CHAPTER 4: NUCLEAR INSTRUMENTATION

MODULE 1: LOG AND LINEAR RANGES

Introduction

- A CANDU reactor generates thermal power from heat produced by nuclear fission.
- Measurements of the actual thermal power output respond too slowly to power level changes for the purpose of controlling the reactor (there is a time lag of about 25 sec between neutron flux change and its detection by the thermal output measurement).
- To control the reactor adequately, it is necessary to have fast responding instrumentation.
- The method of measuring reactor power by observing the radiation directly associated with the fission process is used. Each time a fission occurs, radiation (neutron, beta, gamma or alpha) is produced. The magnitude of these radiations is directly proportional to the number of fissions, which is in turn directly proportional to the reactor power level.
- The radiation we choose to monitor is neutron flux. If we can measure the neutron flux, we can estimate the thermal output of the reactor.
- In addition, monitoring neutron flux acts as a safeguard against the possibility of losing control of the reactor. If neutron flux exceeds a predetermined limit, shutdown systems will be triggered by the sensed neutron signal.

Measurement Range

The monitoring and control of a reactor is necessary over a wide range of neutron flux levels. Flux in the operating range can be considered as varying from 10^7 to 10^{14}N/(cm^2.s).

For all practical purposes we can assume that 10^7 N/(cm^2.s) is zero thermal power. In fact significant thermal power contribution does not occur until the flux rises to ~10^{12} (1% FP). A linear scale of power could be produced with an amplifier developing (arbitrarily) 2 volts/10% power change.

- Notice that if 100% FP corresponds to 10^{14} N/(cm^2.s) then 10% FP must correspond to 10^{13} N/cm^2.s).
- A power change from 10% to 100% FP is a change by a factor of 10 or a 1 decade change.
- Similarly, a change in neutron flux from 10^{13} to 10^{14} is a 1 decade change.

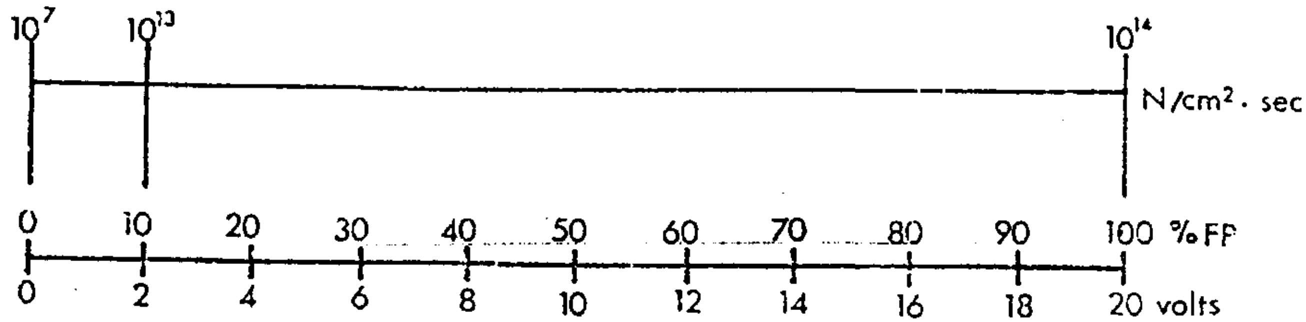

Figure 1: Flux vs. % Thermal Power - Linear Scale.

- A power level change from 10% to 100% will result in an amplifier signal change from 2 to 20 volts. This change of 18 volts for a 1 decade power change will provide sufficient sensitivity for control sensing.
- For a power level change from effectively 0% to 10% FP the amplifier signal changes only 2 volts while the flux has changed <u>6 decades</u>. (10^7 to 10^{13} N/cm^2.s); i.e. the sensitivity in this region is very low. Consequently, there would not be very close control of the flux in this region (<10% FP) as large N flux changes are required to get a significant signal.
- If a log amplifier was used, 2 volts/decade (arbitrarily) could be developed so that as the flux level changes one decade, a recognizable signal change of 2 volts will occur:

Voltage signal = 2 $\log_{10}$ (%FP)

% FP	Voltage Signal
100	4
10	2
1	0
0.1	-2
0.01	-4
0.001	-6

Table 1: Log Voltage Signals Relative to % Thermal Power.

