

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

Ljubljana, Slovenia, June 21 – 24 2010

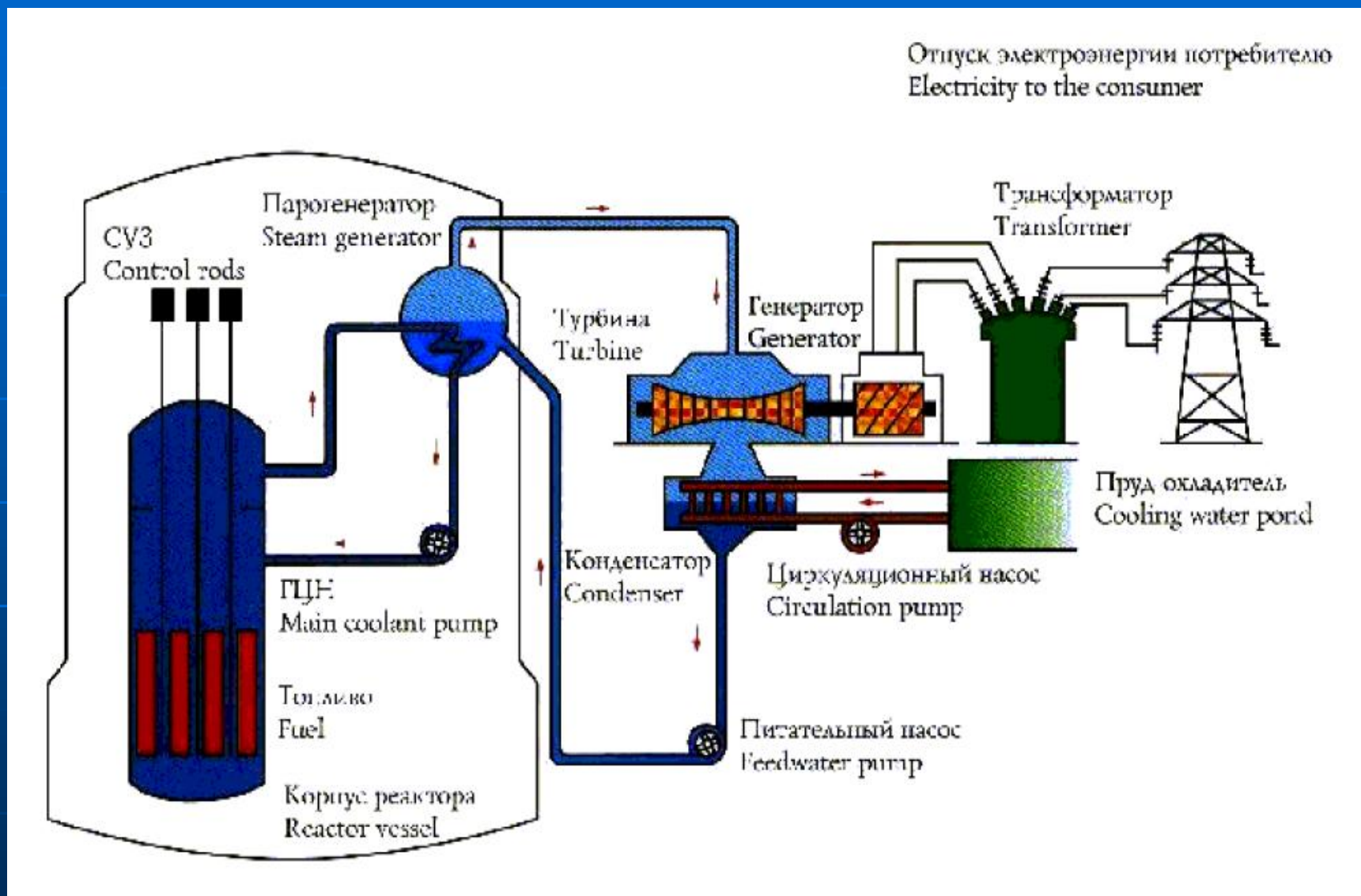
Application of WWER-1000 Reactor Department Simulator for Education and Preserving Knowledge Purposes

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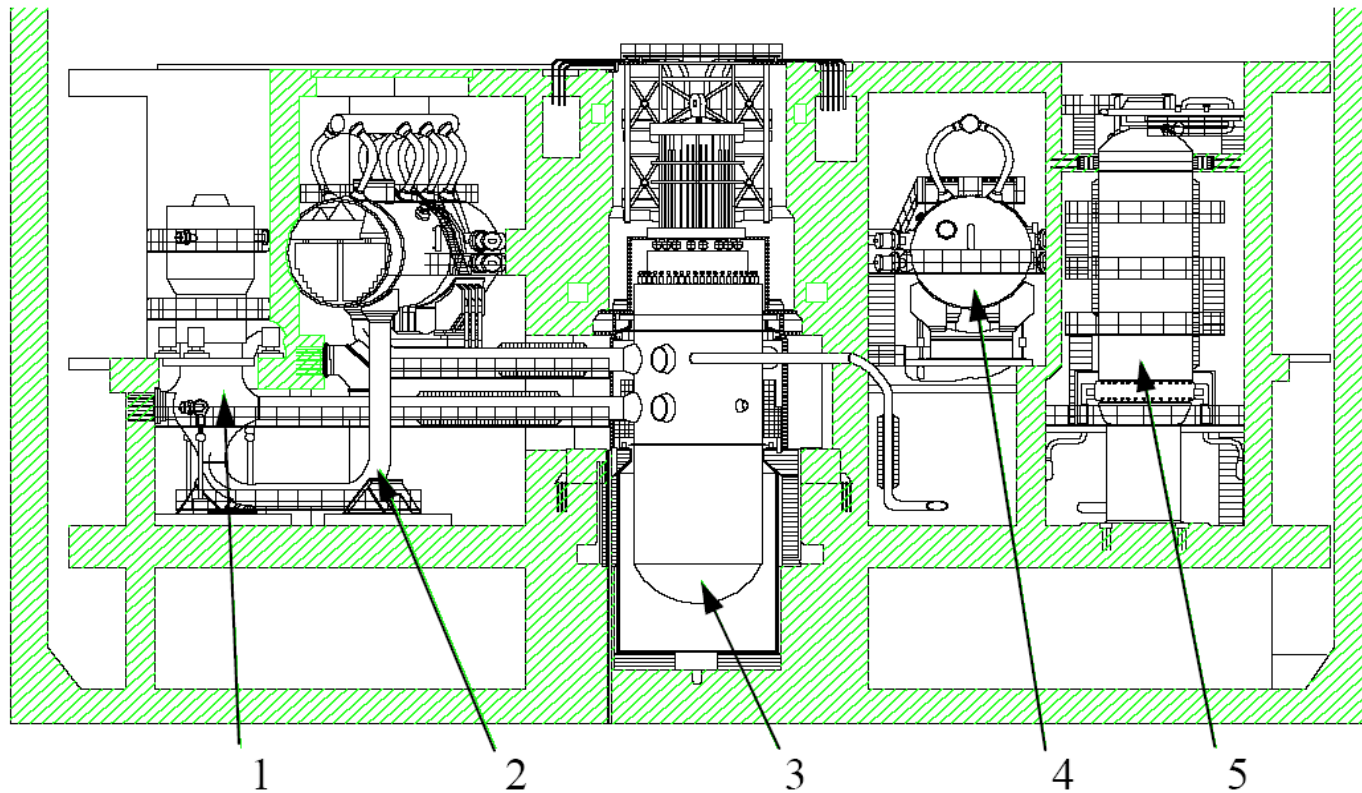
Laboratory of Training Systems
Department of Automatics
Moscow Engineering and Physics Institute
National Research Nuclear University

Key moments of WWER-1000 reactor construction

Schematic diagram of NPP with WWER reactor

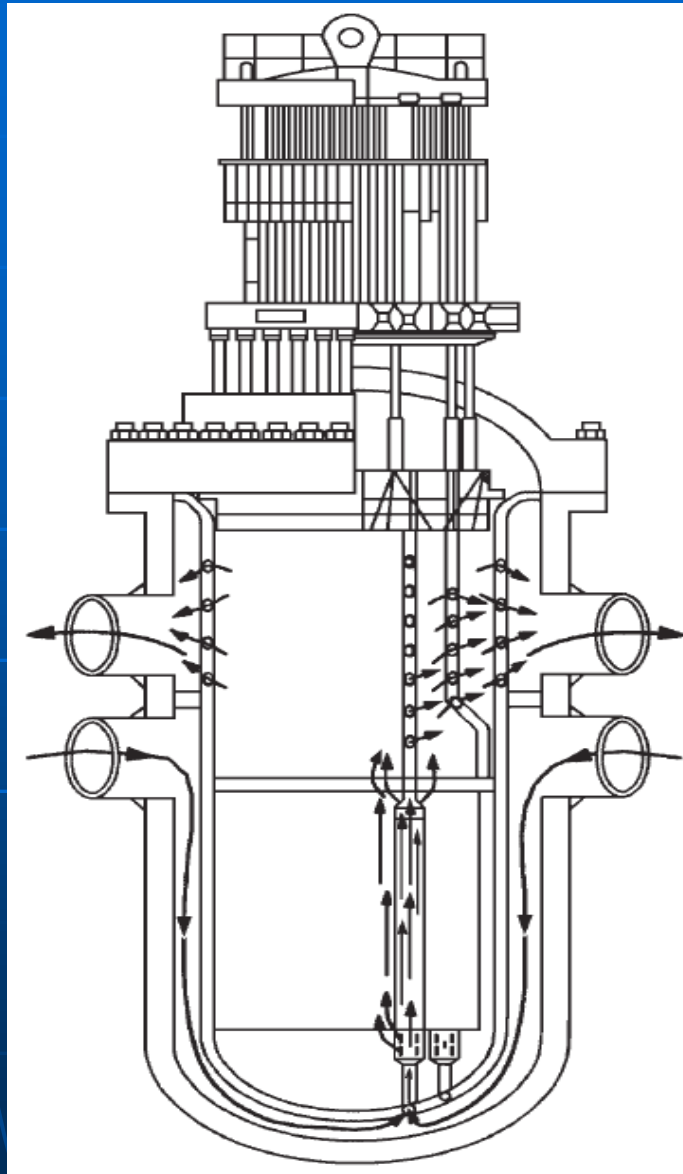


Crosscut view of WWER-1000 containment

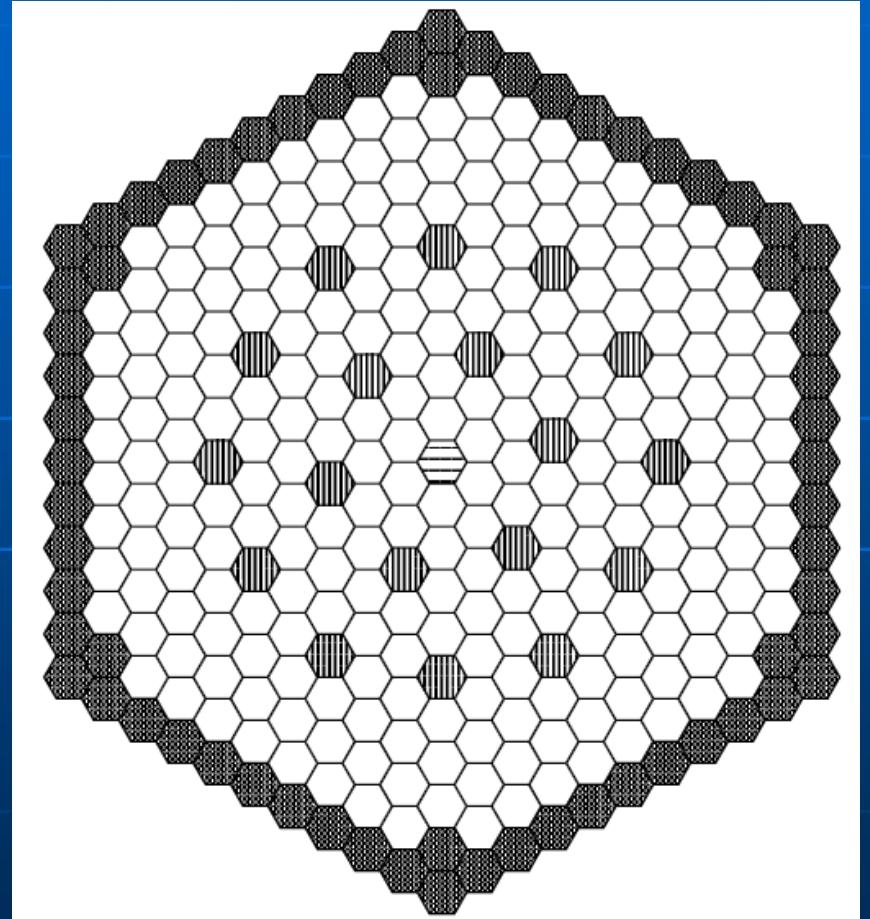
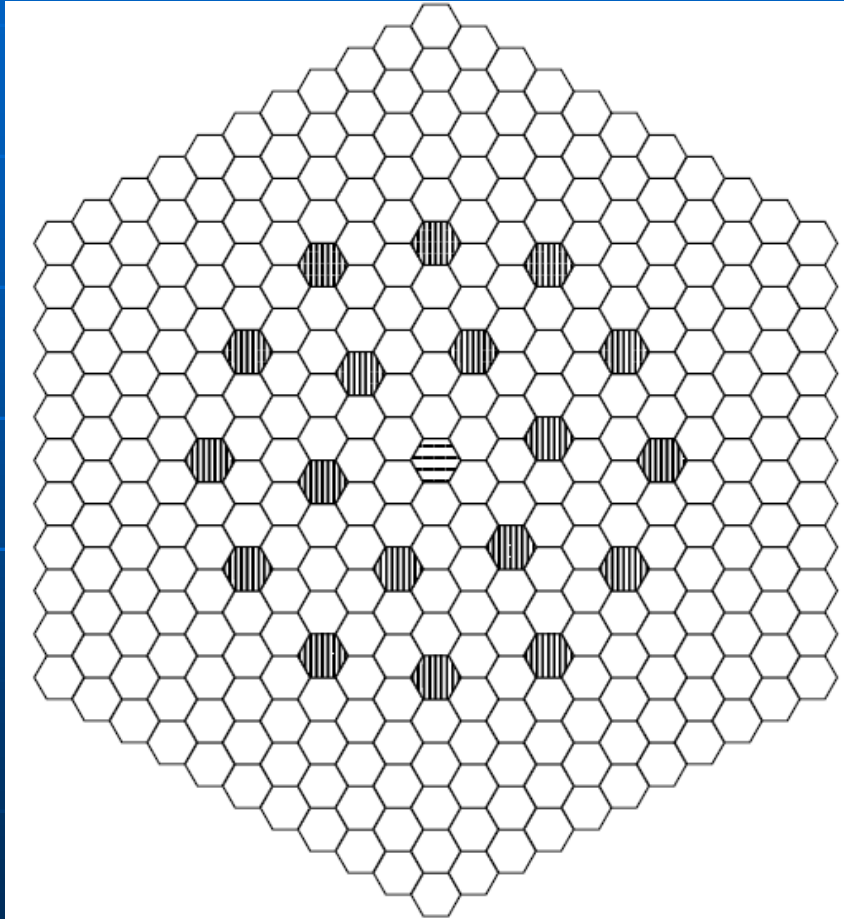


