



---

# Core Physics in Safety Analysis

B. Rouben

Senior Reactor-Physics Consultant

AECL

2005 September



# Physics Analysis for NOP System

---

The NOP (Neutron Overpower Protection) System is basically designed to protect the core against a loss of regulation (LOR).

In an LOR, the Reactor Regulating System loses control of the reactivity, and therefore potentially of the power.

If the reactivity becomes negative, the reactor shuts down and there are no serious consequences.

However, if the reactivity becomes positive, the power will increase; if left unchecked, the increase may lead to damaging fuel overpower.

cont'd



# Physics Analysis for NOP System

---

- The NOP system is a double system: one for each emergency shutdown system.
- It consists of in-core detectors distributed through the core. These measure the local neutron flux. The system can therefore sense a global or a local power increase.
- The “mission” of the NOP system is to prevent dryout in any fuel channel by initiating a reactor shutdown when detector readings rise to appropriate “trip setpoints”.

cont'd



# Physics Analysis for NOP System

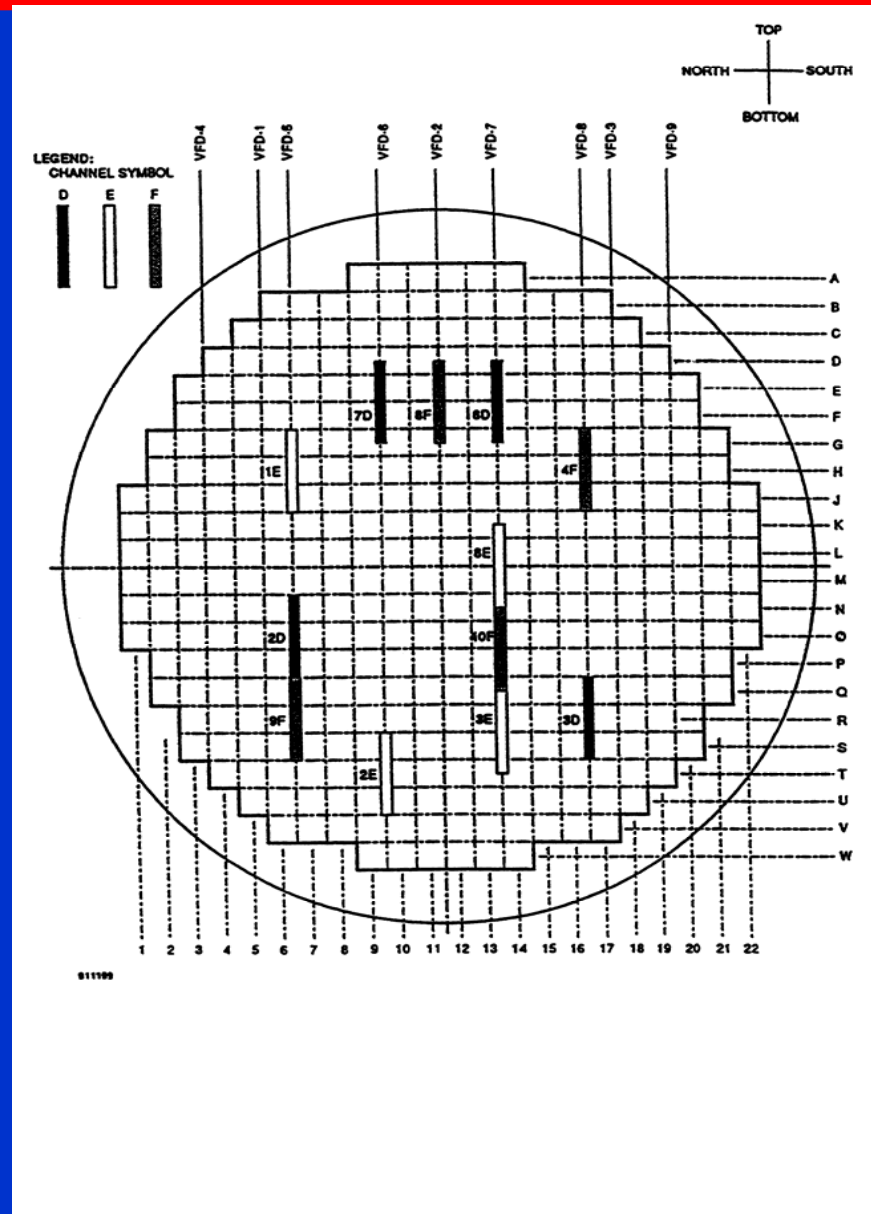
---

- The CANDU 6 ROP system has:
  - 34 detectors for SDS-1, in vertical penetrations
  - 24 detectors for SDS-2, in horizontal penetrations
- See examples of detector locations in the C-6 core in the next Figure.

