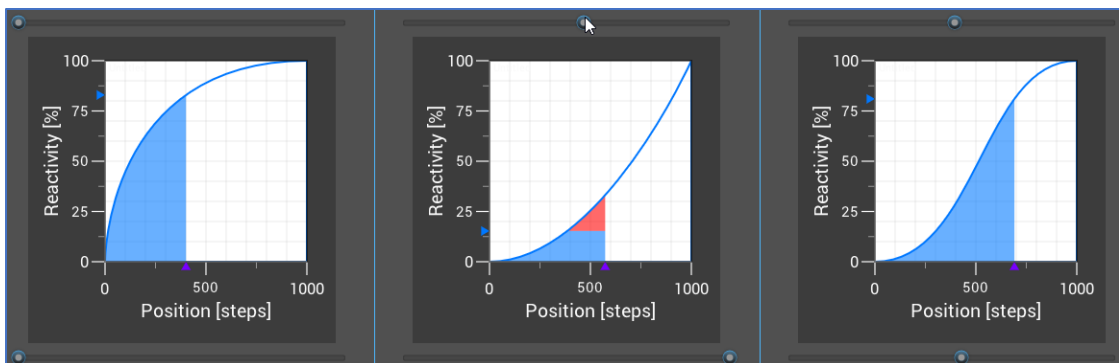
This tab serves as an area to define control rod parameters.



There are four general settings for each control rod:

- **Rod steps**
This sets the number of *steps* the virtual stepper motor can go through.
- **Rod worth**
This sets the how many *pcm* the corresponding control is worth.
- **Rod speed**
This sets the speed at which the virtual stepper motor moves the rod (in *steps per second*).
- **Two sliders**
The two sliders above and below the rod integral curve control the shape of the rod curve. The function used to form these curves is a numerical approximation of a third order parametric Bezier curve. Using various combinations, many different shapes can be achieved; linear, exponential, asymptotic, the typical S-curve and many other.

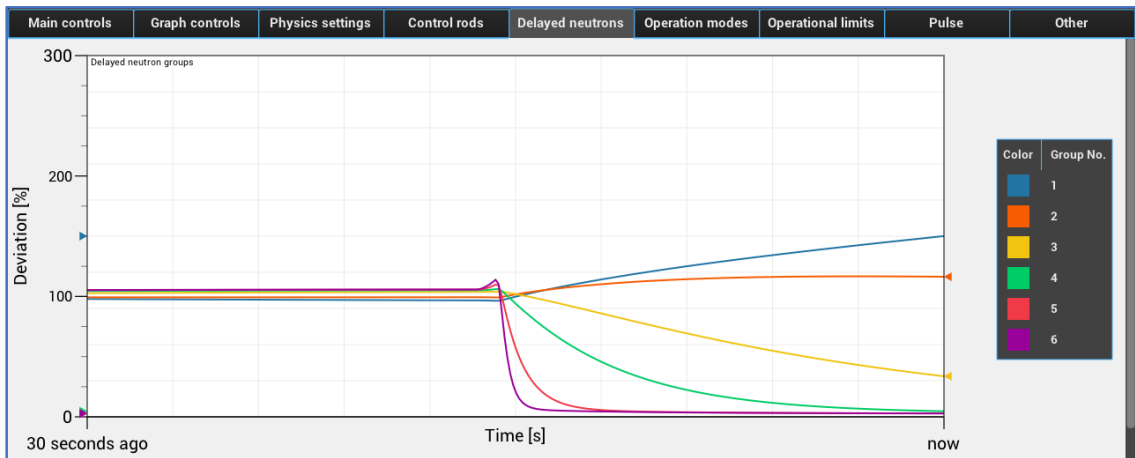
The graph serves two purposes: displaying the integral curve and displaying the current rod position.



As displayed, the horizontal axis represents rod position, while the vertical axis represents the percentage of rod worth inserted. The red coloured area appears whenever the magnet position is higher than the actual control rod position (for example when the rod is disabled or when a change in the curve would cause a rise in reactivity).

