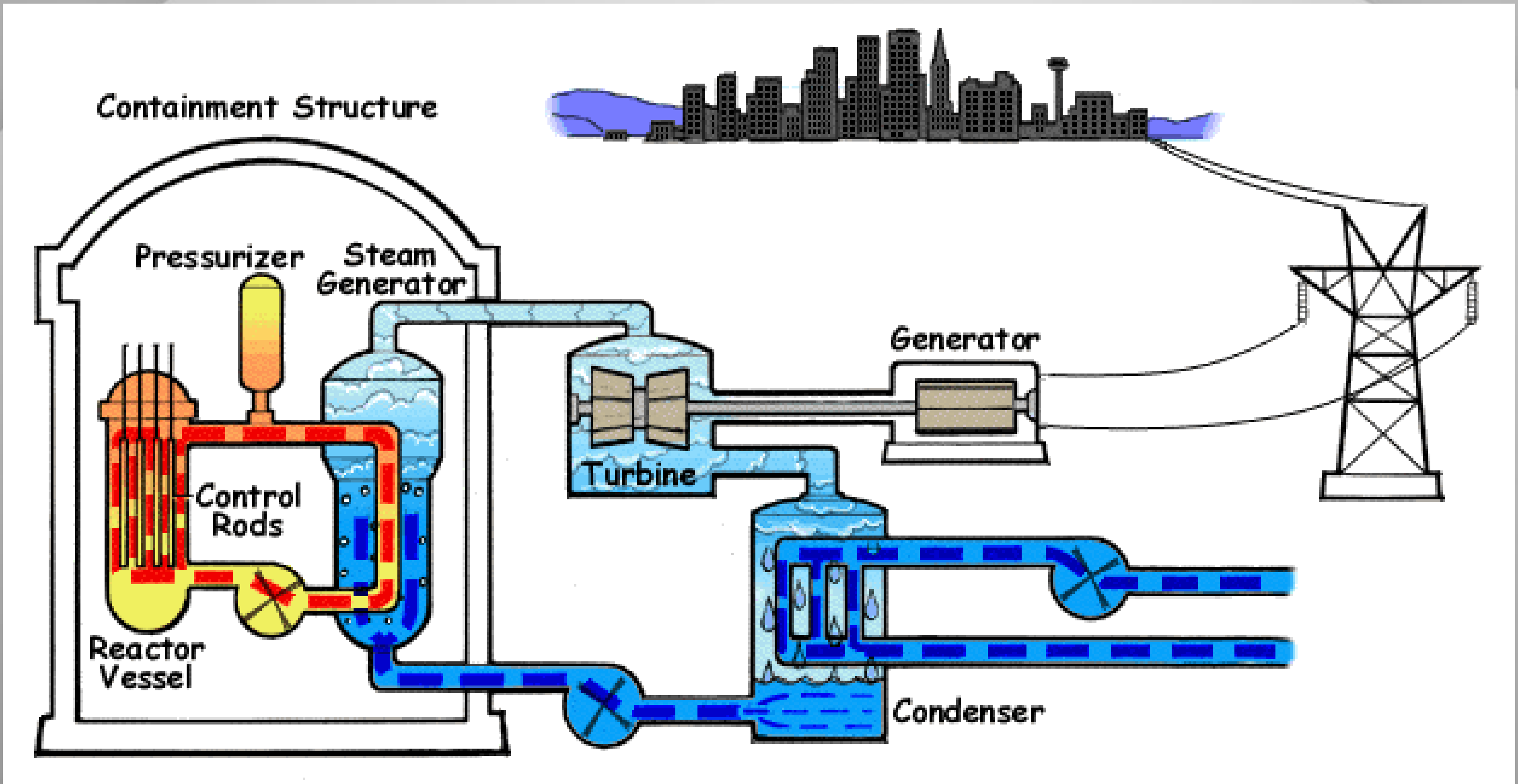
Simulation of Reactor Operation Exercise Using IAEA Advanced PWR-Simulator

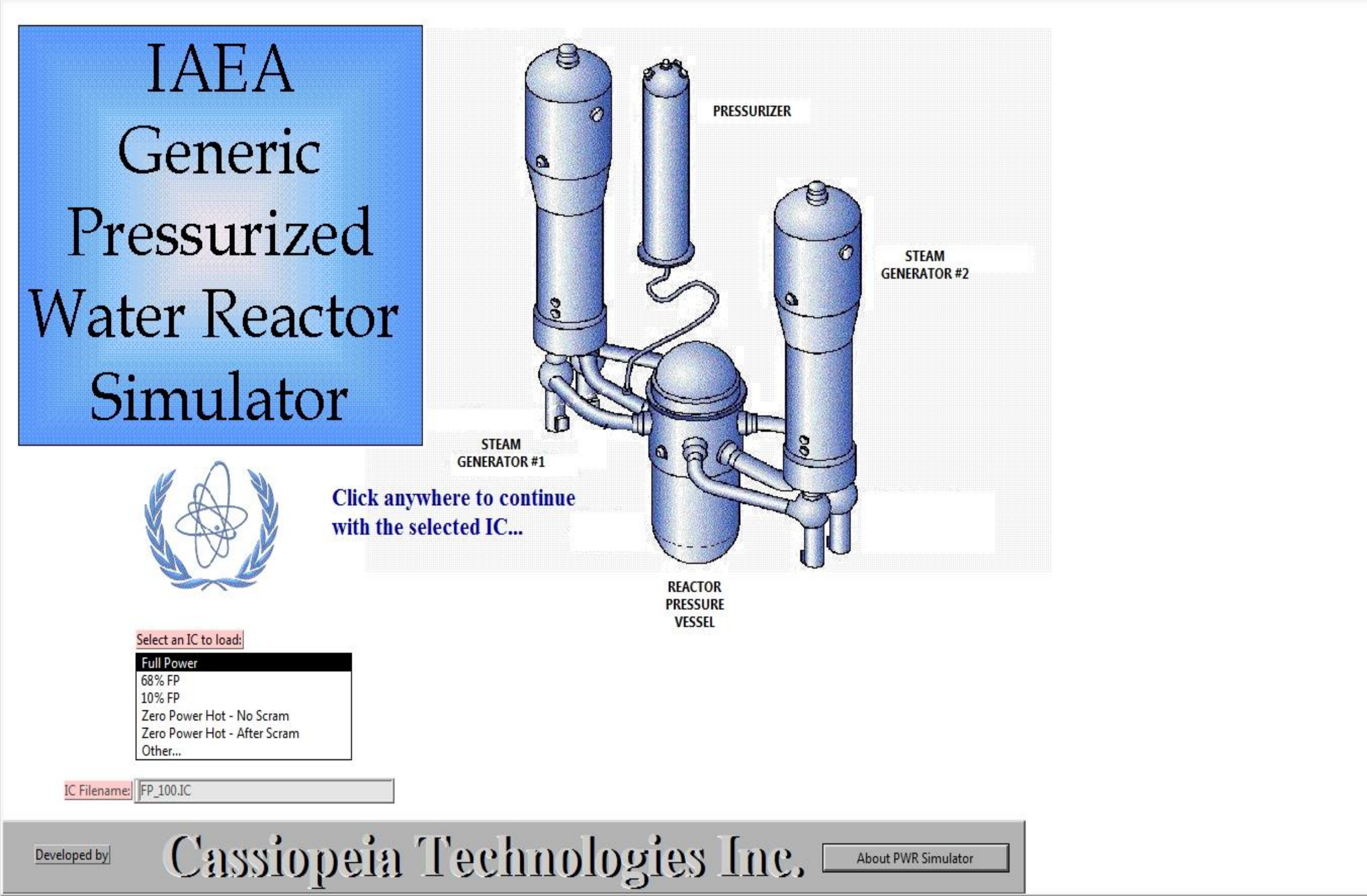
Deswandri
PRTRN – OR TN
BRIN

Pressurized Water Reactor



https://www.nrc.gov/reading-rm/basic-ref/students/animated-pwr.html

IAEA Advanced PWR Simulator

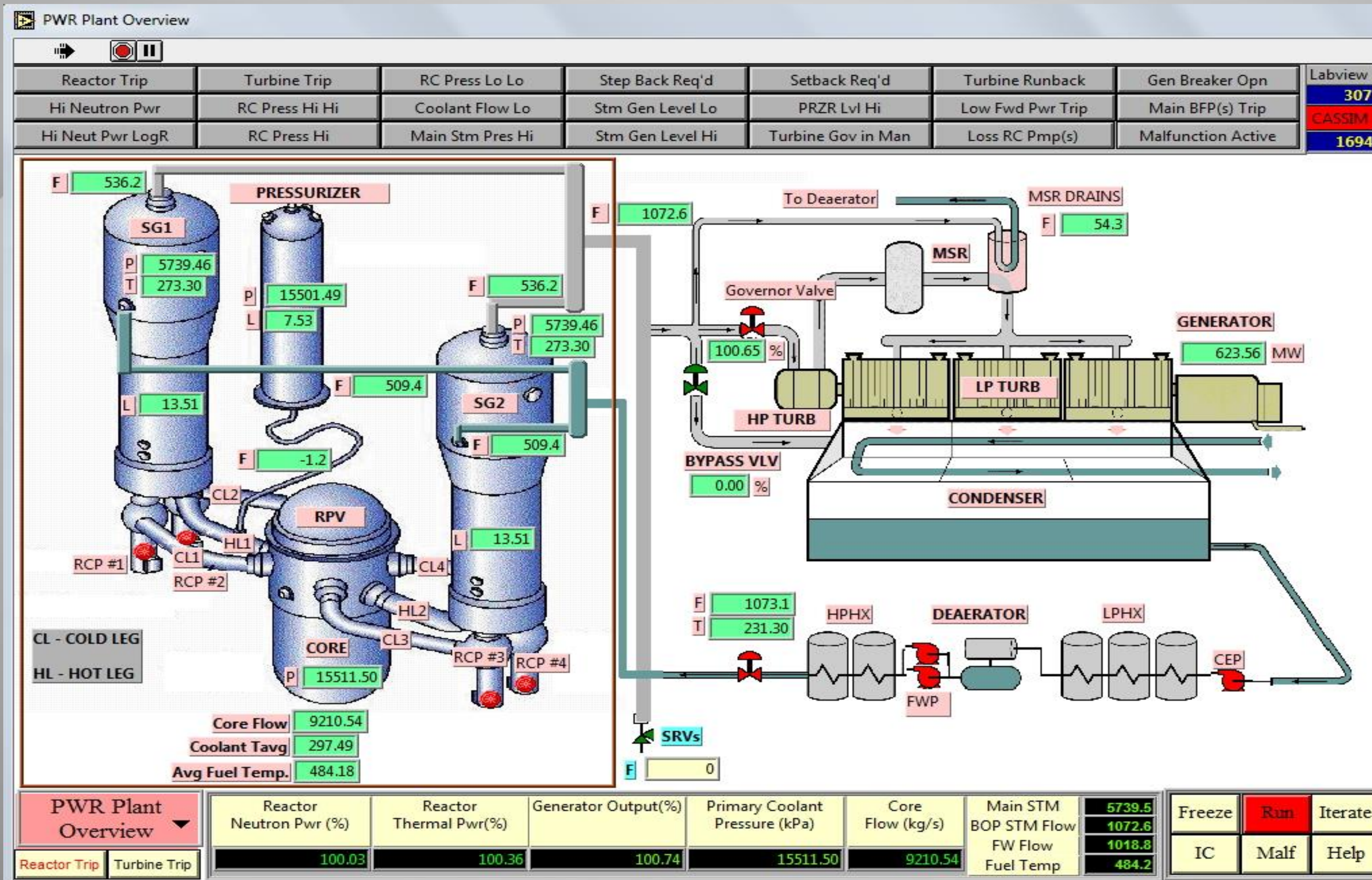


600 MW(e) Passive PWR Simulator

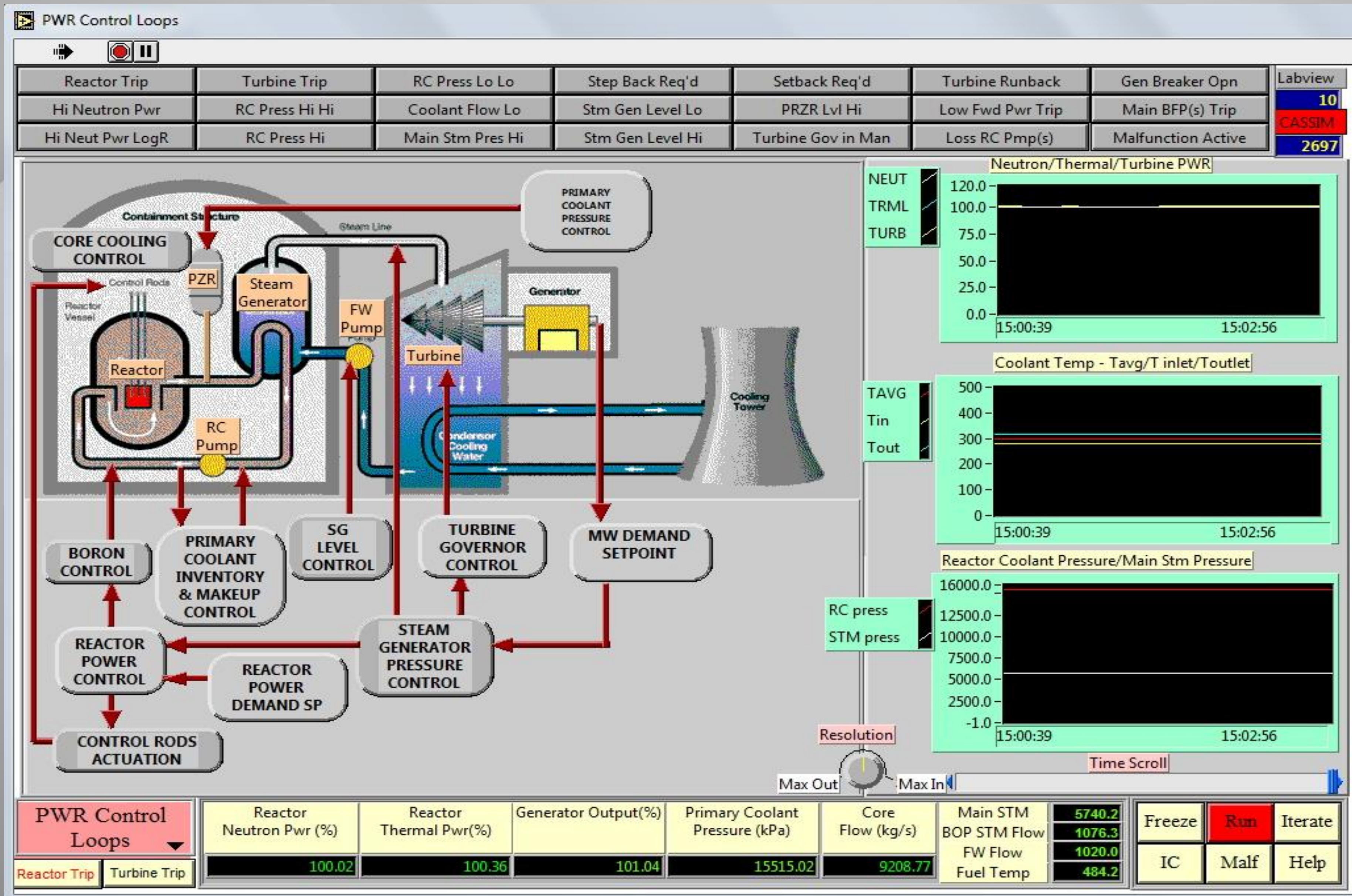
Simulator Display Screens

I. Plant overview
II. Control loops
III. Control/shutdown rods & reactivity
IV. Reactor power control
V. Trip parameters
VI. Reactor coolant system
VII. Coolant inventory & pressurizer
VIII. Coolant inventory control
IX. Coolant pressure control
X. Turbine generator
XI. Feedwater & extraction steam
XII. MW demand SP & SGPC
XIII. Passive core cooling
XIV. Trends