Now if the power level only changes from 10^{-3} to 10^{-2} %FP, the voltage will change from -6 to -4 volts, a readable amount.

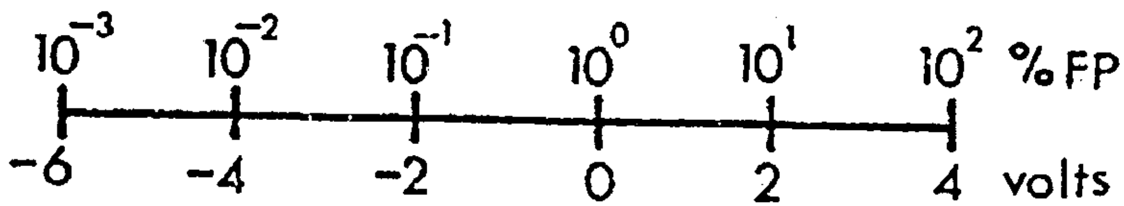

Figure 2: Log Voltage Scale Relative to % Thermal Power.

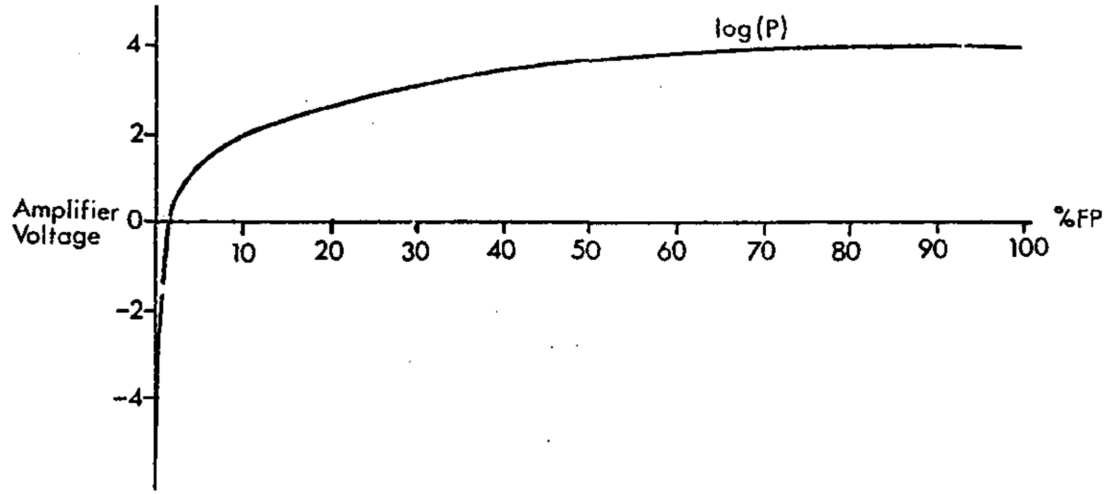

Figure 3: Graph of Log Amplifier Signal Relative to % Thermal Power.

- **Notice now that if the operation is below 10% FP that a useable signal change is developed.**
- **As the power rises above 10% FP, the response-curve will <u>flatten out</u>. The signal can be considered as bunching up towards the top end of the scale.**
- **Significant changes in %FP at the top of the scale will result in only small changes in signal from the log amplifier.**
- **A linear amplifier could be utilized over the last decade to allow close control of power fluctuations. Now as the power varies from 10 - 100%, the signal will change linearly with respect to power changes allowing closer control.**
- **<u>Log control</u> is used over more than six decades as the thermal power is raised to about 10% FP and then linear control is used over the last decade where useful power production occurs.**