1.2.5. Delayed groups

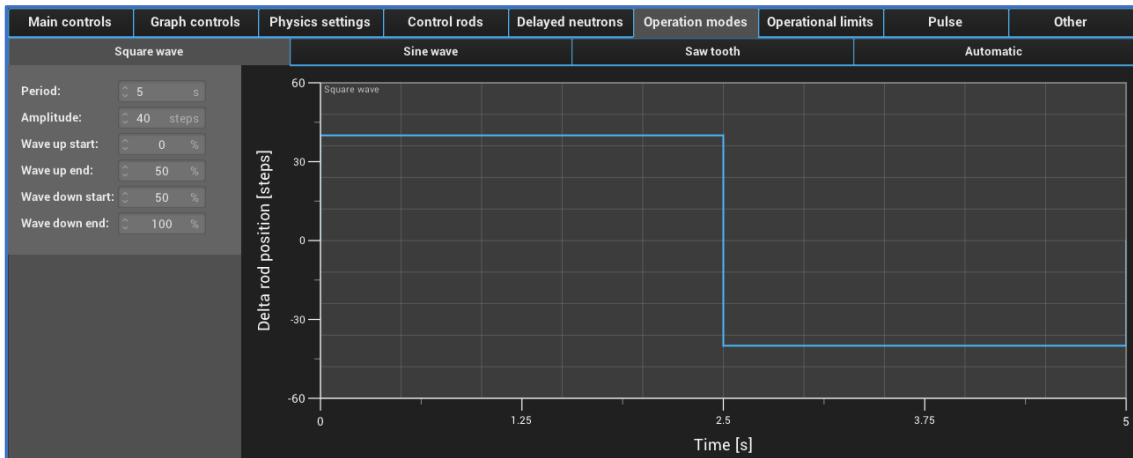
This tab serves as a display of delayed neutron concentrations relative to concentrations in stable conditions.



Each delayed neutron group has its own line colour, displayed in the key on the right side of the graph. The linear vertical axis, displaying $\frac{\text{delayed neutrons}}{\text{delayed neutrons in stable conditions}}$ goes from 0% to 300% and cannot be changed (yet).

1.2.6. Operation modes

This tab serves as an area to change the behaviour of different operation modes.



Three operation modes can be changed here, more on operation modes and how they work under **Concepts**.

All three operation modes have two parameters in common:

- **Period**
The period of the operation mode is the time the mode needs to complete one cycle. Cycles repeat until the operation mode is changed to something else. This can be set to anything from 0.1 **seconds**.
- **Amplitude**
The amplitude of the operation mode is the maximum deviation in **steps** of the regulating rod from the original rod position (the position the rod magnet was at before the simulated movement began).

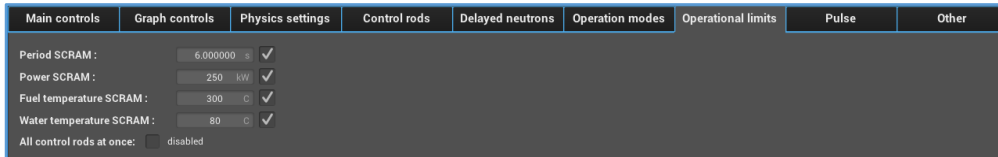
Every operation mode has additional parameters that determine the shape of rod movement over time. A real time display of how the rod movement will look like is located on the graph under the settings. For square wave and saw tooth modes, individual settings are expressed as a point in time defined by $x \cdot period$, where x is given in **%**.

Another set of three tabs can be found under the main tab buttons. Each tab represents one operation mode.

- **Square wave**
 - Wave up start – upwards jump of control rod
 - Wave up end – rod return to original position
 - Wave down start – downwards jump of control rod
 - Wave down end – rod return to original position
- **Sine wave**
 - Sine type – a drop down menu to select between a normal sine and a quadratic sine.
- **Saw tooth**
 - Tooth up start – start of upward movement
 - Tooth up peak – start of downward movement to original position
 - Tooth up end – end of movement to original position
 - Tooth down start – start of downward movement
 - Tooth down peak – start of upward movement to original position
 - Tooth down end – end of movement to original position
- **Automatic**
 - Current power stability *checkbox*
 - Toggles (keep steady current power / reach set power)
 - Steady power [**watts**]
 - This setting sets the power the mode should reach (if the first checkbox is unchecked)
 - Avoid period scram *checkbox*
 - Toggles (avoid period SCRAM / don't avoid period SCRAM)
 - Maximum power deviation [**%**]
 - The maximum difference from the set power level that is still tolerated. The control rod position will be adjusted if the difference from the set power level exceeds this margin.

1.2.7. Operational limits

This tab serves as a control area for SCRAM signals and other limits of operation.



