MODELING OF NPP WITH VVER-1200 BY THE COUPLED SYSTEM CODE ATHLET/BIPR-VVER USING QUASI 3D NODALISATION OF REACTOR PRESSURE VESSEL AND STEAM GENERATORS

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ABSTRACT

A detailed model of the primary and secondary loop of the new design of VVER-1200 NPP is being created for the coupled system code ATHLET/BIPR-VVER. On the basis of the previously gained experience, a very detailed 3D modeling of the reactor pressure vessel (RPV) and of the steam generators (SG) is being successfully applied. The nodalization schemas of these objects are chosen to be optimal ones concerning the fidelity to the real geometry and the needed CPU time. The thermal fluid objects (TFO) are modeled in ATHLET as objects of type 'pipe' most of them connected with cross flows, that allow to describe the mixing phenomena in RPV and in SGs near to reality. A pre-processor system supports automatically to prepare the complex and great number of nodalized volumes for the ATHLET input. A detailed modeling of the control and safety systems covers a wide spectrum of initiating events. Generic design data are used to model the 3D neutron-kinetics in BIPR, applying the modernized fuel assembly design for VVER-1200.

As a demonstration of the simulation capabilities of the coupled system code ATHLET/BIPR-VVER for the new reactor design VVER-1200 a RIA transient is analysed. A rod ejection within 0.1 s is simulated at nominal reactor power.

The results are visualized with a special 3D graphical system developed in RCI KI. This advanced tool allows through rotating the whole model or only selected parts of it to visualize the thermal-hydraulic values at any location. By applying the 'cut' function the internal volumes of the 3D objects can be selected and visualized too.

The coupled system code ATHLET/BIPR-VVER is being applied successfully by performing calculations analysing transients for the new design of a NPP with VVER-1200 reactor.

Introduction

The reactor VVER-1200 is a new, perspective project of VVER reactor type. It is a type of modernized reactor VVER-1000 and it is characterized with an increased thermal power - 3200 MW. The basic purpose of the presented study was a development of a calculational scheme to model the 3D processes in NPP with VVER -1200 by the coupled system code ATHLET/BIPR-VVER /1/.

This work is a natural continuation of the previous developments connected to the application of the coupled system code ATHLET/BIPR-VVER in the field of coarse-mesh modelling of the thermal-hydraulics of water-cooled nuclear power plant. Some previous results of three-dimensional modelling of the core thermal-hydraulics parameters for different transients in VVER-440 reactors and also the transient results of 'Disconnection of one loop in VVER-1000' can be found in /2,3,4/. Results of three dimensional modelling of a steam generator of VVER-1000 reactor are presented in /5/. The space modelling of the steam generator is more complicated because in this case the three dimensional grid of the secondary side is connected through heat structures with the primary circuit. The modellimg of the steam generators is done applying a great number of single pipes most of them connected with cross flows.

The present work shows results of the first application of full 3D model of the reactor pressure vessel and 3D steam generator model for VVER-1200 reactor. This calculation scheme allows to carry out calculations of many transients of NPP with VVER-1200 within a reasonable CPU time of 24-72 hours, depending on complexity of the process.

1 Calculation scheme of VVER-1200 power plant

A modernized spatial modelling scheme of a nuclear power plant with VVER-1200 is applied. Previous detail developments and verifications of separate parts of the model /2,3,4,5/ are considered . The new development of the calculation scheme of VVER-1200 power plant is a further successful implementation of the coupled system code ATHLET/BIPR-VVER comprising the lessons learned from the previous developments.

The geometry of the objects for such an approach is modeled with maximum precision, near to the technical devices' drawings, and the accuracy of the modelling increases by the increase of the number of the nodalization points. But with the increase of the number of the nodes increases also the CPU time, therefore the proposed nodalization scheme is chosen to be an optimal one, which allows to have sufficient accuracy and reasonable calculation CPU time (from 24 till 48 hours depending on complexity of the simulated transient).

1.1 Calculation scheme of the primary circuit

The calculation scheme of the primary circuit includes the following basic elements:

- reactor pressure vessel
- hot and cold loops with main circulation pumps
- hot and cold collectors of steam generator
- steam generator tube packages
- pressurizer with heaters, spray valves and safety valves
- make-up and blow down system
- boron injection systems
- systems of emergency boron injection and passive safety systems

Nodalization scheme of the first circuit is presented in Figures 1 – 5.

In Figures 1-3 are shown the nodalizations of: downcomer (with cold leg nozzles), upper plenum, hot and cold loops, hot and cold collectors of the steam generator.

Reactor pressure vessel is modeled (Figure 4) with: 16 downcomer sectors, 4 levels of lower plenum, each one of 163 assemblies is separately modeled and 2 level upper plenum. Each assembly has 12 axial nodes. The source of heat generation is calculated and automatically distributed from the neutron kinetic calculation module of BIPR. Perforated grids plates, perforated barrels and assembly shank are also modeled and taken into account.

The model of the steam generator from the secondary side is presented in Figure 5. The surface of the U-tubes is the connecting thermal-hydraulic link between the primary and secondary sides of the NPP. This surface is modeled in system code ATHLET by quite detail heat structures. The elements of the heat structures are in adjustment with the thermal-fluid hydraulic objects' nodalization of the SG from both sides (primary and secondary). Each U-tube is considered by the modeling of the SGs. It is possible also to combine the U-tubes in dependence of desired different detail description and to decrease possible deviations in the first and secondary circuit (Figure 5).