1. Main Circulation Pump
2. Primary Circuit Pipelines
3. Reactor Vessel
4. Steam Generator
5. Pressurizer

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

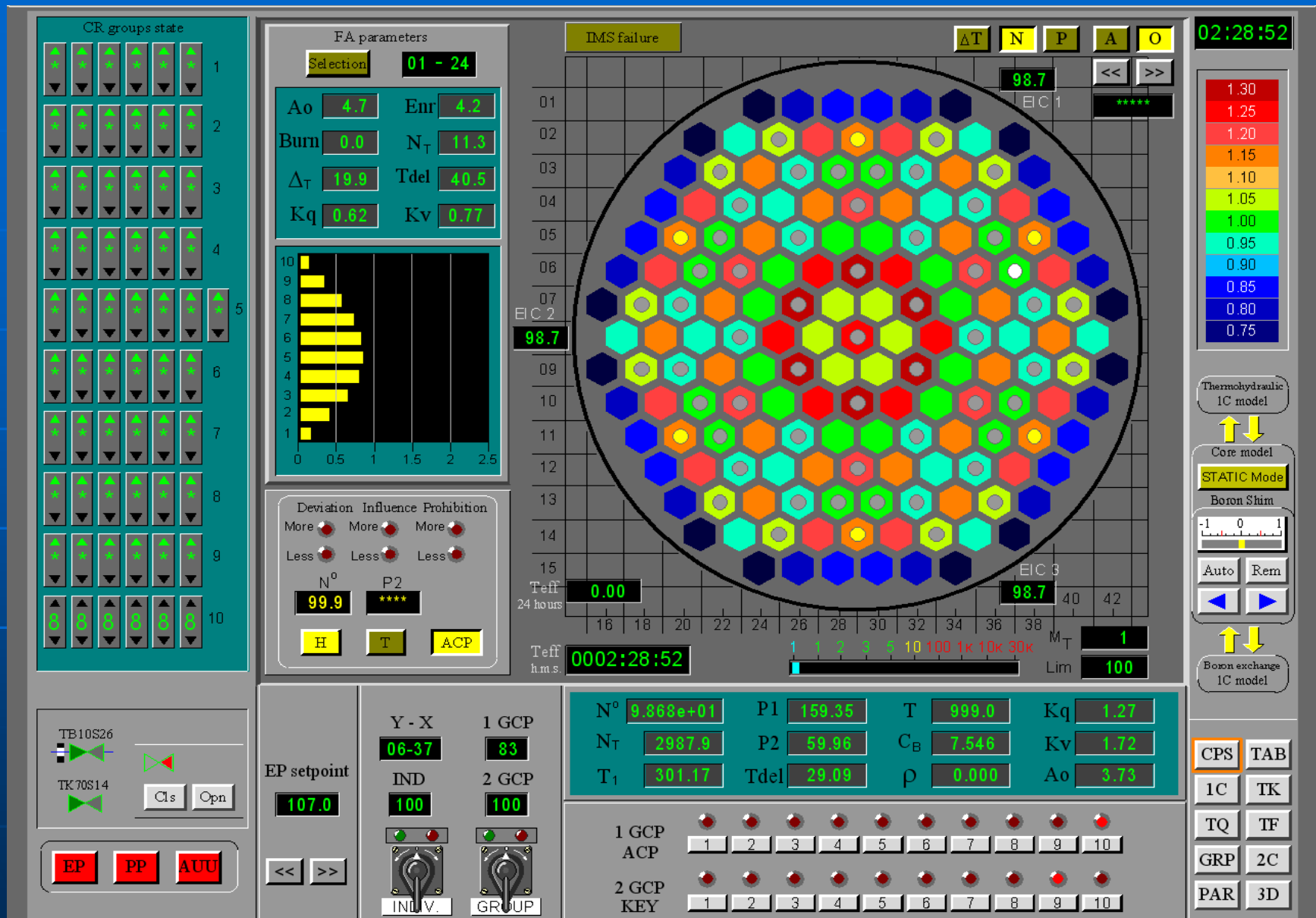
WWER-1000 Reactor Simulator

- 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

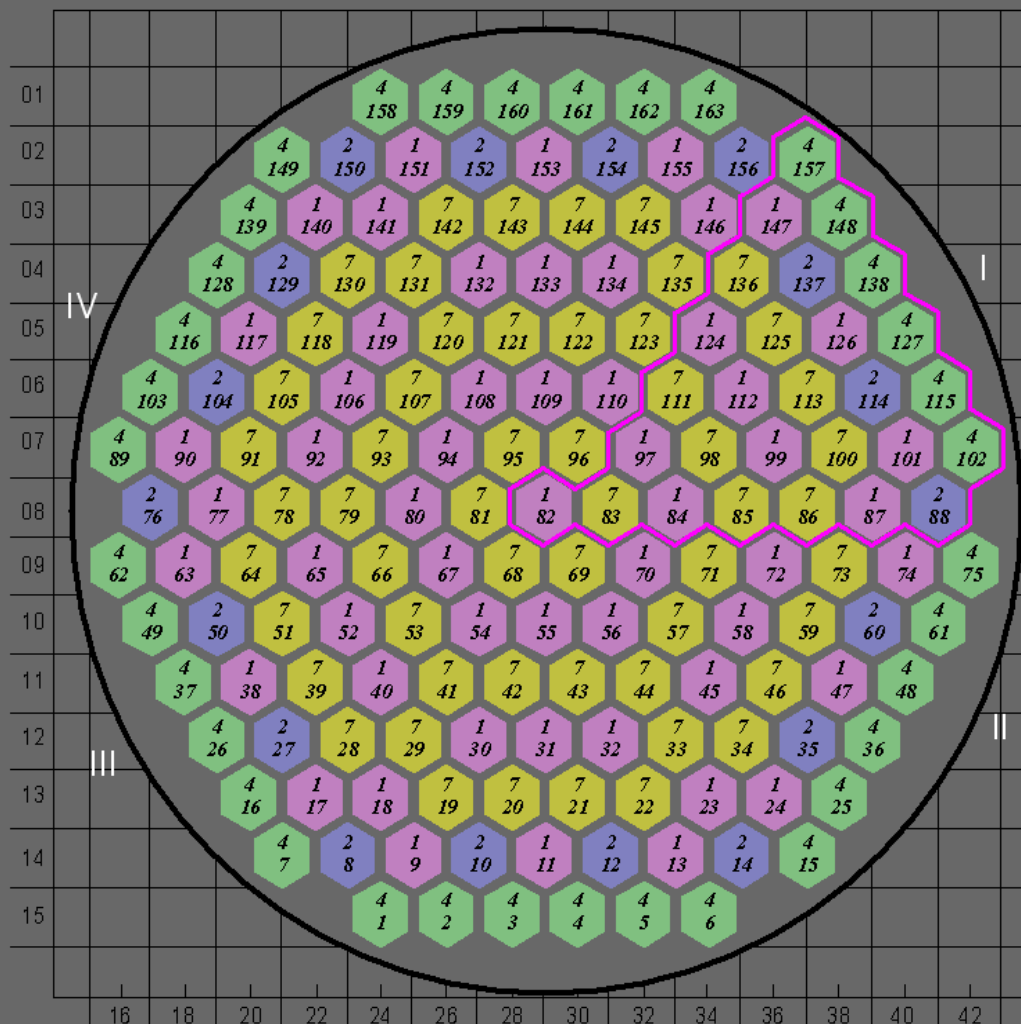
- Reactor
- Primary circuit: main circulation pipelines, main circulation pumps (MCP), steam generators (SG)
- Pressurizer and primary circuit pressure compensating system
- Primary circuit feed and bleed system, including boron regulation
- Secondary circuit steam lines and feed water pipelines
- Control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

