



**The Abdus Salam
International Centre for Theoretical Physics**



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**Joint ICTP-IAEA Workshop on Nuclear Reaction Data for Advanced
Reactor Technologies**

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IAEA Collection of PC-Based Nuclear Reactor Simulators for Educational Purposes

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IAEA COLLECTION OF PC-BASED NUCLEAR REACTOR SIMULATORS FOR EDUCATIONAL PURPOSES

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1. INTRODUCTION

- ❑ Computer based tools are becoming the state of the art for learning about Nuclear Power Plants, particularly about Water Cooled Reactor.
- ❑ The IAEA PC-based simulators are designed to provide insight and understanding of the general design and operational characteristic of various power reactor systems.
- ❑ The simulators provide the general response characteristic of PWR, BWR, WWER, PHWR and have illustrative screens to provide the plant response information.
- ❑ Focus on education, not licensing or reactor operator training, etc.



2. SIMULATOR TYPES

□ Replica Full Scope Simulators

- Plant operation in a control room environment
- Procedure based, cognitive skill based, team work



2. SIMULATOR TYPES

□ Classroom/Desktop Simulators

- Configuration suited to classroom & self - learning tool as complement to textbooks and manuals.
- Provides knowledge of dynamic behavior
- Provides subsystem training, as well as overall plant training (startup, shutdown, malfunctions).



3. IAEA PC-based Simulators Models and Simulation

- ❑ Mathematical models of all systems have been developed to simulate the dynamic features of the NPP
- ❑ They include:
 - Mathematical Model of Reactor System
 - Mathematical Model of Reactor Coolant
 - Mathematical Model of Steam & Feedwater
 - Mathematical Model of Turbine Generator
 - Mathematical Model of Overall Unit System
- ❑ PC-based
- ❑ Manuals describe all models in full detail



Role of PC-based Simulators

- Provide initial educational training to all NPP personnel before NPP is built & full scope simulator in service.
- Provide knowledge of system interfaces, integration and interactions.
- Complement training on a full scope, replica simulator.



PC-Based Simulator Characteristics

- Relatively low cost and affordable.
- Can use highly portable, standard PC platforms.
- Math models are easily configurable and provide flexibility of use.
- Can use graphic icons, control pop-ups, time trends for user interfaces instead of hardwired panels.



4. Simulators Available in the IAEA Collection

- PWR
- Advanced PWR
- BWR
- Advanced BWR
- WWER-1000
- PHWR
- Advanced PHWR (ACR-700)

[PWR Simulator]

- ❑ Developed by Micro-Simulation Technology of USA using the PCTRAN software.
- ❑ PCTRAN is a reactor transient and accident simulation software program that operates on a personal computer.
- ❑ Generic two-loop PWR with inverted U-bend steam generators and dry containment system
- ❑ It could be a Westinghouse, Framatome or KWU design with thermal output in the neighborhood of 1800 MWt (600 MWe).
- ❑ A single loop with the pressurizer is modelled separately from the other loop.



[PWR Simulator]

- ❑ Released in 1985
- ❑ Constantly upgrading its performance and expanding its capabilities.
- ❑ Normal & Abnormal operation
- ❑ Spent fuel pool simulator
- ❑ Severe accident operation:
 - TMI-2 Event
 - Large Break without ECCS
 - Station Blackout

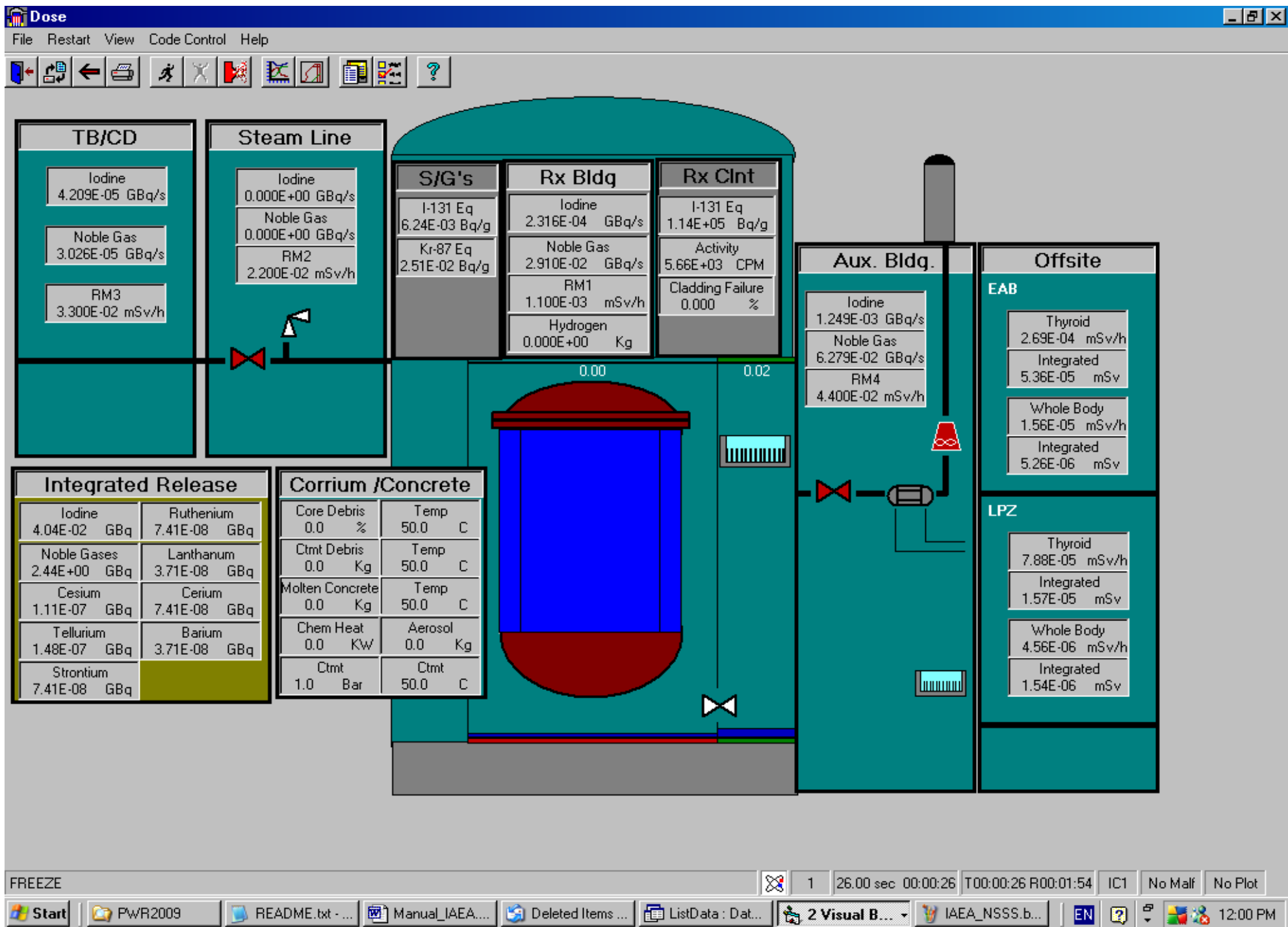


[PWR Simulator]

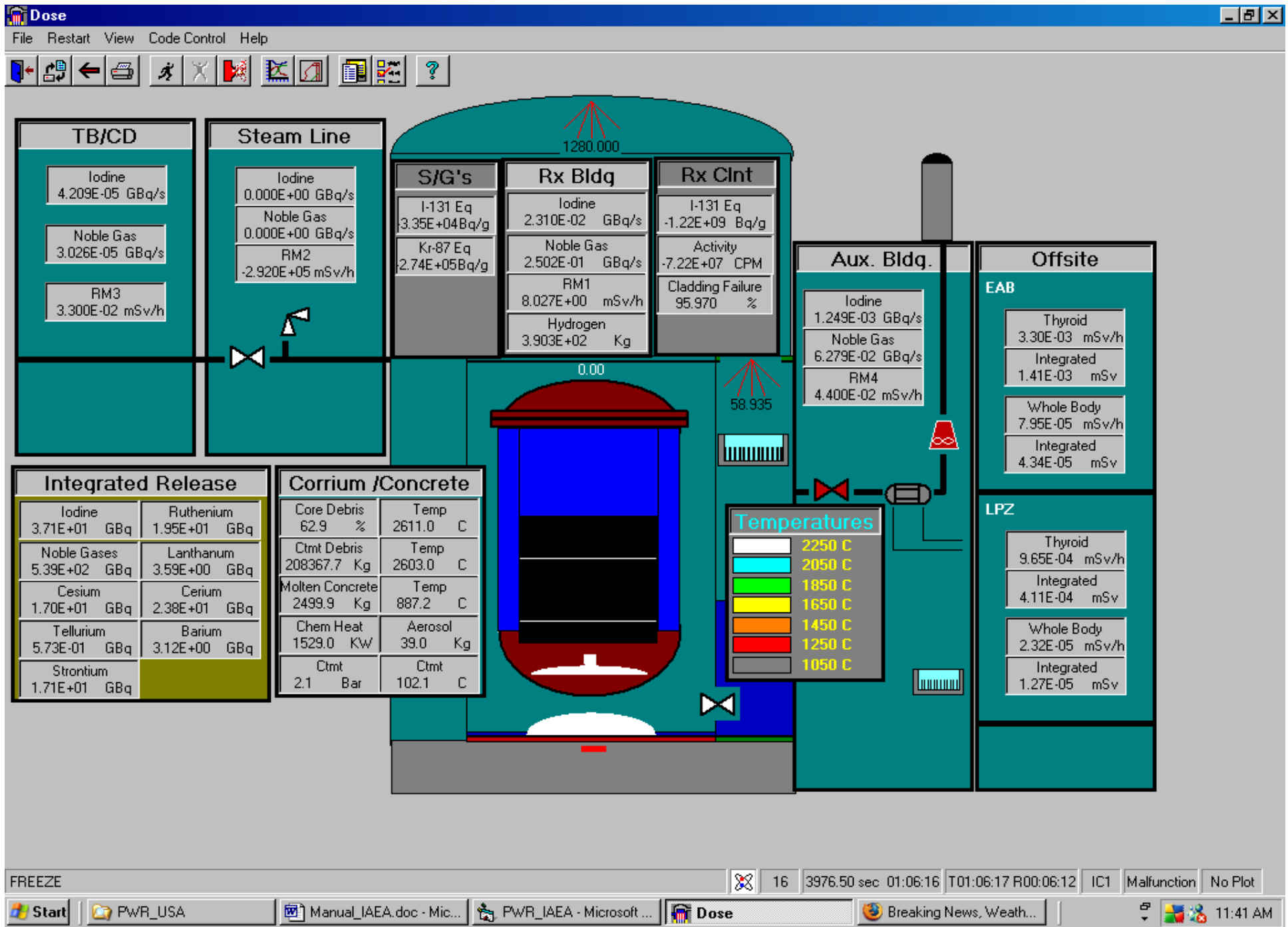
Transient and Accident Analyses

- Uncontrolled Rod Bank Withdrawal
- Hot Full Power Rod Drop
- Moderator Dilution
- Startup of an Inactive RCP
- Reduction in Feedwater Enthalpy
- Excessive Load Increase
- Loss of Reactor Coolant Flow or Normal Feedwater
- Turbine Trip
- Steam Generator Tube Rupture
- Small and Large Break LOCA

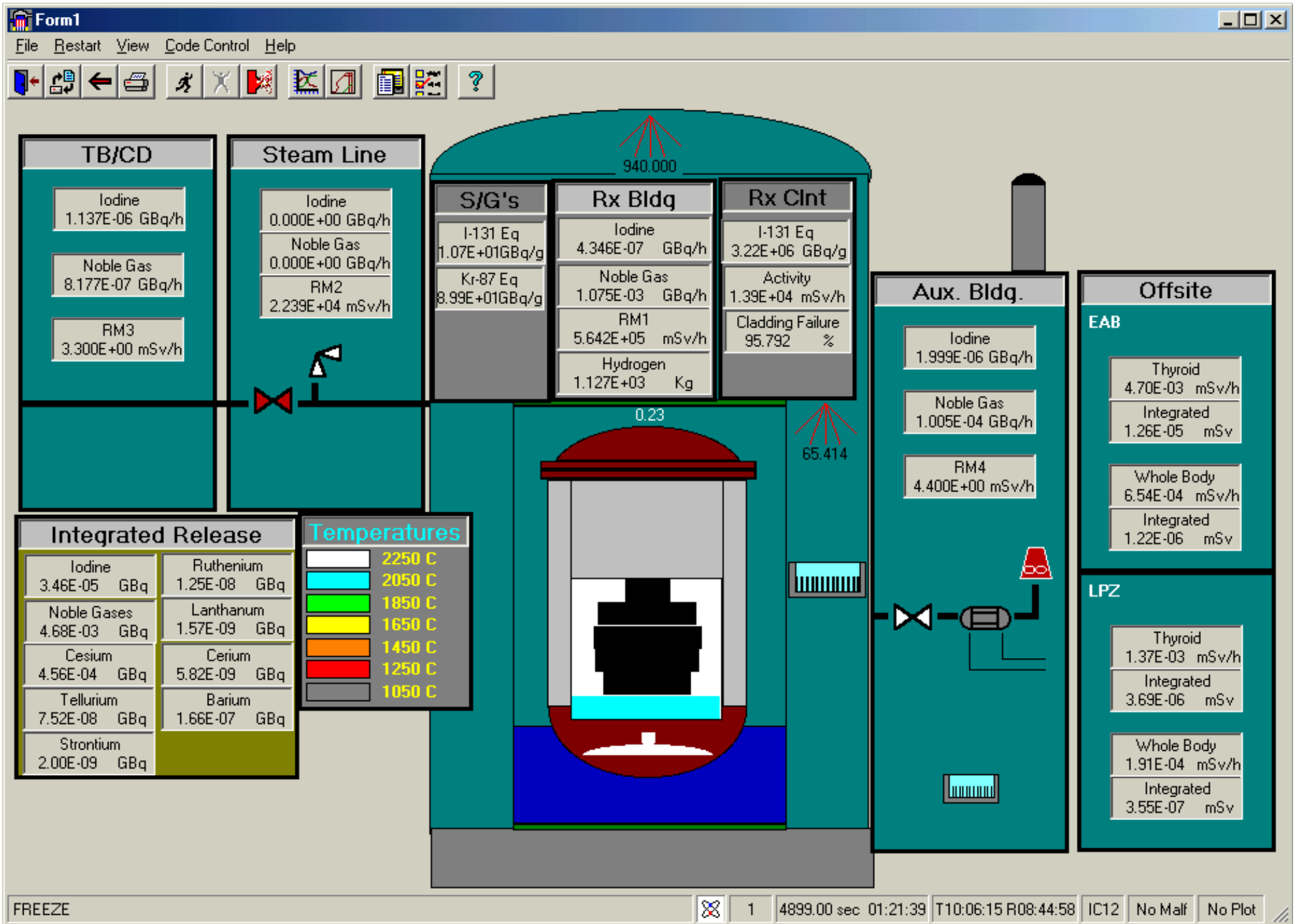




PWR Simulator (Radiation monitoring & Source term mimic)



PWR Simulator (Large Break without ECCS)



PWR Simulator (Severe accident; Core-Concrete Interaction model)

[Advanced PWR]

- ❑ Developed by Cassiopeia Technologies Ins. (CTI)
- ❑ Largely based on a 600 MW(e) Passive PWR Design, similar to AP-600.
- ❑ Reactor Controls based on Korean Standardized 1000 MW PWR Design –Mode K
- ❑ SG pressure control to maintain setpoint at 5.7 Kpa
- ❑ Overall Unit Control allows Reactor-Leading or Turbine-Leading Mode
- ❑ Passive Systems modeled to demonstrate LOCA mitigation



[Advanced PWR]

Key features

- ❑ Larger core, resulting in lower (25 % less) power density
- ❑ Lower fuel enrichment, and the use of radial reflectors for better neutron economy;
- ❑ Longer fuel cycle;
- ❑ About 15 % more safety margin for DNB and LOCA;
- ❑ Reduced worth control rods to achieve load following capability without substantial use of boron;
- ❑ Passive core cooling system which includes core depressurization, SI, and residual heat removal;
- ❑ Passive containment cooling system;
- ❑ In-vessel retention of the molten core in the very unlikely event of a core melt accident.



[Advanced PWR]

Basic operations & Transient recovery

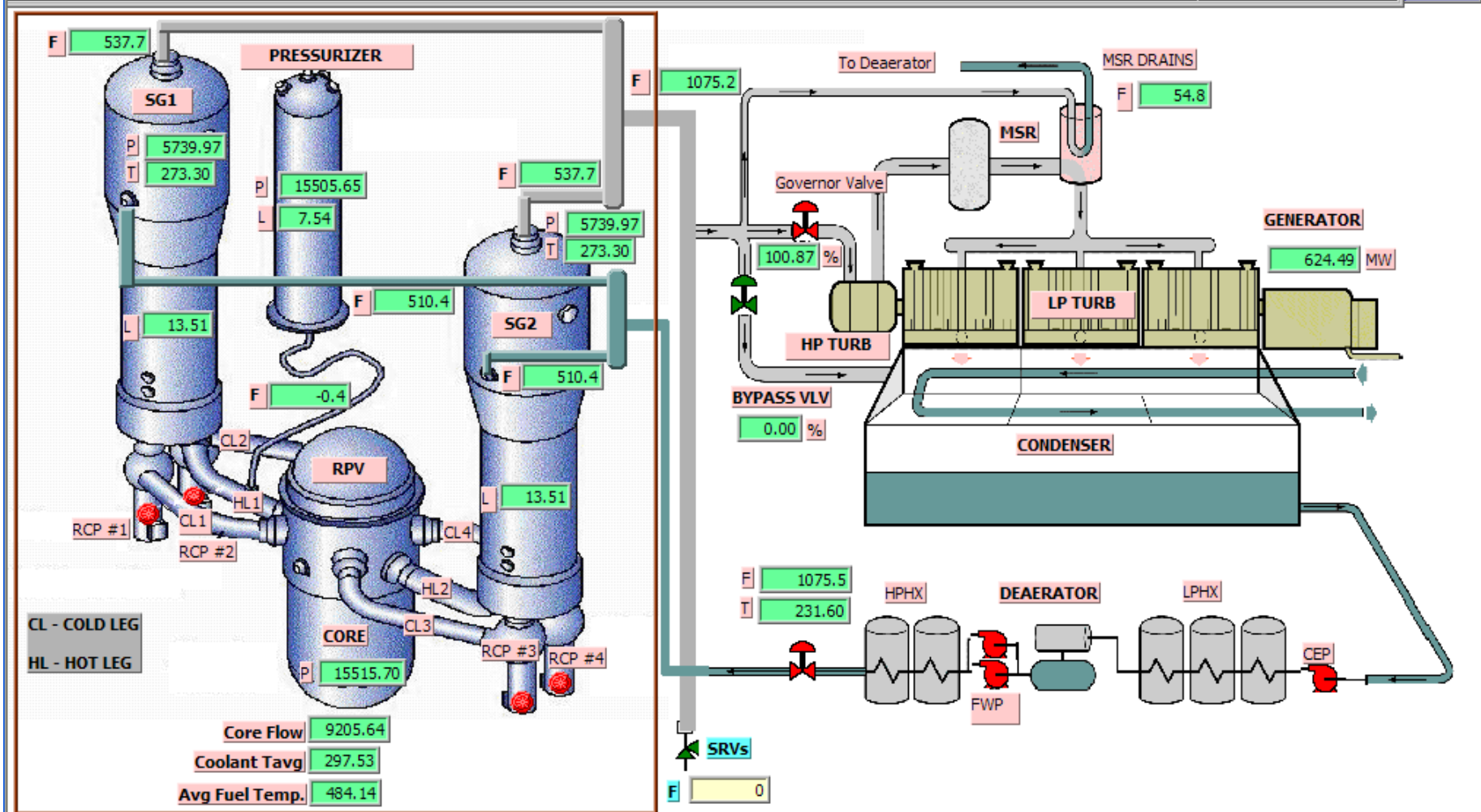
- ❑ Plant load manoeuvring — reactor lead
- ❑ Plant load manoeuvring — turbine lead
- ❑ Power level reduction to 0% FP
- ❑ Reactor trip and recovery
- ❑ Turbine trip and recovery

[Advanced PWR]

20 Malfunction Transient Events

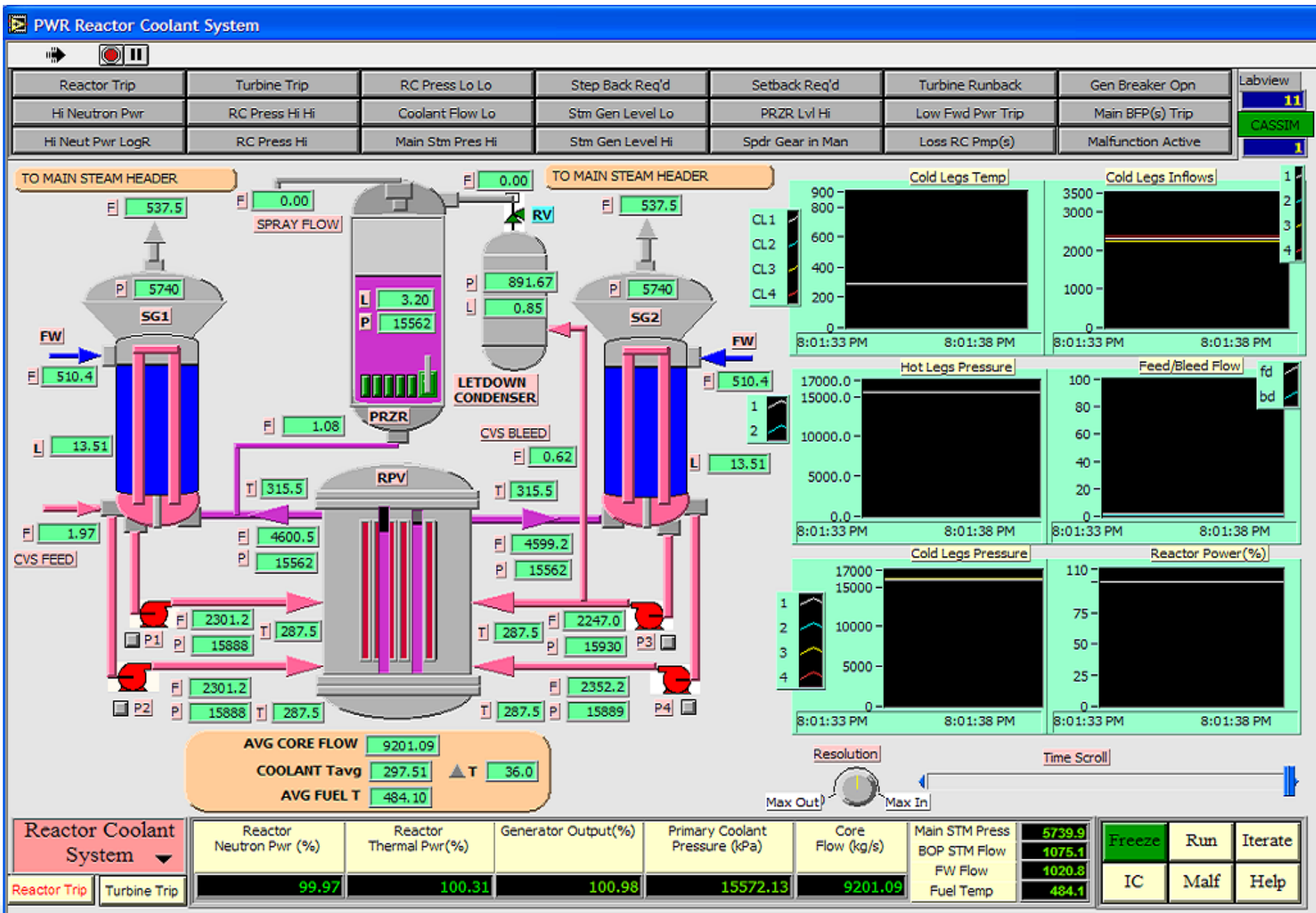
- Fail closed all feedwater level control valves
- FW LCV#1 fails open / closed
- Main BFP trips
- PRZR pressure relief valve (CV22) fails open
- Loss of 2 RC pumps in loop 1
- 100% main steam header break
- RC hot leg #1 LOCA break etc

