IAEA Technical Meeting on the Use of Nuclear Facilities and Simulators as Effective Tools for Education and Preserving Knowledge

Nuclear Training Centre of
Jožef Stefan Institute

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Application of WWER-1000 Reactor Department Simulator for Education and Preserving Knowledge Purposes

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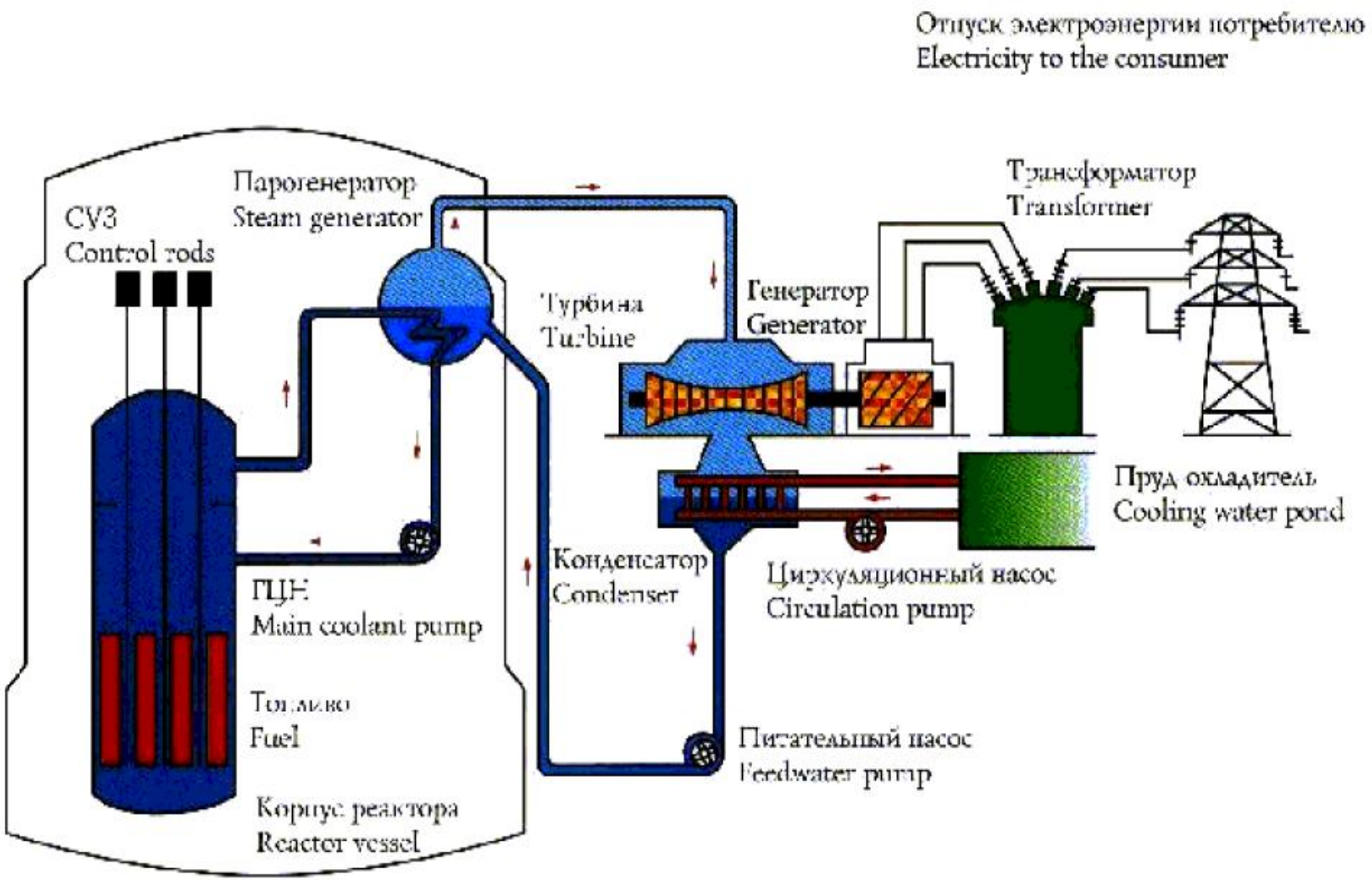
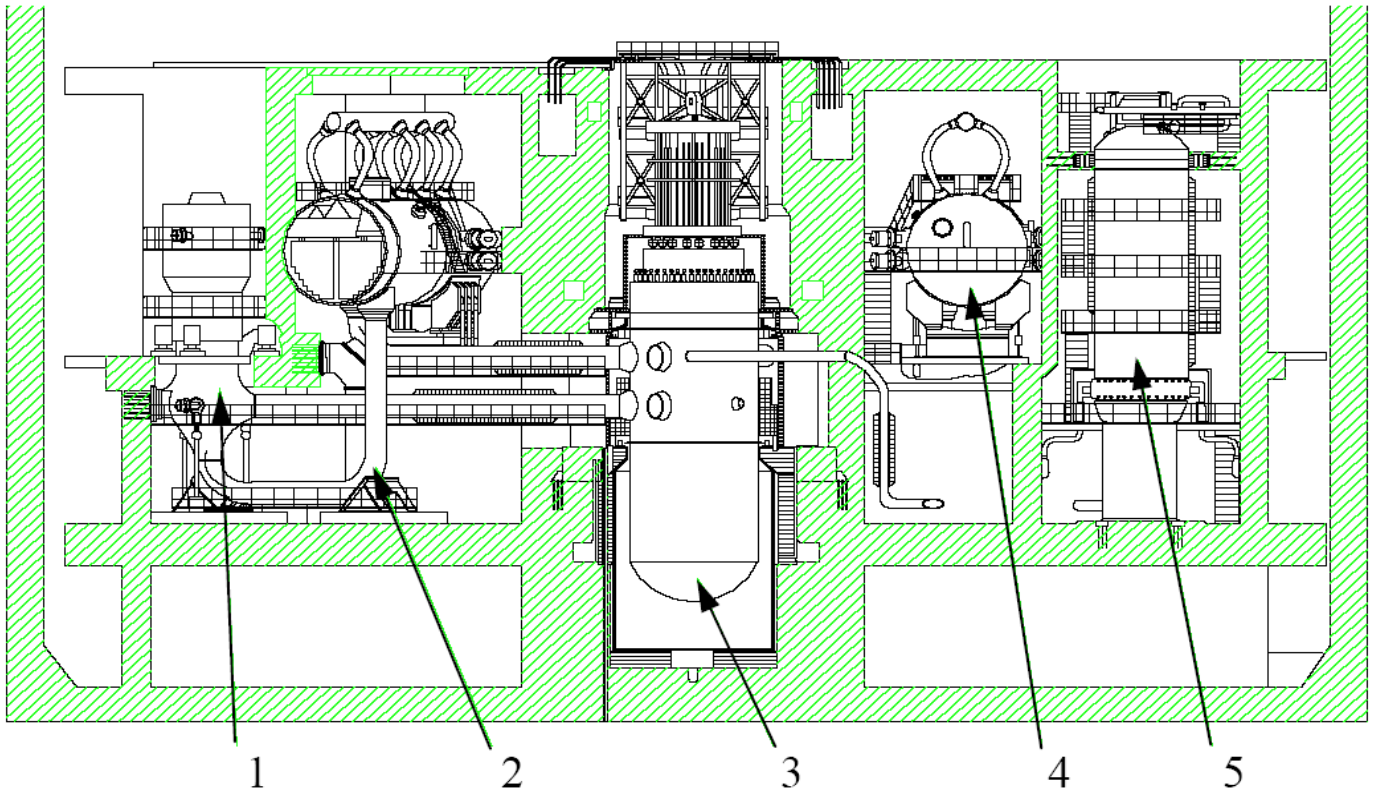
Key moments of WWER-1000 reactor construction

Schematic diagram of NPP with WWER reactor

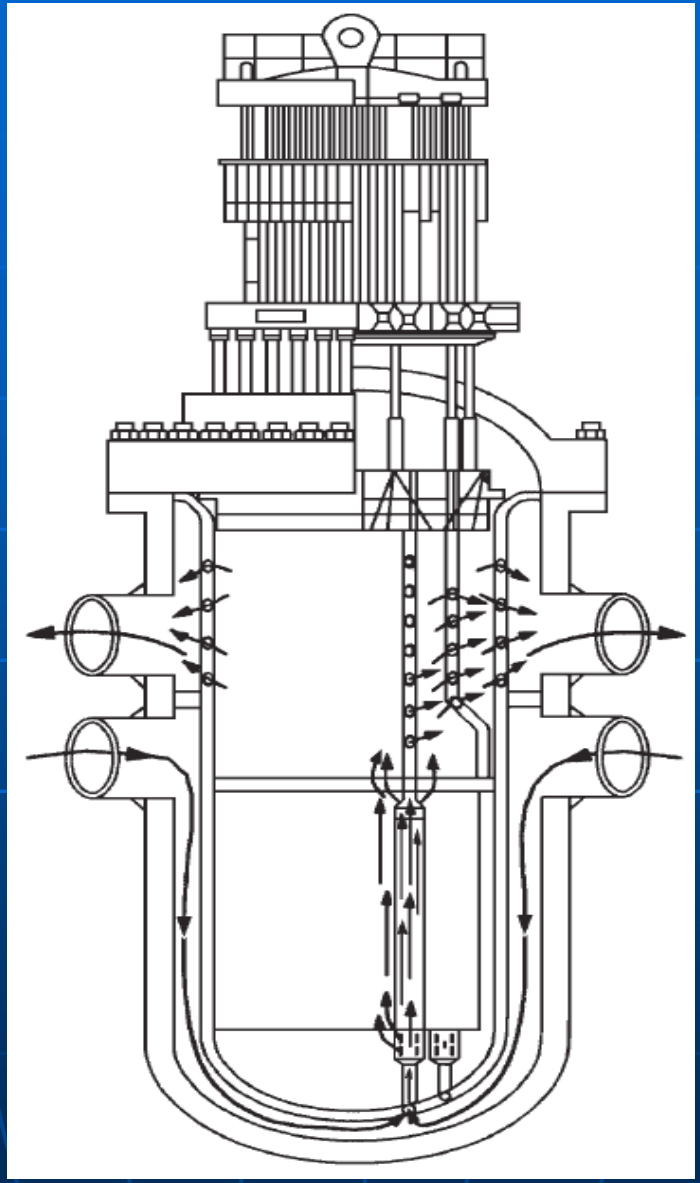


Crosscut view of WWER-1000 containment

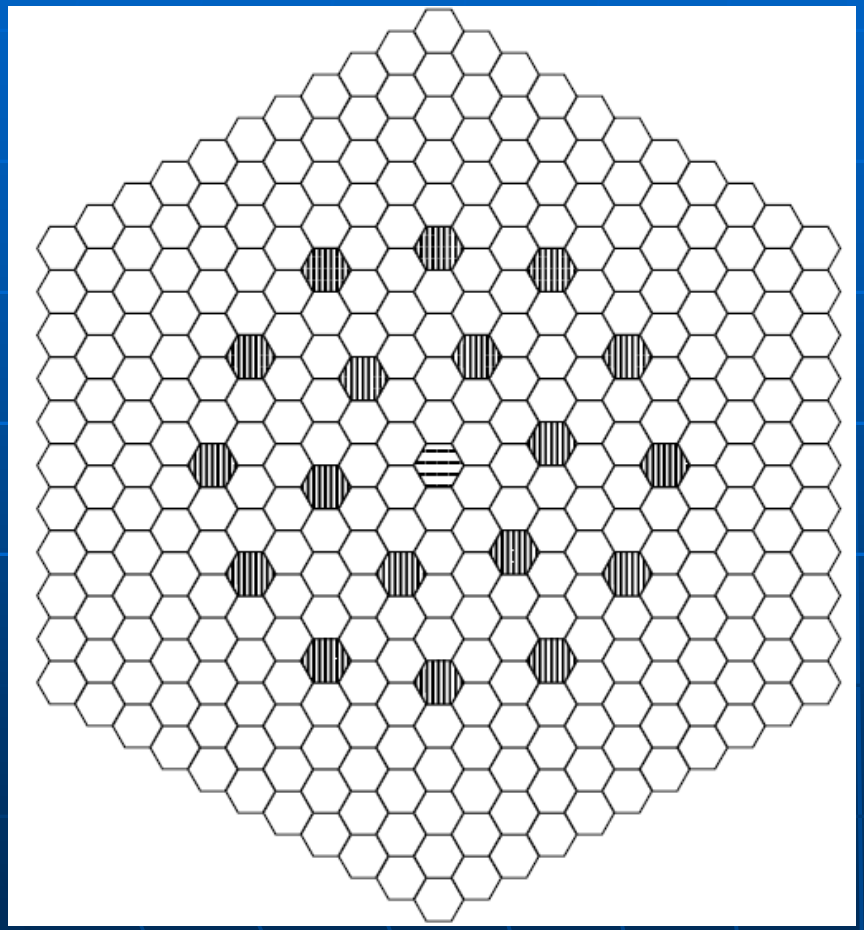


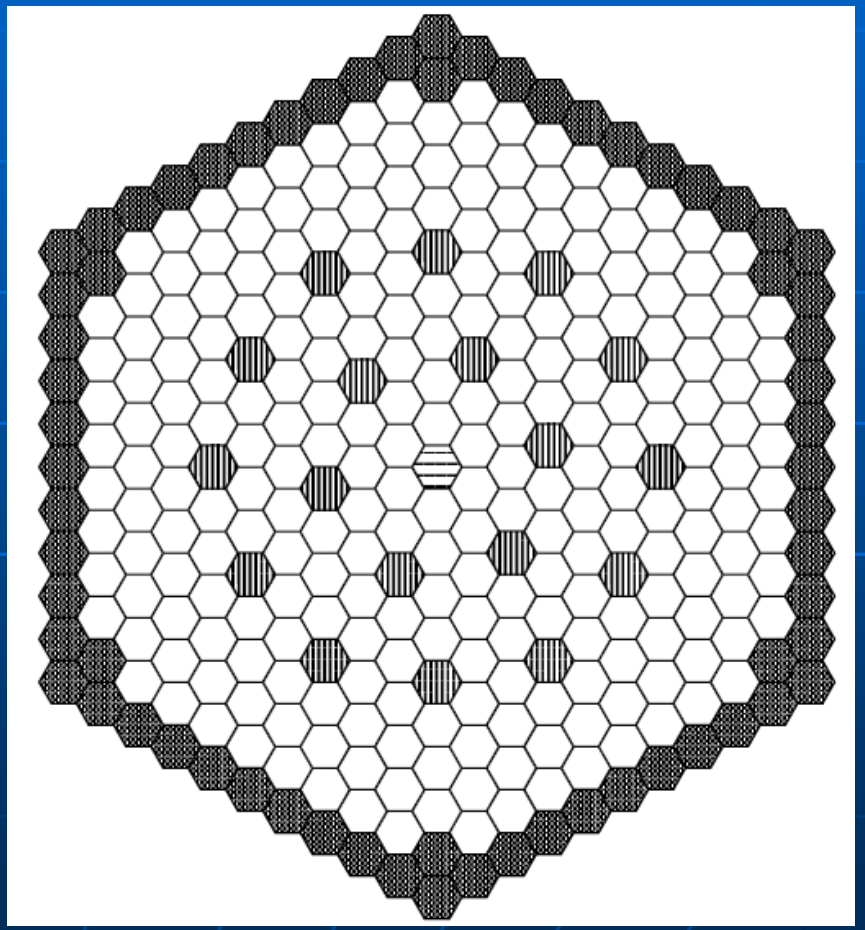
1. Main Circulation Pump
2. Primary Circuit Pipelines
3. Reactor Vessel
4. Steam Generator
5. Pressurizer