Reactor Core



Reactor Core 1st Load

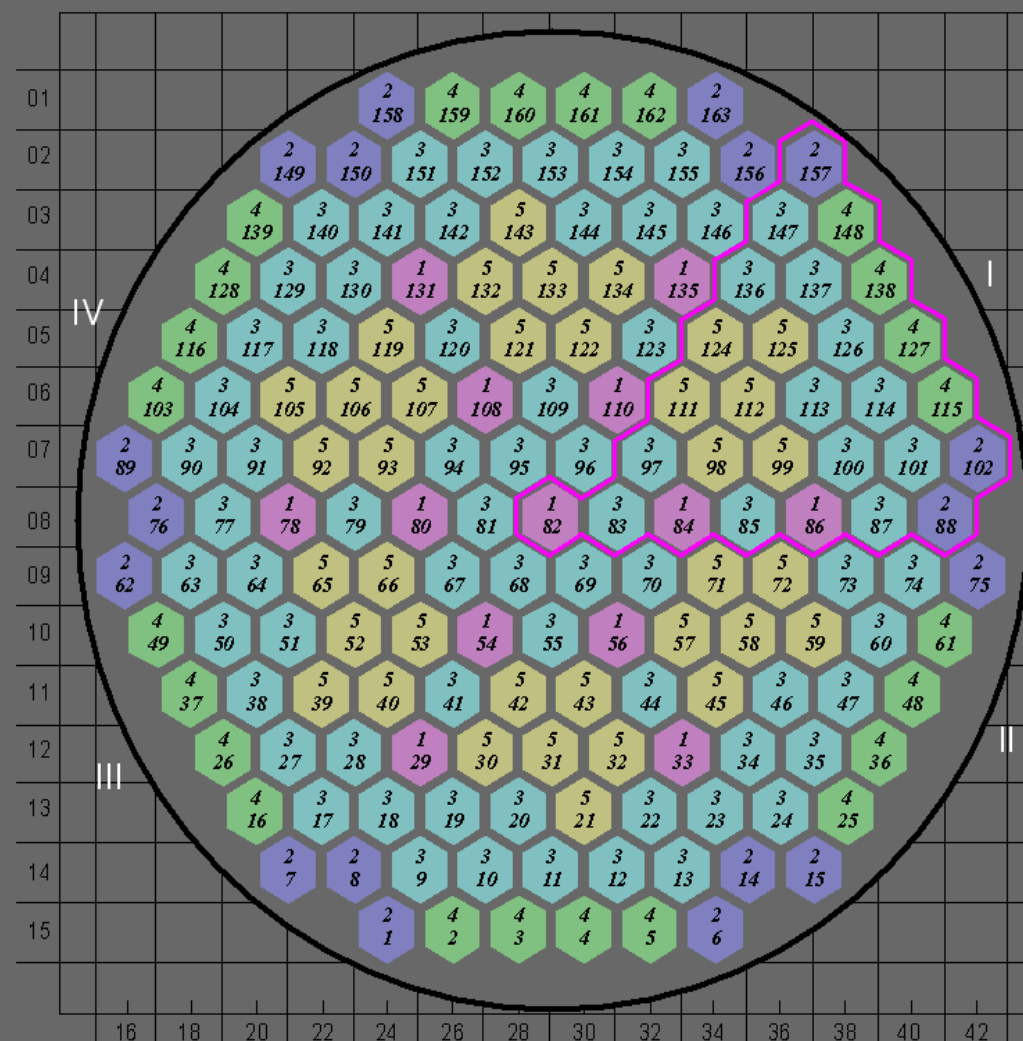
ЮУАЭС, БЛОК 3, ЗАГРУЗКА 1



Выбор сорта кассеты	
1	1007_30FL_3.00%_SBA00_Pr0.0_D24Fe
2	2002_44FL_4.40%_SBA36_Pr0.0_D24Fe
3	3001_44FL_4.40%_SBA00_Pr0.0_D24Fe
4	4005_42FL_4.40%_SBA36_Pr3.6%66_D24Fe
5	5004_42FL_4.40%_SBA00_Pr3.6%66_D24Fe
6	6009_16FL_1.60%_SBA00_Pr0.0_D24Fe
7	7011_20FS_2.00%_SBA00_Pr0.0_D14Fe
8	8013_33FS_3.30%_SBA00_Pr0.0_D14Fe
9	9015_32FS_3.30%_SBA00_Pr3.0%66_D14Fe
10	10017_30FS_3.00%_SBA00_Pr0.0_D14Fe
11	11023_42FL_4.40%_SBA65_Pr3.6%66_D24Fe
12	12085_30FL_3.00%_SBA36_Pr0.0_D24Fe
13	13094_UO2_4.00%_SBA65_Pr3.6%66_D24Zr
14	14140_390A_4.00%_SBA36_Pr3.0%30_D15Zr
15	15141_390A_4.00%_SBA00_Pr3.0%30_D15Zr
16	16144_382A_4.00%_SBA36_Pr3.3%30,3.0%36_D15Zr
17	17146_382A_4.00%_SBA00_Pr3.3%30,3.0%36_D15Zr
18	18149_294A_3.00%_SBA20_Pr2.4%30_D15Zr
19	19150_294A_3.00%_SBA00_Pr2.4%30_D15Zr
20	20153_UO2_4.00%_SBA00_6Gd5_3.0_Pr3.3%66_D15Zr

Reactor Core 5th Equilibrium Load

ЮУАЭС, БЛОК 3, ЗАГРУЗКА 5

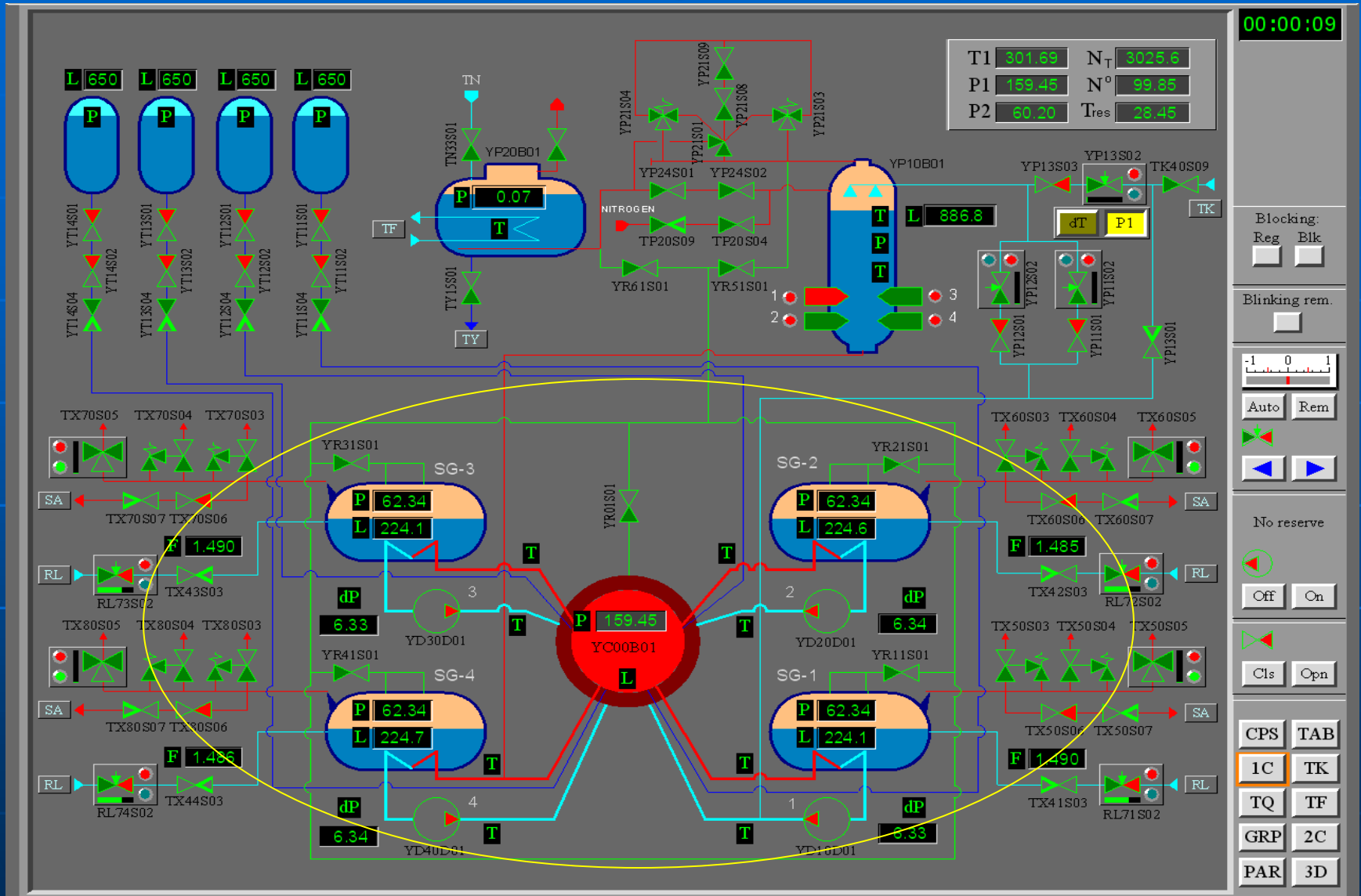


Выбор сорта кассеты	
1	1 007_30FL_3.00%_SBA00_Pr0.0_D24Fe
2	2 002_44FL_4.40%_SBA36_Pr0.0_D24Fe
3	3 001_44FL_4.40%_SBA00_Pr0.0_D24Fe
4	4 005_42FL_4.40%_SBA36_Pr3.6%66_D24Fe
5	5 004_42FL_4.40%_SBA00_Pr3.6%66_D24Fe
6	6 009_16FL_1.60%_SBA00_Pr0.0_D24Fe
7	7 011_20FS_2.00%_SBA00_Pr0.0_D14Fe
8	8 013_33FS_3.30%_SBA00_Pr0.0_D14Fe
9	9 015_32FS_3.30%_SBA00_Pr3.0%66_D14Fe
10	10 017_30FS_3.00%_SBA00_Pr0.0_D14Fe
11	11 023_42FL_4.40%_SBA65_Pr3.6%66_D24Fe
12	12 085_30FL_3.00%_SBA36_Pr0.0_D24Fe
13	13 094_UO2_4.00%_SBA65_Pr3.6%66_D24Zr
14	14 140_390A_4.00%_SBA36_Pr3.0%30_D15Zr
15	15 141_390A_4.00%_SBA00_Pr3.0%30_D15Zr
16	16 144_382A_4.00%_SBA36_Pr3.3%30.3.0%36_D15Zr
17	17 146_382A_4.00%_SBA00_Pr3.3%30.3.0%36_D15Zr
18	18 149_294A_3.00%_SBA20_Pr2.4%30_D15Zr
19	19 150_294A_3.00%_SBA00_Pr2.4%30_D15Zr
20	20 153_UO2_4.00%_SBA00_6Gd5_3.0_Pr3.3%66_D15Zr

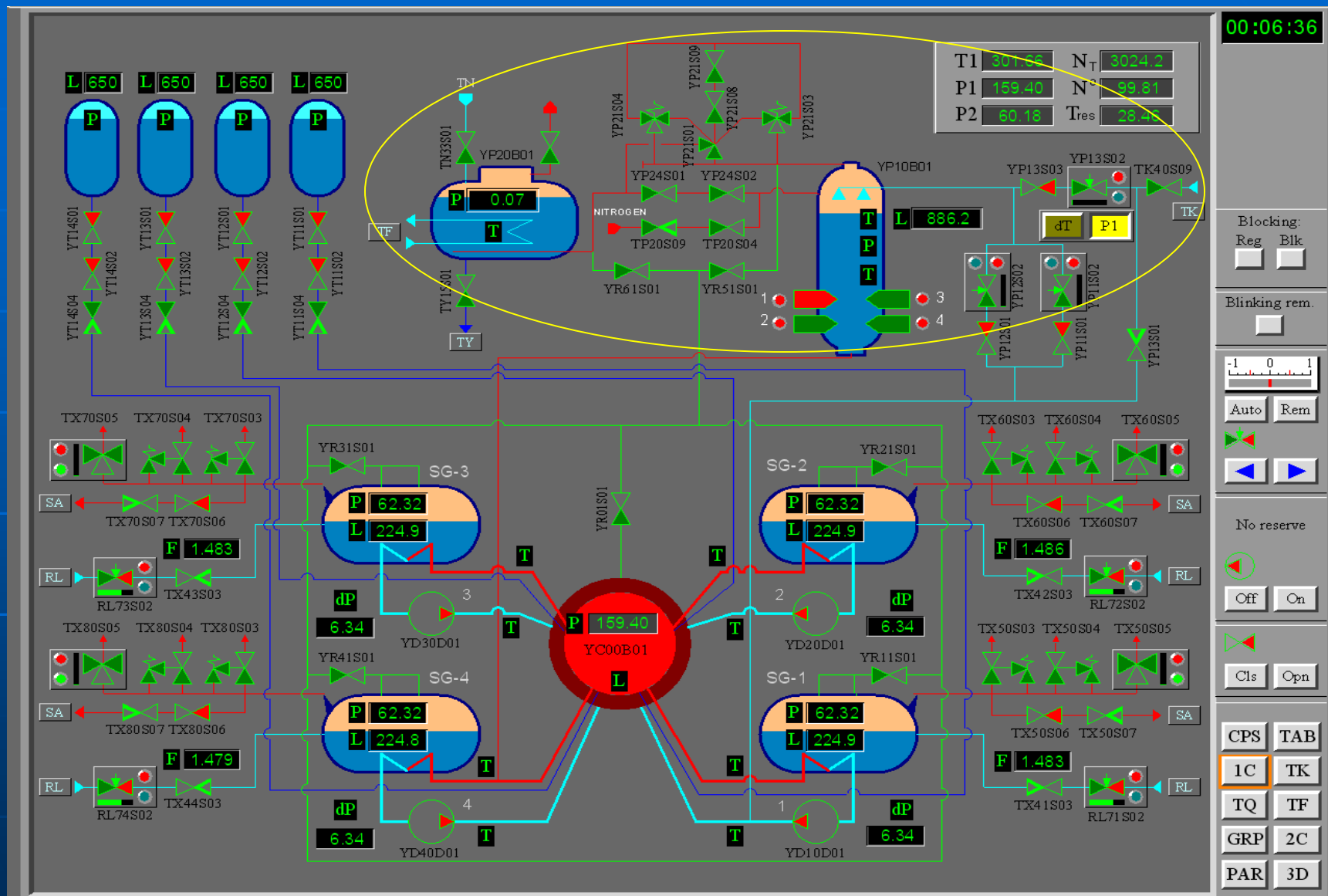
FA of 1st and 5th Core Loads

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 1 st year	5
UO2 enrichment 4.4% + Boron Absorber Removed after 1 st year	3