Reactor Trip	Turbine Trip	RC Press Lo Lo	Step Back Req'd	Setback Req'd	Turbine Runback	Gen Breaker Opn	Labview
Hi Neutron Pwr	RC Press Hi Hi	Coolant Flow Lo	Stm Gen Level Lo	PRZR Lvl Hi	Low Fwd Pwr Trip	Main BFP(s) Trip	28
Hi Neut Pwr LogR	RC Press Hi	Main Stm Pres Hi	Stm Gen Level Hi	Turbine Gov in Man	Loss RC Pmp(s)	Malfunction Active	CASSIM
							120



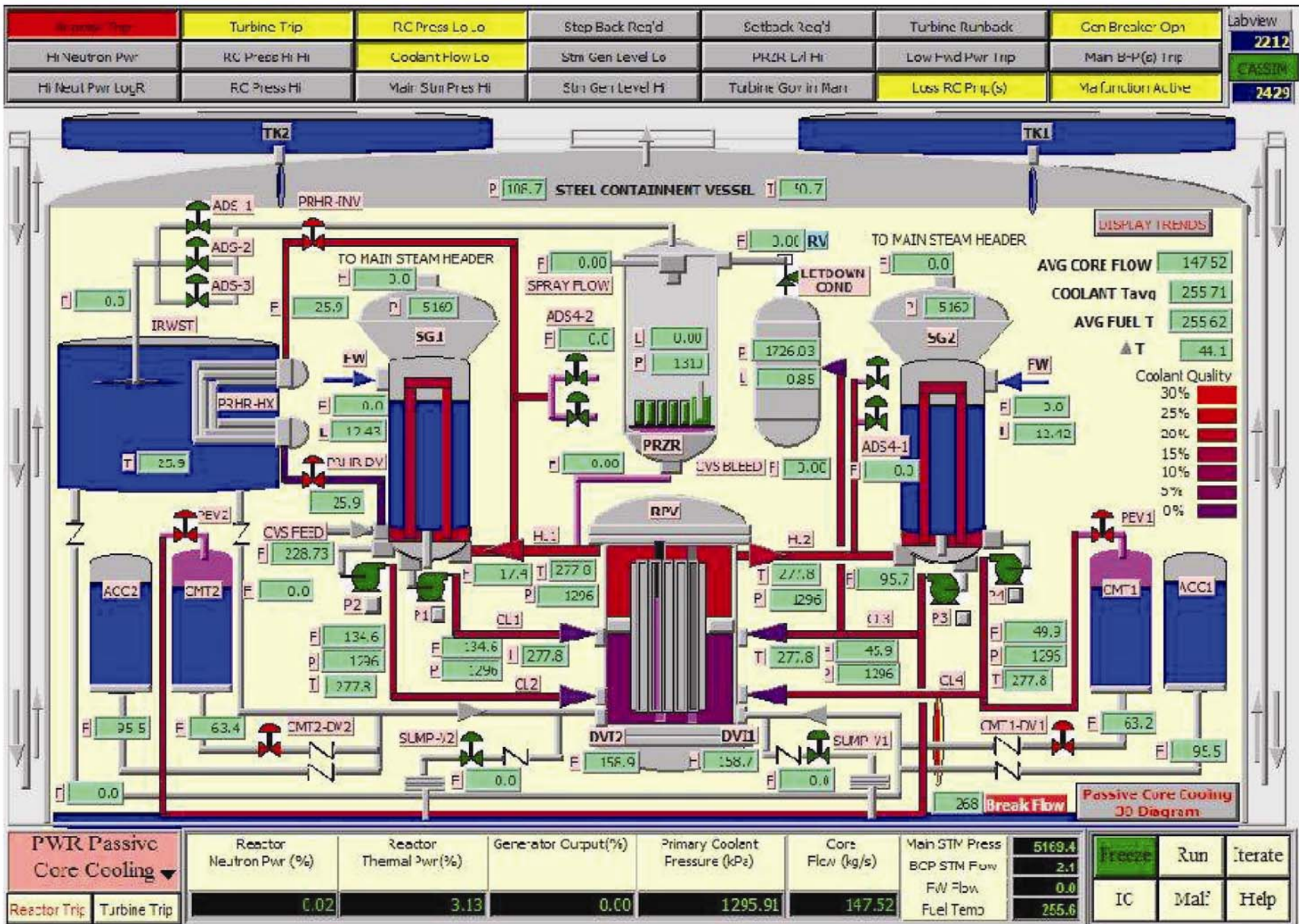
PWR Plant Overview	Reactor Neutron Pwr (%)	Reactor Thermal Pwr (%)	Generator Output (%)	Primary Coolant Pressure (kPa)	Core Flow (kg/s)	Main STM Press	5740.0	Freeze	Run	Iterate
						BOP STM Flow	1075.2	IC	Malf	Help
Reactor Trip	99.97	100.32	100.89	15515.70	9205.64	FW Flow	1020.7			
Turbine Trip						Fuel Temp	484.1			



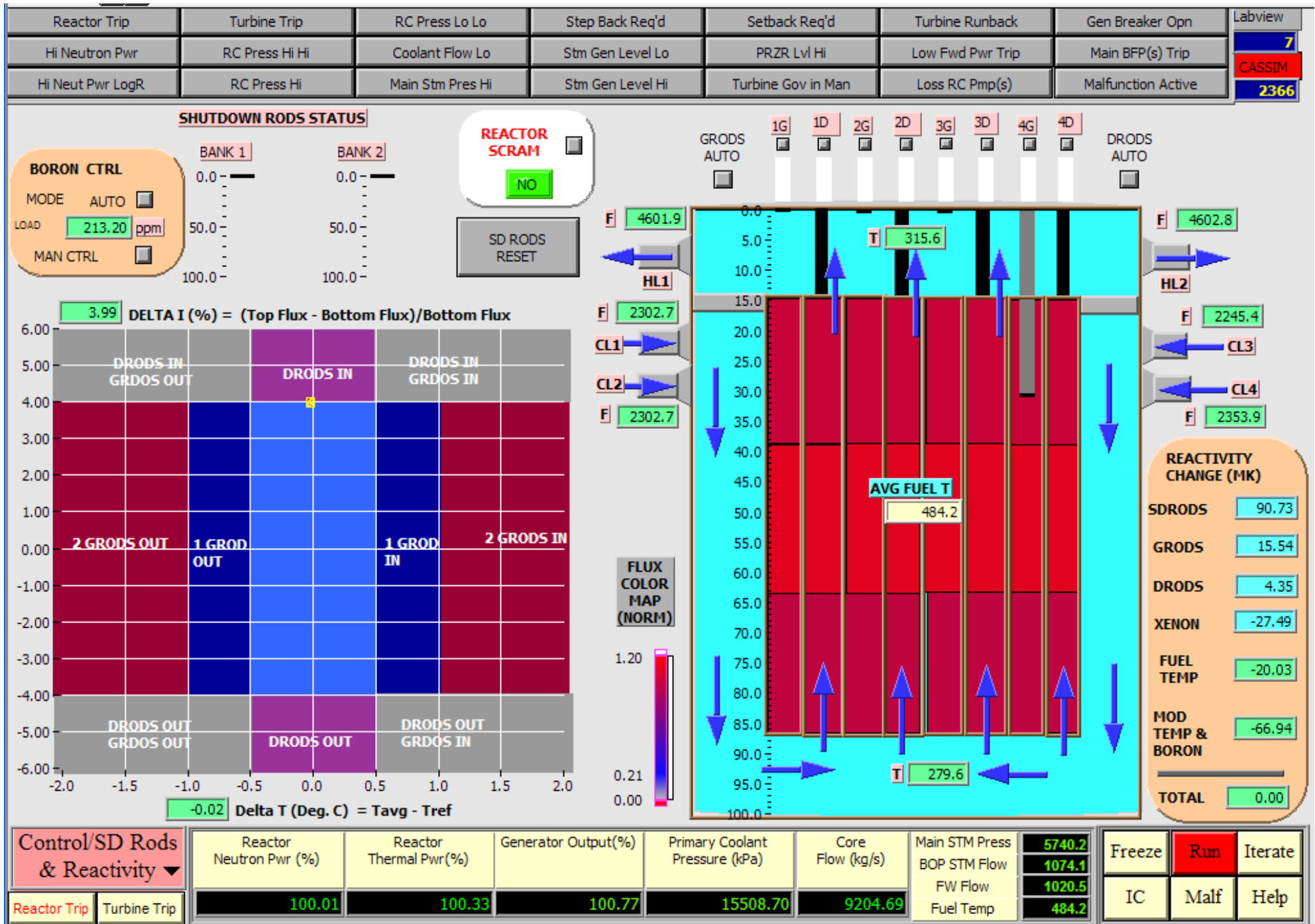


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 International Atomic Energy Agency
 Passive PWR Simulator Display Screen (RCS)





Passive PWR Simulator Display Screen (Core cooling)



Passive PWR Simulator Display Screen (Rods & Reactivity)

HOLD POWER

MODE **SETBACK** **STEPBACK** **SCRAM**
REACTOR LEAD NO NO NO

MW DEMAND SETPOINT

0.00 %FP
-0.0001 DEC

LIMITS

MAX 110.00
MIN 0.00
(% full power)

ACTUAL SETPOINT

100.00 %FP
0.0000 DEC

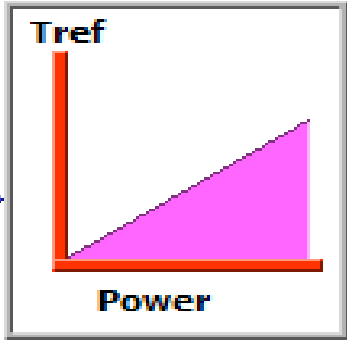
REACTOR POWER SETPOINT

100.00 %FP
0.0000 DEC

TAVG
297.51

DEMANDED POWER SETPOINT

100.00 %FP
0.0000 DEC



TREF
297.60

GRAY RODS CONTROL

MODE AUTO

SPEED 0.67 %/s
AVE POS 7.6 %

POWER ERROR
-0.006 %

DERIVATIVE

DEMANDED RATE SETPOINT

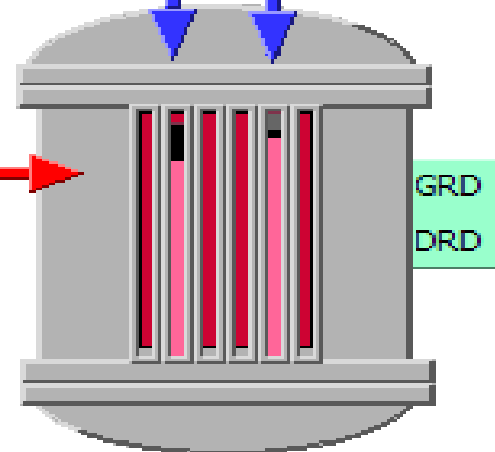
0.000 %FP/s
-10.0000 DEC/s

Current Reactor Pwr (%)
99.99

BORON CTRL

MODE AUTO

LOAD 213.2 ppm
MAN CTRL



TOP FLUX (%)
98.24

BOTTOM FLUX (%)
94.50

DARK RODS CTRL

MODE AUTO

SPEED 0.01 %/s
AVE POS 14.0 %

PWR RATE
-0.05 %/s
-3.2930 DEC/s

Passive PWR Simulator Display Screen

Reactor Trip	Turbine Trip	RC Press Lo Lo	Step Back Req'd	Setback Req'd	Turbine Runback	Gen Breaker Opn
Hi Neutron Pwr	RC Press Hi Hi	Coolant Flow Lo	Stm Gen Level Lo	PRZR Lvl Hi	Low Fwd Pwr Trip	Main BFP(s) Trip
Hi Neut Pwr LogR	RC Press Hi	Main Stm Pres Hi	Stm Gen Level Hi	Turbine Gov in Man	Loss RC Pmp(s)	Malfunction Active

Labview

7

CASSIM

31352

REACTOR TRIP PARAMETERS

FIRST OUT	SCRAM CAUSES
<input type="radio"/>	Low Coolant Pressure Trip
<input type="radio"/>	Low Steam Generator Level Trip
<input type="radio"/>	High Coolant Pressure Trip
<input type="radio"/>	High Neutron Flux Trip
<input type="radio"/>	High Log Rate Trip
<input type="radio"/>	Low Coolant Flow Trip
<input type="radio"/>	Low Pressurizer Level Trip
<input type="radio"/>	Low Feedwater Discharge Header Pressure Trip
<input type="radio"/>	High Steam Flow Trip
<input type="radio"/>	Departure from Nucleate Boiling (DNB) Trip
<input type="radio"/>	Containment High Pressure Trip
<input type="radio"/>	Manual Trip

SDS Reactor Trip Setpoint For High Neutron Flux
 %FP

REACTOR STEPBACK CAUSES

- Hi RC Pressure
- Loss of 1 RC Pump
- Loss of 2 RC Pumps
- Hi Log Rate
- Manual Stepback
- Hi Zone Flux

Press to clear

REACTOR SETPBK CAUSES

- Main Steam Header Press Hi
- Hi Pressurizer Level
- Manual Setback in progress
- Lo Steam Generator Level
- Lo Deaerator Level
- Hi Flux Tilt
- Hi Zonal Flux

Press to clear

Trip Parameters <input type="button" value="Reactor Trip"/> <input type="button" value="Turbine Trip"/>		Reactor Neutron Pwr (%) 99.99	Reactor Thermal Pwr (%) 100.36	Generator Output (%) 101.05	Primary Coolant Pressure (kPa) 15515.00	Core Flow (kg/s) 9206.13	Main STM Press 5739.8	BOP STM Flow 1076.4	FW Flow 1020.9	Fuel Temp 484.2	<input type="button" value="Freeze"/>	<input type="button" value="Run"/>	<input type="button" value="Iterate"/>
											<input type="button" value="IC"/>	<input type="button" value="Malf"/>	<input type="button" value="Help"/>

Passive PWR Simulator Display Screen (Trip Parameters)

[BWR Simulator]

- ❑ Developed by Cassiopeia Technologies Inc. (CTI),
- ❑ Represents a generic 1300 MW(e) BWR with internal recirculation pumps and fine motion control rod drives.
- ❑ Containment model based on ABWR added in 2008
 - Drywell and wetwell with the suppression pool
- ❑ Improvement on the reactor level response
- ❑ Implement the logic for ABWR Rx internal pump trips and runbacks



[BWR Simulator]

Simulator display screens

- BWR plant overview screen
- BWR control loops screen
- BWR power/flow map & controls screen
- BWR reactivity & controls screen
- BWR scram parameters screen
- BWR turbine generator screen
- BWR feedwater and extraction steam screen
- BWR Containment



[BWR Simulator]

Malfunction 1

- Loss of feedwater : both FW pumps trip
- Increasing/Decreasing core flow due to flow control failure
- Increasing/Decreasing steam flow from dome due to pressure control failure
- TBN throttle PT fails low
- Safety relief valve (SRV) on one main steam line fails open
- Feedwater level control valve fails open
- Turbine trip with bypass valve failed closed

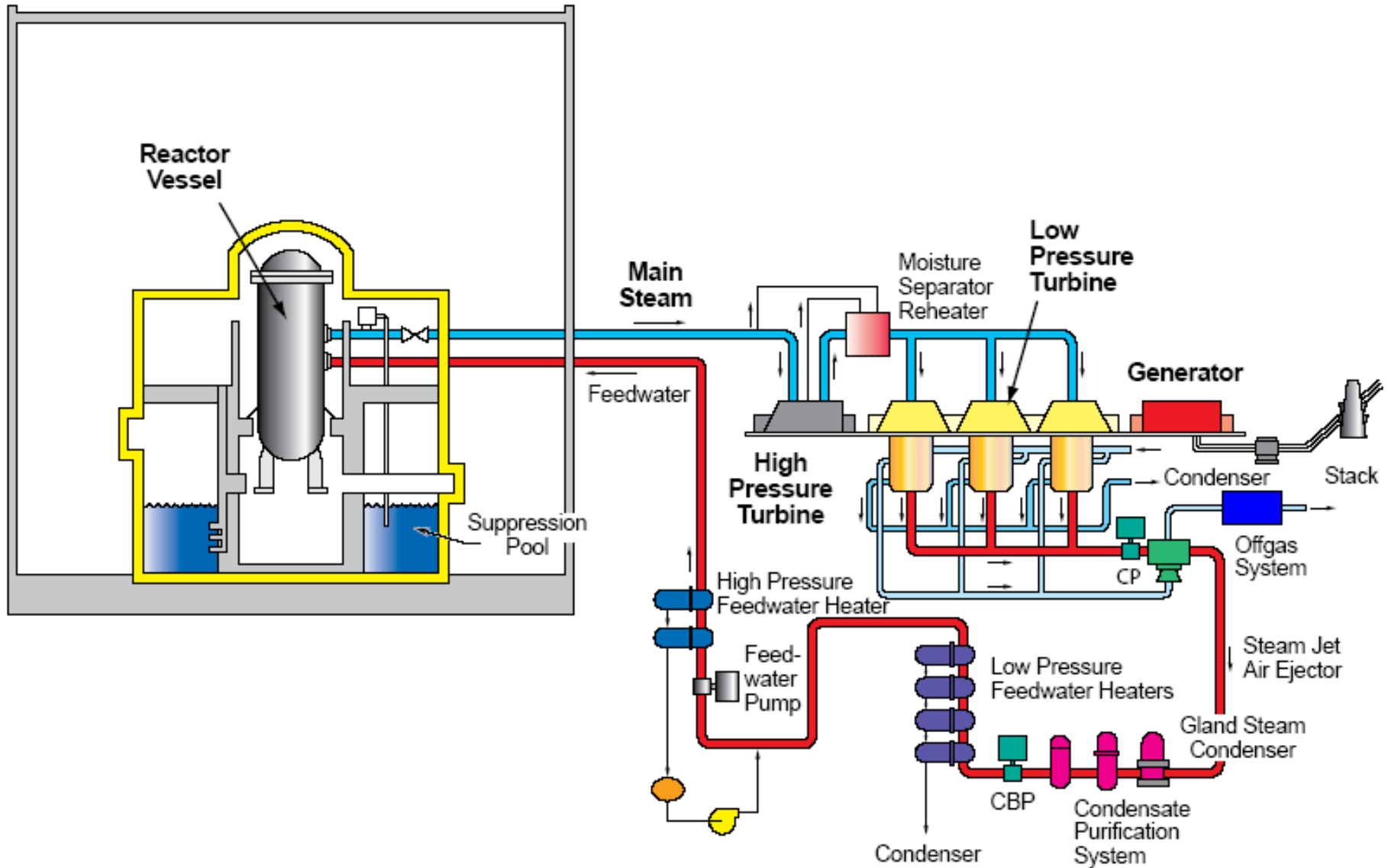


[BWR Simulator]

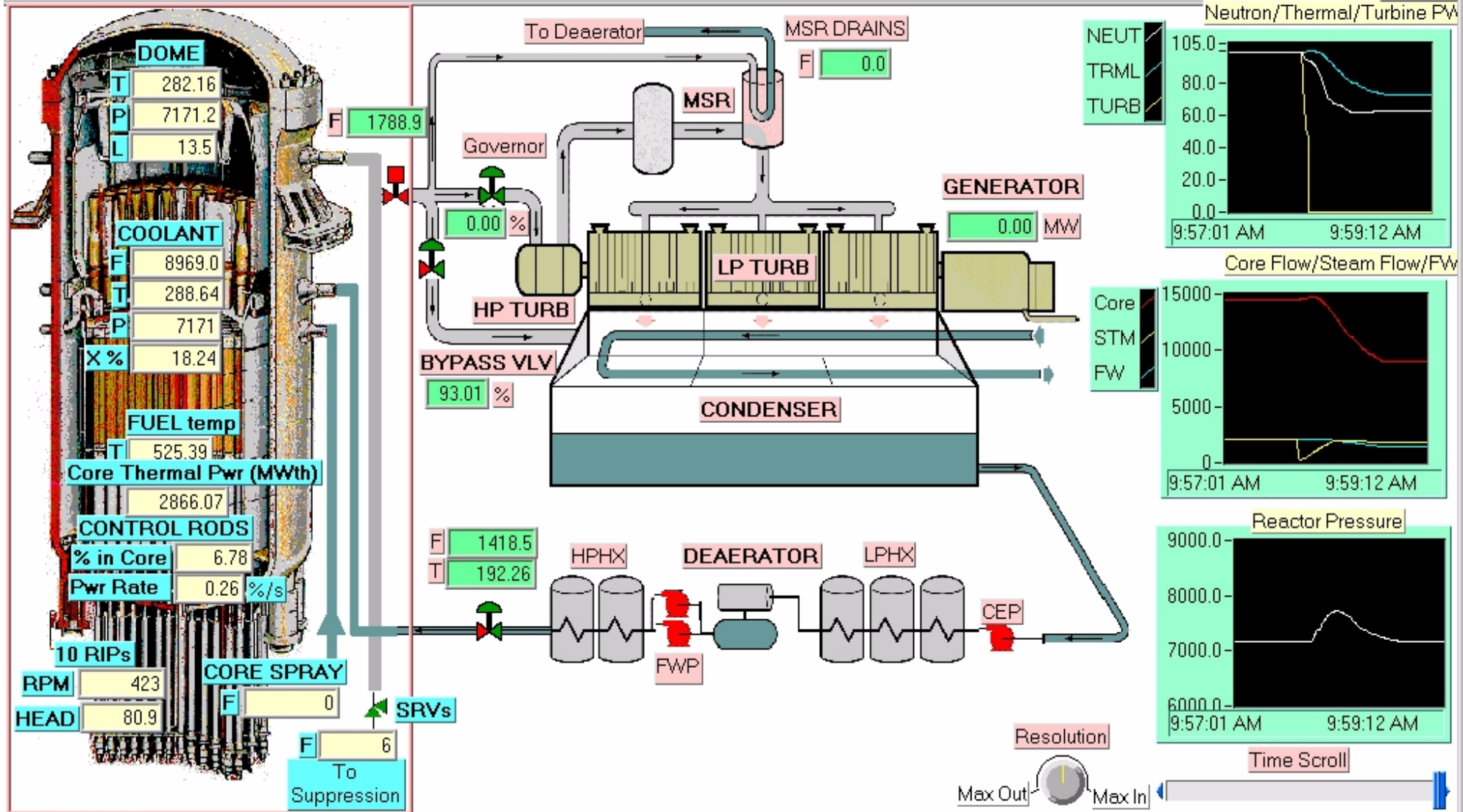
Malfunction 2

- Inadvertent withdrawal of one bank of rods
- Inadvertent insertion of one bank of rods
- Inadvertent reactor isolation
- Loss of feedwater heating
- Power loss to three reactor internal pumps
- Steam line break inside drywell
- Feedwater line break inside drywell
- Reactor vessel bottom break - 3000 kg/sec LOCA
- Load rejection



