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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.

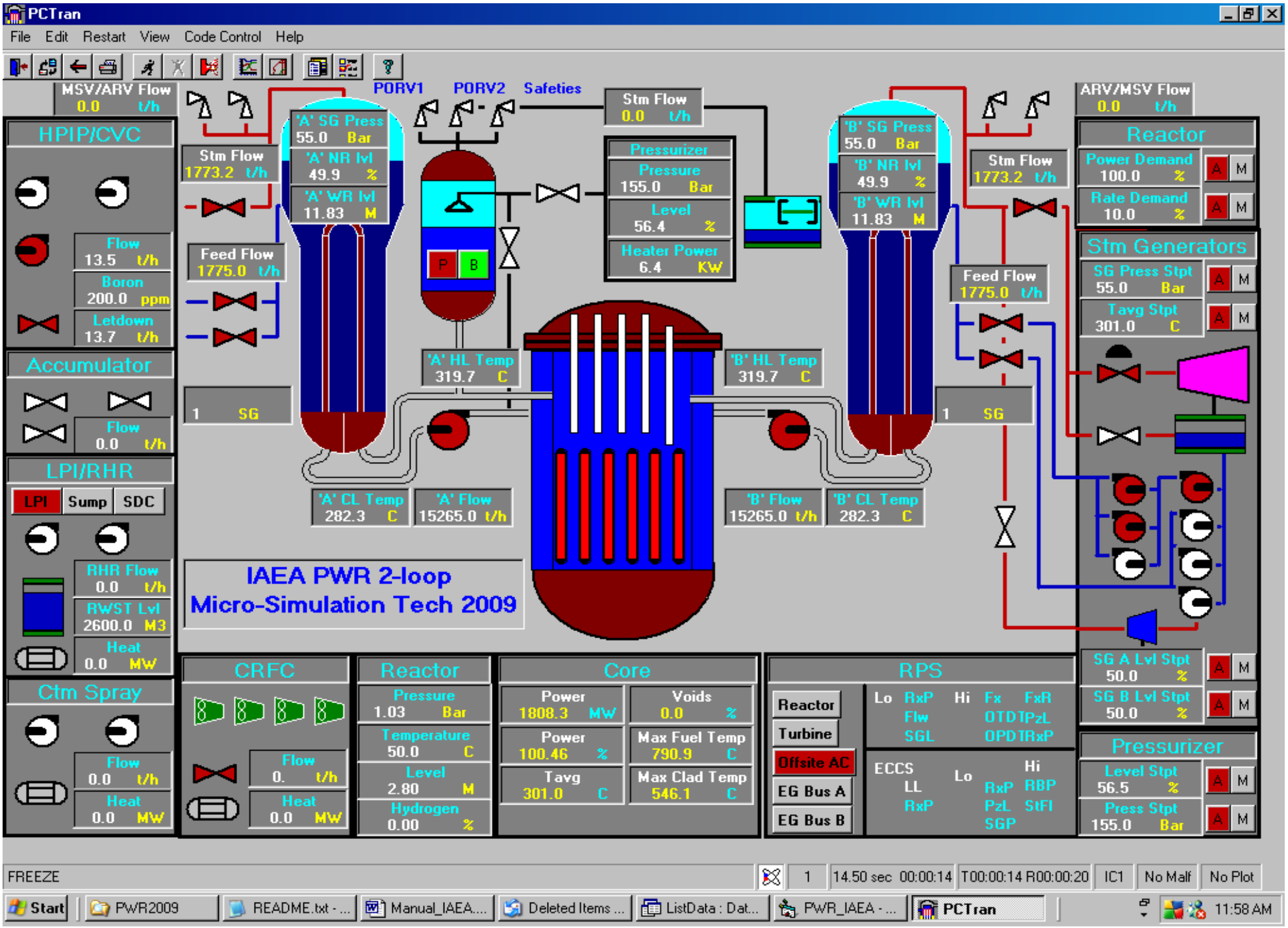
[PWR Simulator]

- 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

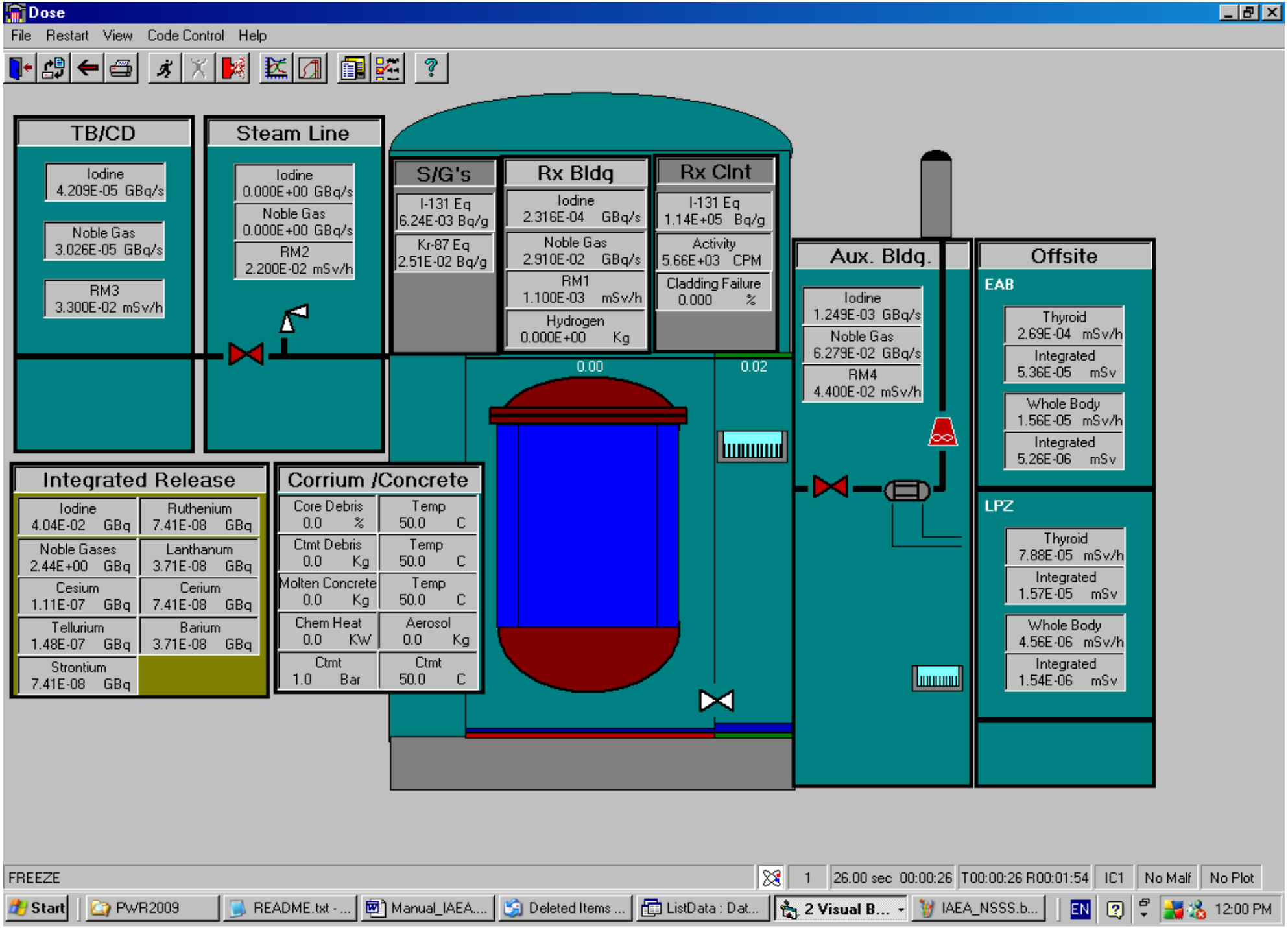
[PWR Simulator]

Transient and Accident Analyses

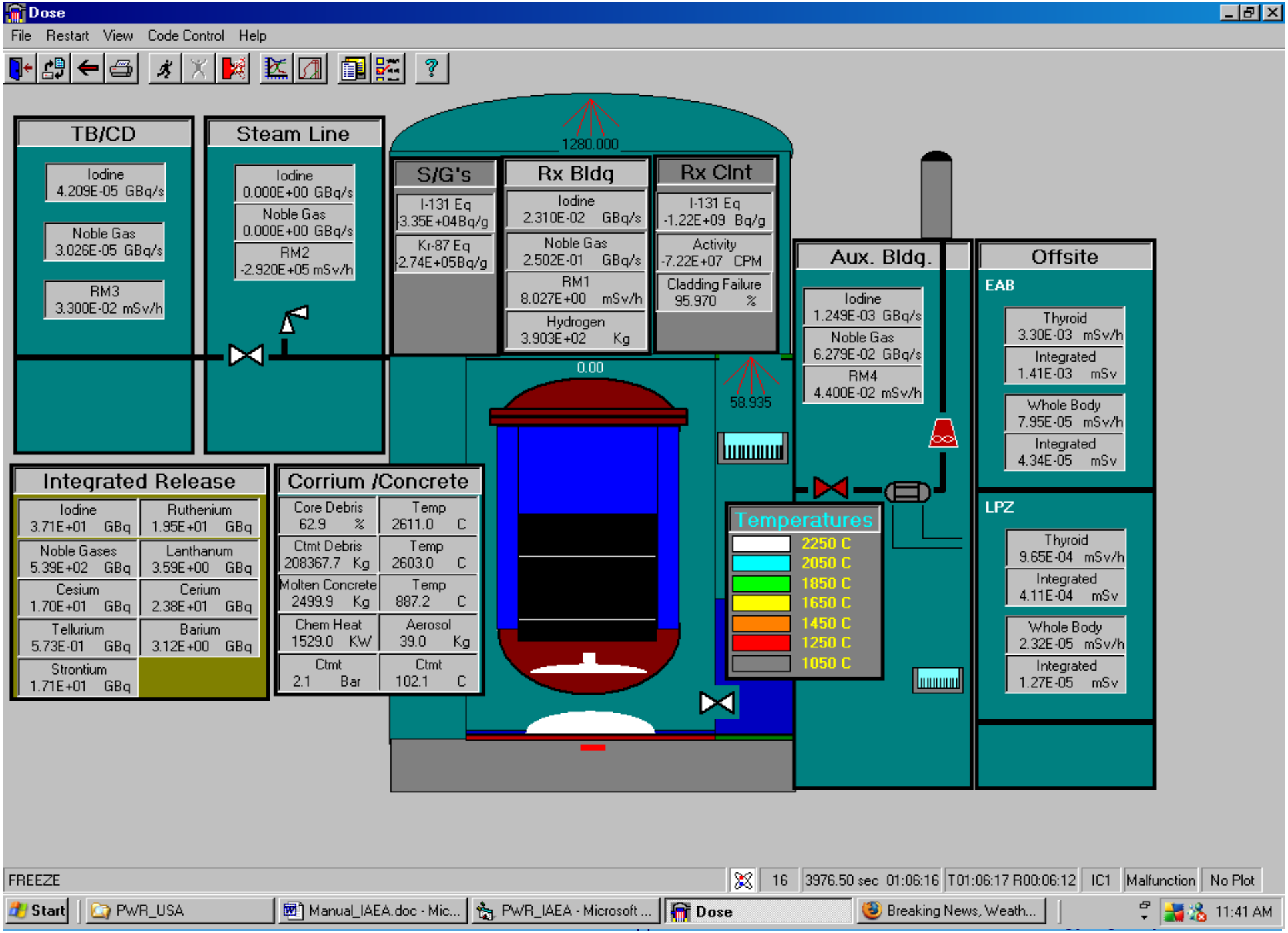
- Uncontrolled Rod Bank Withdrawal
- Hot Full Power Rod Drop
- Moderator Dilution
- Startup of an Inactive RCP
- Reduction in Feedwater Enthalpy
- Excessive Load Increase
- Loss of Reactor Coolant Flow or Normal Feedwater
- Turbine Trip
- Steam Generator Tube Rupture
- Small and Large Break LOCA



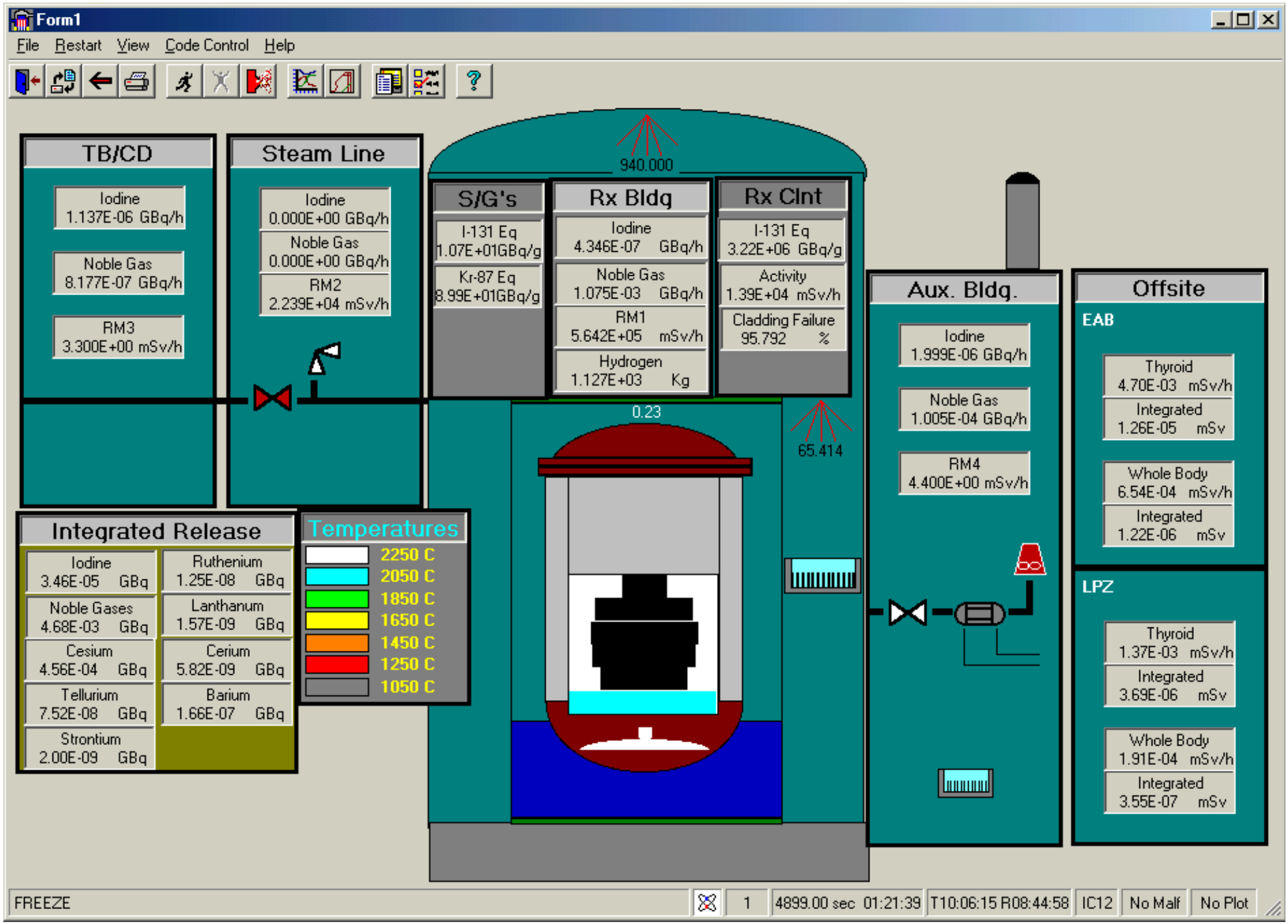
PWR Simulator Display Screen



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

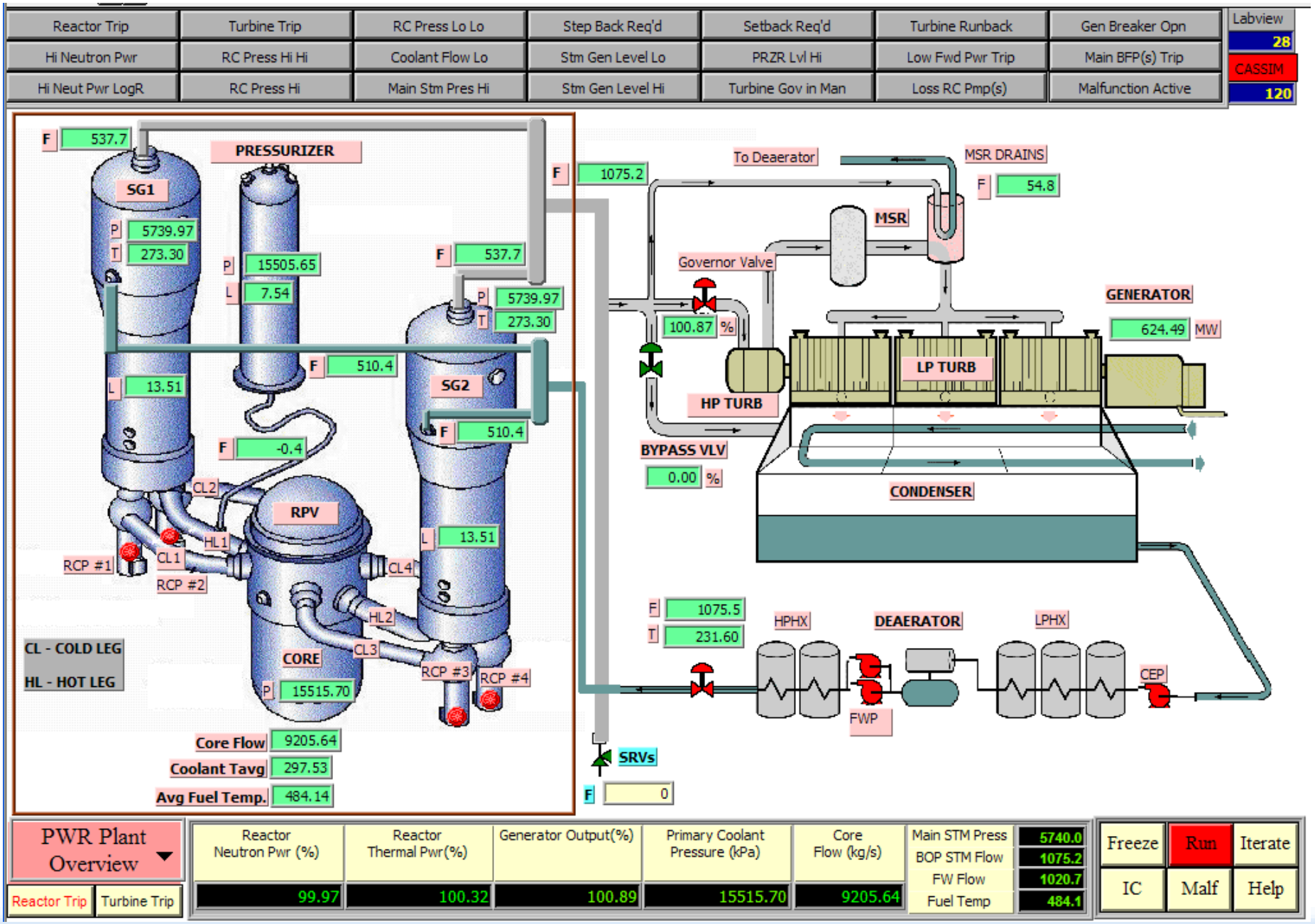
- Larger core, resulting in lower (25 % less) power density
- Lower fuel enrichment, and the use of radial reflectors for better neutron economy;
- Longer fuel cycle;
- About 15 % more safety margin for DNB and LOCA;
- Reduced worth control rods to achieve load following capability without substantial 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