cont'd

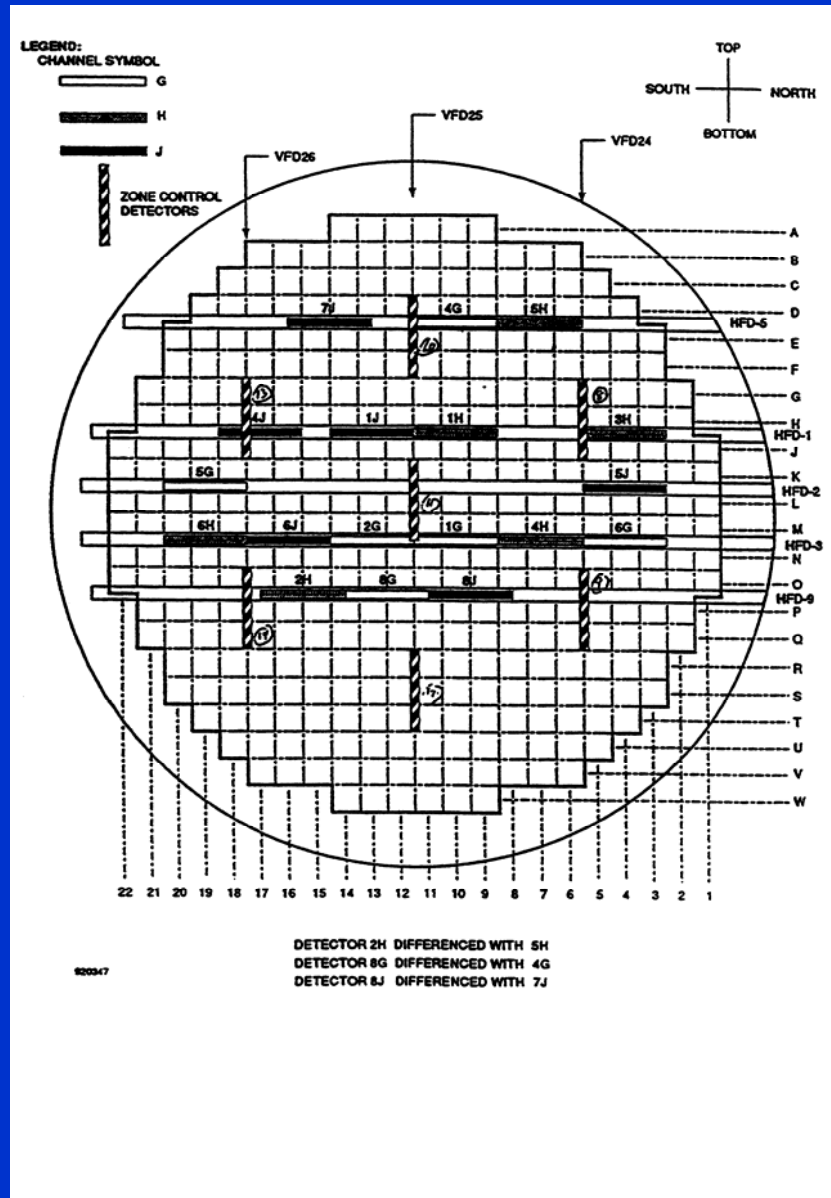


# Location of Some Vertical In-Core ROP Detectors in CANDU 6





# Location of Some Horizontal In-Core ROP Detectors in CANDU 6





# Physics Analysis for NOP System