WWER-1000 reactor general view



WWER-1000 Fuel Assemblies





Computer Simulating Systems

- WWER-1000 Reactor Simulator
- WWER-1000 Reactor Department Multi-Functional Analyzer (MFA-RD)

WWER-1000 Reactor Simulator

- Is a part of IAEA Collection of PC-Based Simulators for Education
- Provides insight of the design as well as a clear understanding of the operational characteristics of WWER-1000 reactor
- Demonstrates main physical phenomena in WWER-1000 reactor
- Can be used as an introductory educational tool as well as a tool for developing of nuclear engineering courses

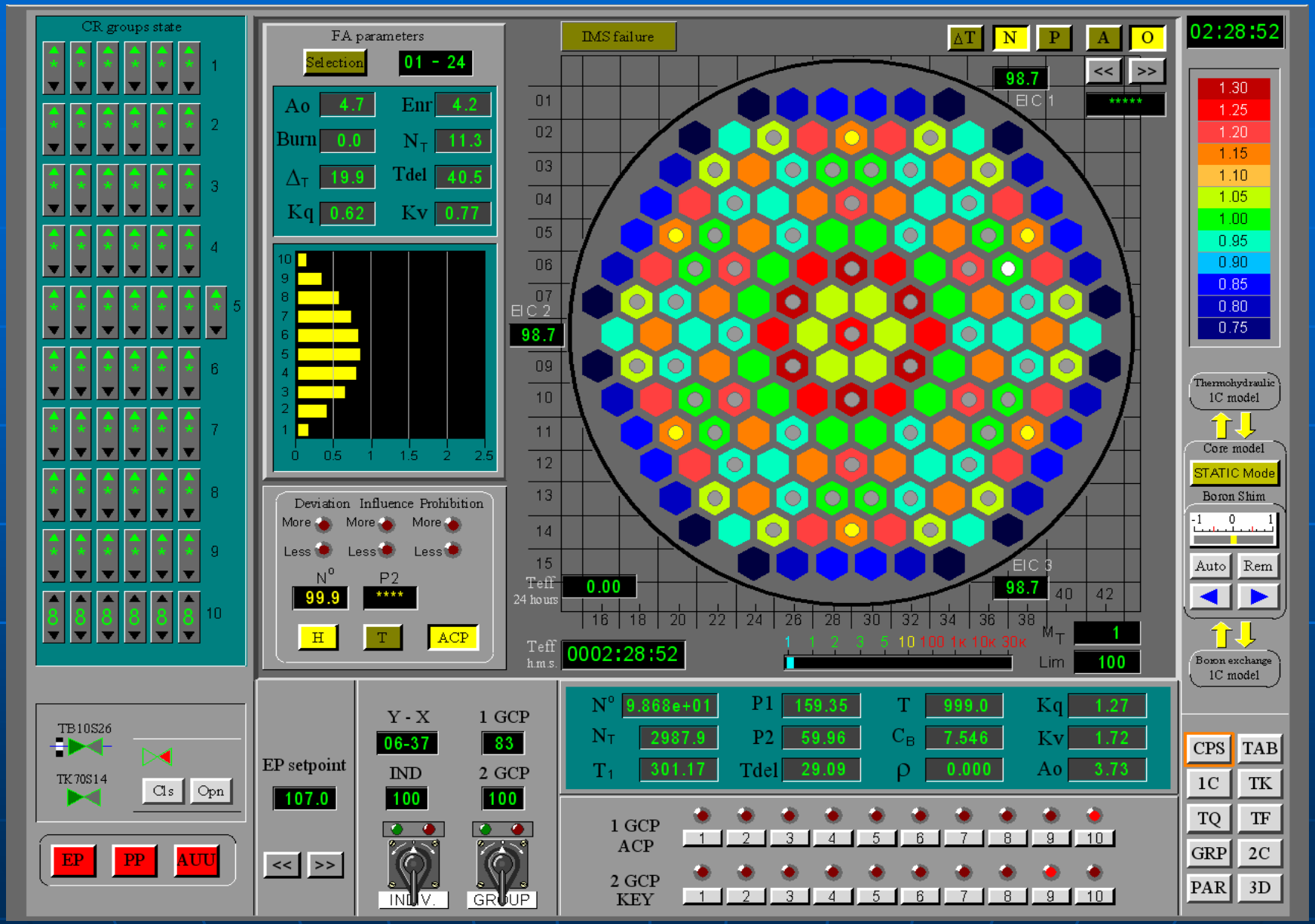
WWER-1000 Reactor Simulator

- Application is limited to providing general response characteristics of WWER-1000 reactor
- Is not intended to be used for plant-specific purposes such as design, safety evaluation, licensing or operators training

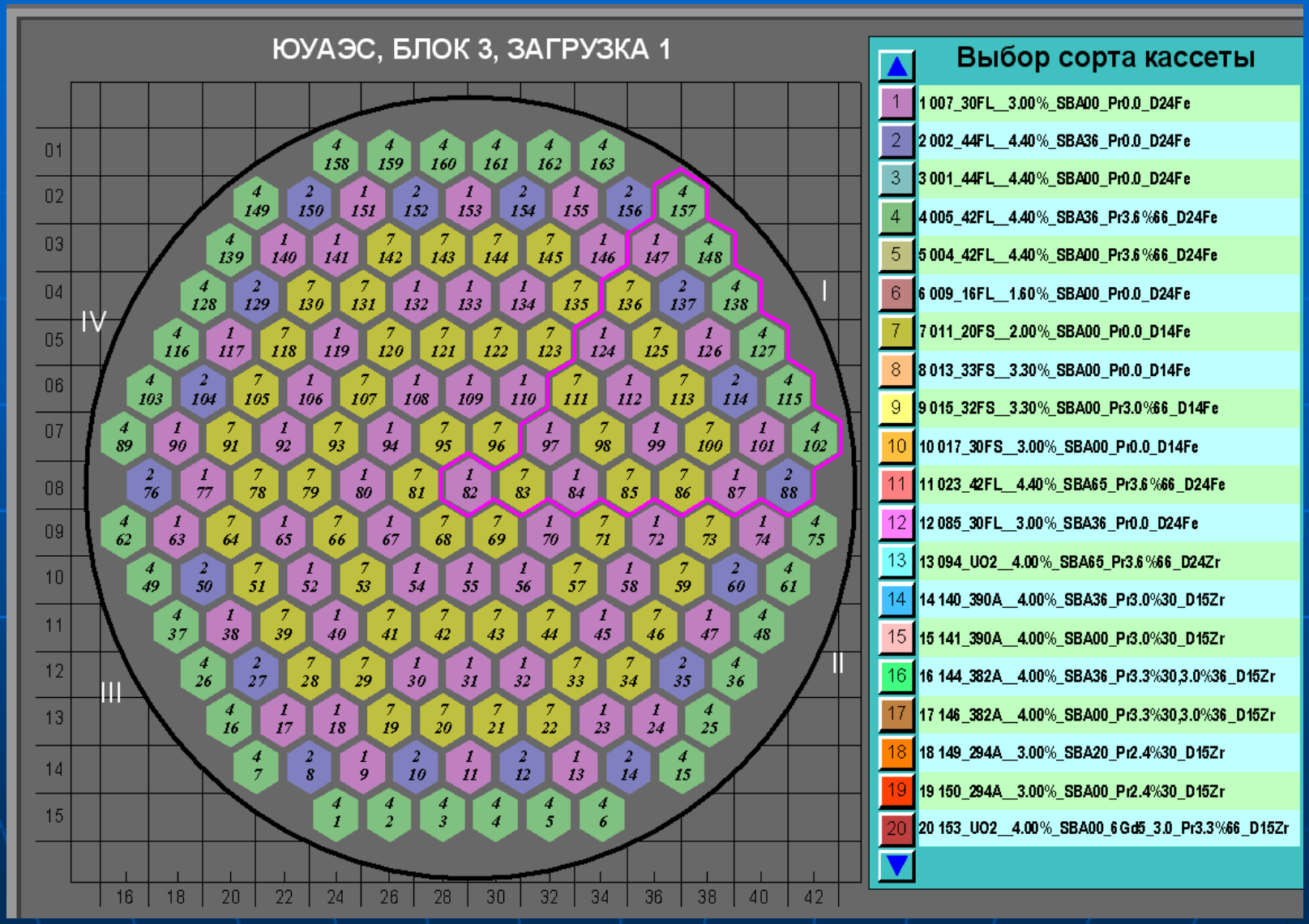
Scope of modeling

- Reactor
- Primary circuit: main circulation pipelines, main circulation pumps (MCP), steam generators (SG)
- Pressurizer and primary circuit pressure compensating system
- Primary circuit feed and bleed system, including boron regulation
- Secondary circuit steam lines and feed water pipelines
- Control and protection system
- Safety systems