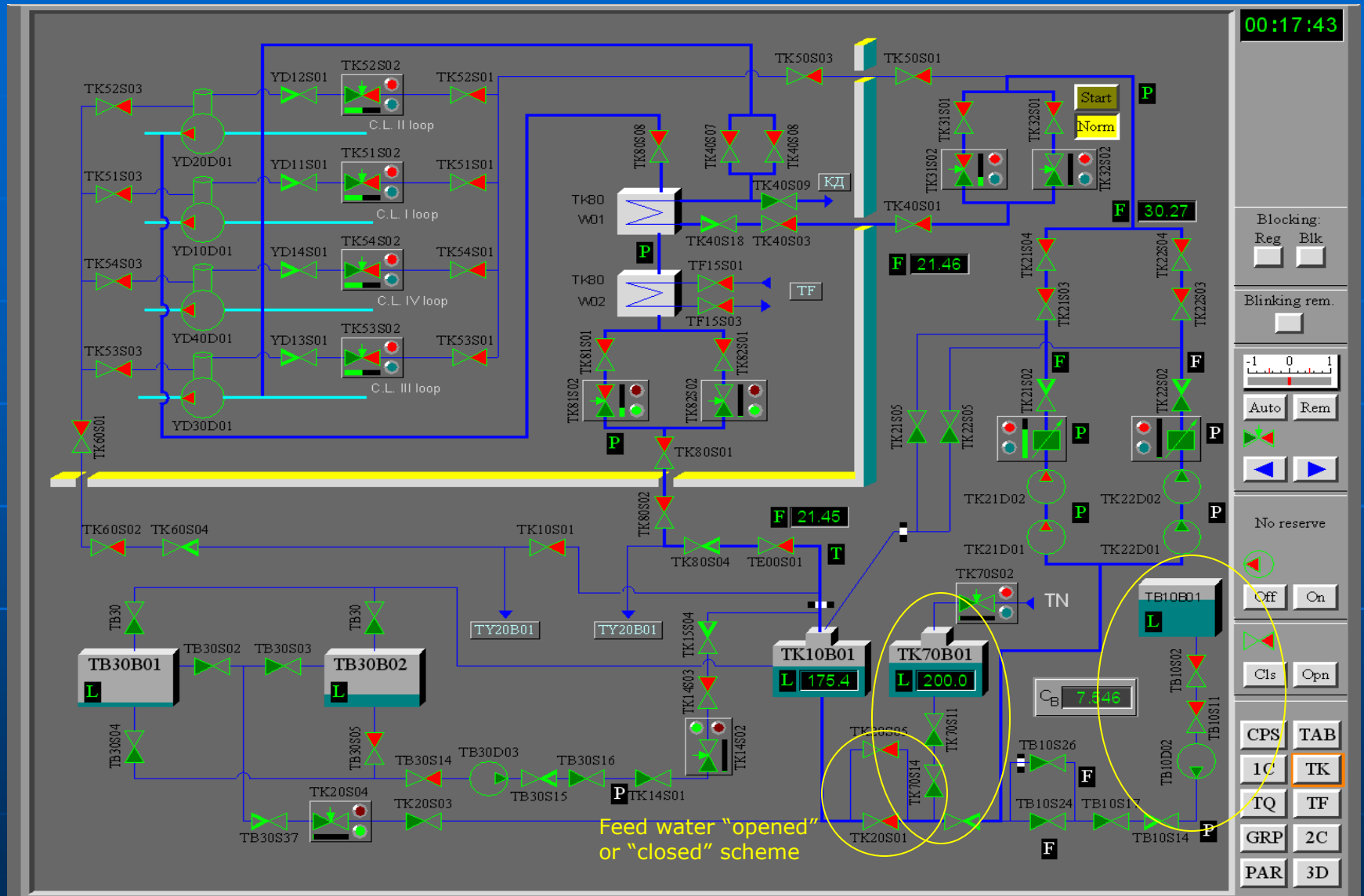
Primary circuit: main circulation pipelines, main circulation pumps (MCP), steam generators (SG)



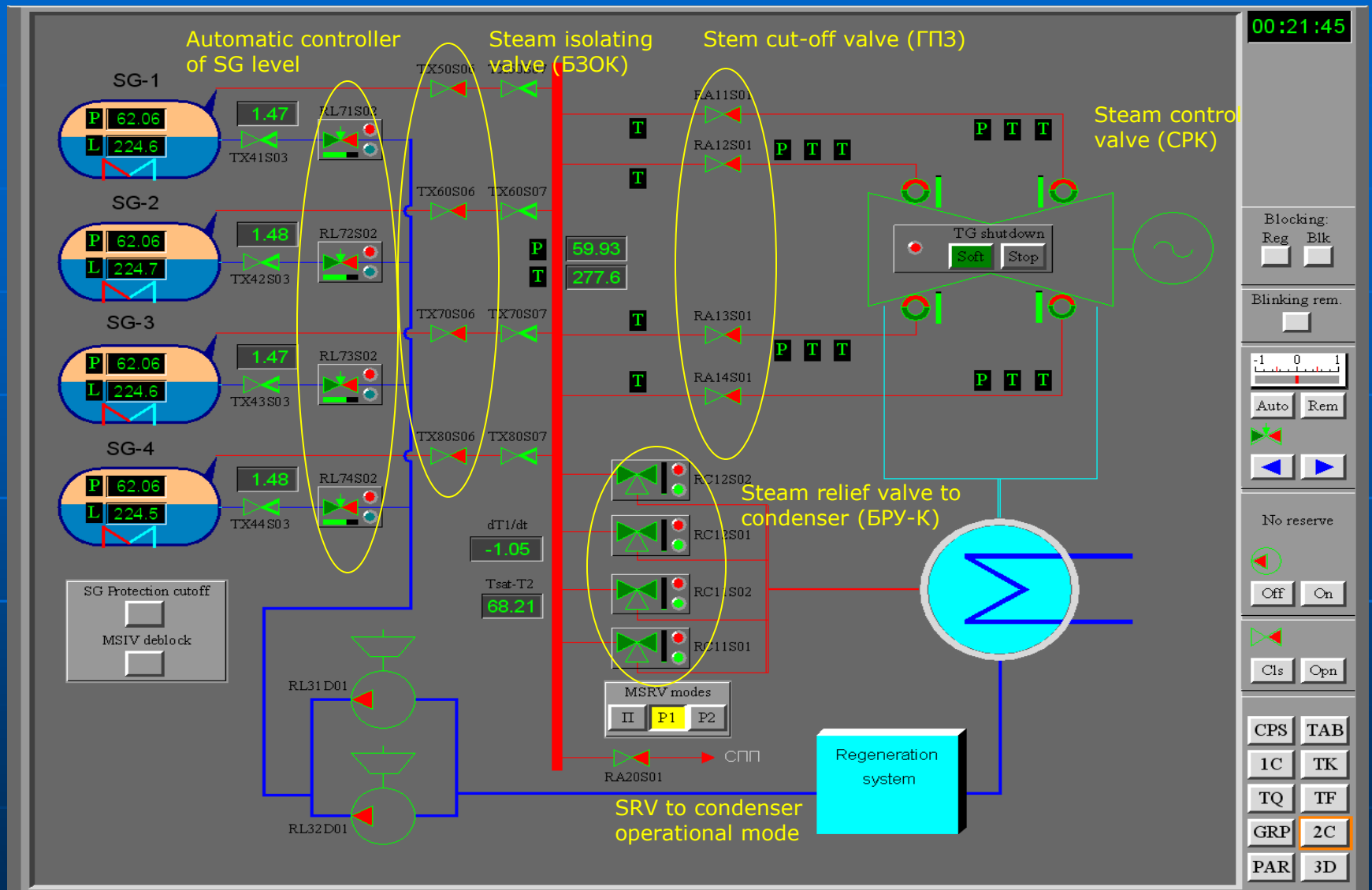
Pressurizer and primary circuit pressure compensating system



Primary circuit feed and bleed system, including boron regulation



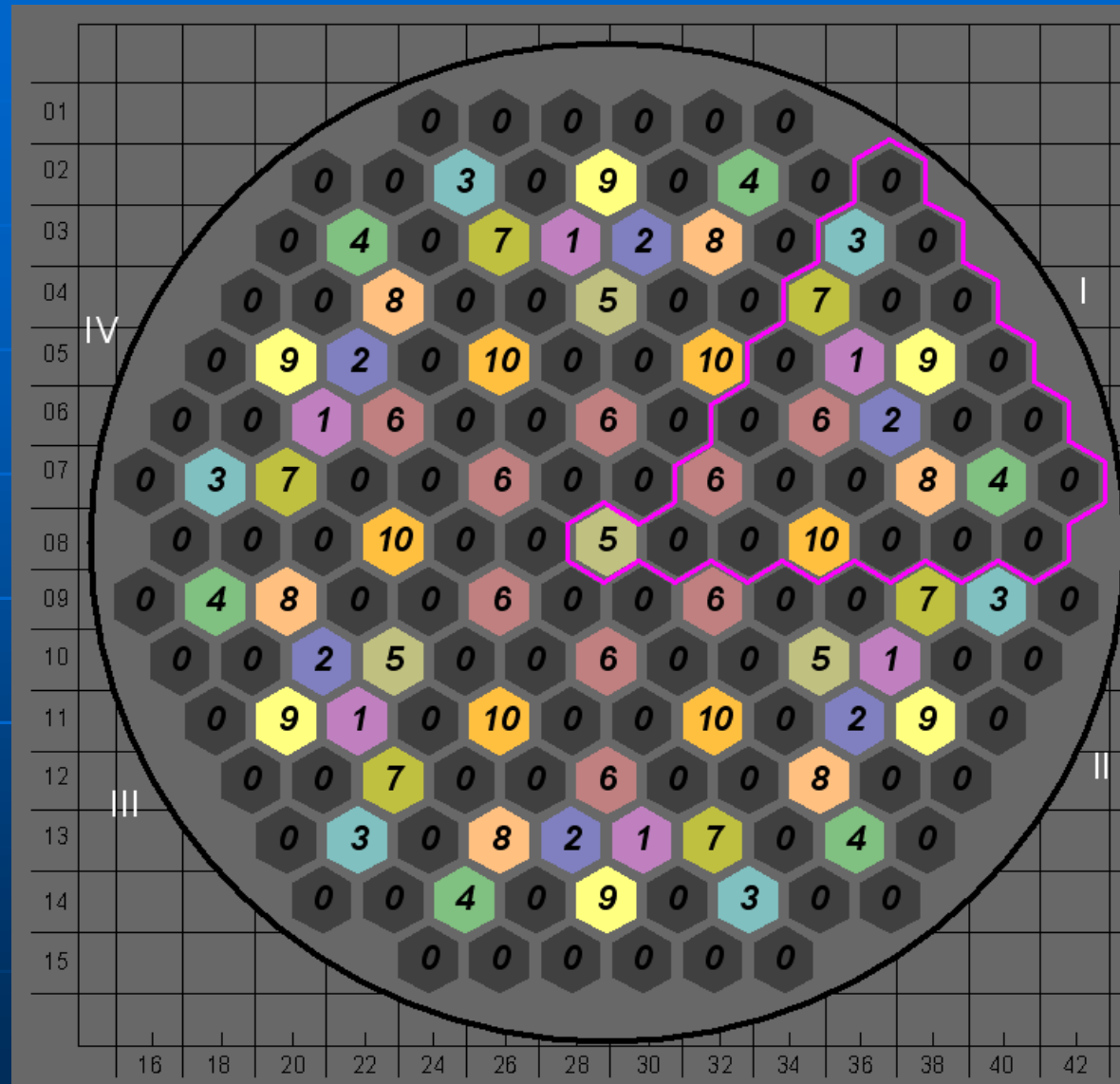
Secondary circuit steam lines and feed water pipelines



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

EP

EP deblock.

EP from CR

P mss > 80

P1 > 180

N > Setpoint

T < 10 sec

< 2 ГЦН

dT s1 < 10

dT s1-2 > 75

T h.l. > 330

P1 < 150 N > 75

P1 < 140

dP MCP < 2.5

L SG - 650

F < 46

L Press < 400

PP-1

PP from CR

T < 20 sec

P1 > 172

MCP trip

PCR

TDFWP trip

N heat > Setpoint

Generator trip

MSV closed

PP-2

PP-2 deblock

N > Setpoint

P1 > 165

CR drop

AUU

AUU from CR

2 MCP trip

TDFWP trip

Generator trip

MSV closed

SG

L SG1 > 39.5

L SG1 < 22

MSIV1 closed

MSSV SG1 opened

P SG1 > 84

L SG2 > 39.5

L SG2 < 22

MSIV2 closed

MSSV SG2 opened

P SG2 > 84

L SG3 > 39.5

L SG3 < 22

MSIV3 closed

MSSV SG3 opened

P SG3 > 84

L SG4 > 39.5

L SG4 < 22

MSIV4 closed

MSSV SG4 opened

P SG4 > 84

MSC

P mss < 52

P mss < 56

P mss > 62

1C

L Press. < 500

TK disbalance

L TY20B01 > 1500

MSSV Press. opened

00:37:00

Blocking:

Reg

Blk

Blinking rem.

