CHAPTER I
INTRODUCTION

1.1 Motivation

In the nuclear generating plant, nuclear energy is produced as heat from a physical process, nuclear fission. This heat boils the water used to drive a turbine to generate electricity as shown in Figure 1.1.

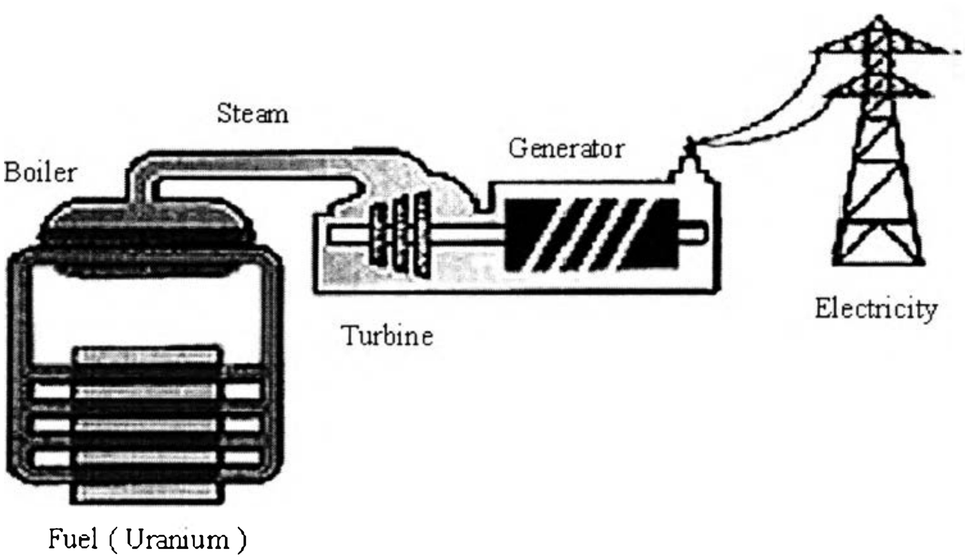
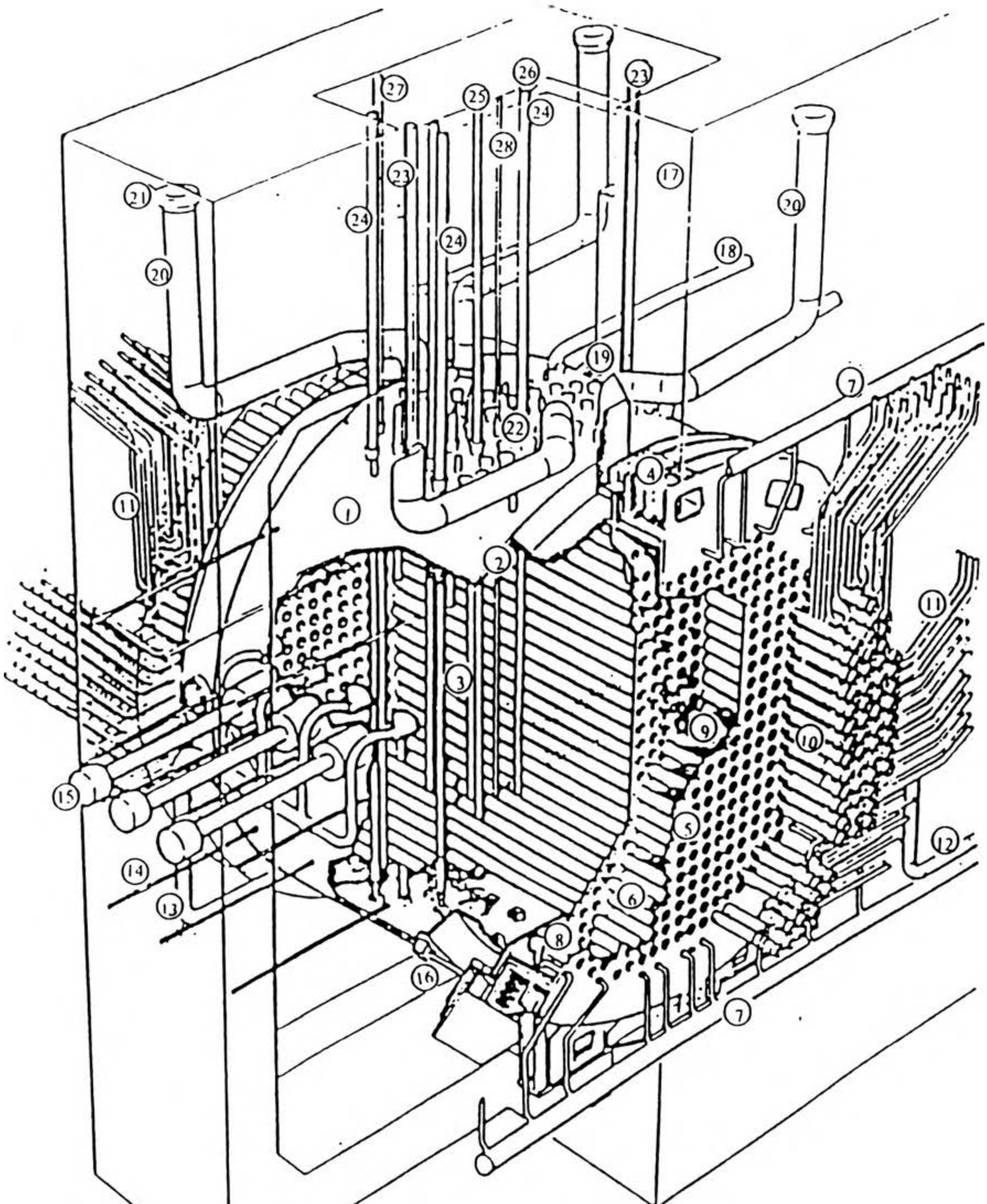