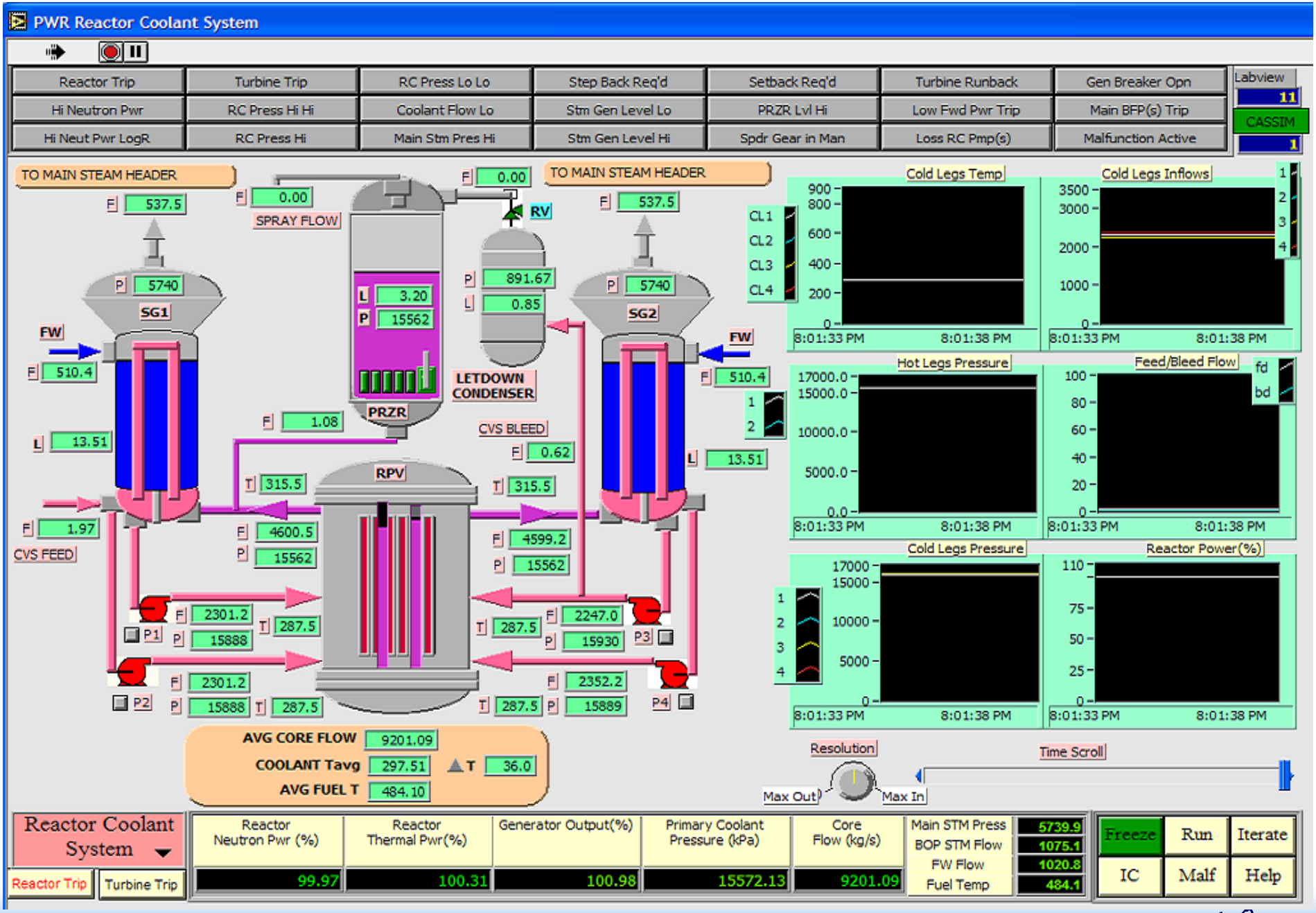
[Advanced PWR]
20 Malfunction Transient Events

- 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



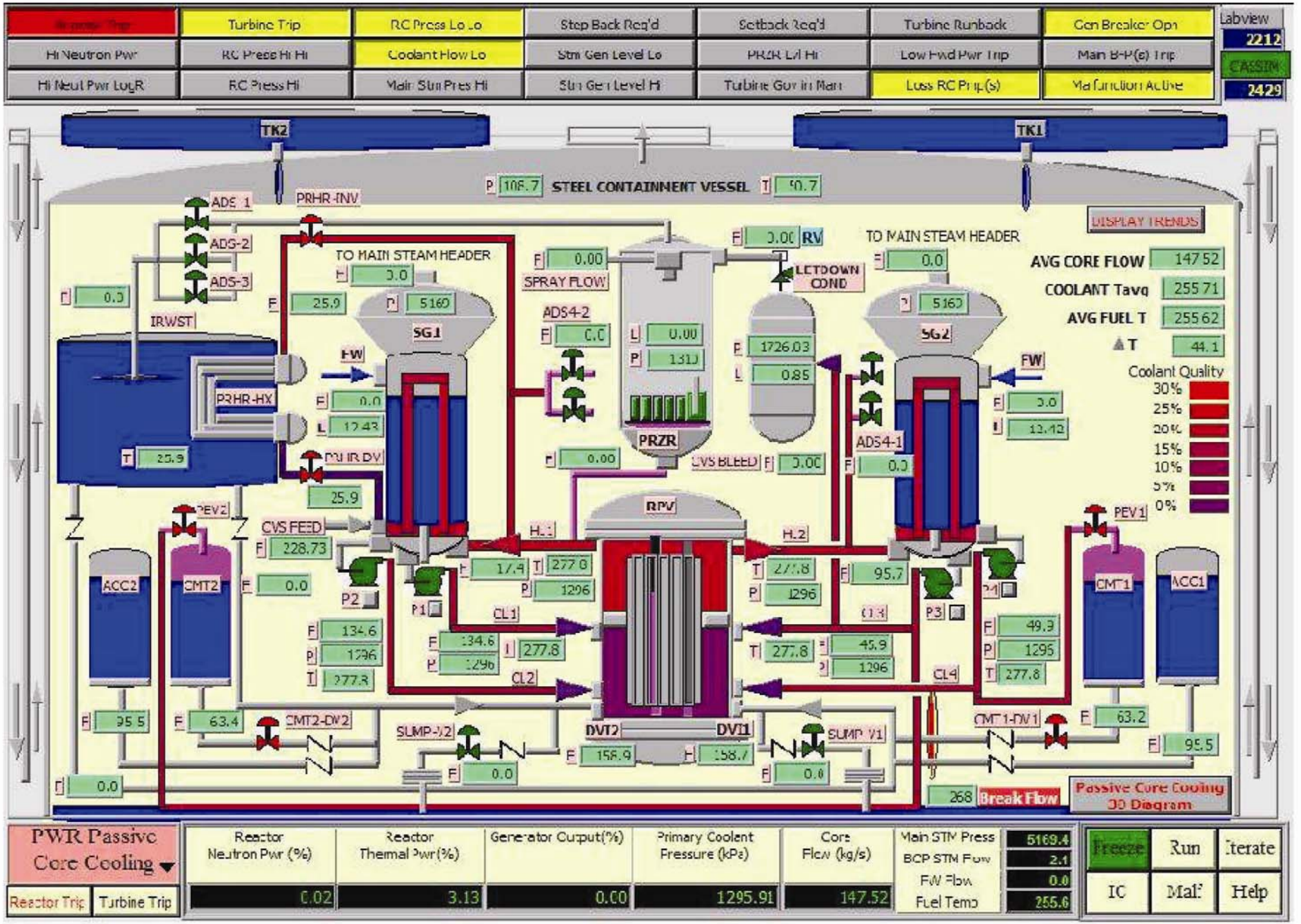
International Atomic Energy Agency

Passive PWR Simulator Display Screen (Overview)

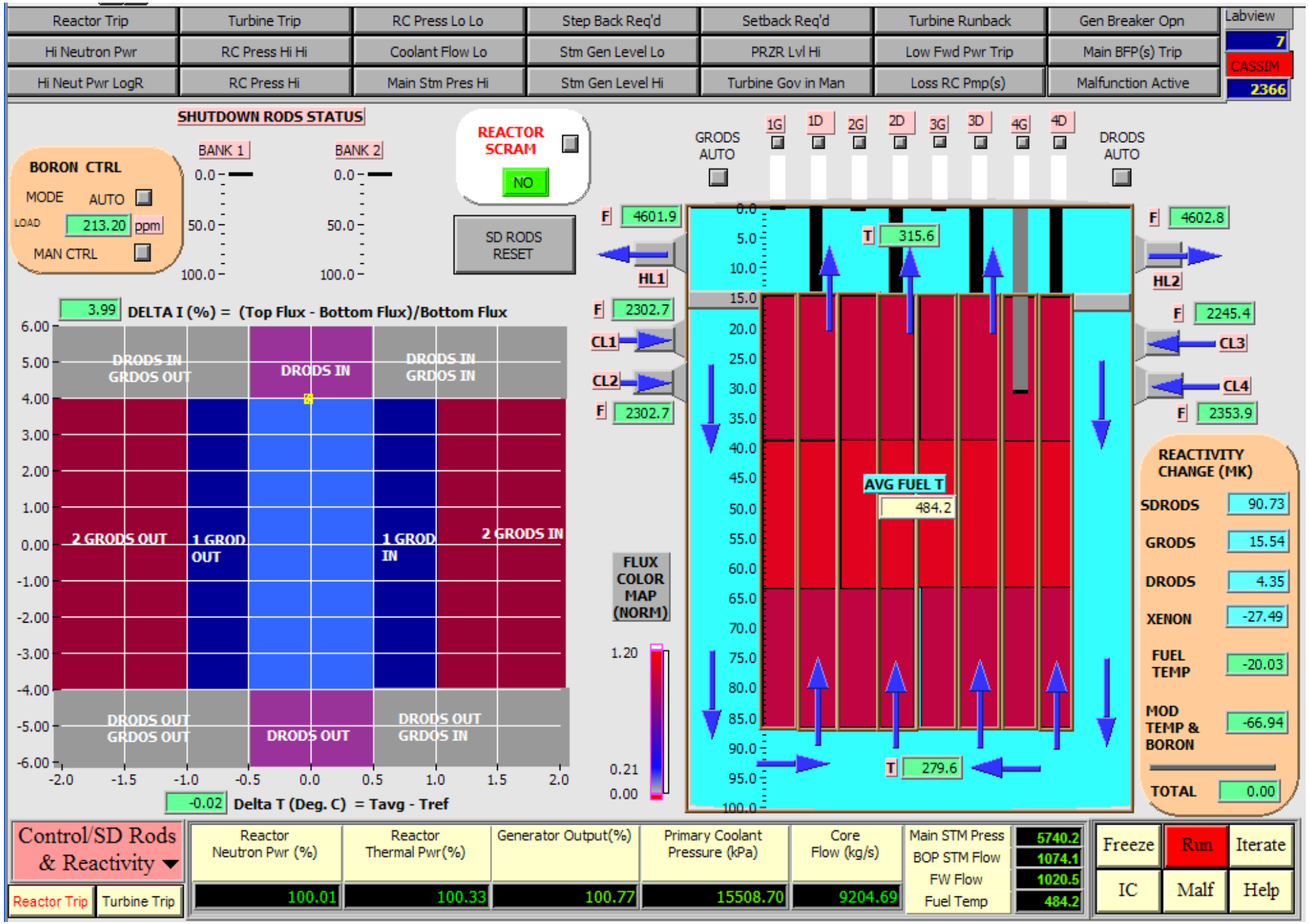


International Atomic Energy Agency

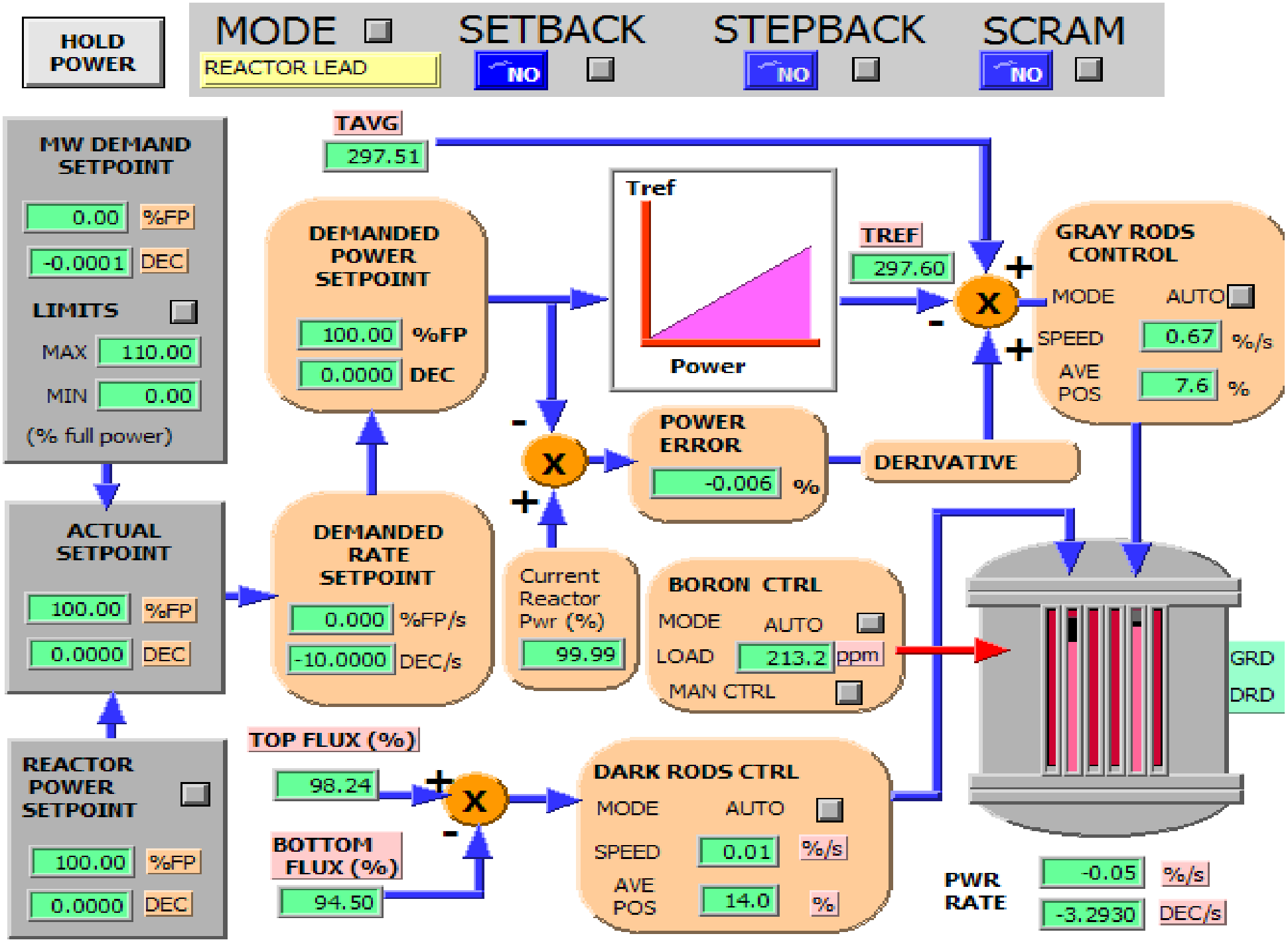
Passive PWR Simulator Display Screen (RCS)



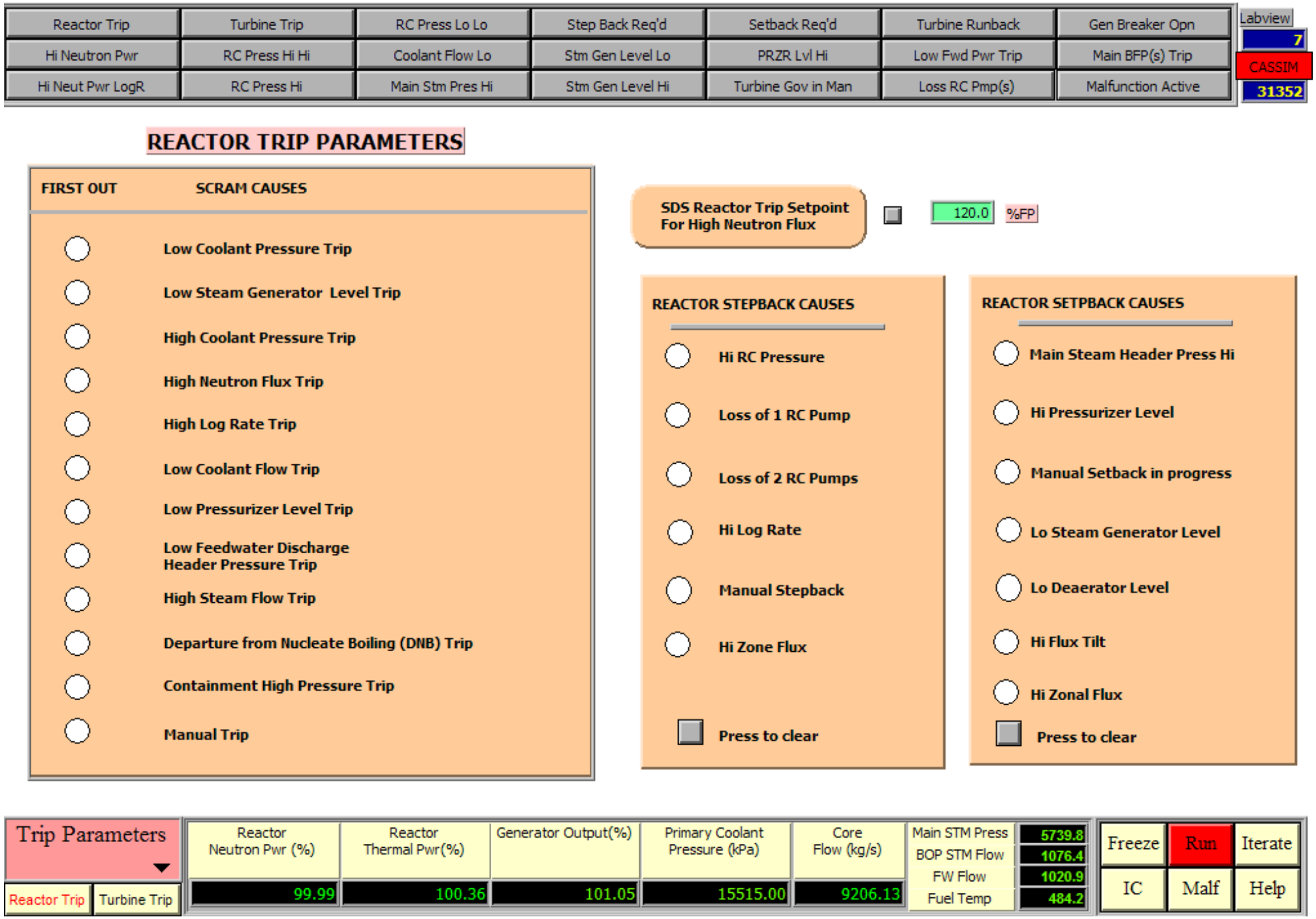
Passive PWR Simulator Display Screen (Core cooling)



Passive PWR Simulator Display Screen (Rods & Reactivity)



Passive PWR Simulator Display Screen



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]