Deblocking

CPS

TAB

1C

TK

TQ

TF

GRP

2C

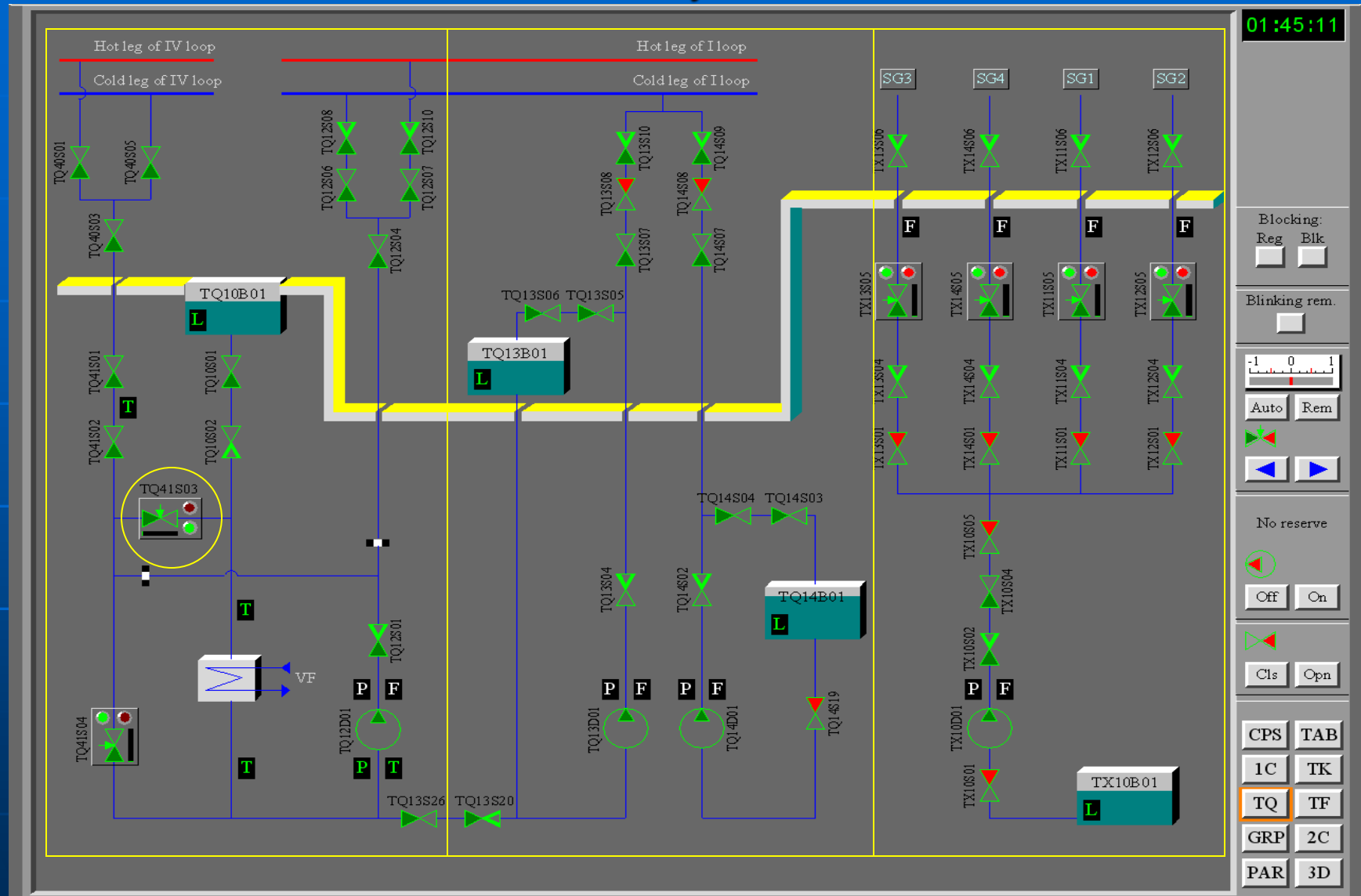
PAR

3D

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 caused 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

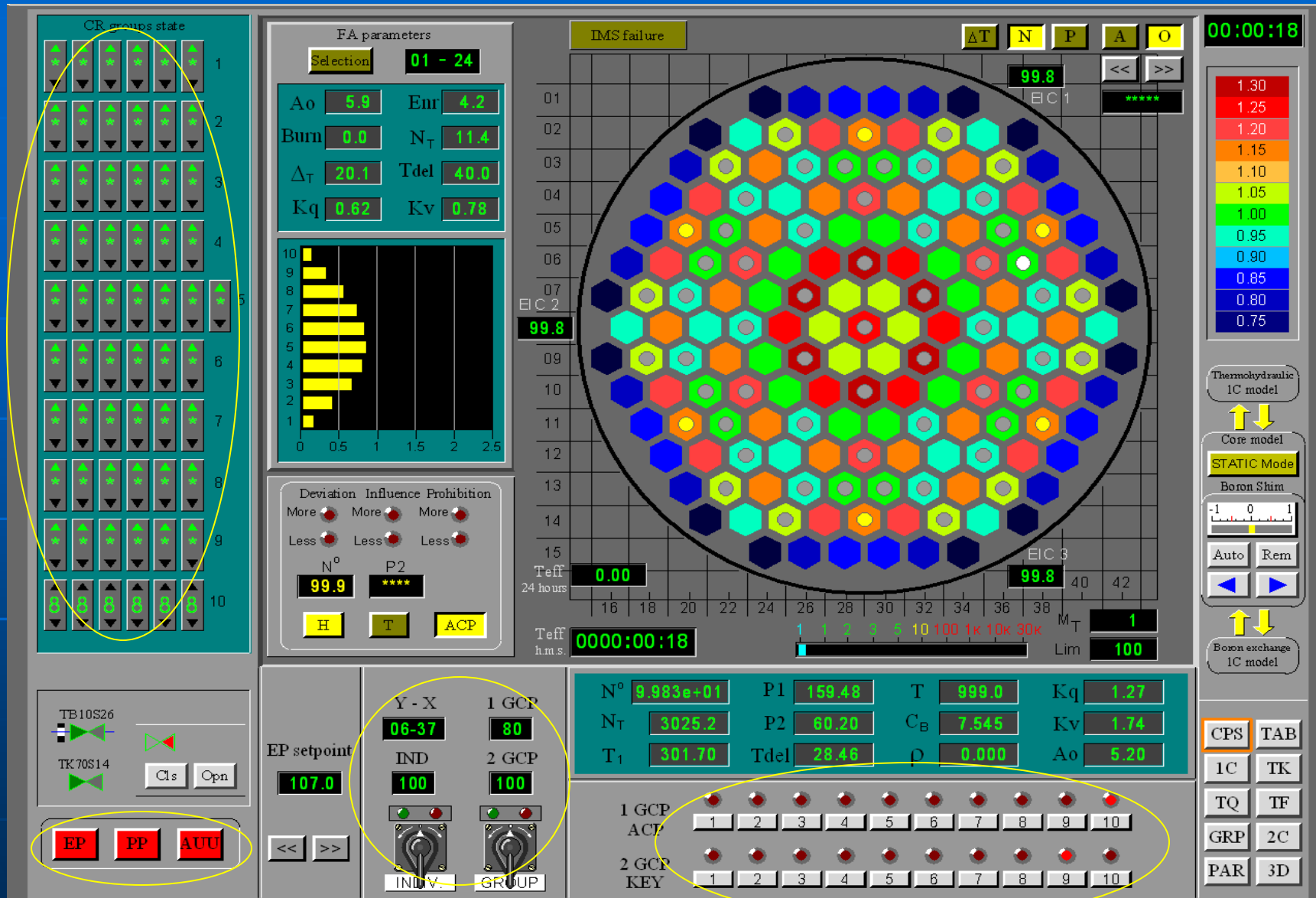
Simulator interface and main controls

- 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

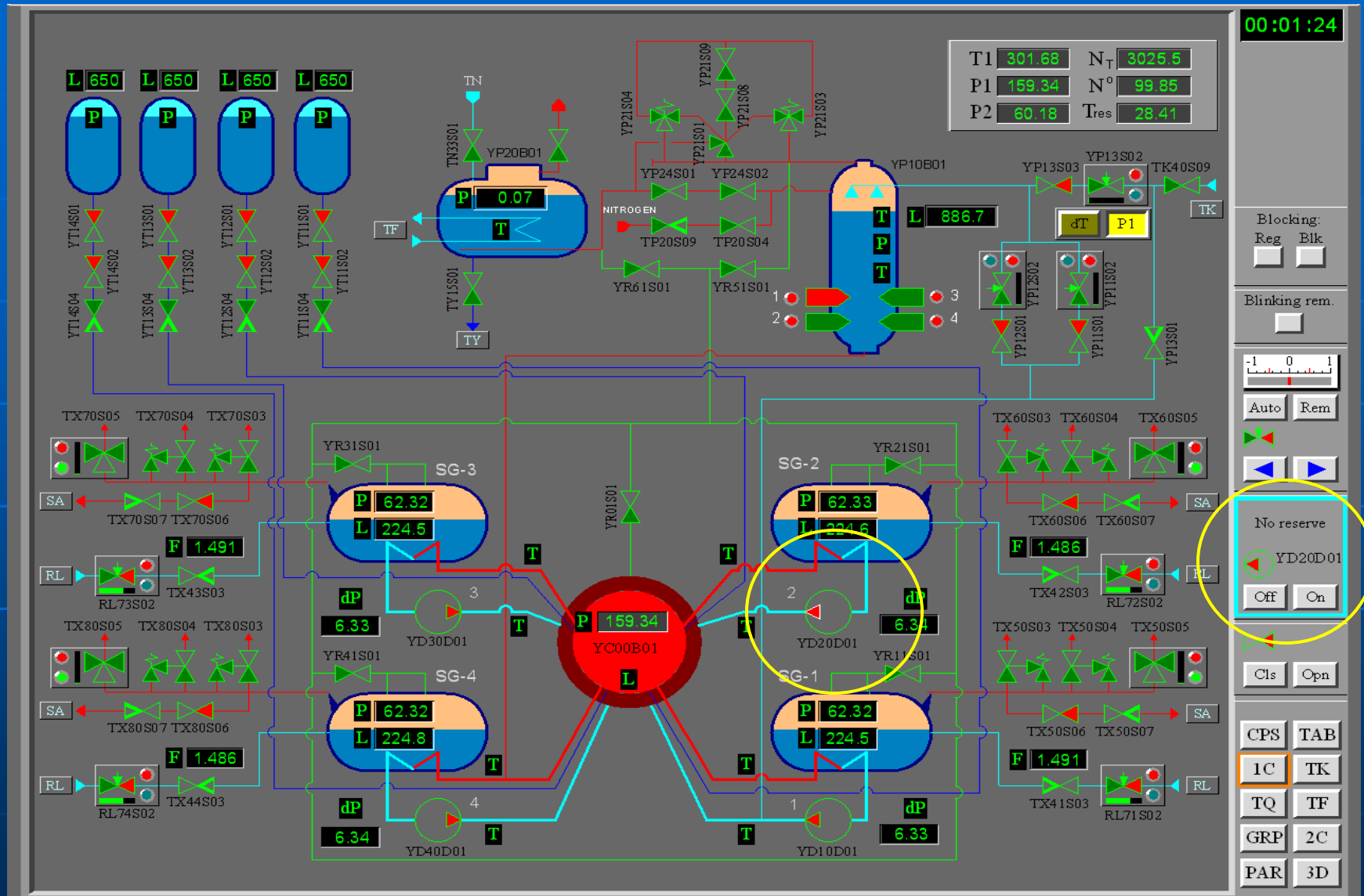
Display screen: axial and radial values distribution



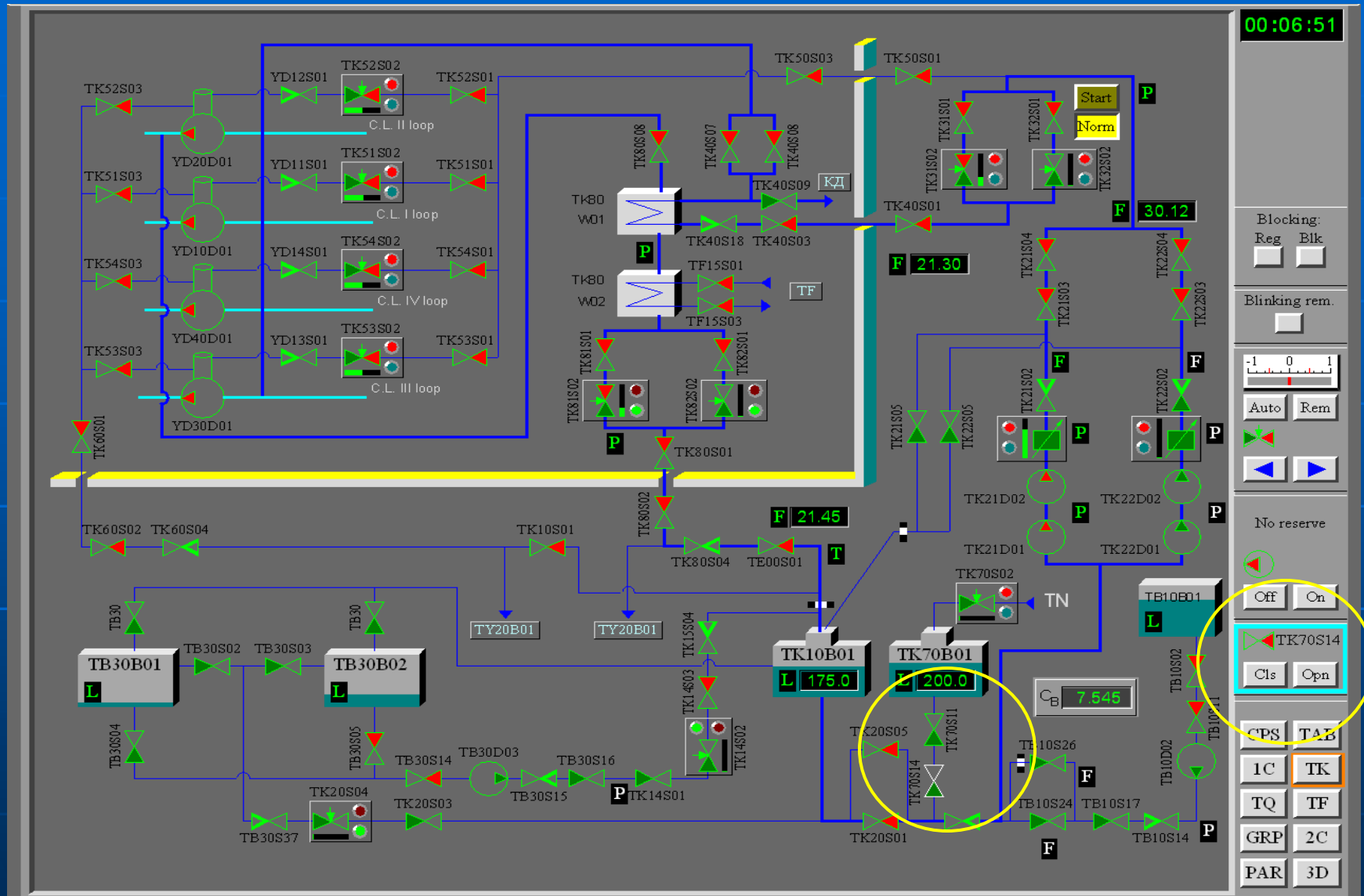
Main display screen and control rods operation