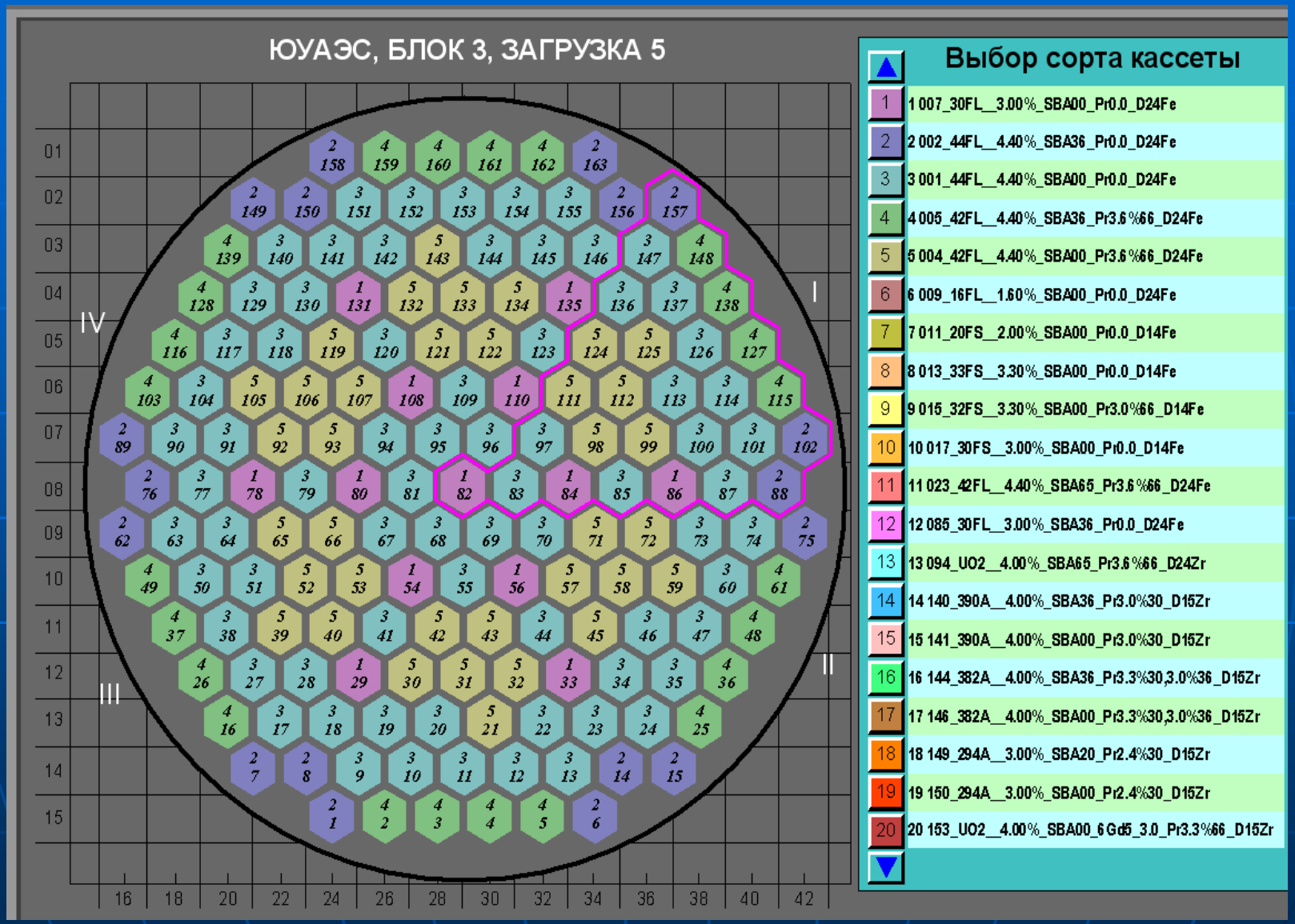
Reactor Core



Reactor Core 1st Load



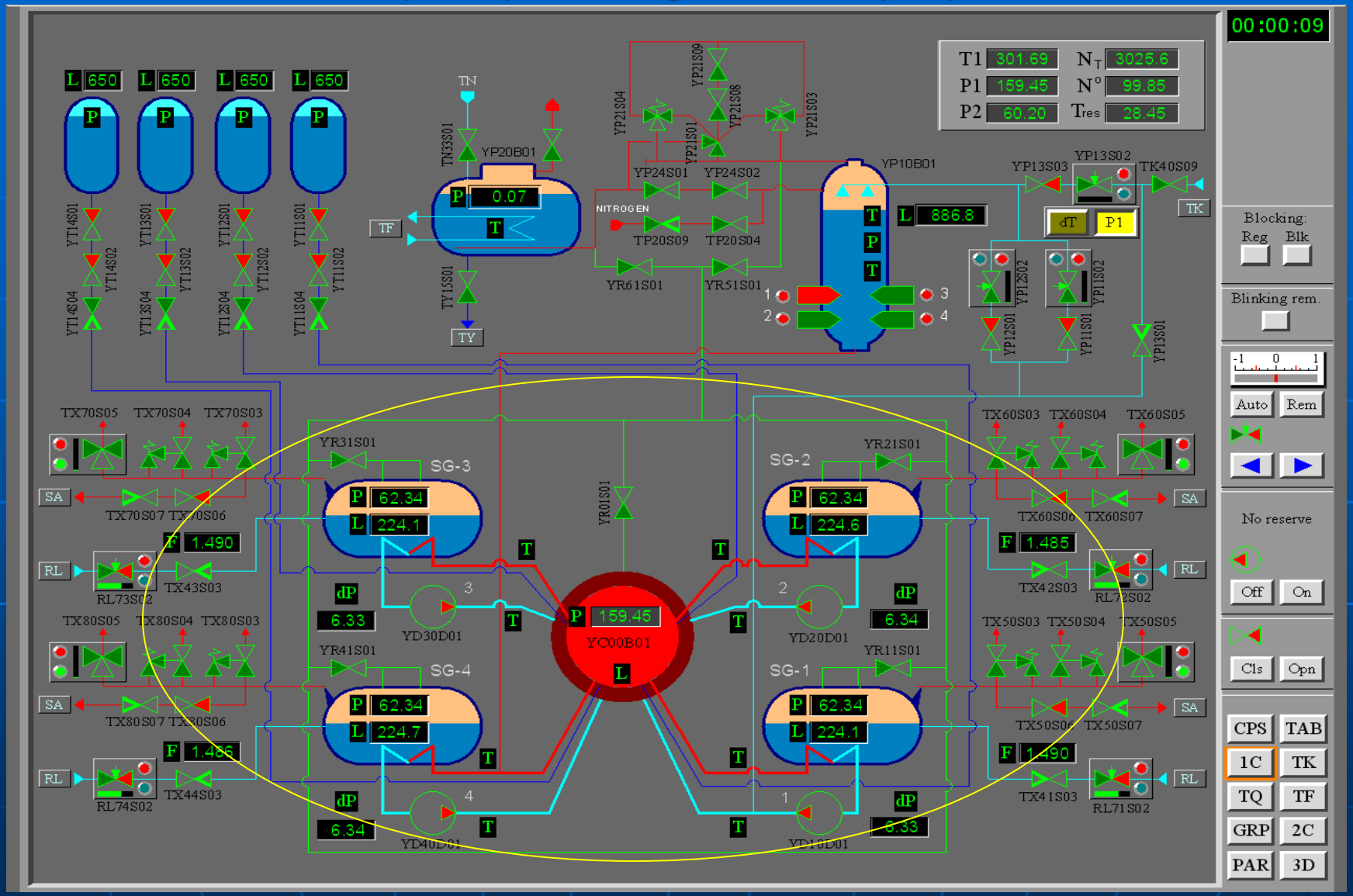
Reactor Core 5th Equilibrium Load



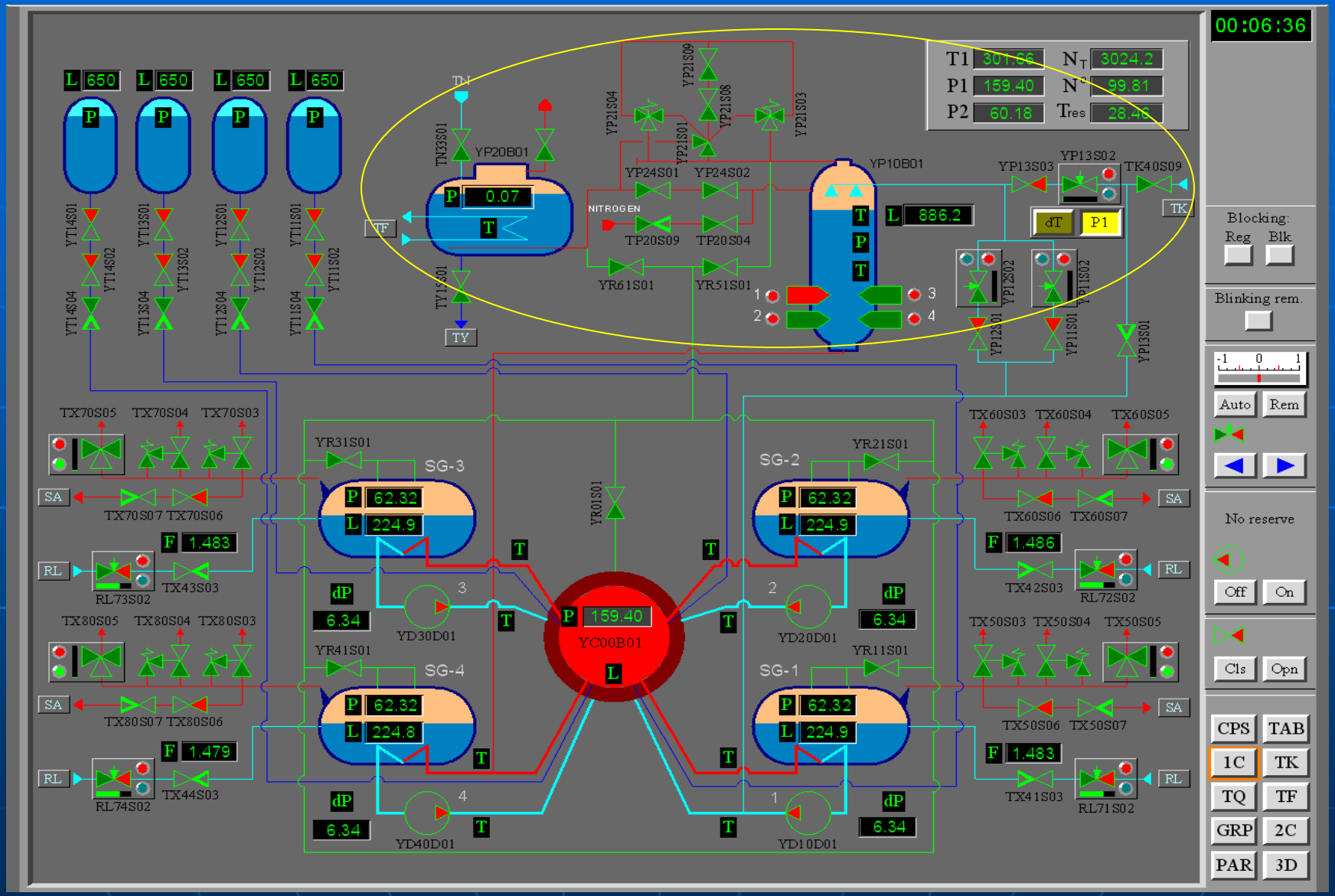
FA of 1st and 5th Core Loads

FA description	FA ID number on the core map above
UO2 enrichment 2%	7
UO2 enrichment 3%	1
UO2 enrichment 4.23% + Boron Absorber Inserted	4
UO2 enrichment 4.4% + Boron Absorber Inserted	2
UO2 enrichment 4.23% + Boron Absorber Removed after 1st year	5
UO2 enrichment 4.4% + Boron Absorber Removed after 1st year	3

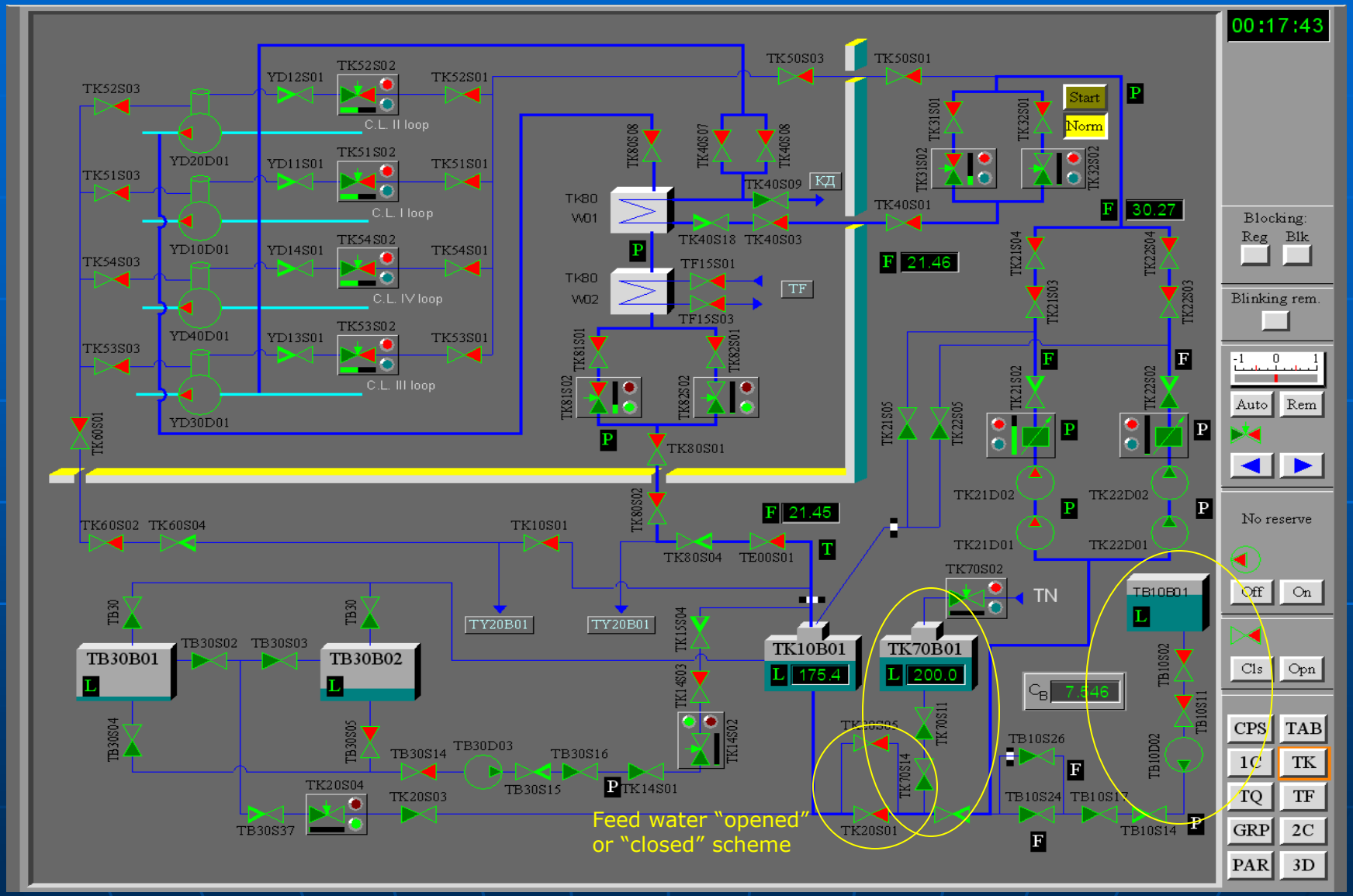
Primary circuit: main circulation pipelines, main circulation pumps (MCP), steam generators (SG)



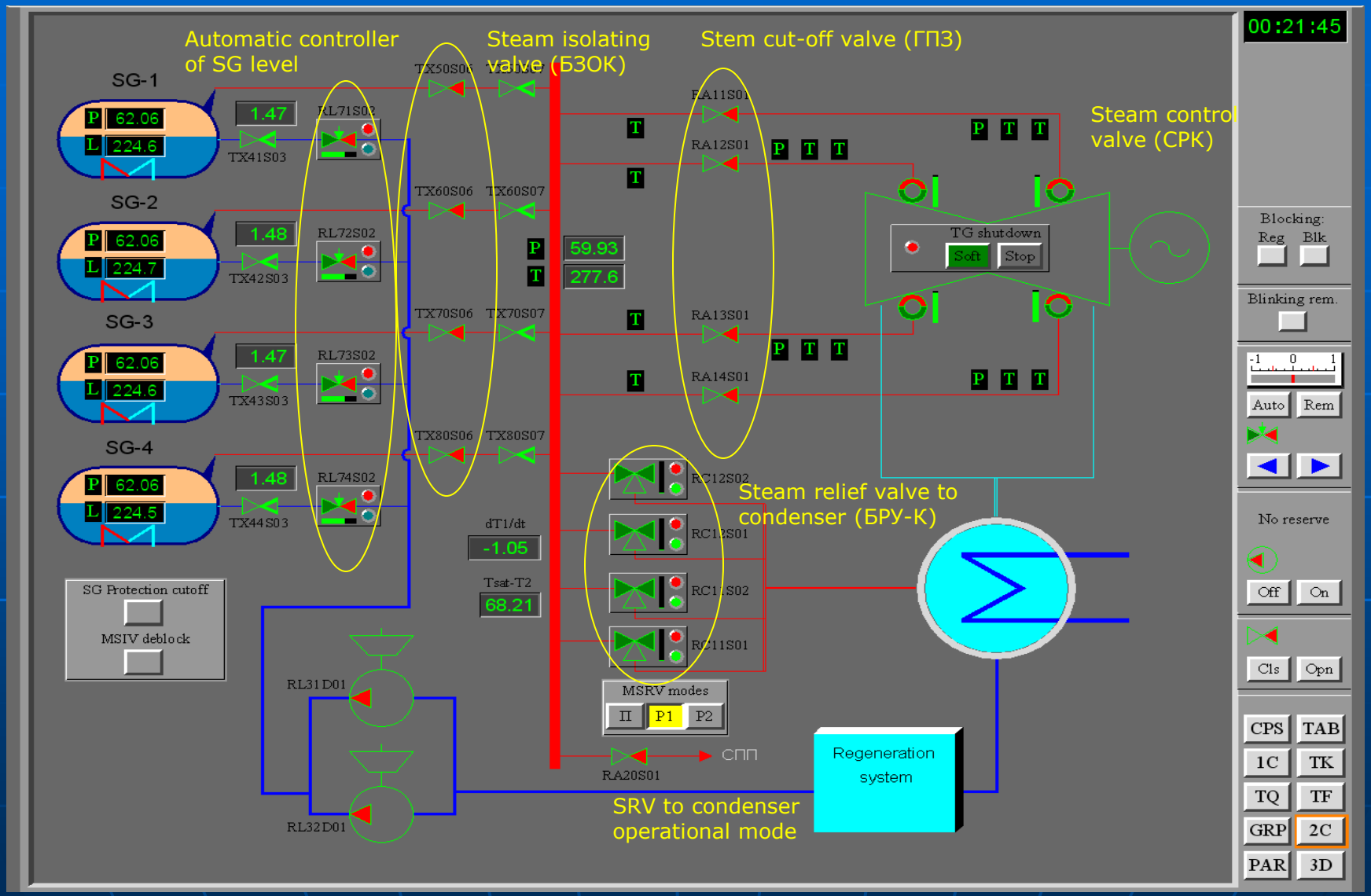
Pressurizer and primary circuit pressure compensating system