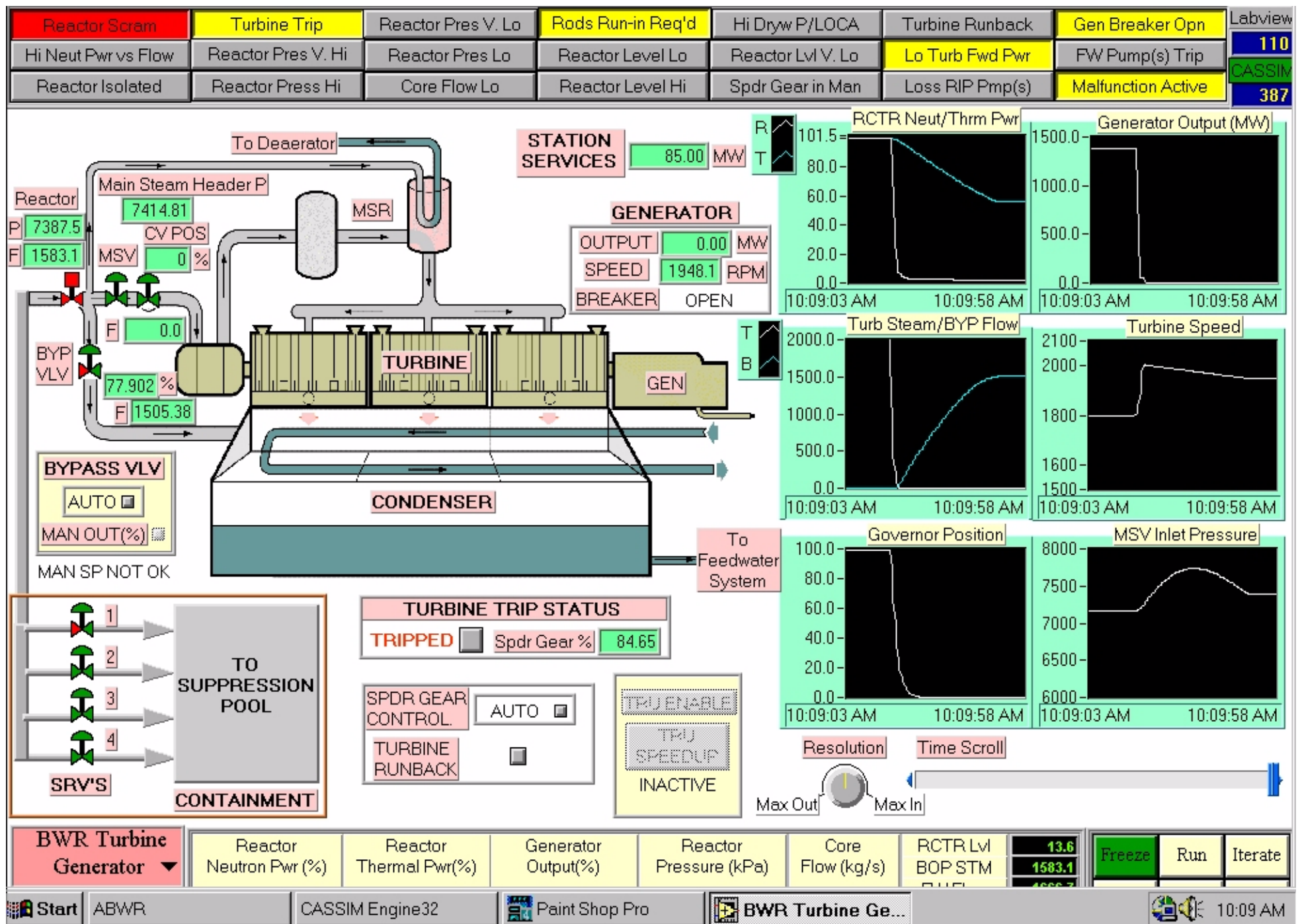


Reactor Scram	Turbine Trip	Reactor Pres V. Lo	Rods Run-in Req'd	Hi Dryw P/LOCA	Turbine Runback	Gen Breaker Opn	Labview
Hi Neut Pwr vs Flow	Reactor Pres V. Hi	Reactor Pres Lo	Reactor Level Lo	Reactor Lvl V. Lo	Lo Turb Fwd Pwr	FW Pump(s) Trip	245
Reactor Isolated	Reactor Press Hi	Core Flow Lo	Reactor Level Hi	Spdr Gear in Man	Loss RIP Pmp(s)	Malfunction Active	CASSIM
							884



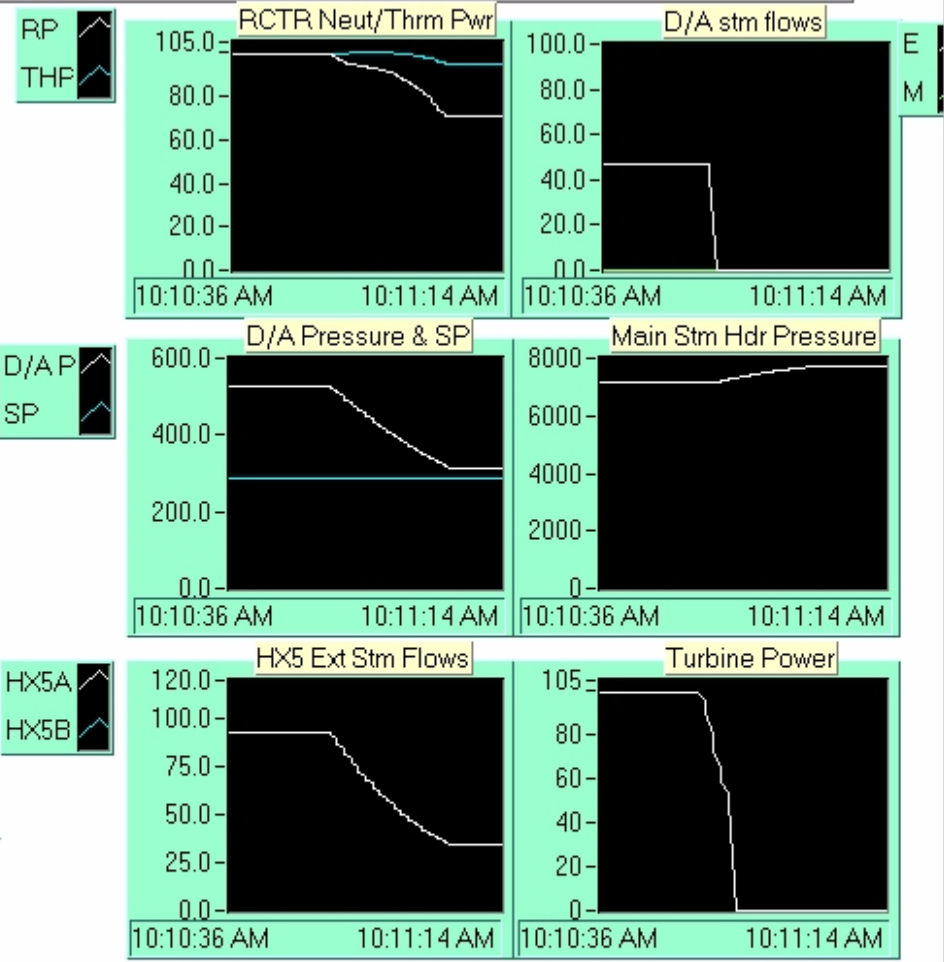
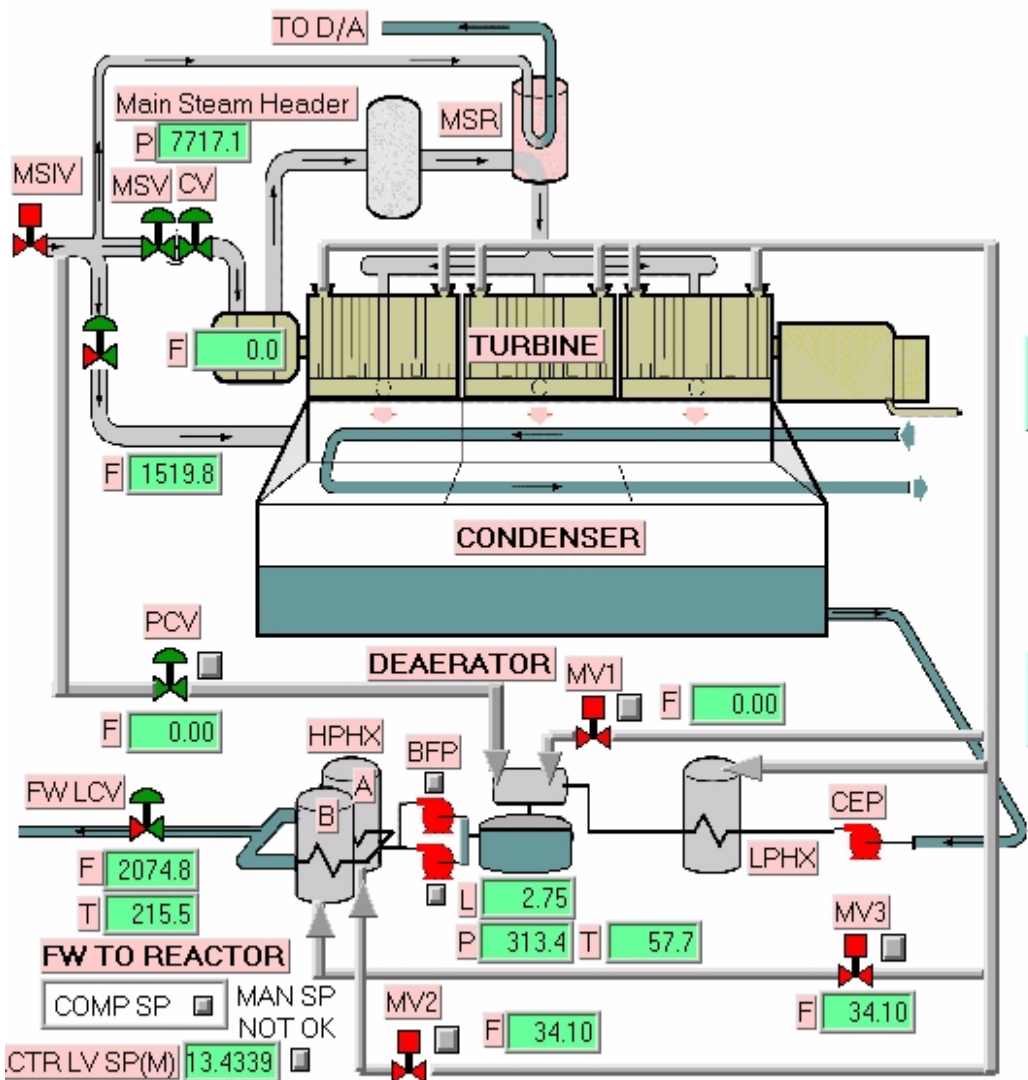
BWR Plant Overview		Reactor Neutron Pwr (%)	Reactor Thermal Pwr(%)	Generator Output(%)	Reactor Pressure (kPa)	Core Flow (kg/s)	RCTR Lvl	13.5	Freeze	Run	Iterate
Reactor Trip	Turbine Trip	62.71	73.02	0.00	7171.19	8969.02	BOP STM	1788.9	IC	Malf	Help
							FW Flow	1418.5			
							Fuel Temp	525.4			

Active BWR Simulator Display Screen (Overview)



Active BWR Simulator Display Screen (Turbine Generator)

Reactor Scram	Turbine Trip	Reactor Pres V. Lo	Rods Run-in Req'd	Hi Dryw P/LOCA	Turbine Runback	Gen Breaker Opn	Labview
Hi Neut Pwr vs Flow	Reactor Pres V. Hi	Reactor Pres Lo	Reactor Level Lo	Reactor Lvl V. Lo	Lo Turb Fwd Pwr	FW Pump(s) Trip	76
Reactor Isolated	Reactor Press Hi	Core Flow Lo	Reactor Level Hi	Spdr Gear in Man	Loss RIP Pmp(s)	Malfunction Active	CASSIM
							241



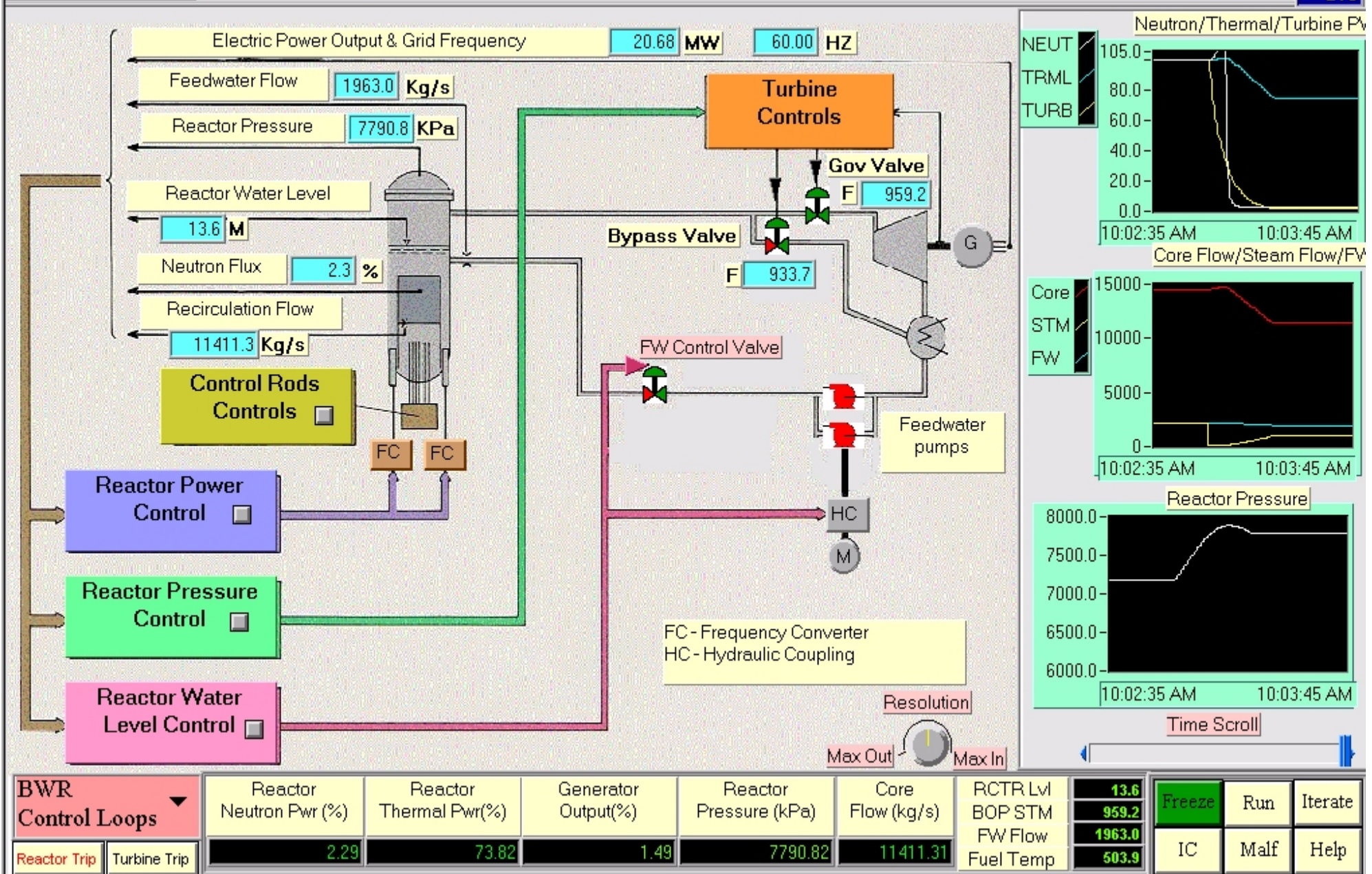
Resolution Time Scroll

Max Out Max In

BWR Feedwater & Extr Steam	Reactor Neutron Pwr (%)	Reactor Thermal Pwr(%)	Generator Output(%)	Reactor Pressure (kPa)	Core Flow (kg/s)	RCTR Lvl BOP STM	13.5	Freeze	Run	Iterate
	FW TO REACTOR	2074.8	215.5	313.4	57.7	FW Flow	2074.8			

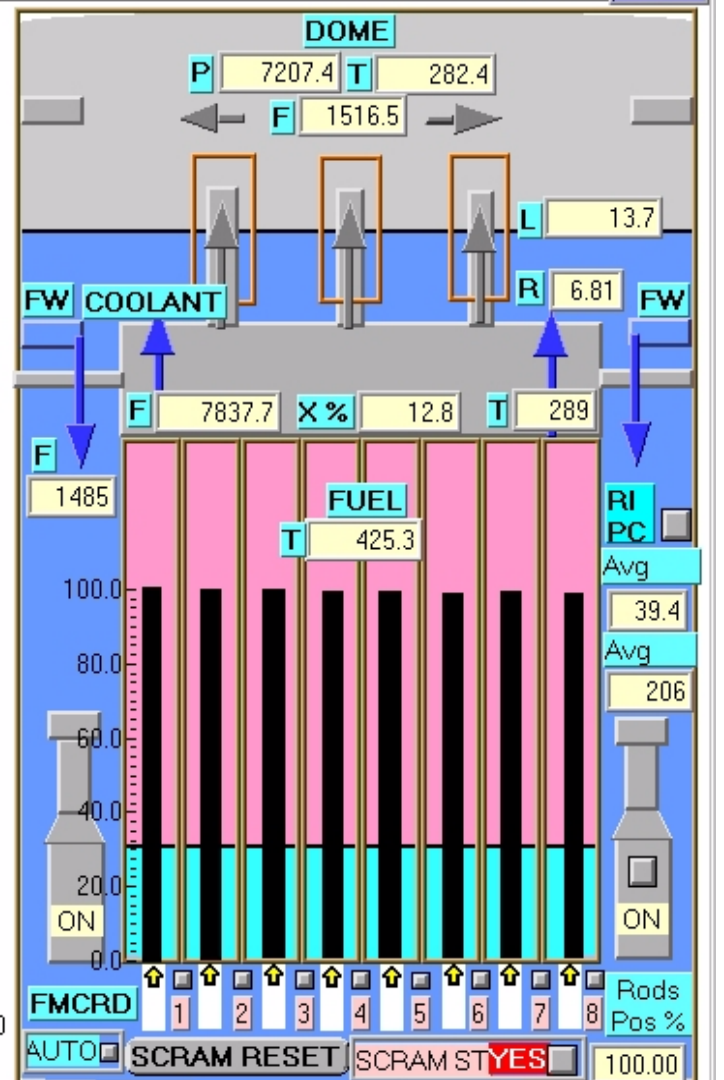
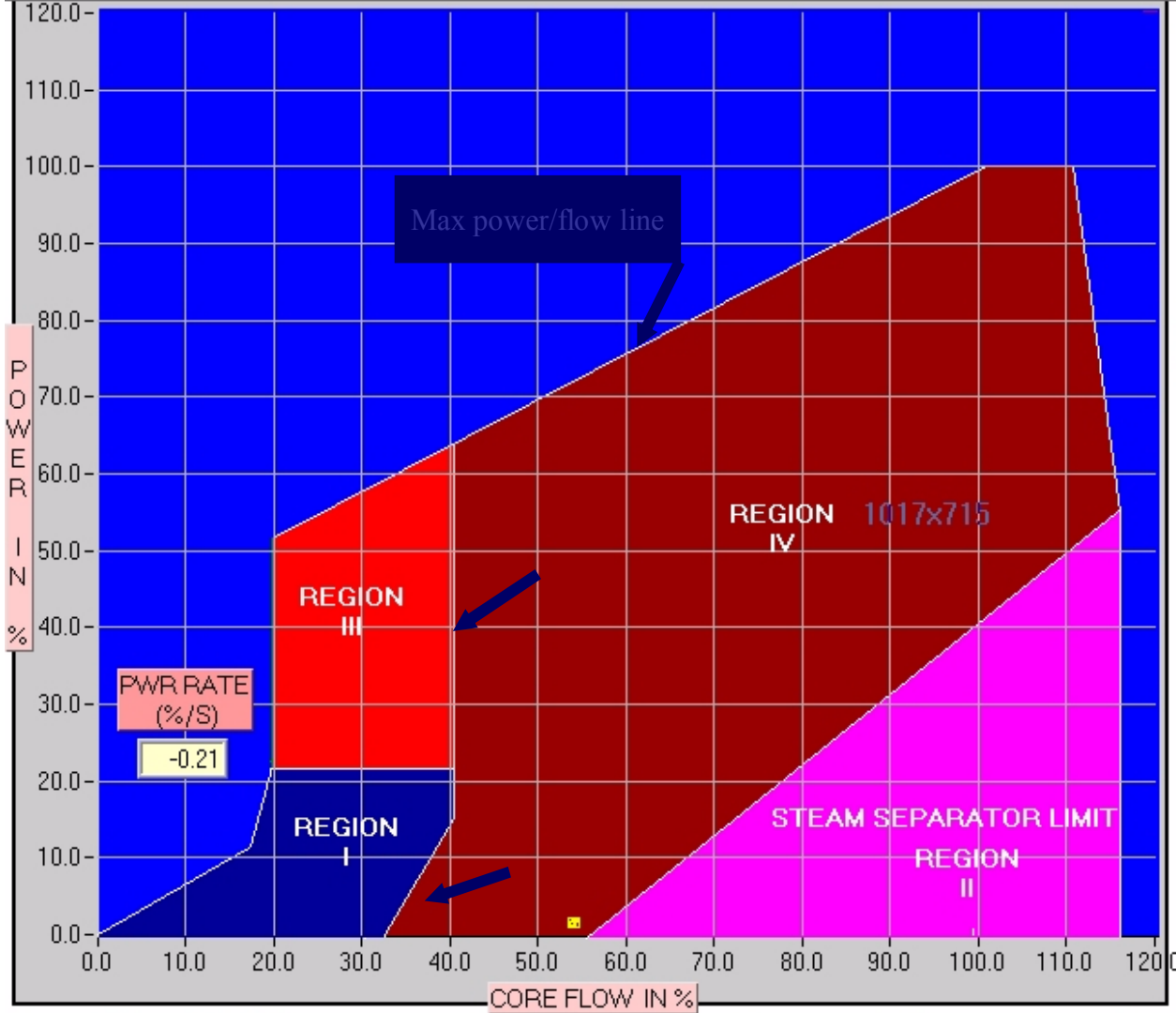
Active BWR Simulator Display Screen (Feedwater & Ext steam)

