



3. *Detector Systems*

- ◆ **This chapter describes the CANDU detector systems.**



3.1 Zone-Control Detectors

- ◆ **To vary the amount of water in the zone-control compartments,**
- ◆ **the Reactor Regulating System utilizes the readings of detectors associated with the zone controllers.**
- ◆ **These are fast-response platinum detectors, placed interstitially between fuel channels.**



3.1 Zone-Control Detectors

- ◆ **There is one detector (plus one spare) for each zone-control compartment.**
- ◆ **Each detector is located close to the midpoint of the zone-control compartment to which it is associated (see Figure 3.1).**



3.1 Zone-Control Detectors

- ◆ **To determine changes required in the water fills of the various compartments,**
- ◆ **the RRS compares the 14 instantaneous detector readings, ϕ_i ,**
- ◆ **with a set of reference readings, ϕ_i^{ref} , corresponding to the desired power distribution at full power.**



3.1 Zone-Control Detectors

- ◆ **In the bulk-control function,**
- ◆ **the average of the 14 readings ϕ_i is used as the indicator of current power,**
- ◆ **and the water fills in all compartments are uniformly increased or decreased**
- ◆ **to move the reactor power down or up to the desired power.**
- ◆ **Bulk control is exercised automatically by the RRS every half second.**



3.1 Zone-Control Detectors

- ◆ **In the spatial-control function,**
- ◆ **the relative values of the ϕ_i are compared to the reference relative values**
- ◆ **to determine the reactor zones in which the flux is low (i.e., in which power should be raised),**
- ◆ **and those in which it is high (i.e., in which power should be reduced).**



3.1 Zone-Control Detectors

- ◆ **The water fills are then moved differentially.**
- ◆ **In zones where power is to be increased the water level is lowered,**
- ◆ **and where power is to be decreased the water level is raised.**
- ◆ **The RRS exercises the spatial-control function automatically every 2 seconds.**



3.1 Zone-Control Detectors

- ◆ **Because the zone-control detectors provide essentially “point” readings in the core**
- ◆ **(the detectors are 3 lattice pitches long but span a very small part of each zone),**
- ◆ **it is legitimate to ask whether they represent fairly the zones to which they are associated.**
- ◆ **In order to ensure that the readings used by the RRS do reflect zone-average values,**
- ◆ **the zone detectors are calibrated every two minutes to zone fluxes obtained by the on-line flux-mapping program (see Section 3.3).**



3.2 Neutronic Protection System

- ◆ **CANDU reactors are equipped with protection systems which detect an emergency situation**
- ◆ **and actuate the safety system(s) discussed in the previous Section.**
- ◆ **The CANDU-6 neutronic protection systems are described here.**



3.2 Neutronic Protection System

- ◆ **There is a separate neutronic protection system for each of the two shutdown systems.**
- ◆ **Each protection system is triplicated and consists of out-of-core ion chambers**
- ◆ **and in-core self-powered detectors.**



3.2 Neutronic Protection System

- ◆ **Triplication means that there are three separate “logic” (or “safety”) channels for each protection system.**
- ◆ **These channels are labelled D, E, and F for SDS-1**
- ◆ **and G, H, and J for SDS-2.**
- ◆ **In each protection system, it suffices that two of the three logic channels be “tripped” for the corresponding shutdown system to be actuated.**



3.2 *Neutronic Protection System*

- ◆ There are three ion chambers in each protection system, one per logic channel.
- ◆ The ion chambers are located at the outside surface of the calandria (see Figure 3.2).
- ◆ Each ion chamber trips its logic channel when the measured rate of change of the logarithm of the flux,
- ◆ i.e. the quantity $\frac{d \ln \phi}{dt}$
- ◆ exceeds a pre-determined setpoint (e.g. 10% per second, i.e., 0.10 s^{-1} , for SDS-1 in the CANDU 6).



3.2 Neutronic Protection System

- ◆ **There are also a number of fast-response (platinum or inconel) in-core detectors in each protection system:**
- ◆ **34 for SDS-1, located in vertical assemblies (see Figures 3.3a, 3.3b and 3.3c),**
- ◆ **and 24 for SDS-2, located in horizontal assemblies (see Figure 3.4).**



3.2 Neutronic Protection System

- ◆ **The detectors are distributed among the various logic channels,**
- ◆ **so that channels D, E and F contain 11 or 12 detectors each,**
- ◆ **while channels G, H, and J contain eight each.**



3.2 Neutronic Protection System

- ◆ **The detectors trip the logic channels on high neutron flux:**
- ◆ **when the reading of any one detector reaches a pre-determined setpoint, the logic channel to which it is connected is tripped.**
- ◆ **Because the in-core detectors are designed to protect the reactor against high local flux,**
- ◆ **the in-core-detector system is sometimes referred to as the regional-overpower-protection (ROP) system.**



