The following description refers to interested public. This is the reason for the popular language avoiding too many scientific terms:

**NuclearReactor - a simplified Online Simulation of a nuclear chain reaction**

*First of all, if you start the program, there is a button "ENGLISH" for changing the language in the main window of the simulator.*

**NuclearReactor** is a so-called Monte-Carlo simulation of a strongly simplified nuclear reactor. With this programme you can try to control a chain reaction. Different experiments are possible, which illustrate the basic physical principles. You just have to download and to start the executable. Alternatively, you can start the programme directly via internet. Here is the description of the basic functions of the programme:

The programme calculates the life history of each neutron individually. This is a so-called Monte-Carlo simulation. The stochastic processes that determine the fate of a neutron are calculated by the help of a random number generator. The PC plays dice with the neutrons. The calculation efforts are huge, that's why only up to 100000 neutrons can be simulated in the same time, otherwise the calculation would become boringly slow. In a real reactor there are very much more neutrons.... That's why you should have a powerful PC - clock rates of 1, better 2 GHz are advised.

When you start the programme a window appears. What's depicted and what are the control buttons for?

On the left side you find the reactor core, that's where the nuclear fuel is and where the fission takes place. It consists of fuel elements containing Uranium-235 (green), of the water as moderator (yellow) and the control rods (blue), which are made from a strongly neutron-absorbing material.

When the reactor is operating, a lot of neutrons fly around there. There are two kinds of neutrons: fast ones (red dots), which are liberated during the fission of a uranium nucleus, and thermal ones, which are the result of a collision of a fast neutron with a hydrogen nucleus of a water molecule. The latter are slowed down, because during the collision they transfer all their kinetic energy to the hydrogen. This is how the moderator works. Only thermal neutrons can cause a new fission when they hit another uranium nucleus. While fast neutrons literally run over the playground, thermal ones are quite slowly migrating. They are not faster than the thermal movement of the water molecules, that's why their name.

A thermal neutron can - with a certain probability - induce a fission, as long as it is located in green the fuel region. In the result, three new neutrons are born, which are fast in the beginning. With a little luck they will be **thermalized** in the moderator (= neutron brake) region (yellow), before they fly off the core. At this place the circle of life of the neutrons closes and the chain reaction becomes possible.

After staring the programme you'll not find many neutrons in the core. There are just very few of them generated by spontaneous fission or coming from cosmic radiation. They are soon absorbed by the safety and control rods and a chain reaction does not develop.

To start-up the reactor, you need to introduce the neutron source. In principle, the reactor can also be launched without it, since a few neutrons always are found. But using a source we'll immediately get a measurable neutron density in the core - a good condition for controlling the reactor, similar to switching the light on at the car by night. Press IN below the Neutron Source button. Now fast neutrons shot out-of the source in all possible direction. They're moderated and can already cause fissions from time to time. As a consequence, the neutron density increases. But the reactor is still subcritical. You can find that out by extracting the source again. After this, the neutron density rapidly decreases, that means there is no self-sustaining chain reaction.

Now take out the safety rods after re-inserting the neutron source. Since less neutrons are absorbed, their number further increases. Due to the multiplication of neutrons, the reactor works as a neutron amplifier. But it is still subcritical - after extracting the source, the number of neutrons decreases.

Now you can try to make the reactor supercritical. Pull out the control rods; let's say until the half of the core height. Now the number of neutrons continues to rise even if the source is out. This rise occurs exponentially - take care! Don't forget to switch into the next measuring range of the neutron detector. If its reading exceeds 120 % of the measuring range, the reactor is scrammed (*scram = safety control rod axe man*, a term introduced during the first chain reaction experiment of Fermi. One of the men of the team had to stand-by with an axe to cut the rope of the safety rod in case of emergency. Today the word "scram" is used for an emergency shut-down). All control and safety rods are immediately injected into the reactor core, to stop the chain reaction.

Be careful, don't change to fast to the higher measuring range neither. There is a minimal reading of 3 %, if you violate this, scram is triggered, too. This is a penalty for an inattentive reactor operator. There are still a couple of other interlocks. Control rods can be pulled only when safety rods are already out. Those can be extracted only if the neutron detector is in the lowest measuring range.

After a while, the supercritical reactor produces more and more fissions per unit time, causing the power meter to come close to the 100 % margin. Attention! At 120 % nominal power scram in initiated! Stabilise the power, for example at 100 % - for this lower the control rods. Seek for the point where the reactor becomes critical. that means where accurately one of the three neutrons generated during a fission act initiates one new fission in the next generation. The other two neutrons either leave the reactor or are absorbed in the control rods or even by the moderator. If you want to lower the power..... But I guess you already understood how it works. Scram can be initiated also manually by pressing the corresponding button, with other words, nothing bad can happen! Go a couple of times up and down with the power and you'll soon get the right feeling for the machine. You can once try to start-up the reactor without neutron source or perhaps once extract all control rods completely. That's all very educating.....