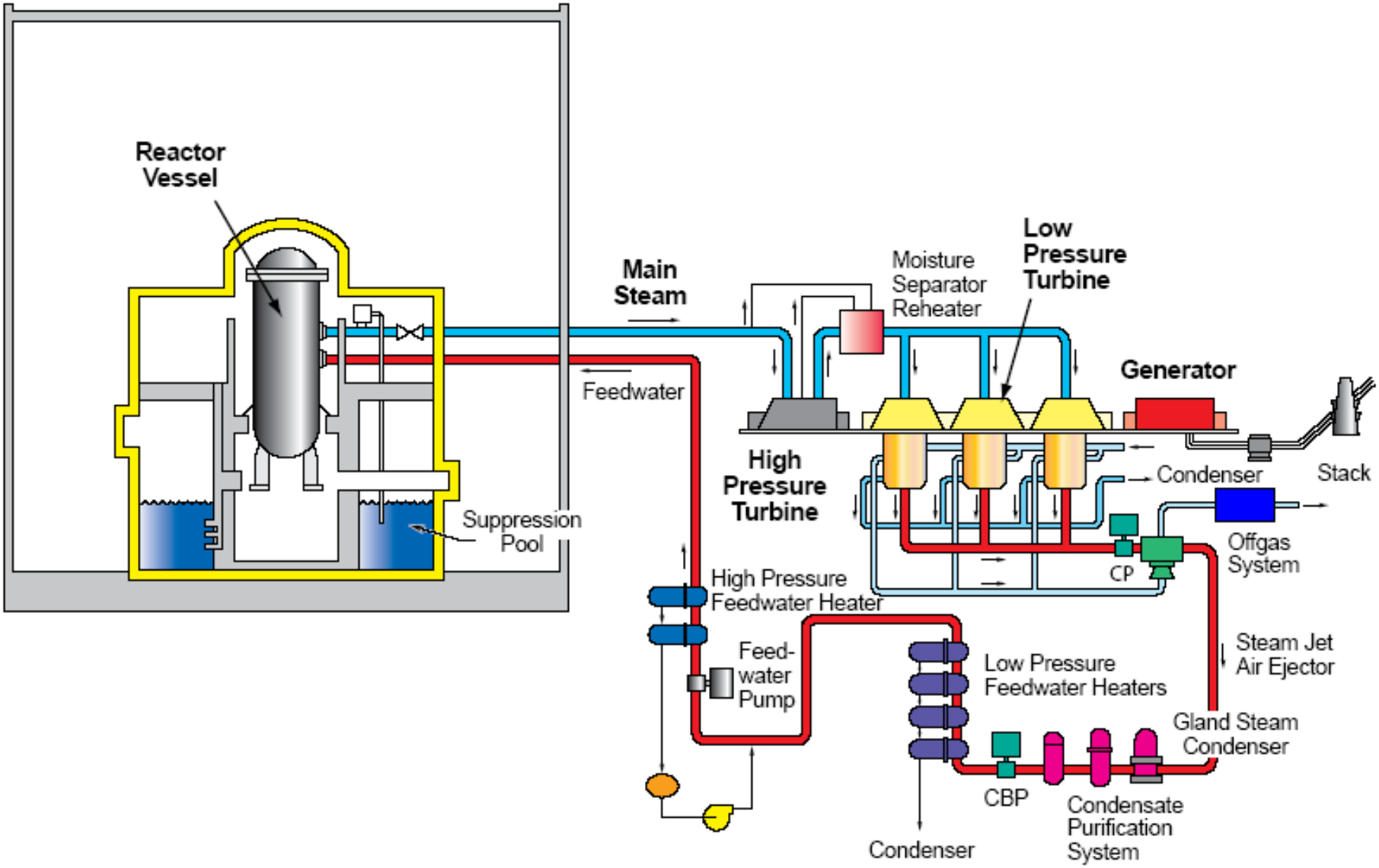
Malfunction 1

- 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

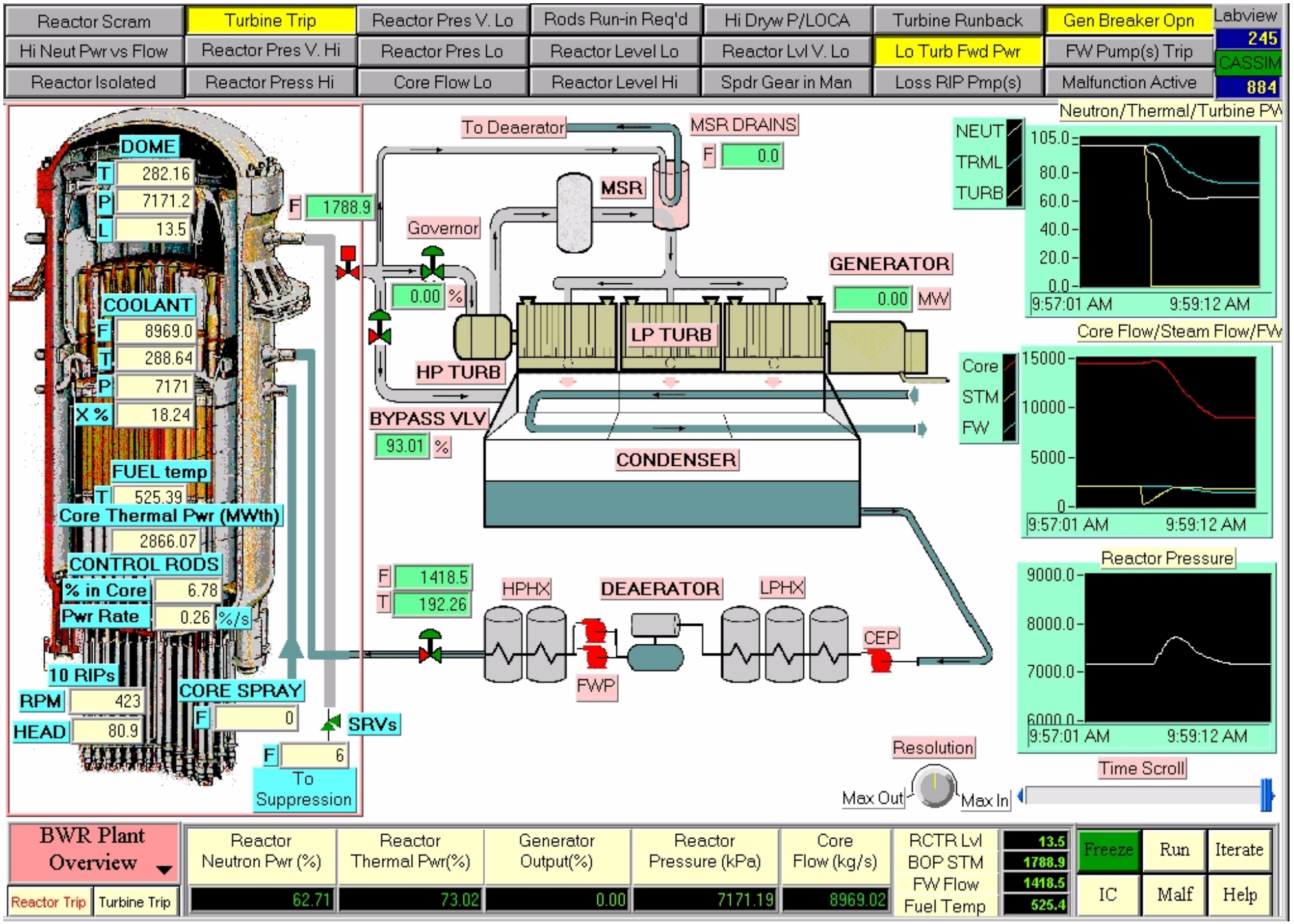
[BWR Simulator]

Malfunction 2

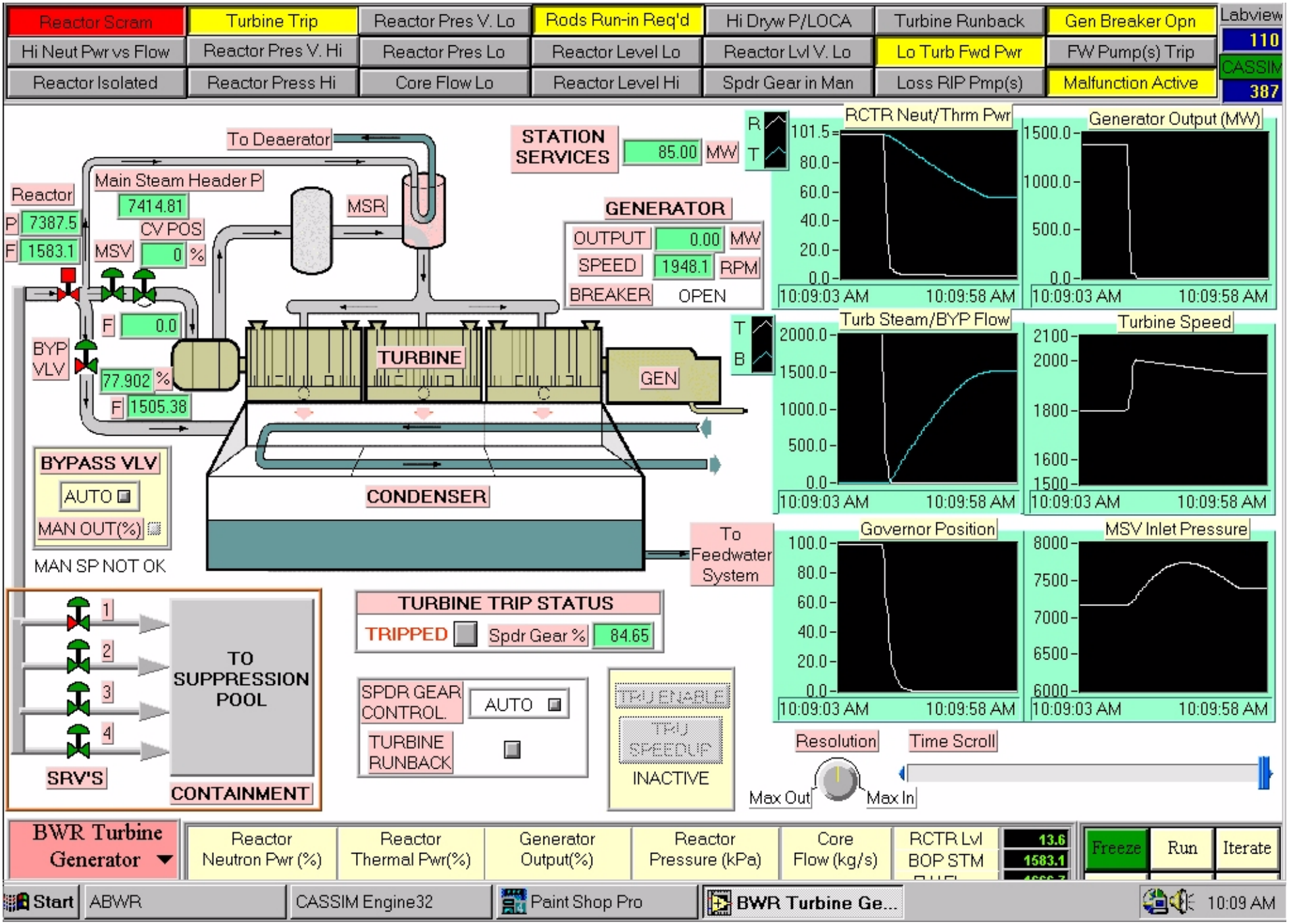
- Inadvertent withdrawal of one bank of rods
- Inadvertent insertion of one bank of rods
- Inadvertent reactor isolation
- Loss of feedwater heating
- Power loss to three reactor internal pumps
- Steam line break inside drywell
- Feedwater line break inside drywell
- Reactor vessel bottom break - 3000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



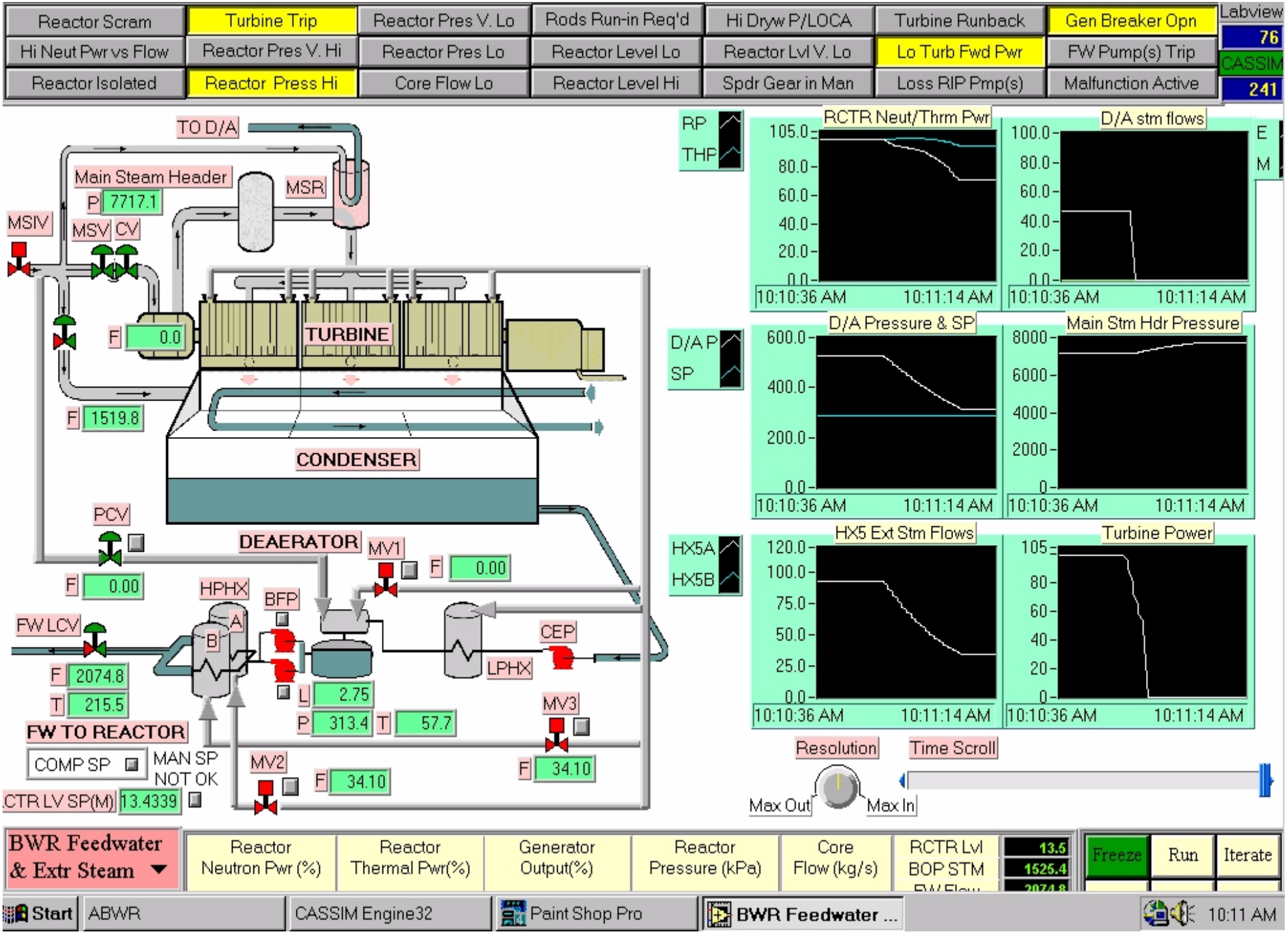
Active BWR Plant (Overview)



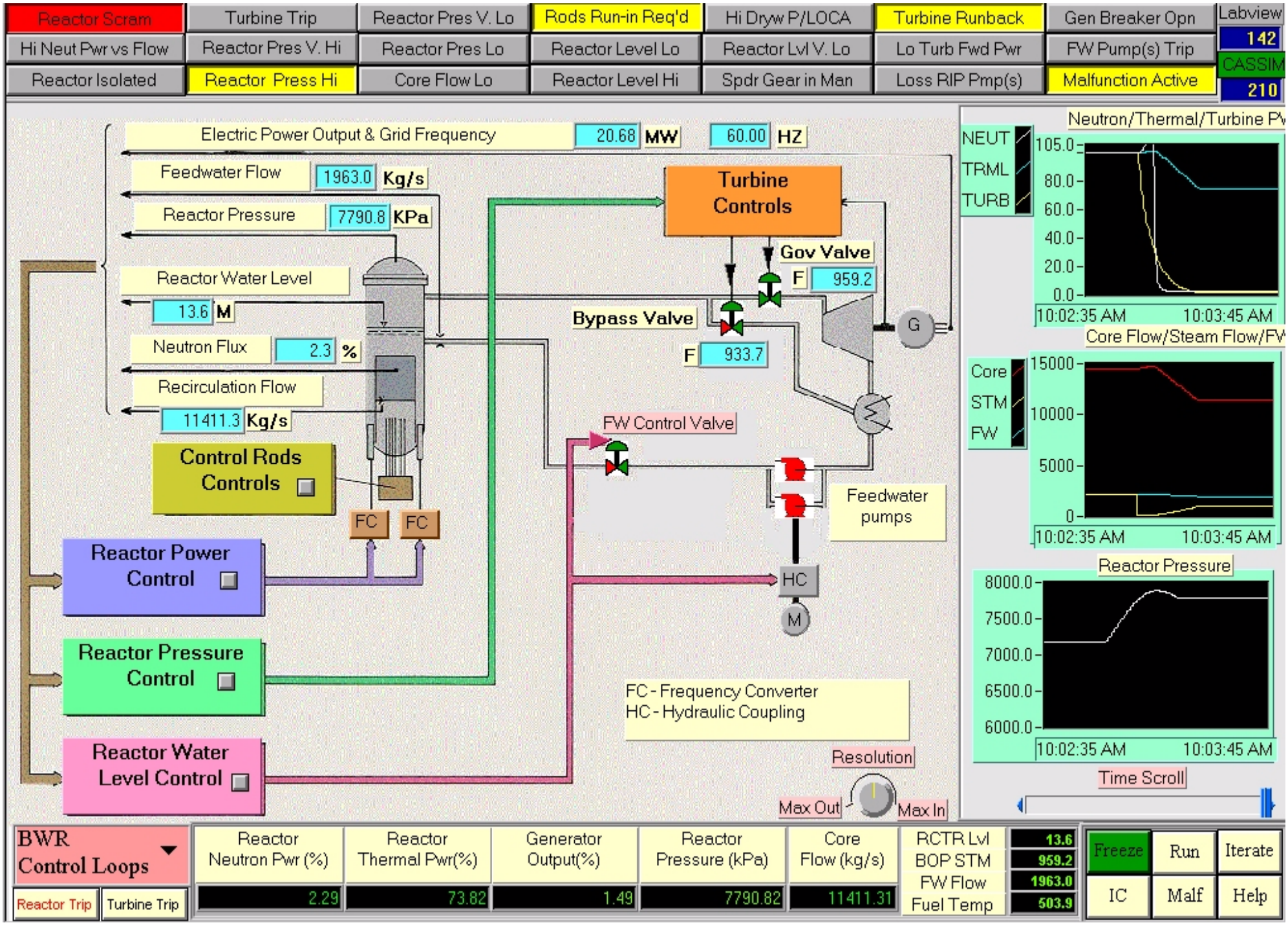
Active BWR Simulator Display Screen (Overview)



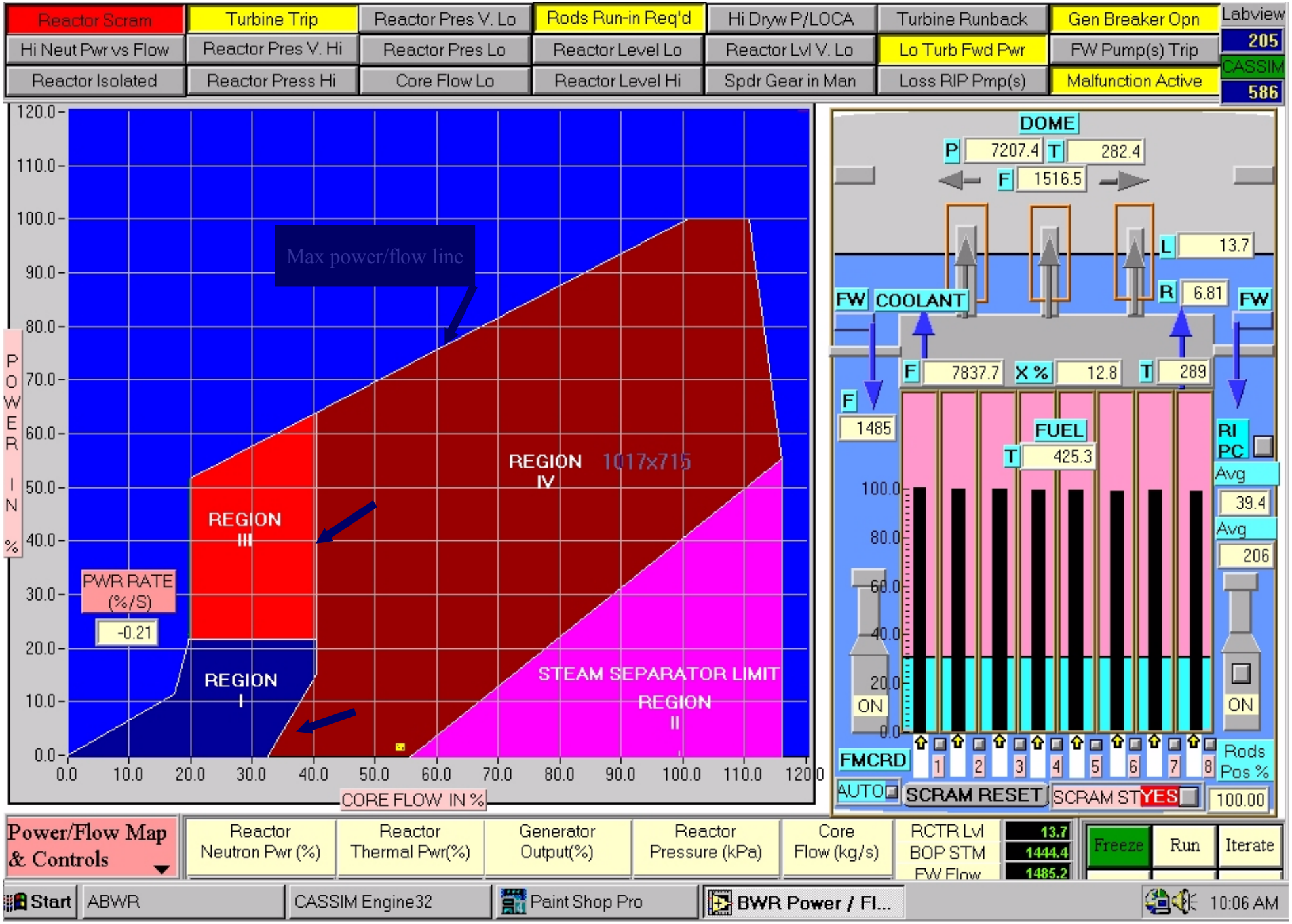
Active BWR Simulator Display Screen (Turbine Generator)



