SH2705 Compact Reactor Simulator- Exercises in Reactor Kinetics and Dynamics

Project Report: Predictions of Reactor Behavior

Aurora Jahan, Faisal Ahmed Moshiur

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Chapter 1

Introduction

This scientific report aims to investigate and predict the behavior of a generic Nordic Boiling Water Reactor (BWR) under two specific transient scenarios. The reactor model used for simulation consists of a core length of 3.7 meters and operates at a nominal power of 2500 MW. The reactor dynamics include six delayed neutron feedbacks, and decay heat is simulated according to the ANSI/ANS-5.1-1979 standard, correlated to the nominal power.

Reactor Model and Parameters

The simulation model for the reactor is based on the diffusion approximation with two energy groups (fast and thermal neutrons) to approximate the neutron flux. The reactor dynamics are time-dependent, and decay heat is accounted for according to the ANSI/ANS-5.1-1979 standard, correlated with the nominal power.

The reactor simulation model incorporates various scramming mechanisms directly coupled with accident-initiating events and deviations of key process parameters. The model includes important plant parameters and SCRAM limits, some of which are as follows:

Table 1.1: Plant parameters

Parameter	Value
Power	2500 MW_{th}
Pressure in steam dome	7.0 MPa
Recirculation flow rate	7800 kg/s
Feedwater flow rate	1350 kg/s
Water level above the core	4.3 m
Feedwater temperature	185 °C
Safety Release Valves flow rate	1200 kg/s

Table 1.2: SCRAM Limits and Properties

Property	SCRAM limit
High nominal power	$>$ 106%
Low coolant level	$<$ 3.1 m
High coolant level	$>$ 5.0 m
Steam Pressure	$>$ 7.4 MPa
Wetwell liquid temperature	$>$ 35 °C

Chapter 2

Case 1- manual activation of the reactor SCRAM

2.1 Description

In this case, we consider a scenario where operators manually scram the reactor during regular operation at nominal power. The manual SCRAM initiates a rapid shutdown of the nuclear reactions, leading to a series of changes in various system parameters within the reactor.

2.2 Predictions

Power

The control rods will be lowered into the core in a manual SCRAM. So the neutrons responsible for causing fission will be absorbed by the control rods. Thus, the fission rate will decrease.

Reactor power is the energy produced in unit time from the fission reaction. Thus, if the fission rate decreases, the reactor power will decrease.

Pressure

The energy deposited into the coolant per unit of time decreases when the power decreases. So the coolant water will not boil as much as before. Thus the steam production rate will decrease.

If the steam production rate decreases, the pressure will decrease.

Void fraction

When the reactor power decreases, less water will boil in the core. Thus, the void fraction will decrease.

Main recirculation flow rate

The recirculation flow control system's (RFCS) purpose is to control the recirculation system flow rate through the reactor core.

This system will sense and slow down the recirculation pump when the power decreases. The logic for this is that if not as much heat as before is being produced, there is less need for cooling the core.

So, the main recirculation flow rate will decrease when the recirculation pumps slow down.

Steam flow rate

After the SCRAM, the reactor will not produce as much power. So the steam production rate will decrease. With decreased steam production, the steam flow rate will decrease as well.

Water level

At first, when the reactor power sharply decreases, less water will be evaporated. So the amount of water in the RPV will increase, so the water level will initially increase.

But less water will be pumped into the RPV when the feedwater flow rate decreases. Thus, the water level will start to decrease.

But the auxiliary feedwater system will start when it reaches the 3.1 m SCRAM condition. So the water level will be restored.

Feedwater flow rate

The feedwater control system regulates feedwater flow to the reactor vessel to maintain the reactor water level. When the reactor water level initially rises, and the steam flow rate decreases, the feedwater control system will sense these changes. It will decrease the feedwater flow rate accordingly.

Auxiliary feedwater system (AFWS)

When the water level gets close to the 3.1 m SCRAM condition, the auxiliary feedwater system will start, restoring the water level.