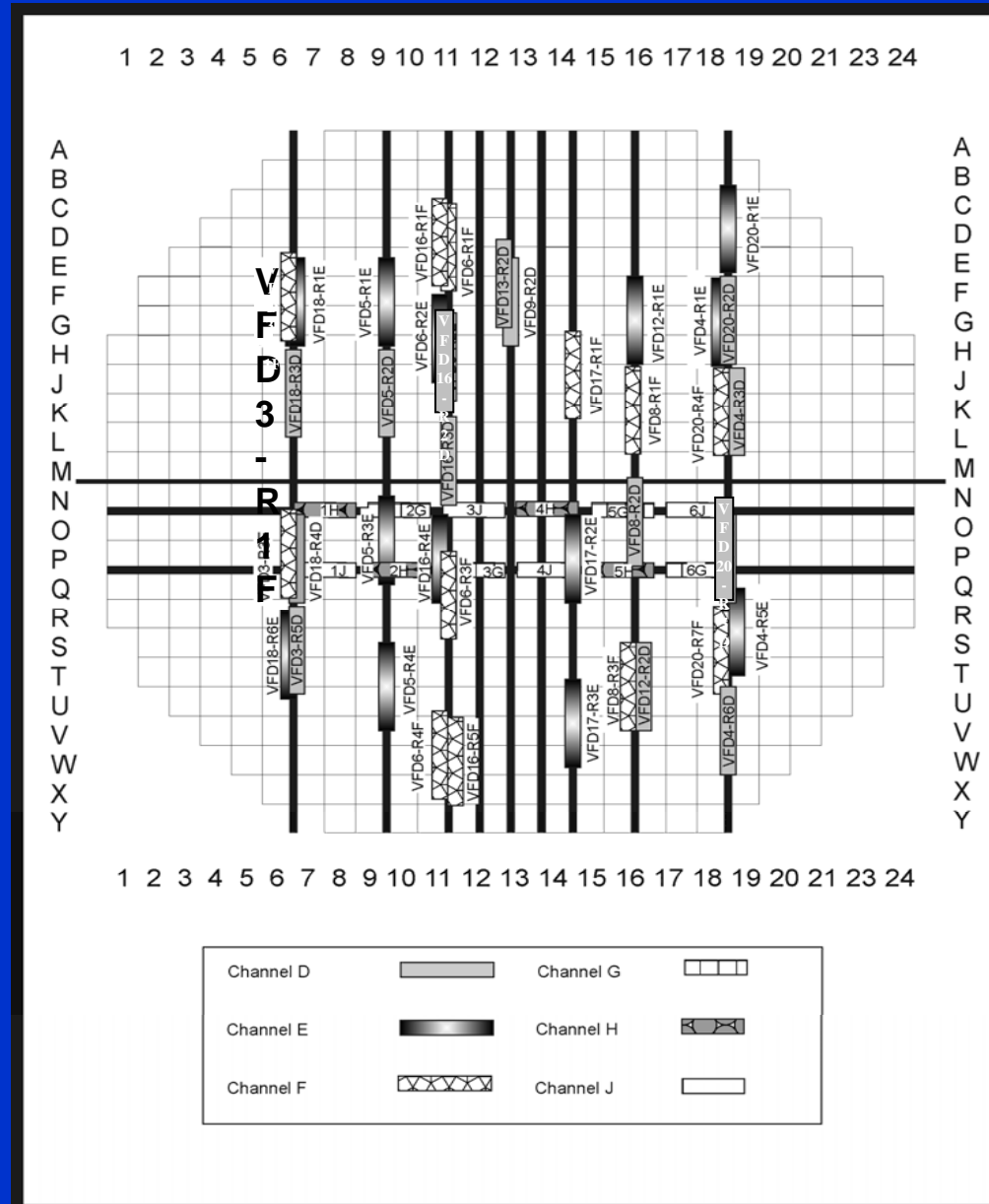
---

- The Bruce B NOP system has:
  - 54 detectors for SDS-1
  - 48 detectors for SDS-2
- See examples of detector locations in the core for SDS-1, SDS-2 (in Bruce A) in the next Figure.