Plant Overview Screen



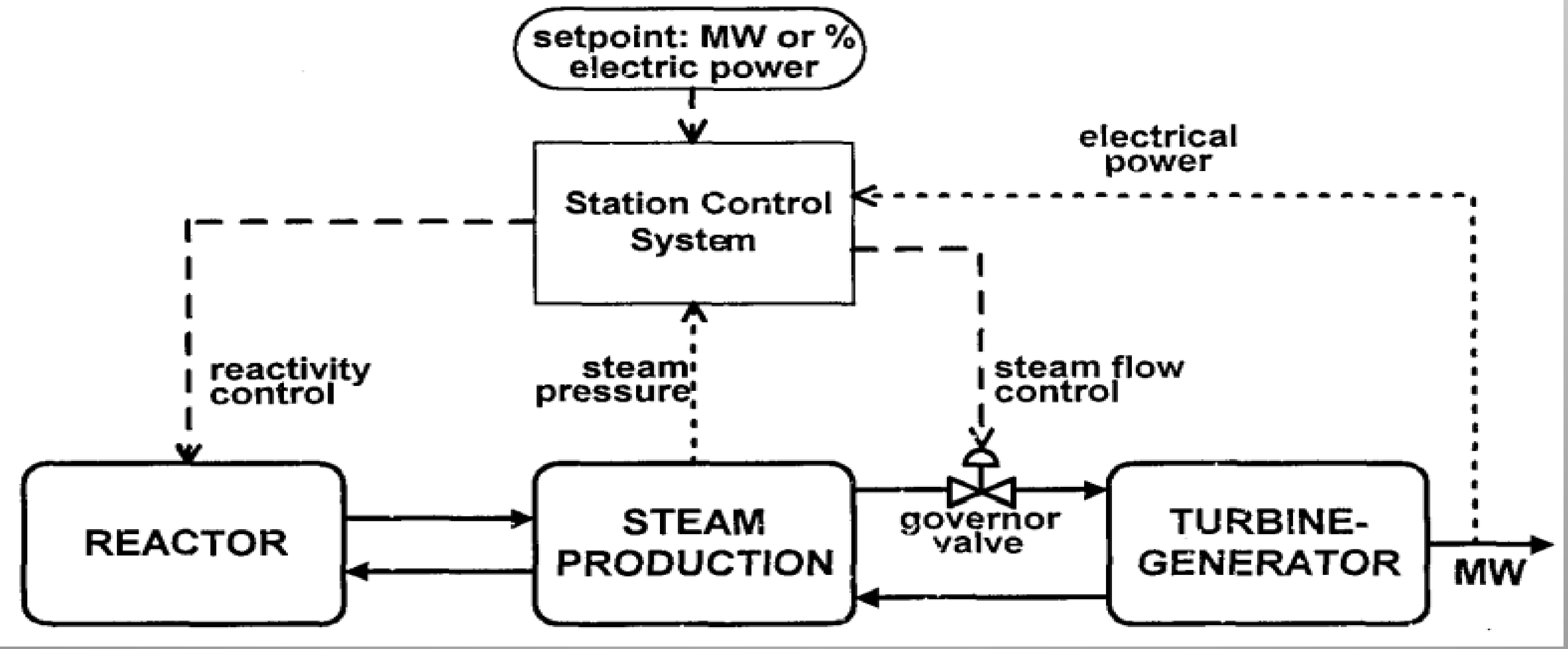
PWR Control Loops Screen



PWR Control Modes

Turbine Leading

- Setpoint diatur berdasarkan permintaan daya keluaran generator (megawatt).
- Jika terdapat perbedaan antara setpoint dengan tingkat daya aktual, sistem kontrol melakukan koreksi dengan mengubah bukaan katup pengatur dan dengan demikian mengubah jumlah aliran uap yang menuju turbin.
- Sistem kontrol menyesuaikan daya reaktor dengan mengubah posisi perangkat kontrol reaktivitas untuk menjaga tekanan generator uap pada setpointnya.



Source: *Dr. George Bereznai*; *www.nuceng.ca/canteachmirror/library/20044402.pdf*

PWR Control Modes

Reactor Leading

- Setpoint diatur berdasarkan permintaan daya keluaran reaktor.
- Jika terdapat perbedaan antara setpoint dengan tingkat daya reaktor aktual, sistem kontrol melakukan koreksi dengan mengubah posisi perangkat kontrol reaktivitas dan dengan demikian mengubah fluks neutron reaktor.
- Sistem kontrol tekanan generator uap menyesuaikan aliran uap dan dengan demikian mengubah daya turbin dengan mengatur posisi katup pengatur untuk menjaga tekanan generator uap pada setpointnya.

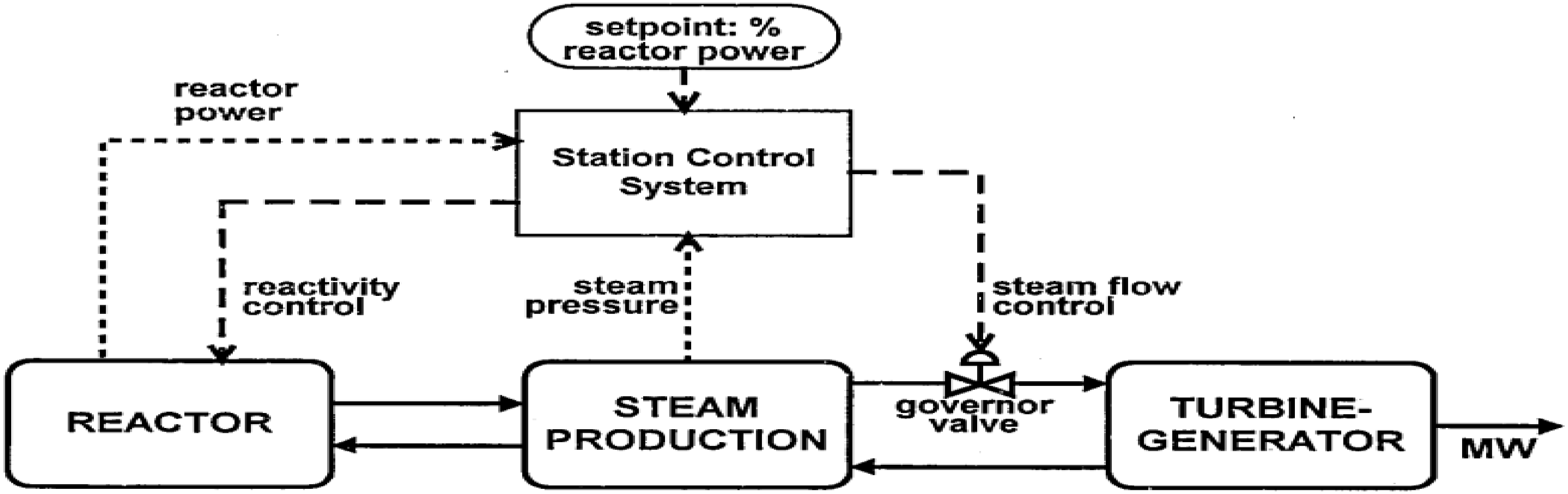


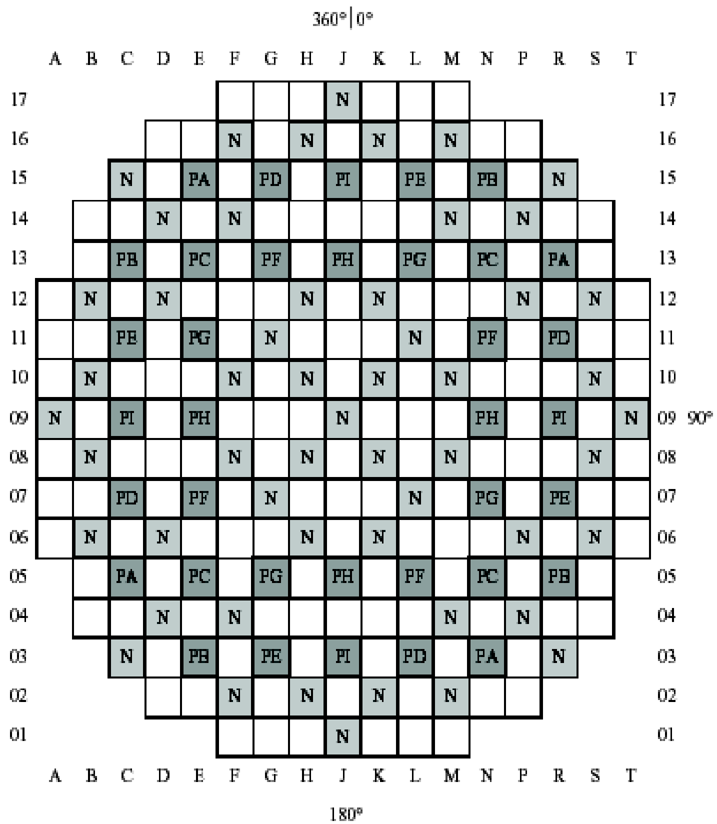
Figure 5: Simplified reactor-leads-turbine overall unit control system

Source: *Dr. George Bereznai*; *www.nuceng.ca/canteachmirror/library/20044402.pdf*

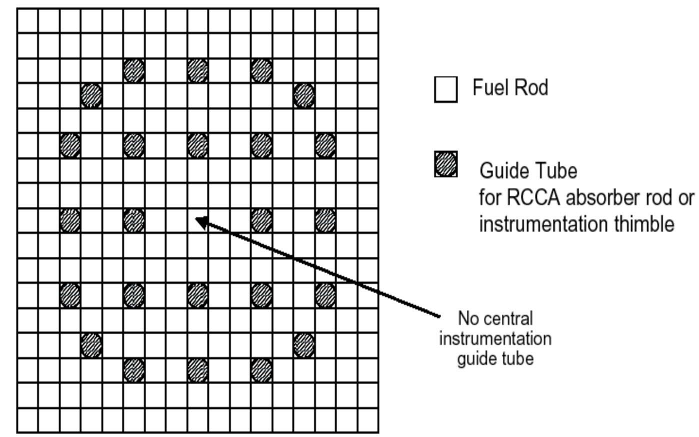
PWR Control Means

RCCA Pattern

- 89 RCCA for maximizing the shutdown margin
- 53 for shutdown (N)
- 36 for control
  - 9 banks of 4 rods symmetrically located (PA to PI)
  - The 4 rods move at the same time with the same signal
- Assignment of bank to control groups can be changed during the fuel cycle



17x17 ASSEMBLY



Rod Cluster Control Assembly (RCCA):

- Shutdown rod bank
- Heavy-worth control rods bank (dark rod)
- Light-worth control rods bank (gray rod)

Soluble neutron absorber (boric acid)

Source: *Dr.* Larry Foulke; Lecture Material on the IAEA Workshop on Nuclear Power Plants Simulator, Politecnico di Milano, Milan, Italy, 2011