Reactor Scram	Turbine Trip	Reactor Pres V. Lo	Rods Run-in Req'd	Hi Dryw P/LOCA	Turbine Runback	Gen Breaker Opn	Labview
Hi Neut Pwr vs Flow	Reactor Pres V. Hi	Reactor Pres Lo	Reactor Level Lo	Reactor Lvl V. Lo	Lo Turb Fwd Pwr	FW Pump(s) Trip	142
Reactor Isolated	Reactor Press Hi	Core Flow Lo	Reactor Level Hi	Spdr Gear in Man	Loss RIP Pmp(s)	Malfunction Active	CASSIM
							210



Active BWR Simulator Display Screen (Control Loops)

Reactor Scram	Turbine Trip	Reactor Pres V. Lo	Rods Run-in Req'd	Hi Dryw P/LOCA	Turbine Runback	Gen Breaker Opn	Labview
Hi Neut Pwr vs Flow	Reactor Pres V. Hi	Reactor Pres Lo	Reactor Level Lo	Reactor Lvl V. Lo	Lo Turb Fwd Pwr	FW Pump(s) Trip	205
Reactor Isolated	Reactor Press Hi	Core Flow Lo	Reactor Level Hi	Spdr Gear in Man	Loss RIP Pmp(s)	Malfunction Active	CASSIM
							586



Power/Flow Map & Controls	Reactor Neutron Pwr (%)	Reactor Thermal Pwr (%)	Generator Output (%)	Reactor Pressure (kPa)	Core Flow (kg/s)	RCTR Lvl	13.7	Freeze	Run	Iterate
						BOP STM	1444.4			
						FW Flow	1485.2			

Active BWR Simulator Display Screen (Power/Flow map & Control)

Reactor Scram	Turbine Trip	Reactor Pres V. Lo	Rods Run-in Req'd	Hi Dryw P/LOCA	Turbine Runback	Gen Breaker Opn	Labview
Hi Neut Pwr vs Flow	Reactor Pres V. Hi	Reactor Pres Lo	Reactor Level Lo	Reactor Lvl V. Lo	Lo Turb Fwd Pwr	FW Pump(s) Trip	109
Reactor Isolated	Reactor Press Hi	Core Flow Lo	Reactor Level Hi	Spdr Gear in Man	Loss RIP Pmp(s)	Malfunction Active	CASSIM
							482

PLANT MODE
TURBINE-FOLLOW-REACTOR

RODS RUN-IN
NO

SCRAM
YES

Reactor Pressure (kPa) 6955.70 SP (kPa) 7170.00

HOLD POWER

LIMITS

MAX 105.00
MIN 0.00
(% Pwr vs flow)

ACTUAL SETPOINT
0.07 %FP
-1.1818 DEC

RCTR PWR SETPOINT
100.00 %FP
2.0000 DEC

REACTIVITY EFFECTS

DEMANDED POWER SETPOINT
1.91 %FP
0.2808 DEC

DEMANDED RATE SETPOINT
0.00 %PP/s
+VE
0.0000 DEC/s

POWER ERROR
0.05 %
+VE
-1.3010 DEC

REACTIVITY CHANGE (MK)
FMCRD -100.00
VOID -31.50
XENON -28.00
FUEL TEMP -1.38
MOD TEMP 4.53
TOTAL -156.35

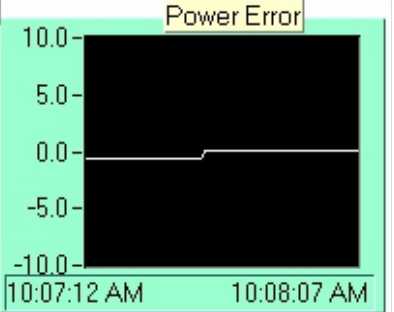
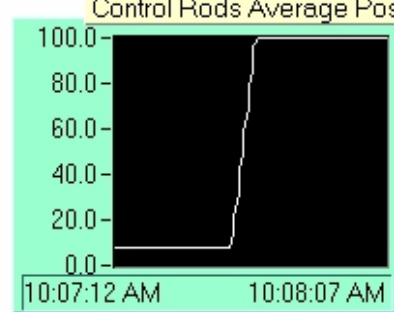
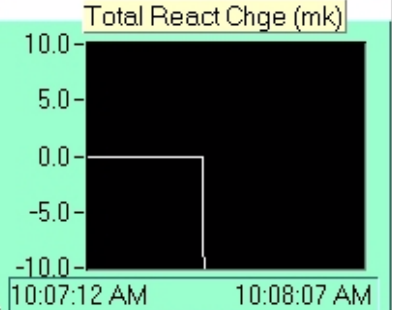
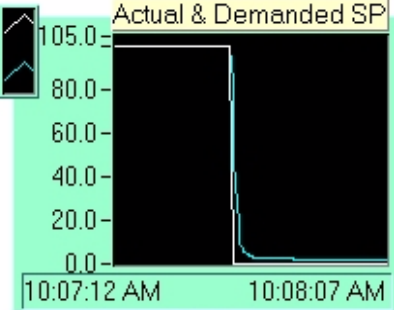
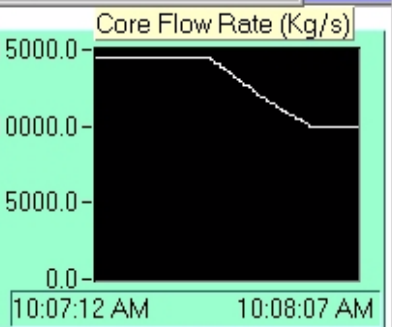
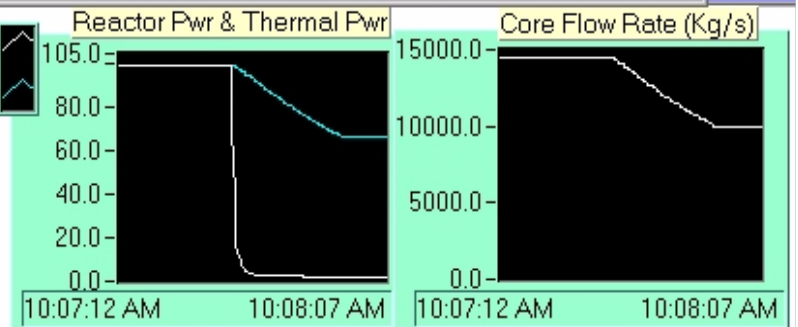
FMCRD MK WORTH
100% IN CORE
-100 MK

100% OUT OF CORE
+70 MK

CONTROL RODS

MODE AUTO
SPEED 0.67 %/s
AVE POS 100.0 %

POWER LEVEL READINGS
NEUT PWR 2.0095 %FP
0.3031 DEC
THML PWR 67.04 %FP
PWR RATE %/s -0.35
PWR LOG -0.17315 /s
-0.7616 DEC/s



Resolution Time Scroll

Max Out Max In

BWR Reactivity & Setpoints

Reactor Trip Turbine Trip

Reactor Neutron Pwr (%)	Reactor Thermal Pwr (%)	Generator Output (%)	Reactor Pressure (kPa)	Core Flow (kg/s)	RCTR Lvl BOP STM	FW Flow	Fuel Temp
2.01	67.04	96.00	6955.70	9943.20	13.5	2009.5	1864.0
							479.5

Freeze	Run	Iterate
IC	Malf	Help

Active BWR Simulator Display Screen (Reactivity & Setpoints)

BWR Scram Parameters

Reactor Scram	Turbine Trip	Reactor Pres V. Lo	Rods Run-in Req'd	Hi Dryw P/LOCA	Turbine Runback	Gen Breaker Opn	Labview
Hi Neut Pwr vs Flow	Reactor Pres V. Hi	Reactor Pres Lo	Reactor Level Lo	Reactor Lvl V. Lo	Lo Turb Fwd Pwr	FW Pump(s) Trip	40
Reactor Isolated	Reactor Press Hi	Core Flow Lo	Reactor Level Hi	Spdr Gear in Man	Loss RIP Pmp(s)	Malfunction Active	CASSIM
							28

REACTOR SCRAM PARAMETERS

FIRST OUT	SCRAM CAUSES
<input type="radio"/>	High Neutron Flux / Low Core Flow
<input type="radio"/>	High Drywell Pressure /LOCA detected
<input type="radio"/>	Reactor Water Level Low
<input type="radio"/>	Reactor Pressure High
<input type="radio"/>	Reactor Water Level Abnormally High
<input type="radio"/>	Main Steam Isolation Valve Closed/ Reactor Isolated
<input type="radio"/>	Main Steam Line Radioactivity High
<input type="radio"/>	Turbine Power/Load Unbalance - Loss of Line
<input type="radio"/>	Earthquake Acceleration Large
<input type="radio"/>	Manual Scram

BWR Scram Parameters	Reactor Neutron Pwr (%)	Reactor Thermal Pwr(%)	Generator Output(%)	Reactor Pressure (kPa)	Core Flow (kg/s)	RCTR Lvl BOP STM	13.5	Freeze	Run	Iterate
Reactor Trip	99.48	99.49	99.45	7170.50	14501.77	FW Flow	2126.1	IC	Malf	Help
Turbine Trip						Fuel Temp	582.6			

Active BWR Simulator Display Screen (Scram Parameters)

[Advanced BWR Simulator]

- ❑ Developed by Cassiopeia Technologies Incorporated (CTI), Canada
- ❑ Largely based on GE ESBWR passive BWR design
- ❑ Released in 2009



[Advanced BWR Simulator]

Simulator display screens

- Passive BWR plant overview screen
- Passive BWR control loops screen
- Passive BWR power/flow map & controls screen
- Passive BWR reactivity & controls screen
- Passive BWR scram parameters screen
- Passive BWR turbine generator screen
- Passive BWR FW and extraction steam screen
- Passive BWR Containment
- Passive BWR cleanup/shutdown cooling screen



[Advanced BWR Simulator]

Maneuver, shutdown, startup

- Power maneuver: 10% power reduction and return to full power
- Reduction to 0% full power and back to 100% full power
- Turbine trip and recovery
- Reactor scram and recovery
- Reactor Shutdown Cooling
- Reactor Startup and Warmup



[Advanced BWR Simulator]

Malfunction 1

- Loss of feedwater : both FW pumps trip
- Increasing/Decreasing core flow due to flow control failure
- Increasing/Decreasing steam flow from dome due to pressure control failure
- TBN throttle PT fails low
- Safety relief valve (SRV) on one main steam line fails open
- Feedwater level control valve fails open
- Turbine trip with bypass valve failed closed



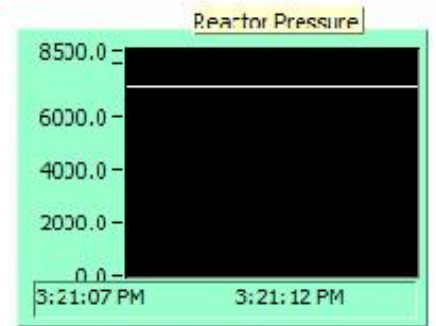
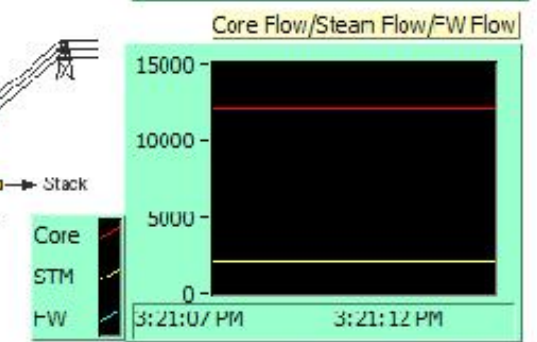
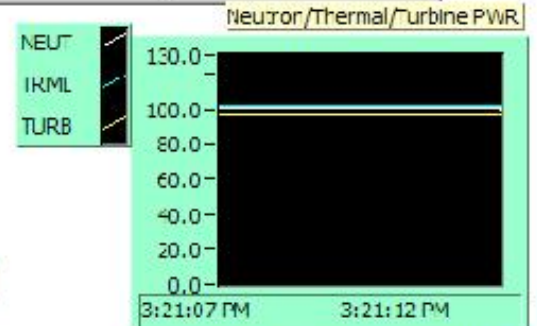
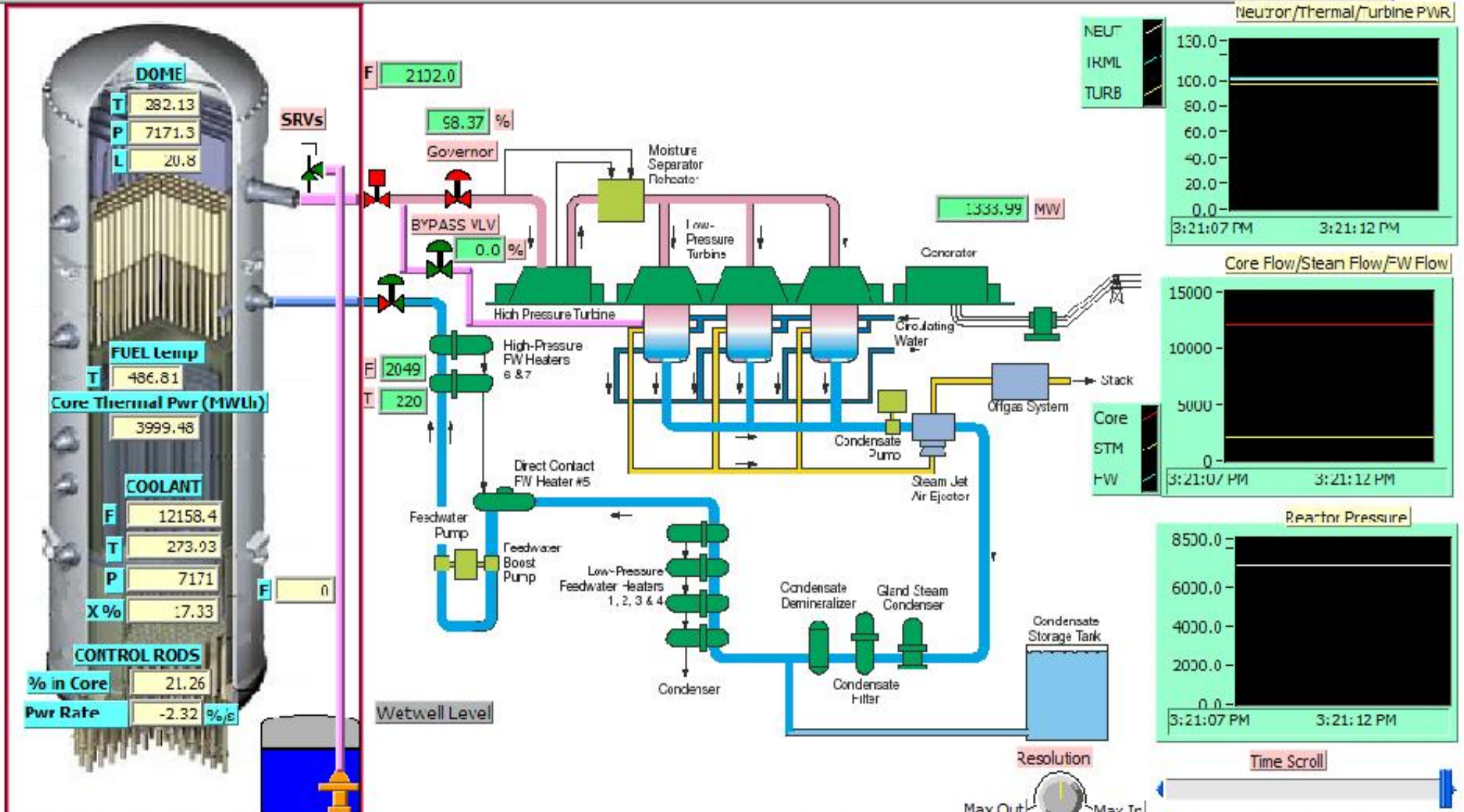
[Advanced BWR Simulator]

Malfunction 2

- Inadvertent withdrawal of one bank of rods
- Inadvertent insertion of one bank of rods
- Inadvertent reactor isolation
- Loss of feedwater heating
- Power loss to three reactor internal pumps
- Steam line break inside drywell
- Feedwater line break inside drywell
- Reactor vessel bottom break - 3000 kg/sec LOCA
- Load rejection



Reactor Scram	Turbine Trip	Reactor Pres V. Lo	Rods Run-in Req'd	Hi Dryw P/LOCA	Turbine Funback	Gen Breaker Opn	Labview
Hi Neut Pwr vs Flow	Reactor Pres V. Hi	Reactor Pres Lo	Reactor Level Lo	Reactor Lvl V. Lo	Lo Turb Fwd Pwr	FW Pump(s) Trip	16
Reactor Isolated	Reactor Press Hi	Core Flow Lo	Reactor Level Hi	Turbine Gov. in Man	Loss RTP Pmp(s)	Malfunction Active	CASSIM
							60



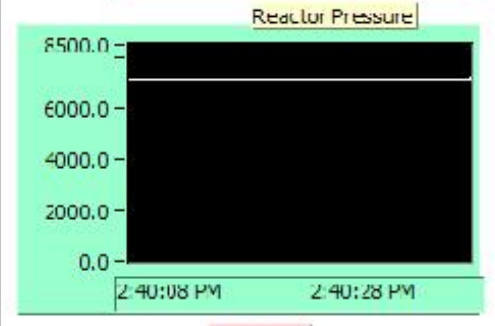
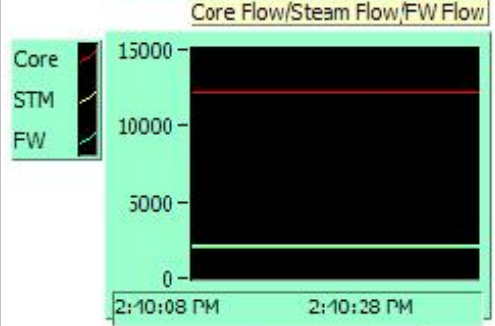
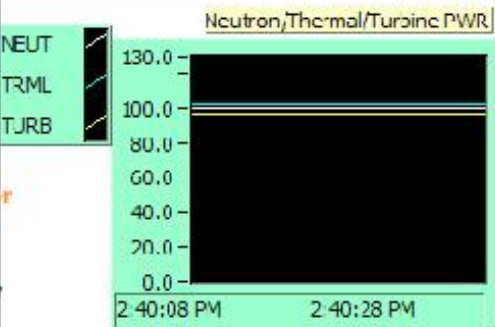
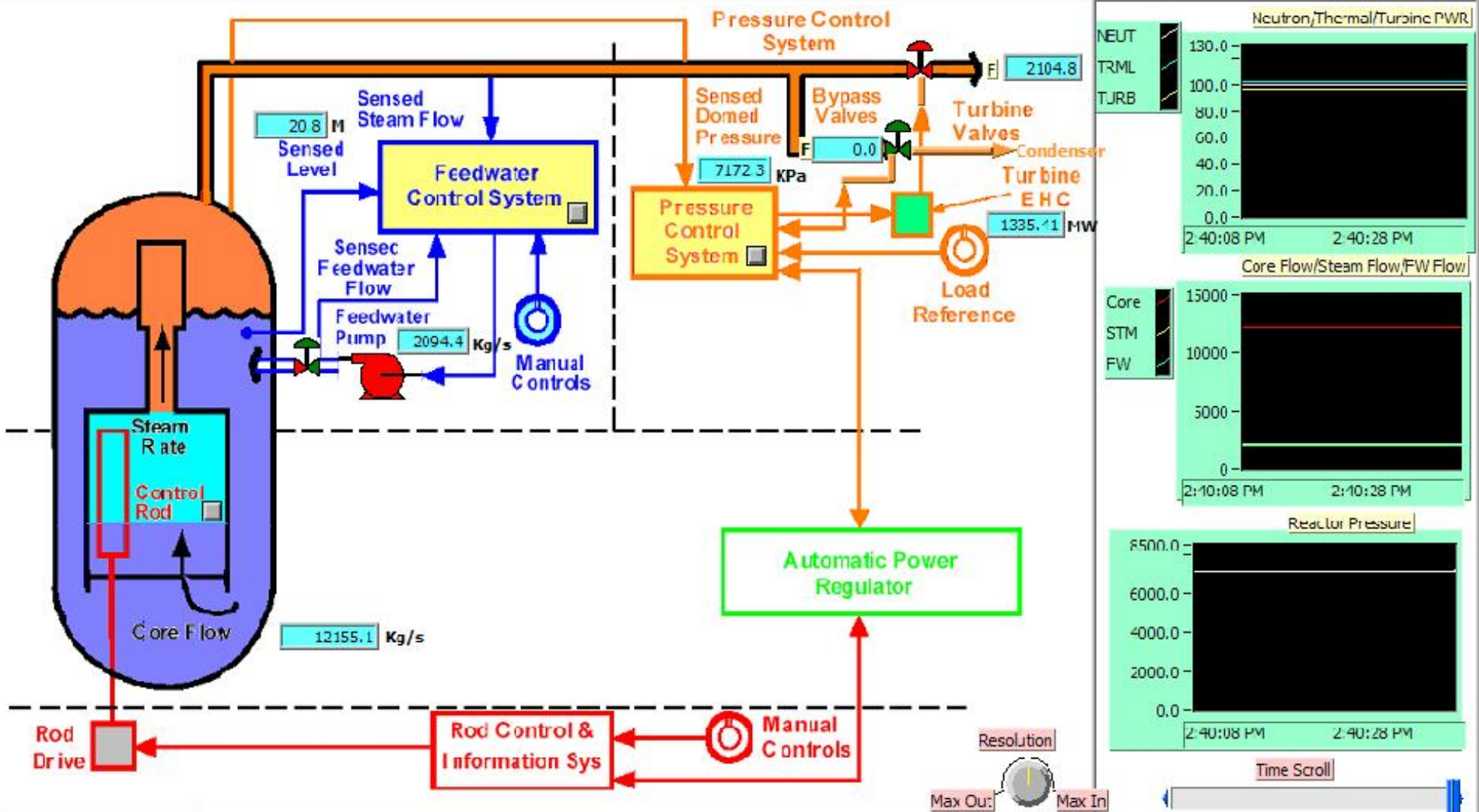
Resolution Max Out Max Tr

