CHAPTER 4: NUCLEAR INSTRUMENTATION

MODULE 2: LOG RANGE DETECTORS

Ion Chambers

Ion chambers are modified versions of a gas ionization detector but the electrodes are more closely spaced as parallel cylinders. The electrodes are coated with B-10 to provide neutron sensitivity. The relatively large surface area for the electrodes, small plate separation distance, and higher flux levels combine to produce a DC micro-amp signal as a function of the flux level.

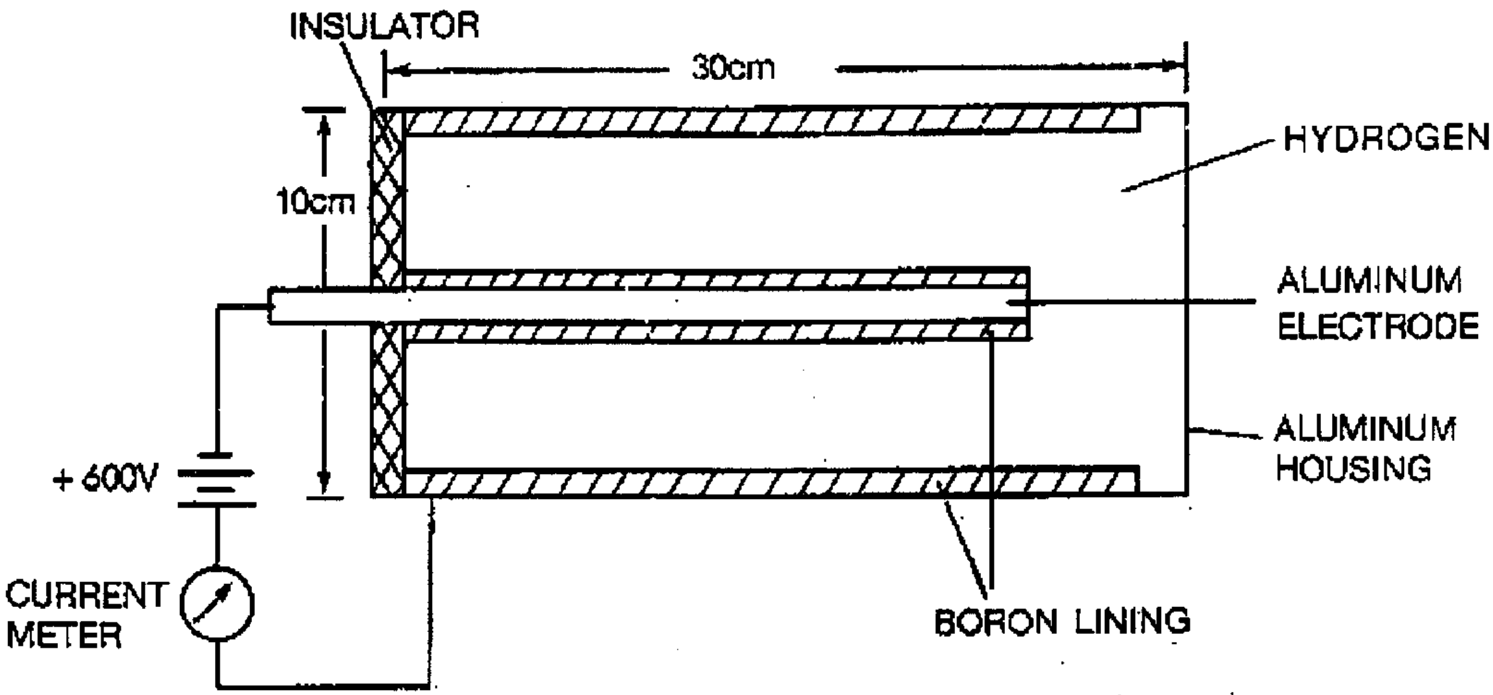

Figure 1: A Simplified Ion Chamber.

Basically, an ion chamber consists of an insulated electrode sealed within a gas tight housing. Gas which is chemically stable under irradiation is used to fill the chamber. Hydrogen is one such filling gas.

Since neutrons are uncharged, a coating of material which will emit charged particles under neutron bombardment must be used to line the chamber. Boron-10 was chosen because its high cross-section for (n, α) with thermal neutrons gives high sensitivity. This is important because ion chambers are mounted outside the reactor core where the number of neutrons is limited.