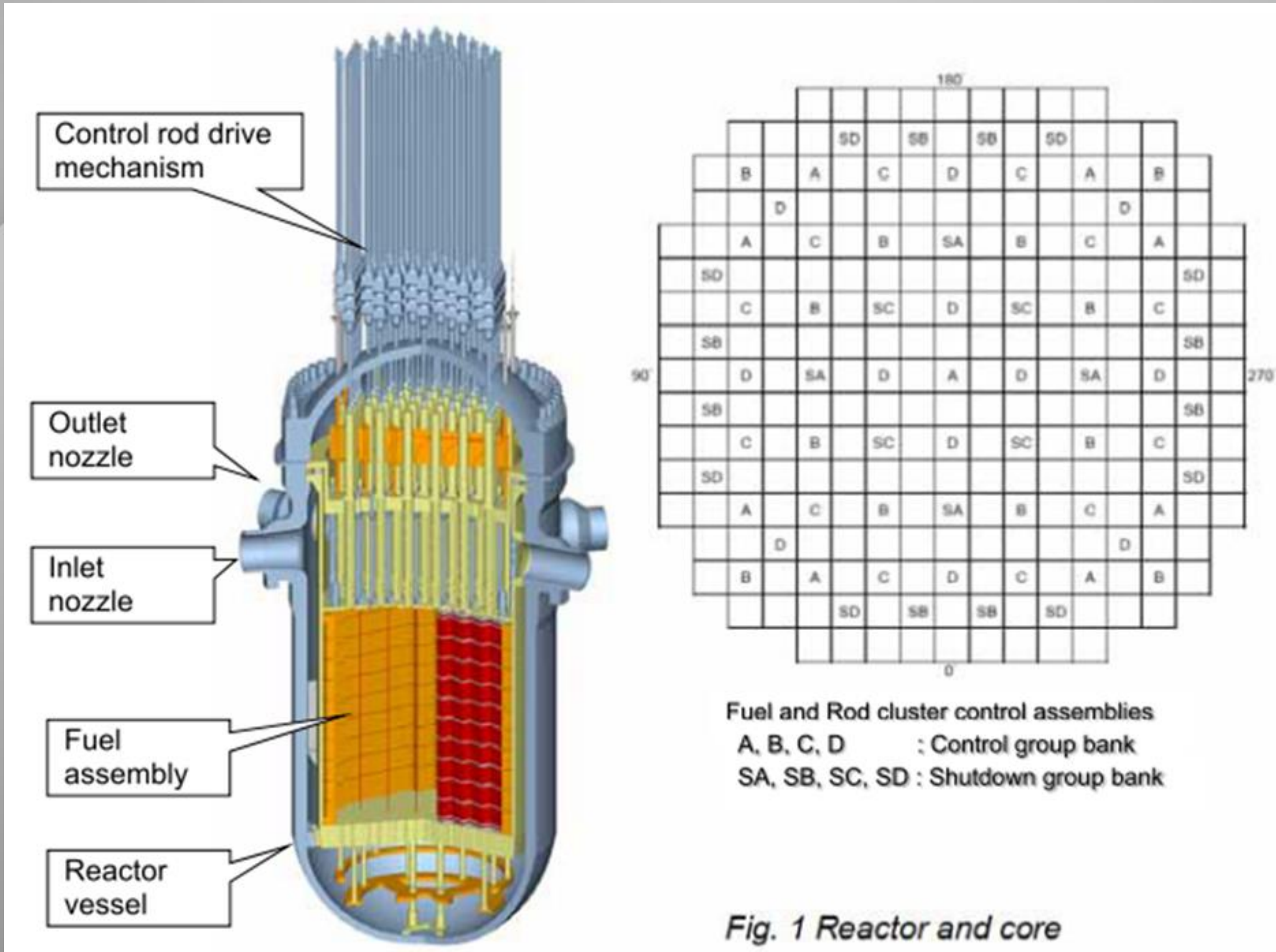
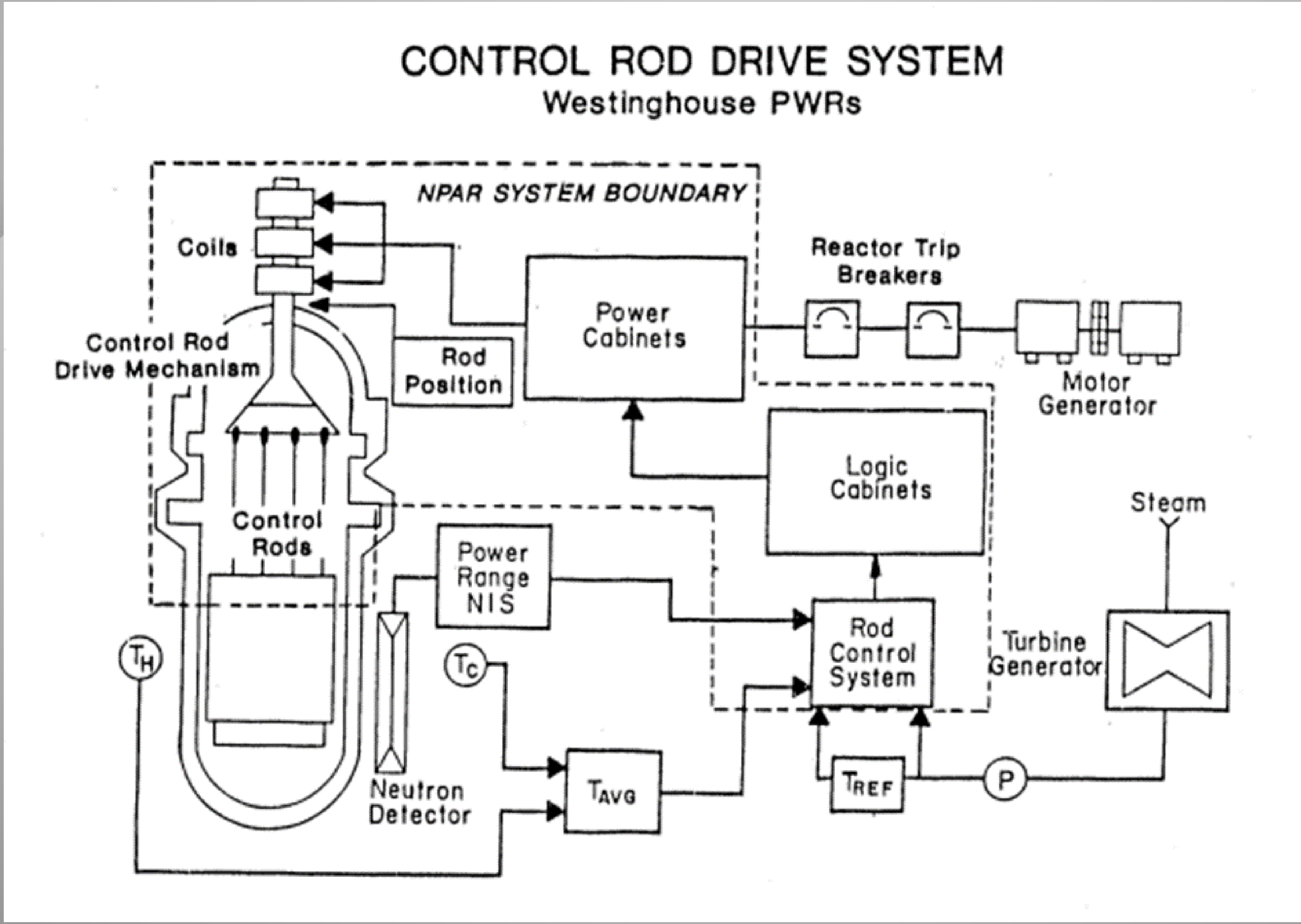


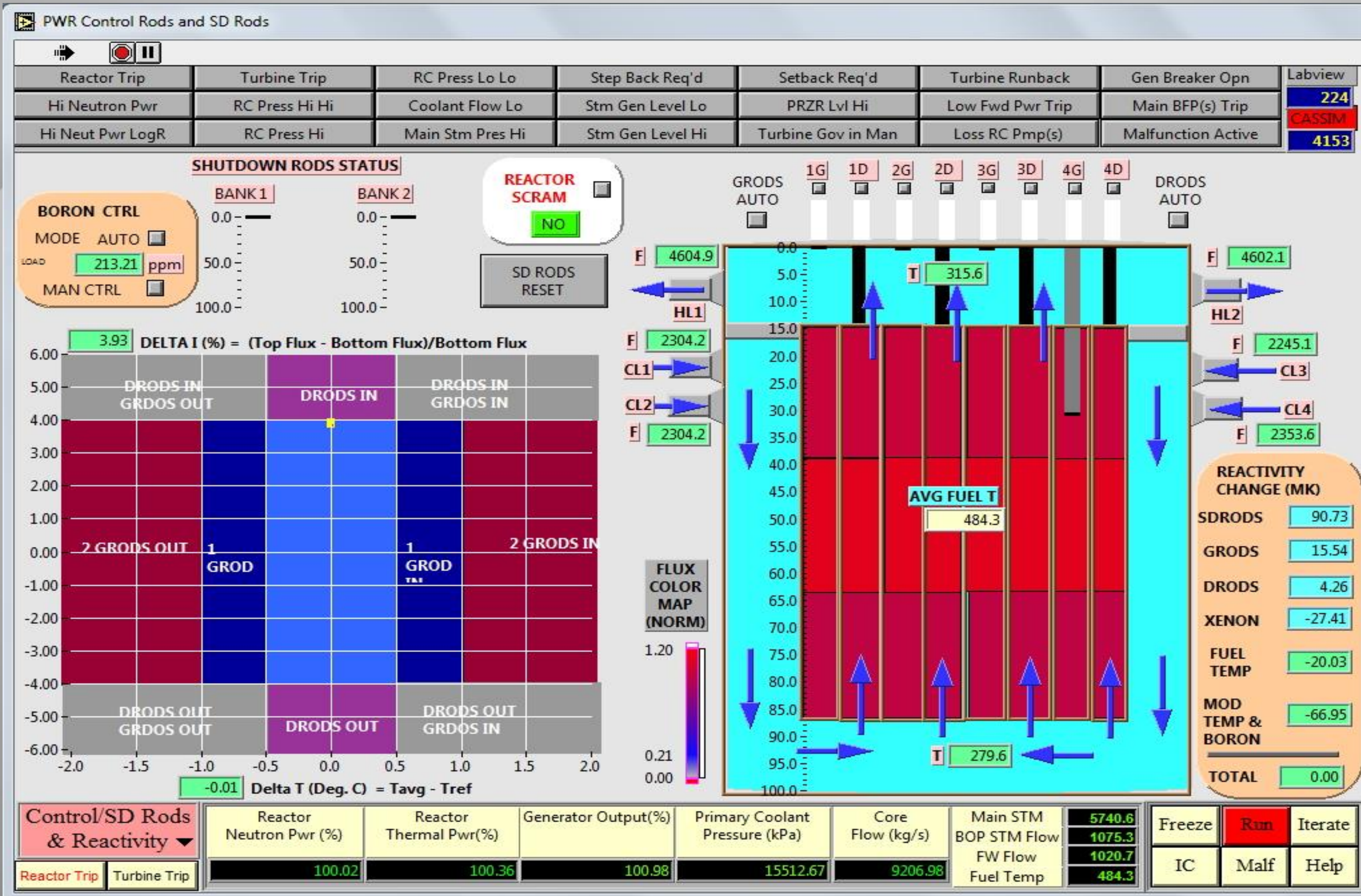
Fig. 1 Reactor and core

Source: APWR, Mitsubishi Heavy Industries, IAEA INPRO 7th Dialogue Forum, Nov. 2013,



(Source: Gunther and Sullivan, DETECTION AND MITIGATING ROD DRIVE CONTROL SYSTEM DEGRADATION IN WESTINGIIOUSE PWRs, BNL-NUREG-45316, Dec. 1991)

Control Rods & Reactivity Screen



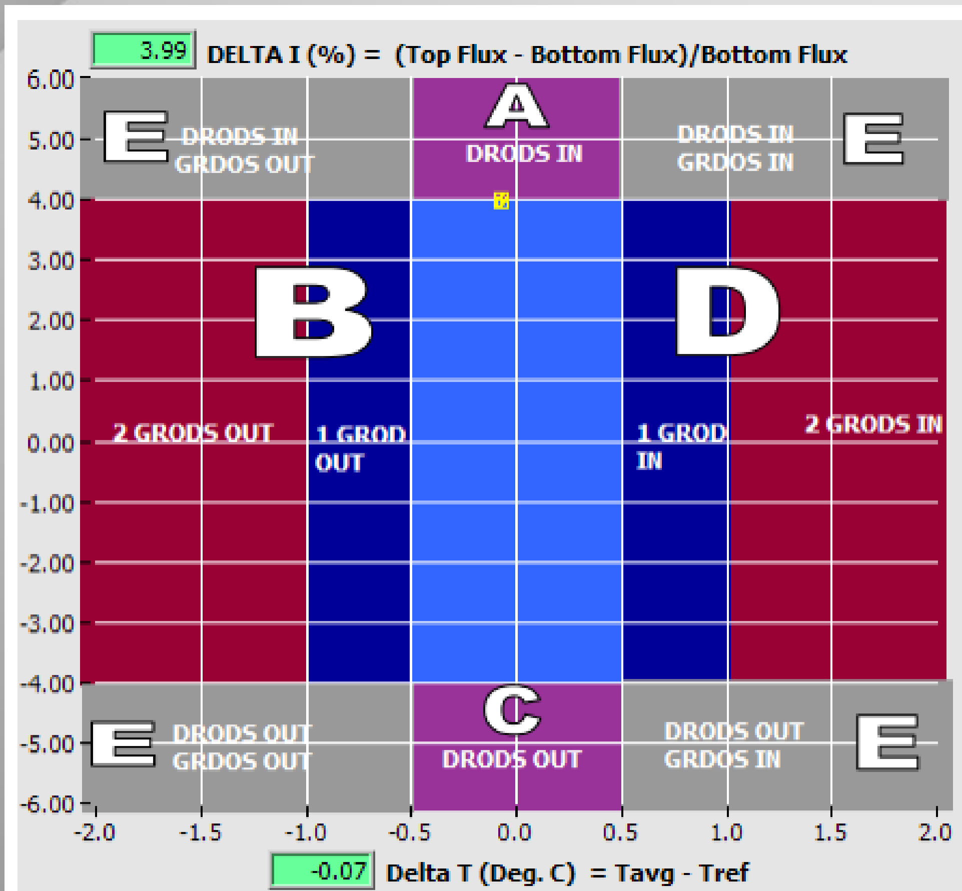
Mode K Reactor Control Strategy

(Paper - “Automatic Reactor Power Control for a Pressurized Water Reactor “ by Jung-In Choi et al, Kyungwon University, Korea (August 27, 1992) - Nuclear Technology, Volume 102, May 1993, p.277)

- Double closed loop control
  (1) reactor coolant temperature
  (2) axial power difference
- Heavy-worth control rods bank (dark rods) dedicated to axial shape control.
- Light-worth control rods bank (gray rods) for controlling coolant temperature at setpoint.