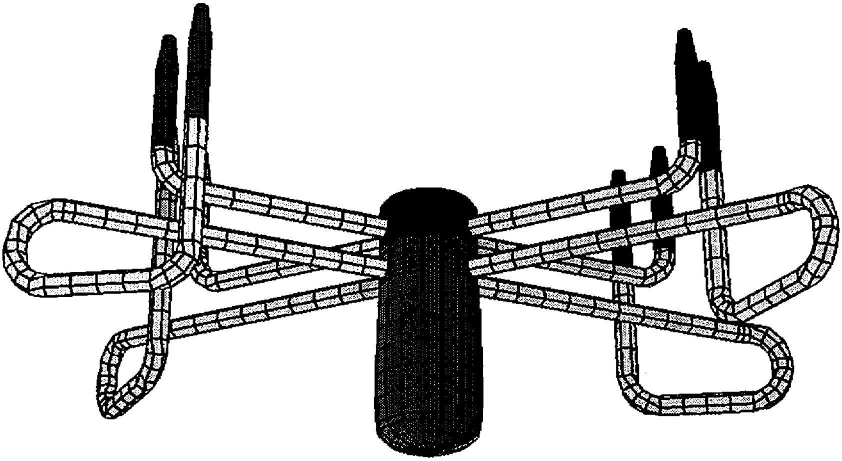

Fig. 1 Primary circuit nodalization (one side view)

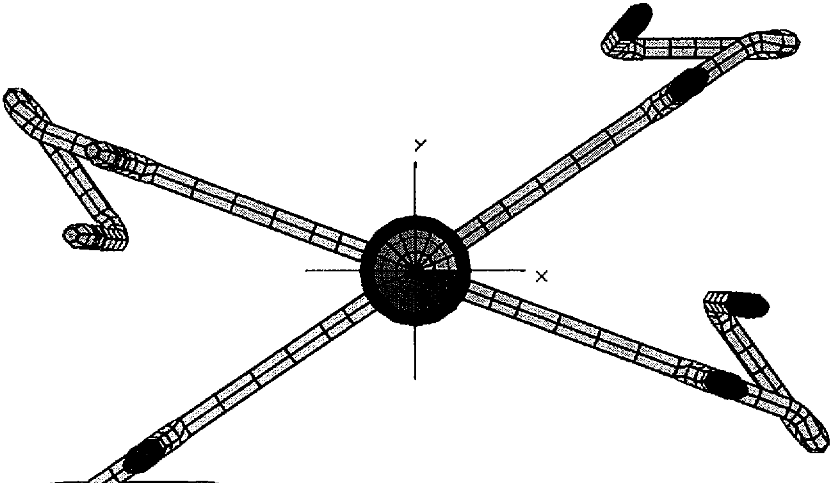

Fig. 2 Primary circuit (upper view)

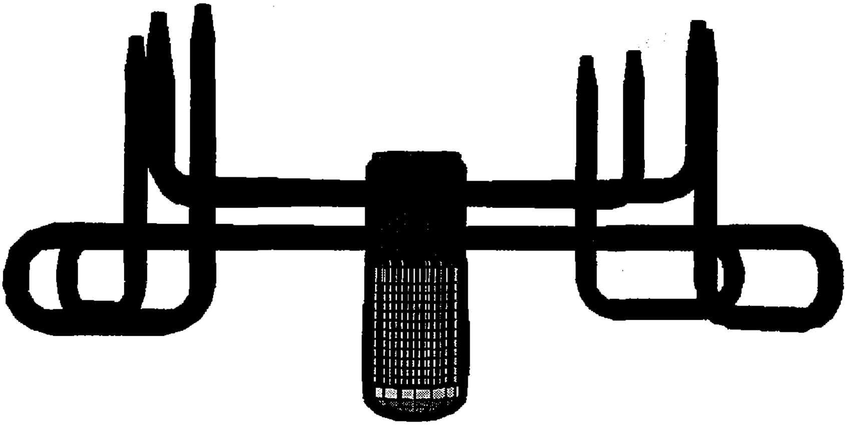

Fig. 3 Primary circuit (in a slit view)

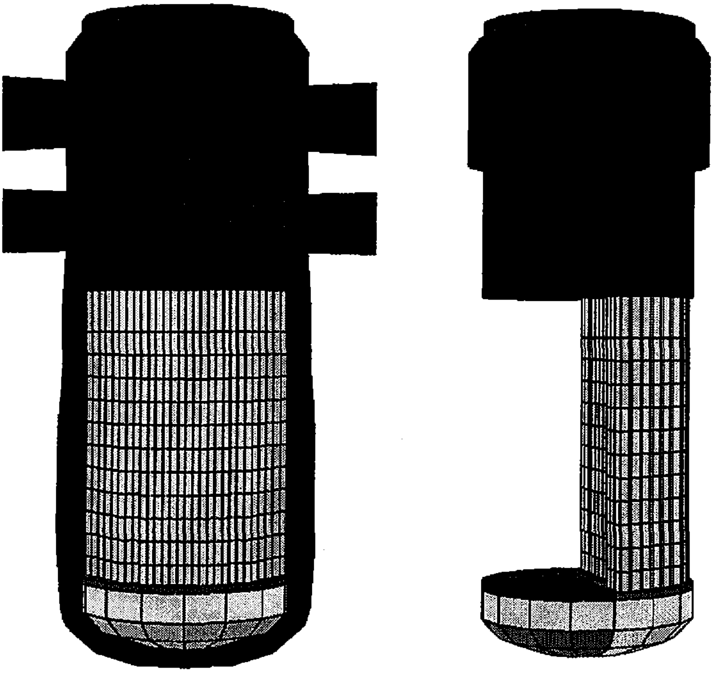

Fig. 4 Reactor pressure vessel nodalization scheme: downcomer, upper plenum, assemblies and lower plenum