Time Scroll

P-BWR Plant Overview		Reactor Neutron Pwr (%)	Reactor Thermal Pwr (%)	Generator Output (%)	Reactor Pressure (kPa)	Core Flow (kg/s)	RCTR Lvl	BOP STM Flow	FW Flow	Fuel Temp	Freeze	Run	Iterate
Reactor Trip	Turbine Trip	99.98	101.87	96.32	7171.26	12158.36	20.0	2102.0	2040.4	486.8	IC	Malf	Help

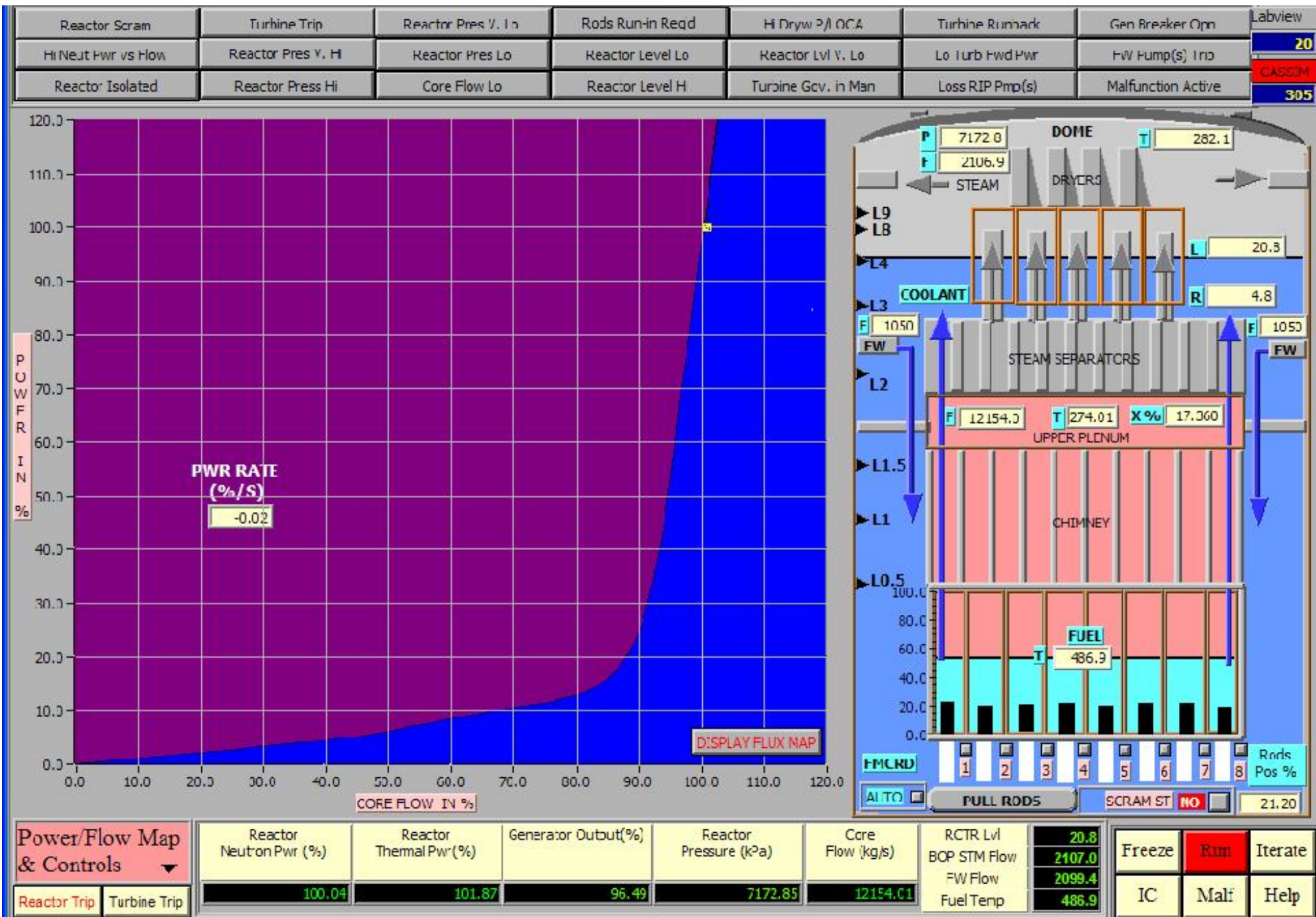
Passive BWR Simulator (Overview)

Reactor Surm	Turbine Trip	Reactor Pres V. Lo	Rods Run in Req'd	Hi Dryw P/LOCA	Turbine Runback	Gen Breaker Opn	Labview
Hi Neut Pwr vs Flow	Reactor Pres V. Hi	Reactor Pres Lc	Reactor Level Lo	Reactor Lvl V. Lo	Lc Turb Fwd Pwr	FW Pump(s) Trip	22
Reactor Isolated	Reactor Press Hi	Core Flow Lo	Reactor Level Hi	Turbine Gov. in Man	Loss RIP Pmp(s)	Malfunction Active	CASIM
							210



P-BWR Control Loops	Reactor Neutron Pwr (%)	Reactor Therna Pwr(%)	Generator Output(%)	Reactor Pressure (kPa)	Core Flow (kg/s)	RCTR Lvl	20.8	Freeze	Run	Iterate
	Reactor Trip	Turbine Trip	99.96	101.86	96.42	7172.36	12155.07			

44
Passive BWR Simulator (Control loops)



45
Passive BWR Simulator (Power/Flow map & controls)

Reactor Scram	Turbine Trip	Reactor Pres V. Lo	Rods Run-in Req'd	H Dryw P/LOCA	Turbine Runback	Gen Ereaker Opn	labview
Hi Neut Pwr vs Flow	Reactor Pres V. Hi	Reactor Pres Lo	Reactor Level Lo	Reactor Lvl v. Lo	Lc Turb Fwd Pwr	FW Pump(s) Trip	578
Reactor Isolated	Reactor Press Hi	Core Flow Lo	Reactor Level Hi	Turbine Gov. in Man	Loss RIP Pmo(s)	Malfunction Active	CASSEM
							1691

PLANT MODE
TURBINE-FOLLOW-REACTOR

RODS RUN-IN
NO

SCRAM
NO

RCTR TRMI

Reactor Pressure (kPa) 7174.78 SP (kPa) 7170.00

HOLD POWER

LIMITS
MAX 105.00
MIN 0.00
(% Pwr vs flow)

ACTJAL SETPOINT
100.00 %FP
2.0000 DEC

RCTR PWR SETPOINT
100.00 %FP
2.0000 DEC

REACTIVITY EFFECTS

DEMANDED POWER SETPOINT
100.00 %FP
2.0000 DEC

DEMANDED RATE SETPOINT
0.30 %P/s
+VE
0.0000 DEC/s

POWER ERROR
0.23 %
-VE
-1.6270 DEC

REACTIVITY CHANGE (MK)
FMCRD 99.61
VOTD -20.34
XENON -12.75
FUEL TEMP -5.12
MOD TFMP -42.93
TOTAL -0.02

FMCRD MK WORTH
100% IN CORE 170 MK
100% OUT OF CORE + 119 MK

CONTROL RODS
MODE AUTO
SPEED 0.67 %/s
AVE POS 21.0 %

POWER LEVEL READINGS

NEUT PWR
99.98/1 %FP
1.9999 DEC

THML PWR
101.88 %FP

PWR RATE %/s
-0.10

PWR LOG RATE
0.00007 /s
-3.1128 DEC/s

Reactor Pwr & Thermal Pwr

Core Flow Rate (Kg/s)

Actual & Demanded SP

Total React Chge (mk)

Control Rods Average Pos

Power Error

Resolution Time Scrl

Max Out Max In

P-BWR Reactivity & Setpoints	Reactor Neutron Pwr (%)	Reactor Thermal Pwr(%)	Generator Output(%)	Reactor Pressure (kPa)	Core Flow (kg/s)	RCTR Lvl	20.8	Freeze	Run	Iterate
	Reactor Trip	Turbine Trip	99.99	101.88	97.15	7174.78	12128.83			
								FW Flow	2091.5	
								Fuel Temp	487.3	
								IC	Malf	Help

Passive BWR Simulator⁴⁶ (Reactivity & Setpoints)

Reactor Scram	Turbine Trip	Reactor Pres V. Lo	Rods Run-in Req'd	Hi Dryw P/LOCA	Turbine Runback	Con Breaker Opn	Labview
Hi Neut Pwr vs Flow	Reactor Pres V. Hi	Reactor Pres Lo	Reactor Level Lo	Reactor Lvl V. Lc	Lo Turb Fwd Pwr	FW P_imp(s) Trip	15
Reactor Isolated	Reactor Press Hi	Core Flow Lo	Reactor Level Hi	Turbine Gov. in Man	Loss R/P Pmp(s)	Malfunction Active	CA33IM
							1886

Main Steam Header
P: 7175.04
F: 2126.5

STATION SERVICES
85.00 MW

GENERATOR
OUTPUT: 1347.02 MW
SPEED: 1300.0 RPM
BRFAKFR: CLOSED

TURBINE TRIP STATUS
RESET: GOV Position %: 99.43

TO SUPPRESSION POOL
SRV'S: 1, 2, 3, 4

CONTAINMENT

P-BWR Turbine Generator
Reactor Trip: Turbine Trip:

Reactor Neutron Pwr (%)	Reactor Thermal Pwr (%)	Generator Output (%)	Reactor Pressure (kPa)	Core Flow (kg/s)	RCTR Lvl	20.8
103.04	101.88	97.26	7175.05	12124.97	DOP STM Flow	2123.5
					FW Flow	2094.1
					Fuel Temp	407.3

RCIK Neut/Inrm Pwr
150.0
125.0
100.0
75.0
50.0
25.0
0.0
2:47:29 PM 3:08:21 PM

Generator Output (MW)
2000.0
1500.0
1000.0
500.0
0.0
2:47:29 PM 3:08:21 PM

Turb Steam/BYP Flow
8000.0
6000.0
4000.0
2000.0
0.0
2:47:29 PM 3:08:21 PM

Turbine Speed
2000
1500
1000
500
0
2:47:29 PM 3:08:21 PM

Governor Position
120.0
100.0
80.0
60.0
40.0
20.0
0.0
2:47:29 PM 3:08:21 PM

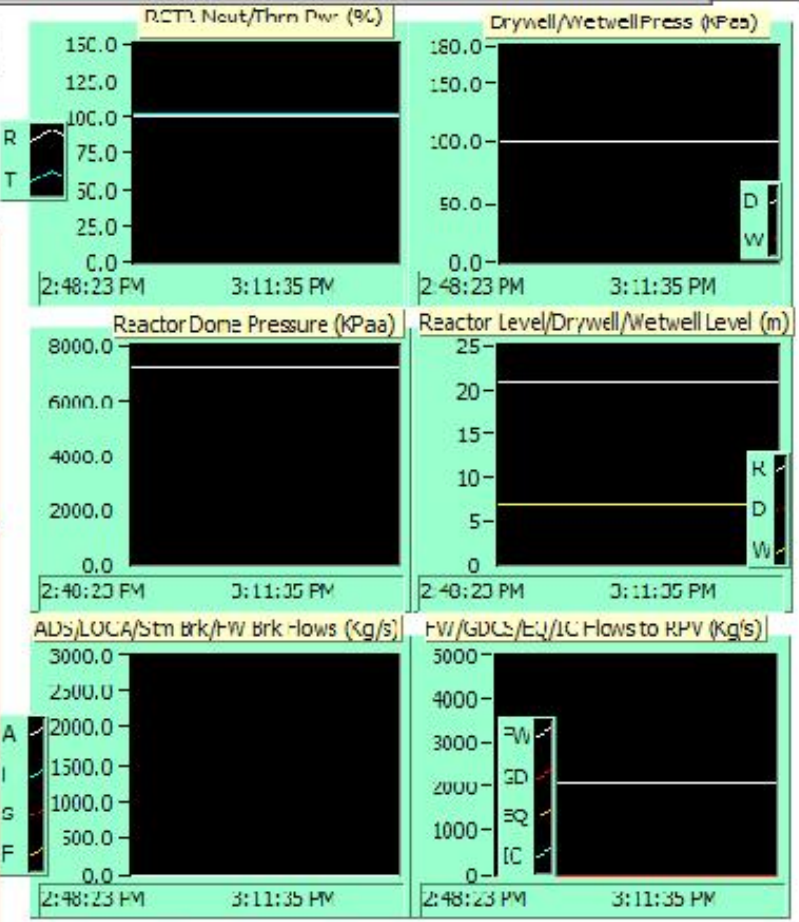
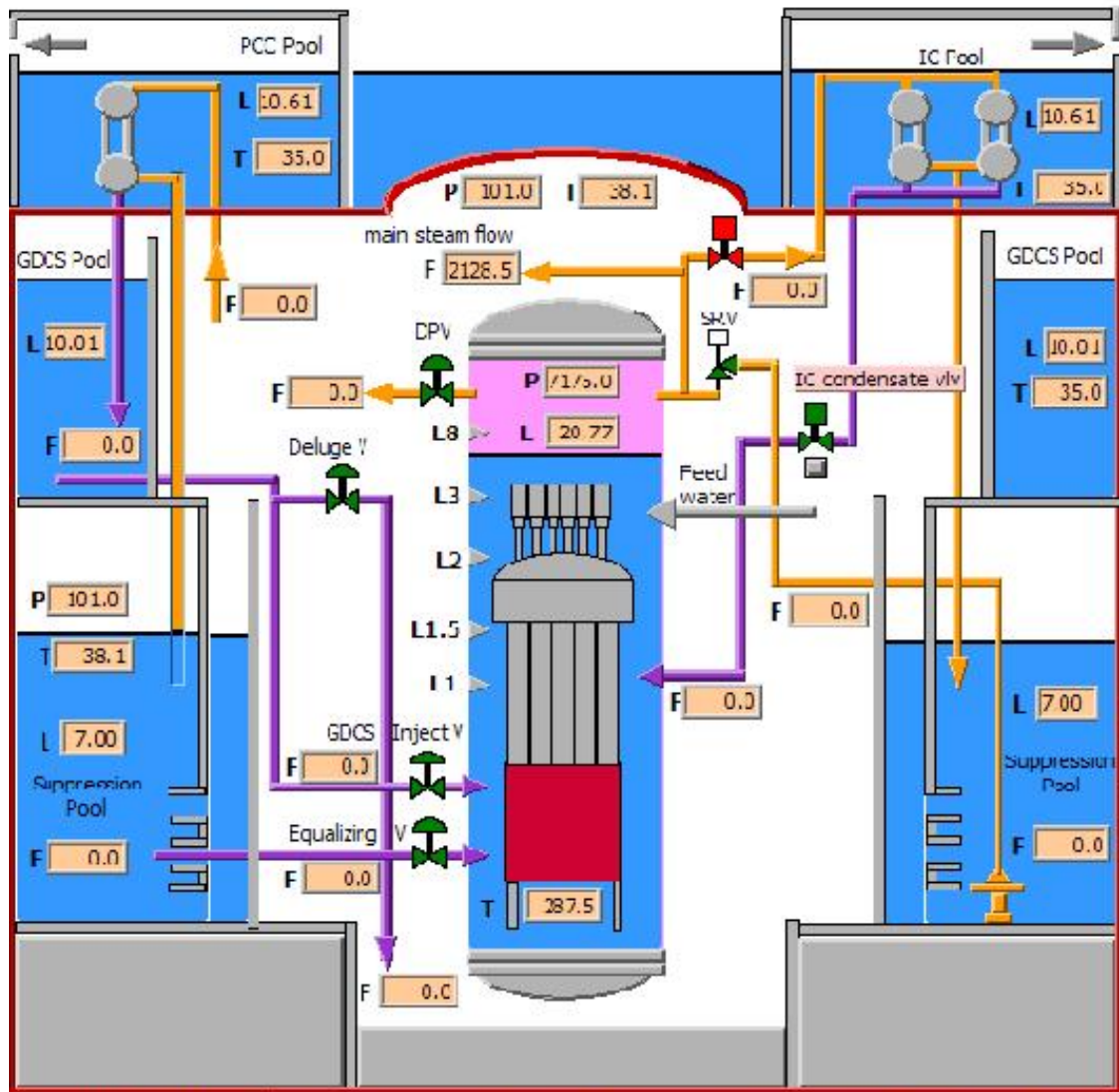
MSV Inlet Pressure
8000
6000
4000
2000
0
2:47:29 PM 3:08:21 PM

Resolution: Time Scroll:

Max Out: Max In:

47
Passive BWR Simulator (Turbine Generator)

Reactor Sram	Turbine Trp	Reactor Pres V. Lo	Rods Run-in Req'd	Hi Dryw P./OCA	Turbine Runback	Gen Breaker Opn	Labview
HI Neut Pwr vs Flow	Reactor Pres V. Hi	Reactor Pres Lo	Reactor Level Lo	Reactor Lvl V. Lc	Lo Turb Pwd Pwr	FW Pump(s) Trp	19
Reactor Isolated	Reactor Press Hi	Core Flow Lo	Reactor Level H	Turbine Gov. in Man	Loss RIP Pmp(s)	Malfunction Active	CASSIM
							2056



P-BWR Containment		Reactor Neutron Pwr (%)	Reactor Thermal Pwr (%)	Generator Output (%)	Reactor Pressure (kPa)	Core Flow (kg/s)	RCTR Lvl BOP STM Flow	Freeze	Run	Iterate
Reactor Trip	Turbine Trp	100.09	101.89	97.33	1175.05	12122.81	FW Flow 2085.9 Fuel Temp 487.4	IC	Malf	Help

Passive BWR Simulator (Containment)

[WWER-1000 Simulator]

- ❑ Originally developed by Moscow Engineering and Physics Institute, Russian Federation for personnel training.
- ❑ The present configuration of the Simulator is able to respond to operating conditions normally encountered in WWER-1000 power plant operation.
- ❑ **W**ater **W**ater **E**nergy **R**eactor **1000** MWe
- ❑ Manual updated in 2009