Primary circuit feed and bleed system, including boron regulation



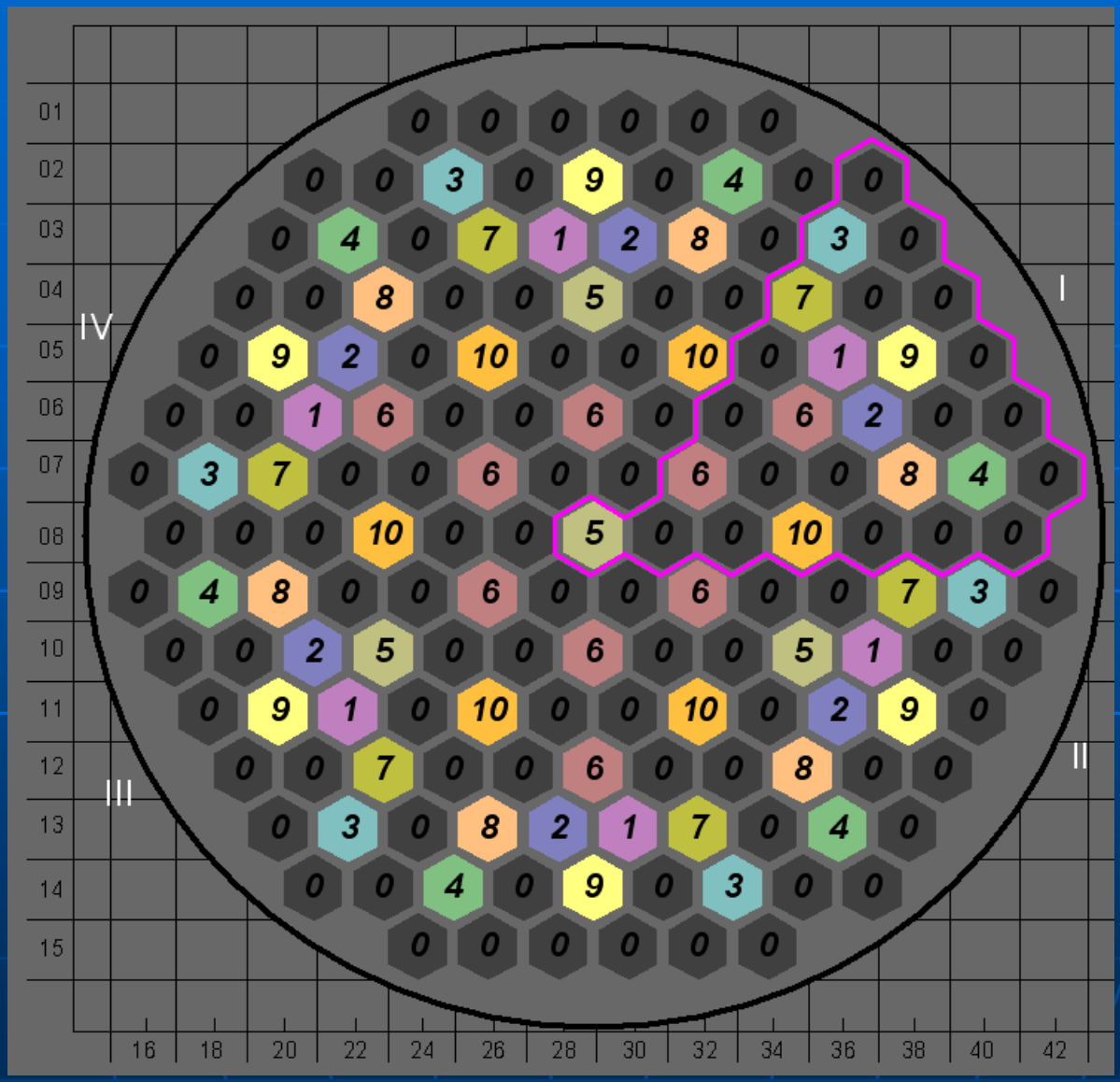
Secondary circuit steam lines and feed water pipelines



Control and protection system (CPS)

- Control rods (CR) system
- Boron regulation system
- Ex-core instrumentation system
- Systems of
  - emergency protection (EP)
  - preventive protection (PP)
  - accelerated unit unload (AUU)
  - etc.

Control rod system

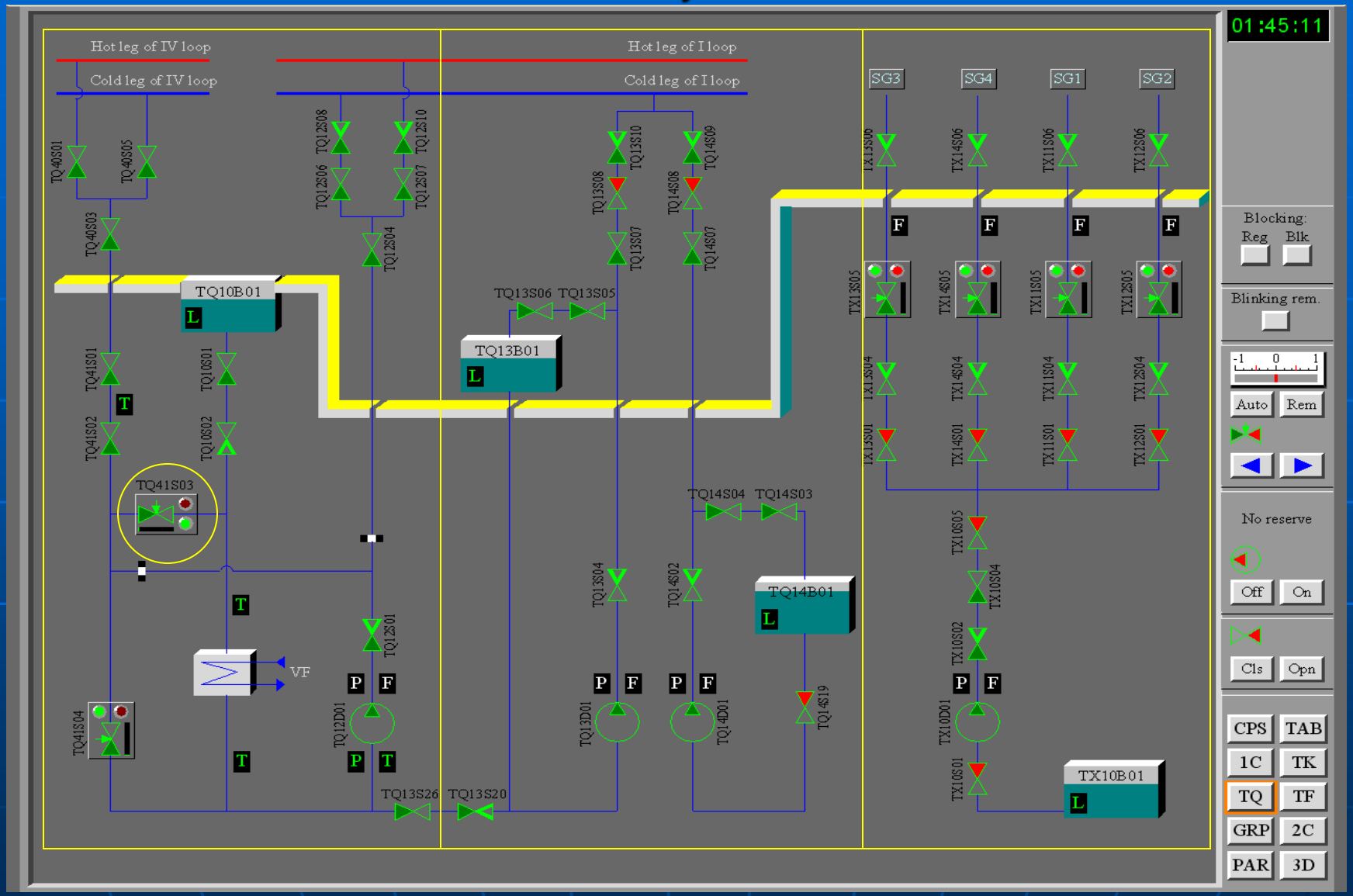


CPS signals page

Safety systems

- Emergency (and normal operation) core cooling system
- Emergency boron supply system (low and high pressure parts)
- Steam generators emergency feed water system
- Primary and secondary circuit over-pressure protection systems
- Control and protection system

Emergency core cooling, boron supply and steam generators feed water systems



Scope of simulation

- Normal operational conditions, including reactor startup, working at rated power level and reactor shutdown
- Abnormal operational conditions like reactor cooling pump trip, valves closure etc.
- If malfunction can be removed it's possible to come back to normal operational conditions

Physical phenomena into reactor core simulation

- Transients on prompt and delayed neutrons
- Xenon transients coursed by changes of reactor power level
- Xenon radial and axial power distribution oscillations
- Samarium poisoning
- Fuel burnup (without core refueling)
- Residual heat

Simulator training tasks

- Give simulator user practical skills of simulator control
- Help to become familiar with reactor construction and operational experience
- Demonstrate physical phenomena in the reactor and reactor core

Training task description gives

- Learning objectives
- The sequence of actions to be performed by simulator user
- The reference to the corresponded simulator display pages outputs and controls

Groups of training tasks

- First group demonstrates physical phenomena in the reactor core:

  1. two different core loadings
  2. reactivity effects (after scram)
  3. free reactor offset and power oscillations
  4. reactor offset oscillations at rated power level

- Second "group" gives simulator user an opportunity to return reactor to rated power level after scram from the hot shutdown conditions

- Third group of training tasks deals with some of malfunction implementation at rated power level:

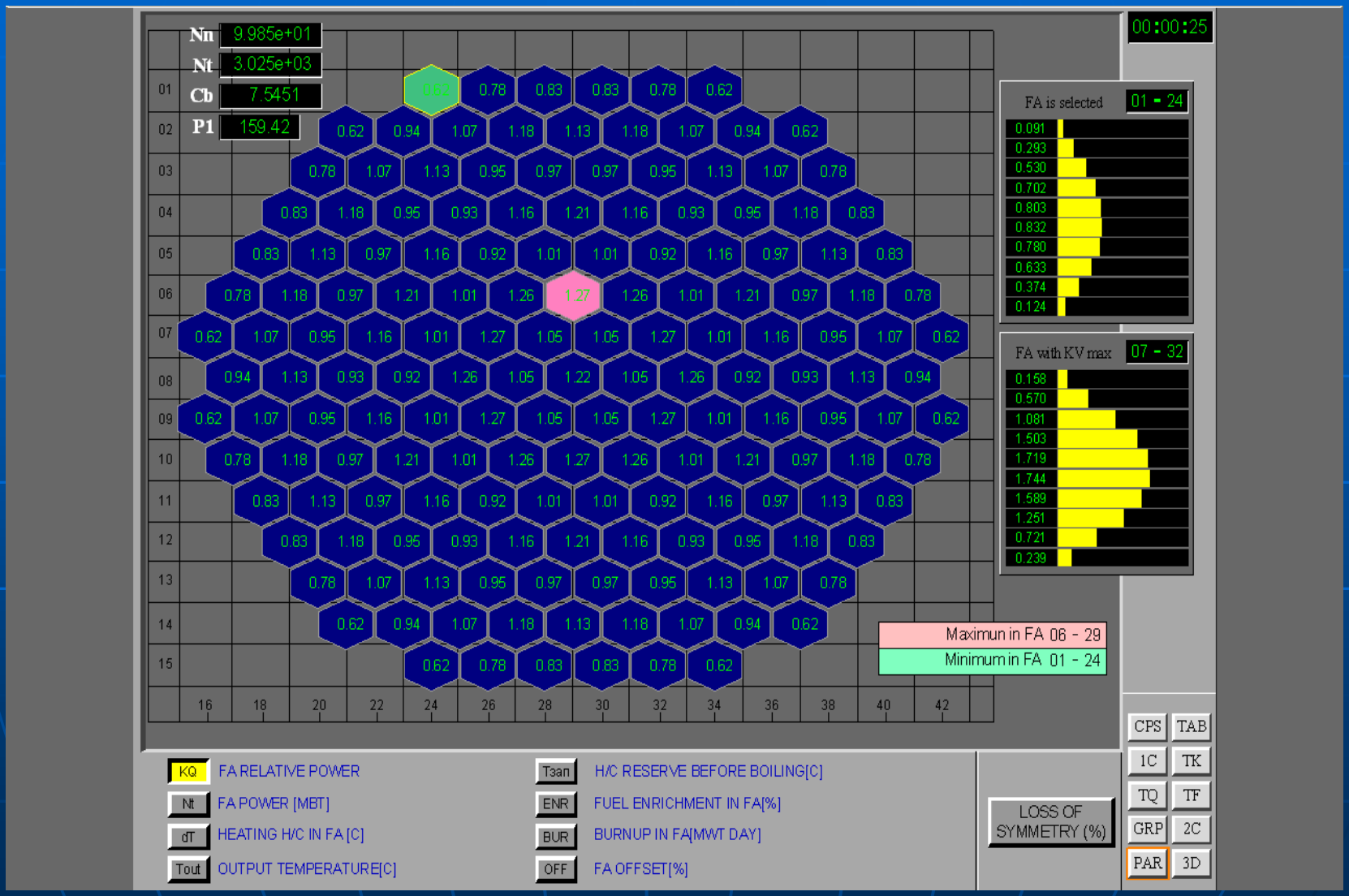
  6. main cooling pump wheel jam
  7. steam isolation valve closure on one of the steam generators
  8. main cooling pump trip
  9. feed water pump trip
  10. turbine governor valves closure

  An additional task to each of the last five above-mentioned is to return reactor to rated power level if and when malfunction is removed