Five SCRAM settings are located here, along with an enable/disable option:

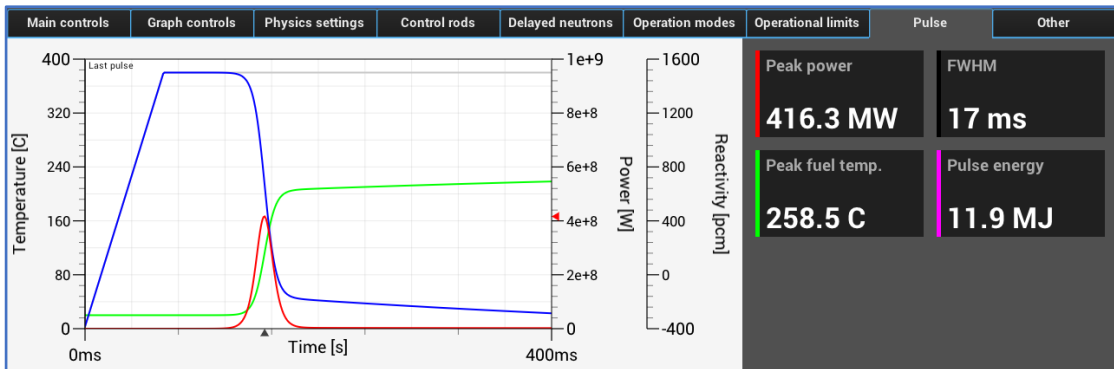
- **Period SCRAM**
This setting controls the period limit in *seconds*, under which the reactor automatically SCRAMs. The default is 4s.
- **Power SCRAM**
This setting controls the power limit in *kilowatts*, above which the reactor automatically SCRAMs. The default is 250kW.
- **Fuel temperature SCRAM**
This setting controls the fuel temperature limit in *°C*, above which the reactor automatically SCRAMs. The default is 300°C.
- **Water temperature SCRAM**
This setting controls the water temperature limit in *°C*, above which the reactor automatically SCRAMs. The default is 80°C.

As mentioned, each setting has an enable/disable option (a checkbox) that disables or enables automatic SCRAMs on that signal. By default, all automatic SCRAM signals are enabled.

The lower checkbox, *All control rods at once* enables or disables manual movement of all rods at once and not just one at a time maximum.

1.2.8. Pulse

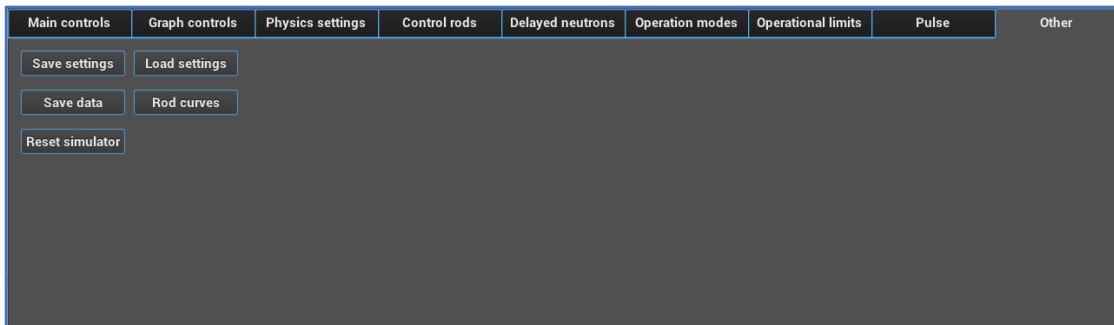
This tab displays information about the last pulse performed. A detailed graph of the pulse is also displayed on the left side of the tab.



Peak power, full width at half maximum, peak fuel temperature and pulse energy are displayed on the right.

1.2.9. Other

This tab serves mostly as a control panel for IO (input-output) operations.



Four buttons are located in this tab:

- **Save settings** – saves all settings to a chosen directory
- **Load settings** – loads a settings file
- **Save data** – saves the full history of reactor operation
- **Rod curves** – saves rod calibration curves in table format
- **Reset simulator** – resets the simulator entirely (equal to restarting the program)

1.3. Bottom row

The bottom row is a dark-coloured part of the simulator where information about the simulator version, framerate, serial connection with the box, speed factor and time elapsed are displayed.



2. Keyboard controls

Several keyboard bindings were created to remove the need for more buttons and enable basic reactor control from any tab.

