

**Massachusetts Institute of Technology  
Department of Nuclear Science and Engineering**

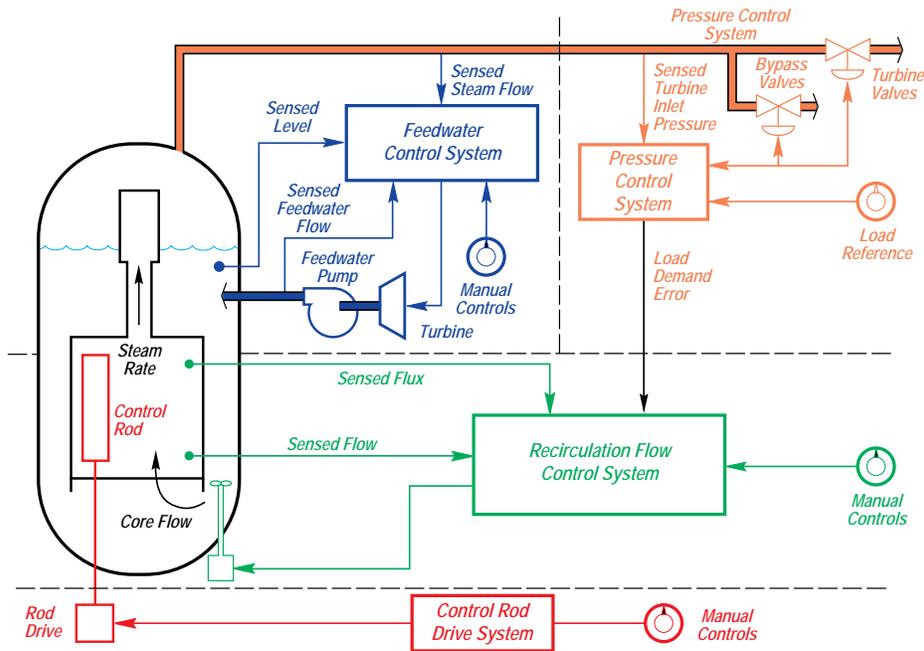
**22.06 Engineering of Nuclear Systems**

**Dynamic Behavior of BWR**

The control system of the BWR controls the reactor pressure, power and water level, as follows:

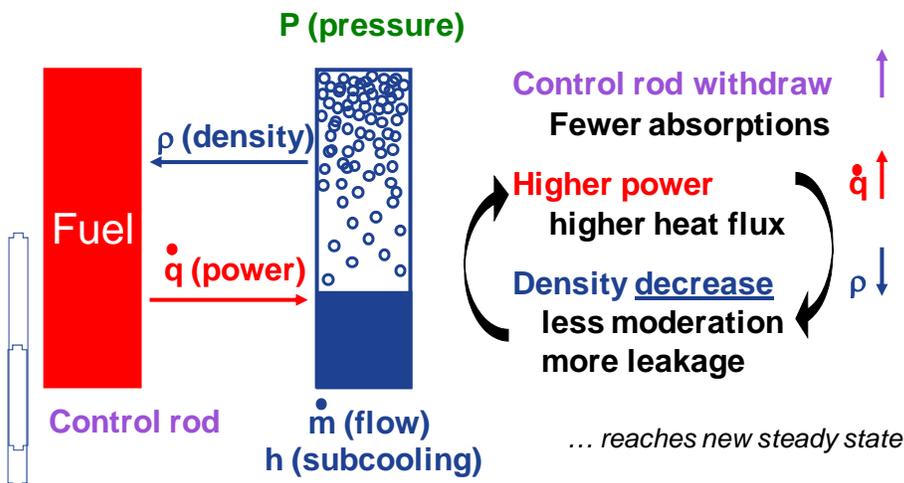
- The reactor pressure is controlled by the turbine control valves
- The reactor power (reactivity) is controlled by the recirculation pumps (via void reactivity feedback) and the Control Rods (CRs)
- The level is controlled by the Feed Water (FW) flow. Why do we want to control level?

A schematic of the BWR control system is shown below.