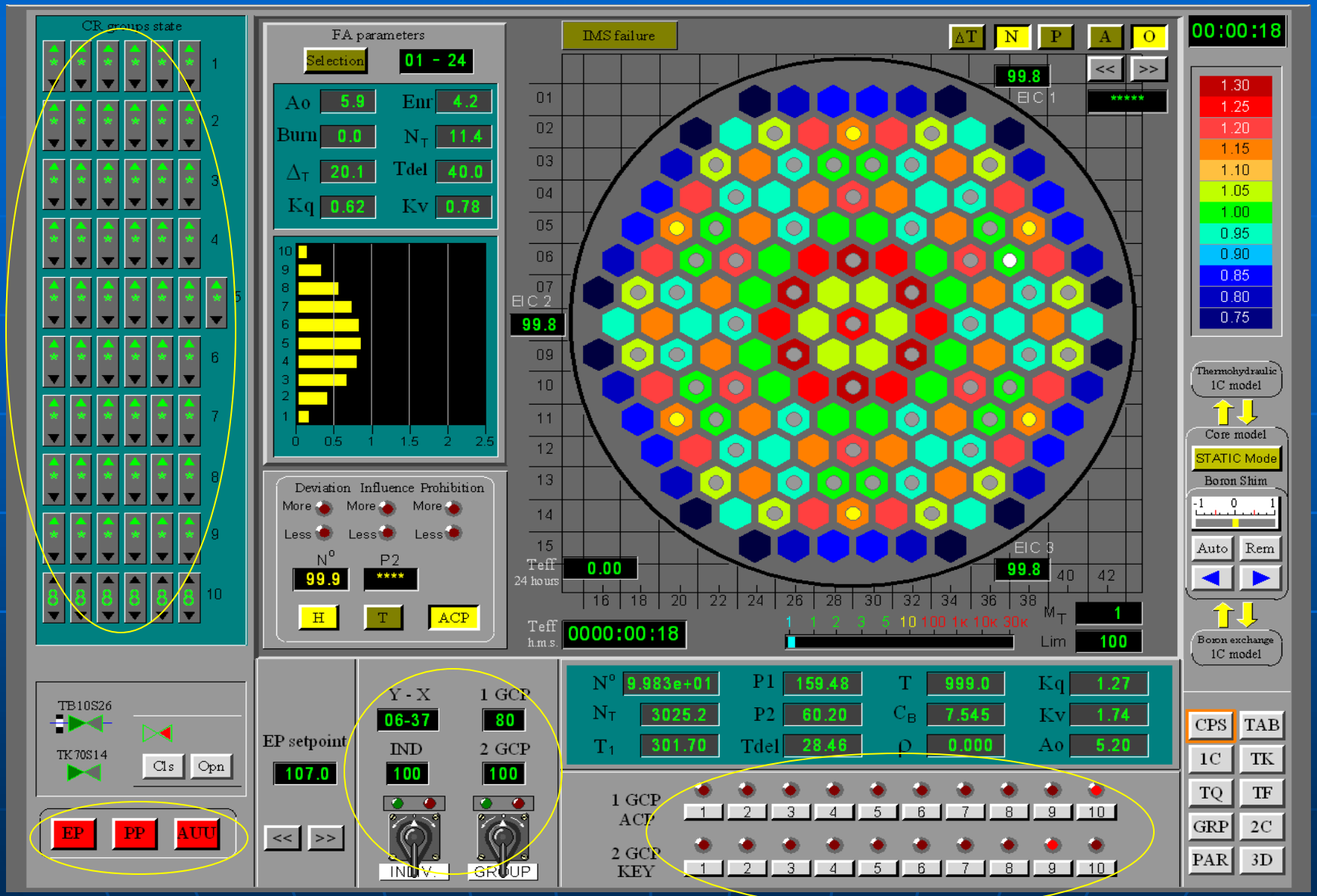
Simulator interface and main controls

- Display screens show:
  - reactor construction
  - important physical values
  - axial and radial values distribution
- Main controls are:
  - Control rod operation
  - Pump operation
  - Valve operation
  - Automatic controller operation

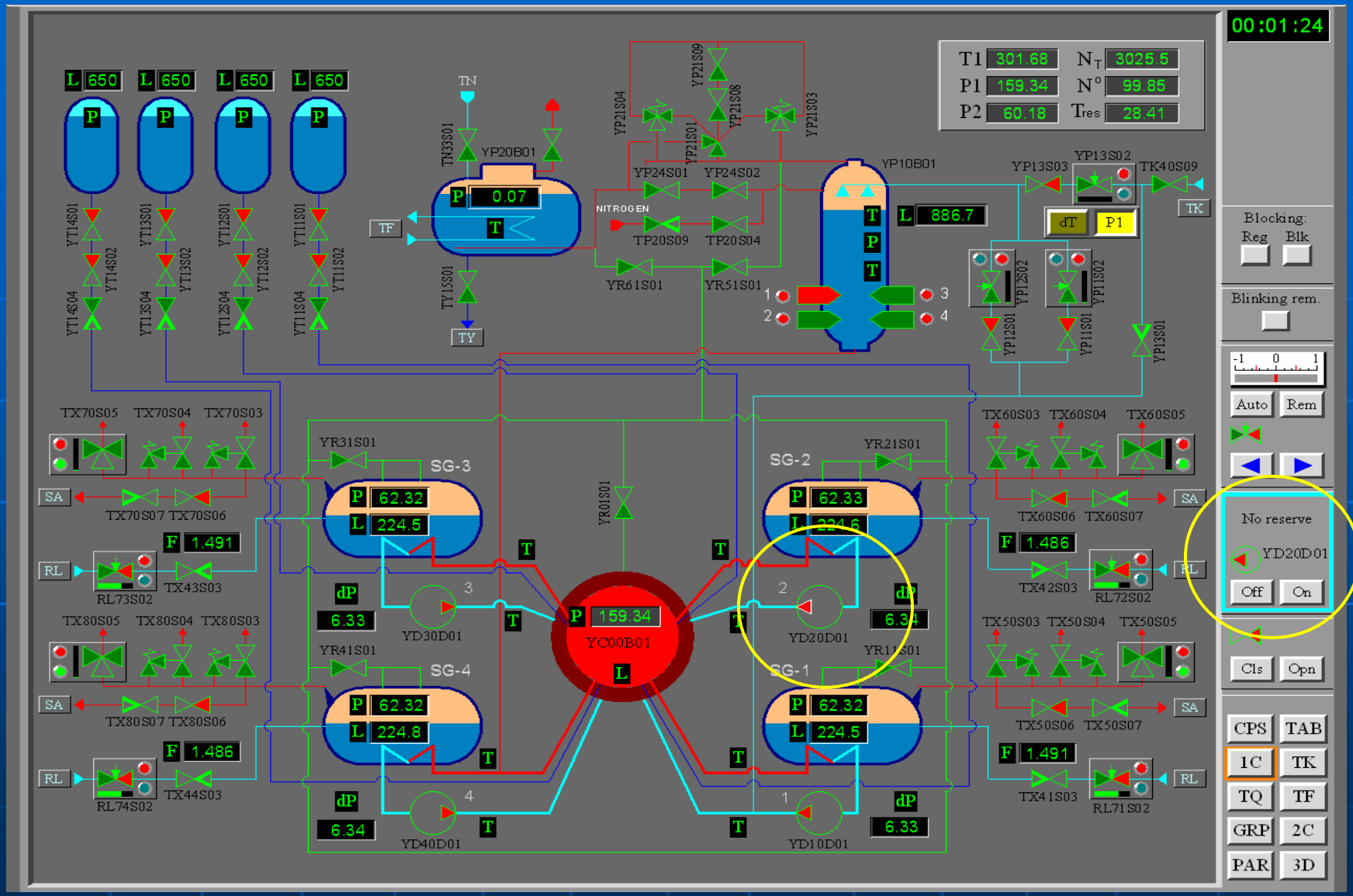
Display screen: axial and radial values distribution



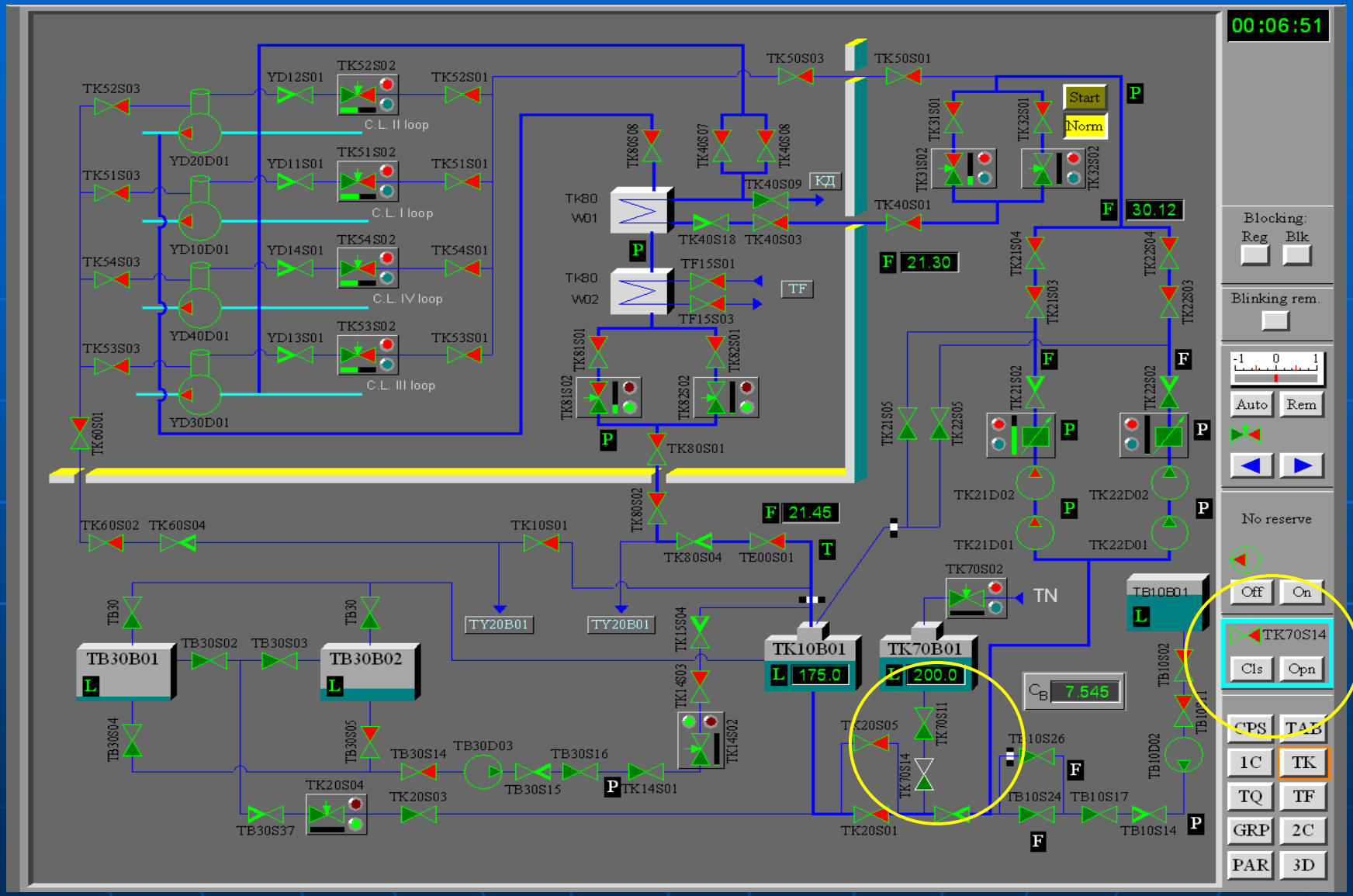
Main display screen and control rods operation