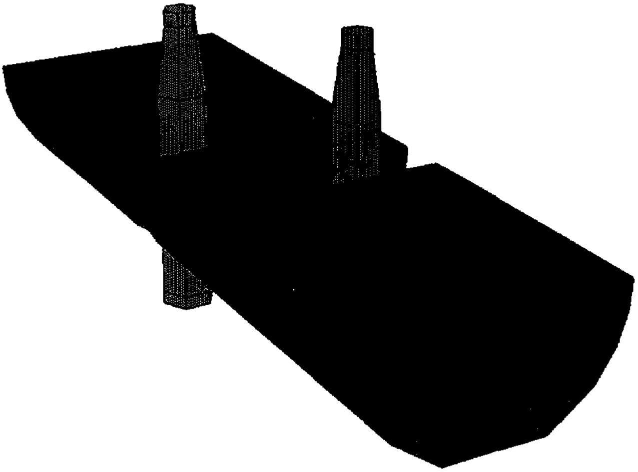

Fig. 5 A set of thermo-fluid objects describing the steam generator U-tubes and the collectors to which they are connected

1.2 Calculation scheme of the secondary circuit

Calculation scheme of the secondary circuit consist of the following main parts:

- steam generators
- steam line system with preventive valves from steam generator up to the turbine, BRU-A, BRU-K, fast closing isolation valve, BRU-CH, reverse valves
- steam line system beginning from main, auxiliary and emergency feed water pumps up to the steam generator, including a regulating and cutting-off armature
- emergency cooling down system of the steam generators

The model of each steam generator from the secondary side includes:

- main volume of the steam generator (Fig. 6), modeled by means of a cylinder with a volume equal to the real volume of the SG. This SG construction has an elliptical form of the both sides. The main volume of the steam generator is divided into several parts, which coincides to those described in /3/ with a high degree of detail modelling. The elements being in the region of thr elliptical end of the steam generator are in a correct adjustment with actual volume achieving that by changing (decreasing) the volume of the grid elements. All neighboring parts are connected with each other, forming a three dimensional connected grid.
- steam lines and steam collectors - Fig. 6
- feed water system with collector and supply lines – Fig. 7
- wide and narrow steam generator level measurement device

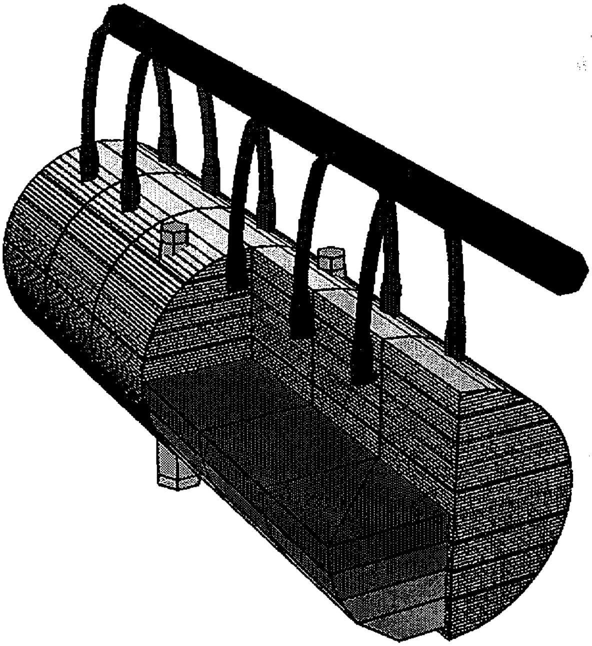

Fig. 6 Full scheme of hydraulic nodalization of the steam generator and its elements without feed water collector

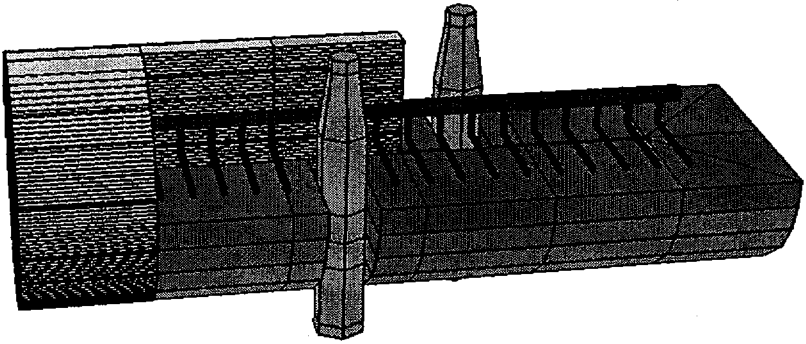

Fig. 7 Feed water collector location

2 Steady state calculation

In accordance with the above described NPP nodalization scheme an input deck was developed for the coupled sytem code ATHLET/BIPR-VVER and steady state calculation was carried out. The initial conditions applied for the present thermal hydraulic calculation are presented in Table 1.

Table 1 Initial conditions

Parameter	Value
Power, MW	3328 (104%)
Temperature at core inlet, °C	298
Pressure at core outlet, MPa	16.3
Number of operating RCPs	4
Core coolant flow rate, m^3/hour	86000
Steam pressure at steam generator outlet, MPa	7.08
Feed water temperature,°C	225

The reached calculated steady state parameters of the NPP after some iteration steps between ATHLET and BIPR are presented in a three dimensional visualization way - Figures 8-12. The presented figures in Chapter 3 are examples of performing a RIA transient (rod ejection).The main NPP parameters after the steady state calculations have converged to stabilized values. Some small oscillations of the feed water rate and of the steam mass flow could be explained with the operation of the feed water and turbine regulators which are trying to keep the prescribed positions of the regulating valves' positions.

