CHAPTER I
INTRODUCTION

In the past two decades, Nuclear energy has become one of the important energy sources in many countries. Canada developed the technology for a nuclear generating system. CANDU nuclear reactors have been built to generate a significant part of the electrical energy in Canada.

In 1996, the CANDU-6 at Point Lepreau was detected to have several of its outlet feeder pipes corroding much faster than expected in the primary heat transfer system (PHTS). Subsequently, measurements at Darlington and Bruce stations also indicated the occurrence of accelerated corrosion of outlet feeder pipes (Lister *et al.*, 1998). Therefore, the corrosion of the outlet feeder pipes has become a major issue for operating and safety consideration in the CANDU nuclear generating stations.

Carbon steel is utilized as the material of construction of coolant feeder pipes in CANDU reactors. Carbon steel pipes represent 27% of the surface area in the coolant loop system (Supa-Amornkul, 2001). The feeder pipes transferring the high temperature water become covered with an oxide film that is mainly magnetite or Fe_3O_4 structure (Lister *et al.*, 1998). It has been generally accepted that the stability of the magnetite oxide film formed on the carbon steel is important in determining the corrosion rate of feeder pipes.

The method, extensively employed for controlling the corrosion in high temperature water, is to create a reducing environment by adding hydrogen (H_2) to the feed water, creating hydrogen water chemistry and reducing the electrochemical corrosion potential (ECP). The exposure conditions have been confirmed that affect the structure of the oxide film. The predominant outer oxide structure under an oxidizing condition is maghemite or γ-Fe_2O_3, defect structure, which eventually increases the ionic mass transfer through the film and the corrosion rate (Kim, 1996) However, due to the complexity of operation, it is usually not feasible to control the oxygen content at this location although this technique is theoretically effective for corrosion control of feeder pipe steel.

Under normal operating conditions, the magnetite film can dissolve into the heavy water (D_2O) coolant, since the temperature rises while flowing through the heat generating core, from 265 °C to 310 °C, resulting in higher solubility of magnetite. High coolant velocity, ranging from 8.0 m/s to 16.0 m/s, can also enhance the dissolution of steel by increasing the mass transfer of iron ions into the coolant and removing the oxide layer as the coolant velocity increases.

Therefore, the modification of pipe steel by alloying it with an appropriate element may be a better method for inhibiting the corrosion of steel.

Chromium (Cr) is an alloying element that has been used in many applications because of its properties in terms of resistivity to corrosion. Iron-based alloys containing at least 12% Cr can self-passivate the oxide film even at room temperature (Uhlig and Revie, 1985). It can also enhance the formation rate and stability of the magnetite film, which can be attributed to a higher current decaying rate, lower passive current and a wider range of passive potential, compared with the carbon steel or lower modified-Cr steel (Cheng and Steward, 2004).

This work investigated the characteristics of the oxide films formed on various steels in high temperature water and the influence of chromium modification of steels on the chemical composition, structure and electrochemical properties of the oxide films. The impedance and polarization behavior of the oxide film on steels containing different chromium contents, A106B carbon steel, 0.33%Cr Steel (Qinshan), 2.5%Cr, Modified steel and 304L stainless steel, in simulated primary heat transfer fluid of CANDU reactors were studied by electrochemical methods. In addition, surface analysis techniques were used to determine the chemical composition and structure of the oxide films. A Scanning Electron Microscope (SEM) coupled with Energy Dispersive X-ray Analyzer (EDXA) was used to investigate the morphology and chemical composition of the oxide films, respectively. Transmission Electron Microscopy (TEM) was used to investigate the depth profile of the oxide film and the electron diffraction pattern was used to reveal the structure of the oxide films. The electrochemical characterization including the polarization curve and the electrochemical impedance technique were applied in order to compare the corrosion behavior of each steel.