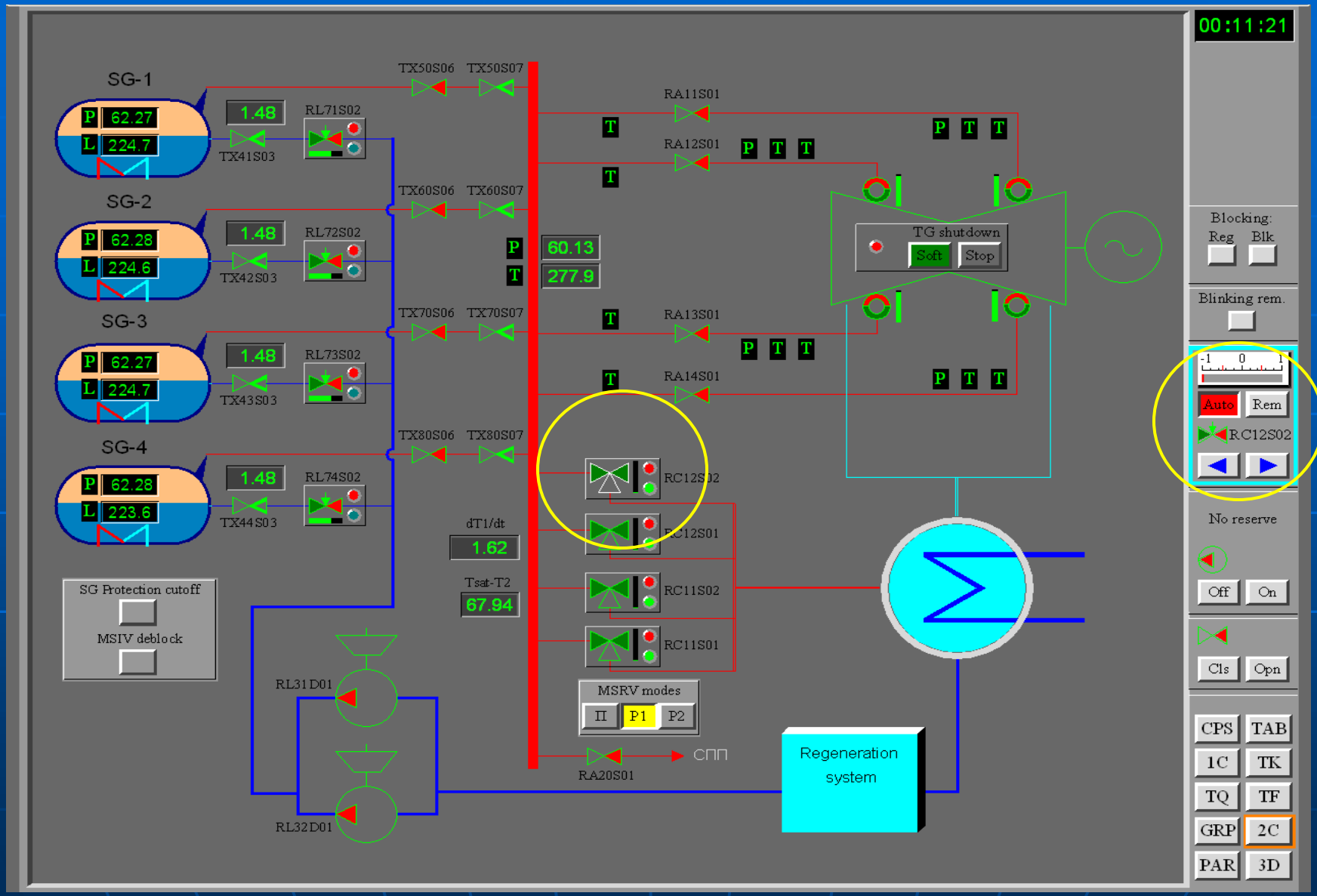
Pump operation



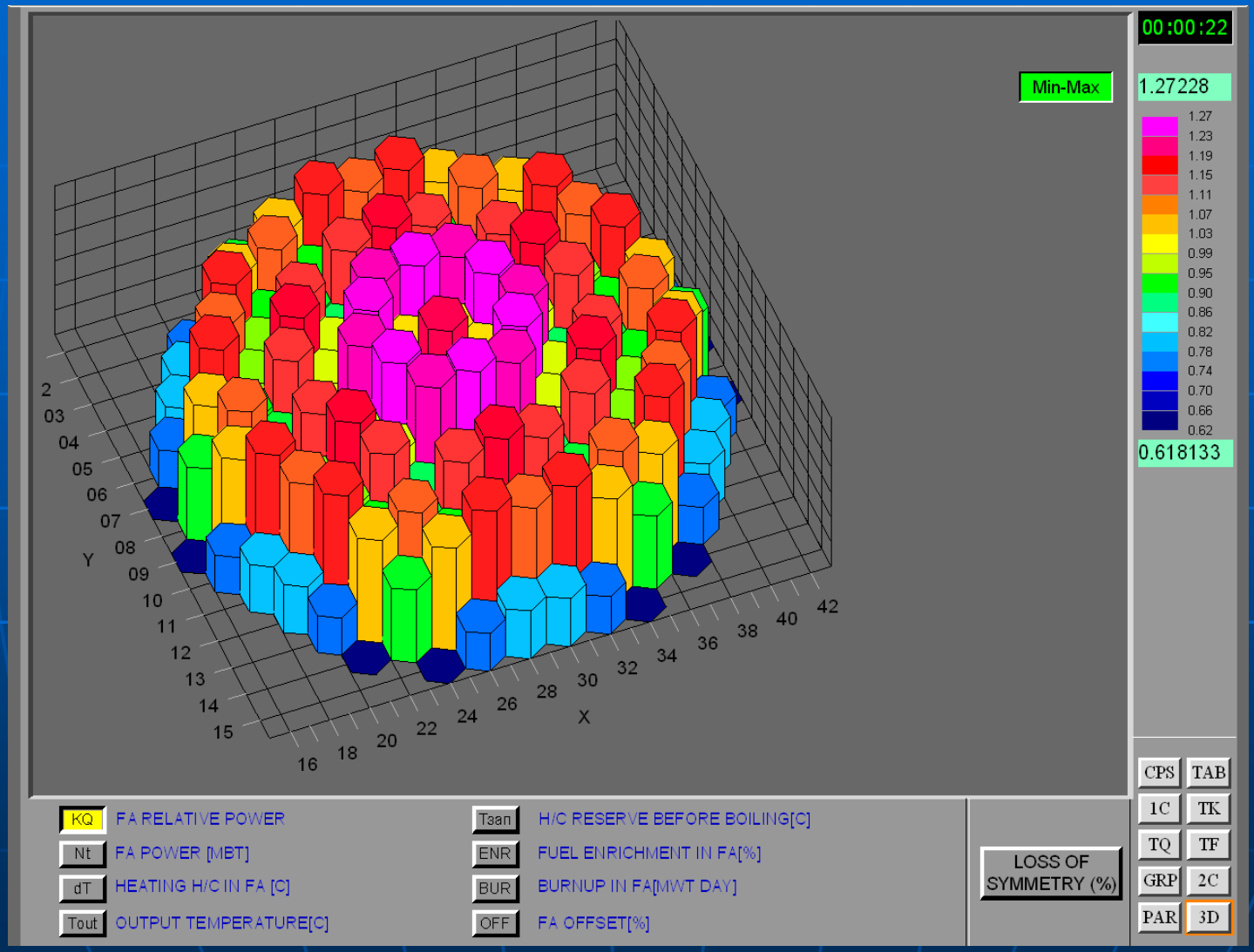
Valve operation



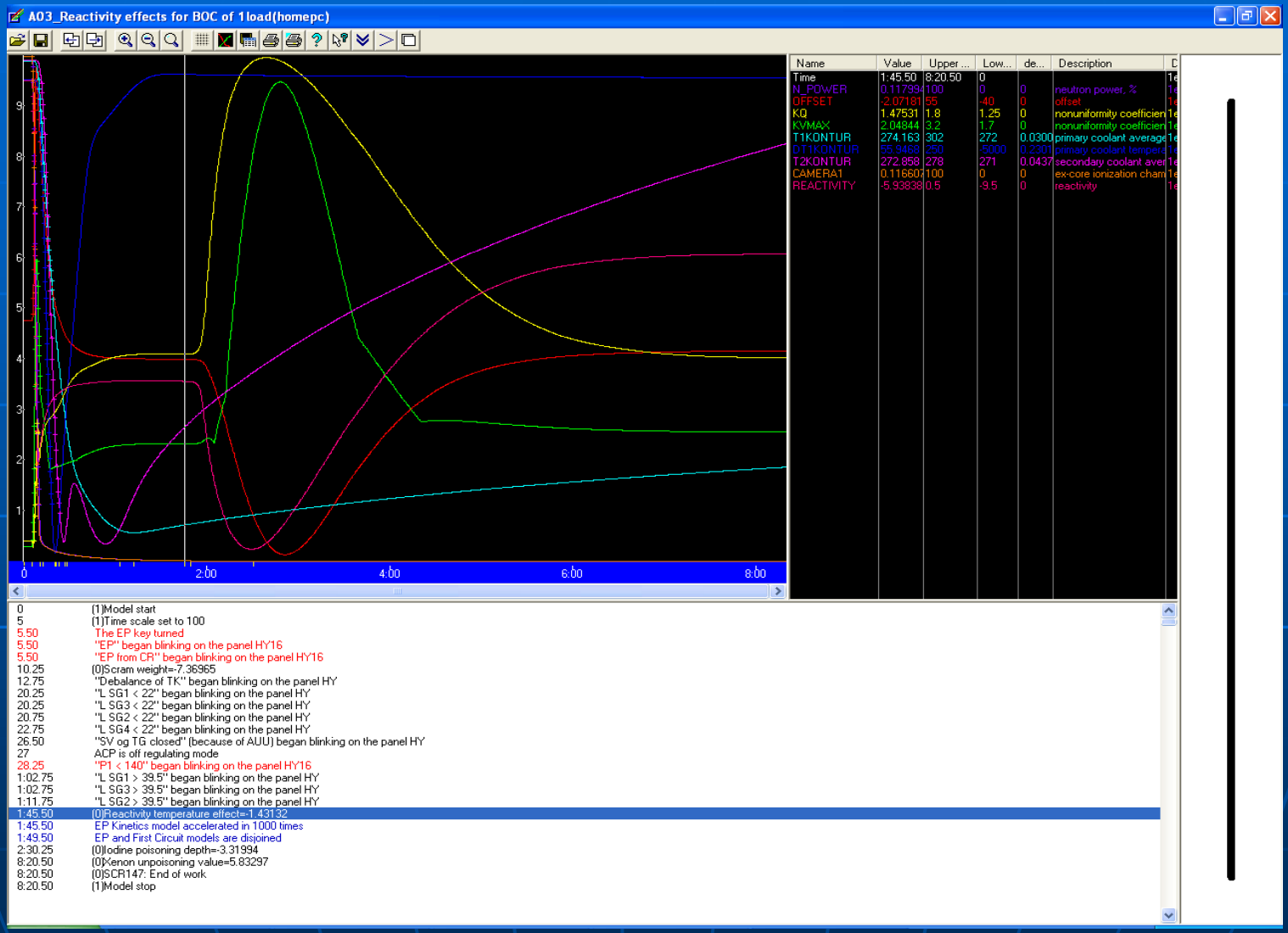
Automatic controller operation



Task selection, simulator start, stop and exit



Simulation protocol analysis

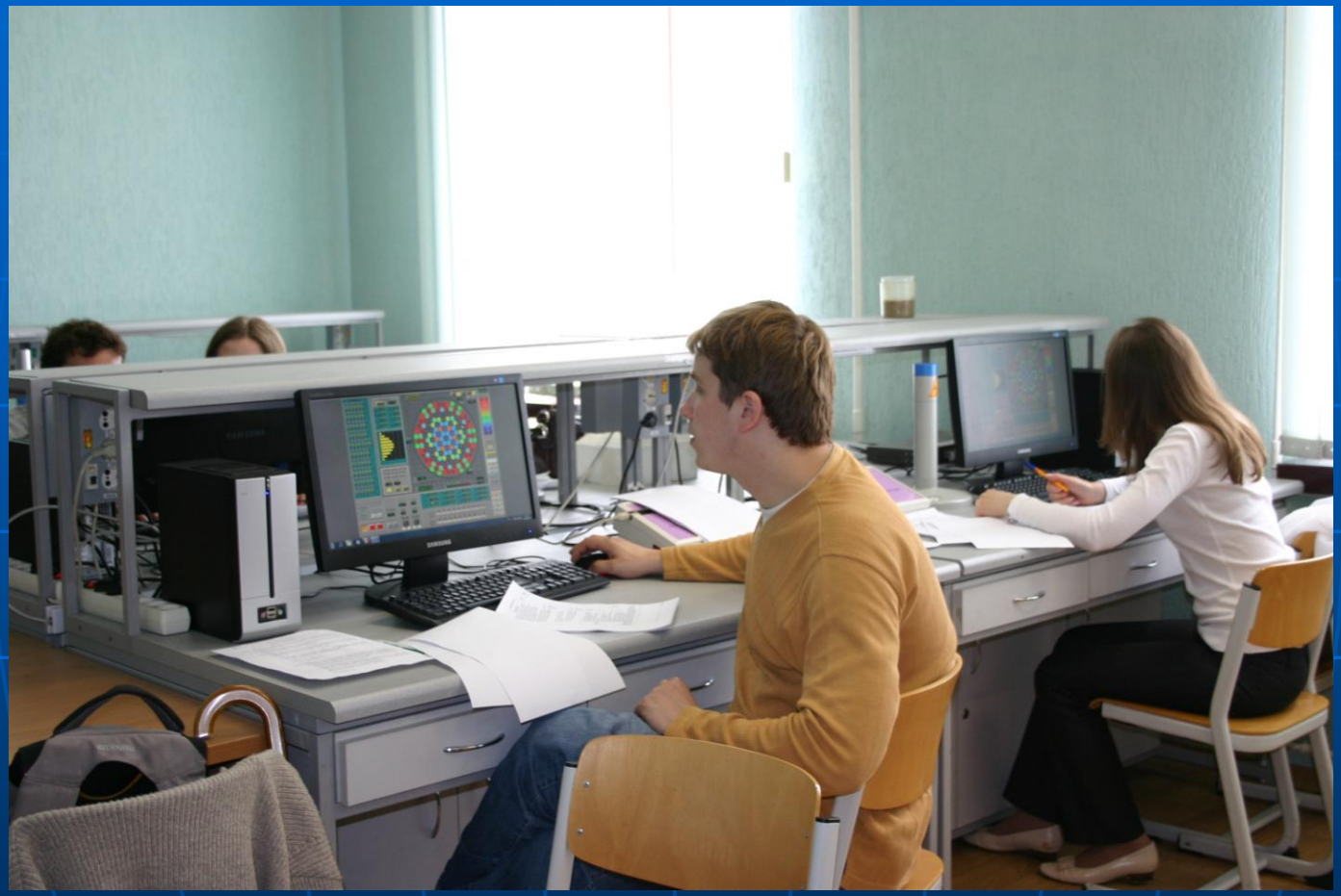


Application of the WWER-1000 Reactor Simulator for Educational Purposes

IAEA program “NPP Simulators for Education”

http://www.iaea.org/NuclearPower/Technology/Training/simulators.html

Application of the WWER-1000 Reactor Simulator for Educational Purposes



IAEA Workshop "NPP Educational Basics Principle Simulators"
Belorussia, Minsk, Belorussian State University, 24-28 May 2010

WWER-1000 Reactor Department Multi-Functional Analyzer (MFA-RD)

is a further development of WWER-1000 Reactor Simulator

WWER-1000 Simulator and MFA-RD

- WWER-1000 Reactor Simulator gives an understanding of the reactor construction and operational characteristics
- MFA-FD can be used for WWER-1000 reactor steady-state and transients analysis

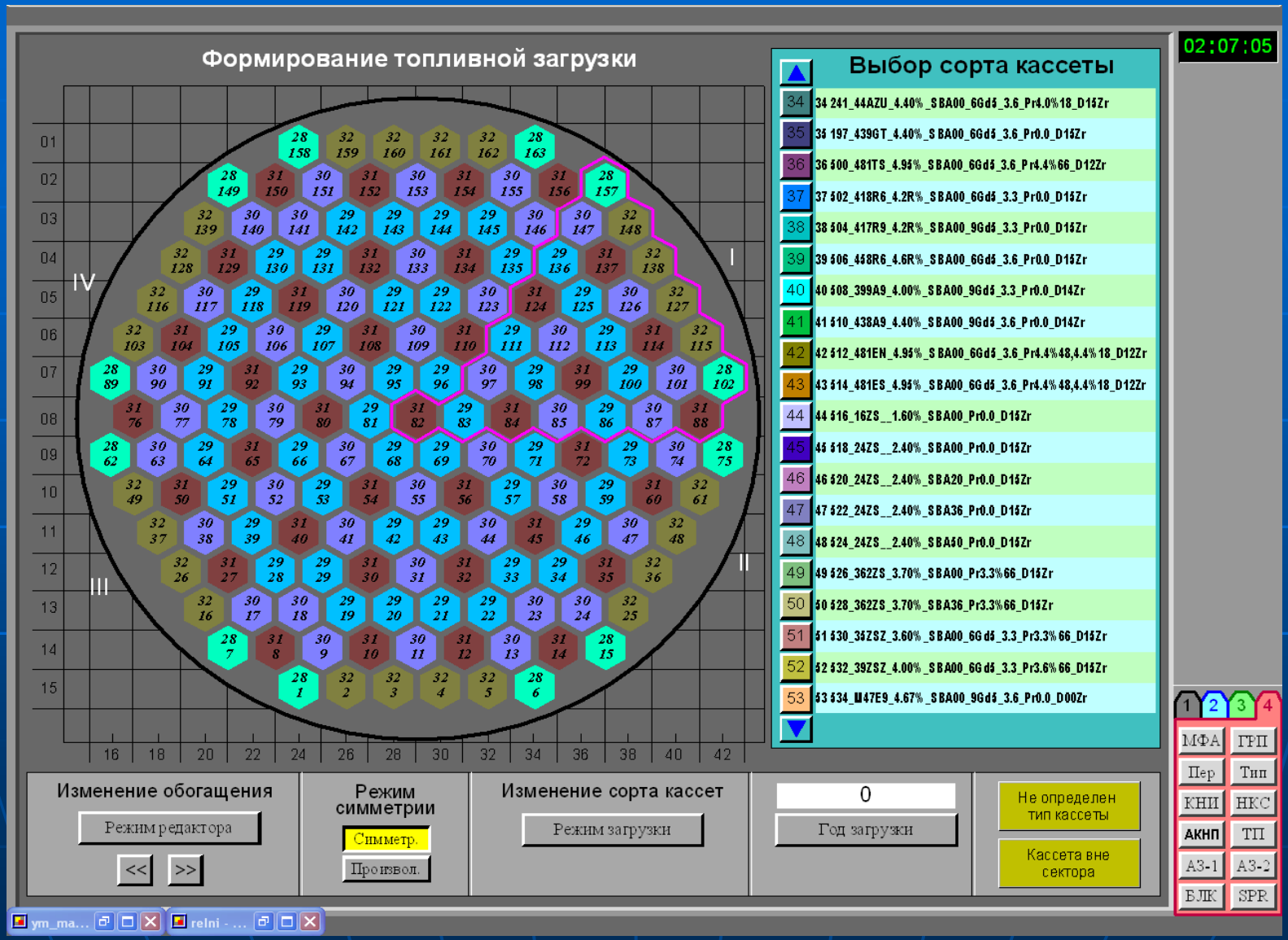
WWER-1000 MFA-RD

- is an upgraded and extended modern analogue of WWER- 1000 Reactor Simulator
- was benchmarked against a wide range of WWER-1000 experimental and calculated data
- was certified for WWER-1000 type reactors computations by the State Atomic Inspection of Russia
- is specifically adapted to solution of numerous educational problems in the field of neutron physics, thermal-hydraulics and control of nuclear power plants