cont'd



# Location of Some SDS-1 (Vertical) and SDS-2 (Horizontal) NOP Detectors in Bruce A







# Physics Analysis for NOP System

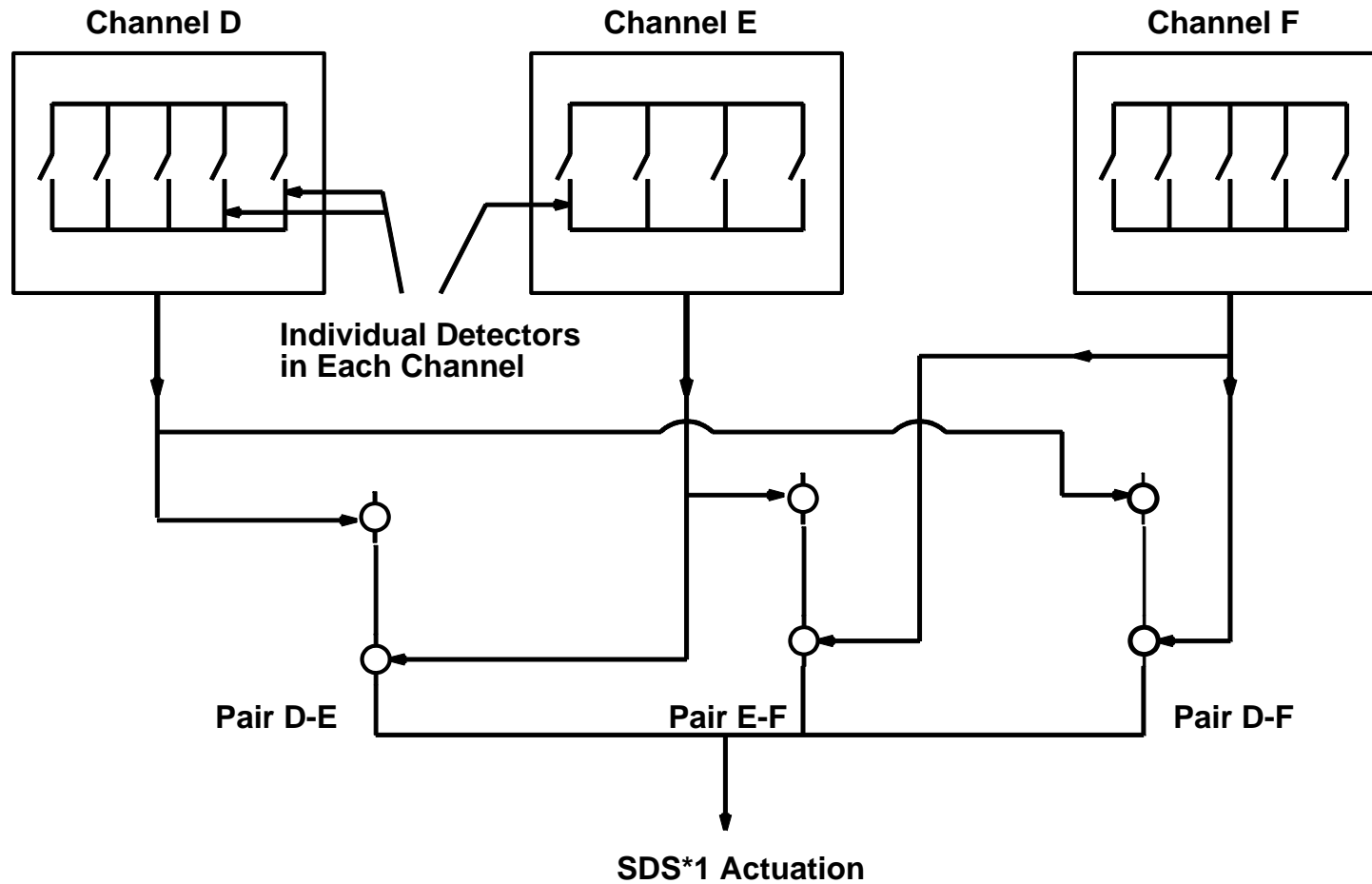
---

- For each shutdown system, detectors are subdivided into 3 logic channels [D, E, F for SDS-1, G, H, J for SDS-2]
- To avoid spurious trips and allow testing of system, the trip logic is triplicated (see Figure)
  - If any detector in a channel reaches its setpoint, that channel trips
  - If two separate channels trip, the corresponding shutdown system is actuated.



# Triplicated Logic for SDS-1

---





# Physics Analysis for NOP System

---

- Back to the hypothetical slow LOR; if the reactivity is positive, the reactor power will increase.
- Channel powers will increase, and at some point fuel dryout may occur in some channel – this is what we want to avoid.
- At the same time, the flux increases at detector locations. Rising detector signals indicate a power increase.

Cont'd



# Physics Analysis for NOP System

---

- We want to design the NOP system so that it recognizes the LOR and acts to protect against fuel dryout.
- We can accomplish this by designing the detector trip setpoints so that, in the event of a global or local power increase from a wide set of anticipated flux shapes, the system logic initiates a reactor shutdown before fuel dryout is reached.

cont'd



## Physics Analysis for NOP System

---

- The NOP system design is therefore typically based on the analysis of hundreds of flux shapes from which an LOR may develop, e.g.:
  - The nominal reactor configuration
  - Configurations with different amounts of H<sub>2</sub>O in zone controllers
  - Drained zone controller(s)
  - Adjuster bank(s) out of core
  - Other combinations of non-standard reactivity-device positions
  - Power recovery from short shutdown, or other power maneuvers; these may involve complicated changes in H<sub>2</sub>O fills, adjuster positions, Xe-135 concentration, etc.



## Physics Analysis for NOP System

---

- The role of reactor physics is to calculate all the flux shapes, and provide values of detector readings and channel powers
- The calculations are done as steady-state – the LOR is assumed to evolve slowly
- Self-consistency is sought between power and coolant-density distribution; this involves iterations between RFSP-IST and a thermalhydraulics code, e.g. NUCIRC at AECL, TUF at OPG or Bruce Power
- The thermalhydraulics code must also provide the values of “critical channel powers” (CCP) at which different channels will go into dryout