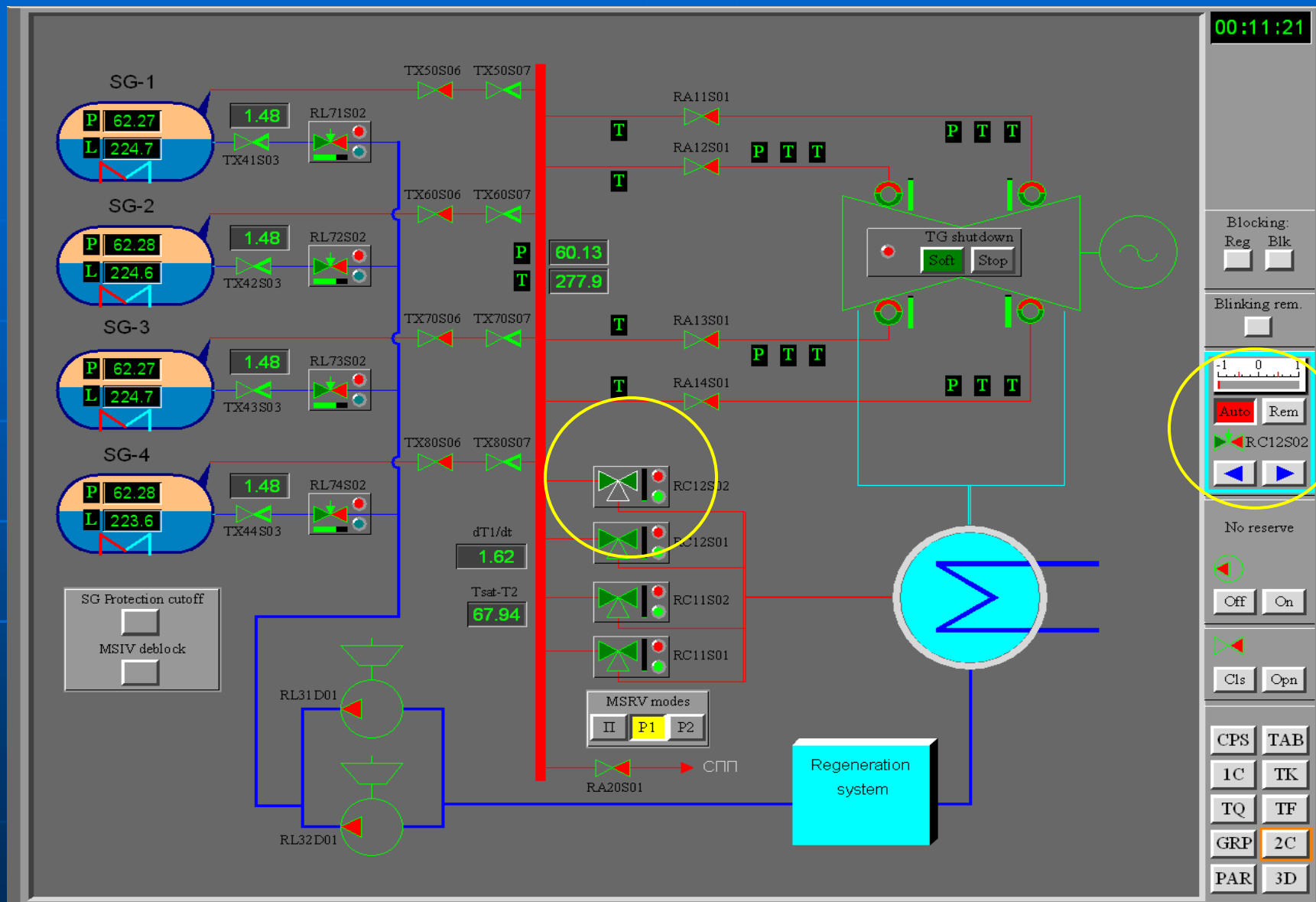
Pump operation



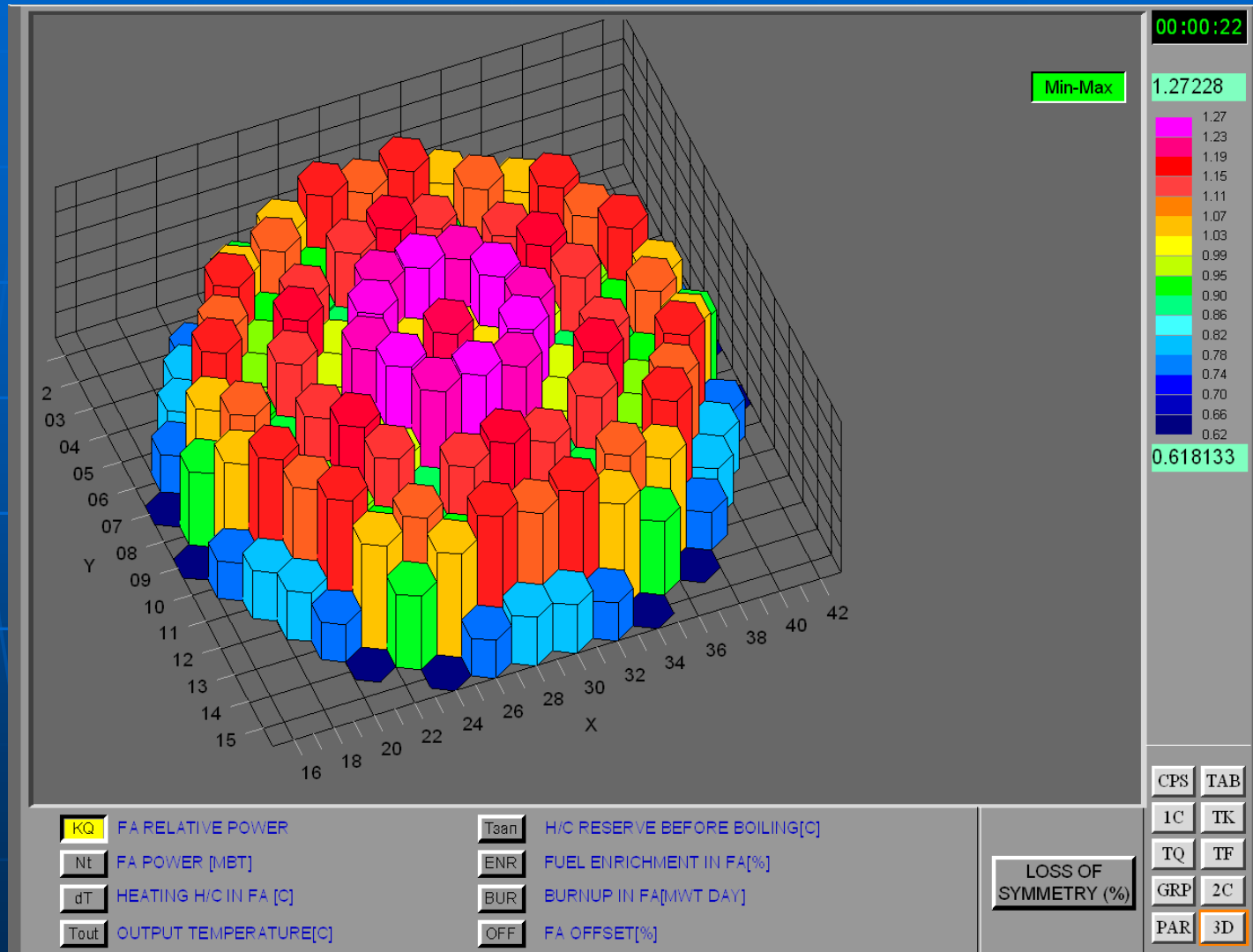
Valve operation



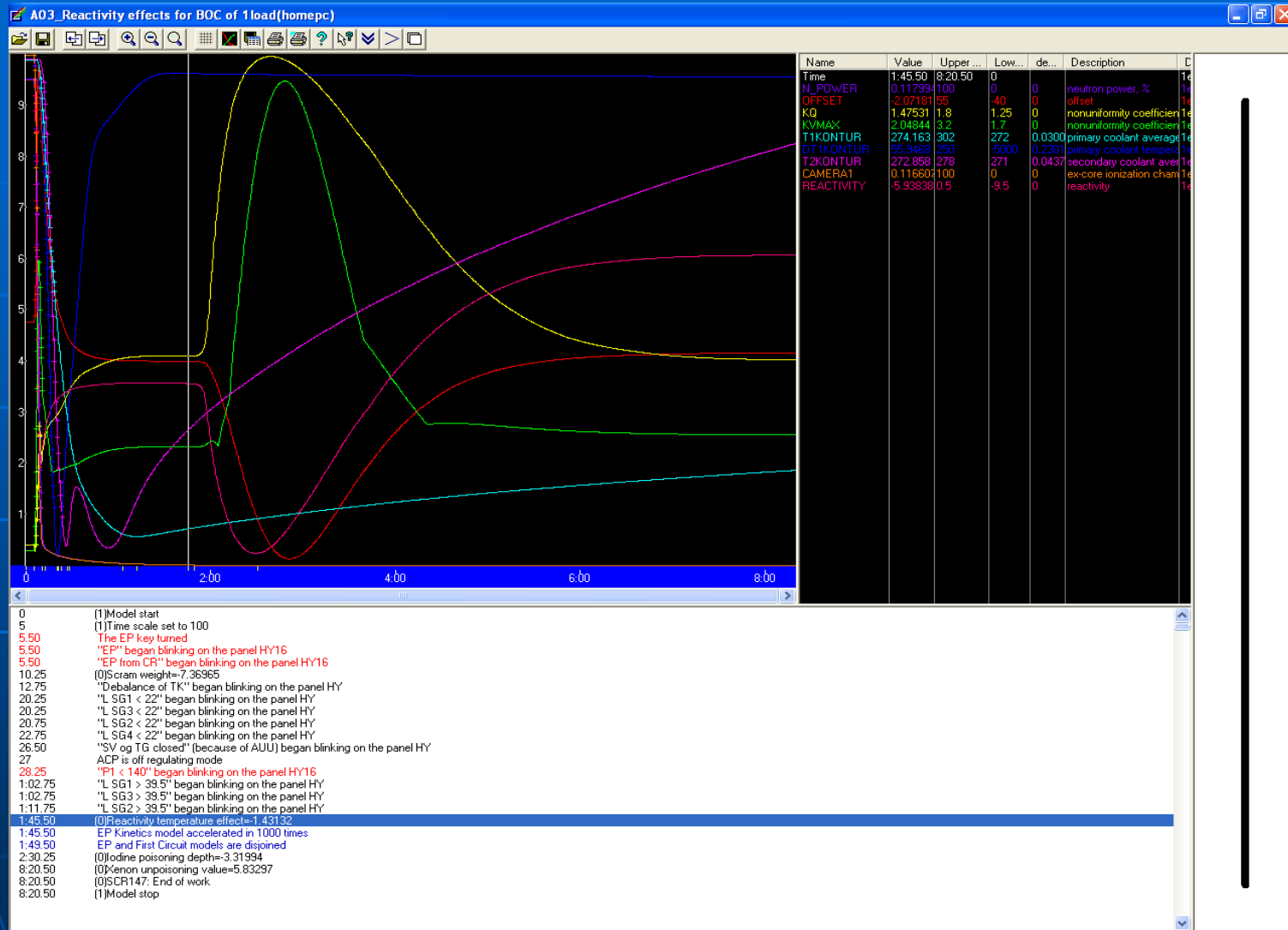
Automatic controller operation



Task selection, simulator start, stop and exit



Simulation protocol analysis



Application of the WWER-1000 Reactor Simulator for Educational Purposes



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Nuclear Power Technology Development Section

IAEA Collection of PC-Based Simulators for Education

The International Atomic Energy Agency (IAEA) has established a programme in nuclear reactor simulation computer programs to assist Member States in education and training. The objective is to provide, for a variety of advanced water-cooled reactor types, insight and practice in their operational characteristics and their response to perturbations and accident situations. To achieve this, the IAEA arranges for the supply or development of simulation programs and training material, sponsors training courses and workshops, and distributes documentation and computer programs.