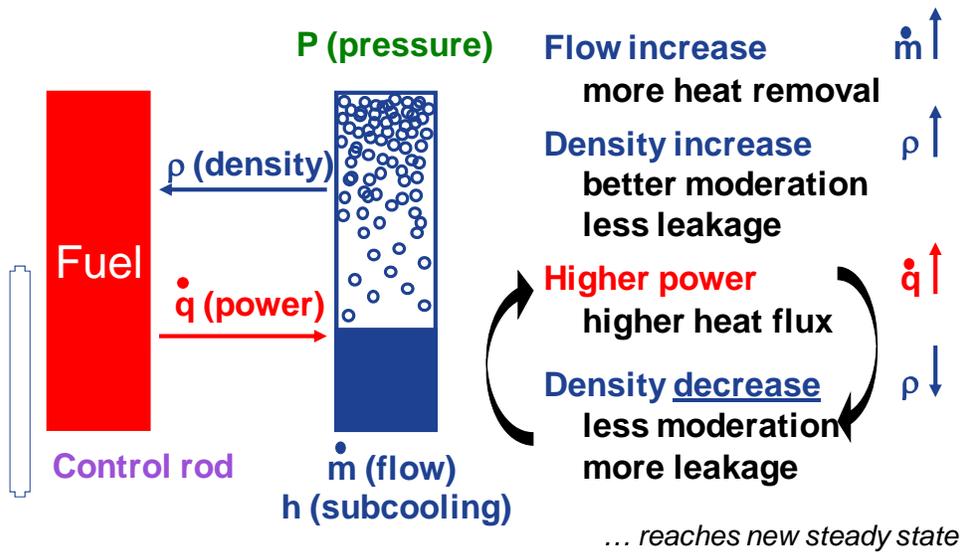
Courtesy of GE Hitachi Nuclear Systems. Used with permission.

How does the BWR respond to a change in CR position (e.g. CR withdrawal)?



Courtesy of GE Hitachi Nuclear Systems. Used with permission.

How does the BWR respond to a change in core flow (e.g. flow increase)?



Courtesy of GE Hitachi Nuclear Systems. Used with permission.

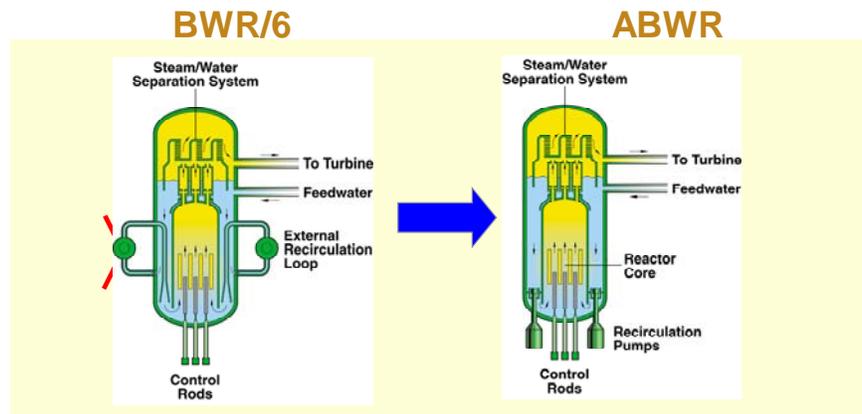
In both cases the void reactivity feedback takes the system back to a (different) steady-state condition.

Predict the response of the BWR to:

- (i) an increase in coolant subcooling at the core inlet (for example this could be caused by a decrease in the feedwater temperature)
- (ii) an increase in reactor pressure (for example, this could be caused by partially closing the turbine valve)
- (iii) an increase in turbine load. Without the control system, would the BWR naturally follow the turbine load?

# IAEA Simulator Quick Reference Guide

The IAEA BWR simulator simulates an Advanced Boiling Water Reactor (ABWR). ABWR has no external recirculation loops and pumps; uses internal pumps instead. The LB-LOCA is eliminated by design.



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## SIMULATOR STARTUP

- Select program 'BWR' for execution - the executable file is BWR.exe
- Click anywhere on 'BWR simulator' screen
- Click 'OK' to 'Load Full Power IC?'
- The simulator will display the 'Plant Overview' screen with all parameters initialized to 100% Full Power
- At the bottom right hand corner click on 'Run' to start the simulator

## SIMULATOR INITIALIZATION

If at any time you need to return the simulator to one of the stored initialization points, do the following:

- 'Freeze' the simulator
- Click on 'IC'
- Click on 'Load IC'
- Click on 'FP\_100.IC' for 100% full power initial state
- Click 'OK' to 'Load C:\BWR\_Simulator\FP\_100.IC'
- Click 'YES' to 'Load C:\BWR\_Simulator\FP\_100.IC'
- Click 'Return'
- Start the simulator operating by selecting 'Run'.

## LIST OF BWR SIMULATOR DISPLAY SCREENS

- (1) BWR Plant Overview
- (2) BWR Control Loops
- (3) BWR Power/Flow Map & Controls
- (4) BWR Reactivity & Setpoints
- (5) BWR Scram Parameters

- (6) BWR Turbine Generator
- (7) BWR Feedwater & Extraction Steam
- (8) BWR Trends

## GENERIC BWR SIMULATOR DISPLAY COMMON FEATURES

The generic BWR simulator has 8 interactive display screens or pages. Each screen has the same information at the top and bottom, as follows:

- The top of the screen contains 21 plant alarms and annunciations; these indicate important status changes in plant parameters that require operator actions;
- The top right hand corner shows the simulator status:
  - The window under 'Labview' (this is the proprietary graphical user interface software that is used to generate the screen displays) has a counter that is incrementing when Labview is running; if Labview is frozen (i.e. the displays cannot be changed) the counter will not be incrementing;
  - The window displaying 'CASSIM' (this is the proprietary simulation engine software that computes the simulation model responses) will be green and the counter under it will not be incrementing when the simulator is frozen (i.e. the model programs are not executing), and will turn red and the counter will increment when the simulator is running;
- To stop (freeze) Labview click once on the 'STOP' (red "Stop" sign) at the top left hand corner; to restart 'Labview' click on the  $\Rightarrow$  symbol at the top left hand corner;
- To start the simulation click on 'Run' at the bottom right hand corner; to 'Stop' the simulation click on 'Freeze' at the bottom right hand corner;
- The bottom of the screen shows the values of the following major plant parameters:
  - Reactor neutron power (%)
  - Reactor thermal power (%)
  - Turbine generator output power (Gross) (%)
  - Reactor pressure (kPa)
  - Core flow (kg/s)
  - Reactor water level (m)
  - Balance of plant (BOP) steam flow (kg/s) — that means steam flow after the main steam isolation valve
  - Feedwater flow (kg/s)
  - Average fuel temperature (Deg. C)
- The bottom left hand corner allows the initiation of two major plant events:
  - 'Reactor trip' or 'reactor scram'
  - 'Turbine trip' These correspond to hardwired push buttons in the actual control room.
- The box above the trip buttons shows the display currently selected (i.e. 'plant overview'); by clicking and holding on the arrow in this box the titles of the other displays will be shown, and a new one can be selected by highlighting it;
- The remaining buttons in the bottom right hand corner allow control of the simulation one iteration at a time ('Iterate'); the selection of initialization points ('IC'); insertion of malfunctions ('Malf'); and calling up the 'Help' screen (online hyperlinked "Help" is not

available yet). As a general rule, all dynamic display values shown in display boxes on the screens follow the following conventions:

- All pressure values are designated as “P” next to the display box, and have units of kPa;
- All temperature values are designated as “T” next to the display box and have values of deg. C;
- All flow values are designated as “F” next to the display box and have values of kg/s;
- Steam qualities are indicated as “X” next to the display box and have % as units.

Valve status and pump status as shown by dynamic equipment symbols are represented as follows:

- Valve status — red for valve fully open; green for valve fully closed; partial red and green indicates partial valve opening;
- Pump status — red for running; green for stopped.

## **Abnormal Events Studied with the IAEA BWR Simulator**

- Inadvertent withdrawal of control rods
- Total loss of feedwater flow
- Safety Relief Valve (SRV) fails open
- Reactor pump trip
- Steam line break

The IAEA BWR simulator has a more realistic control system than PRISM. In particular, it tries to stabilize the reactor following an abnormal event without scram, whenever possible. Why is scram generally undesirable?

### **Exercise 1: Inadvertent withdrawal of control rods**

Set reactor at 100% power in simulator

In the “Malfunction” menu select “Inadvertent Withdrawal of One Bank of Rods” with 5 s delay

Run simulation and observe reactor power (heat released in the fuel), steam quality, fuel temperature, pressure

Note the “high neutron power vs flow” warning sign, indicating operation in an abnormal region of the power/flow map

How does the control system react? Observe control rod reactivity and pump speed

### **Exercise 2: Total loss of feedwater flow**

Set reactor at 100% power in simulator

In the “Malfunction” menu select “Loss of Feedwater – Both FW Pumps Tripped” with 5 s delay

Do you expect the reactor to trip? If so, upon what signal?

Run the simulation and observe what happens. In particular observe reactor level and power. Why does the power zig-zag up and down? How would the power vary with time, if the control rods did not move?

Go to the BWR Scram Parameters. Why did the reactor trip?

Does the turbine also trip eventually?

### **Exercise 3: Safety Relief Valve (SRV) fails open**

Set reactor at 100% power in simulator

In the “Malfunction” menu select “SRVs on 1 Main Steam Line Fail Open” with 5 s delay

Run the simulation and observe what happens. In particular observe reactor pressure, reactor level and power.

Would the power go up or down, if the control rods did not move?

The reactor reaches a new quasi-steady state with half of the steam flow rate going to the suppression pool. Is this an acceptable situation in the long term?

### **Exercise 4: Reactor pump trip**

Set reactor at 100% power in simulator

In the “Malfunction” menu select “Power Loss to 3 Reactor Internal Pumps” with 5 s delay

Run the simulation and observe the variation of reactor power and steam quality.

What do the control rods do?

Does the reactor trip? Check out the power/flow map. Is the reactor in a stable region of the map?

### **Exercise 5: Steam line break**

Set reactor at 100% power in simulator

In the “Malfunction” menu select “Steam Line Break inside Drywell” with a 5 s delay

Run the simulation.

What is the first warning sign?

How can we surely determine it was a break?

What does the ECCS do following the break?

Why does the Main Steam Isolation Valve (MSIV) close?

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