Figure 1.1 Nuclear power plant

The development of nuclear reactors followed different paths in different countries depending on their facilities. CANDU represents the commercial unique power reactor system of Canada called Canada Deuterium Uranium. The objective of the CANDU is to produce electricity by using a reactor system compatible with the material and manufacturing resource available (AECL, 1973). CANDU produces the electric power from utilizing natural uranium as a fuel. A feature of the CANDU is that individual fuel channels can be refueled while the reactor is at full power. In order to permit the economic use of natural uranium fuel the moderator is an important part of reactor in terms of neutron efficiency. In the CANDU, the moderator is heavy water (Snell and Sobolewski, 1992).

The reactor structure of CANDU is shown in Figure 1.2 and Figure 1.3. The reactor is enclosed in a reactor vessel called the calandria. The complete separating circuit of the moderator system from the heat transport system is a principal feature of the CANDU. The moderator is the significant component for the safety in the nuclear reactor to slow the neutrons in order to promote further nuclear fission that produces the required thermal energy. The moderator is pumped from the calandria through two parallel heat exchangers, which removes the heat received from the fuel. The moderator is kept cool below 65°C. In addition to the main circulation system, the moderator system is utilized to maintain chemical purity and to control the activity level of the water (AECL, 1973).

Apart from these practical requirements, the moderator is also required to act as a heat sink in unlikely accident situations, such as a loss of coolant accident coincident with a failure of cooling system. The circulating moderator prevents the melting and exploding of fuel owing to the high temperature during the accident. The heat sink capacity is assured by removing sufficient heat to prevent failure of the assembly. The moderator's role as a heat sink is defined by the available moderator sub-cooling, which is a function of moderator pressure and temperature, both of which vary spatially. Additionally, the heavy water is maintain at relatively uniform temperature and circulated in an effort to eliminate hot spot.



1 Calandria
2 Calandria Shell
3 Calandria Tubes
4 Embedment Ring
5 Fueling Tubesheet
6 End Shield Lattice Tubes
7 End Shield Cooling Pipes
8 Inlet-Outlet Strainer
9 Steel Ball Shielding
10 End Fitting
11 Feeder Pipes
12 Moderator Outlet
13 Moderator Inlet
14 Flux Monitor and Poison Injection
15 Ion Chamber
16 Earthquake Restraint
17 Vault Wall
18 Vault Cooling Pipes
19 Moderator Overflow
20 Pressure Relief Pipes
21 Pressure Relief Disc
22 Reactivity Control Rod Nozzles
23 Viewing Port
24 Shutoff Rod
25 Adjust Rod
26 Control Absorber Rod
27 Zone Control Rod
28 Vertical Flux Monitor

Figure 1.2 Internal structure of a CANDU reactor.