**NuclearReactor - more features**

**Burn-up**

NuclearReactor offers a couple of virtual experiments, among others the simulation of burn-up, which means that you can study the effect of the expiring fuel during the reactor operation. In the end, the chain reaction stops by itself, because the quantity of fissile material decreases and the fission products start to absorb neutrons. The effect is of course again modelled in a qualitative way - the duration of a reactor campaign is only several minutes - a real reactor runs over a year or more...

**Fission Counter**
The fission counter located directly below the neutron detector displays the total number of fissions that took place until the given moment. This is proportional (of course only in a qualitative sense...) to the total energy produced by te reactor.

Run the reactor once with and another time without reflector and you can see how the reflector helps to get more energy from your fuel!

**Digital Control Rod Position Display**

On the right side of the buttons for moving the control rods there is now a digital control rod position displayed. The number ranges from 0 % (control rods down) to 100 % (control rods up). This display helps orientating.

**Neutron Density Distributions**

In the right top corner of the main window there are two new buttons for the display of Neutron Density Distributions: "Vertical" and "Horizontal". When you click there, after a couple of seconds you'll get a new window with the instantaneous neutron density distributions. The red curve shows the distribution of the fast neutrons, the black curve that one of the thermal neutrons.

A second click on the button brings new distributions up, while the old ones remain in a faint colour. This allows you to compare the distributions found at two instants. Use this feature, for example, to study the influence of the reflector or the distortion of the vertical distributions by the control rods!

**Dialog Box Safety Circuit**

You've produced a SCRAM (safety shut-down) - what was wrong? This box tells you the reason!

**How does a neutron reflector work?**

The code offers the demonstration of the working principle of the reflector. in combination with the burn-up option there are many nice new experiments possible. A reflector is basically nothing else than "moderator" substance put around the "reactor core". The two terms "moderator" and "reactor core" are explained in the text below.

The neutron reflector is the surrounding space of the reactor core filled with moderator. Nothing else. Very often, the moderator is water, but there are types of reactors using graphite or heavy water. The moderator brakes the fast neutrons released during the fission act. This happens by an elastic scattering. Similar to what we observe when playing pool billiard, the neutron hits the nucleus of the moderator substance, e.g. a proton being the nucleus of hydrogen in the water, and it transfers its momentum to the moderator nucleus. Translated to pool billiard, the first ball hits the second one and stops while the second starts moving with the previous velocity of the first one. Elastic scattering is not always so optimal, but the neutrons always loose energy and become slower. In the end, the neutrons obtain a comparatively low speed (2200 km/s), which is equal to the thermal movement of the moderator atoms. This is the reason why we speak about "thermal" neutrons. The purpose of moderation is to improve the chance of the neutrons to trigger new fission acts. Slow neutrons are much better in this business than fast ones. In this way, the chain reaction can be sustained much easier than without moderator.

But what does the moderator do outside the reactor core? Pretty easy: All neutrons leaving the core are lost for the chain reaction unless something reflects them back into the core. You can see this after starting the programme. In this state, the surrounding space of the core is still empty, which is shown with the white colour. Start up the reactor and try to stabilize the power. Find a control rod position where the power doesn't change after extracting the neutron source. Now the reactor is critical. How to do this, you can read in the main manual.

Now switch on the reflector by clicking on the button "reflector". The space around the core fills with yellow = moderator. Immediately, fast neutrons start to be moderated by the reflector. Some of them manage to migrate back into the core, which also happens with some of the thermal neutrons that left the core. The result: The reactor becomes supercritical without changing the control rod position, indicated by a rise of the power. This kind of reflection is not working like a mirror; it is rather a diffuse reflection. For this reason, the back-scattered neutrons are called "albedo". You can press the button "reflector" for a second time, then the reflector is again taken out and the accumulated neutrons disappear. Don't hesitate to experiment with all the control elements - the worse that can happen is a scram = emergency shut-down.

**Drain Moderator**

There is still a second button that is new in version 1.1 of NuclearReactor. It's the "Drain Moderator" button. When you press this, the moderator is taken also out of the core itself. The consequence: The chain reaction is stopped very efficiently without the control rods. To drain the moderator is therefore a possible way to perform an emergency shut-down ....but only for small research reactors, where the moderator is not used as a coolant in the same time! In a power reactor, often water is moderator and coolant in the same time. The coolant is still needed to remove the residual decay heat from the fuel that is continuously produced by the radioactive fission products even if no fission is happening anymore. The corresponding thermal power can amount up to 6 % of the nominal power of the reactor.