3.2 Neutronic Protection System

- ◆ **The setpoints of the in-core detectors are determined by an extensive analysis of hypothetical loss-of-regulation (LOR) accidents.**
- ◆ **The analysis involves the calculation of hundreds of different flux shapes which can apply in the reactor.**



3.2 Neutronic Protection System

- ◆ **The ROP setpoints are designed to protect against critical values of channel power being reached;**
- ◆ **the current criterion for critical channel power is fuel dryout.**
- ◆ **The setpoints must also ensure the efficacy of the shutdown systems**
- ◆ **in arresting the power pulse which follows a hypothetical loss-of-coolant accident.**



3.2 Neutronic Protection System

- ◆ **In summary, there are two separate ways in which a protection-system logic channel can be tripped:**
- ◆ **on a high rate of log neutron flux at the corresponding ion chamber, and**
- ◆ **on high neutron flux at any one detector belonging to the logic channel.**



3.2 Neutronic Protection System

- ◆ **A shutdown system is actuated whenever two of the three corresponding logic channels are tripped.**
- ◆ **The triplicated tripping logic described here is shown schematically in Figure 3.5.**
- ◆ **The triplication assures an extremely high reliability of shutdown-system actuation under accident conditions.**
- ◆ **The triplication also allows on-line testing of the electronics in the logic channels**



3.3 Flux-Mapping System

- ◆ **The CANDU 6 is provided with a flux-mapping system**
- ◆ **to synthesize the 3-dimensional flux distribution in the reactor from in-core detector readings.**
- ◆ **The system consists of 102 vanadium detectors placed at various positions in the core (see Figure 3.6).**
- ◆ **Each detector is one lattice pitch long.**



3.3 Flux-Mapping System

The flux-mapping procedure consists of assuming the 3-dimensional flux distribution can be written as a linear combination of a number of basis functions or flux modes,

- ♦ i.e. that the thermal flux at any point in the core, (r), can be expressed as a linear combination of flux modes $\psi_n(r)$:**

$$\phi(r) = \sum_{n=1}^m A_n \psi_n(r) \quad (3.1)$$

- ♦ where m = number of modes and A_n is the amplitude of mode n .**



3.3 Flux-Mapping System

- ◆ Using this linear expansion, the mode amplitudes A_n are determined
- ◆ by a least-squares fit of the calculated fluxes at the 102 detectors to the measured fluxes.
- ◆ For a detector d at position r_d , the mapped flux is, from Eq. (3.1):

$$\phi(r_d) = \sum_{n=1}^m A_n \psi_n(r_d) \quad (3.2)$$

- ◆ and this can be compared to the measured flux at the detector, F_d .



3.3 Flux-Mapping System

- ◆ **The flux-mapping procedure determines the amplitudes A_n by minimizing the sum of squares of differences between the mapped and measured fluxes, i.e. minimizing**

$$\varepsilon = \sum_{d=1}^{102} w_d (\phi_d - F_d)^2 \quad (3.3)$$

- ◆ **where the w_d are chosen weights.**



3.3 Flux-Mapping System

- ◆ **Once the amplitudes have been evaluated,**
- ◆ **the flux at any point in the reactor can be calculated very easily from Eq. (3.1).**
- ◆ **Thus, the 3-dimensional flux and power distributions in the core can be derived.**
- ◆ **The flux-mapping procedure is very quick.**



3.3 Flux-Mapping System

- ◆ **The flux modes $\psi_n(\mathbf{r})$ used in flux mapping consist in the first instance of a number (~ 15) of**
- ◆ **pre-calculated harmonics of the neutron diffusion equation.**
- ◆ **These harmonics represent various possible global perturbations of the flux distribution (see Figure 3.7).**



3.3 Flux-Mapping System

- ◆ **For situations in which the reactor is operated with mechanical control absorbers in-core or adjusters out-of-core,**
- ◆ **the harmonics are complemented by a number of “device modes” which represent the more localized perturbations due to device movement.**



3.3 Flux-Mapping System

- ◆ **The flux-mapping procedure is carried out automatically in the on-line computer every two minutes.**
- ◆ **It provides the mapped values of average zonal flux to the regulating system.**
- ◆ **These zonal fluxes are used to calibrate the zone-control detectors,**
- ◆ **to ensure that the readings of the zone detectors faithfully represent the overall flux distribution in the reactor.**



3.3 Flux-Mapping System

- ◆ **Flux mapping can also be done “off line”,**
- ◆ **using recorded flux measurements at the detectors**
- ◆ **corresponding to any desired time in the reactor history.**