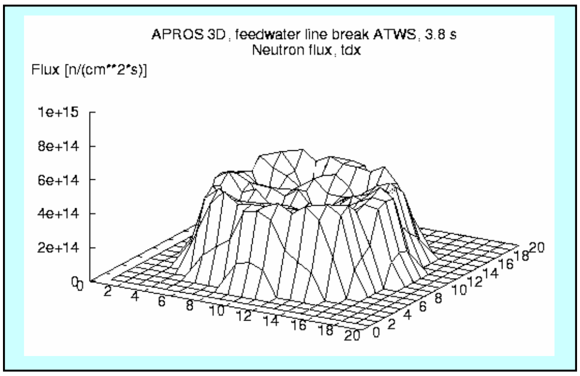
Nuclear Reactor Models

APROS includes one- and three-dimensional core neutronics models. These are based on time dependent two-group neutron diffusion equations computing the local flux at each time step, with accuracy comparable to the codes used for core supervision at a nuclear power plant. The models are valid for both BWR and PWR cores with either square or hexagonal fuel lattice. The reactivity level and the axial power distribution of the core can be tuned in both models.

Solution system

In the models the basic equations are discretized with conventional discretization methods. For the 1-D reactor model the discretization with a few approximations results in a block tridiagonal matrix equation, which is solved with a sparse matrix solver. The 3-D model uses a finite difference approximation and an iterative solver.

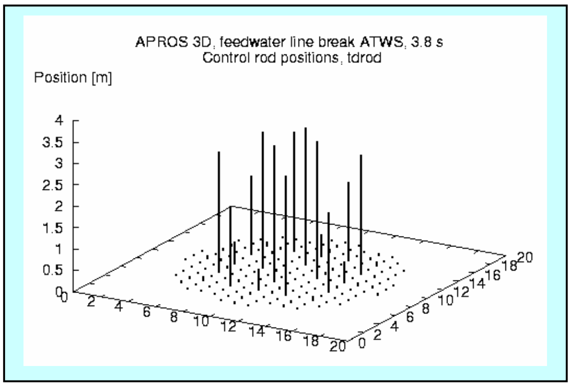
The delayed neutrons are calculated in each cell using six groups. First order discretization for the time derivative is used in the solution of the delayed neutron precursor group concentrations. The burnable poison is included in the reactor parameters. The models include calculation of local iodine, xenon, promethium and samarium concentrations. The concentrations are obtained



from the basic equations using first order discretization of the time derivative term. A user selectable speedup factor for the iodine/xenon concentration calculation has been included.

The model also includes local decay heat calculations. The history of reactor operation can be included in the calculation. The decay heat model is based ANSI-standard correlation that includes 23 decay heat precursors for each calculation cell.

The reactor core model takes into account the following reactivity effects: Fuel (type and exposure), burnable poison, control rods, fuel temperature, moderator density, void fraction, fission product poisoning (Xenon, Promethium and Samarium) and neutron sources. Many of the feedback effects can be tuned with additional



conservativity factors according to safety analysis needs. The control rods are described with cross sections; the control rod tip smoothening is included in the calculation.

Core thermal hydraulics

Calculation of fuel rod temperatures, coolant conditions and boric acid concentration is performed within the thermal hydraulic model of APROS. In radial direction a fuel rod consists of an optional central hole, fuel, gap and cladding.

The five- and six-equation thermal hydraulics models can be selected in connection of both the one- and three-dimensional core neutronics models. In the three-dimensional core model core thermal hydraulics is described with a number of one-dimensional thermal hydraulic flow channels extending from the whole core being described with one channel into each fuel assembly being described with its own channel. Each thermal hydraulic channel has its own thermal hydraulic properties. In addition to thermal hydraulic channels, the 3-D reactor core consists of fuel assemblies, reflector assemblies and control assemblies.

Reactor model configuration

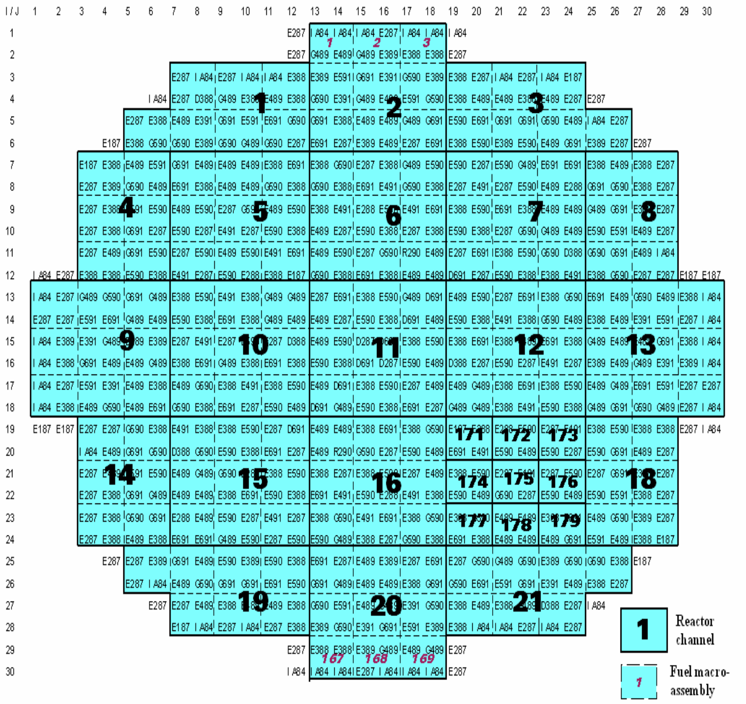
In one-dimensional core model the basic options available are the selection of the thermal hydraulic model, selection of the core axial division and selection of control rod description (control and scram group, or each control rod separately described). These selections have to be in accordance with the cross-section library with properly condensed data.

In three-dimensional model each assembly and control rod are described separately in most cases. The options available in the core construction are the choice of the thermal hydraulic model and the placement of the fuel assemblies into the thermal hydraulic flow channels (one or several assemblies per channel) and the axial division of the core. These choices depend on the accuracy and speed requirements set to the application.

The three-dimensional core model uses the cross-section libraries generated with standard fuel management codes. In three-dimensional core model use of macro assemblies with appropriate cross section files is possible, too. Both 1-D and 3-D reactor calculations may include one or more hot channels or hot rods, which are calculated on-line. This feature can be used in sessions involving fuel bundles with partly blocked flow channels.

Connection with the process model

Either 1-D or 3-D reactor model can be directly connected to the nuclear power plant process model. The choice depends on the actual focus of the current analysis task, be it a pipe break or LaSalle oscillations. A training simulator may include both models, the 1-D model directly connected to the process model and the 3-D model running parallel to it on a separate processor. This configuration ensures real time performance without compromising accuracy of the reactor core calculations.



A 3-D reactor core model with 30 thermal hydraulic channels and 169 fuel macro elements.