2.1. Simulator commands

Some commands have been added to the simulator that reduce the time required for common requests. These commands will work whenever the simulator is running and its window is focused (on top). Just type the command in any case (upper, lower or mixed) – no need to press enter.

- **RESET**
Resets the simulator entirely – equal to pressing the “*Reset simulator*” button in the “*Other*” tab.
- **DEBUG**
Opens the console where low-level information about the simulator is displayed.
- **GODMODE**
Disables all automatic SCRAM mechanisms.

2.2. Reactor related

Each control rod has a control key that tells the program which rod to move.

Rod keys are: **S** for Safety rod, **R** for Regulating rod and **C** for Shim rod. Multiple keys can be pressed at once to move multiple rods at once.

- **<rod-keys> + UP ARROW KEY**
Moves the selected control rod(s) up.
- **<rod-keys> + DOWN ARROW KEY**
Moves the selected control rod(s) down.
- **X**
SCRAMs the reactor (identical to pressing the SCRAM button).
- **0 key**
Resets the SCRAM status and enables control rods (identical to pressing the RESET button).
- **1 key**
Disables or enables the safety rod.
- **2 key**
Disables or enables the regulating rod.
- **3 key**
Disables or enables the shim rod.
- **P**
Fires the Regulating rod if in Pulse mode (identical to pressing the FIRE button).

2.3. Simulator related

Some other important functions are also bound to the keyboard in addition to being accessible from clicking buttons:

- **SPACEBAR**
Pauses or resumes the simulation (identical to pressing the pause/play button).
- **LEFT ARROW KEY**
Slows down the simulation (identical to pressing the slow down button).
- **RIGHT ARROW KEY**
Speeds up the simulation (identical to pressing the speed up button).
- **[SHIFT] + TAB KEY**
Selects the next tab (if SHIFT is pressed, selects the preceding tab).
- **CONTROL + <mode-key>**
Puts the reactor in a stable state. Multiple modes can be chosen:
 - **D**
Demo mode – serves for demonstration purposes (puts the reactor in an exactly critical state).
 - **F**
Feedback mode – serves for demonstration of temperature effects (puts the reactor in a critical state on high power, where temperature effects are evident).

3. Concepts

3.1. Control rod movement

Control rods cannot move if their magnet is not attached. Moving the control rod manually via the keyboard shortcuts only moves the magnet, so it is ineffective if the control rod is not attached to the magnet. Control rods can be reattached by leading the magnet to the control rod position (usually the bottom) and pressing BACKSPACE or the RESET button to enable the control rod.

In any other operation mode than Manual, the Regulating rod cannot be moved by the user since the simulator controls its movement.

3.2. Pulsing

In Pulse mode, the Regulating rod is disabled and drops down to the bottom. The magnet should then be moved to the desired final position of the control rod (to where it will be fired). When satisfied with the magnet position, press F or the FIRE button to eject the control rod. We advise to first slow down the simulation and set the display time to a short interval (to see the pulse in more detail as it unfolds).

3.3. Simulation speed

When slowing down or speeding up the simulation, the speed factor just moves along the following values: **0.01**(slowest), **0.05**, **0.1**, **0.2**, **0.3**, **0.4**, **0.5**, **0.75**, **1**, **1.5**, **2**, **4**, **5**, **7.5**, **10**, **15**, **20**, **50**, **100**, **250**, **1000**(fastest).

3.4. Operation modes

Operation modes only affect the Regulating rod. Other rods are always in Manual mode.

There are 7 modes of operation:

- **Pulse mode** – described above.
- **Square wave** – described under Operation modes tab.
- **Sine wave** – described under Operation modes tab.
- **Saw tooth** – described under Operation modes tab.
- **Automatic** – Once selected, keeps steady reactor power or reaches set power level by only moving the Regulating rod.
- **Manual** – default mode (user moves all rods).

3.5. SCRAM signals

Any SCRAM signal immediately disables and drops all control rods to their bottom position. Rod magnets have to be then moved down as well, to lock on the control rods once pressing the 0 KEY or the RESET SCRAM button. The manual scram signal is sent whenever the user SCRAMs the reactor either by pressing X or the SCRAM button. Additionally, 5 seconds after pressing P or the FIRE button in pulse mode, a manual SCRAM signal is sent for safety reasons (this also happens on the real TRIGA reactor).