Currently the IAEA has simulation programs available for distribution that simulate the behaviour of the following reactor types:

- Boiling Water Reactor (BWR)
- Passive Boiling Water Reactor (BWR)
- CANDU Reactor: Introduction to CANDU and User Manual
- Advanced CANDU Reactor
- Pressurized Water Reactor (PWR)
- Passive Pressurized Water Reactor (PWR)
- WWER-1000

These desktop simulator codes provide insight and understanding of the designs as well as a clear understanding of the operational characteristics of the various reactor types. The simulators operate on personal computers and are provided for a broad audience of technical and non-technical personnel as an introductory educational tool. The preferred audience, however, are faculty members interested in developing nuclear engineering courses with the support of these very effective hands-on educational tools. The application of the simulator programs is limited to providing general response characteristics of selected types of power reactor systems and they are not intended to be used for plant-specific purposes such as design, safety evaluation, licensing or operator training.

Databases

- THERPRO
- Irradiated Nuclear Graphite Properties

Our Program

- Water Cooled Reactors
- Gas Cooled Reactors
- Fast Reactors
- Small and Medium Size Reactors
- Non-Electric Applications
- Support for Near Term Deployment

NPTDS Highlights

- About NPTDS
- Meetings
- Publications
- Technical Working Groups (TWG)
- Coordinated Research Projects (CRP)
- Technology Training

Nuclear Power Technology Development with Sights and Sounds

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

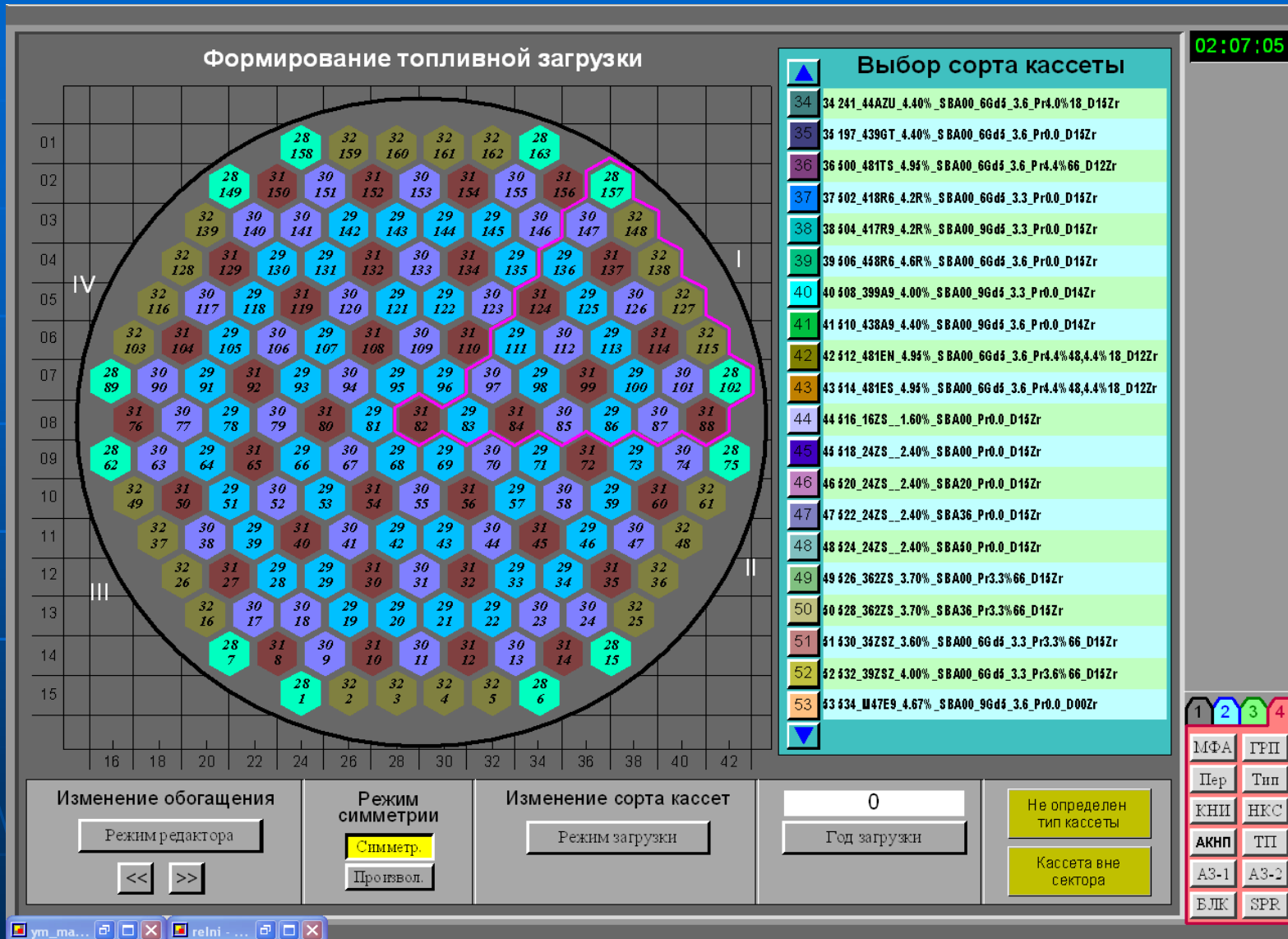
WWER-1000 MFA-RD

- 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

Выбор цепочки кассет

Замыкающая кассета в цепочке

←

34	34 241_44AZU_4.40%_SBA00_6Gd5_3.6_Pr4.0%18_D15Zr
35	35 197_439GT_4.40%_SBA00_6Gd5_3.6_Pr0.0_D15Zr
36	36 500_481TS_4.95%_SBA00_6Gd5_3.6_Pr4.4%66_D12Zr
37	37 502_418R6_4.2R%_SBA00_6Gd5_3.3_Pr0.0_D15Zr
38	38 504_417R9_4.2R%_SBA00_9Gd5_3.3_Pr0.0_D15Zr
39	39 506_458R6_4.6R%_SBA00_6Gd5_3.6_Pr0.0_D15Zr
40	40 508_399A9_4.00%_SBA00_9Gd5_3.3_Pr0.0_D14Zr
41	41 510_438A9_4.40%_SBA00_9Gd5_3.6_Pr0.0_D14Zr
42	42 512_481EN_4.95%_SBA00_6Gd5_3.6_Pr4.4%48,4.4%18
43	43 514_481ES_4.95%_SBA00_6Gd5_3.6_Pr4.4%48,4.4%18
44	44 516_16ZS_1.60%_SBA00_Pr0.0_D15Zr
45	45 518_24ZS_2.40%_SBA00_Pr0.0_D15Zr
46	46 520_24ZS_2.40%_SBA20_Pr0.0_D15Zr
47	47 522_24ZS_2.40%_SBA36_Pr0.0_D15Zr
48	48 524_24ZS_2.40%_SBA50_Pr0.0_D15Zr
49	49 526_362ZS_3.70%_SBA00_Pr3.3%66_D15Zr
50	50 528_362ZS_3.70%_SBA36_Pr3.3%66_D15Zr
51	51 530_36ZSZ_3.60%_SBA00_6Gd5_3.3_Pr3.6%66_D15Zr
52	52 532_39ZSZ_4.00%_SBA00_6Gd5_3.3_Pr3.6%66_D15Zr
53	53 534_1M47E9_4.67%_SBA00_9Gd5_3.6_Pr0.0_D00Zr

02:10:50

Перестановки кассет

Режим перестановок

Ввод

Режим симметрии

Симметр.

Произвол.

Симм. кассета
была выбрана

Кассета уже
была выбрана

Кассета вне
сектора

ym_ma...
relni - ...

МФА

ГРП

Пер

Тип

КНП

НКС

АКНП

ТП

А3-1

А3-2

БЖК

Control rods location and CR banks configuration



Multi-cycles fuel burnup calculation

XIPI

Инициализация и моделирование выгорания на основе данных XIPI

02:25:04

Путь к каталогу xipi(input): G:\MFA-RO\KALININ\KAЭC-2-1\INPUT\xipi1

Путь к каталогу xipi(output): G:\MFA-RO\KALININ\KAЭC-2-1\INPUT\xipi1_nut

управление режимом выгорания

точность
1.00

макс. шаг[с.]
10000

Nset=100.0 N=100.00

установить мощность[%]

индикатор выполнения

МУЛЬТИПУСК
ПУСК
ПАУЗА

DT Авт.

Npredict 100
Nstop 75.00
EndBrn 0
dt_powdec 10000

BRN
STOP

ускорение 1.0

0.01 0.1 1 10 100 1к 10к 100к 1м

подгрузка

текущ.
бл. 3
зг. 1

начало
выг. 1

загрузить начало
загрузить XIPI
згр. парам. начала

загрузить конец
перезагрузить
згр. парам. конца

Загрузить произвольное состояние

Параметры топлива загр./выгр.

D:\ENIKOTSO\KALININ\KAЭC-2-1\MOD

режим выгорания

номер блока
номер загрузки

начало

текущ.

3

3

kaln

станция

1

1

-1

конец мульти

☐ пауза в конце
☐ сохранять состояния на конец кампаний
☐ сохранять состояния на начало кампаний
☐ выбор опций печати в файл

☐ пауза перед точкой state_save_tim
☐ сохранять состояния в точках state_save_tim
☐ пауза около g файлов
☐ Сохранять параметры выгорания

параметры активной зоны

N нейтронная, % 100.0

N тепловая, Мвт 3000.0

T средняя по петлям, C

P в активной зоне, кг/см2 160

Q борной кислоты, г/кг 4.80655

Положение упр. группы APM, см 1

Выгорание, эфф.суток 0.000

ρ 0.0000

Модель A3

СТАТИКА

-

0

+

Авт. Дис.

Борный рег-р

1

2

3

4

CY3

PRN

DIF

XIPI

EFF

BRN

APX

DAT

N1

N2

N3

TUN

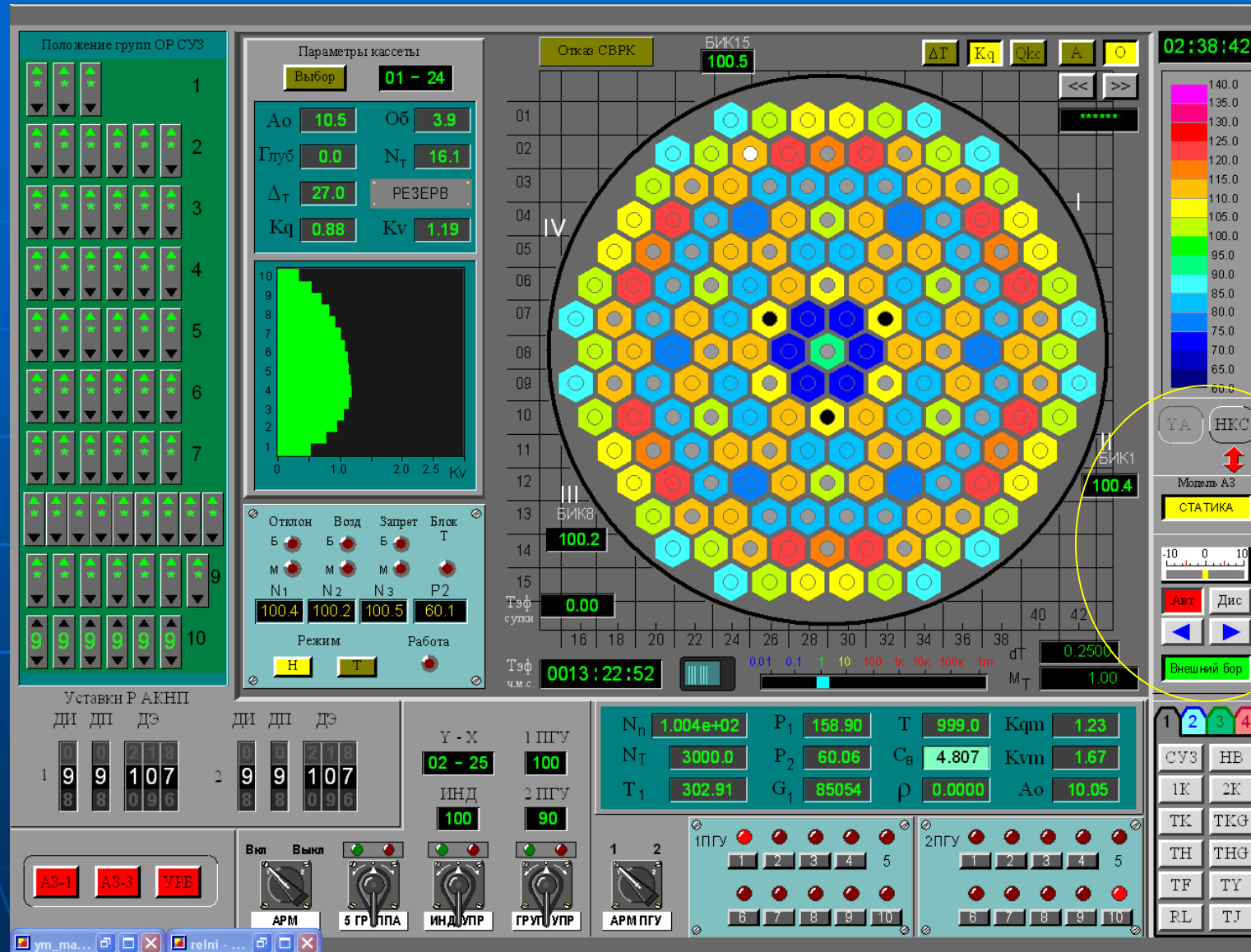
ym_ma...

relni - ...