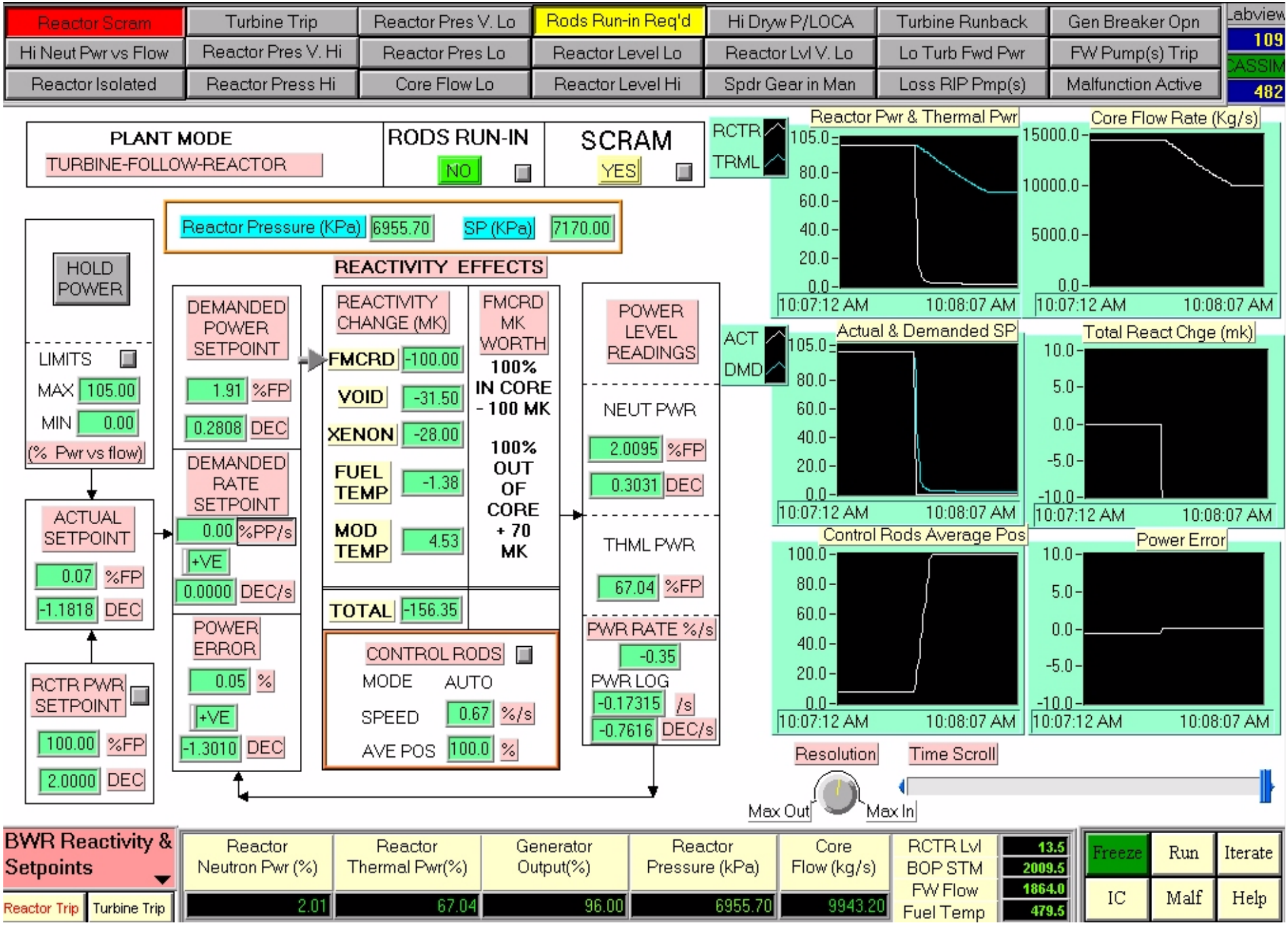
Active BWR Simulator Display Screen (Feedwater & Ext steam)



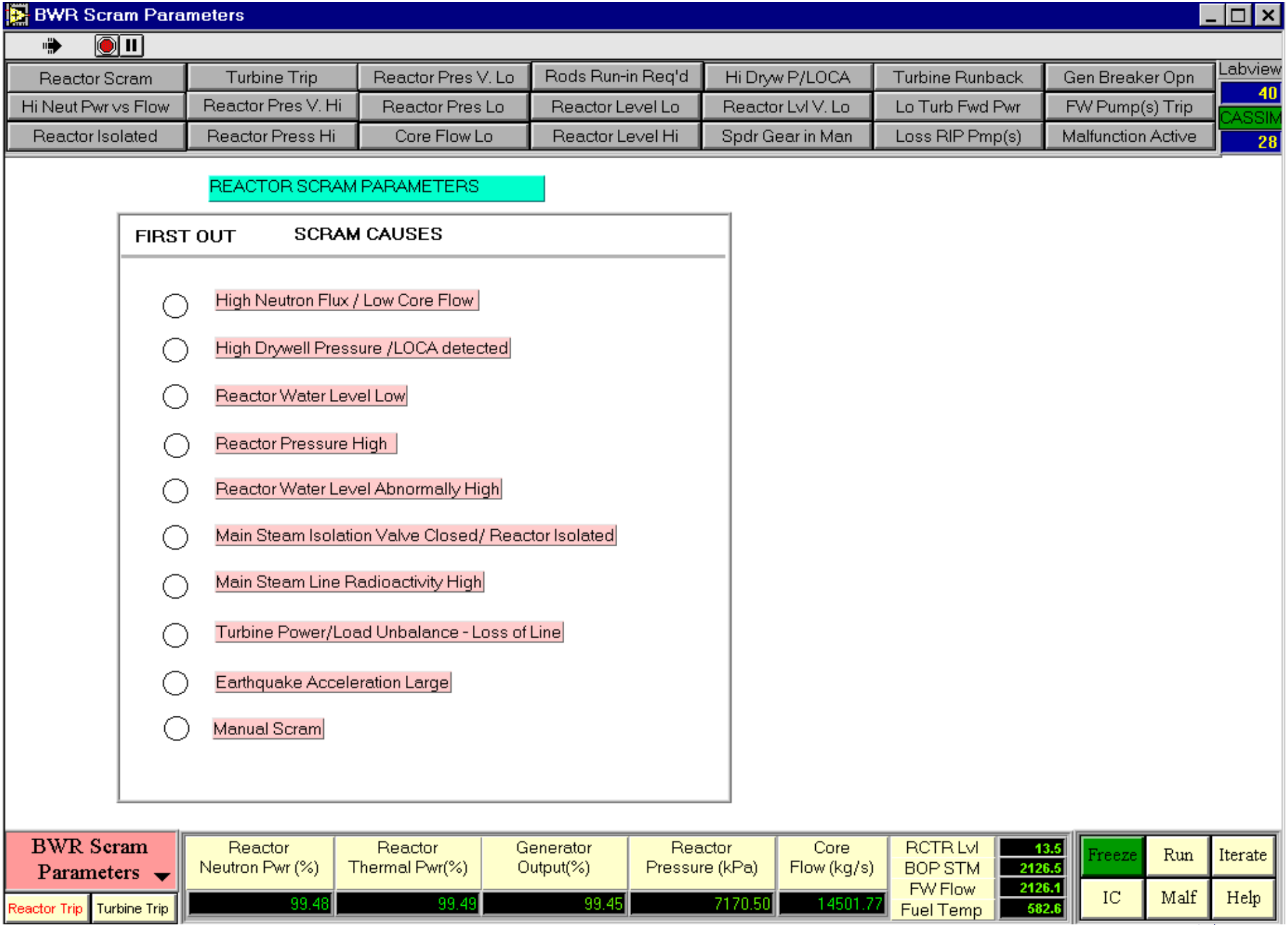
Active BWR Simulator Display Screen (Control Loops)



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



Active BWR Simulator Display Screen (Reactivity & Setpoints)



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

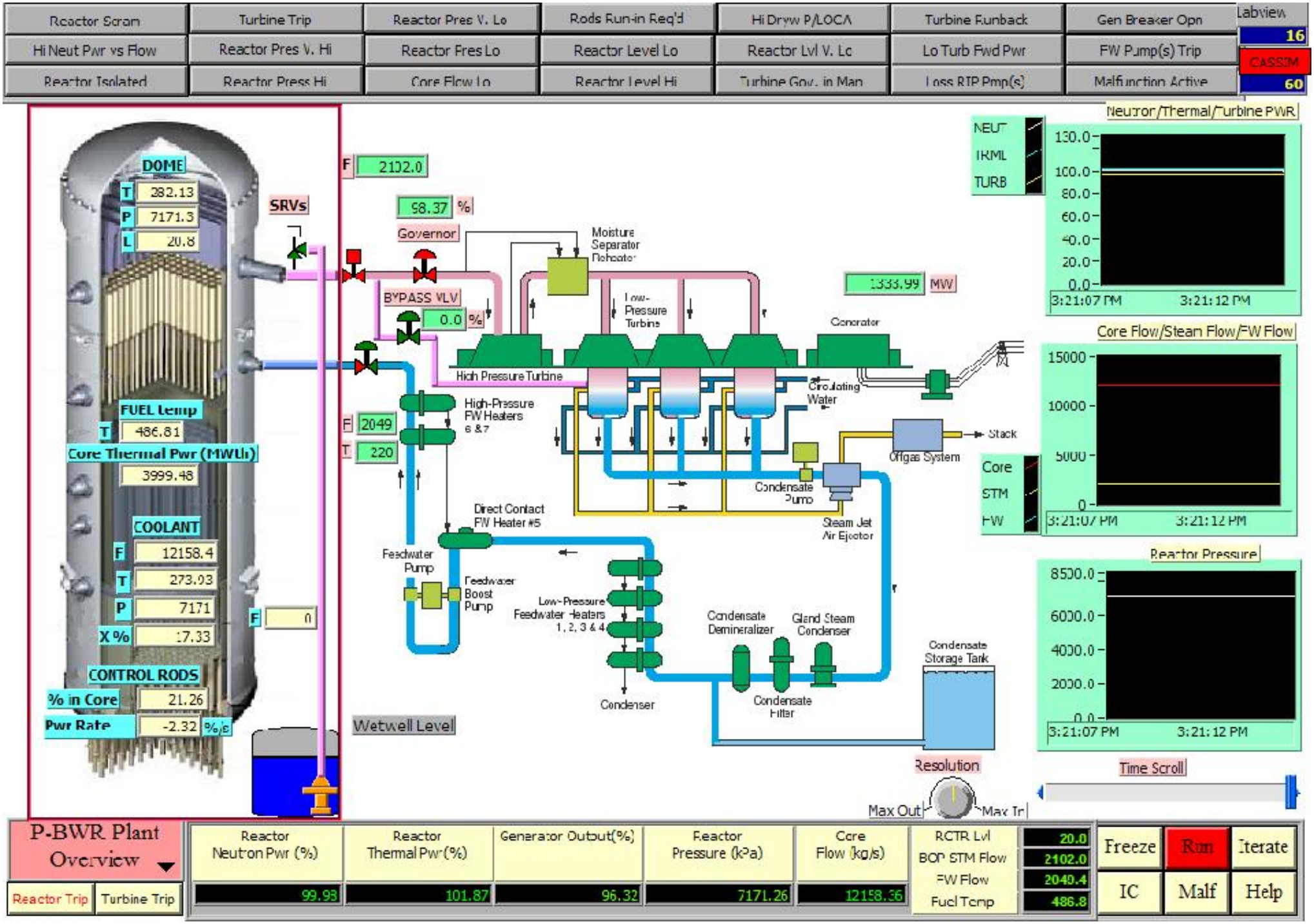
- Power maneuver: 10% power reduction and return to full power
- Reduction to 0% full power and back to 100% full power
- Turbine trip and recovery
- Reactor scram and recovery
- Reactor Shutdown Cooling
- Reactor Startup and Warmup

[Advanced BWR Simulator]
Malfunction 1

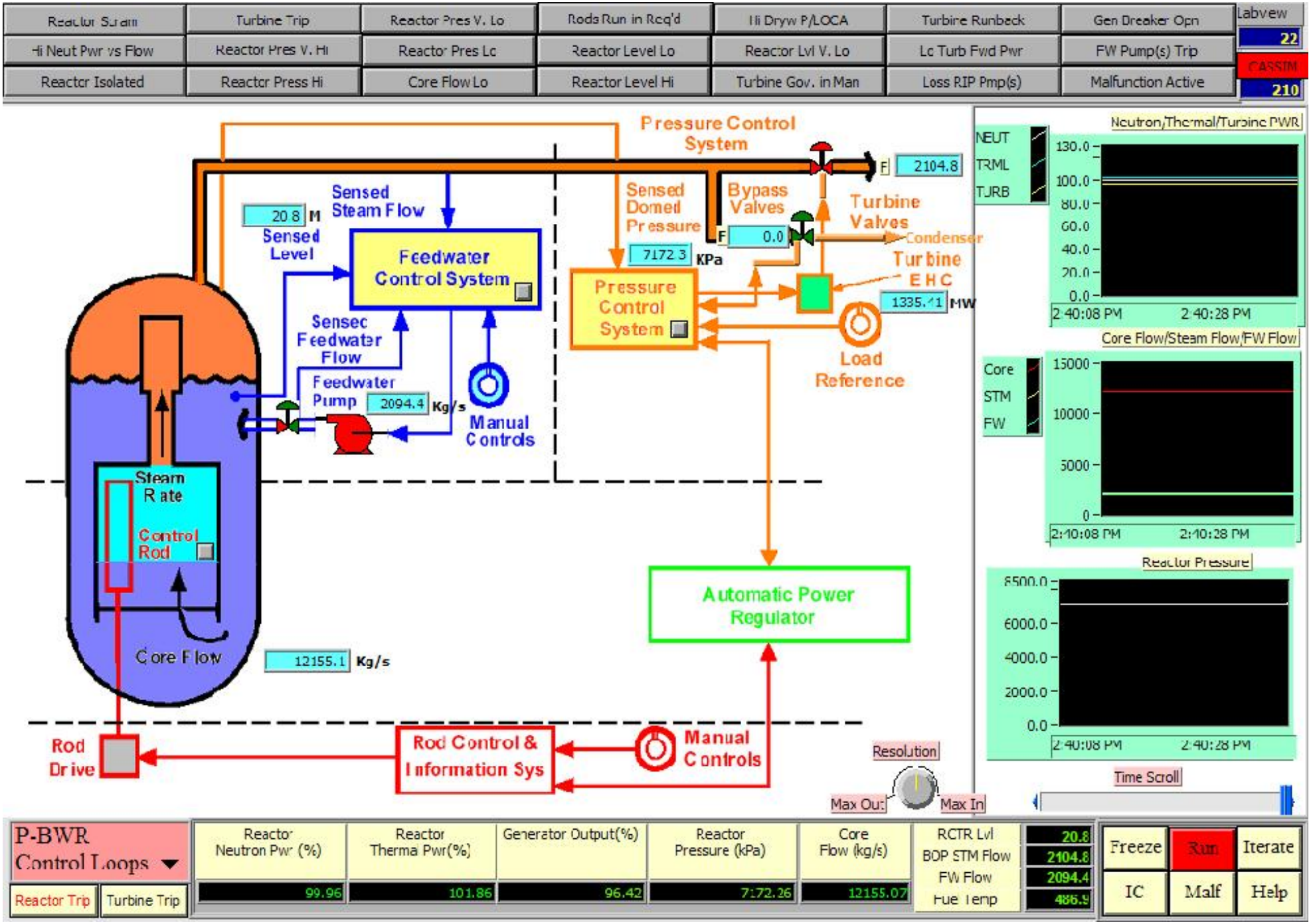
- Loss of feedwater : both FW pumps trip
- Increasing/Decreasing core flow due to flow control failure
- Increasing/Decreasing steam flow from dome due to pressure control failure
- TBN throttle PT fails low
- Safety relief valve (SRV) on one main steam line fails open
- Feedwater level control valve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

[Advanced BWR Simulator]
Malfunction 2

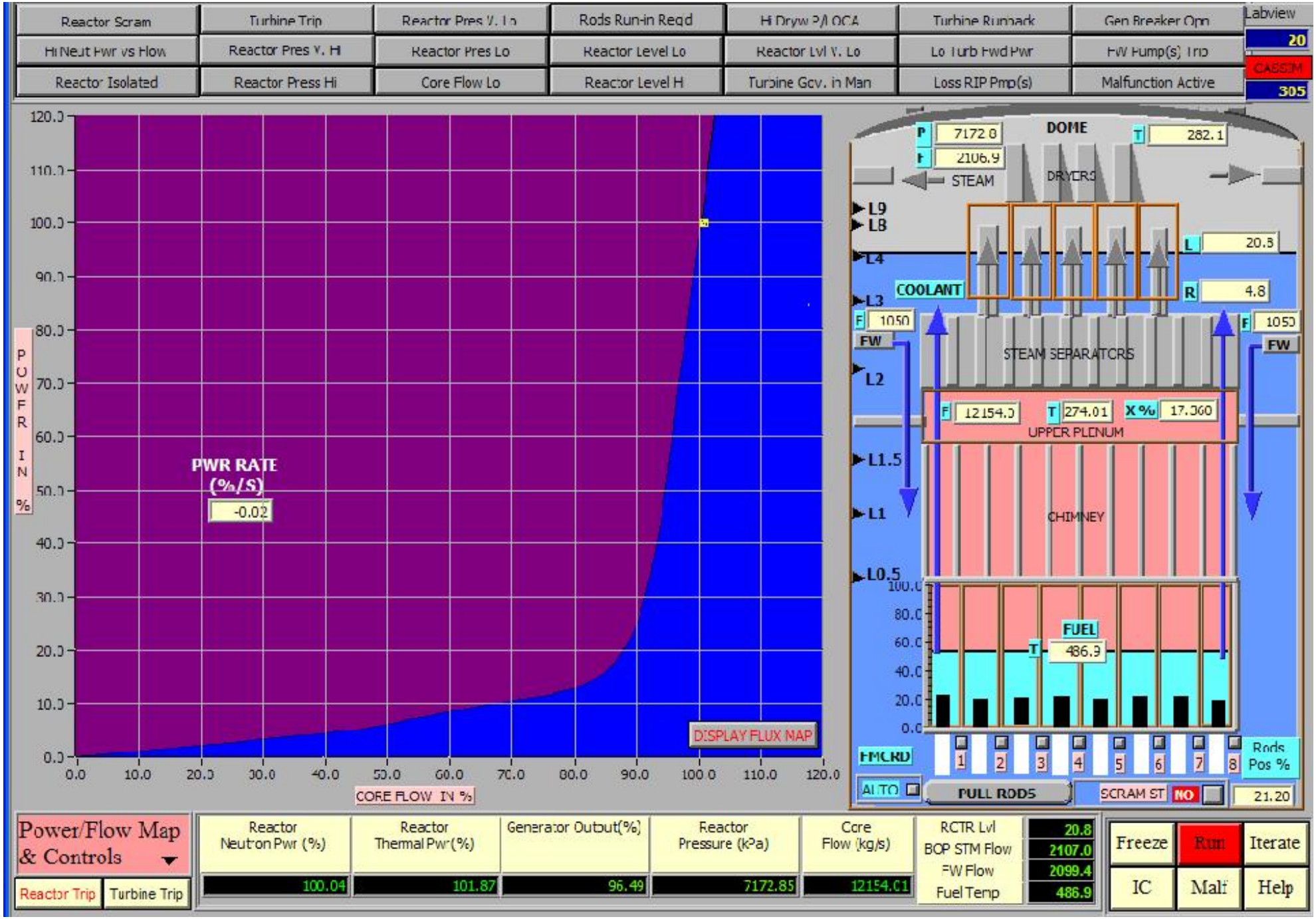
- Inadvertent withdrawal of one bank of rods
- Inadvertent insertion of one bank of rods
- Inadvertent reactor isolation
- Loss of feedwater heating
- Power loss to three reactor internal pumps
- Steam line break inside drywell
- Feedwater line break inside drywell
- Reactor vessel bottom break - 3000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