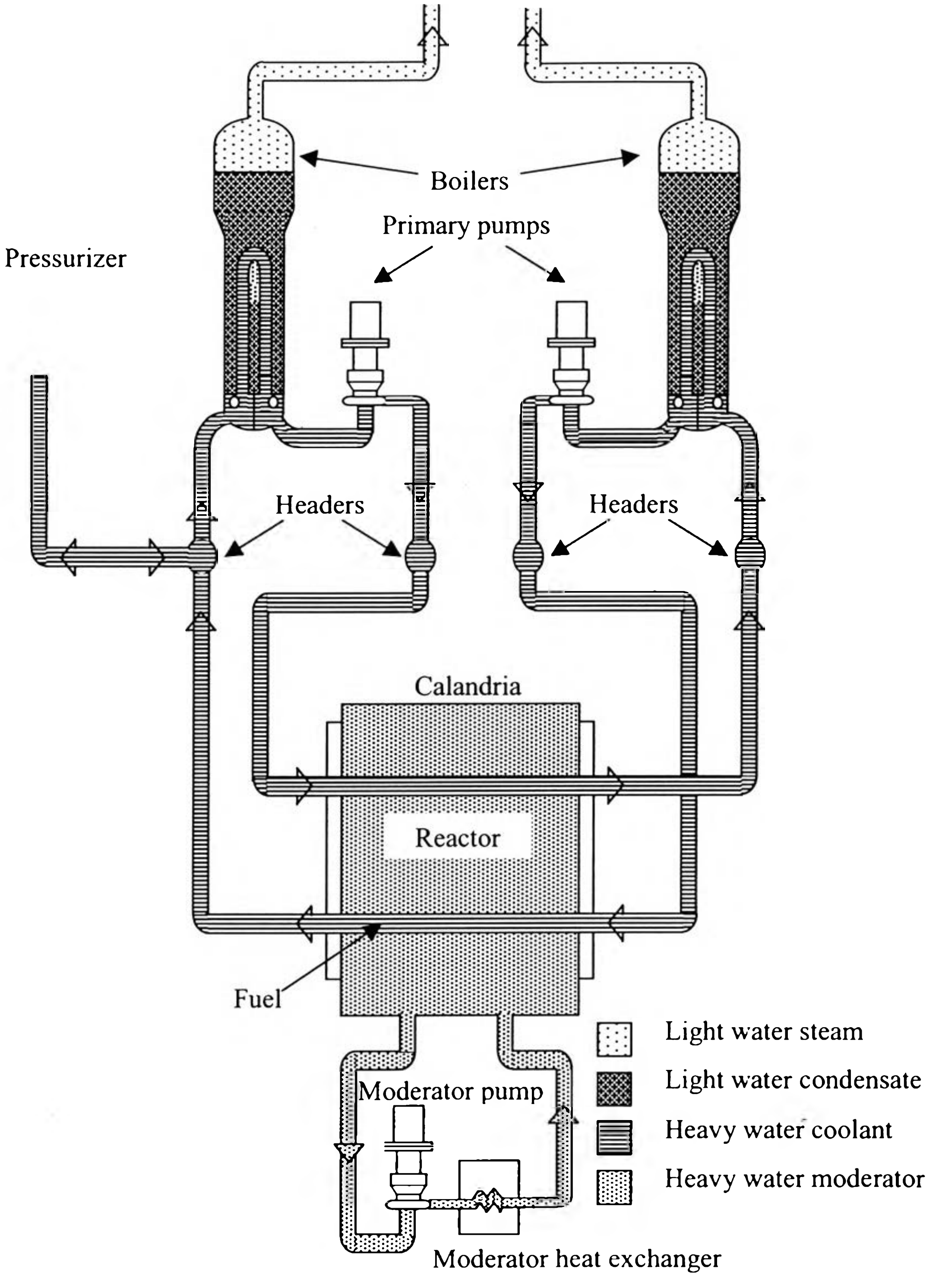


Figure 1.3 CANDU reactor simplified diagram

Because the internal structure of calandria assembly is complex as shown in Figure 1.2, the flow condition in the calandria of the reactor is expected to be highly complicated, which involves different flow impingement angles at different velocity magnitudes over the surfaces in the calandria. Also the temperature caused by the heat from the fuel channels is not uniform within the calandria. Particularly at the top of the core, it is believed that there is a stagnant region. For the safety of a nuclear reactor, the temperature distribution is an important parameter. Thus knowledge of an accurate moderator temperature variation has become desirable to measure and vital to support the claims made with respect to the moderator's ability as a heat sink. Due to access limitations, high and dangerous irradiative heating within the reactor, in practice, the problem associated with direct measurement of the temperature in the nuclear reactor during reactor operation is difficult.

The moderator temperature distribution has been calculated using different computational codes. In parallel with numerical simulations, some measured data from single locations in the reactor have been measured.