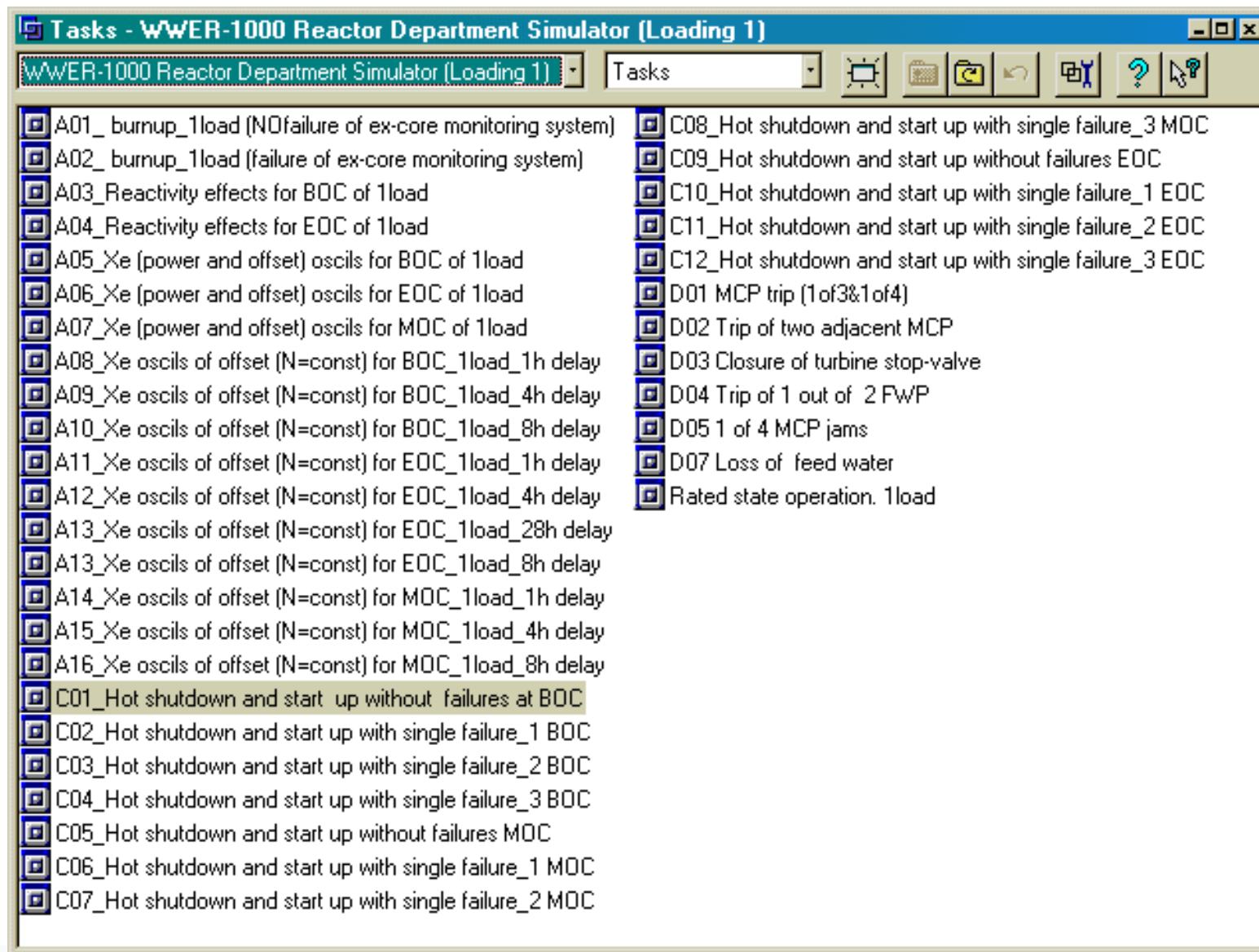


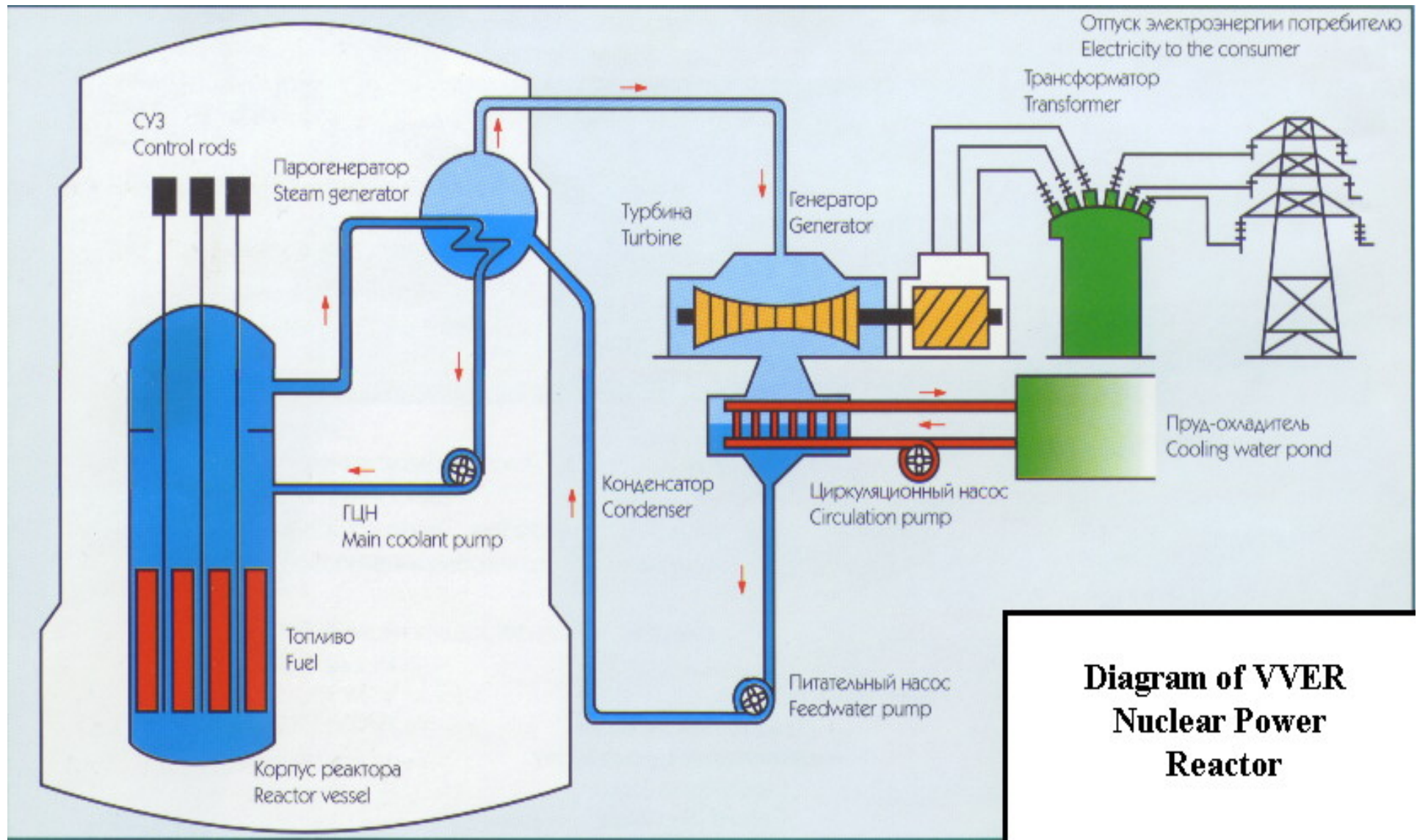
[WWER-1000 Simulator]

- Ten display pages are available in the Simulator.
 - Reactivity control page (CPS),
 - Annunciator page (TAB),
 - Primary circulation loop page (1C),
 - Feed and bleed system page (TK),
 - Process support systems page (TQ),
 - Extraction water cooling system page (TF),
 - Secondary circulation loop page (2C),
 - Trends page (GRP),
 - Reactor core parameters page (PAR),
 - Three dimension diagram page (3D).



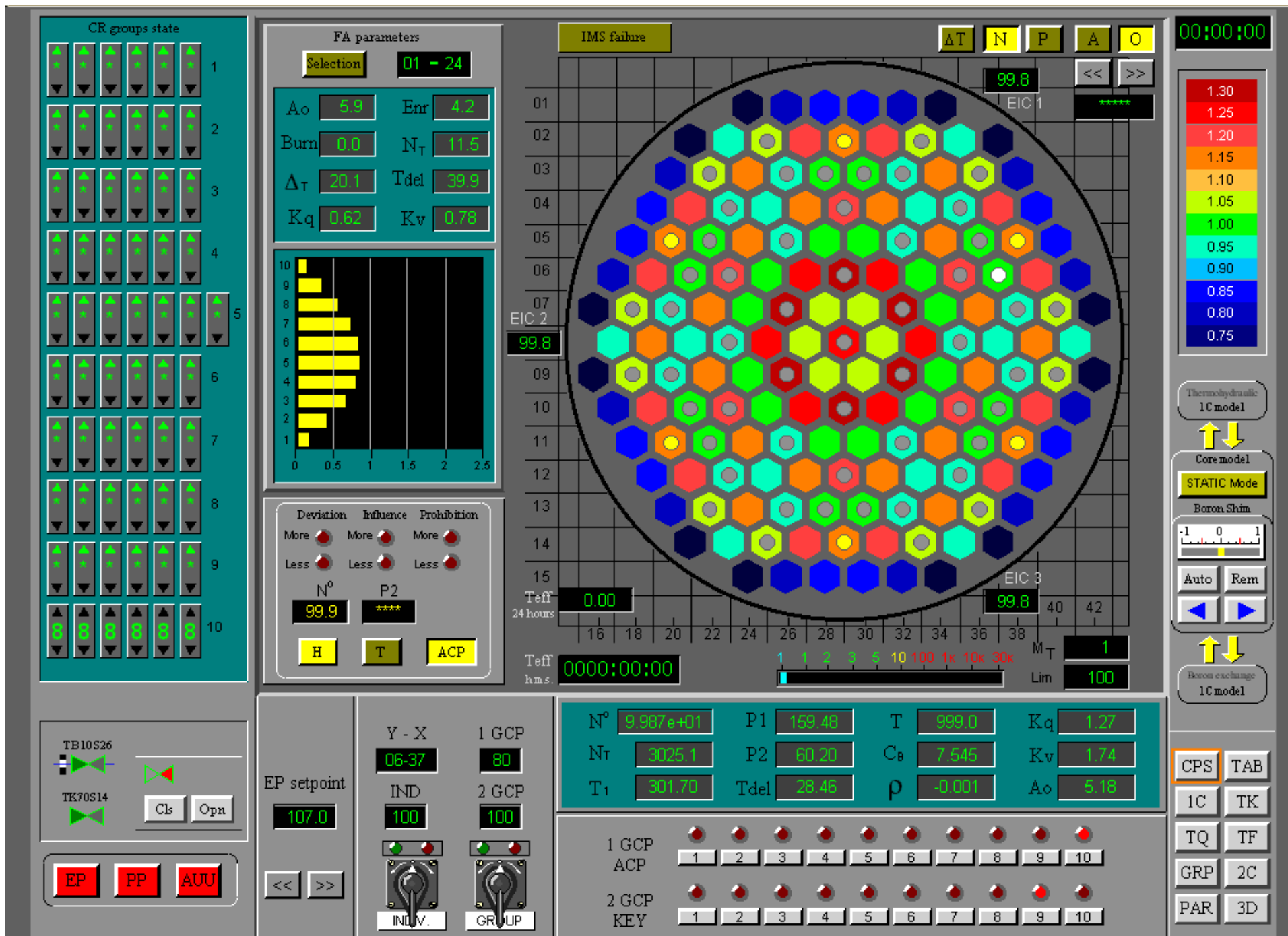
[WWER-1000 Simulator]



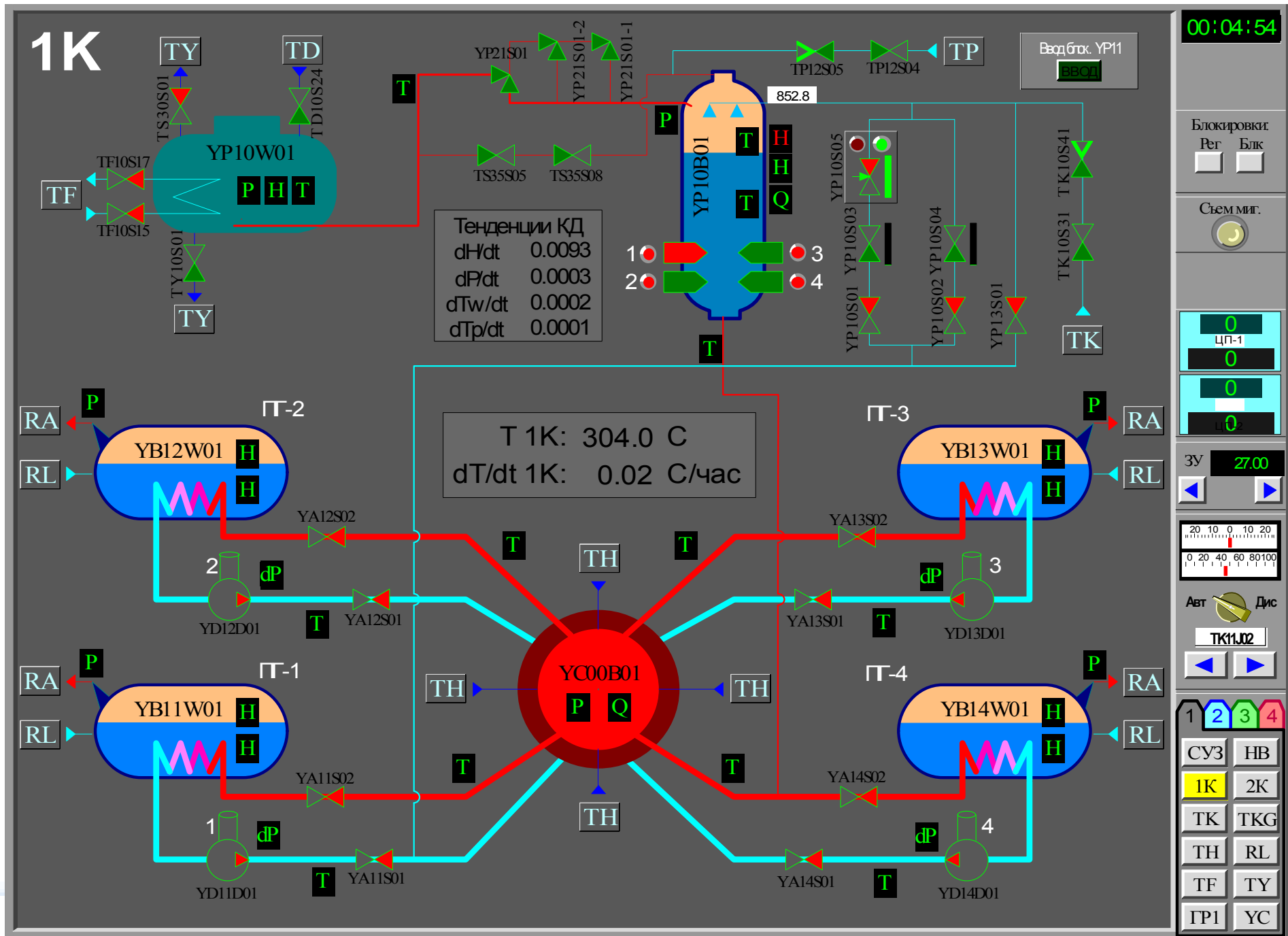


**Diagram of VVER
Nuclear Power
Reactor**

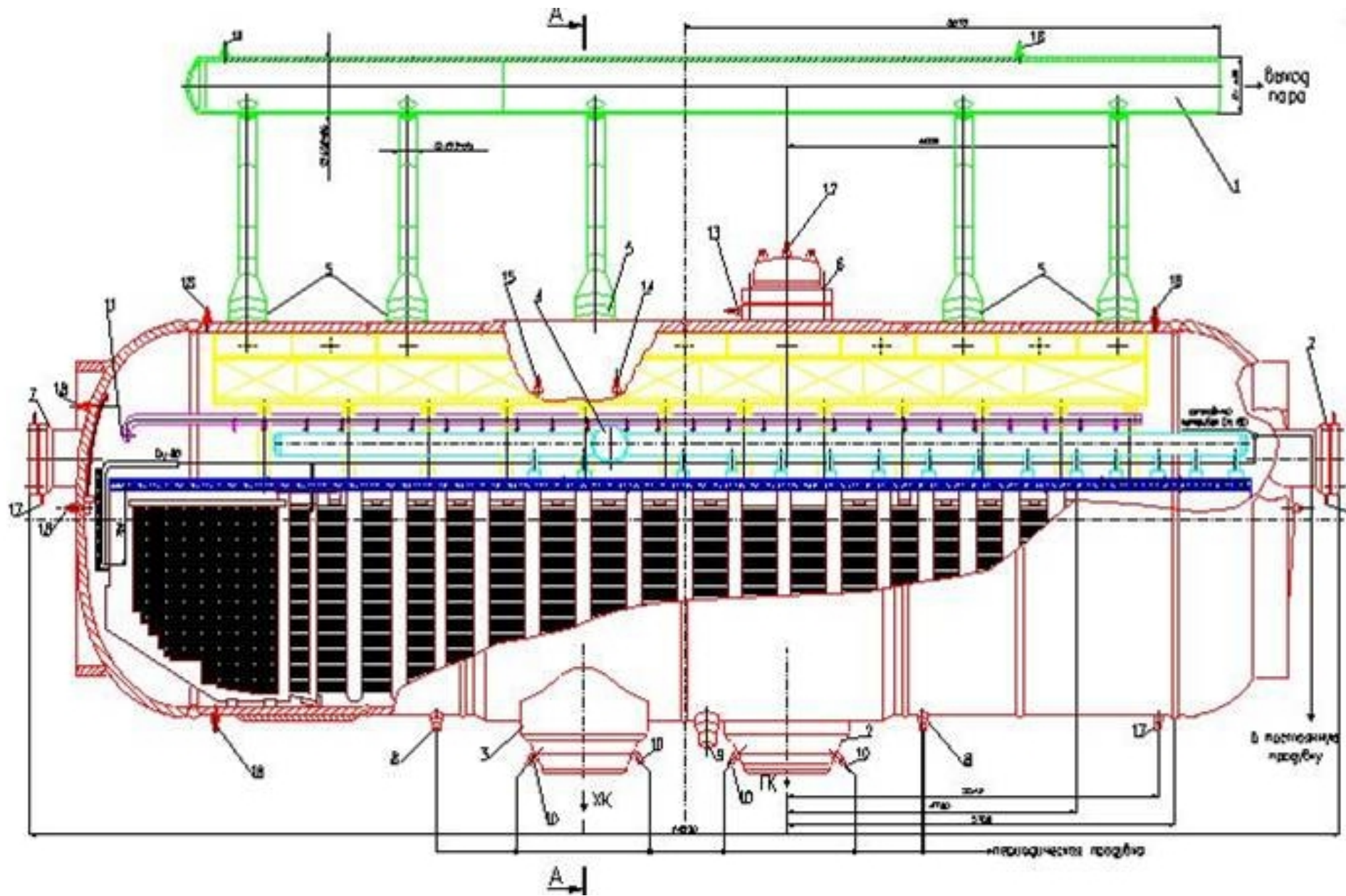
WWER-1000 NPP Diagram



WWER-1000 Simulator (Control & Protection System)

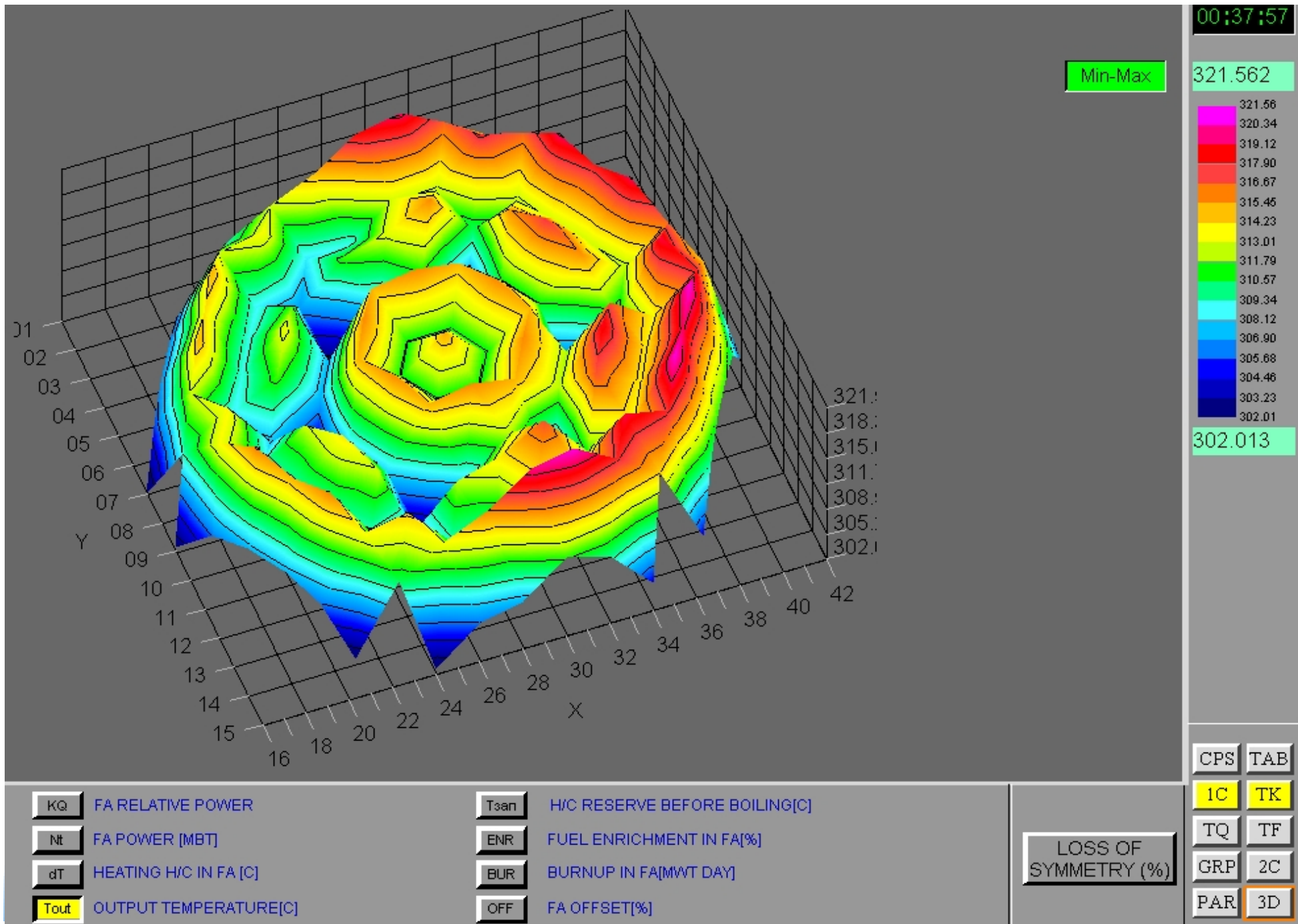


WWER-1000 Simulator (Reactivity Control Display Screen)



WWER-1000 General View of Steam Generator





WWER-1000 3D Diagram (Core Output temperature)⁵⁶

[PHWR Simulator]

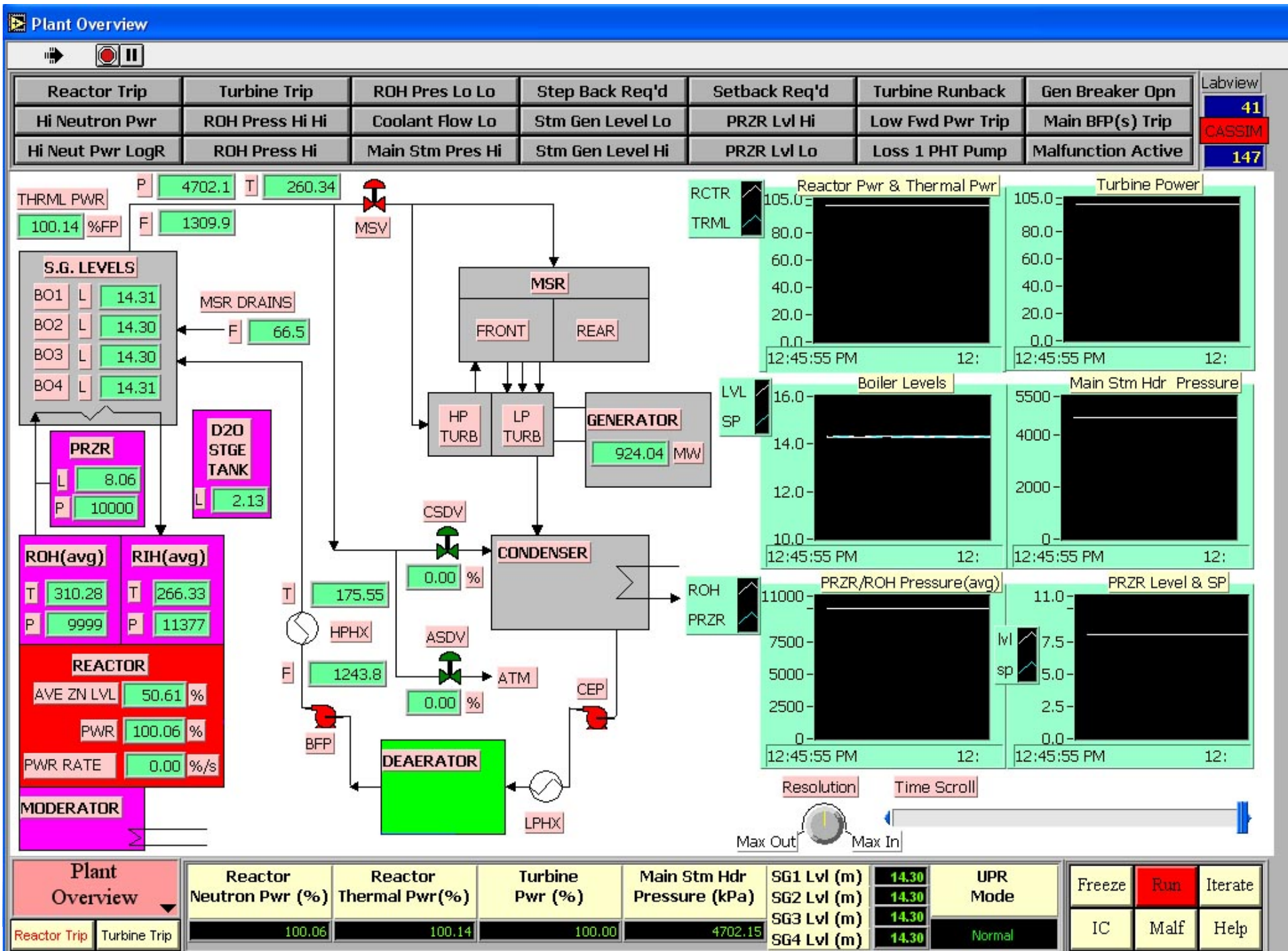
- ❑ Developed by Cassiopeia Technologies Inc.,
- ❑ Largely based on the CANDU-9 system,
with a capacity of approximately 900 MW(e)