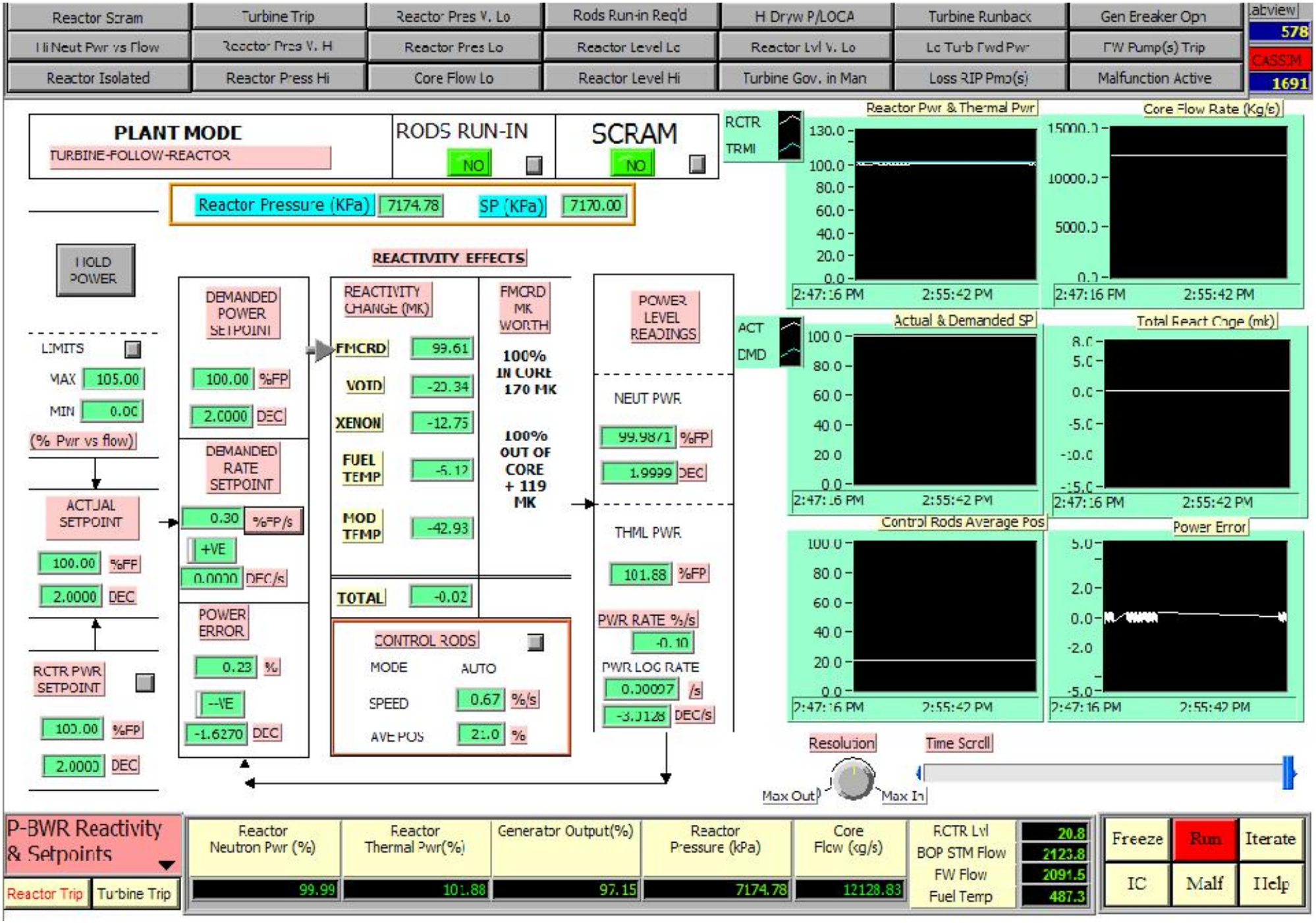
Passive BWR Simulator (Overview)



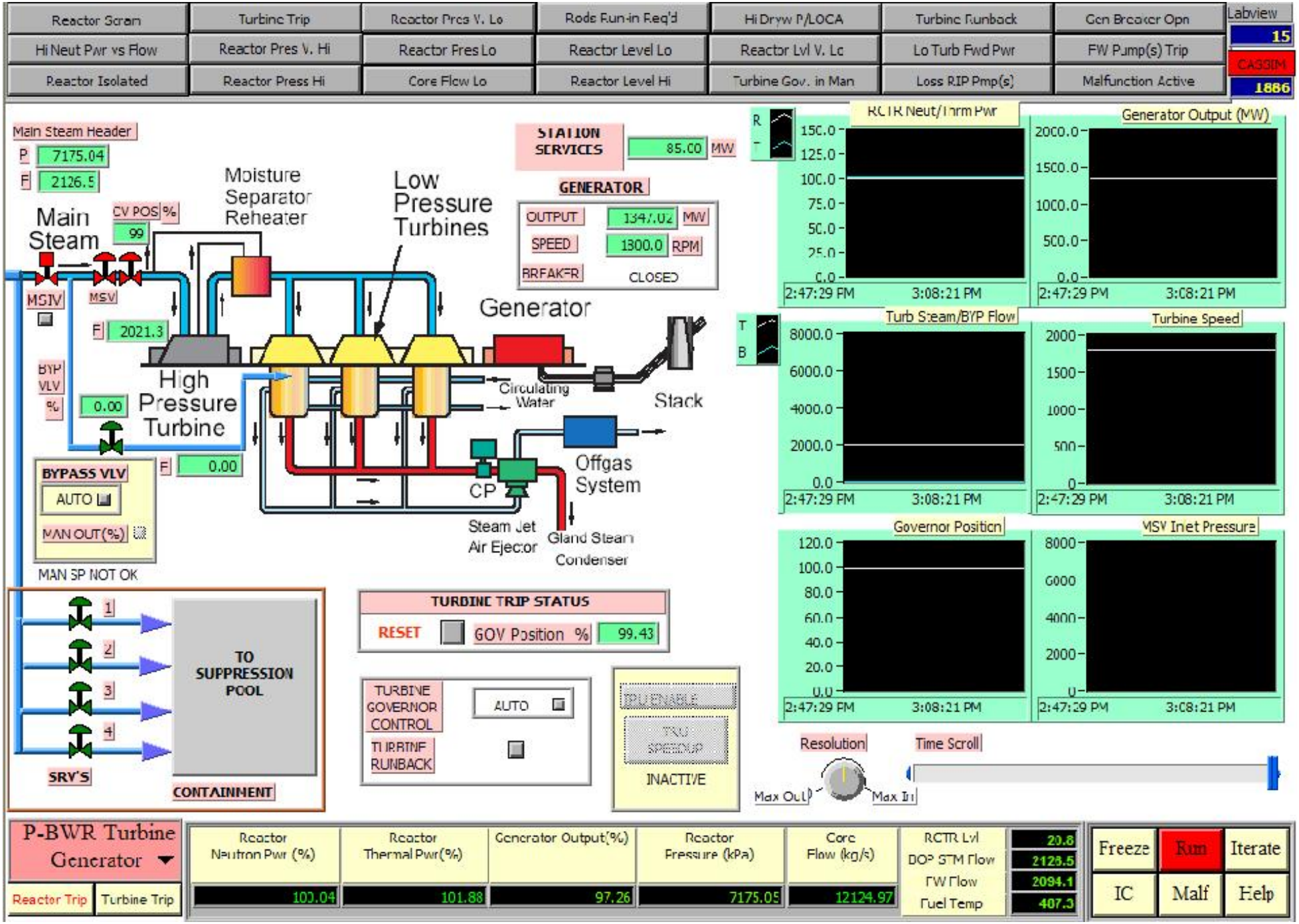
Passive BWR Simulator (Control loops)



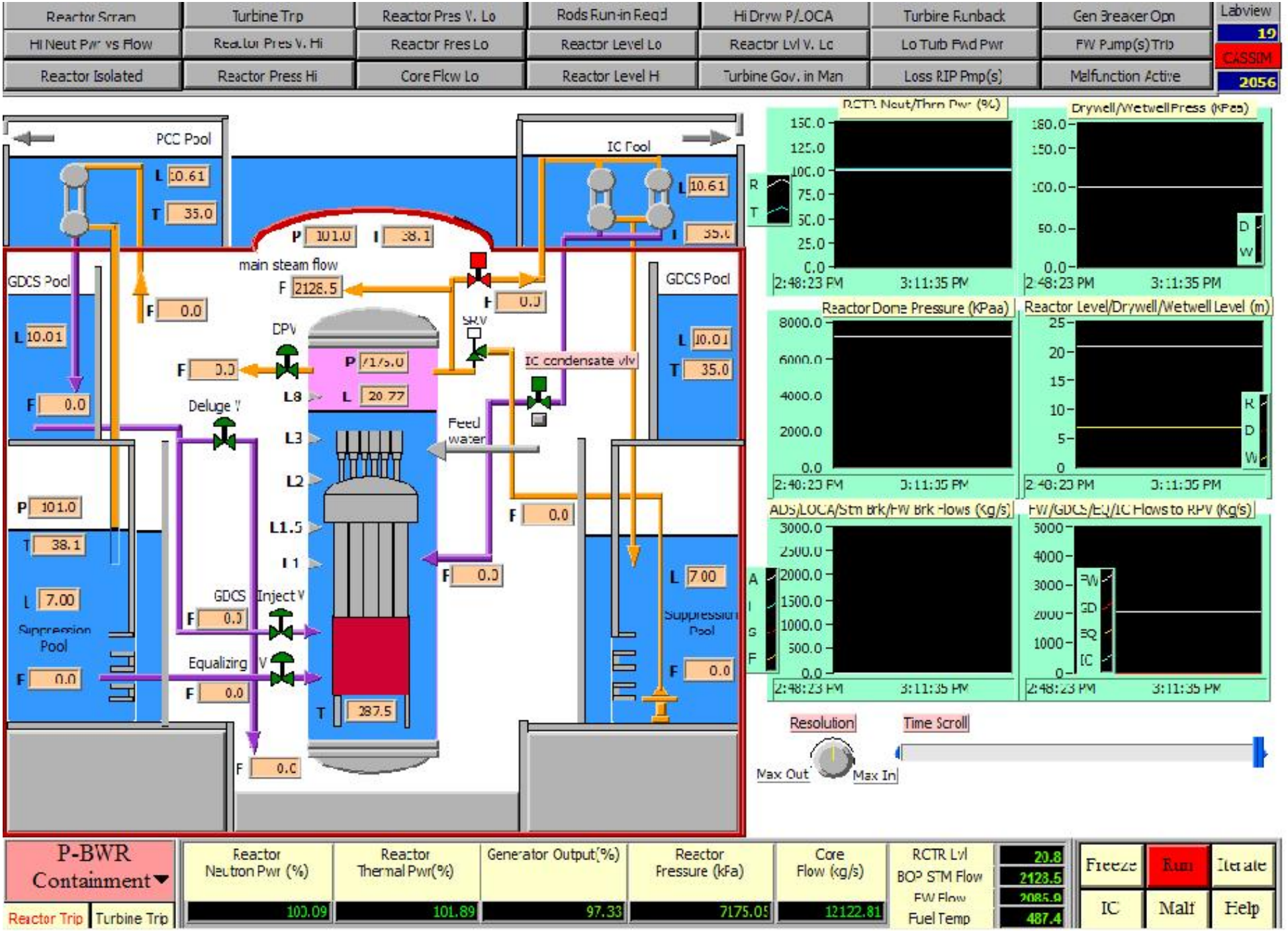
Passive BWR Simulator (Power/Flow map & controls)



Passive BWR Simulator[46] (Reactivity & Setpoints)



Passive BWR Simulator (Turbine Generator)



Passive BWR Simulator (Containment)

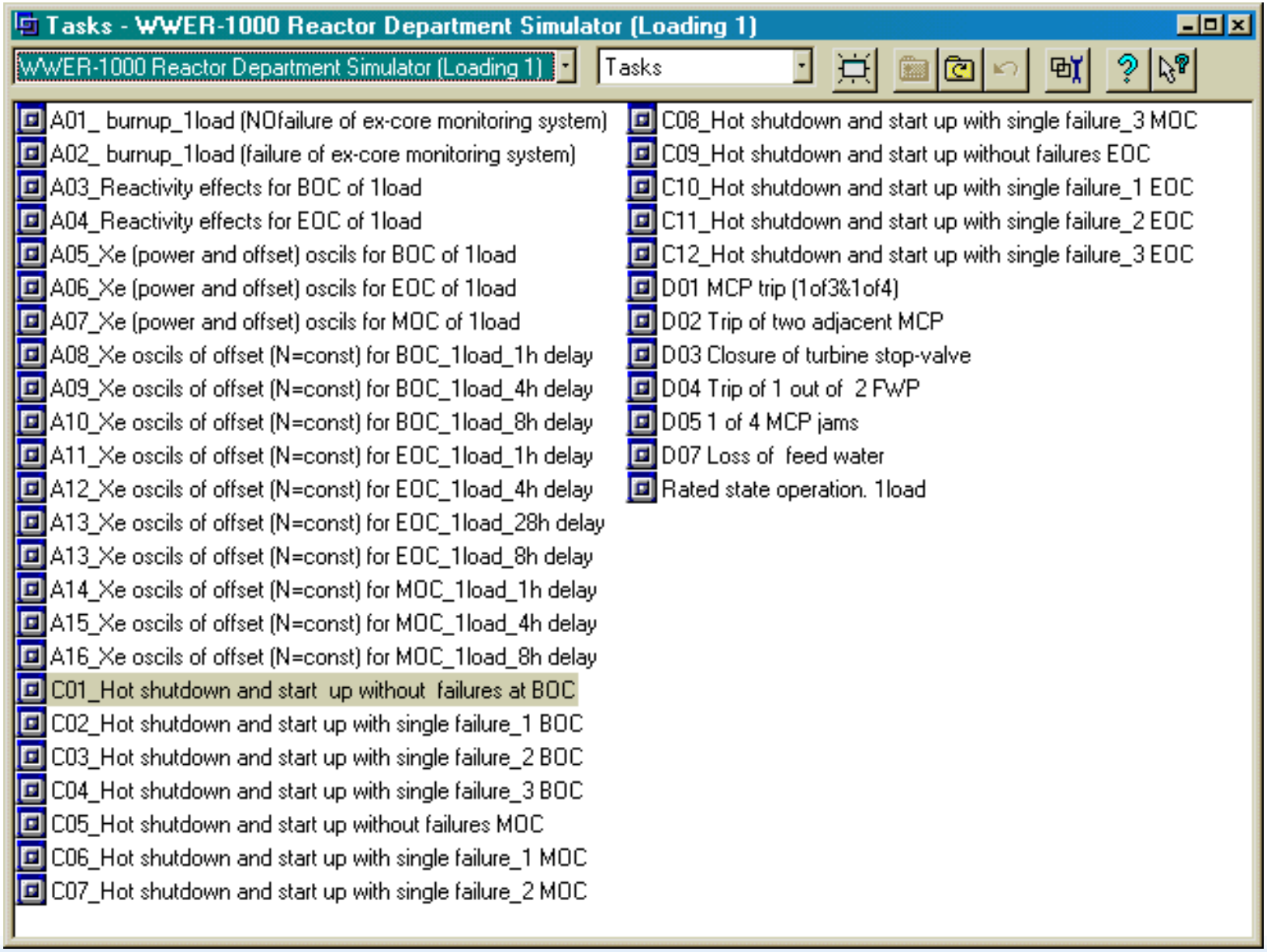
[WWER-1000 Simulator]

- 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.
- Water Water Energy Reactor 1000 MWe
- Manual updated in 2009

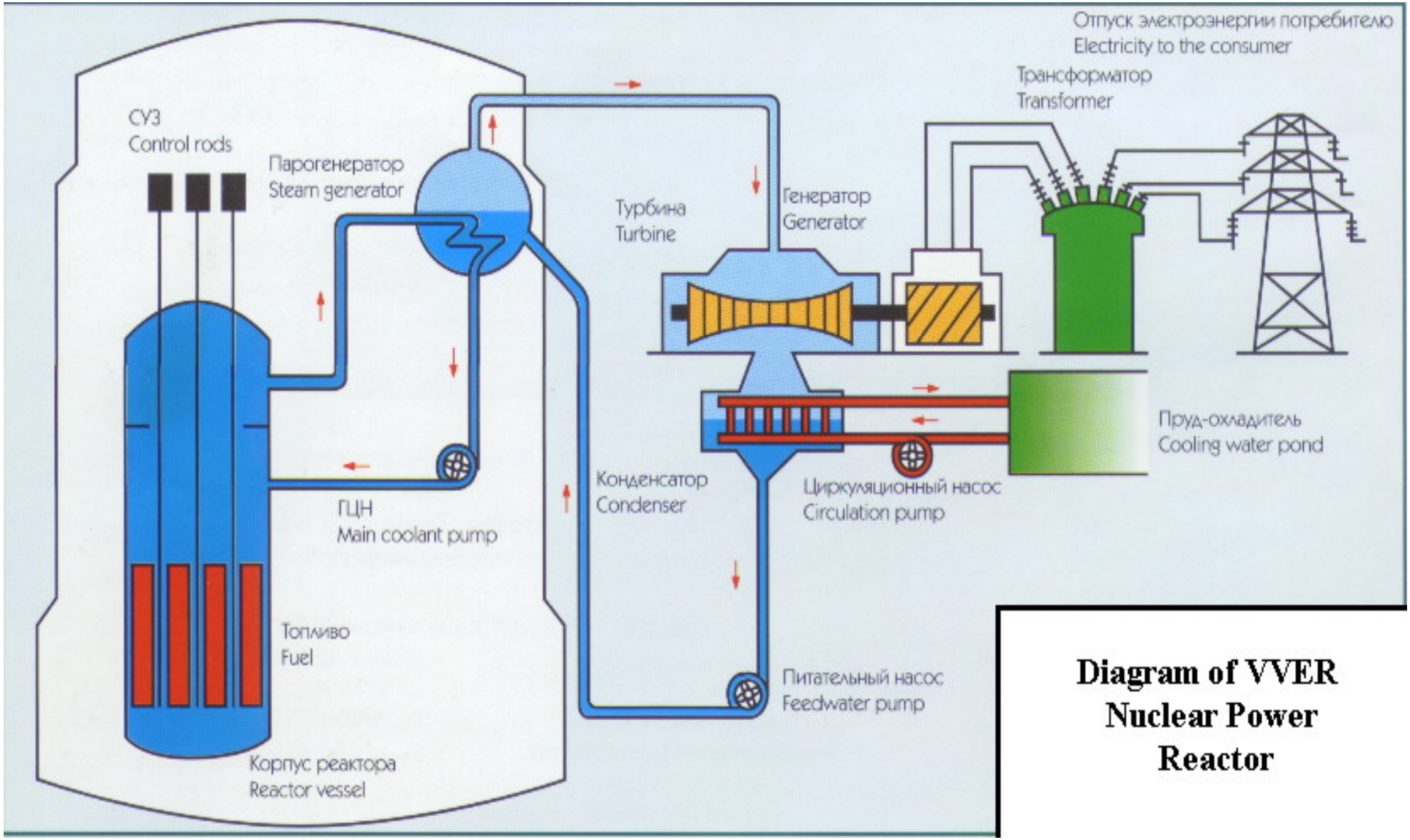
[WWER-1000 Simulator]

- Ten display pages are available in the Simulator.
  - Reactivity control page (CPS),
  - Enunciator 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).