# NOP Analysis

---

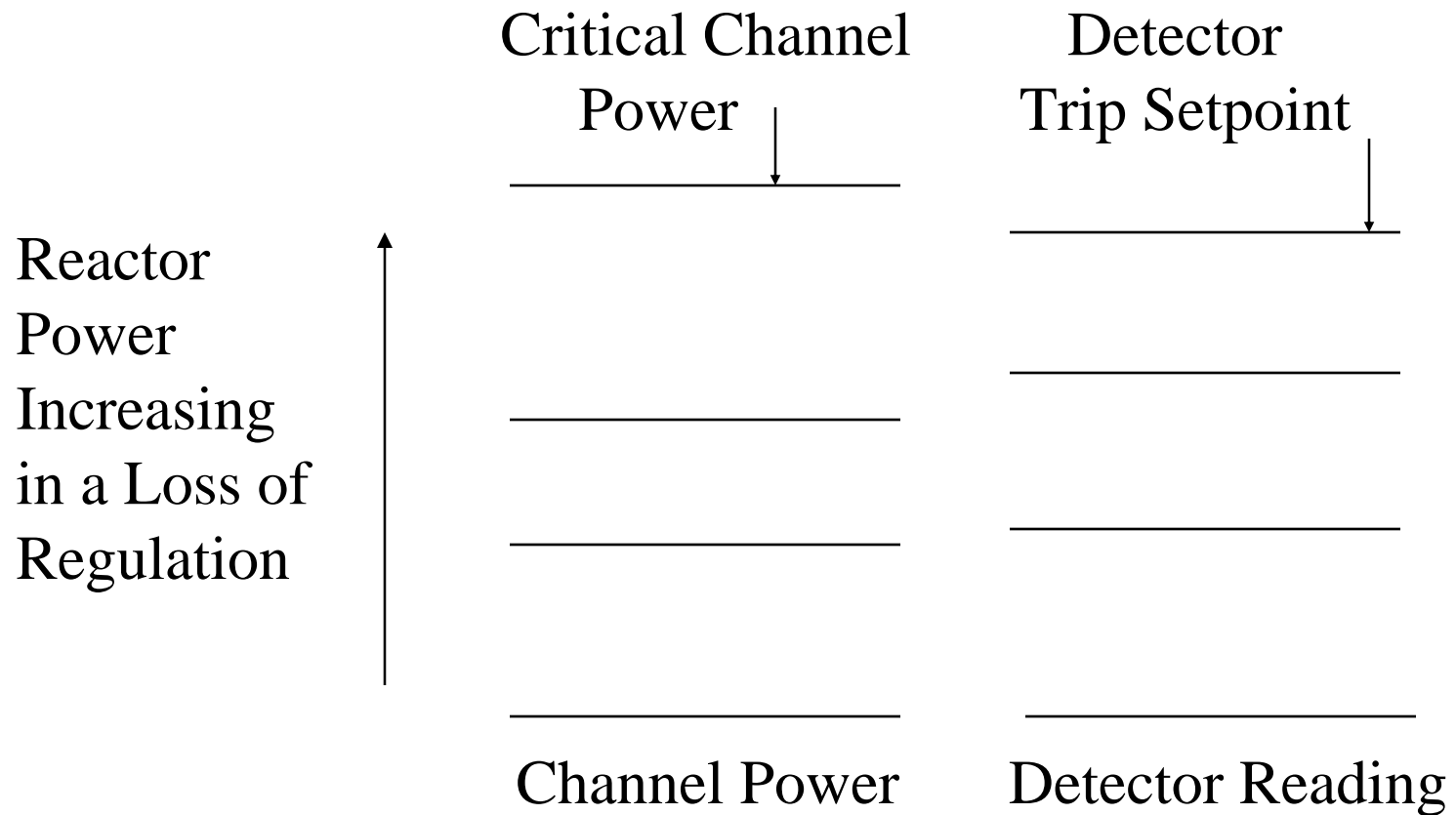
What is the NOP analysis proper?

- The NOP code (SIMBRASS at OPG and Bruce power, ROVER-F at AECL) combines the results of physics and thermalhydraulics calculations to determine detector locations which best “see” each flux shape
- It must choose detector locations and setpoints to provide protection for a wide range of reactor configurations: 2 detectors in different logic channels must “see” each flux shape [i.e., reach setpoint] before any fuel channel reaches dryout
- However, setpoints must not inhibit normal operation
- Analysis often assumes, for conservatism, 2-out-of-3 coverage, with first channel to trip assumed unavailable.



---

NOP objective is that 2 detectors in different safety channels reach their setpoint before any fuel channel reaches its critical channel power







# NOP Analysis (cont'd)

---

- The NOP system useful not only in LOR
- It provides neutronic trips from in-core signals in any situation leading to global or local power excursion, e.g. a loss-of-coolant accident