1.5
1

10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}

2x10^{-14}
2x10^{-13}
2x10^{-12}
2x10^{-11}
2x10^{-10}
2x10^{-9}
2x10^{-8}
2x10^{-7}
2x10^{-6}
2x10^{-5}
2x10^{-4}
2x10^{-3}
2x10^{-2}

3x10^{11}
3x10^{12}

Reactor Power (Fraction of F.P.)

Thermal Neutron Flux (n/cm²/sec)

Initial Startup Range

Low Power Range

Power Range

In Core Detectors
Controls at about 15% F.P.

Ion Chambers of RRS
Controls above 5x10⁻⁷ F.P.
Log vs. Linear Meters

Linear Scale

Log Scale
Four Power Scales

\[10^{-7}, 10^{-6}, 10^{-5}, 10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}, 10^0\]

-7 -6 -5 -4 -3 -2 -1 0 Decades

\[0.0000001, 0.00001, 0.001, 0.01, 0.1, 1, 10, 100\]

%FP
Startup
Instrumentation
Reactor Power After Shutdown

Fraction of FP vs. Days graph
Boron Tri-fluoride Detectors

\[ n + B10 \rightarrow Li7 + \alpha \]
More about Start-up Instrumentation

- He-3 detectors can also be used
  - More sensitive to neutrons
  - Smaller current pulse
- Detectors come in a number of sizes
- Normally detectors are external to the core
- Installed only when needed
Even More About Start-up Instrumentation

- Typically installed in spare ion chamber holes
- Provisions for installing right into the core
  - New cores
  - Extremely long shutdowns
- Detector Burnout
- Damped response
Fission Chambers

- Enriched Uranium lines the walls of a chamber
- Inert fill gas
- Neutrons cause fissions in the U235
- Ionizations from the fission products are detected
- Can incorporate U-238 to breed more active
Run up
Instrumentation
Ion Chambers
Typical Ion Chamber Locations
Ion Chamber Circuits
Gamma Discrimination

- Minimizing the effect of gamma
- Small detectors
  - Minimize gamma energy deposited
- Lead Shielding
  - Lead absorbs gamma but is relatively transparent to neutrons
Ion Chamber Accuracy.

- Moderator Level
  - Changes in moderator level affect the spectrum
- Loss of high voltage
- Low reactor power levels
- High Voltage Drift
Gas Detector Curves

- **Unsaturated Region (Recombination)**
- **Saturated Region (Ion Chambers)**
- **Proportional Region**
- **Limited Proportional Region**
- **Geiger-Mueller Region**
- **Continuous Discharge Region**

**Relative Pulse Size**

- Gamma
- Beta
- Alpha

**Detector Bias Voltage**
Under Load Instrumentation
In-Core Detectors

- Platinum Emitter
- Inconel Sheath
- Current Meter
- Insulator MgO Powder

Diagram showing the flow of current through the detector components.
Major Reactions

- Neutron capture and later beta decay
- Neutron capture followed by a gamma and the gamma releases a Compton or photo electron
- Gamma from external source releases an a Compton or photo electron
Neutron Beta reaction

Collector

Insulator

Emitter

Neutron capture followed by beta decay

Interfering electrons arising from external gamma ray
Neutron Gamma Reaction

Interaction of prompt gamma ray emitted upon neutron capture

Collector

Insulator

Emitter

Interfering electrons arising from external gamma ray
Response of Detectors

- $(n, B)$ response is delayed after a change in neutron population
- $(n, \gamma)$ response is prompt following a change in neutron population
- External $\gamma$ is prompt for fission gammas
- External $\gamma$ is delayed for fission products
Platinum Detectors

- Beta gives 3% of signal
- Neutron capture gammas 60%
- External gammas 40%
Inconel Detectors

- Negligible \((n,B)\)
- Almost all signal from \((n,\gamma)\) followed by photo or Compton electron
- Over prompt response
Vanadium

- Almost all response is \( (n,\beta) \)
- Response is delayed
Detector Location
Overlapping Ranges

Neutron Flux (n/cm² s)

Running Instrumentation (Linear In-Core Flux Detection)
0.15 - 1.5 FP

C

B

Runup Instrumentation (Log Rate External Ion Chambers)
10⁻⁷ - 1.5 FP

A

Startup Instrumentation (scintillation)
0 - 10⁻⁶ FP

Reactor Power

20% 40% 60% 80% 100%
In-Core Detector Accuracy

- Fuelling or reactivity device movement
- Start-up of the reactor
- Long term exposure
- Moderator poison load
For You To Do

■ Read pp. 60-80
■ Answer Questions pp. 86-88, #28-38