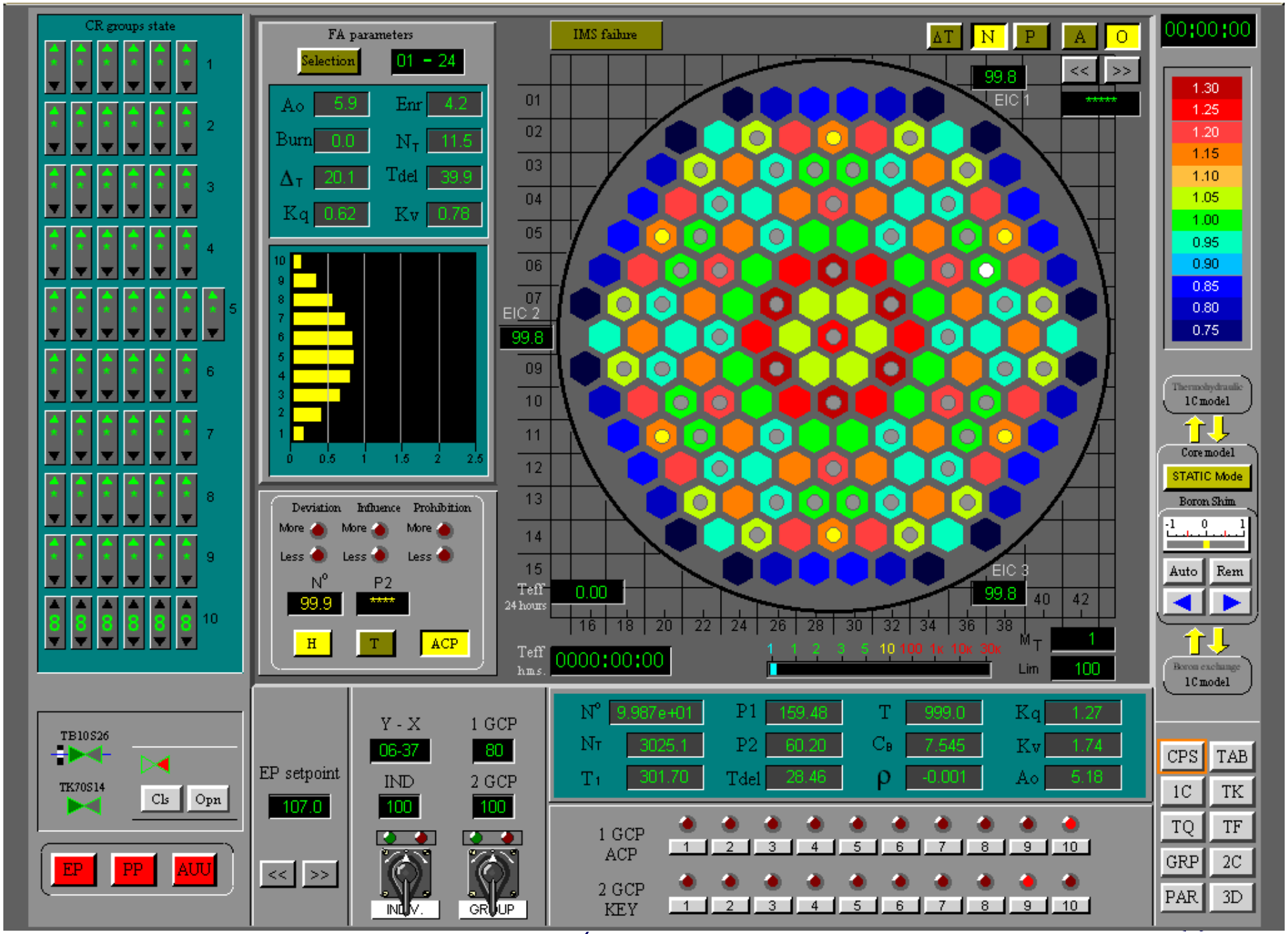
[WWER-1000 Simulator]



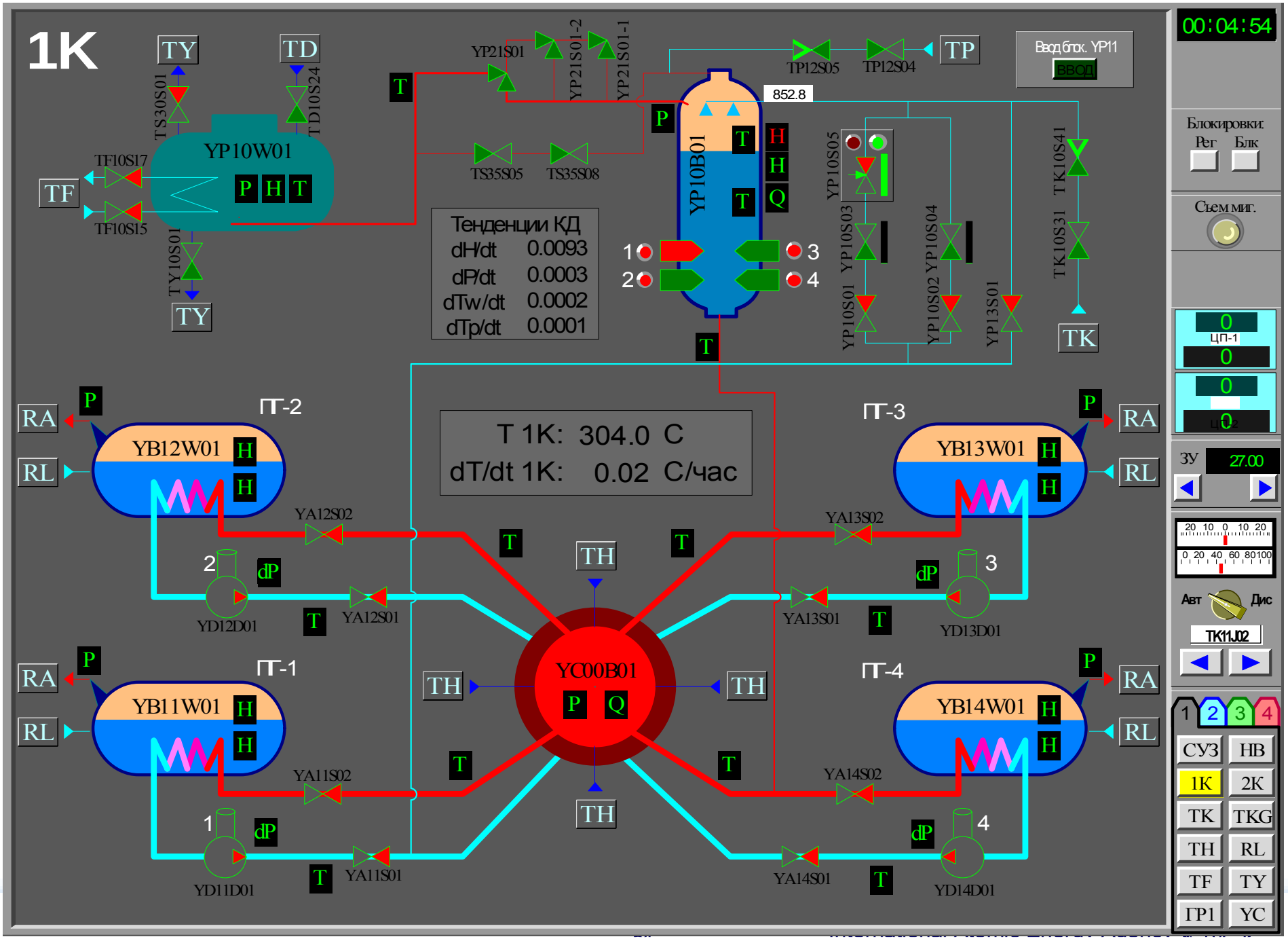
List of training tasks



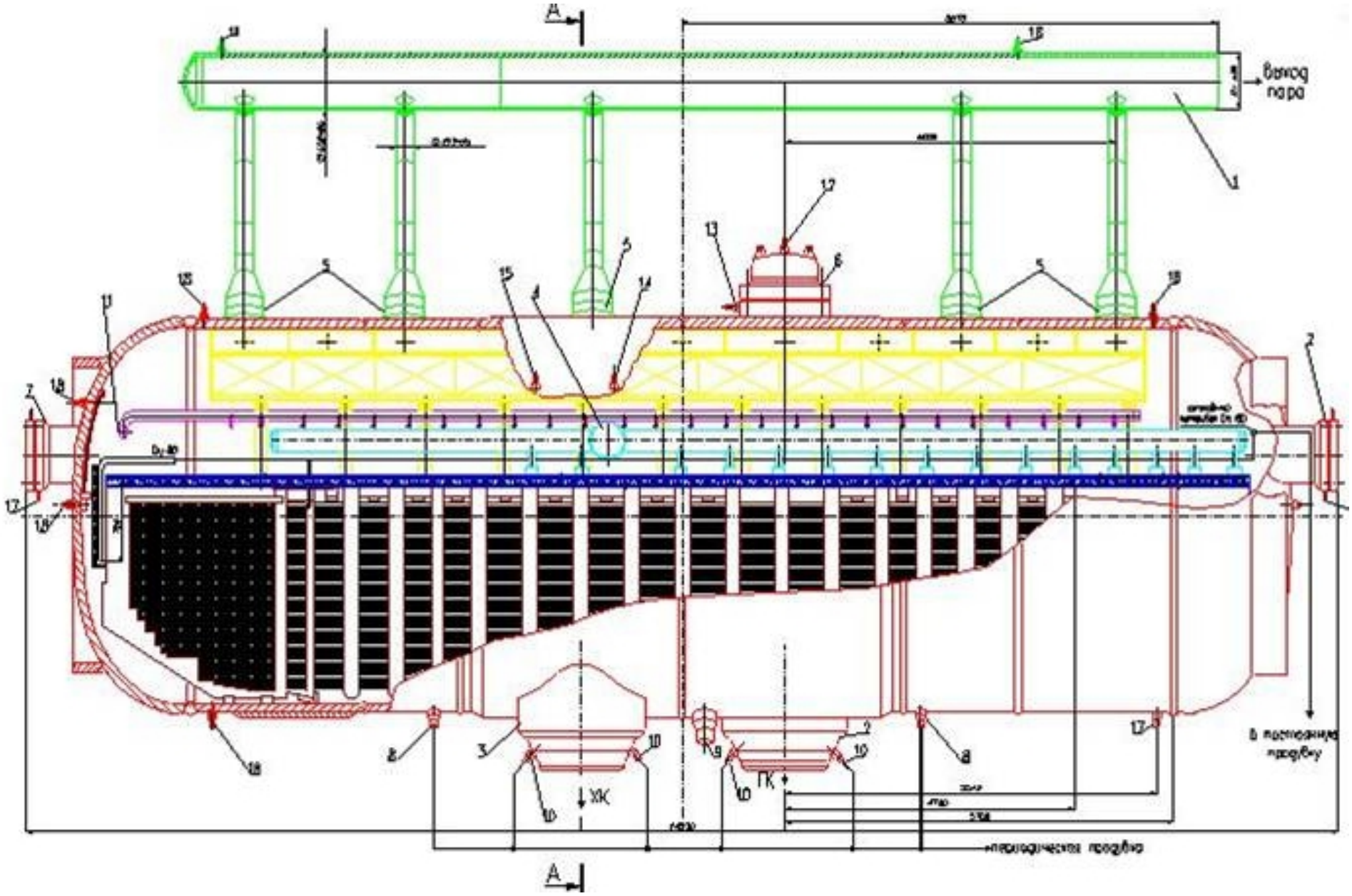
WWER-1000 NPP Diagram



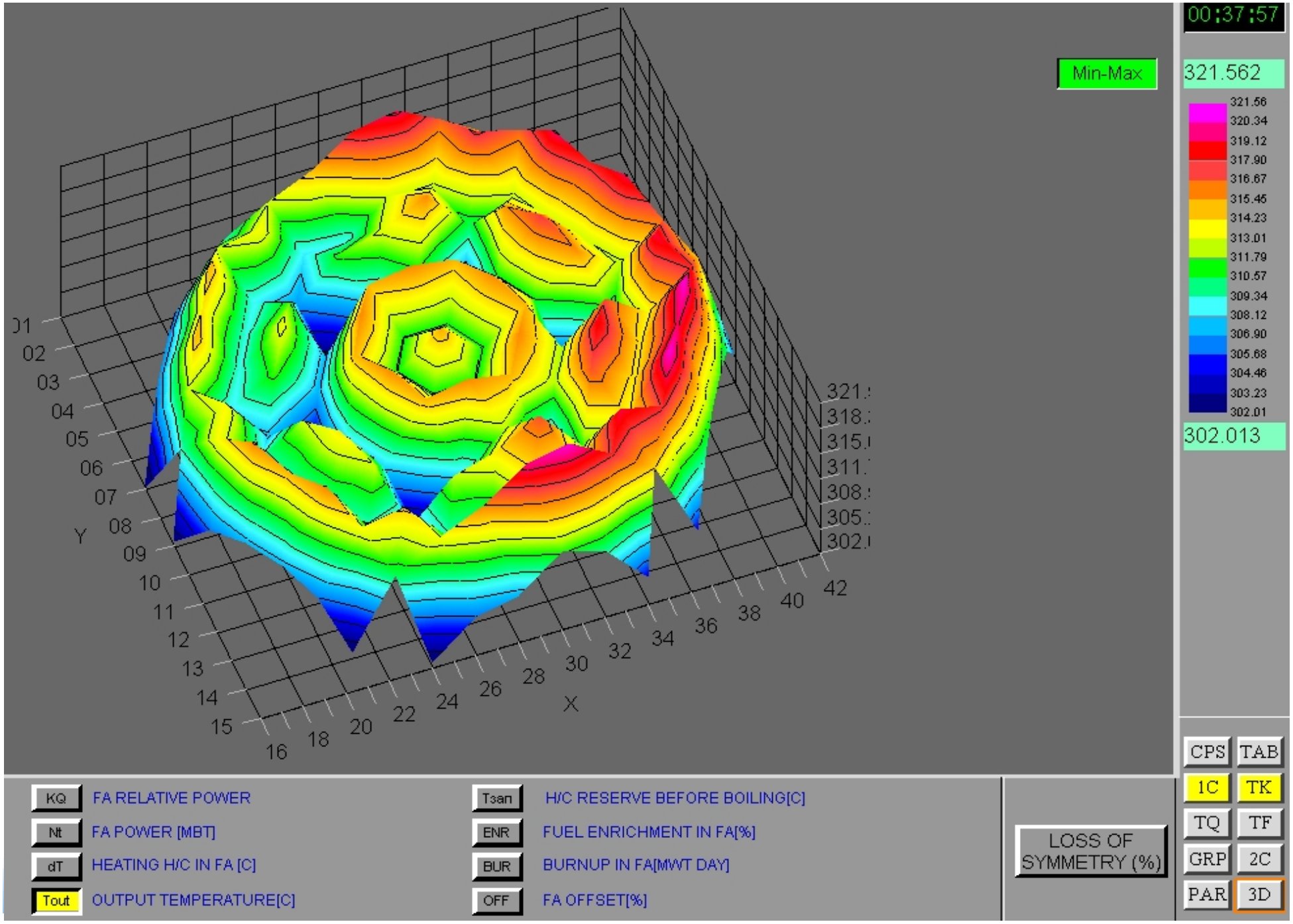
WWER-1000 Simulator (Control & Protection System)



WWER-1000 Simulator (Reactivity Control Display Screen)



WWER-1000 **General View of Steam Generator**



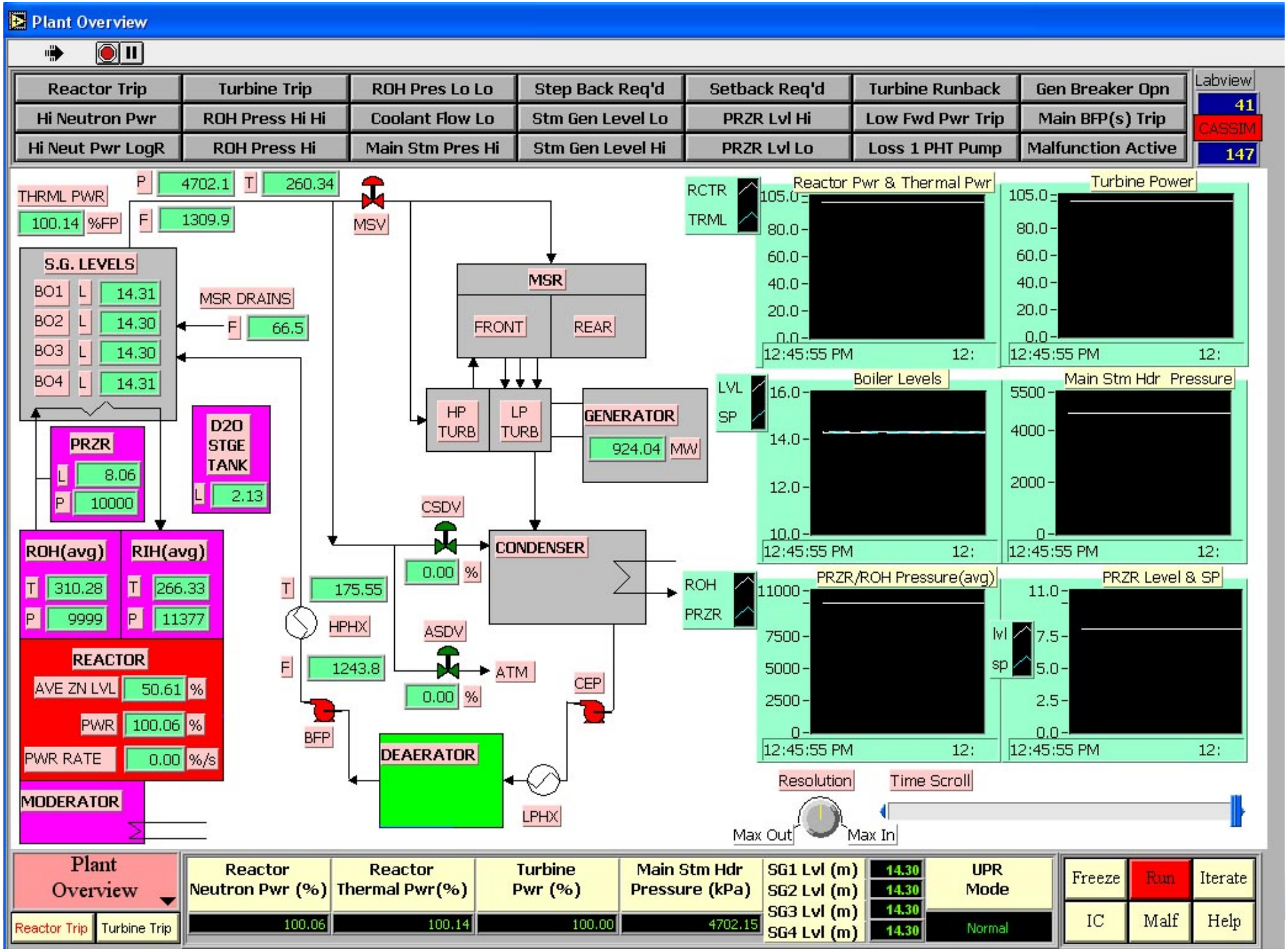
WWER-1000 3D Diagram (Core Output temperature)

[PHWR Simulator]

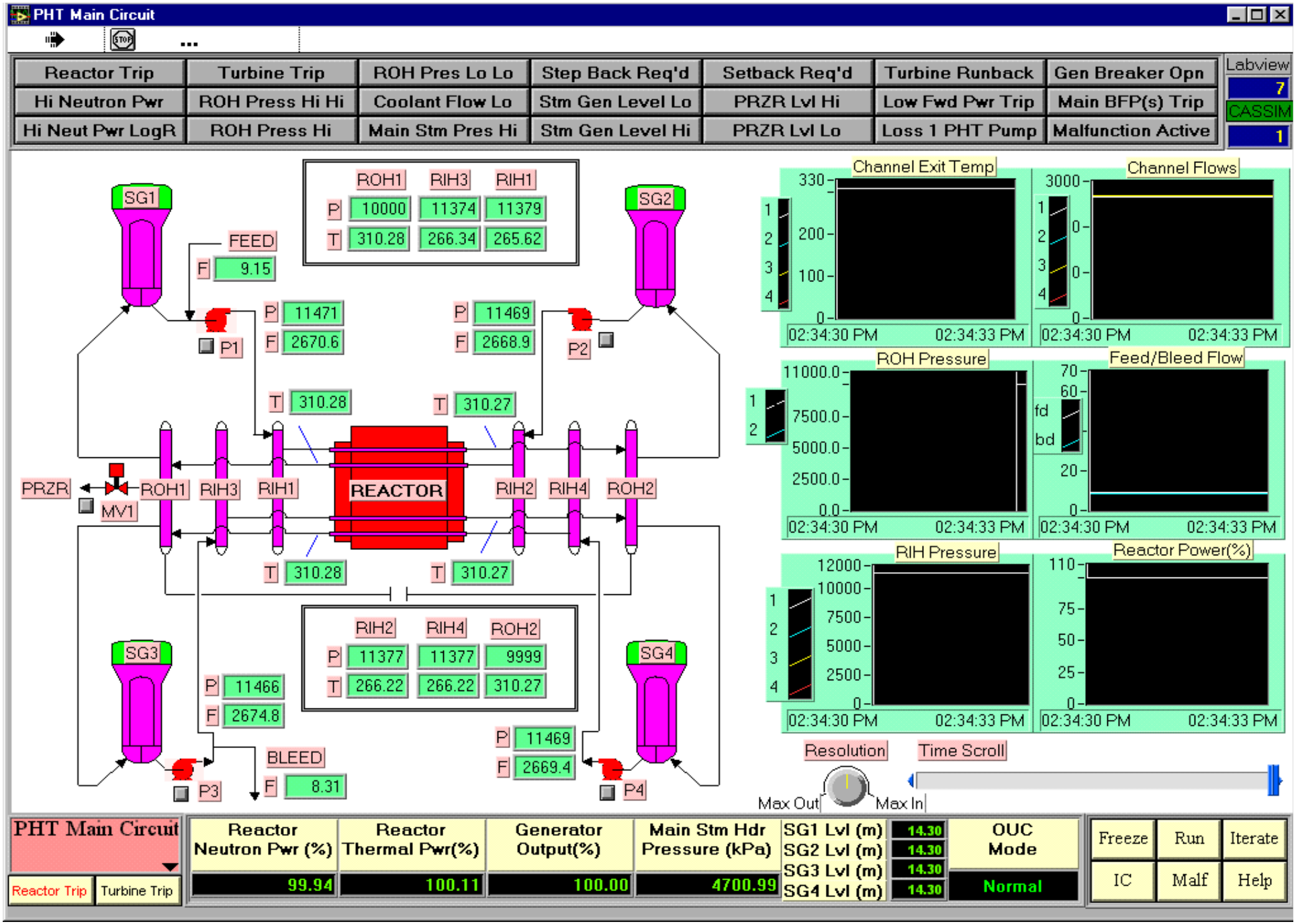
- Developed by Cassiopeia Technologies Inc.,
- Largely based on the CANDU-9 system, with a capacity of approximately 900 MW(e)