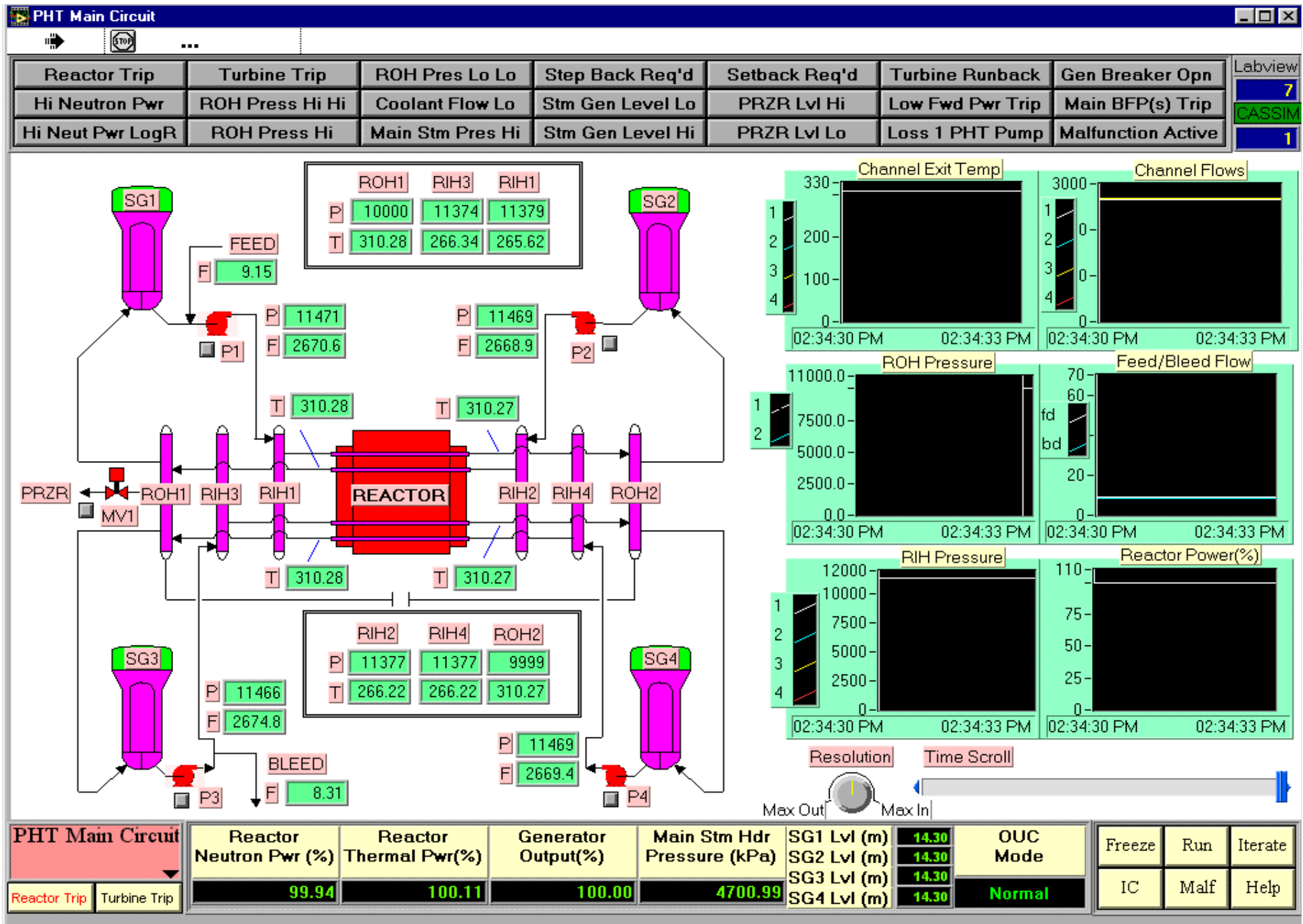
[PHWR Simulator]

- ❑ Ten process screens that provide essential system parameters, along with dynamic trends:
 1. CANDU Overview
 2. Shutoff Rods
 3. PHT (Primary Heat Transport System)
 4. PHT Pressure/Inventory Control
 5. Boiler Feedwater
 6. Turbine Generator
 7. RRS/DPR (Reactor Regulation Sys / Demand Power Regulator)
 8. UPR (Unit Power Regulator)
 9. Reactivity Status & Control Display
 - 10 Real-time trends.

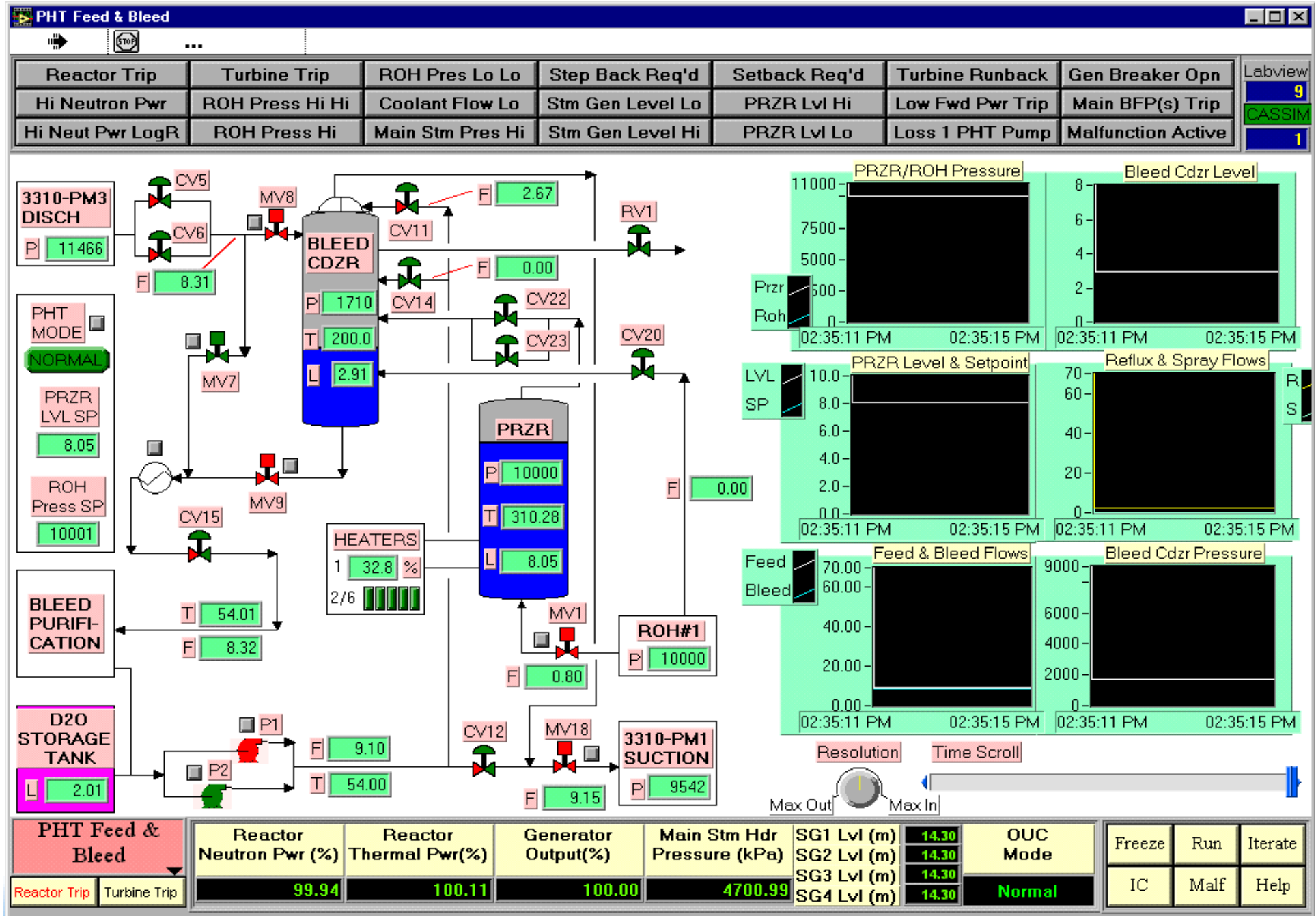




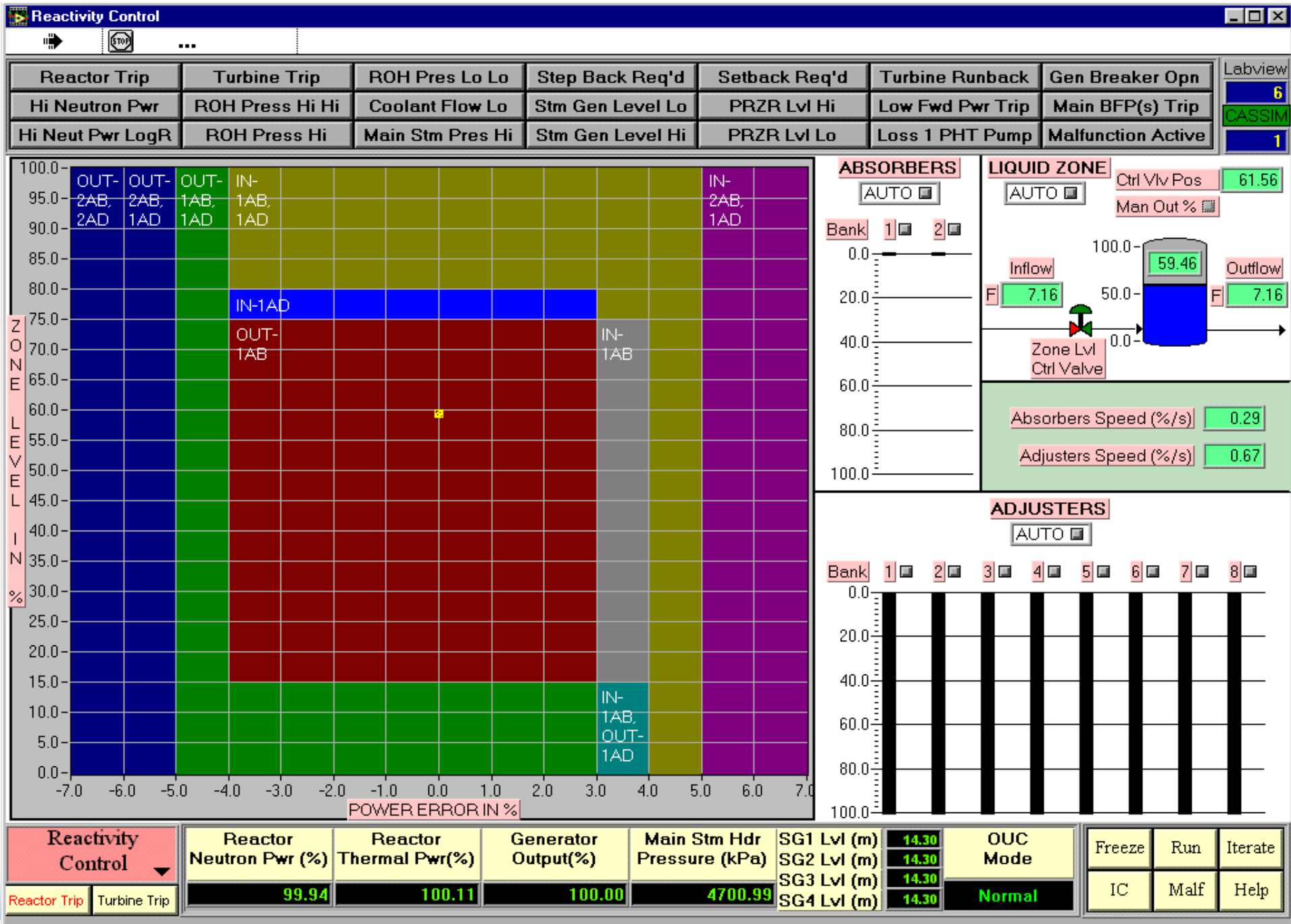
PHWR Simulator (Overview)



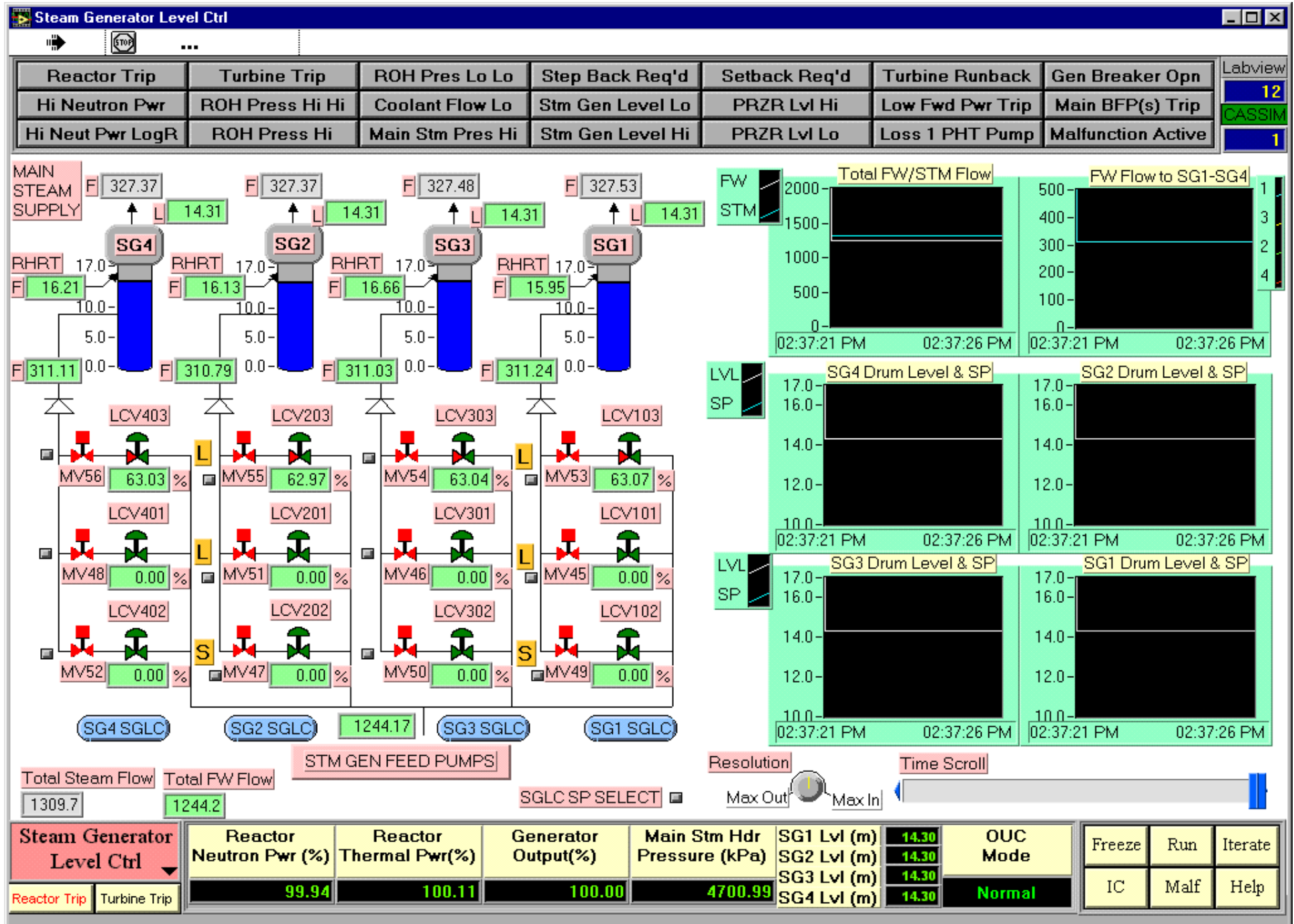
PHWR Simulator (PHT main circuit)



PHWR Simulator (PHT Feed & Bleed)



PHWR Simulator (Reactivity control)



PHWR Simulator (SG level control)

[Advanced PHWR Simulator]

- ❑ Developed by Cassiopeia Technologies Inc. from Canada
- ❑ Largely based on the ACR-700 system.
- ❑ Two major differences:
 - The use of slightly enriched uranium fuel (2.1 wt% U-235 in 42 pins of the fuel bundle),
 - Light water (as opposed to heavy water D2O) as the coolant, which circulates in the fuel channels



[Advanced PHWR Simulator]

ACR Basic operations & Transient recovery

- Plant load manoeuvring — reactor lead
- Plant load manoeuvring — turbine lead
- Power level reduction to 0% FP
- Reactor trip and recovery
- Turbine trip and recovery



[Advanced PHWR Simulator]

ACR Malfunction Transient Events

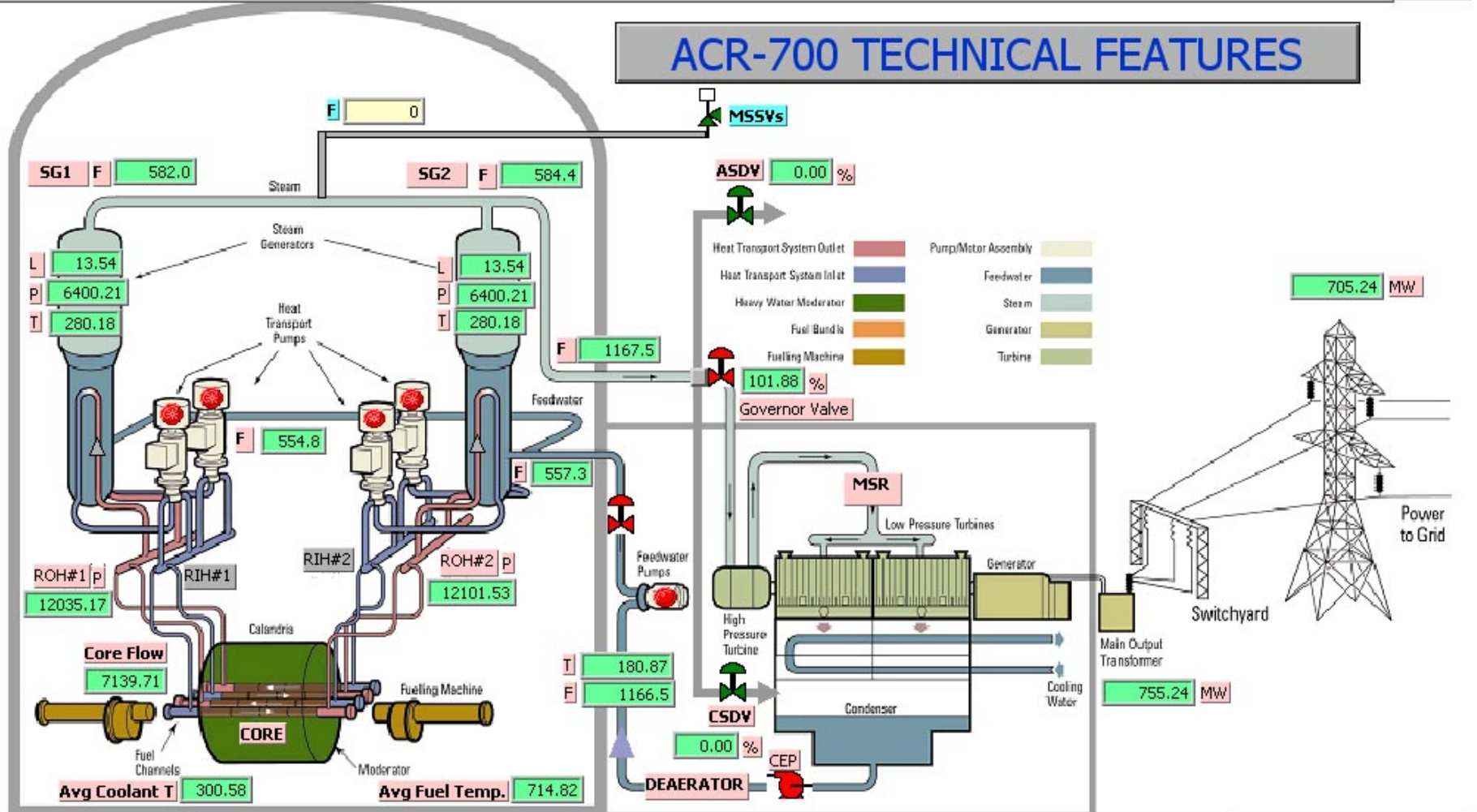
- FW LCV #1 fails open
- Main BFP trips
- Turbine throttle PT fails low
- Turbine spurious trip
- One band of MCA rods drops
- Loss of one RC pump P1
- Loss of 2 PHT pumps
- Primary Coolant RIH #1 LOCA Break, etc