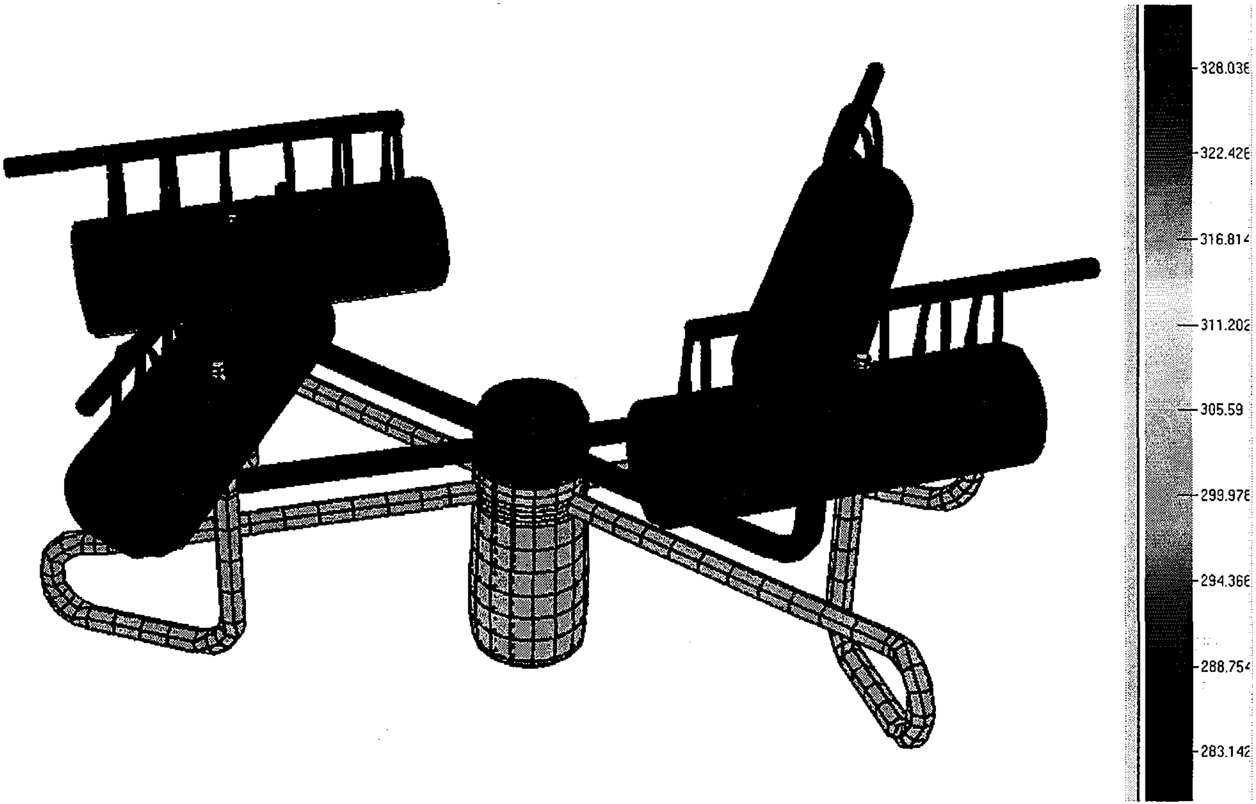

Fig. 8 Coolant temperature spatial distribution after steady state calculation,°C