Source: Lecture Material on the IAEA Workshop on Nuclear Power Plants Simulator, Politecnico di Milano, Milan, Italy, 2011

Mode K Reactor Control Strategy

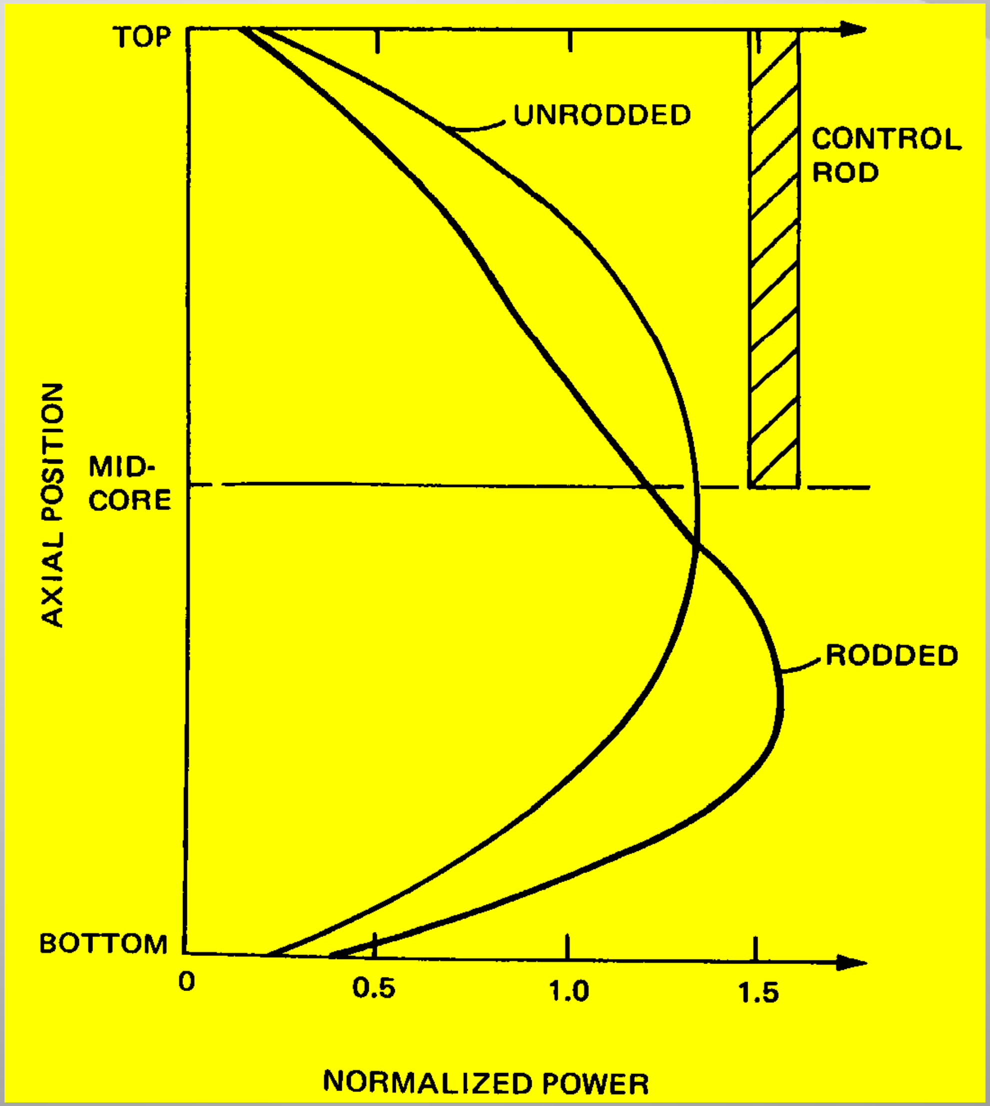


Region A: FT > 4; -0.5 < DT < 0.5
Region C: FT < -4; -0.5 < DT < 0.5
Region B: -4 < FT < 4; DT < -0.5
Region D: -4 < FT < 4; DT > 0.5
Region E: the four corners
FT > 4; DT < -0.5;
FT > 4; DT > 0.5;
FT < -4; DT < -0.5;
FT < -4; DT > 0.5

Boron will be used if Gray rods limiting position has been reached

Axial Flux with Control Rods

Axial Flux with Control Rods



Source: *Dr.* Larry Foulke; Lecture Material on the IAEA Workshop on Nuclear Power Plants Simulator, Politecnico di Milano, Milan, Italy, 2011

Gray Rods Position Limits

Reactor Power (%)	Average Gray Rods Position (average of the rod positions for the individual four banks)
0 – 10 %	93 % - 87 % in core
10 – 20 %	87 % - 83 % in core
20 – 30 %	83 % - 70 % in core
30 – 40%	70 % - 60 % in core
40 – 50 %	60 % - 53 % in core
50 – 60 %	53 % - 48 % in core
60 – 70 %	48 % - 44 % in core
70 – 80%	44 % - 40 % in core
80 – 90 %	40 % - 35 % in core
90 – 100 %	35 % - 30 % in core

- Batasan ini dirancang untuk menjaga:
  - ✓ reaktivitas batang kendali yang cukup pada berbagai titik daya, untuk manuver daya,
  - ✓ margin operasi yang cukup untuk memungkinkan penyisipan batang secara tiba-tiba seperti pada saat reactor power stepback, atau setback
- Jika posisi rata-rata Gray Rods telah tercapai pada posisi daya tertentu, Gray Rods TIDAK akan dipindahkan lagi (hingga rentang daya lain ditemukan).
- Jika batasan Gray Rods sudah tercapai dan daya reaktor target masih belum tercapai,maka soluble boron akan digunakan (injection atau removal) untuk mencapai target daya.

Constant Tav Program

Constant Tav Program

Advantages:

- Least amount of external control
- Preferred by reactor
- Small pressurizer (minimum expansion of coolant volume as power changes)

Disadvantages

- Drop off of steam temperature and pressure
- Poor turbine efficiency

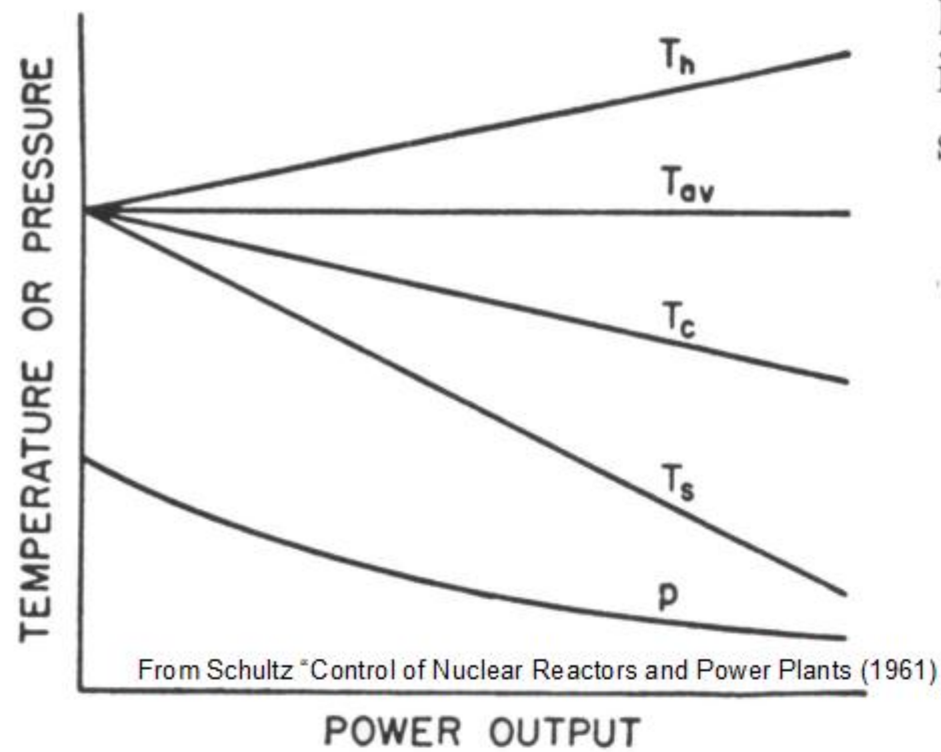


FIG. 8-4. Variations in temperatures and pressure as a function of power output for constant-average-temperature program with fixed coolant flow.

Source: *Dr.* Larry Foulke; Lecture Material on the IAEA Workshop on Nuclear Power Plants Simulator, Politecnico di Milano, Milan, Italy, 2011

Constant Th Program

Constant Th Program

Advantages:

- **Least stressful to materials**

Disadvantages

- **Huge drop off of steam temperature and pressure**
- **Poorest turbine efficiency**
- **Requires external reactivity control**

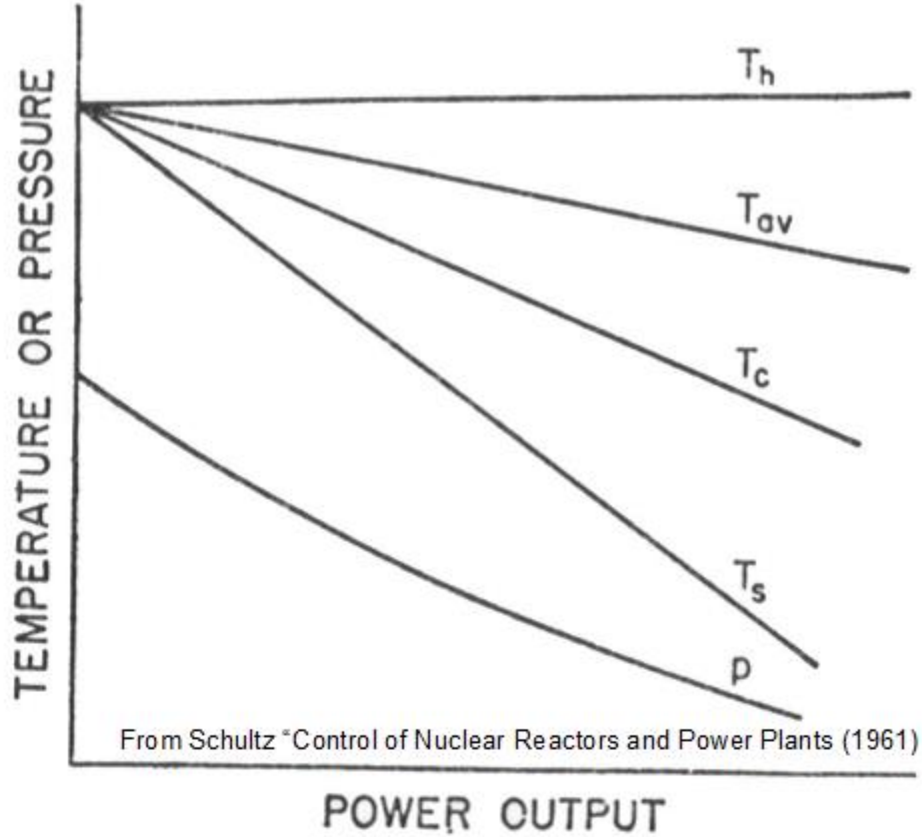
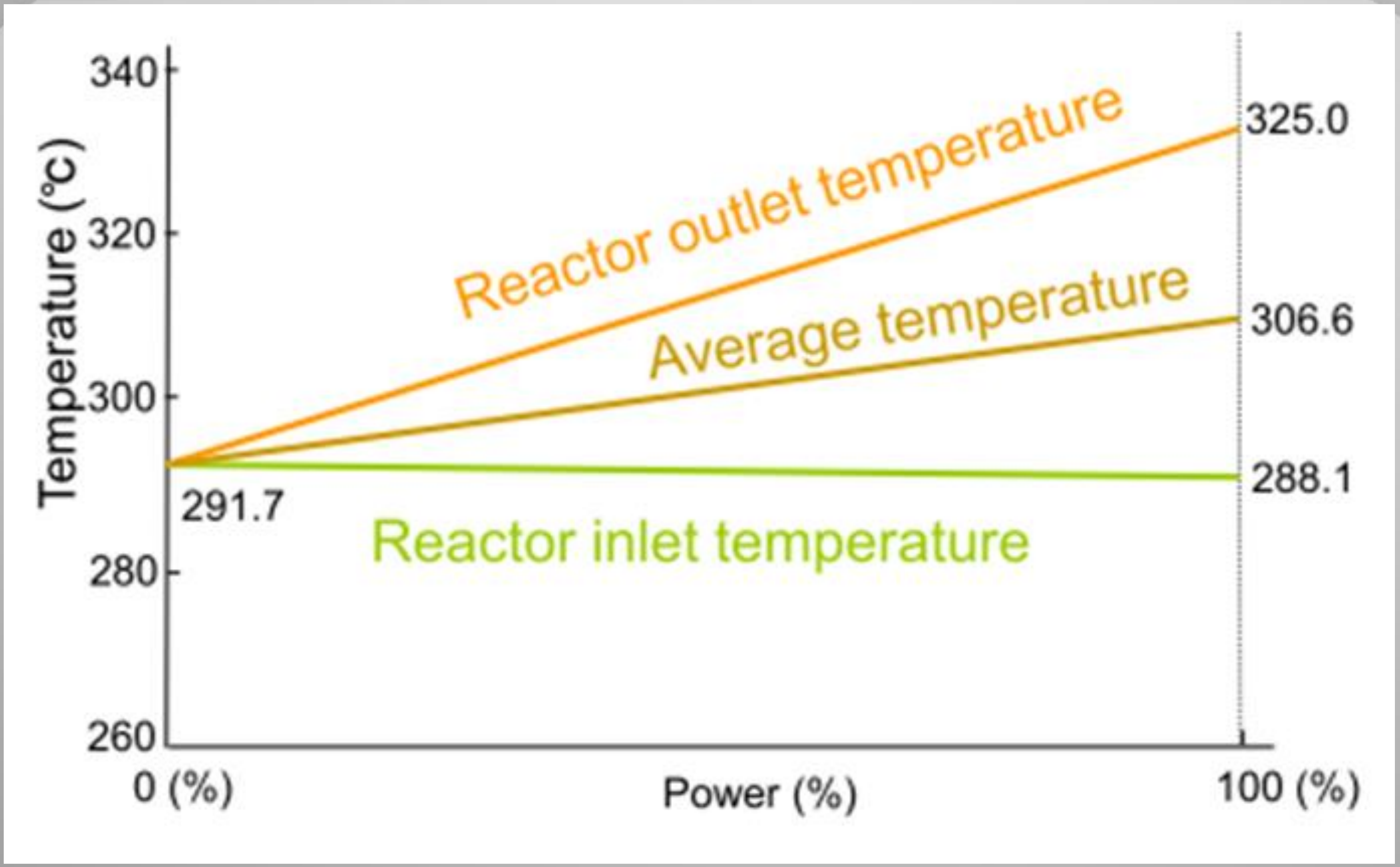