[PHWR Simulator]

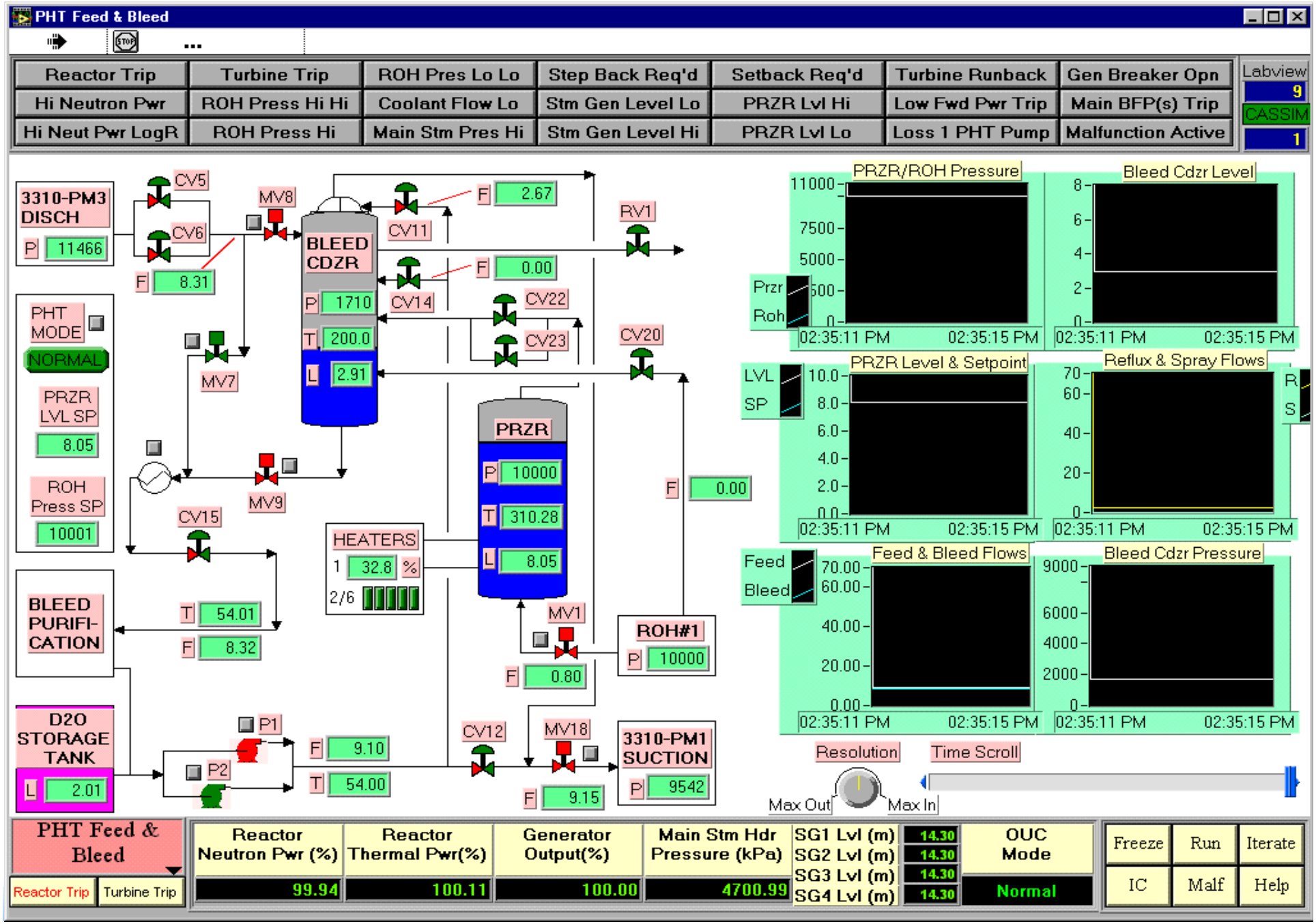
- Ten process screens that provide essential system parameters, along with dynamic trends:
  1. CANDU Overview
  2. Shutoff Rods
  3. PHT (Primary Heat Transport System)
  4. PHT Pressure/Inventory Control
  5. Boiler Feedwater
  6. Turbine Generator
  7. RRS/DPR (Reactor Regulation Sys / Demand Power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



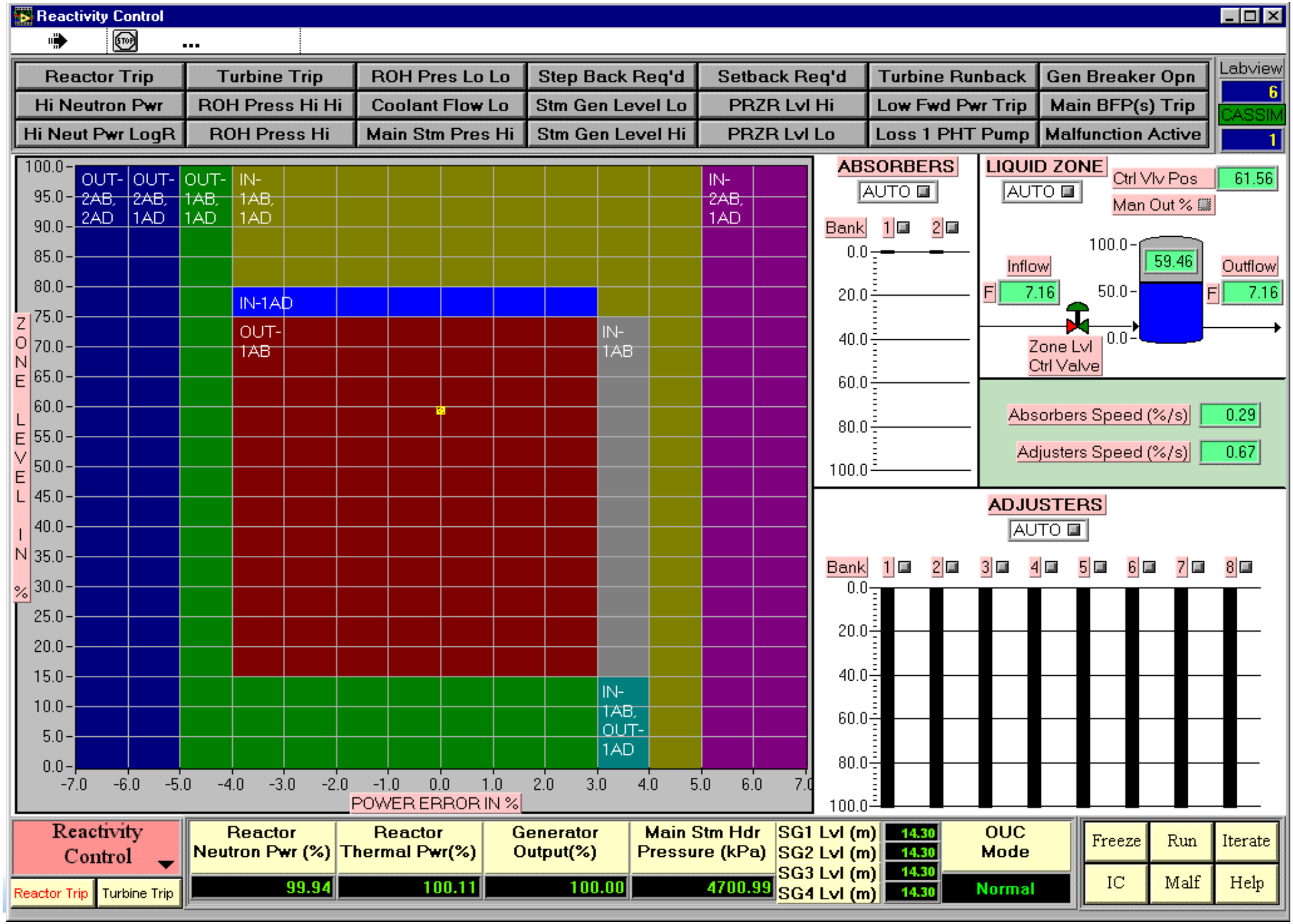
PHWR Simulator (Overview)



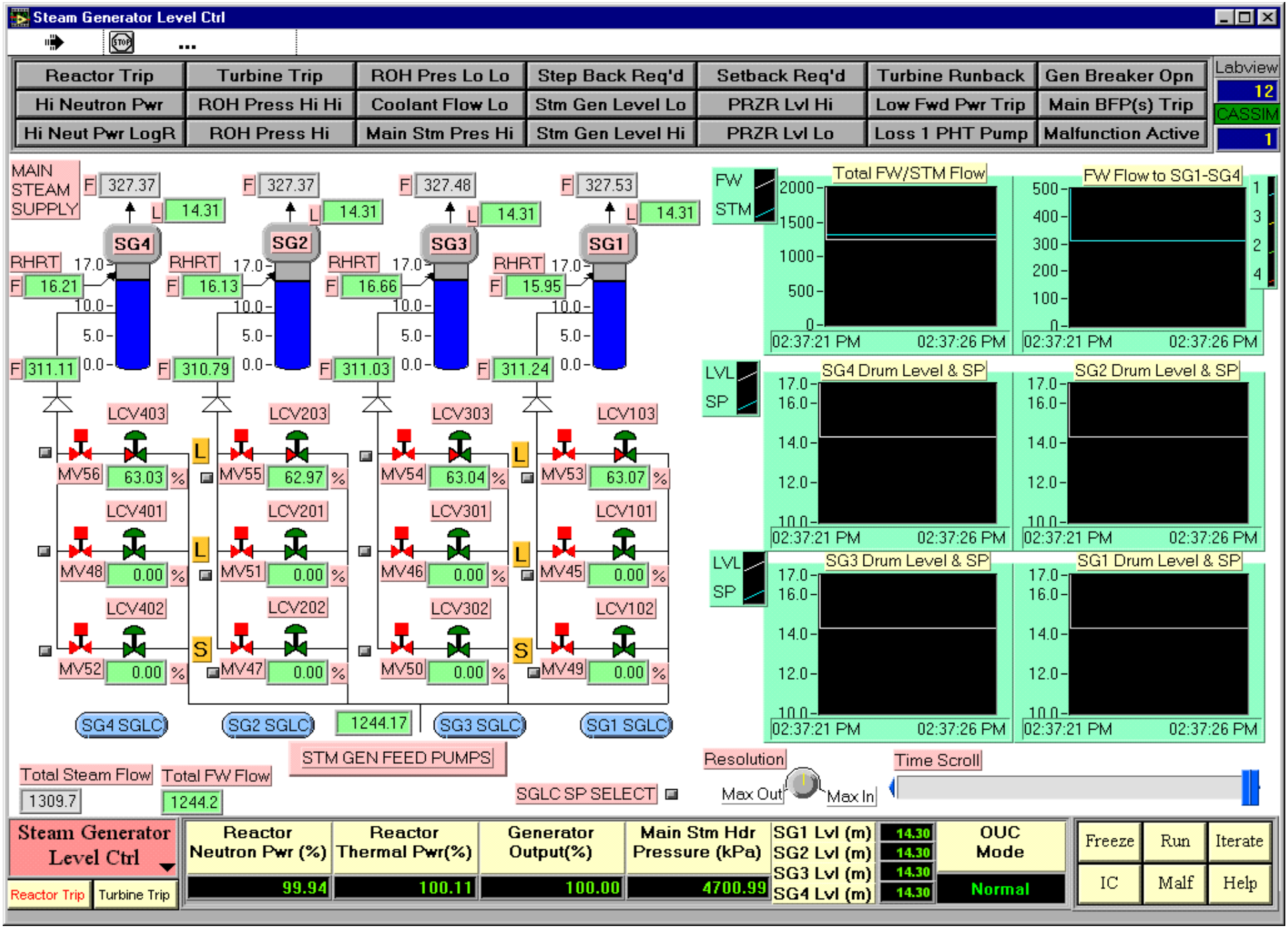
PHWR Simulator (PHT main circuit)



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

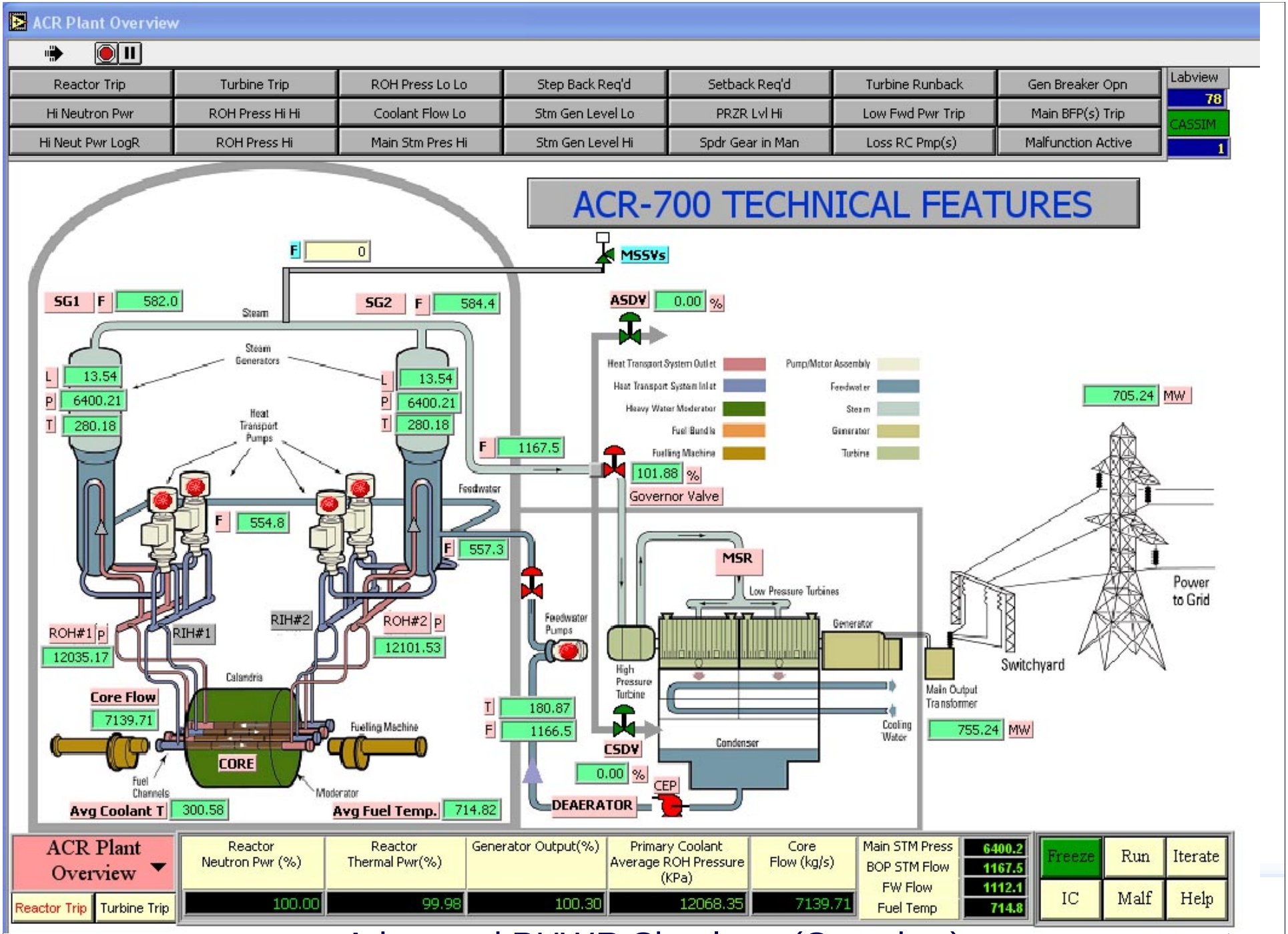
[Advanced PHWR Simulator]
ACR Basic operations & Transient recovery

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

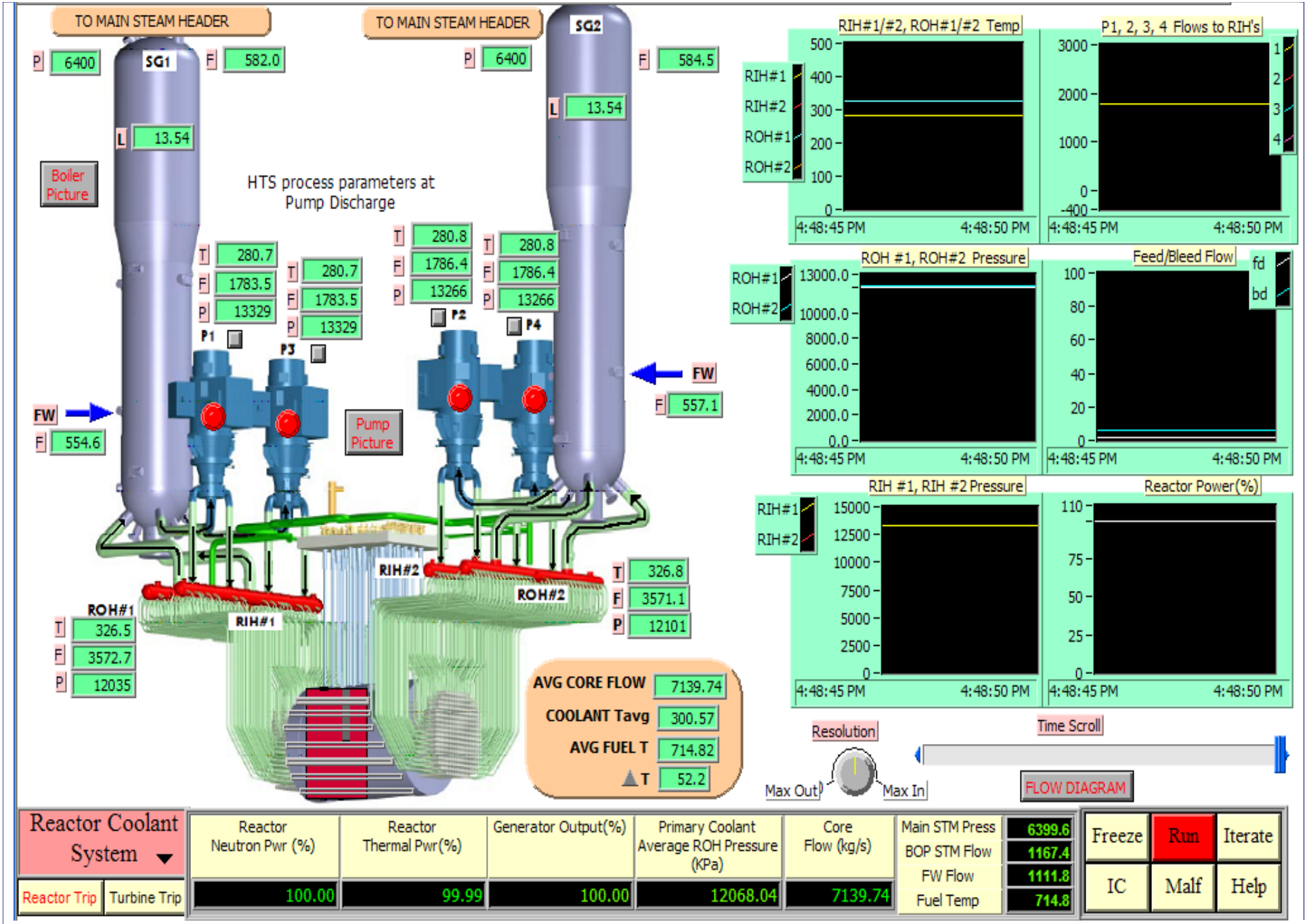
[Advanced PHWR Simulator]