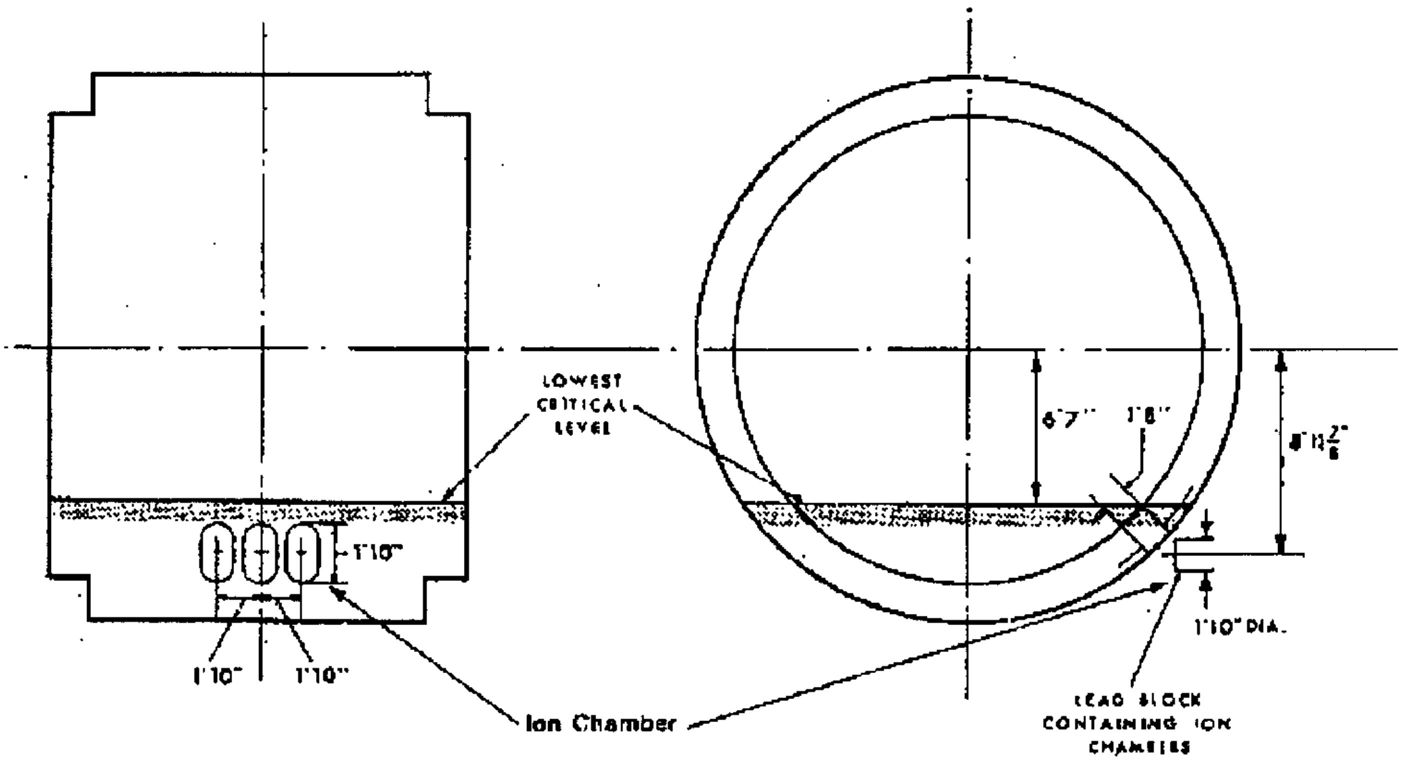

Figure 2: Ion Chambers Locations in a 500MW CANDU reactor.

Principle of Operation

- The metal used for the construction of the housing and electrode is usually pure aluminum because of its low residual activity as a result of neutron bombardment.
- A high polarizing voltage (typically +600 V) is applied to the aluminum housing, while the center electrode is normally kept at ground potential (see Figure 1).

- When the boron lining is bombarded by neutrons, alpha (a) particles are formed:

$$B^{10} + {}_0n^1 \rightarrow Li^7 + He^4 \ (\alpha).$$

- Both Li^7 and alpha particles are positively charged. They ionize the hydrogen atoms and thereby produce free electrons and positive ions.
- As the free electrons are formed, they are attracted to the housing due to the positive polarizing voltage. This creates a current flow which is detected by an external circuit.

- One of the problems with the ion chamber is that the detector is indiscriminate and is affected by other ionizing radiations, especially gamma. (The external alpha and most beta radiation cannot penetrate the housing.)
- Gamma rays will produce photo-compton electrons and subsequent ionization. Therefore, it is important to ensure both at power and after shutdown, when fission product gamma radiation is predominant, that gamma radiation does not give a false (high) indication of reactor power.

Shielding and Scatterer

- To minimize the effect of gamma radiation, the active part of the ion chamber is kept small.
- Another technique is to shield the ion chamber.
- Gamma compensation can be provided by using a 1/4 inch thick lead shield in the front and a polystyrene scatterer at the side of the ion chamber.
- The polystyrene scatters the neutrons but not the gamma. Ion chambers installed at the side of the scatterer measure essentially only neutrons.
- Lead shielding is also used, and can result in the neutron to gamma current ratio being kept at about 1000 to 1 at high power level.