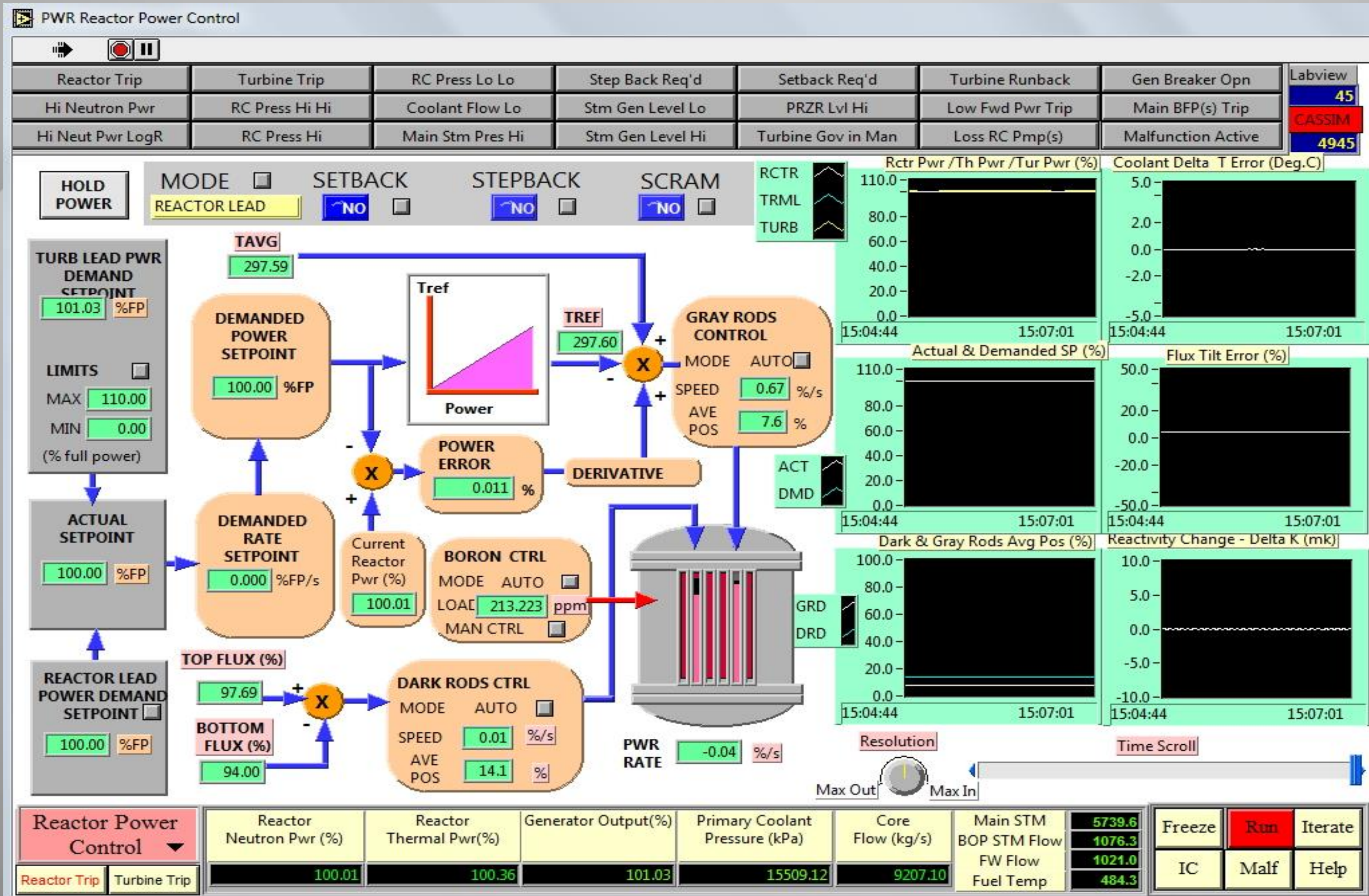
FIG. 8-6. Variations in temperatures and pressure as a function of power output for constant-outlet-temperature program.

Source: *Dr.* Larry Foulke; Lecture Material on the IAEA Workshop on Nuclear Power Plants Simulator, Politecnico di Milano, Milan, Italy, 2011



Temperatur terprogram pendingin reaktor (APWR, Mitsubishi Heavy Industries, IAEA INPRO 7th Dialogue Forum, Nov. 2013)

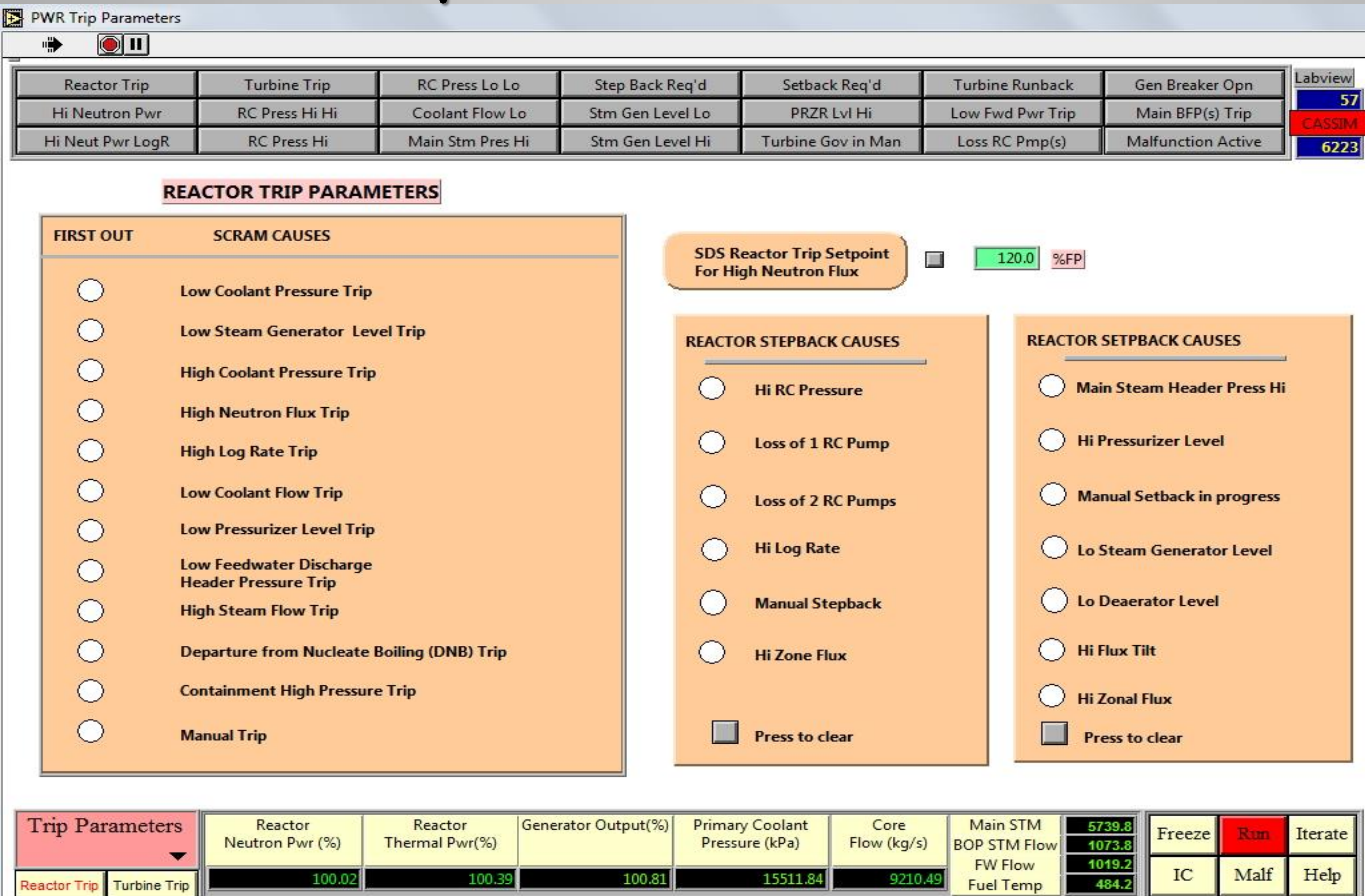
Reactor Power Control Screen



Reactor Power Control Screen

- REACTOR POWER SETPOINT target and rate are specified by the user on the simulator in terms of %FP (Full Power) and %FP/sec.
- TURB LEAD PWR DEMAND SETPOINT is set equal to the TARGET LOAD (% FP) SETPOINT under "TURBINE LEADING" control; the upper and lower limits on this setpoint can be specified here.
- ACTUAL SETPOINT is set equal to the accepted "REACTOR POWER SETPOINT" TARGET under RPC control in "REACTOR LEADING" mode.
- HOLD POWER 'On' will select 'REACTOR LEADING' mode and stops any requested changes in DEMANDED POWER SETPOINT.
- DEMANDED RATE SETPOINT is set equal to the accepted "REACTOR POWER SETPOINT" RATE, limited by the maximum rate of 0.8 % of full power per second.
- DEMANDED POWER SETPOINT is the incremental power target, which is set equal to current reactor power (%) + rate (% / s) * program cycle time (sec). In this way, the DEMANDED POWER STEPOINT is "ramping" towards the REACTOR POWER SETPOINT target, at the accepted rate of change.

Reactor Trip Parameters Screen



Reactor Trip Parameters

- Low reactor outlet header (hot legs) coolant pressure trip — trip setpoint = 14,380 kPa.
- Low steam generator level trip — trip setpoint = 11.94 m
- High reactor outlet coolant pressure trip — trip setpoint = 16,200 kPa
- High neutron flux trip — trip setpoint = 120 % of Neutron Flux at full power
- High log rate trip — trip setpoint = 8 % /s
- Low coolant flow trip — trip setpoint = 2,000 kg/s
- Low pressurizer level trip — trip setpoint = 2.7 m
- Low feedwater discharge header pressure — trip setpoint = 5200 kPa
- High Steam Flow"High Steam Flow" – reactor will be tripped, when the steam flow from Steam Generator #1, OR from Steam Generator #2, exceeds 120 % of Full Power steam flow (644 kg/sec), OR the total steam flow from the main steam header exceeds 120 % of Full Power steam flow (1289 kg/s).
- "DNB Trip" – Departure from Nucleate Boiling (DNB) reactor trip will occur when the average heat flux in the core exceeds 110 % of the nominal full load design value of 464 kW/m^2.
- Containment High Pressure Trip – reactor will be tripped when the containment pressure (which is kept at sub-atmospheric pressure) exceeds 105 kPa, in the unlikely event of a LOCA event occurring inside containment boundary.
- Manual trip

Reactor Stepback & Setback Parameters

- Reactor stepback is the reduction of reactor power in a large step, in response to certain process parameters exceeding alarm limits.
- Reactor setback is the ramping of reactor power at fixed rate, to setback target, in response to certain process parameters exceeding alarm limits.

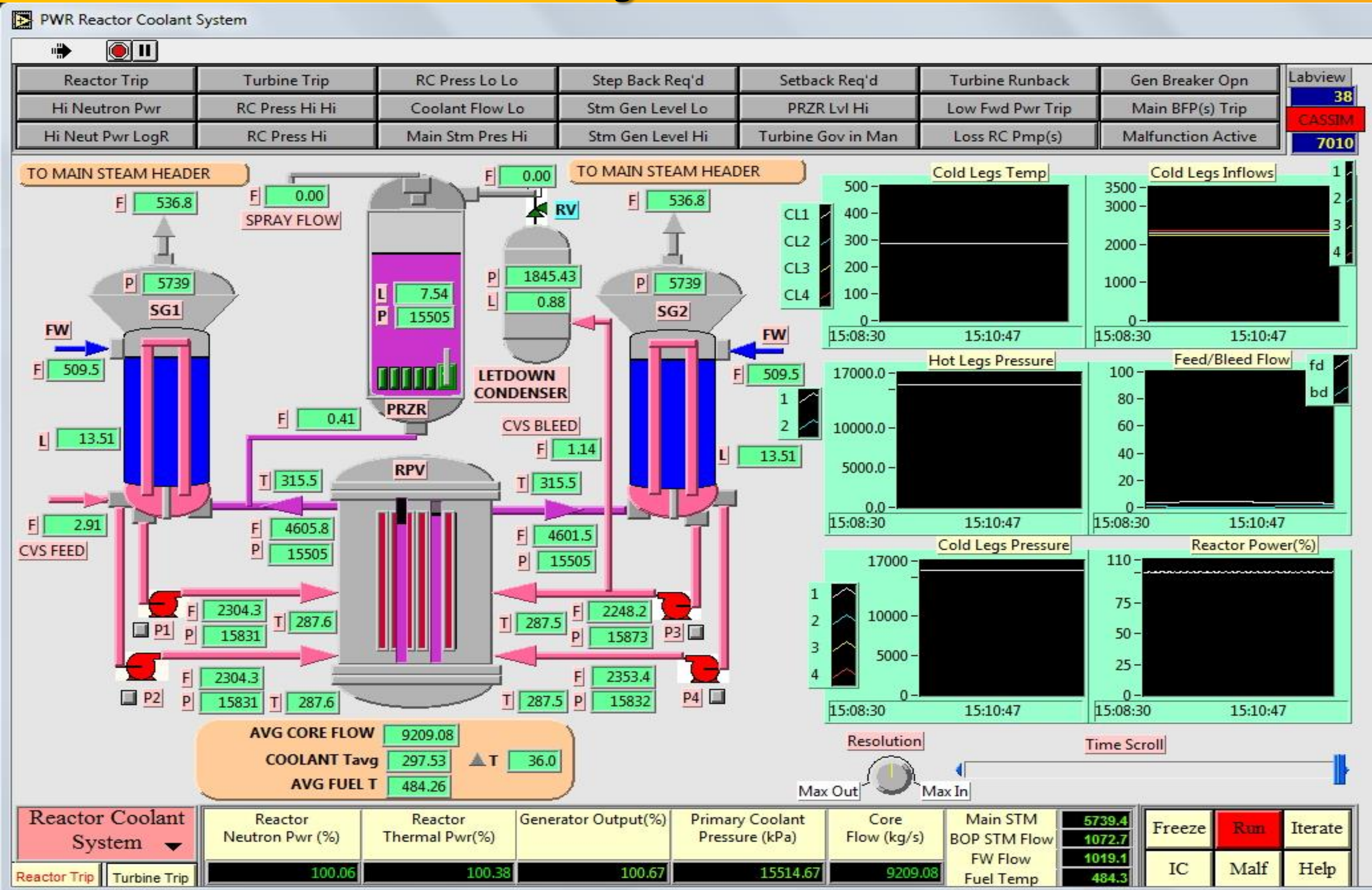
The causes for REACTOR STEPBACK :

- ✓ High reactor coolant pressure (initiated at P > 16051 kPa; target 2 % FP)
- ✓ Loss of one reactor coolant pump (target 60 % FP)
- ✓ Loss of two reactor coolant pumps (target 2 % FP)
- ✓ High log rate (initiated when d(lnP)/dt) > 7 %/s; target 2 % FP)
- ✓ Manual stepback (initiated by operator; target set by operator)
- ✓ Hi zone flux (initiated if zone flux is > 115 % of nominal zone flux at full power)

The causes for REACTOR SETBACK are:

- ✓ Main steam header pressure Hi — setback if > 6150 kPa
- ✓ Hi pressurizer level — setback if > 12 m
- ✓ Manual setback in progress
- ✓ Low steam generator level — setback if < 12 m
- ✓ Low deaerator level — setback if < 2 m
- ✓ Hi flux tilt — setback if > 20 %
- ✓ Hi zonal flux — setback if > 110 %

Reactor Coolant System Screen

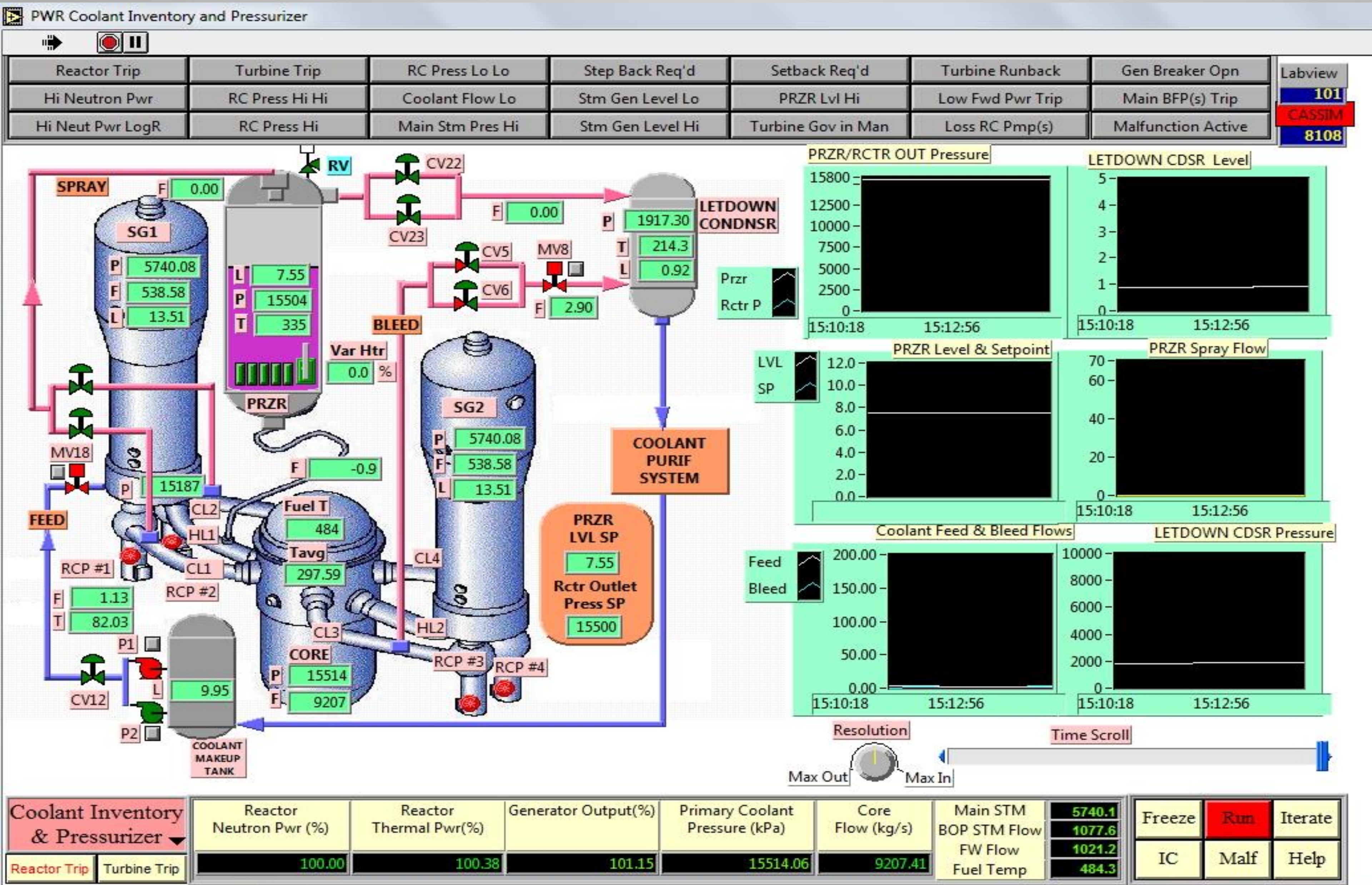


Reactor Coolant System

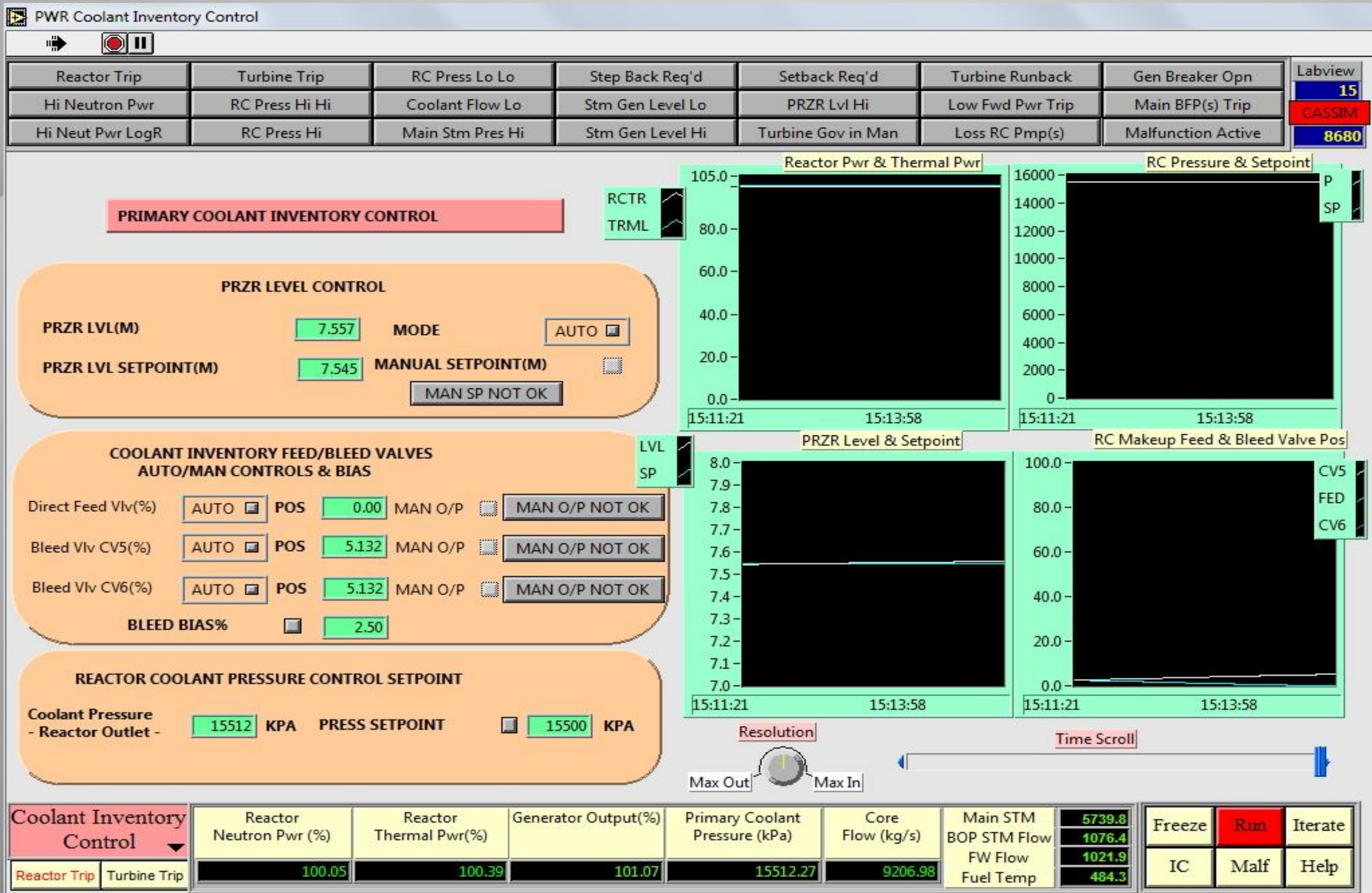
The system components and parameters shown are:

- Average fuel temperature (^{O}C); average coolant temperature (^{O}C); average core flow (kg/s)); Δ T across the core = coolant outlet temperature - coolant inlet temperature.
- Reactor coolant pump's discharge flow (kg); discharge pressure (kPa); discharge temperature (^{O}C)
- Reactor coolant pump pop-up control which allows 'START', 'STOP' and 'RESET' operations
- Pressure (kPa), flow (kg/s) and temperature (^{O}C) at the hot legs outlet of the Reactor Pressure Vessel.
- Coolant flow (kg/s) to the pressurizer from one hot leg.
- For each steam generator (SG) — feedwater flow (kg/s); feedwater level in drum (m); steam drum pressure (kPa); main steam flow from SG to main steam header (kg/s). For SG1, the feed flow (kg/s) from chemical & volume control system (CVS) is shown. More explanation of this feed flow will be provided in the PWR coolant inventory & pressurizer screen.
- In the pressurizer, there are five electric on/off heaters, and one variable heater. They are controlled by the coolant pressure control system. The color will be red when heater is 'on'; green when off. The following process parameters are shown: pressurizer vapor pressure (kPa); pressurizer liquid level (m); spray flow into the pressurizer (kg/s), to control pressure; pressure relief flow (kg/s) to the letdown condenser to relieve over-pressure in the pressurizer.

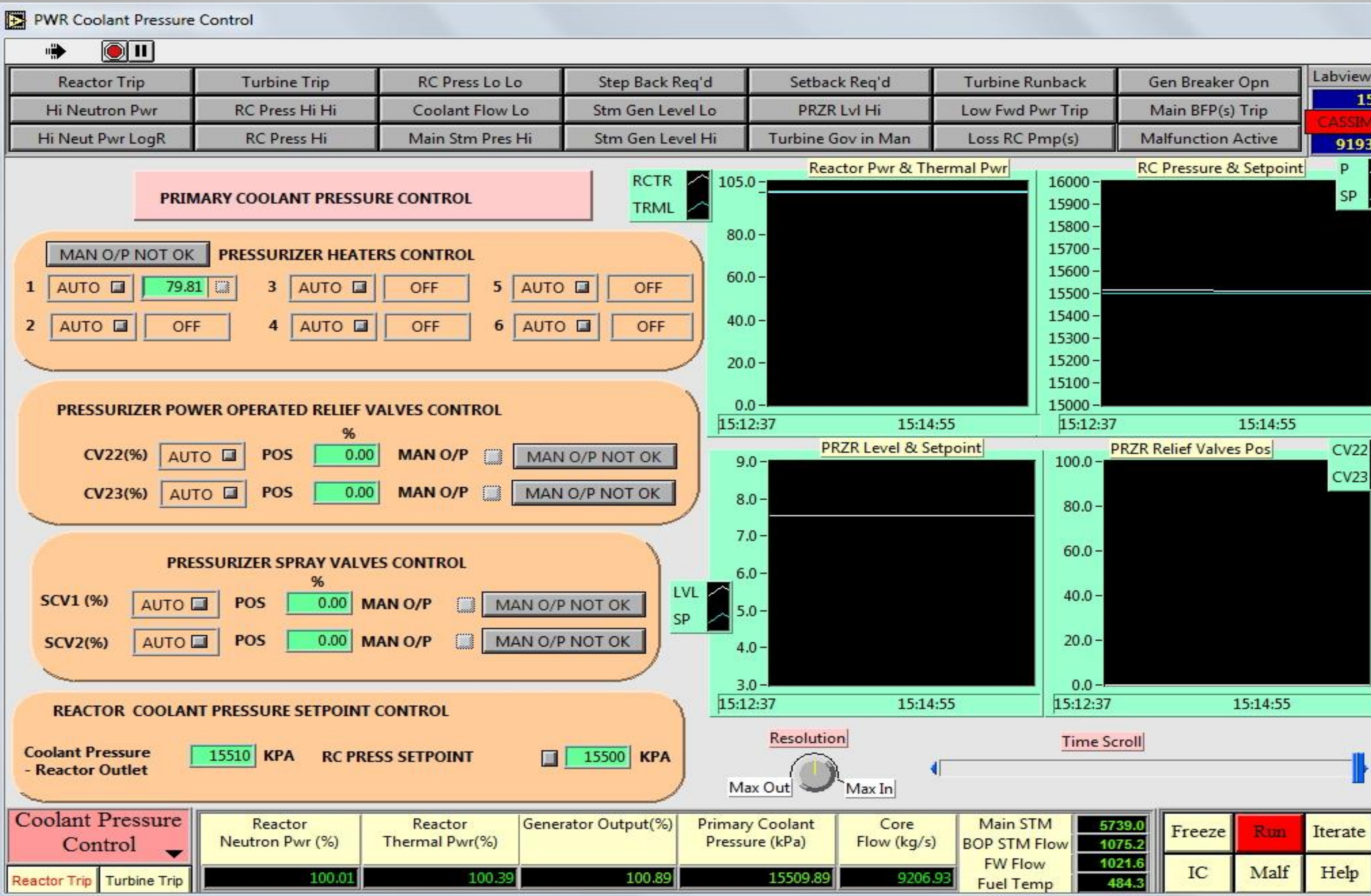
Reactor Coolant Inventory & Pressurizer Screen