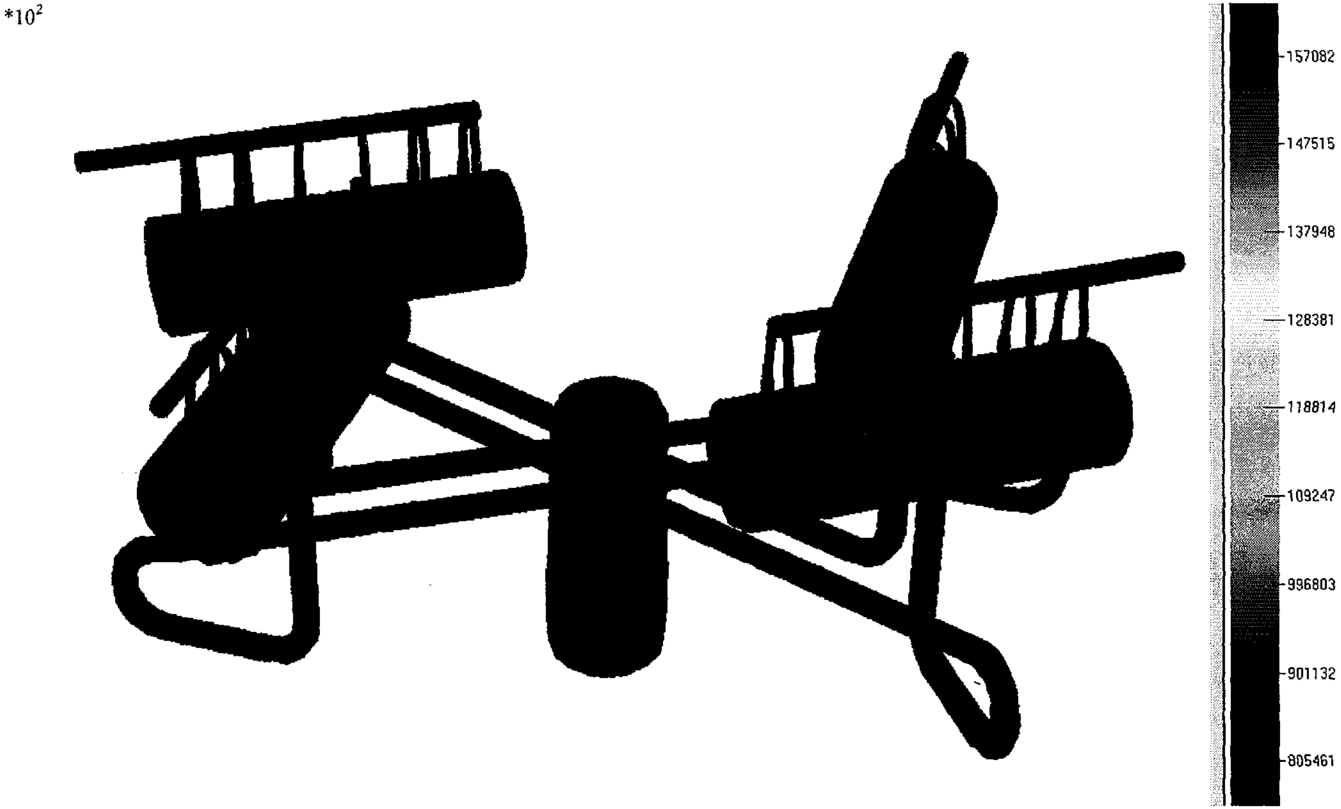

Fig. 9 Coolant pressure spatial distribution before the transient, Pa

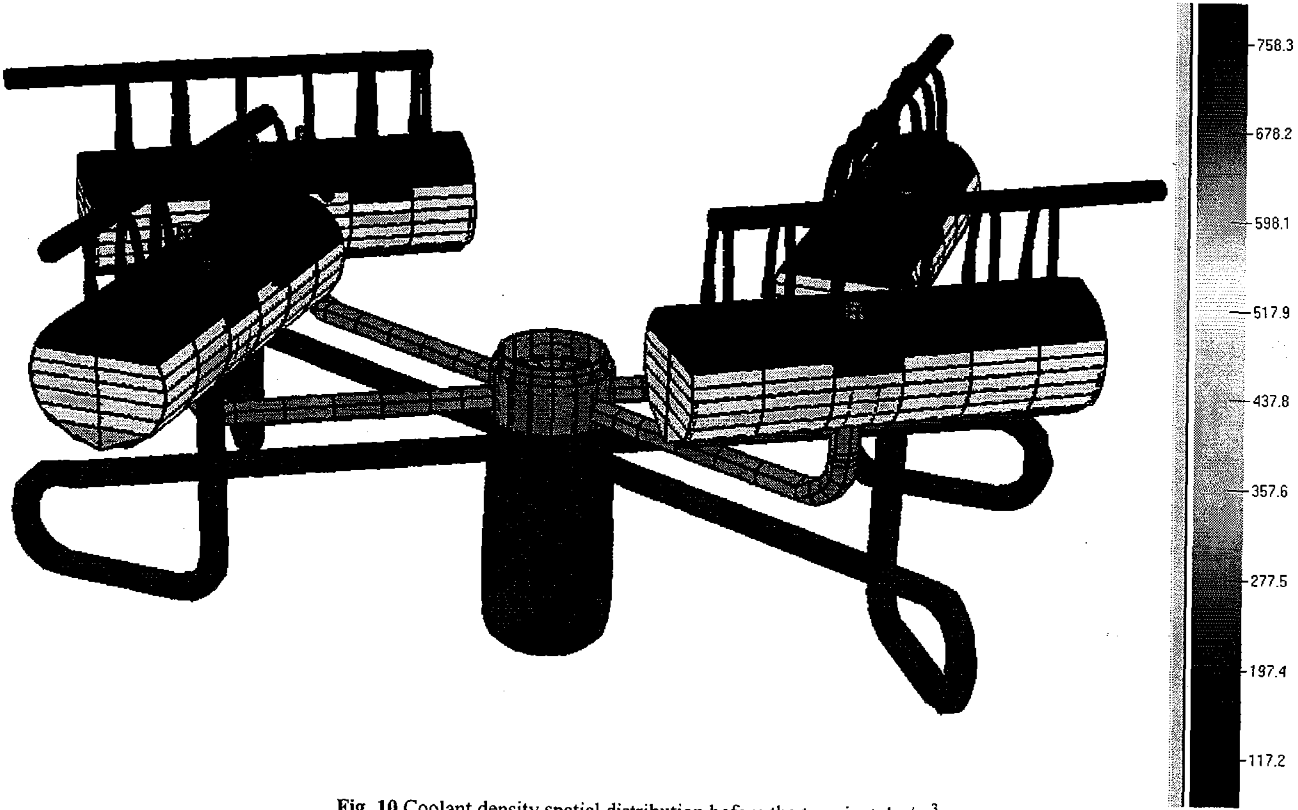

Fig. 10 Coolant density spatial distribution before the transient, kg/m^3

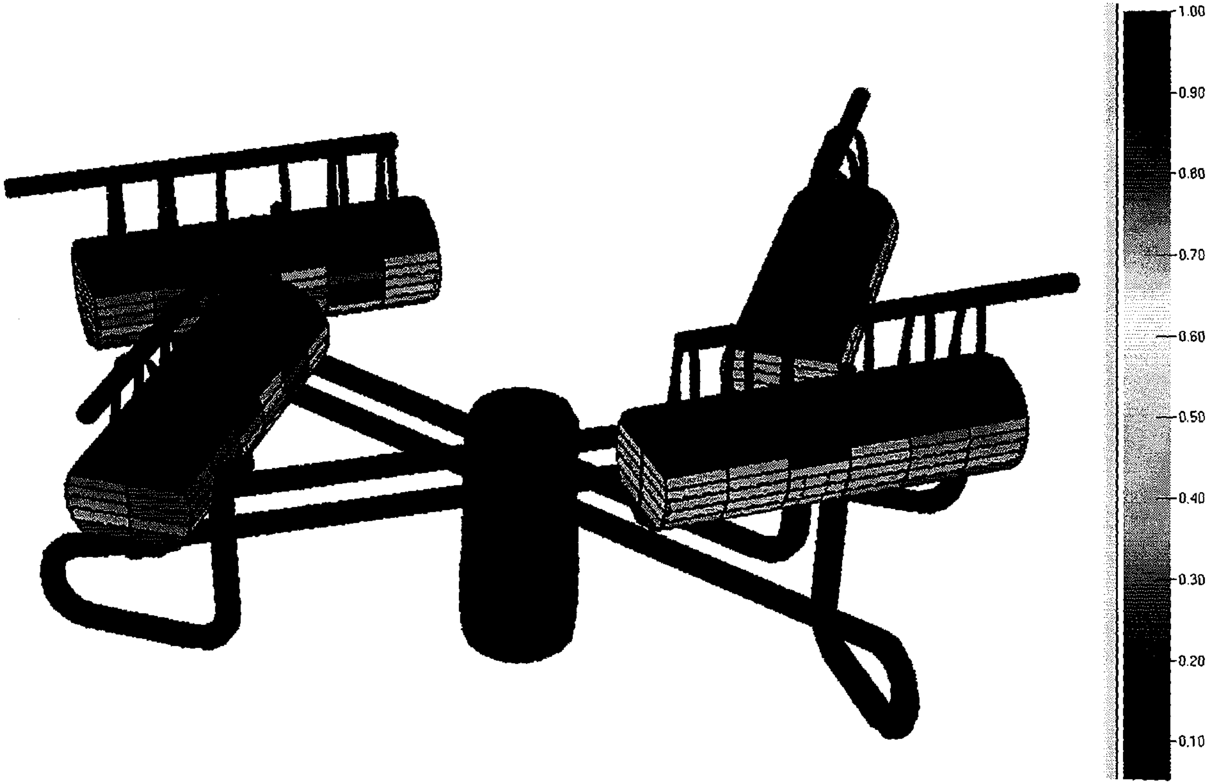

Fig. 11 Vapour fraction of coolant spatial distribution before the transient starts, rel. units

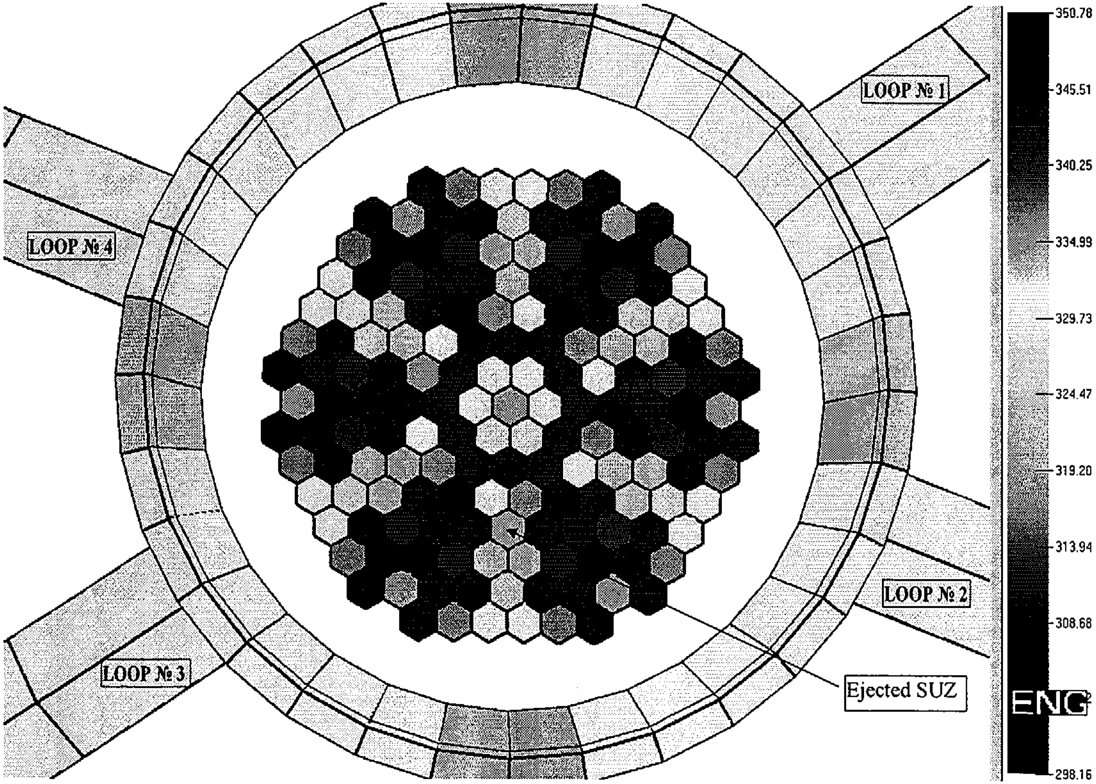

Fig. 2 Coolant temperature at assemblies' outlets, upper plenum and hot legs (top view). The ejected SUZ and loops numbers are shown.

3 Application of the calculational model. Rod ejection accident at full power without scram.

3.1 Brief description of the process

As an example of the developed model application, rod ejection accident at full power without scram is demonstrated.

The location of the ejected rod is shown in Fig. 12. The process is initiated at t = 0 seconds. The control rod is ejected from 0 % position at the core bottom in 0.1 s. The ejection rod results insertion of a positive reactivity which leads to an increase of reactor power. Due to the strong negative Doppler effect the reactor power sharply decreases and reactor continues to operate at a lower power level. It can be seen the clear warping of neutron field at the area of the ejected rod position. The local power peak in this core sector leads to coolant temperature increase in the near located to the core outlet hot legs - second and third loops. Steam generators of these loops are loaded more than the other two. It leads to a pressure and water level increase in these steam generators.

3.2 Calculation results

The time history of the main reactor parameters are presented in Fig. 13-24.

