Chapter 2

GENERAL CONCEPTS

2.1 INTRODUCTION

This part of the course aims at giving the student an understanding of the actions of the Reactor Regulation System (RRS). It is based on the specific RRS of the CANDU-6 reactor. There exists marked differences between different reactor types, because of technological advances, and the philosophy of the designer groups. However, once a given RRS is understood, it is not very difficult to understand the variations for other reactors.

We will not delve on control theory in this part of the course. We will not determine why specific values of some gains for example have been chosen within different control algorithms. Such an approach is necessary when a new regulating system is being designed, and it is the subject of many specialized studies. As far as we are concerned, it is more important to develop the ability to predict and understand the behavior of an existing complex system, rather than build an entirely new control system.

Furthermore, in order to limit the description complexity, the control algorithms we be described in their normal operating conditions, for example for reactor powers ranging between about 1% Full Power and 100% FP. We will stay away from powers of 0.000001% FP and the special control modes necessary in these circumstances. Similarly, critical approach and the special start-up instrumentation will not be discussed in this course. A # 1.

2.2 OBJECTIVES OF THE REACTOR REGULATING SYSTEM

The Reactor Regulating System (RRS) has many functions and aims many objectives simultaneously. The reactor itself produces all the energy of the power plant. It is thus very important to keep the 2050 MWth that are being generated under close surveillance.

In normal conditions, the regulating system aims, among other things, to maintain the reactor critical. It will thus have to compensate the different phenomena that tend to make the core super critical or sub critical.

One of the main task or the regulating system will then consist in maintaining the reactor power at a level fixed by the operator, while taking into account the status of all the plant systems. it goes without saying that a reactor that could not maintain power, ie an unstable core, would be of no practical interest, because public safety could not be insured or the desired constant electrical energy output would be unachievable.

Another regulating system function is to adequately maintain the power distribution in the core. In fact, the CANDU-6 is divided into fourteen control zones; each of these zone has a target power, determined by the designer. This is to prevent negative effects, on the fuel for example, of having high powered zones neighboring zones at low power, the total power remaining constant. When power tilts occur, corrective measures are immediately taken, automatically, to prevent them from developing.

Another task or the regulating system is to determine and prevent, if possible, too fast variations of different parameters. This is to prevent spurious shutdown system activation. Shutdown systems are designed to rapidly stop the fission reaction in the core; this is to ensure public safety. They should not be solicited by events induced by normal regulation.

The regulating system also permits to obtain much information about the reactor, by posting measured or calculated parameter values, or by emitting alarms, when certain parameter levels are attained. The regulating system also permits changing the values of different parameters by following operating procedures. The man-machine interface permits the operator to do this with relative ease.

2.3 SPACE-TIME EFFECTS

The only way to predict the dynamic behavior of a nuclear reactor during transients, and to obtain a final stable state is to utilize the methods of space-time kinetics coupled to thermal hydraulics in three dimensions. Such tools exist, with different levels of complexity for the purposes of safety calculations, design calculations, or training simulators.

Point kinetics is widely used to understand the behavior of a nuclear reactor, reduced (theoretically) to a single point. The assumption here is that the spatial shape of the neutron flux does not change during transients. The most important parameter in point kinetics is the reactivity, and reactivity appears in most discussions concerning core dynamics; we will not escape using it in this course. We should keep in mind that reactivity is not directly observable or measurable, and by consequence, reactivity per se is not taken into account by RRS. The concept of reactivity is used to give explanations in a quasi quantitative manner of reactor behavior. It is also used to compare relative efficacy of absorbing devices.

This being said, a nuclear reactor operated at a non-zero power level undergoes many different perturbations continually. The fuel, when exposed to neutrons suffers variations in absorption and production rates. This comes from fission product evolution; fission products can also be fissile elements themselves. The exact distribution of these fission products depends on the flux history to which the fuel has been exposed. This is referred to as fuel burn-up. A variation in the level of the liquid controllers is required to compensate for this. We say that the variation in reactivity due to burn-up of the fuel is compensated in the other direction by the reactivity of the zone controllers. Burn-up effects are mostly global, and affect almost identically all control zones.

When fuel in channel reaches the end of its useful life in the core, it is replace by new fuel. These refuelings, numbering about two per day, generate local effects tending to increase power, which has to be compensated if total power is to be maintained at a constant value.

Xenon, which is a very strong absorber of thermal neutrons, causes particular problems to the operation of a nuclear power plant. First, during power maneuvers, Xenon will tend to increase the effect of the maneuver: if power is being reduced, Xenon will make it reduce further, and conversely, if power is increased, Xenon will make it increase even more. This is a global phenomenon. Furthermore, a local power variation will induce oscillations in the Xenon concentration, with a period of about twenty four hours; RRS will have to compensate adequately to prevent these oscillations.

Thermal hydraulic feedback effects, such as density, void and temperature of coolant, as well as fuel temperature and moderator temperature generate both local and global effects which will have to be compensated as well.

2.4 CONTROL METHOD

The control of the reactor is base essentially upon observable variables, such as flux detector readings, temperature , pressure, flow, level and position "detectors". These parameters are processed electronically (amplified, filtered...) and sent to the control computers. The different control algorithms in turn read the values of these parameters, as well as the results of the calculations performed by the algorithms themselves, and by their programmed logic, determine the desired positions of the different devices (in a general sense). Changes in setpoints are sent for example to the zone controllers, the adjuster rods, the absorber rods, to the addition system of boron and gadolinium. The center of all these activities is the control room, which is divided in different areas, or panels, reporting specific information on the main systems of the power plant.

Reactor control and the man-machine interface are executed within the control computers, numbering two, named DCCX and DCCY ("Digital Control Computer") These two computers, X and Y, are identical and perform the same calculations. Normally, the X computer performs the actual control. If X fails, then Y would automatically take this actual control.

2.5 REACTOR REGULATING SYSTEM

The control of the reactor is performed by a computer program residing in DCCX (and also in DCCY). This program is known as RRS. This program is the entity which will be studied in this course.

RRS is really made up of many components, of which the most important ones are:

- Program MCP : Power Measurement and Calibration
- Program CEP : Power Error Calculation

- Program CBL : Zone Level Control
- Program CBC : Adjuster Control
- Program CBS : MCA Control
- Program FLU : Neutron Flux Mapping
- Program BCP : Power Setback
- Program EBA : Shut-off rod removal

Each of these eight programs is in turn divided in two parts. There is a slow part, executed every two seconds, and a fast part, executed each half second. The collection of the slow parts is known as Slow Regulation of the Reactor (SRR). The collection of the fast parts is known as Fast Reactor Regulation (FRR). The one exception to this rule is the FLU program, whose complete execution is so long that it is only partially executed at each forty seconds, and completed every two minutes.

The sequence of execution is determined by an administrator program, and is not always done in the same order. It is instead determined by the relative importance of the different tasks to accomplish within the remaining time window.

There exists another program, the Reactor Stepback, which is not strictly part of the reactor regulating system. It is executed every 0.5 seconds, and if it is acting on devices, it is then performed every 0.25 seconds. Reactor Stepback is used to rapidly insert the mechanical absorbers in the core when certain undesirable conditions appear in the power plant or the core.

2.6 SHUTDOWN SYSTEMS

We note that there are two shutdown systems:

- shutdown system # 1, SDS1, which acts by quickly inserting 28 shutoff rods in the core
- shutdown system # 2, SDS2, which acts by adding liquid poison at high pressure in the moderator