ACR Plant Overview

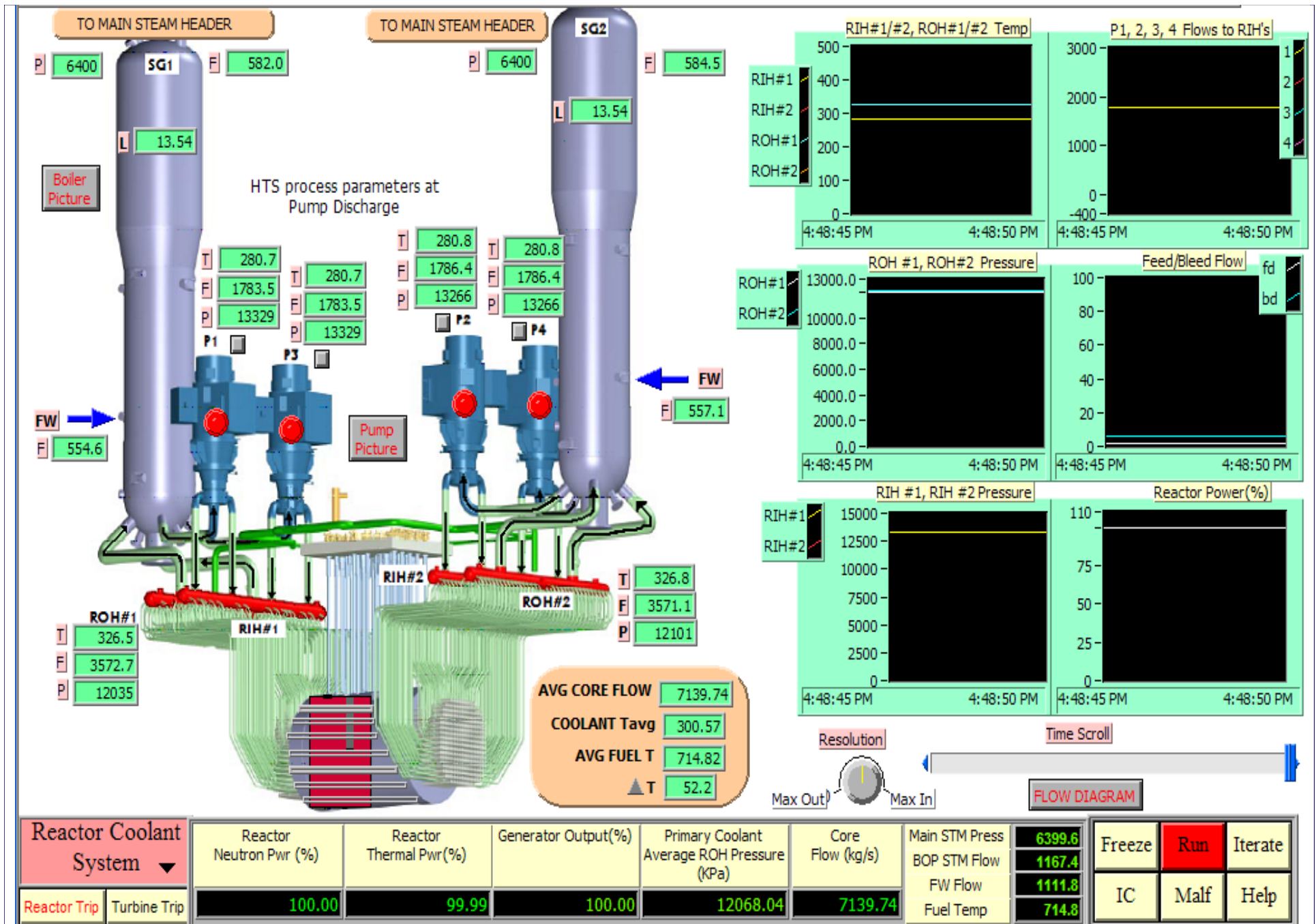
Reactor Trip	Turbine Trip	ROH Press Lo Lo	Step Back Req'd	Setback Req'd	Turbine Runback	Gen Breaker Opn	Labview
Hi Neutron Pwr	ROH Press Hi Hi	Coolant Flow Lo	Stm Gen Level Lo	PRZR Lvl Hi	Low Fwd Pwr Trip	Main BFP(s) Trip	78
Hi Neut Pwr LogR	ROH Press Hi	Main Stm Pres Hi	Stm Gen Level Hi	Spdr Gear in Man	Loss RC Pmp(s)	Malfunction Active	CASSIM
							1

ACR-700 TECHNICAL FEATURES

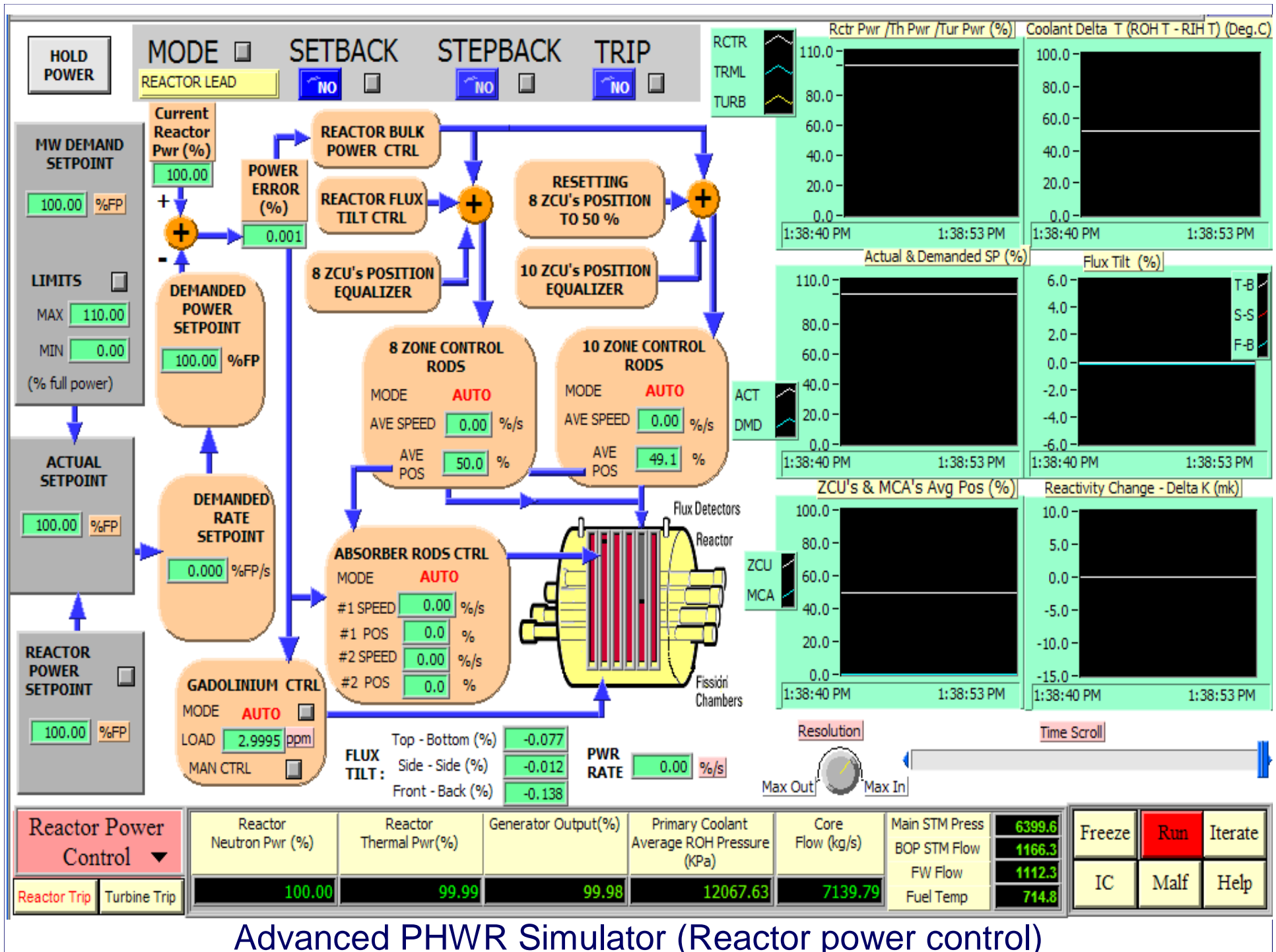


ACR Plant Overview		Reactor Neutron Pwr (%)	Reactor Thermal Pwr (%)	Generator Output (%)	Primary Coolant Average ROH Pressure (KPa)	Core Flow (kg/s)	Main STM Press	6400.2	Freeze	Run	Iterate
Reactor Trip	Turbine Trip	100.00	99.98	100.30	12068.35	7139.71	BOP STM Flow	1167.5	IC	Malf	Help
							FW Flow	1112.1			
							Fuel Temp	714.8			

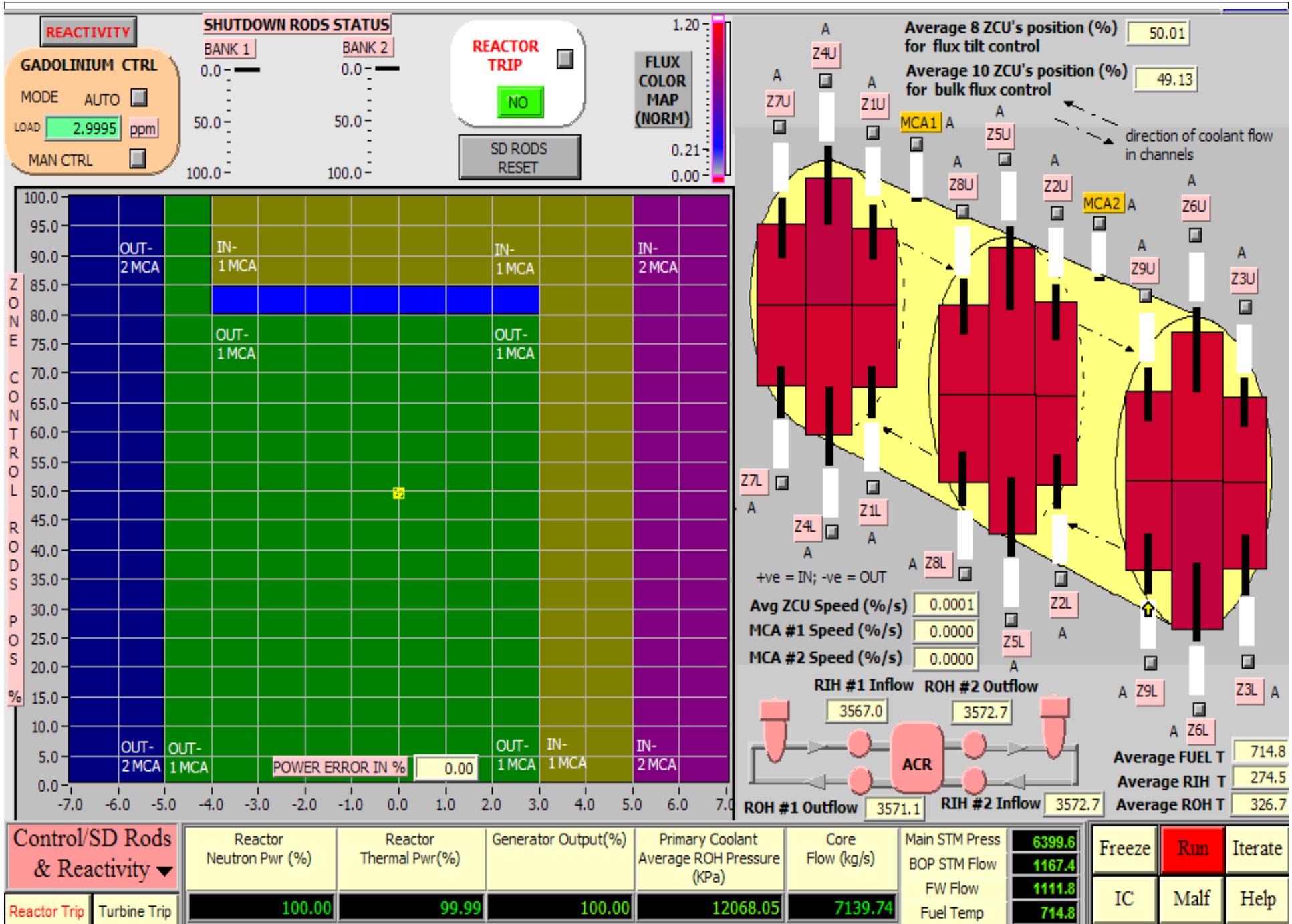
Advanced PHWR Simulator (Overview)



Advanced PHWR Simulator (Reactor coolant system)



Advanced PHWR Simulator (Reactor power control)



Advanced PHWR Simulator (Control/SD rods & reactivity)

REACTOR TRIP PARAMETERS

FIRST OUT	TRIP CAUSES
<input type="radio"/>	Low ROH Pressure Trip <input type="button" value="ENABLE"/>
<input type="radio"/>	Low Steam Generator Level Trip <input type="button" value="ENABLE"/>
<input type="radio"/>	High Reactor Outlet Pressure Trip
<input type="radio"/>	High Neutron Flux (ROP) Trip <input type="radio"/> Containment High Pressure Trip
<input type="radio"/>	High Log Rate Trip
<input type="radio"/>	Low Coolant Flow Trip <input type="button" value="ENABLE"/>
<input type="radio"/>	Low Pressurizer Level Trip <input type="button" value="ENABLE"/>
<input type="radio"/>	Low Feedwater Discharge Header Pressure Trip <input type="button" value="ENABLE"/>
<input type="radio"/>	Manual Trip

SDS Reactor Trip Setpoint For High Neutron Flux

120.0 %FP

REACTOR STEPBACK CAUSES

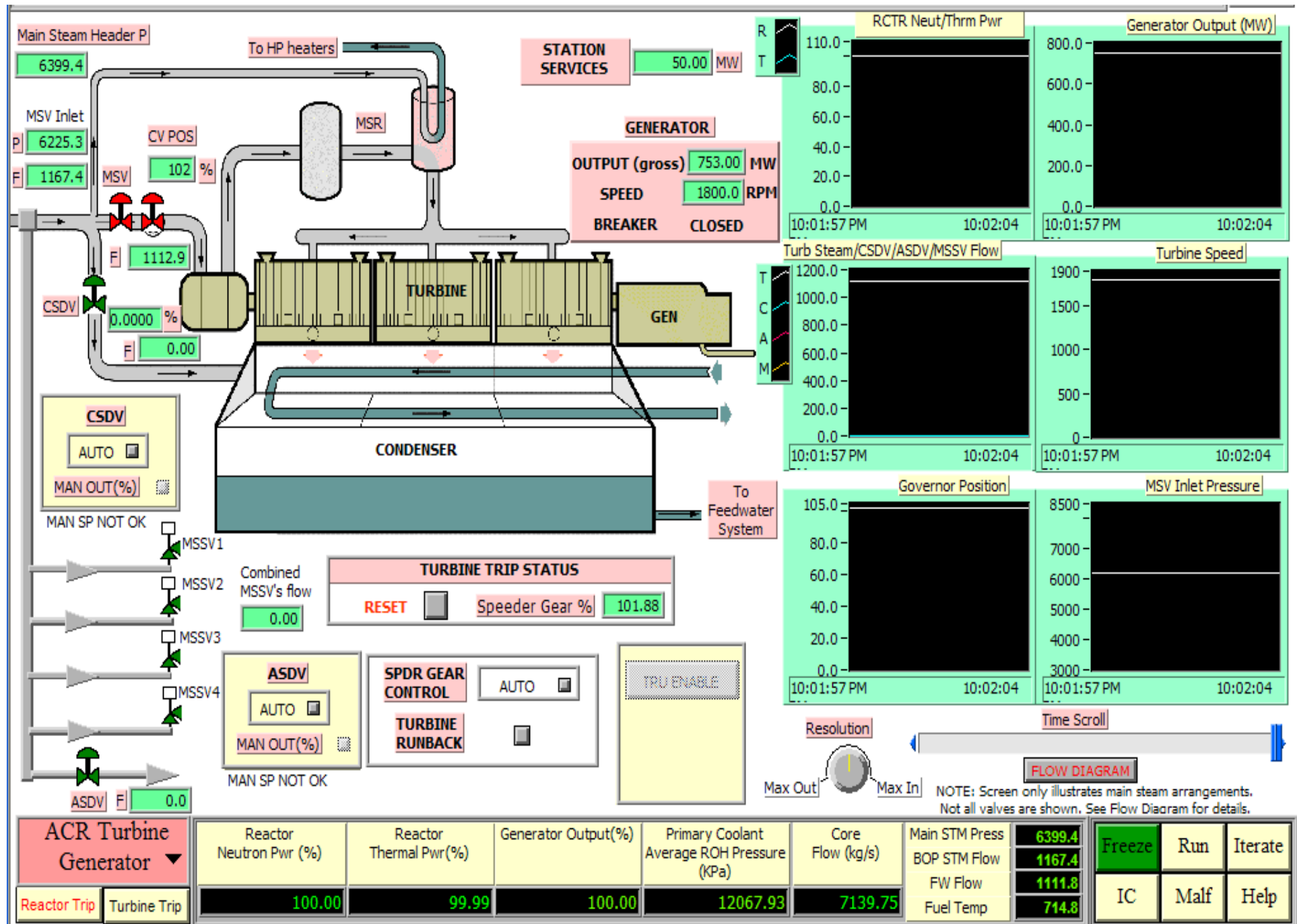
- 2 Heat Transport Pumps Trip
- 1 Heat Transport Pump Trip
- Heat Transport Pressure Hi
- Hi Zone Powers
- Hi Log Rate
- Low Steam Generator Level
- Manual Stepback
- Press to clear

REACTOR SETPBACK CAUSES

- Hi Local Neutron Flux
- Hi Flux Tilt
- Main Steam Header Press Hi
- Lo Deaerator Level
- High Moderator Temperature
- Low Moderator Pump Delta Pressure
- Hi Pressurizer Level
- Low Steam Generator Level Setback
- Hi End Shield Inlet Temperature
- High Bleed Condenser Pressure
- Turbine Trip or Loss of Line
- Manual Setback
- Press to clear

Trip Parameters		Reactor Neutron Pwr (%)	Reactor Thermal Pwr (%)	Generator Output (%)	Primary Coolant Average ROH Pressure (kPa)	Core Flow (kg/s)	Main STM Press	BOP STM Flow	FW Flow	Fuel Temp	Freeze	Run	Iterate
Reactor Trip	Turbine Trip	100.00	99.98	100.00	12068.14	7139.73	6399.8	1167.4	1111.8	714.8	IC	Malf	Help

Advanced PHWR Simulator (Reactor trip parameters)



Advanced PHWR Simulator (Turbine Generator)

5. Obtaining the Simulators

- ❑ Available free of charge to institutions in all IAEA Member States for non-profit education and training

<http://www.iaea.org/NuclearPower/Education/Simulators/>

- ❑ Contact : S. Bilbao@iaea.org



6. Training

- IAEA organizes courses/workshops periodically
 - October 12~23, 2009, International Centre for Theoretical Physics (ICTP), Trieste, Italy

- Customized courses and workshops organized at the request of interested organizations



7. Conclusion

- ❑ Technology training is one of the key priorities of IAEA
- ❑ IAEA has developed a suite of PC-based simulators that currently contains
 - A. Active and Advanced PWR,
 - B. Active and Advanced BWR,
 - C. WWER-1000,
 - D. PHWR and Advanced PHWR.



7. Conclusion

- ❑ These simulators, including the associated documentation are distributed at no cost to interested parties in IAEA Member States.
- ❑ Furthermore, the IAEA sponsors training courses and workshops on a regular basis, and would also be willing to support additional training events on this topic at the request of Member States.



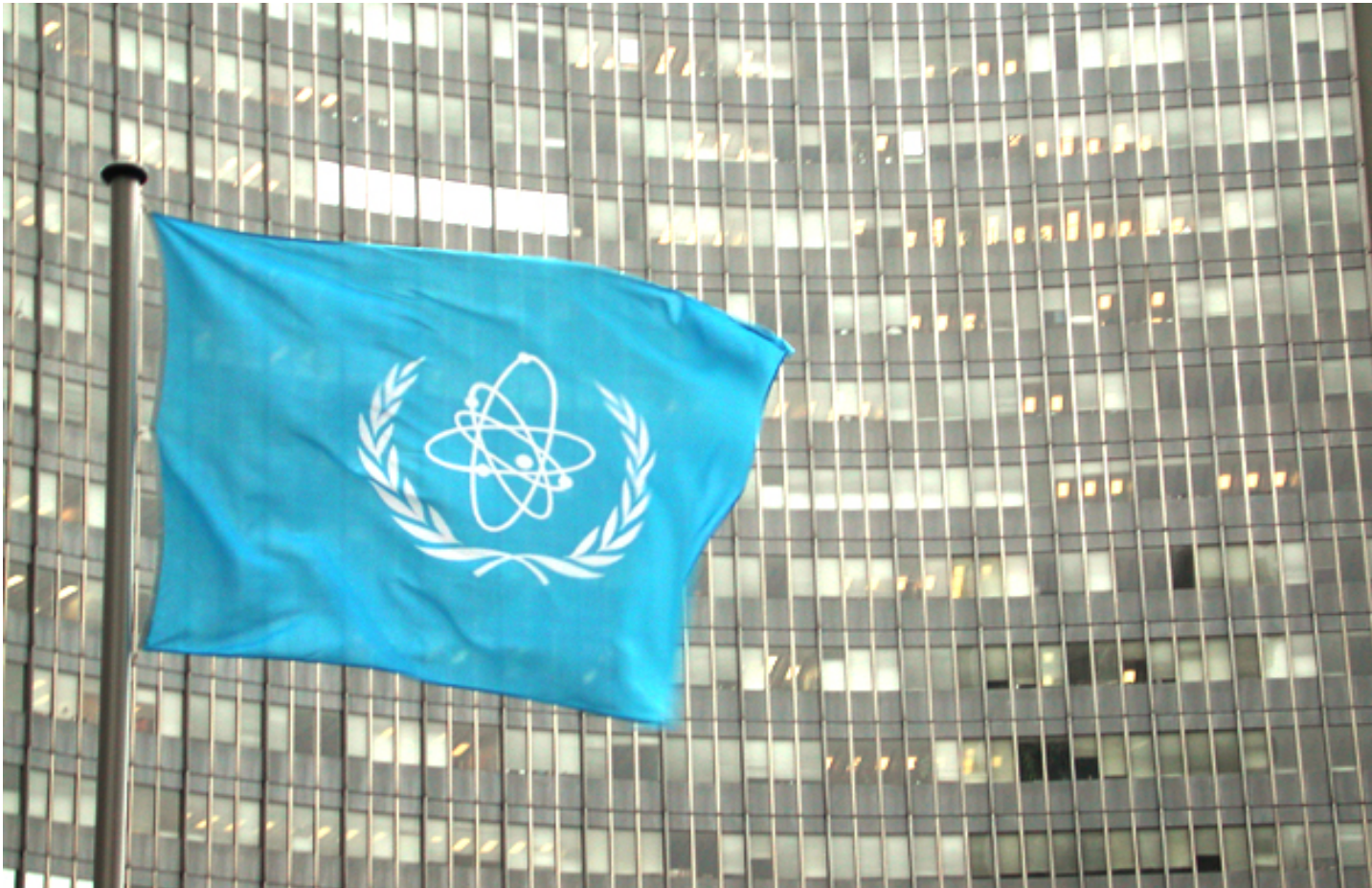
Acknowledgements

The IAEA appreciates the contributions of:

- ✓ **Dr. Bereznai, University of Ontario Institute of Technology, Canada**
- ✓ **Dr. Lam, Cassiopeia Technologies Incorporated, CTI, Canada**
- ✓ **Dr. Po, Microsimulation Technologies, USA**
- ✓ **Dr. Tikhonov, Moscow Engineering and Physics Institute, Russia**



IAEA



...atoms for peace