ACR Malfunction Transient Events

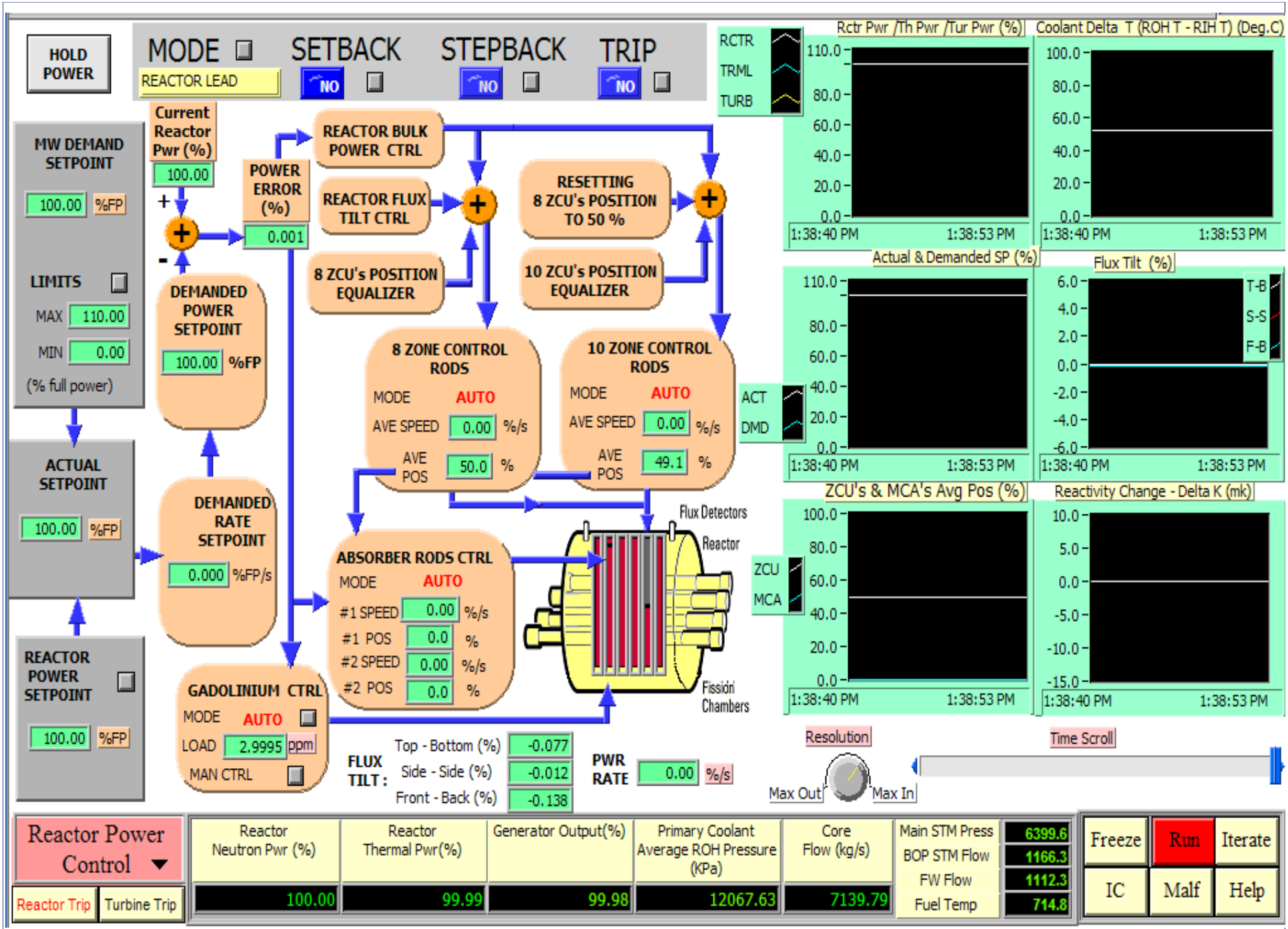
- FW LCV #1 fails open
- Main BFP trips
- Turbine throttle PT fails low
- Turbine spurious trip
- One band of MCA rods drops
- Loss of one RC pump P1
- Loss of 2 PHT pumps
- Primary Coolant RIH #1 LOCA Break, etc



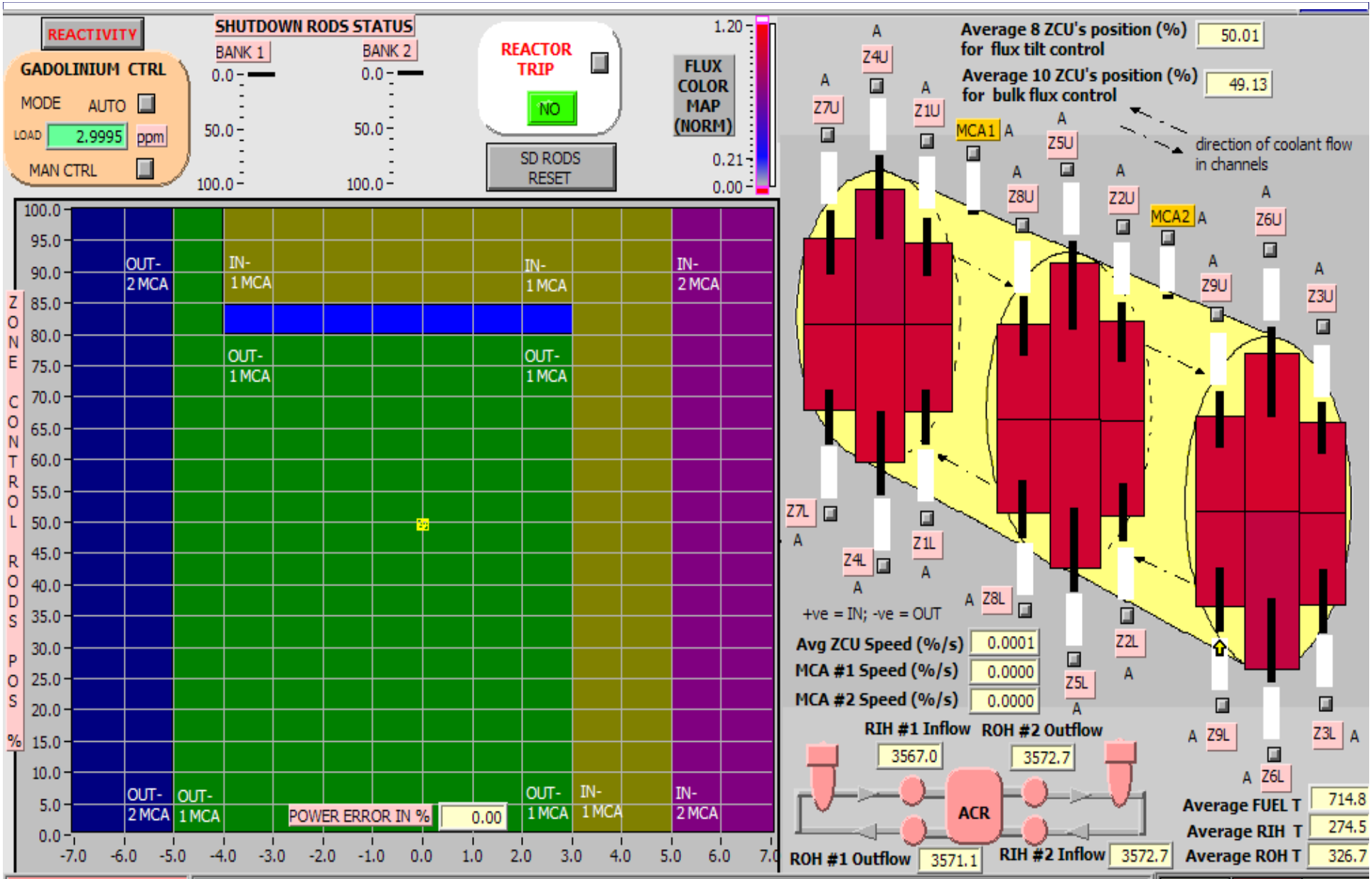
Advanced PHWR Simulator (Overview)



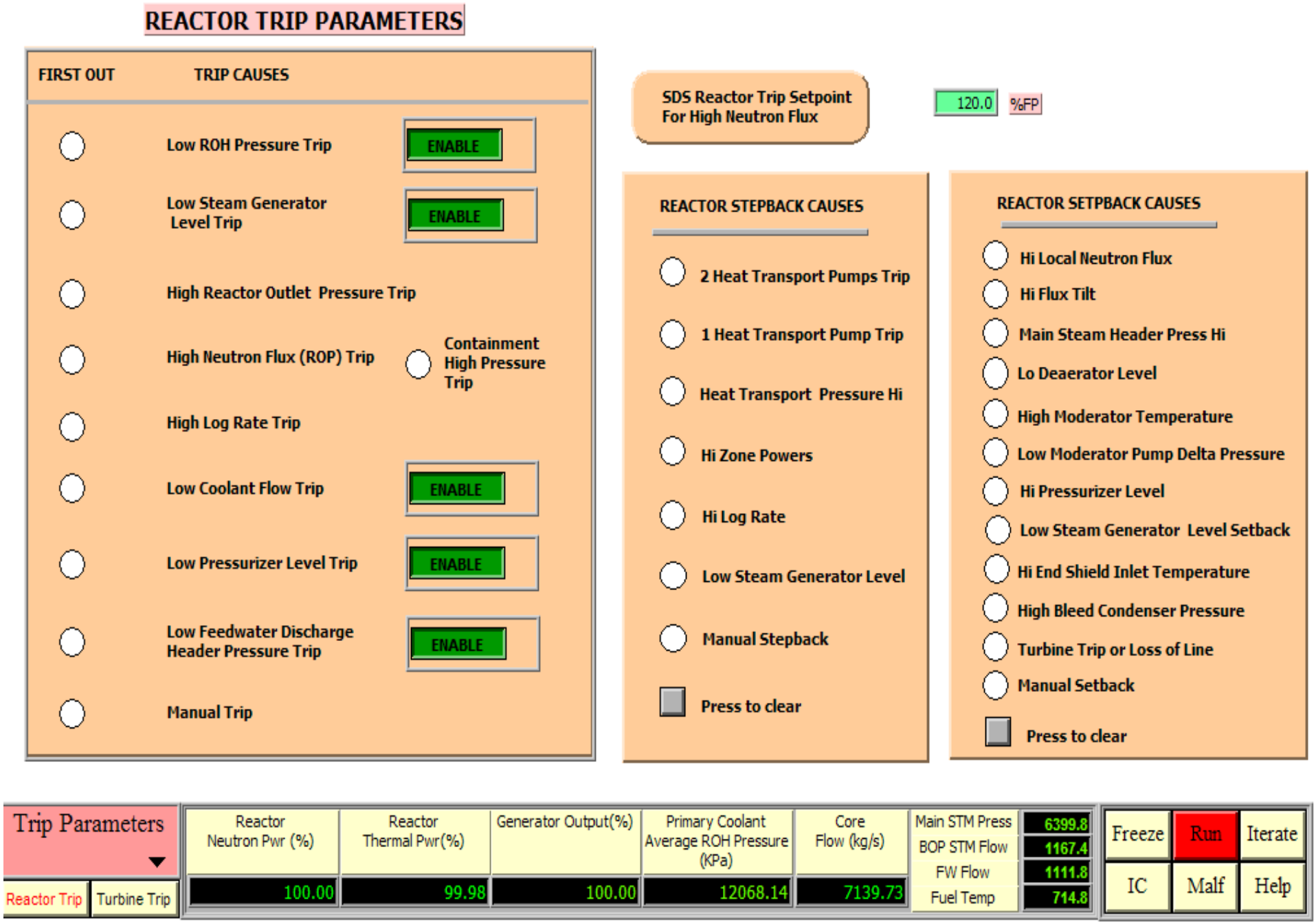
Advanced PHWR Simulator (Reactor coolant system)



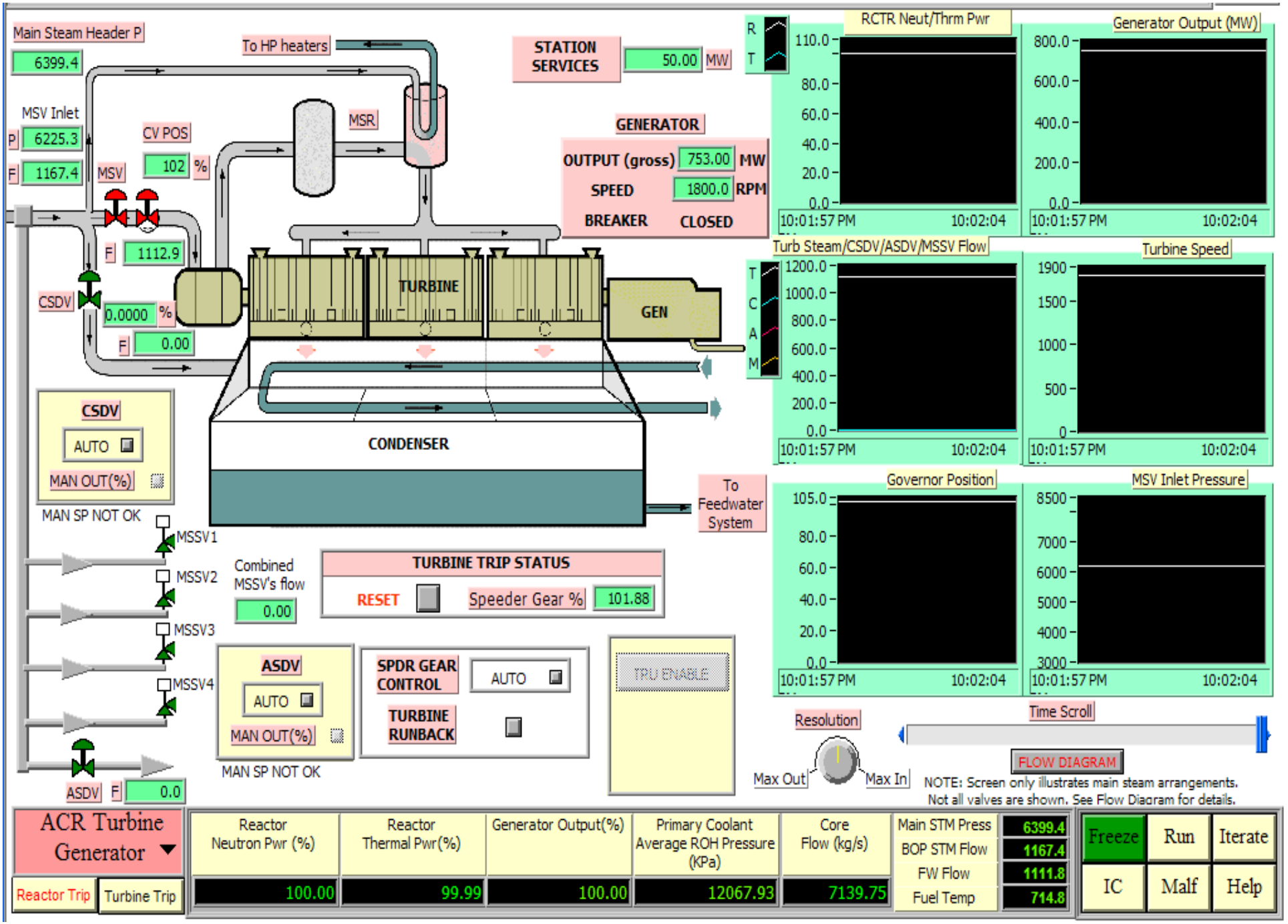
Advanced PHWR Simulator (Reactor power control)



Advanced PHWR Simulator (Control/SD rods & reactivity)



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

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- ✓ **Dr. Tikhonov, Moscow Engineering and Physics Institute, Russia**

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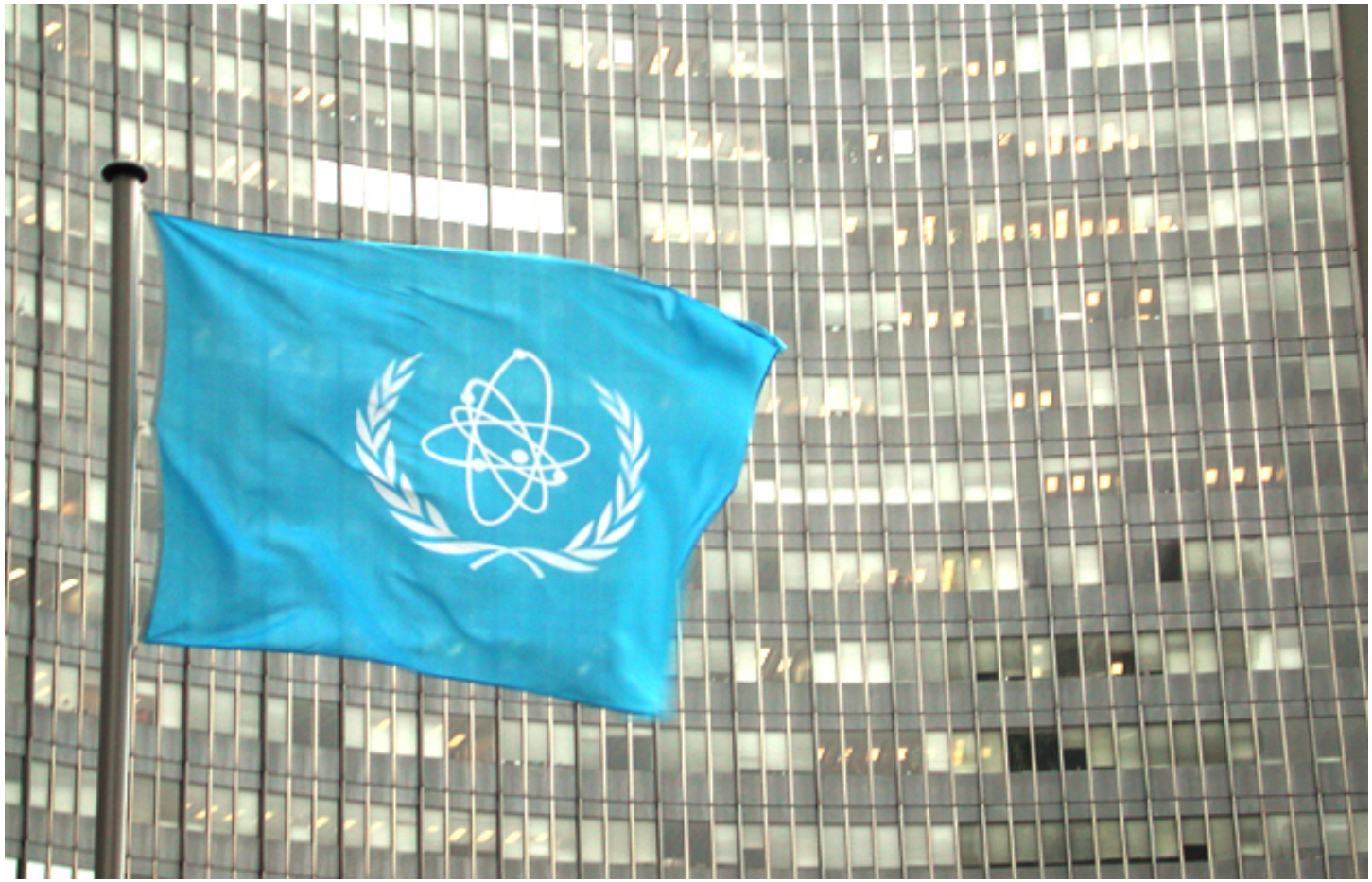

…atoms for peace