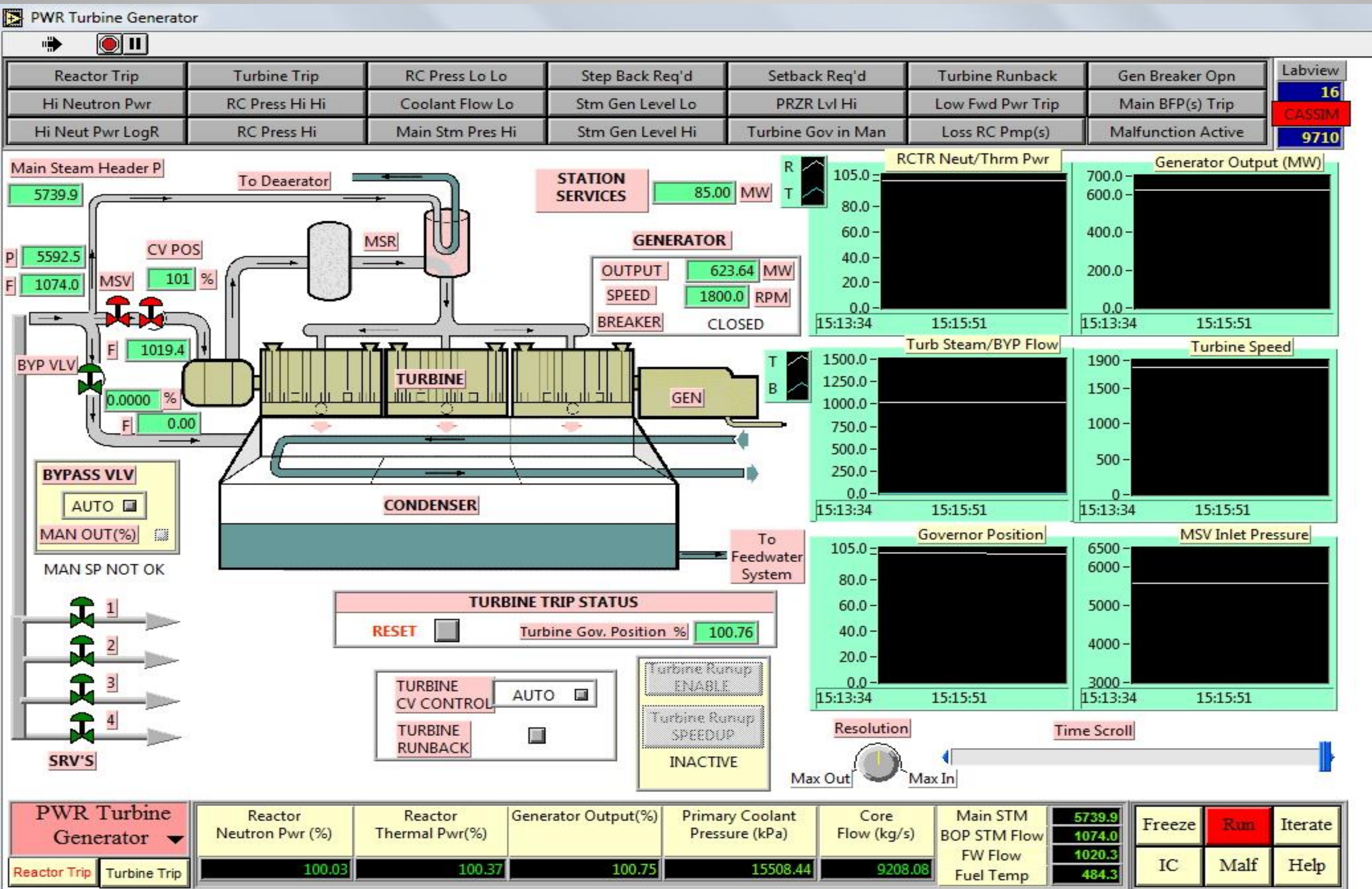
Reactor Coolant Inventory Control Screen



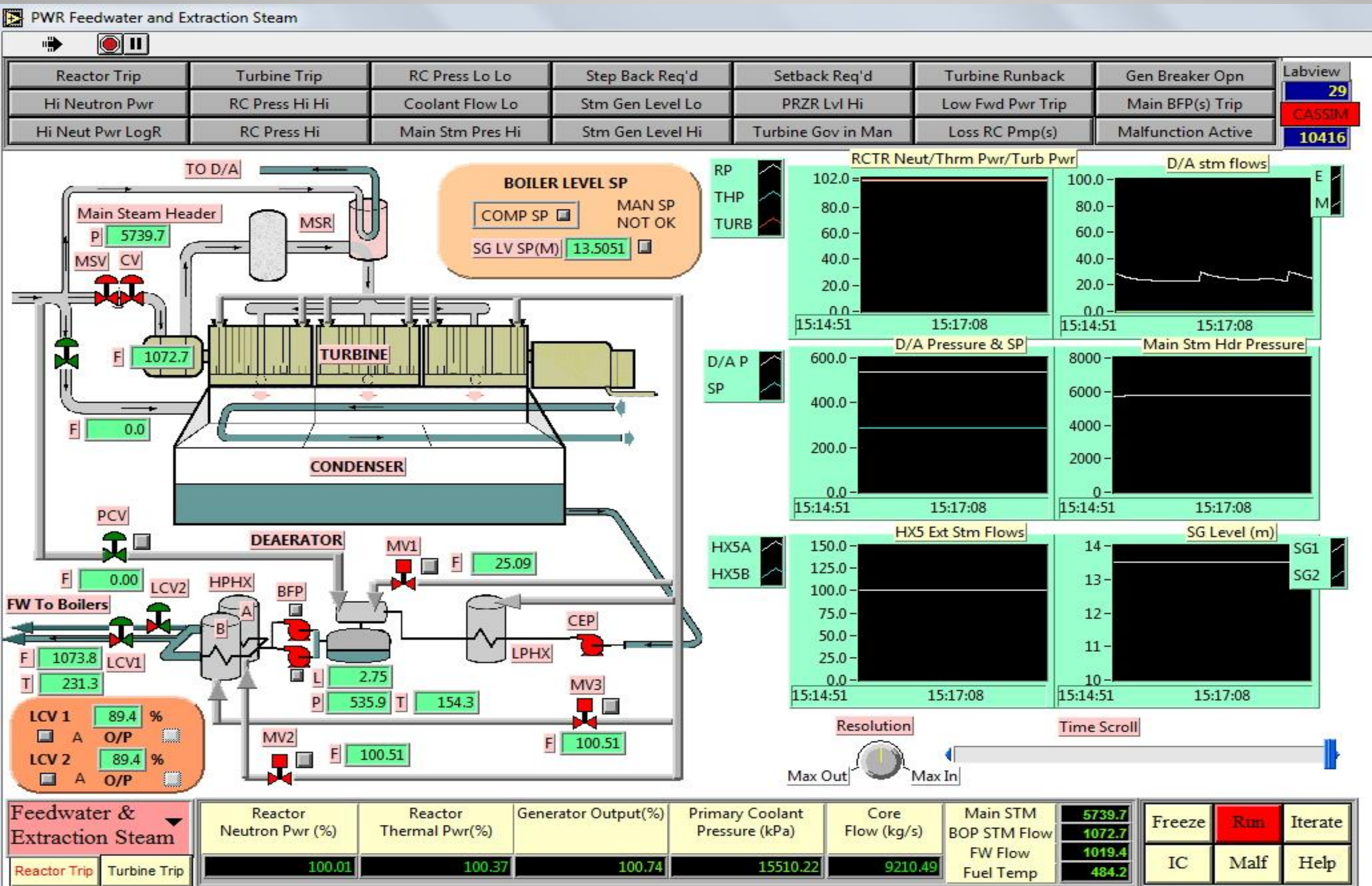
Reactor Coolant Pressure Control Screen



Turbine Generator Screen



Feedwater & Extraction Screen



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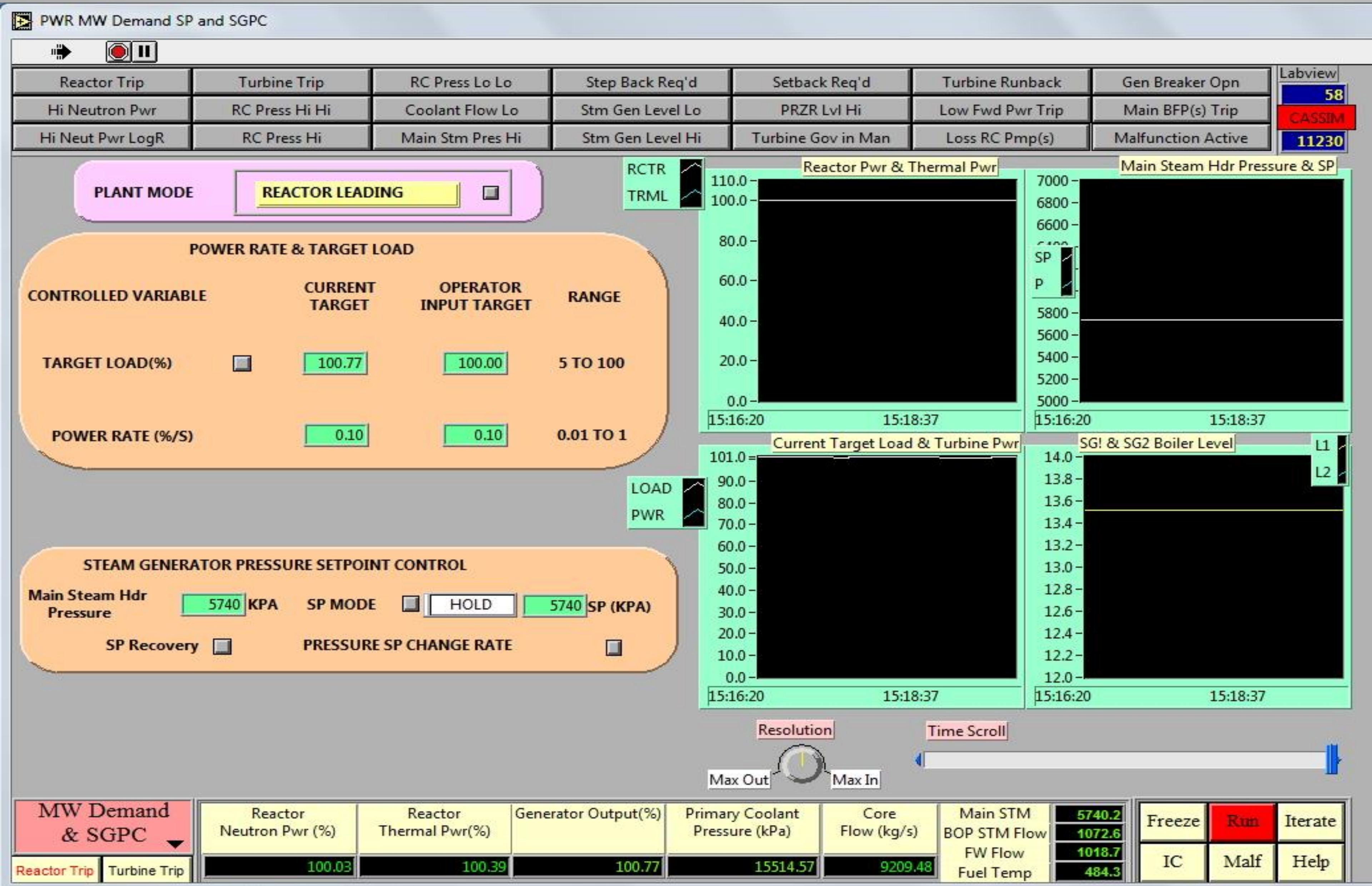
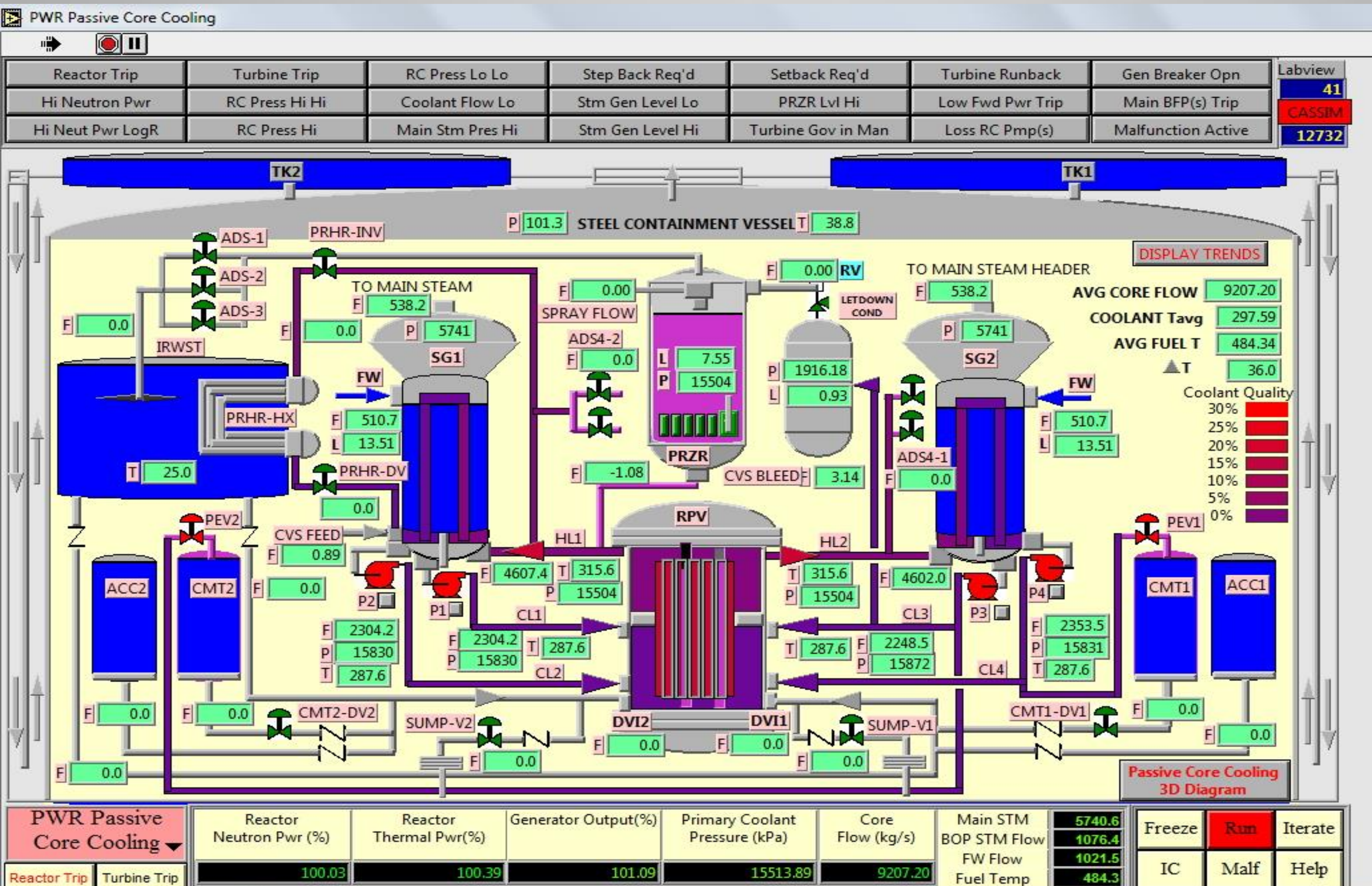
MW Demand & SGPC Screen