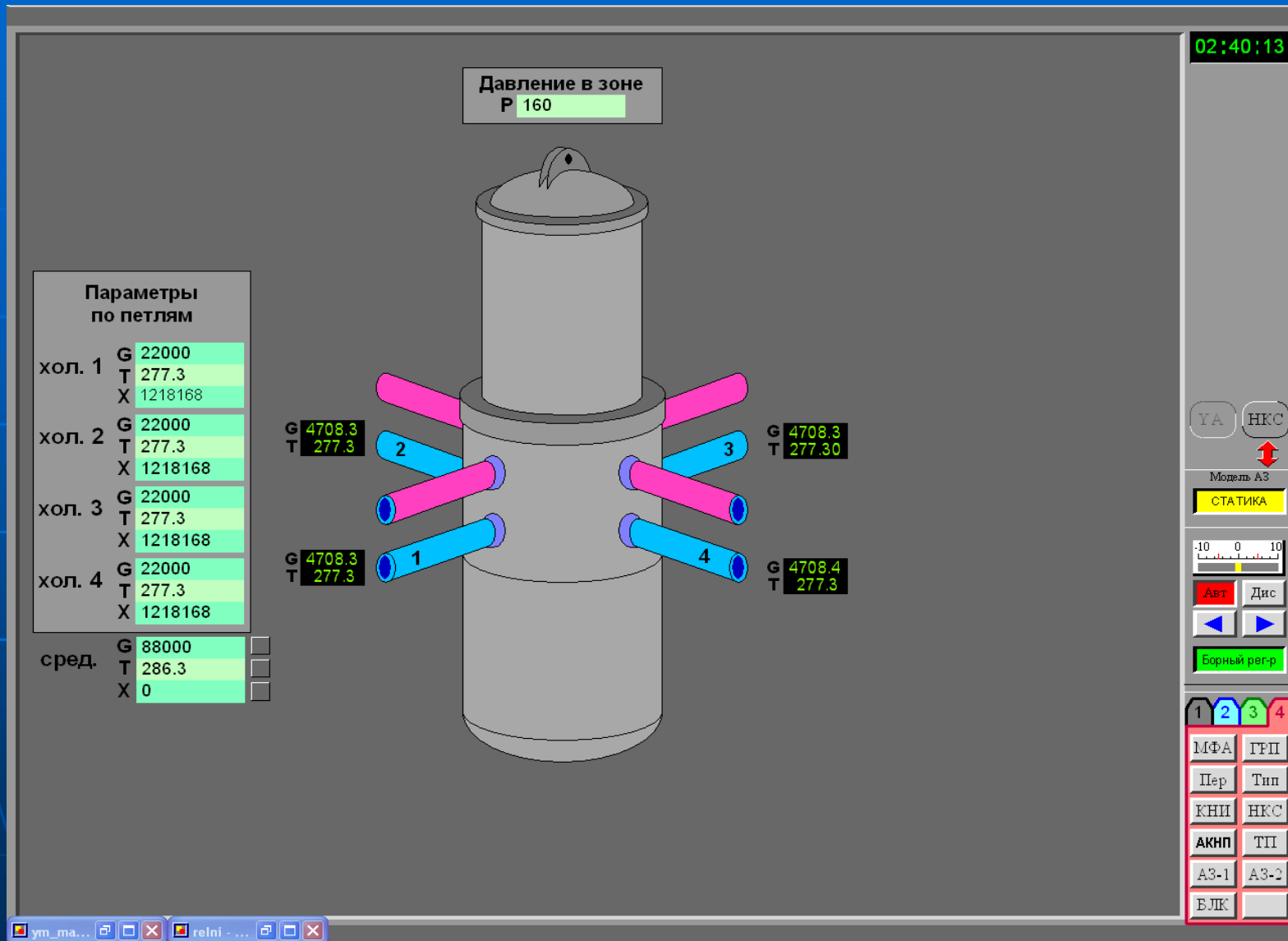
MFA-RD reactor core computational features

- 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

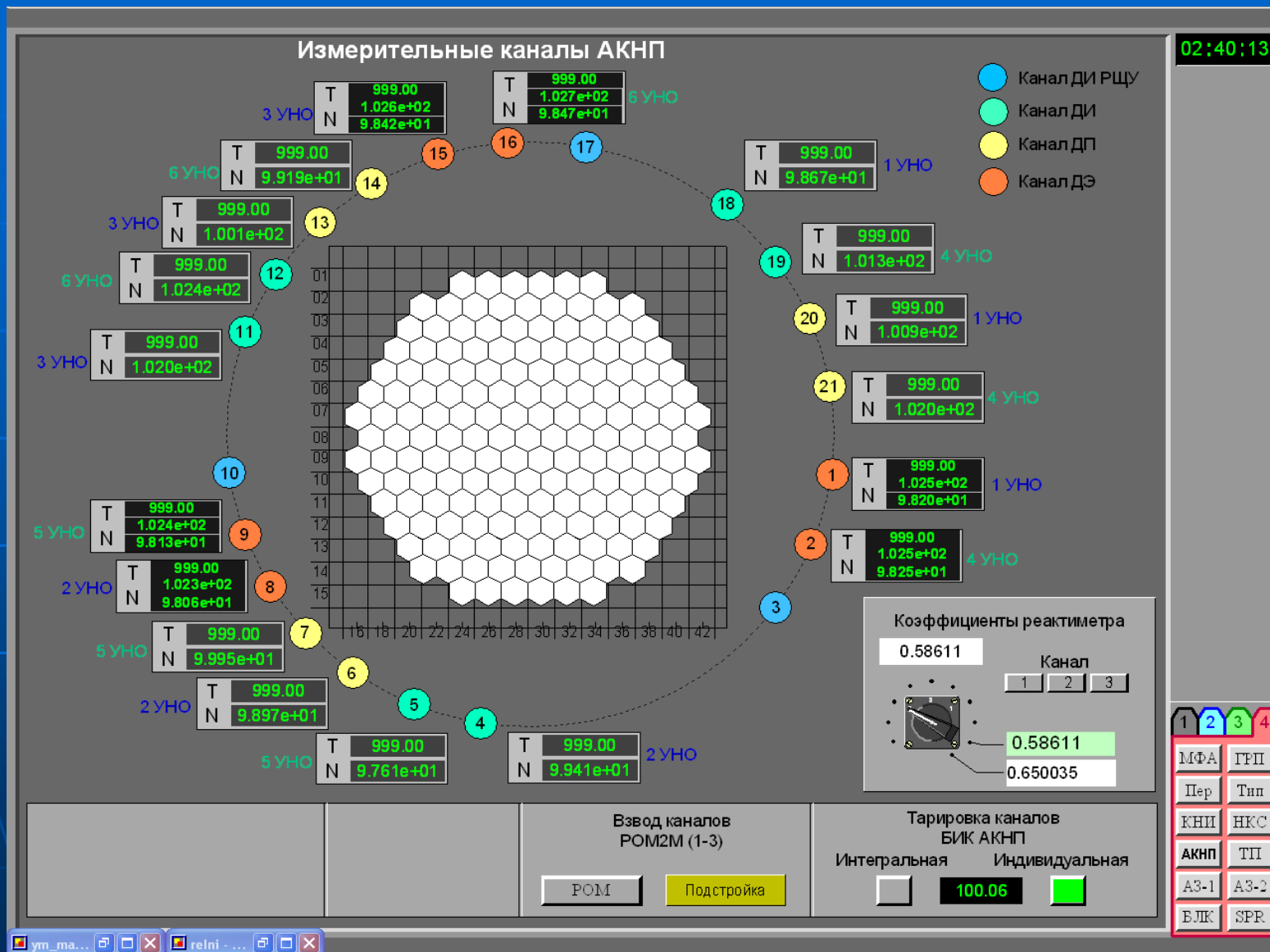
Reactor core computational modes



Boundary conditions for core thermal-hydraulics model



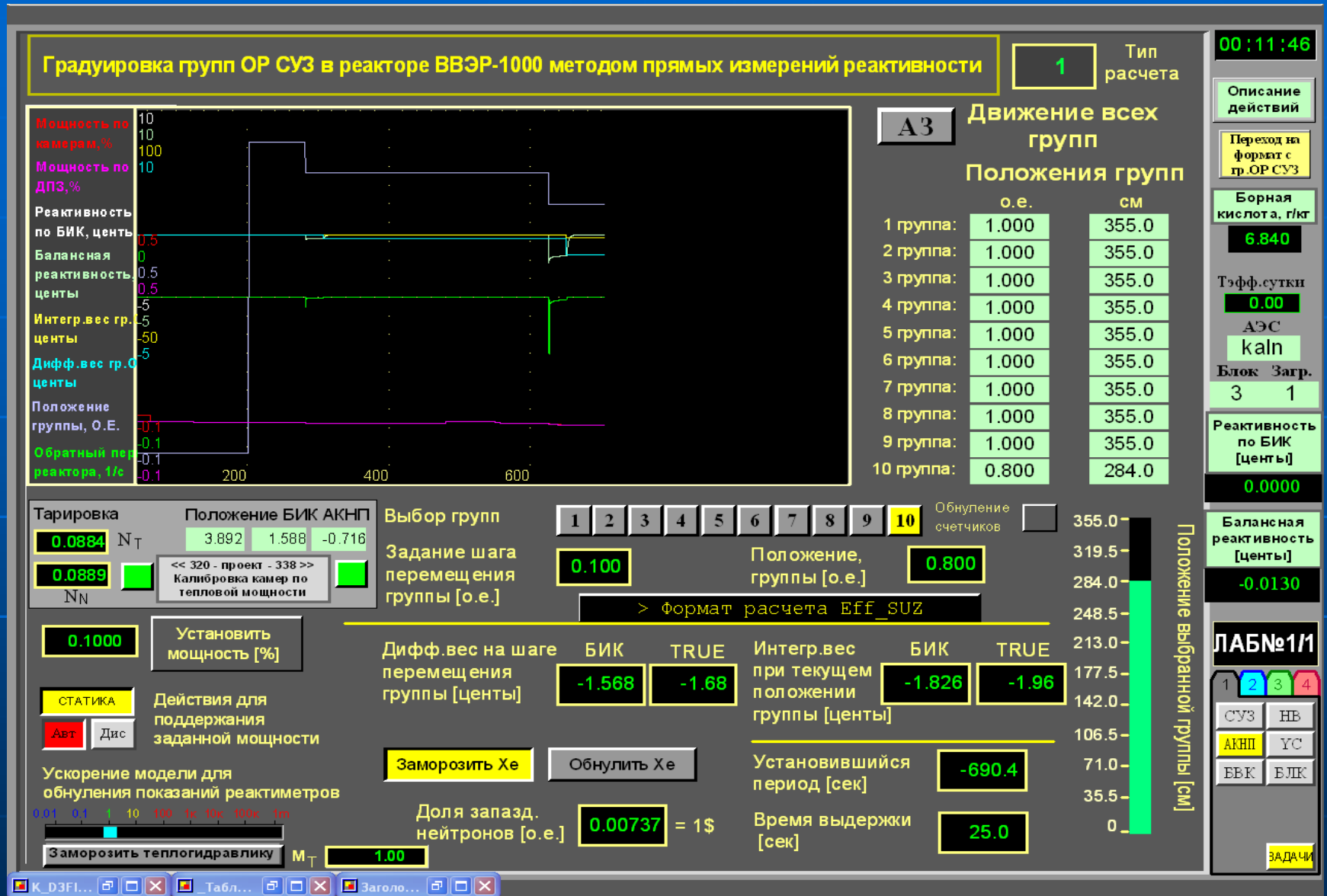
Ex-core instrumentation model



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



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

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Thank You for Your Attention