Automatic depressurization system (ADS)

The purpose of the Automatic Depressurization System (ADS) is to rapidly lower reactor pressure in case of emergency. When the reactor pressure gets close to the 7.4 MPa, the ADS will start and depressurize the RPV even more. So the pressure will go down again.

Chapter 3

Case 2- Feed water enthalpy decrease

3.1 Description

In this case, we consider a scenario with a gradual decrease in feed water enthalpy during normal operation at nominal power. This situation is caused by the loss of feedwater preheaters, reducing the feedwater temperature from 185 °C to 161.5 °C over 60 seconds. This analysis aims to understand the system's response to such a feedwater enthalpy decrease and its impact on various parameters within the reactor.

3.2 Predictions

Power

When the feedwater preheater is not functioning, the feedwater coming into the RPV will be colder than normal. Due to the negative coolant temperature coefficient, the negative change in coolant temperature will cause a positive change in reactivity. This will increase the power of the reactor initially.

But when the reactor power increases, the recirculation pump will be slowed down by the recirculation flow control system to control the rise in power. This will reduce the power for some time.

But the continued decrease in incoming coolant temperature will cause a continued increase in reactivity. So the power will increase again, followed by further slowing down of the recirculation pump.

If the recirculation pump reaches 0 rpm, but the power is still increasing, at some point, the power will hit the 106% SCRAM condition, and the reactor will SCRAM.

Fuel and cladding temperatures

Due to increased power at the initial phase, the fuel and cladding temperatures will also increase initially. The rise and fall in power may influence the fuel and cladding temperature.

Void fraction

When the reactor power increases, more water will boil in the core. Thus, the void fraction will increase. However, the boiling rate and the void fraction will decrease when the recirculation pumps slow down to decrease power.

Main recirculation flow rate

The recirculation flow control system (RFCS) is responsible for controlling the speed of the recirculation pump to control the reactor power.

Every time the reactor power increases due to the coolant temperature decrease, the recirculation pump will be slowed down. So the recirculation flow rate will decrease in steps.

Steam flow rate

The steam production rate will increase when the reactor power increases at first. So the steam flow rate will increase. But when the recirculation pumps slow down to decrease the power, the steam flow rate will also decrease. However, if SCRAM happens at any point, the steam flow rate will decrease sharply.

Water level

Firstly, the temperature decrease of the coolant will reduce its volume. In addition, when the power increases, the steam production rate will increase. So the water level in the RPV will decrease.

Pressure

The pressure in the system will decrease due to a reduction in water level. But contrary to this phenomenon, when the power increases and causes a higher rate of steam production, the pressure will rise. So these two phenomena will act against each other, and the pressure will follow the dominant effect.

Feedwater flow rate

The feedwater control system regulates feedwater flow to the reactor vessel to maintain the reactor water level. When the reactor water level initially decreases and the steam flow rate increases, the feedwater control system will sense these changes and increase the feedwater flow rate accordingly.

Auxiliary feedwater system (AFWS)

If the water level gets close to the 3.1 m SCRAM condition, the auxiliary feedwater system will restore the water level.

Automatic depressurization system (ADS)

If the reactor pressure gets close to the 7.4 MPa SCRAM condition, the ADS will start and depressurize the RPV even more. So the pressure will go down again.

Chapter 4

Conclusion

In this report, we studied the dynamic behavior of Nordic BWRs under two specific transient scenarios- manual SCRAM and enthalpy decrease of the coolant. For each scenario, we predicted the behavior of the reactor in terms of power, pressure, recirculation flow rate, feedwater flow rate, steam flow rate, void fraction, water level, auxiliary feedwater system, and the automatic depressurization system. By making these predictions, we have prepared ourselves to look at the corresponding simulation results and validate our hypotheses about the dynamic behavior of the model that has undergone the transient scenarios.