The Vertical Flux Detector assemblies (VFD), which could be used for measuring the moderator temperature, are distributed evenly over the reactor as in Figure 1.4. There are 26 such assemblies and each of these assemblies has a cluster of twelve small tubes, called detector wells, inside (inside diameter of 3.43 mm and a length of either from 11 to 13.5 m depending on its location in the reactor). This cluster is in the flux detector capsule tube making up a flux detector unit. This assembly is wrapped by straps to keep it in position and inserted in the permanently fixed "flux detector guide tube". One of the tubes marked "TFD" is normally empty, its purpose being to periodically accommodate a "Travelling Flux Detector". This TFD tube is presently available to insert a thermocouple to measure the temperature along the TFD tube.

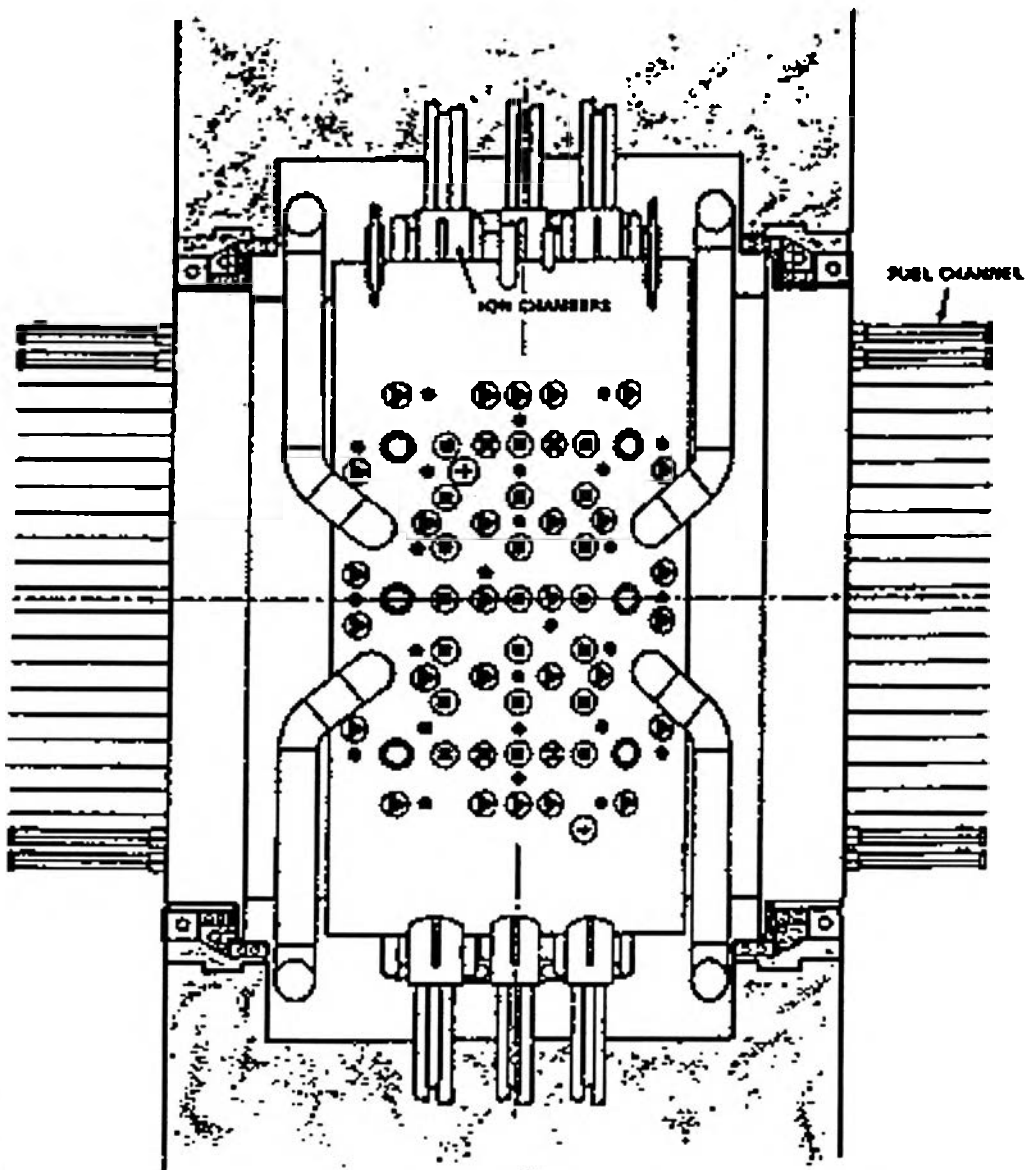


Figure 1.4 Location of vertical assemblies of moderator

This tube is available in all vertical flux detector units shown in Figure 1.5. A possibility using of the TFD tube must be assessed for three primary reasons:

1. Given that the tube is so small, the required travelling instrument and associated drive mechanisms must be developed to proceed with the required measurement precision, both temperature and spatial location.