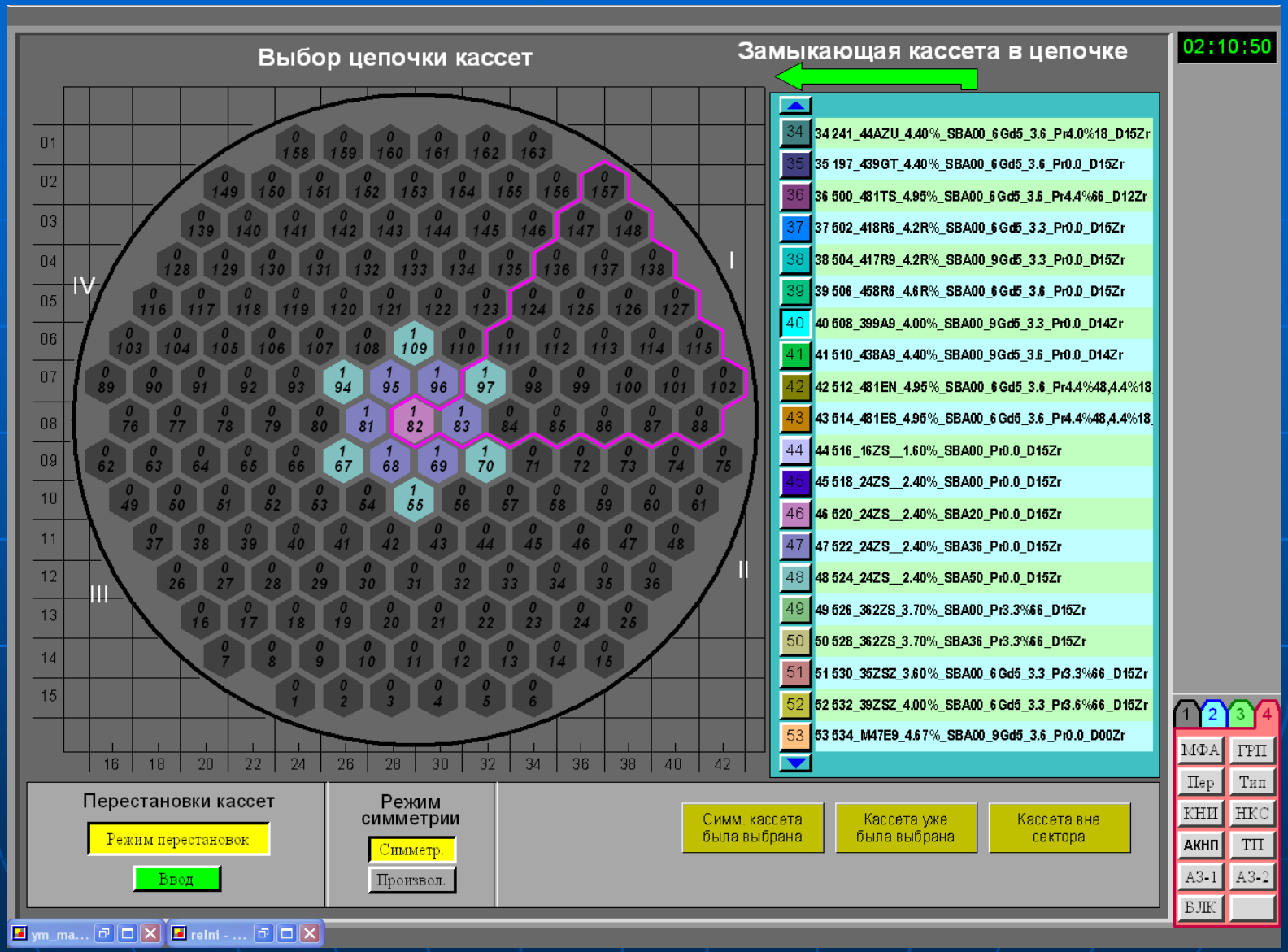
MFA-RD reactor core configuration features

- More than 50 fuel assemblies types in neutron XS-library
- Arbitrary (first) core loading configuration
- Arbitrary and real plant refueling chains simulation manually or from the input file
- Arbitrary control rods location into reactor core and CD banks configuration
- Multi-cycles fuel burnup calculation using arbitrary or real plant refueling chains

