3.5 LWR Dynamics and Control. Part 2

In order to safely operate a Nuclear Reactor, we need to control the reactivity. My name is Carol Ahnert. During this lecture you will learn about various effects that influence the reactivity in a nuclear power plant during operation. We will start with a short summary about the neutron life cycle.

As you may recall from a previous lecture, the effective multiplication factor is the ratio between neutron production and neutron losses. If Keff is equal to 1 the reactor is critical, if it is larger than 1 it is supercritical, and if it is smaller than 1 the reactor is subcritical. This slide shows a schematic representation of the neutron life cycle, with neutrons produced by fission, and neutron losses due to absorption and leakage. The reactivity is a measure of the deviation from a critical situation in the reactor and is expressed in the unit pcm. The acronym pcm stands for per cent mille. In general, the reactivity coefficient of a parameter X is defined as the change in reactivity caused by a change in the parameter X. Let's have a look at the most important reactivity coefficients. The moderator temperature coefficient is the change in reactivity due to a change in the moderator temperature. It has a negative component due to the change in water density with increasing temperature, but also a positive component due to the change in the boron concentration in the water. The net value of this coefficient should be negative for safety reasons. Because of this, there is a limitation on the boron concentration in the water during long burnup cycles. In these cases, the addition of gadolinium oxide in some fuel rods is needed. The reactivity coefficient related to the fuel temperature is always negative because of the so-called nuclear Doppler effect. This effect causes the resonance peaks to broaden and the resonance absorption to increase. These increased neutron losses lead to a decrease in reactivity. The power reactivity coefficient is the addition of the previous coefficients, and should be negative for safety reasons. The reactivity coefficient related to the void fraction is mostly relevant in BWRs, where steam is present in the reactor core. The technical specification requirements that should be followed during the operation of the reactor are: The reactivity coefficients should always be negative. The absolute values of the coefficients should be small. Any reactivity increase should be compensated, with the negative reactivity of the available control system. The negative reactivity of the control system should provide a shutdown margin of more than 3%. That means that in any situation the control system should be able to put the core in a subcritical situation.

We will now look at the effect of several fission products on the reactivity in the core. These fission products are produced during the nuclear fission reactions, along with several free neutrons. The ratio of neutrons and protons in the fission products, is roughly the same as that in the uranium-235. This means the fission products are found below the stability band on the nuclide chart. The graph indicates where the fission products can be found on the nuclide chart. These unstable nuclides are highly radioactive and decay mainly through beta-minus decay. The fission products xenon-135 and samarium-149 are especially relevant, due to their high absorption cross sections. The build-up of these nuclides depends on the reactor power. The effects of these so-called neutron absolvers are mostly seen in nuclear power plants during start-up, a scram, and a power level change. During the operation of the reactor, the xenon-135 reaches an equilibrium concentration. After shutdown the concentration increases, due to the higher decay rate of iodine-135, which decays to xenon-135. After a while, most of the iodine is decayed and the xenon concentrations decreases again due to the decay of xenon-135. The concentration of samarium-149 also reaches an equilibrium during operation. However, after the shutdown it behaves different than the xenon. Since samarium-149 is a stable isotope, it will not decay over time. The unstable nuclide promethium-149 decays to samarium-149, which leads to an increase in the concentration of samarium in the core and a new equilibrium is reached. After a restart of the core, it takes some time for the samarium-149 levels to reach the previous equilibrium state.

During the next lecture, we will discuss the operationtional control of a nuclear reactor.