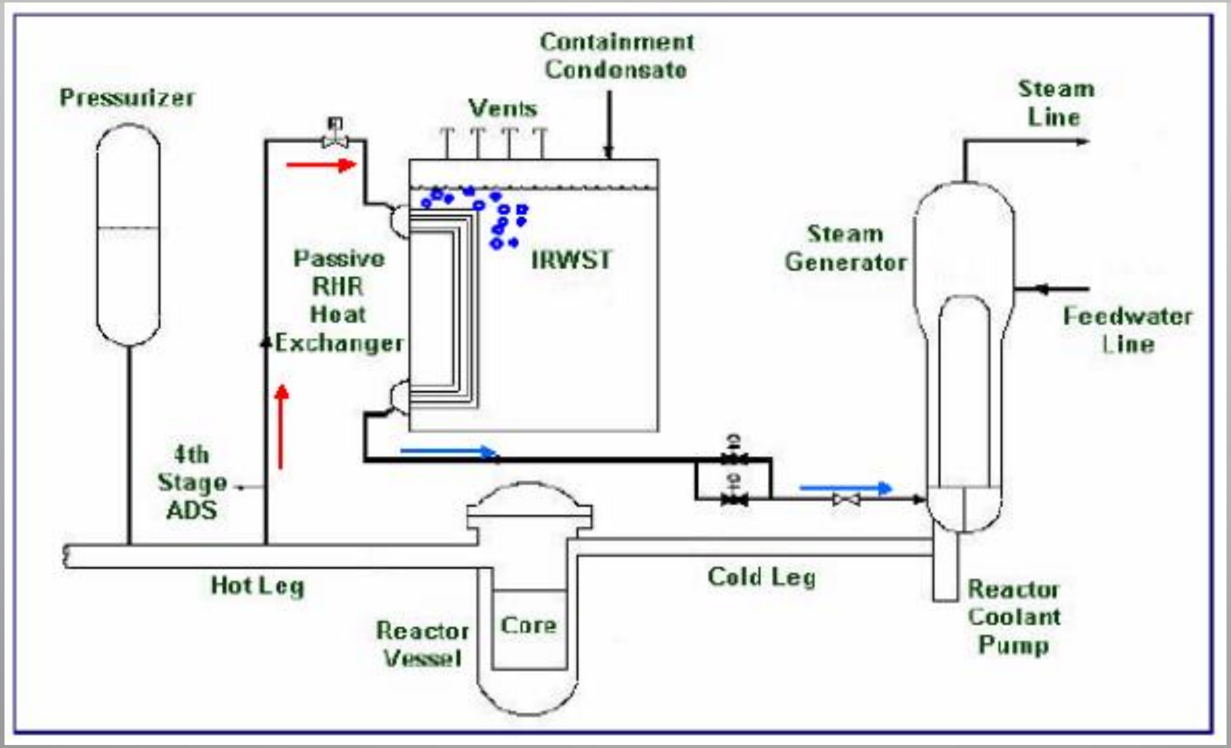
Passive Core Cooling Screen



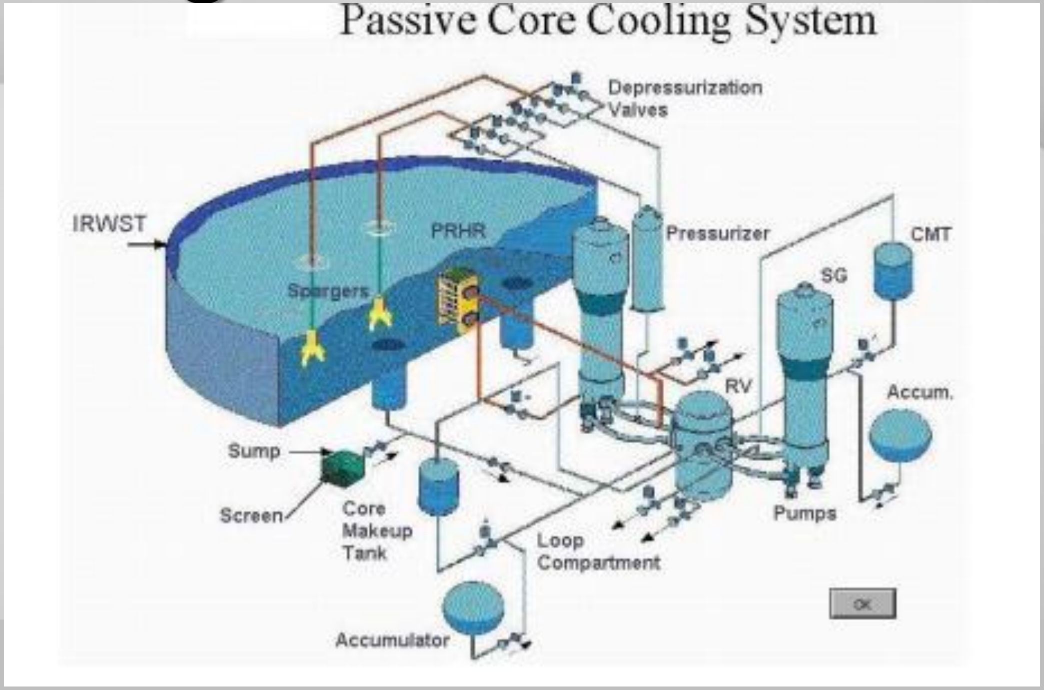
Passive Core Cooling Screen

Passive Residual Heat Removal (PRHR) System :

- Terdiri dari penukar kalor jenis C-Tube yang berada di dalam In-containment Refueling Water Storage Tank (IRWST), yang terisi air.
- Berfungsi untuk memindahkan panas dari teras melalui loop sirkulasi alamiah. Air panas naik melalui saluran masuk PRHR yang terpasang pada salah satu pipa hot legs. Air panas memasuki tubesheet di header atas penukar kalor PRHR pada tekanan dan suhu sistem penuh.



Passive Core Cooling Screen



Core Make-up Tank (CMT)

CMT secara efektif menggantikan high-pressure safety injection systems yang terdapat pada PWR konvensional. CMT terdiri dari tangki stainless steel volume besar dengan jalur inlet yang terhubung pada salah satu pipa cold legs ke bagian atas CMT dan jalur outlet yang terhubung pada bagian bawah CMT ke jalur Direct Vessel Injection (DVI). Jalur DVI terhubung ke downcomer bejana reaktor. CMT berisikan cold borated water. Katup inlet CMT secara normal terbuka dan karenanya CMT normalnya berada pada tekanan sistem primer. Katup outlet CMT secara normal tertutup, mencegah sirkulasi alamiah selama operasi normal. Ketika katup outlet terbuka, jalur sirkulasi alamiah terjadi. Air borat dingin mengalir ke bejana reaktor serta fluida primer panas mengalir ke atas dan masuk ke bagian atas CMT.

Passive Core Cooling Screen

Automatic Depressurization System (ADS)

ADS terdiri dari empat tahap katup yang berfungsi untuk pengurangan tekanan sistem primer secara terkendali. Tiga tahap pertama terdiri dari dua rangkaian katup yang terhubung ke bagian atas pressurizer. Tahap pertama terbuka pada level cairan CMT. Tahap ADS kedua dan ketiga terbuka segera setelahnya dengan mengikuti timer. Katup ADS 1-3 mengeluarkan uap sistem primer ke dalam saluran sparger yang mengalir ke IRWST. Uap tersebut dikondensasikan melalui kontak langsung dengan air yang sangat dingin di IRWST. Tahap keempat ADS terdiri dari dua katup besar yang terpasang pada saluran ADS pada setiap hot leg. Katup ADS-4 terbuka pada level cairan CMT rendah dan secara efektif menurunkan tekanan sisi primer ke kondisi tekanan containment. Katup ADS-4 mengalir langsung ke dalam ruangan bangunan containment.

Accumulators (ACC)

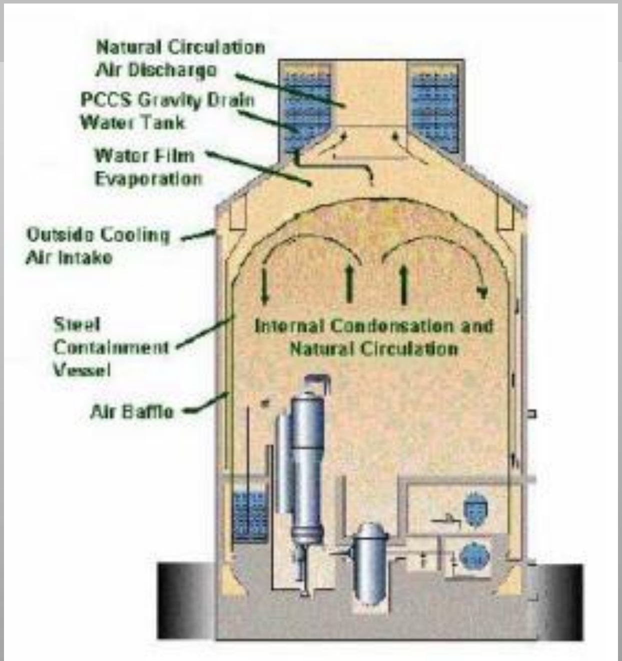
Akumulator ini mirip dengan yang ditemukan pada PWR konvensional. Akumulator ini berupa tangki bulat besar yang sekitar tiga perempatnya diisi dengan air dingin yang mengandung boraks dan diberi tekanan awal dengan nitrogen. Saluran keluar akumulator terhubung ke saluran DVI. Sepasang check-valve mencegah aliran injeksi selama kondisi operasi normal. Ketika tekanan sistem turun di bawah tekanan akumulator, check-valve terbuka sehingga memungkinkan injeksi cairan pendingin ke downcomer reaktor melalui saluran DVI.

Passive Core Cooling S

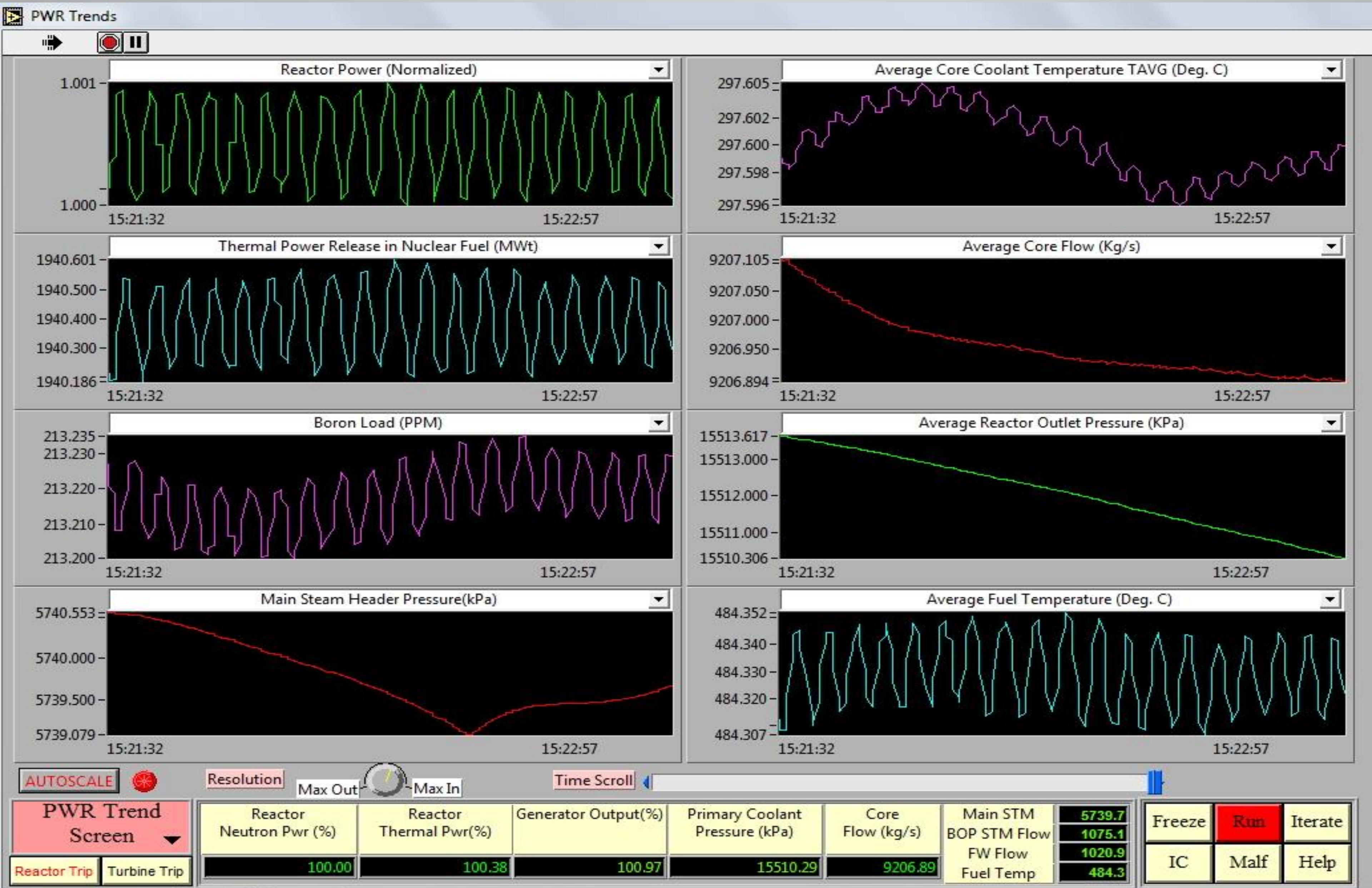
In-containment Refueling Water Storage Tank (IRWST)

IRWST adalah kolam beton yang sangat besar yang diisi dengan air dingin yang mengandung borat. Kolam ini berfungsi sebagai penyerap panas untuk penukar panas PRHR dan sumber air untuk injeksi IRWST. IRWST memiliki dua saluran injeksi yang terhubung ke saluran DVI bejana reaktor. Jalur aliran ini biasanya diisolasi oleh dua check-valve yang dipasang secara seri. Ketika tekanan primer turun di bawah tekanan air di IRWST, jalur aliran terbentuk melalui DVI ke downcomer bejana reaktor. Air IRWST cukup untuk membanjiri kompartemen containment bagian bawah hingga ke tingkat di atas kepala bejana reaktor dan di bawah outlet saluran ADS-4.

Containment and Passive Containment Cooling System (PCCS)



Reactor Trends Screen




thank you