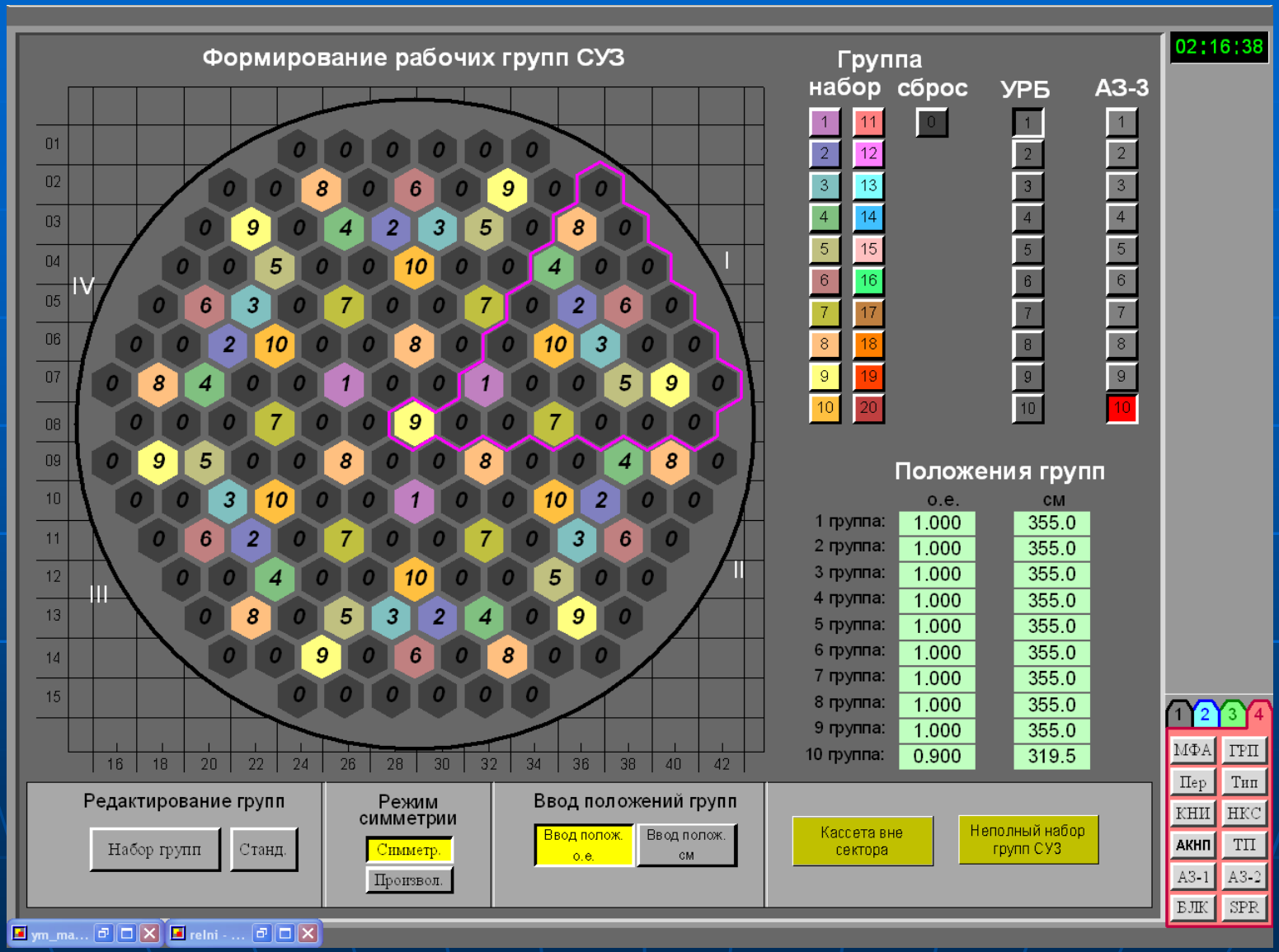
Core loading configuration



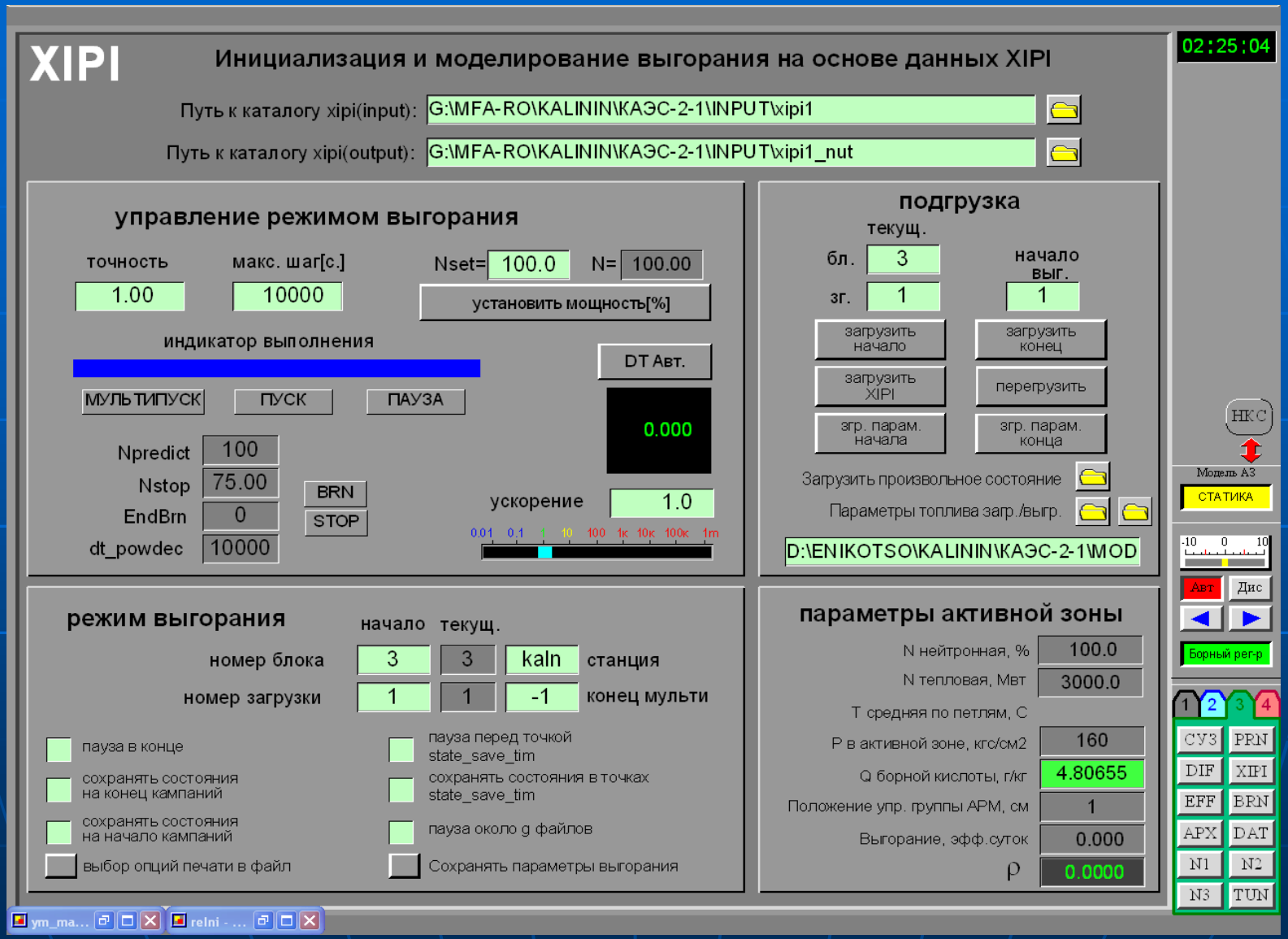
Refueling chains simulation



Control rods location and CR banks configuration



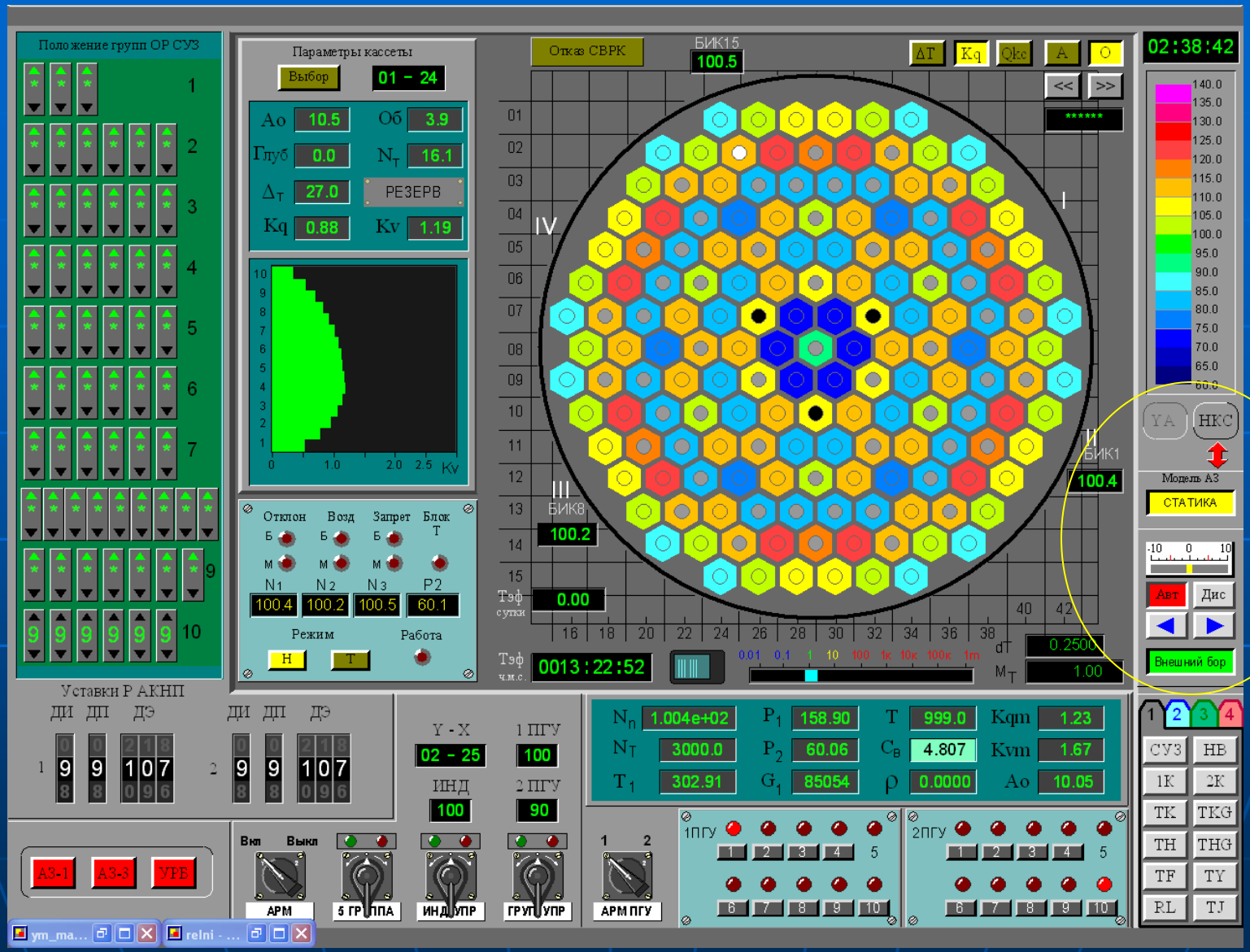
Multi-cycles fuel burnup calculation



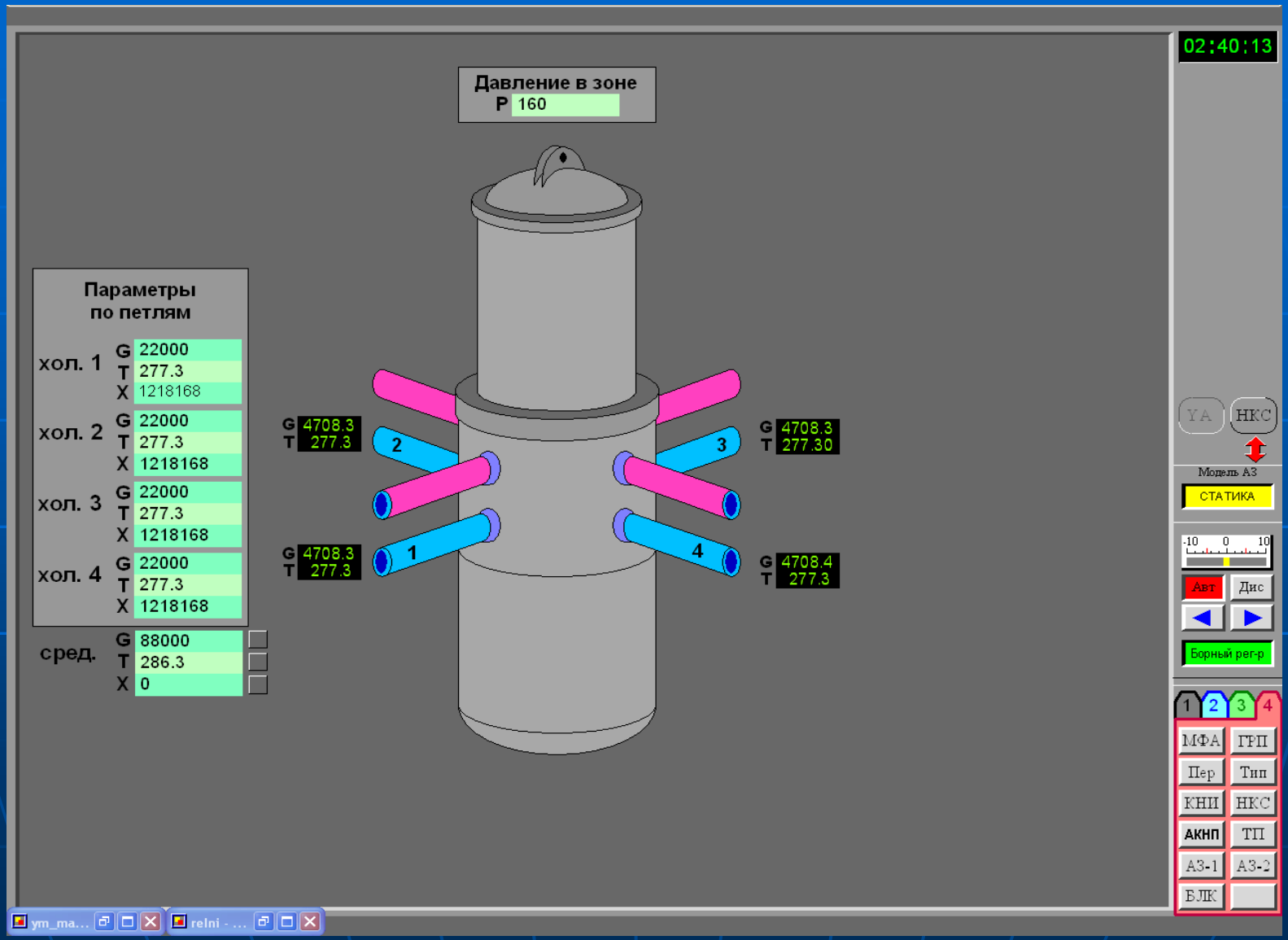
MFA-RD reactor core computational features

- Statics and dynamics reactor core computational modes
- Boron regulator to find a critical boron concentration for an arbitrary core state
- Reactor core model easy connection or disconnection from the primary circuit model (boundary conditions for core thermal-hydraulics model)
- Ex-core instrumentation model allows to reproduce directly real plant measurements

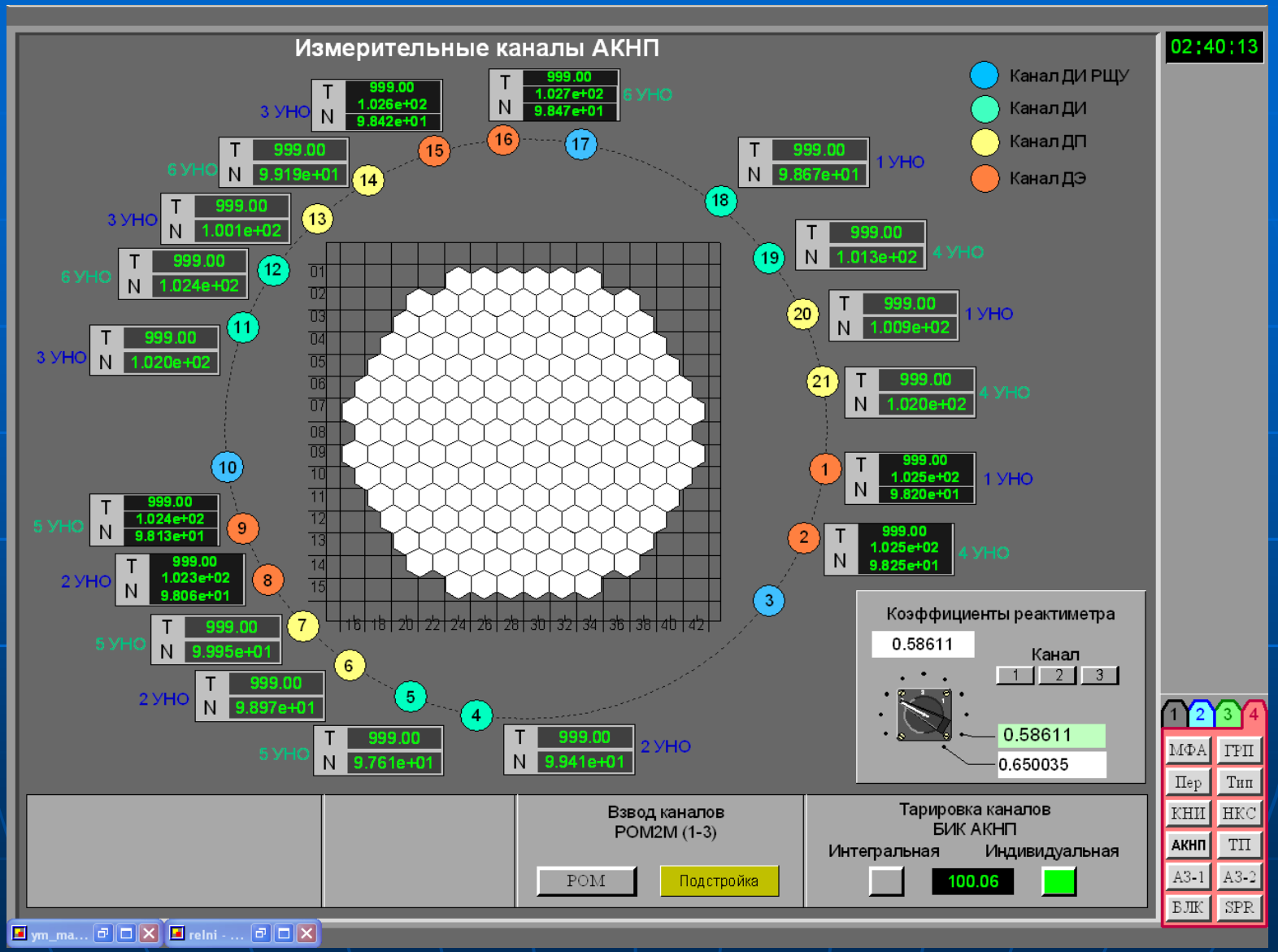
Reactor core computational modes



Boundary conditions for core thermal-hydraulics model



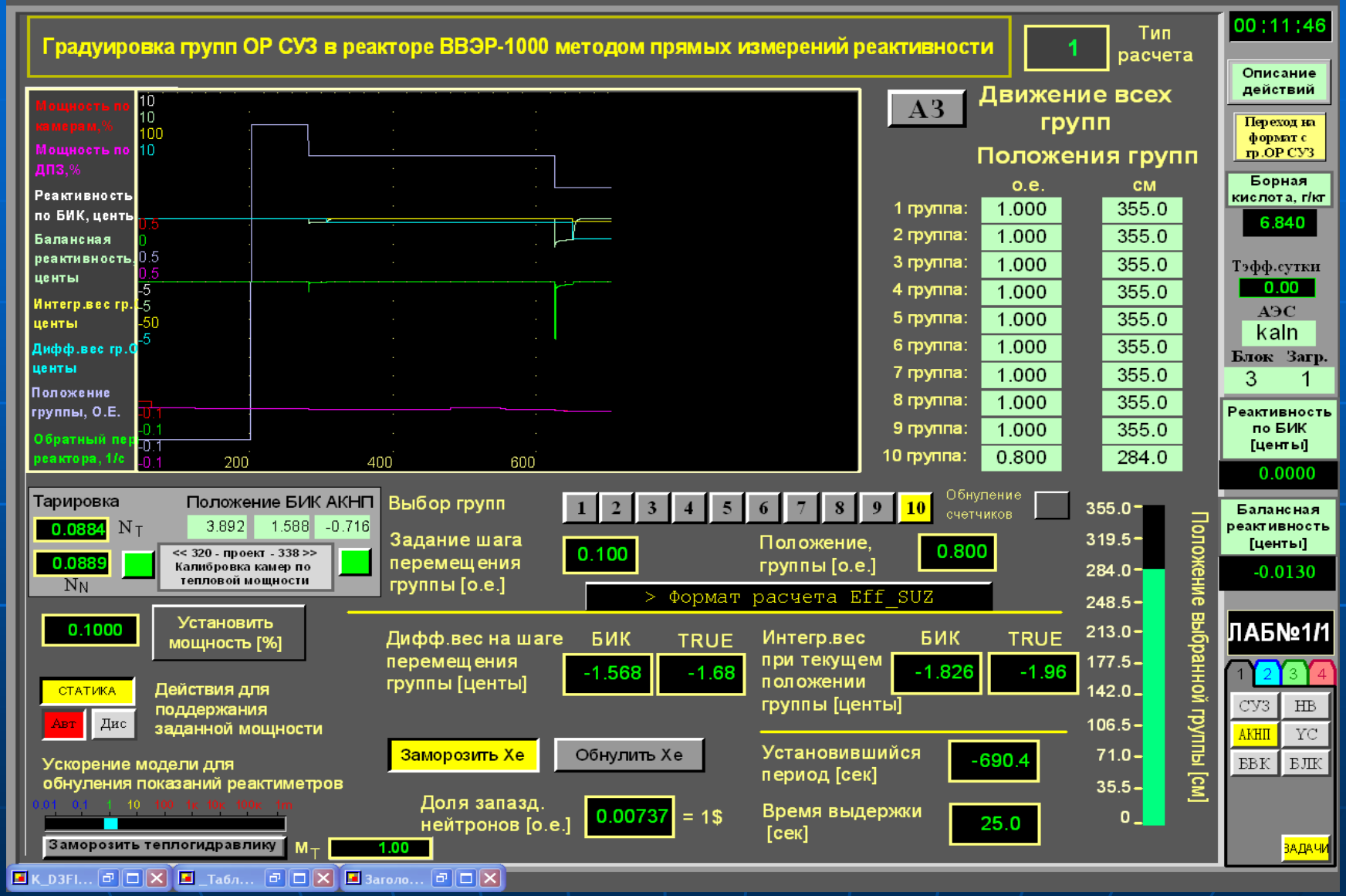
Ex-core instrumentation model



MFA-RD training tasks

- Reactivity effects and coefficients computation and analysis
- CR banks worth calculation and analysis
- Reactor scram simulation, comparison of "measured" data with computational one
- Fuel management
- Xenon transients computation and analysis
- Xenon transients control
- Automatic Power Regulator parameters setup

Measurement of CR bank worth



MFA-RD application for educational purposes

Laboratory of “Reactor Safety and Operation”,
Department of Automatics, MEPhI

MFA-RD application for educational purposes

Laboratory of “Computer Simulating Systems for NPP”,
Department of Automatics, MEPhI

MFA-RD application for lectures and practical works in MEPhI

- Lectures “Automatics in Nuclear Power Plants”
  Labs “Control and Protection Systems”
- Lectures “Numerical modeling of physical processes in equipment of NPP”
  Labs “Control and Safety of operation of NPP”

Laboratory of Training Systems Team

www.eniko.ru

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Thank You for Your Attention