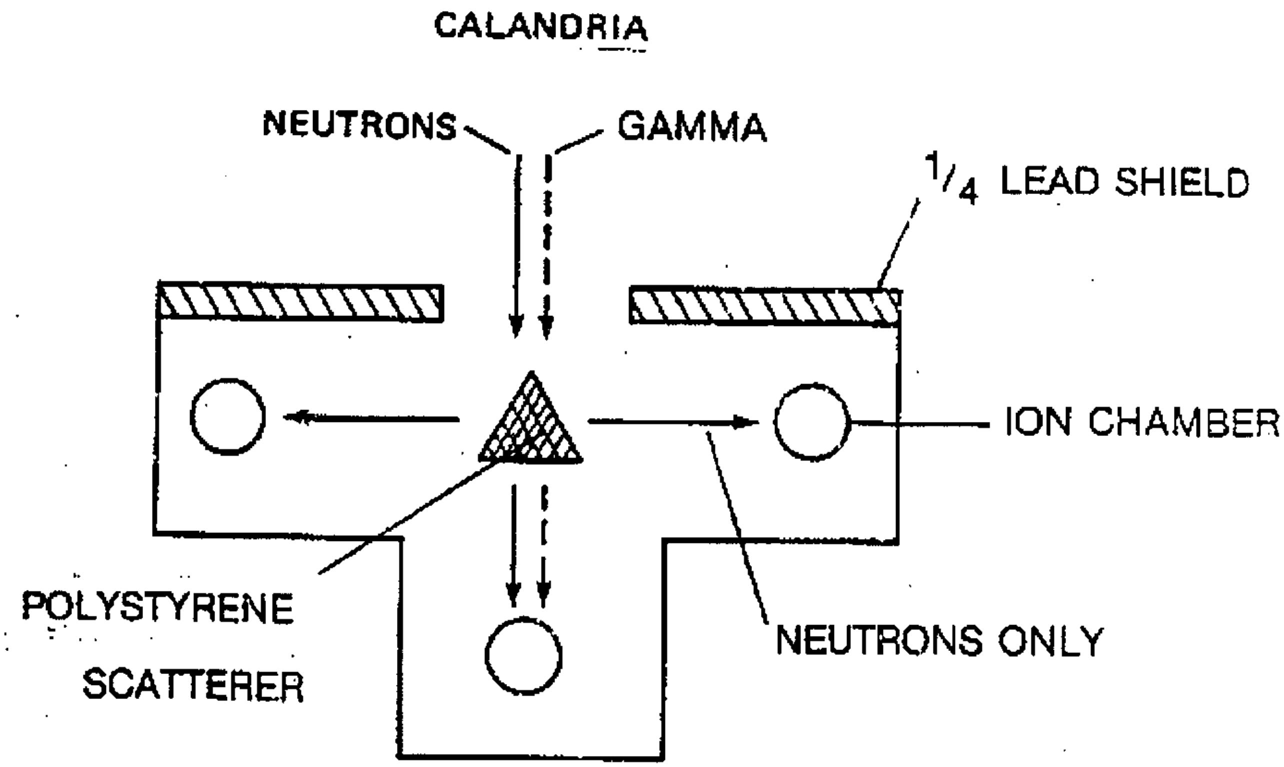

Figure 3: Ion Chambers with Shielding and Scatterer.

Regulating and Shutdown System Ion Chambers

- Ion chambers are used for the Reactor Regulating System (RRS) and Shut Down Systems (SDS) because of their fast response time.
- In a typical CANDU installation, a total of 12 ion chambers is used - 6 for RRS and 6 for SDS.
- At low reactor power level, say below 15% full power, control of bulk reactor power is important. Ion chambers, because of their fast response time, and high sensitivity are used for low power neutron flux detection.
- The ion chamber are located outside of the fuelled region of the reactor (hence their reading is often referred to as "out of core") and will generate a signal in the range from 10^{-5} to 100 μA over seven decades of flux.
- Loss of polarizing voltage at the ion chamber causes the instrumentation to read zero reactor power regardless of the actual power. The voltage monitor is set to alarm if the measured voltage at the ion chamber drops 5% below the operating voltage.
- There are two sets of three ion chamber housings, one horizontal and one vertical.
- There are two ion chambers in each ion chamber housing; one for the RRS and one for the SDS. The regulating channels must be completely independent of each other and of the shutdown system channels.
- There is also a pneumatically operated boron shutter located in each housing to introduce a change in flux to that pair of ion chambers. The shutter is withdrawn at a set speed to simulate a rate of change of flux to test the trip system from the ion chamber right through to the trip relay.
- The testing of the shutdown system by operating the shutter will also affect the regulating system since the flux variations will be sensed by both ion chambers in the housing. The test circuits are interlocked to allow the operation of only one shutter at a time. Similarly, maintenance would be carried out on one channel at time, and at full power when possible so that any changes and effects can be tested.