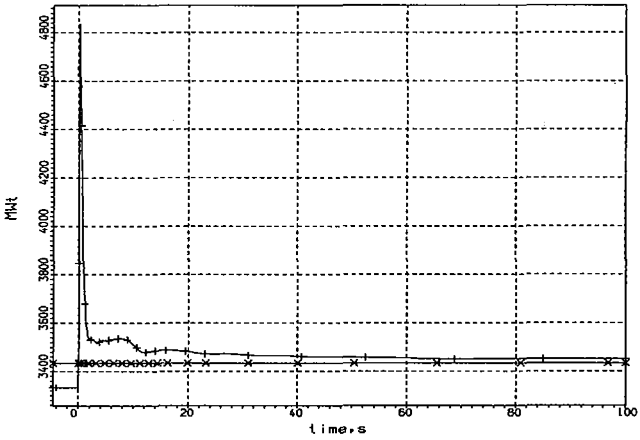

Fig. 13 Neutron power (+) and power set point of the scram 107% (x)

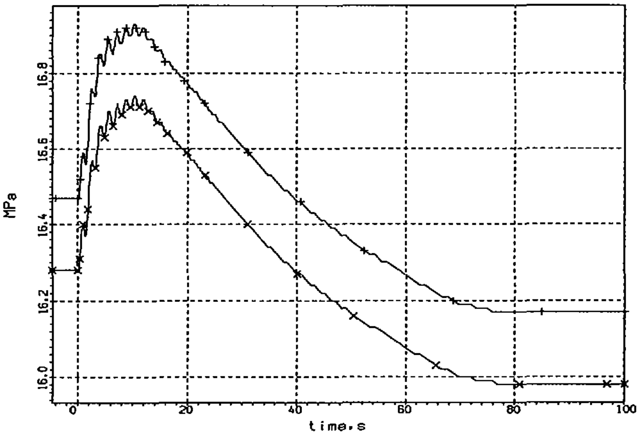

Fig. 14 Reactor pressure histories at inlet (+) and outlet (x)