2. Given that the tube is not in direct contact with the moderator. Indeed, it is close to the middle of a nest of similar small tubes, and the effect of heat transfer between the TFD tube and the moderator must be determined.

3. Given that the tube and associated capsule and guide tube are subject to irradiative heating by the gamma- and neutron- flux in the reactor core.

In the reactor circumstance, the flux detector assembly is heated by gamma and neutron irradiation and cooled by the moderator. The temperature in the TFD well, since it is close to the center of the flux detector assembly, is affected by both the irradiative heating of the components, metal and liquid, between it and the moderator, and the related heat transfer mechanisms. Both of these effects must be modeled to allow translating the temperature measured inside the TFD to the local moderator temperature (Steward, 2000).

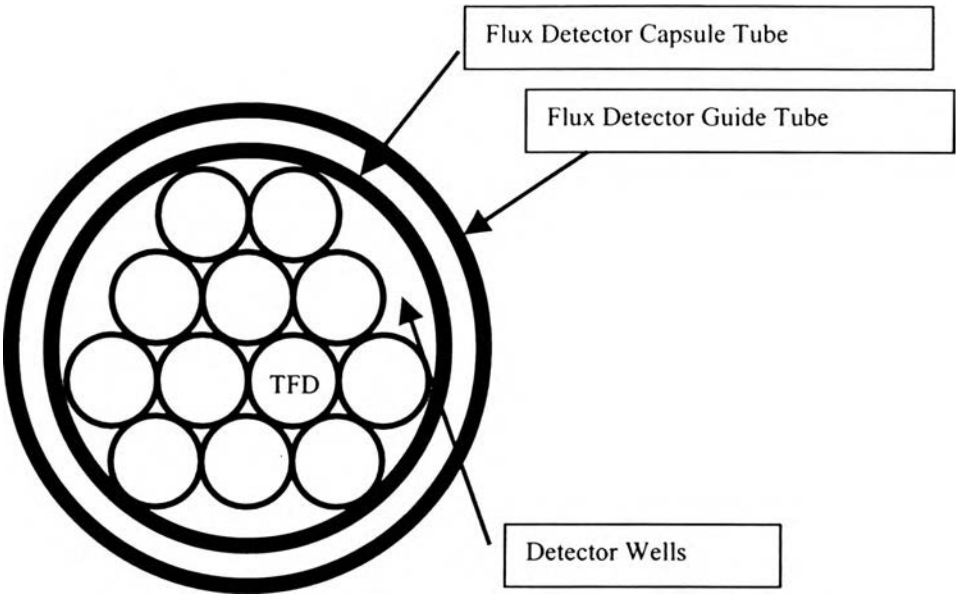


Figure 1.5 Cross section of vertical flux detector assembly

1.2 Objectives

This work was concerned upon the safety of CANDU. Due to irradiative heating, it desired to measure the temperature distribution in the moderator of a CANDU nuclear reactor. The main objectives were to determine the heat transfer characteristics of the Vertical Flux Detector assembly (VFD) by using the test cell duplicated from a small section of the VFD with electrical heaters to simulate the irradiative heating in the reactor core. Apart from the experiments, a numerical calculation using the new commercial software, FLUENT was also applied to determine the temperature profile and heat transfer characteristics in the VFD. The temperature difference between the measured temperature and the actual moderator temperature would be correlated with the heat transfer characteristics of the VFD.

1.3 Scope of Research Works

In this work, electrical heaters within the test cell were introduced to simulate the heat generation of CANDU. It was designed with the same geometry as the VFD. The theory of the heat transfer analysis used in the experiment was steady state condition through the VFD. Certain parameters were analyzed to determine their effects on the measurement technique, such as the velocity of water flowing through the test cell, the outside heat transfer coefficient, the rate of generation of heat by the electrical heaters, the position of the strap wrapped around the detector wells, the position of heaters within the test cell, and the position of thermocouples within the test cell. The temperature distribution within the VFD is utilized to determine the heat transfer characteristics within the various sections of the VFD.