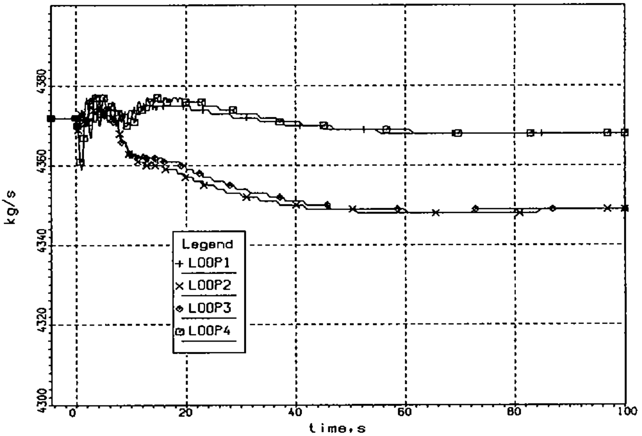

Fig. 15 Loops' coolant mass flows

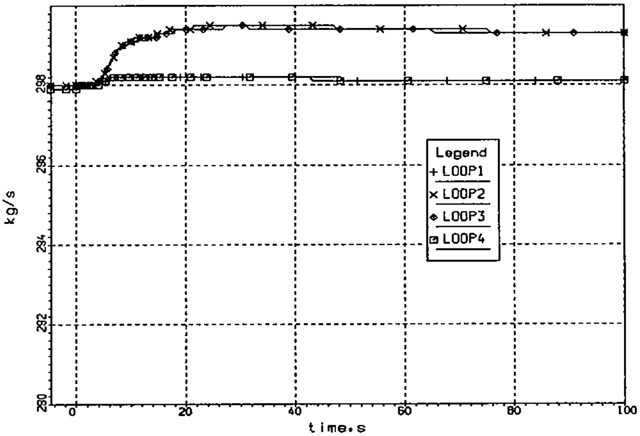

Fig. 16 Cold legs' coolant temperatures

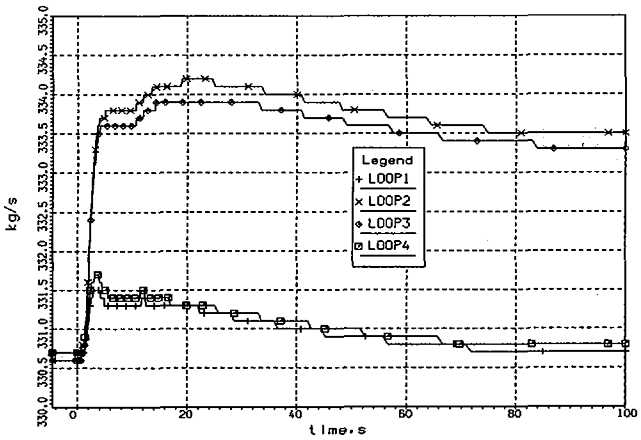

Fig. 17 Hot legs' coolant temperature

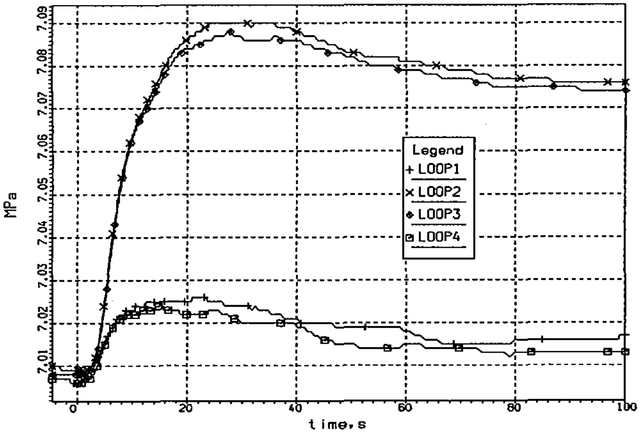

Fig. 18 Pressure at the steam generator outlets

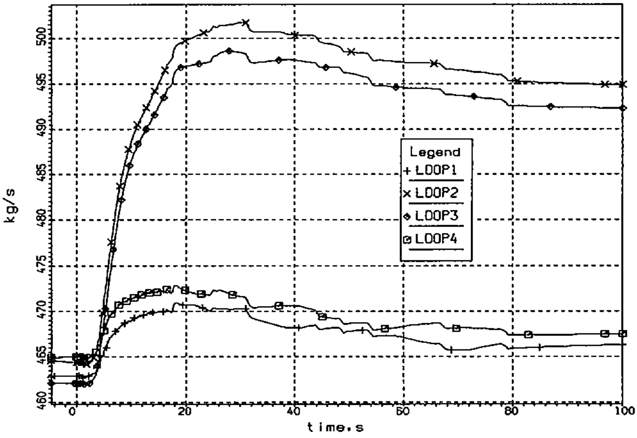

Fig.19 Steam mass flow at the steam generators outlet

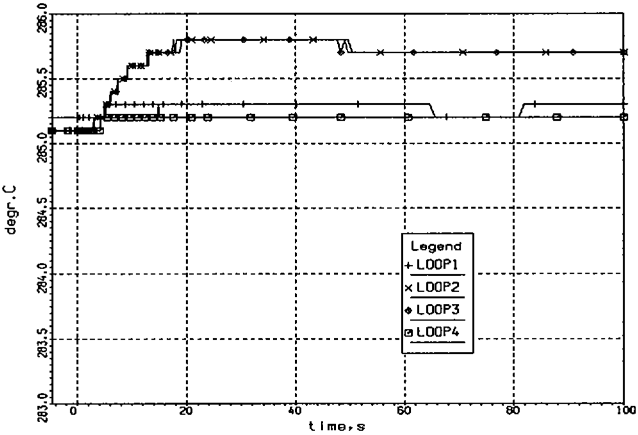

Fig. 20 Steam temperature at the steam generators outlets

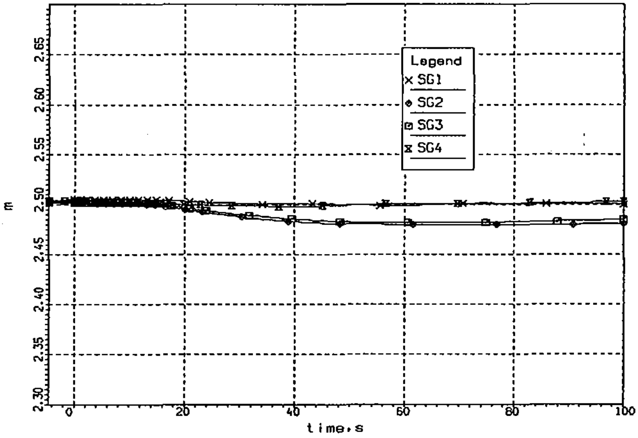

Fig. 21 Water level of steam generators by large level measurement.

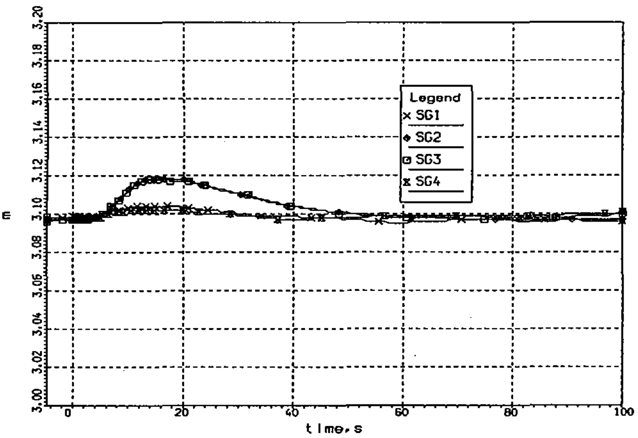

Fig. 22 Water level of steam generators by narrow level measurement

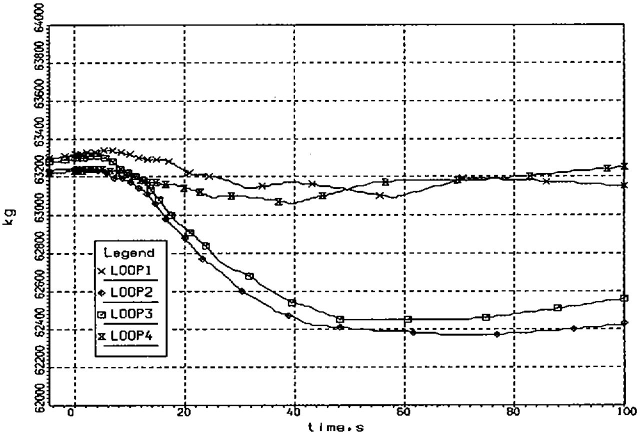

Fig. 23 SG water mass

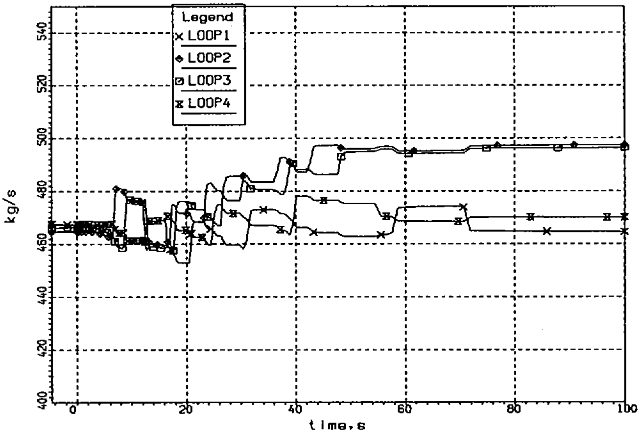

Fig. 24 SG feed water mass flow

Conclusion

- Calculational model of a VVER-1200 power plant for the coupled system code ATHLET/BIPR-VVER has been created and tested
- The developed methodology is applied for analogical calculational models for all types of NPP with VVER reactors
- The model allows to follow visually the main process parameters at any location of the NPP
- The model allows as exact as desired to describe (nodalize) any parts of the reactor and steam generators, which are of more detail interest

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